The Use of Small Scale Hydroelectric Power in South Africa,

Hydro and Economic Potential for Rural Electrification

by

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ABSTRACT

Small hydro generation refers to generating capacity of less than 10 MW with the most common being Run-of-River. In South Africa, the level of rural electrification is approximately 50 percent with most of the energy needs being met with biomass fuels.

The purpose of this study was to investigate the hydropotential regions that were identified by Eskom and the Department of Minerals and Energy in 2002 and determine sites for small scale development for rural electrification purposes. Technical and feasible analyses were carried out in order to assess the applicability of this kind of energy generating system. The aim of this study was to consider the Free Basic Electrification policy and Solar Home Systems to assess the electrical demand of rural households and possible funding transfer scheme respectively.

Furthermore, to formulate an appropriate methodology that can be used given the available data and resources currently available in South Africa. In total, six sites were identified and analysed in this paper, namely: (1) Berg River at gauge G1H013, (2) Mzimvubu River at gauge T3H008, (3) Orange River at gauge D1H003, (4) Mlambonja River at gauge V1H041, (5) Thukela River at gauge V1H002 and (6) Mkomazi River at gauge U1H005 which are in the Eastern Cape, Western Cape and KwaZulu-Natal Provinces.

Flow gauge data were analysed in order to develop monthly mean Flow Duration Curves which were used to determine the design flow, power generation (through Power Duration Curve construction) and renewable energy potentially produced from each scheme. Costing functions were utilised in order to determine the initial capital cost of the system which was used to assess the project's feasibility.

In order to predict potential power output of the schemes, the streamflow and hydraulic head of the six rivers were assessed. The potential renewable energy production ranged from about 240 to 6060 MWh/year. Through this energy production, it was found between 165 and 10100 houses could be electrified depending on the electrical allowance provided. This significantly exceeds existing housing numbers. Costing bands ranged from 3 – 7 R/kWh which was high but within reason based on the community income and the transfer of the Solar Home Systems pricing policy.

The results of this study provide a good foundation for future work in the estimation of hydropower potential in South Africa and will hopefully be a stepping stone to better estimation of both technical and exploitable hydropower potential for South Africa.

PREFACE

I, Devan E Reddy, hereby declare that the work contained within this document is my own and has not been submitted in part, or in whole to any other University. Any information obtained from others has been duly referenced and acknowledged throughout the course of this paper. The research was carried out under the supervision of Mrs Robynne A. Chrystal and Professor Derek D. Stretch and was submitted to the University of KwaZulu-Natal, Department of Civil Engineering, in accordance with the requirements for the completion of a Master's of Science degree in Civil Engineering.

______________ ______________

D.E Reddy Date

As the candidate's supervisor, I have approved this thesis for submission,

______________ ______________

Mrs R.A Chrystal Date

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ABBREVIATIONS AND SYMBOLS USED

C_{cw}	Civil Works Cost
CDM	Clean Development Mechanism
C_{em}	Electromechanical Cost
CO_2	Carbon Dioxide
DA	Drainage Area
DEM	Digital Elevation Model
DME	Department of Minerals & Energy
DWAF	Department of Water & Forestry
E_{avail}	Available Energy
e_g	Generator efficiency
Eskom	South African electricity public utility
e_t	Turbine Efficiency
FBE	Free Basic Electricity
FDC	Flow Duration Curve
g	Gravitational Acceleration
GE	Google Earth
GHG	Green House Gas
GIS	Geographical Information System
H	Hydraulic head
H_g	Gross Head
H_{hydra}	Hydraulic Losses
H_{tail}	Tailrace Effect

HYMAS	Hydrological Modelling Application System
K	Plant Capacity
LCOE	Levelised Cost of Electricity
MAP	Mean Annual Precipitation
MAR	Mean Annual Rainfall
O&M	Operation & Maintenance
P	Power
PDC	Power Duration Curve
P_{des}	Design Power (Capacity)
P_{PDC}	Power at Power Duration Curve
Q'_n	Utilised Flow
Q_{firm}	Firm Flow
Q_n	Available Flow
$Q_{n,used}$	Minimum Flow Used
Q_r	Residual Flow
RETScreen	Renewable Energy Technology Screen
SHS	Solar Home System
SSHEPP	Small Scale Hydro Electric Power Potential
SSHEPS	Small Scale Hydro Electric Power Station
WR2005	Water Resources 2005

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1. INTRODUCTION

1.1 Research Background

Hydro power currently produces about 20 percent of the world's energy needs and is the most important source of renewable energy that currently exists (Gondwe, 2010). A small scale hydropower facility (generating capacity less than 10 MW) generates power through the kinetic energy of moving water as it passes through a turbine. Most small scale hydropower facilities are ''run-of-river,'' meaning that the natural flow of the river is maintained, and that a dammed reservoir is not required in order to store water and generate power (Kosnik, 2010). There are several examples of small hydro plants in South Africa but some have been decommissioned or left to disrepair once transmission lines reached the local grid with the fast expansion of coal fired power stations.

Following South Africa's post-apartheid era, the Government initiated electrification programmes in order to deal with the stark contrast between the rich and poor, which was racially defined. Democratic South Africa has made major improvements over the past and is currently one of the largest electricity produces in Africa with its government utility's company, Eskom.

With about 90 percent electrification in sub-urban areas, this level is approximately 50 percent in rural areas in South Africa (Karekezi, 2002). In the rural areas energy needs are mainly derived from biomass[1] burning which is damaging to both the environment and human health (Brent and Rogers, 2010).

Connecting the scattered pockets of communities in rural areas can prove not only to be difficult but also uneconomical due to difficult terrain.

Small hydro for rural electrification could offer a credible and economical solution.

1.2 Research Question

Are there sites in South Africa that possess good hydro potential for electrification purposes in rural areas and would these potential developments be economically viable for implementation?

1.3 Research Motivation and Goals

In South Africa coal is currently the main source of electricity generation while North African countries are dependent on oil and gas (Karekezi, 2002). With an increase in awareness of

[1] Biomass- A wide range of natural organic fuels such as wood, charcoal, agricultural residues and animal by-product

climate change and South Africa's aim of Green House Gas (GHG) emission reduction as well as the Government's support for reaching the renewable energy target of 10 000 GWh by 2013 (equivalent to about 5 percent of the current electricity generation in South Africa), small hydro could be an effective technology that can add to the target as well as electrify rural households. The current energy resources in South Africa are depicted in Figure 1. 1.

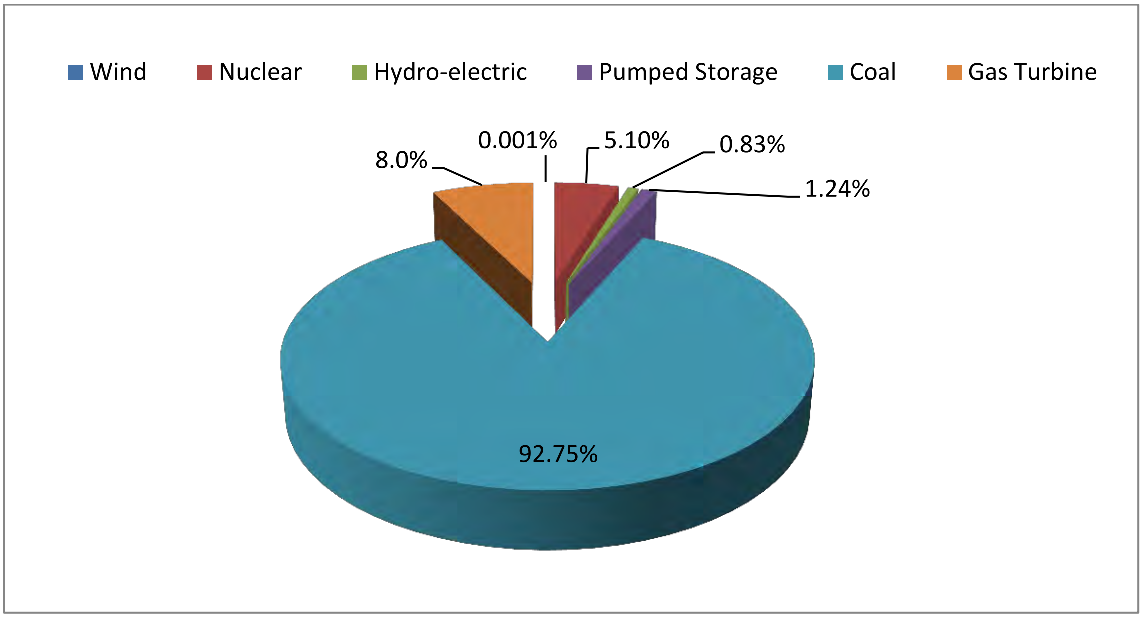


Figure 1. 1: Percentage Contribution to Power Generation year 2011 (After Eskom, 2011)

South Africa has significant potential for renewable energy production in several forms such as wind and solar generation with a total current contribution, in 2011, of about 62 percent as presented in Figure 1. 2. This type of renewable energy's disadvantages can sometimes outweigh their advantages especially in the case of implementing large wind turbines in suburban areas. Solar voltaic cells can be retrofitted onto a home's roof for supplemental power use usually with ease but can lead to large cost due to expensive solar panels and long payback periods.

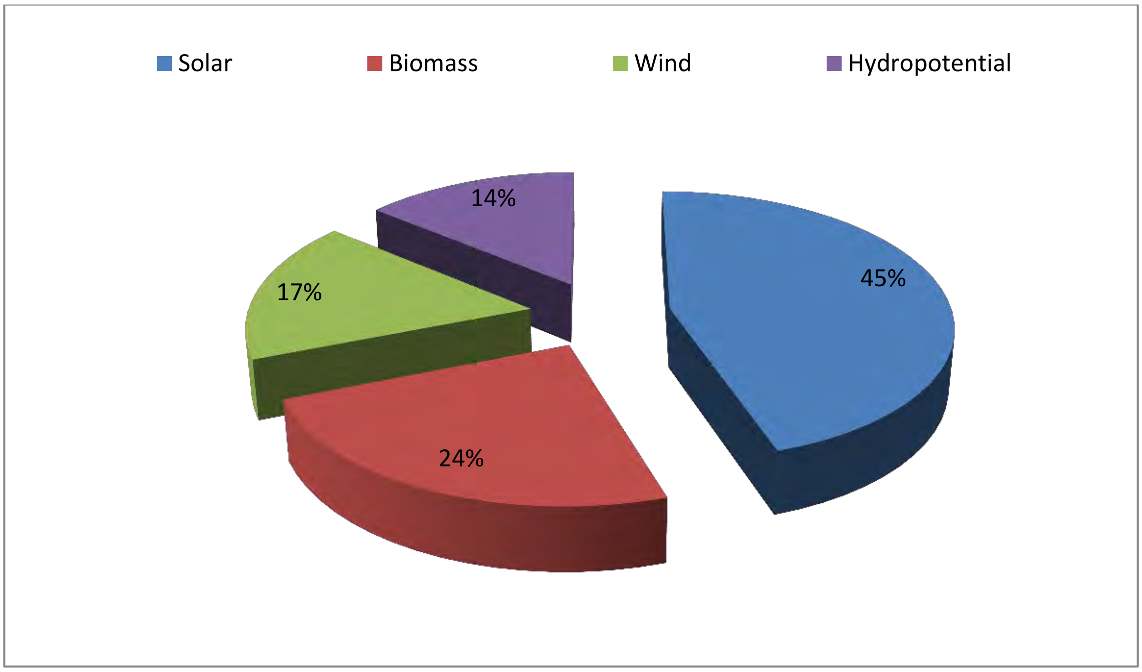
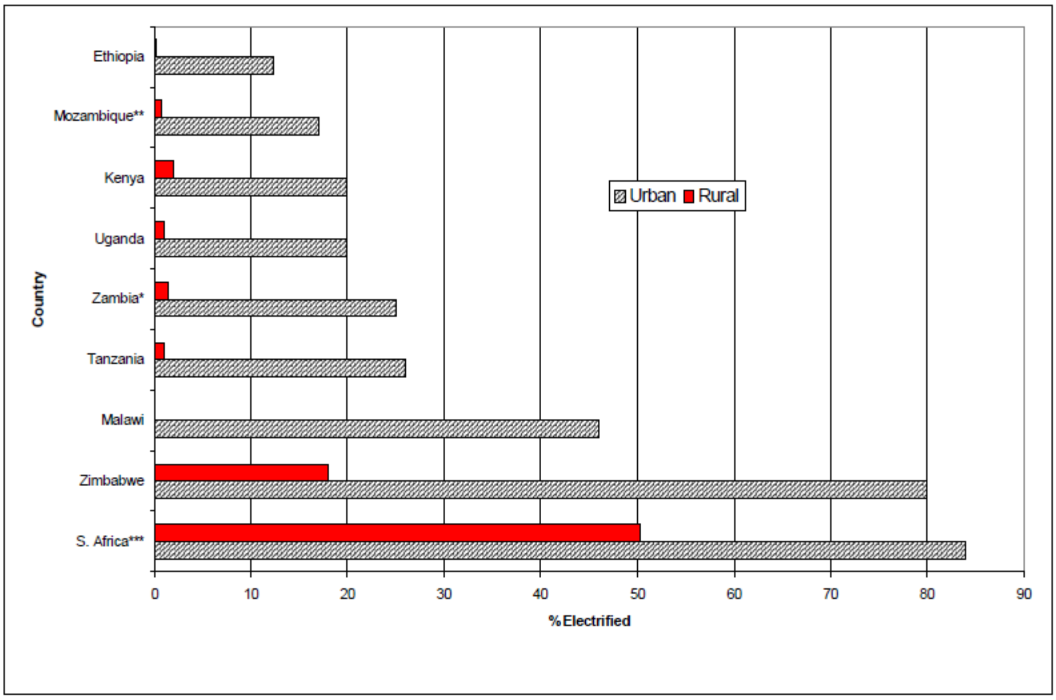


Figure 1. 2: Potential energy production for different forms of renewables by percentage contribution (Department of Minerals and Energy, 2003)

According to the Department of Minerals and Energy[2] (2003) South Africa shows potential for development of all forms of hydropower generation throughout the country in specific sites. Small scale potential generation amounts to 880 GWh/year with about 27 MW currently been exploited.

In South Africa, the level of rural electrification is about 50 percent as can be seen from Figure 1.3. Due to the lack of infrastructure such as transmission lines and great distances between grid centres, it may be uneconomical to extend the grid to isolated rural communities. As a result of the lack of electrification and infrastructure, most low income rural households use alternative sources of energy through biomass fuels (Karekezi, 2002; Karekezi, 1994). Figures 1.3 and 1.4 depict the level of urban and rural electrification and biomass energy as a percentage of total energy for selected countries in Africa respectively.

[2] Department of Minerals and Energy - DME



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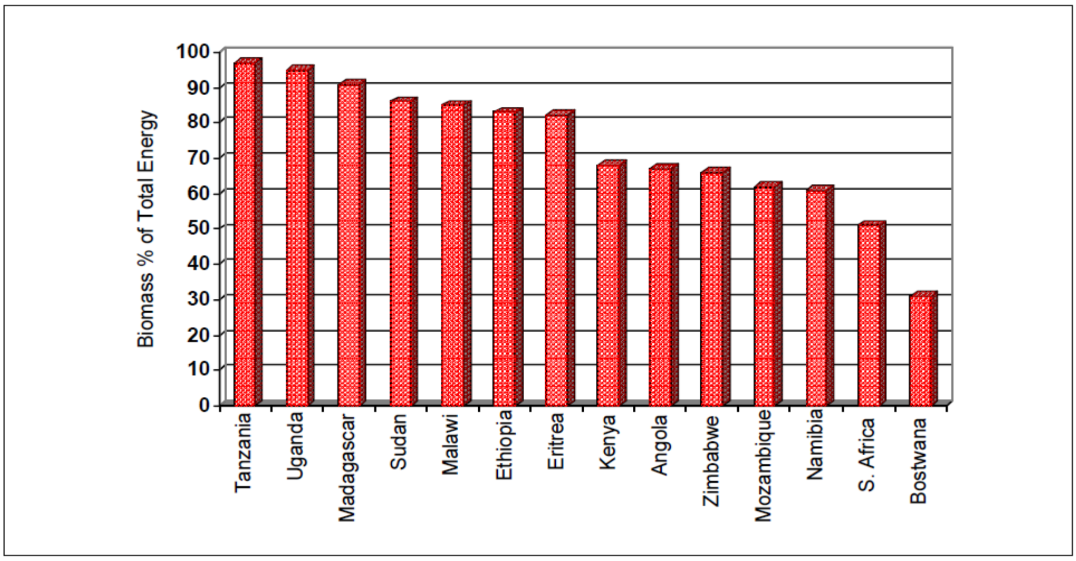


Figure 1. 4: Biomass Energy as a percentage of total energy for selected African countries (Karekezi, 2002)

This form of energy has some serious environmental affects due to pollutants released and can also contribute to respiratory illnesses due to unvented biofuel cooking stoves (Karekezi, 2002).

Many qualitative studies have been carried out in order to determine electricity demand in rural households. Following South Africa's post-apartheid regime the Government has implemented an electrification programme and Free Basic Electricity (FBE) allowance as a means of poverty alleviation. Although some authors argue that the 50 KWh/month allowance is inadequate to meet thermal needs i.e. space heating and the heating of water, this study will determine the demand based on the FBE allowance and increasing this allowance by applying factors to it.

Small hydro generation can also be applied to other demand centres such as suburban areas and the agricultural sector. Findings of this study should be useful for farmers, landowners and electrified communities who wish to expand or secure their electrical needs as well as new Reconstruction and Development Programme (RDP) communities, given their close proximity to rivers capable of good hydro power generation. The cost and benefits of the hydropower station for rural electrification will also aid government in arriving at a better estimate and assessment of the technology for its purpose.

This study will look at formulating a better methodology in assessing sites for small hydro generation using current technology and available data in South Africa. This will be done by quantifying power generated and evaluating the economics of the proposed plant for rural electrification.

1.4 Aims and Objectives

The aim of this research was to evaluate the power and economics of implementing a small hydro power scheme in a rural setting for electrification needs in South Africa.

Sites are identified, by review of research and data, according to their generating capabilities, hydraulic head and corresponding streamflow data from the rivers. Flow Duration Curves (FDC) for the streams are constructed in order to assess the available flow for power generation. The Department of Water and Forestry (DWAF) online hydrological database[3] was utilised to gather the monthly flow volumes of the streamgauges. Streamgauges, quaternary catchments and population density near to the rivers and sites were identified with the aid of Water Resources 2005 maps (WR2005). Hydraulic head was evaluated by using Google Earth elevation profiler and an altitude filler which was used to quantify the power output of the hydroelectric plant.

Demand quantification of rural households was assessed according to the FBE policy (50 kWh/month). With the use of population density maps and some educated assumptions on household occupancy (based on publications of average rural household occupancy said to be 6-7 persons per household) assessments and recommendations can be made of electrical household supply and feasibility of the project.

[3] DWAF website: http://www.dwaf.gov.za/Hydrology/

RETScreen, a Small Hydro Project Model provides a means to assess the available energy at a potential site. Run-of-river schemes are modelled and efficiencies of the turbines determined as well the potential for Green House Gas (GHG) emission mitigation evaluated. Cost contributions by the sites electro-mechanical equipment are made with the use of cost function based formula which uses hydraulic head and plant capacity parameters. Cost contributions for civil works are determined from evaluating overall plant cost and subtracting electromechanical cost.

1.5 Scope of Study

The study investigates the potential of small scale hydropower in improving the level of electrification in rural South Africa. The study is restricted by data availability of rivers in South Africa and hydroelectric power potential regions which were identified in a study performed by the Department of Minerals and Energy (DME) and Eskom in 2002. Hydropower potential comprises 3 main factors namely: (1) moderate to high rainfall in the region resulting in streamflow, (2) Close contour intervals resulting in valley systems and (3) a river network. Six potential sites were assessed to meet the energy needs of the community in the surrounding area. The sites are situated in KwaZulu-Natal (3 sites), Eastern Cape (2 sites) and the Western Cape (1 site) Provinces.

1.6 Outline of Thesis

This thesis is divided into 5 chapters, namely:

Chapter 1 introduces the reader to the topic at hand and is a brief explanation of what the study will involve and where and why the sites for the study were chosen. This chapter also deals with the significance of performing this research.

Chapter 2 provides the theory and examples of hydroelectric generation. This chapter focuses on data requirements for small hydro plants and the computations needed in order to arrive at power outputs of the system. Costing methods are also described here for later feasibility assessment. The Free Basic Electricity policy is discussed for later demand quantification of the "rural village". RETScreen, a feasibility and preliminary assessment tool, is described here as some results will be generated by this software. After relevant literature is reviewed the author concludes with a discussion of the appropriateness of the methods discussed.

Chapter 3 looks at the chosen literature and methods used to generate the results. This shows the approach the author has considered in carrying out the research. The appropriateness of each method chosen for generating results is discussed here. Flow charts and procedures are discussed here to show the path along which the study was performed.

C*hapter 4* shows the summary of results that was quantified after concluding the step-by-step calculation procedure. It also discusses the results in terms of what conclusions can be derived from the information that was obtained and the reasoning which lead to those specific conclusions.

Chapter 5 consolidates the entire thesis, by considering all the factors as mentioned from the results and discussion, and concludes the study in terms of the aims and objectives of the study. It also recommends of further research required and other potential factors to consider for future research.

2. LITERATURE REVIEW

Chapter Two introduces the history and requirements of harnessing water flow into mechanical power. Different types of hydropower schemes are reviewed and existing small – scale hydropower schemes in South Africa to small – scale hydropower schemes internationally. Several types of turbines are reviews for their applicability in terms of hydraulic head and discharge which was used for the site evaluation process. Environmental, social and issues associated with the adoption of small – scale hydropower generation are discussed. Rural household energy demand was considered using the Free Basic Electricity (FBE) policy and the economics for each scheme was evaluated by using the FBE as a basis for income derivation.

2.1 History of Hydropower

Water has been used for milling, pumping and other mechanical functions in the form of water wheels for many years (Fritz, 1984). As the industrial revolution movement in Europe gained strength, so did improvements in efficiency and technology in power recovery of the water wheel (Fritz, 1984). With advances in science and research in technology, mathematicians and engineers significantly improved the capabilities and design of the turbine and led to the modern Francis, Kaplan and Pelton turbines (Fritz, 1984).

In the early part of the 19th century, water provided mechanical power for industrial use which led to the invention of the generator in the 1880's. Water as a means of generating electrical power soon became popular with many turbines converted for the use of electric generation (Fritz, 1984). One of the first hydropower units was installed in the U.S.A in 1882 on the Fox River at Appleton, Wisconsin. It had a capacity of 12.5 kW and was used to deal with local lighting and industry of the growing American city (Fritz, 1984).

Due to the trend of constructing large-scale plants, both hydroelectric and thermal, and the expansion of high-voltage transmission lines, small scale projects were put on hold as the larger projects benefited from shear economy of scale.

Contrary to large developments, small scale hydro projects have recently re-emerged due to the negative environmental factors associated with large scale projects (Fritz, 1984).

2.2 Hydroelectric energy potential and Mean Annual Precipitation comparison

2.2.1 Hydroelectric energy potential worldwide

Hydropower is the largest renewable energy source as it produces about 16 % of the world's electricity and about 80 % of the world's renewable electricity (IRENA, 2012). Hydroelectric energy produces the bulk of the energy requirements in over 65 countries with about 99.3 percent hydro dependence occurring in Norway. China, Canada and the U.S.A have the largest hydropower generation capacity worldwide (IPCC, 2011). The World Hydropower Atlas 2000 (Fraenkel *et al.,* 1991) stated that the world's technically feasible hydropotential is estimated at 14,371 TWh/year while the economically feasible potential is approximately 8080 TWh/year (Paish, 2002). Figure 2. 1 shows the potential exploitable hydropower opportunity by continent. The North American and European continent show the most development in terms of economic potential whilst significant exploitable opportunity remain in Asia, South America and Africa. Small scale hydro power potential is believed to be in excess of 100 GW with China possessing 15 GW of the world's potential less than 10 MW capacity (Fraenkel *et al.,* 1991).

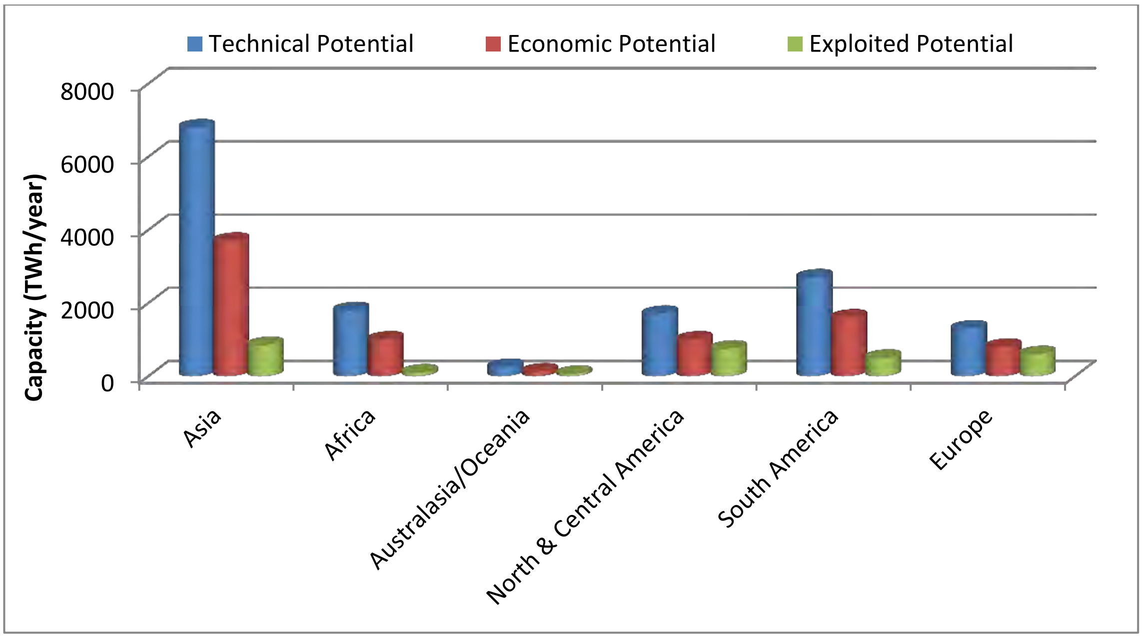


Figure 2. 1: Exploitable Hydro Potential by Continent (after Paish, 2002)

2.2.2 Rainfall Comparison Worldwide

Rainfall is vital for effective hydropower generation and moderate to high regional rainfall, together with ideal topographical conditions for river/stream formation forms the basis for any hydro scheme to exist. The Mean Annual Precipitation (MAP) of several countries was considered which was compared to the rainfall trends of South Africa. Comparison of rainfall patterns allows a depiction of South Africa's rank and potential for hydropower.

Accurate water basin figures and water flow data are not available for public interest in India (Thakkur, 2012). The monsoon, occurring from April to June or till July in north-western regions, is India's primary source of fresh water. The monsoon water replenishes many fresh water lakes and is crucial and sometimes the only source of fresh water for farmers in the agricultural sector. According to Thakkur (2012), Mean Annual Precipitation (MAP) in India ranges from a low of 500 mm in some districts to 2817 mm in Kerala with most states somewhere in between the two MAP values.

China's precipitation varies significantly from an average of 394 mm in July to a mere 31 mm in December (Caraway, 2006). The typhoon/hurricane season lasts from July to October in China and this season is synonymous with high rainfall with the southeast coastal regions receiving rainfall in excess of 1000 mm (Zhou & Huang, 2010). Figure 2. 2 shows the MAP of the Asian continent. Compared to South Africa, China and India receive significantly higher rainfall which is due to the natural phenomena occurring, namely the monsoons and typhoons in India and China.

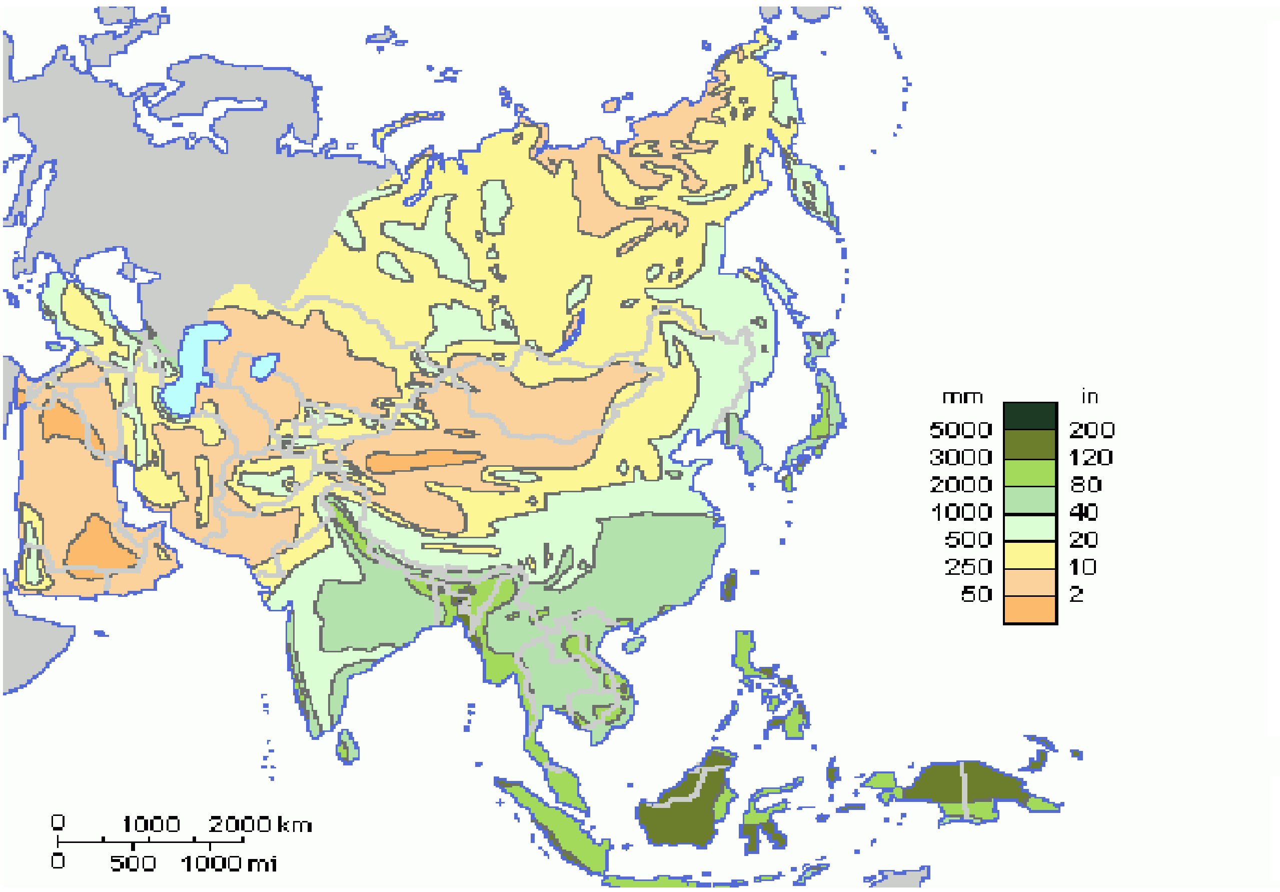


Figure 2. 2: MAP of the Asian Continent (Scholastic Inc., 2013)

The rainfall trends in Kenya vary depending on the long rains occurring from April to July or the short rains occurring from October to November (Verheyden *et al.,* 2005). According to Lieth *et al.* (1999) the MAP for Kenya is approximately 1144 mm. In a study by Unganai (1996) in which several climate stations were combined for assessment, it was found that the MAP ranged from a minimum of 333 mm in Beitbridge to a high of 1118 mm in Chipinge. Zimbabwe's rainy season occurs during November through to March with the dry season occurring in May till August (Unganai, 1996).

The MAP in the Croton River Basin in southern New York State (United States of America) was recorded at 1299 mm (Burns *et al.,* 2005). Figure 2. 3 shows the MAP trends of the USA with the east coast receiving a higher precipitation greater than 1270 mm (50 inches).

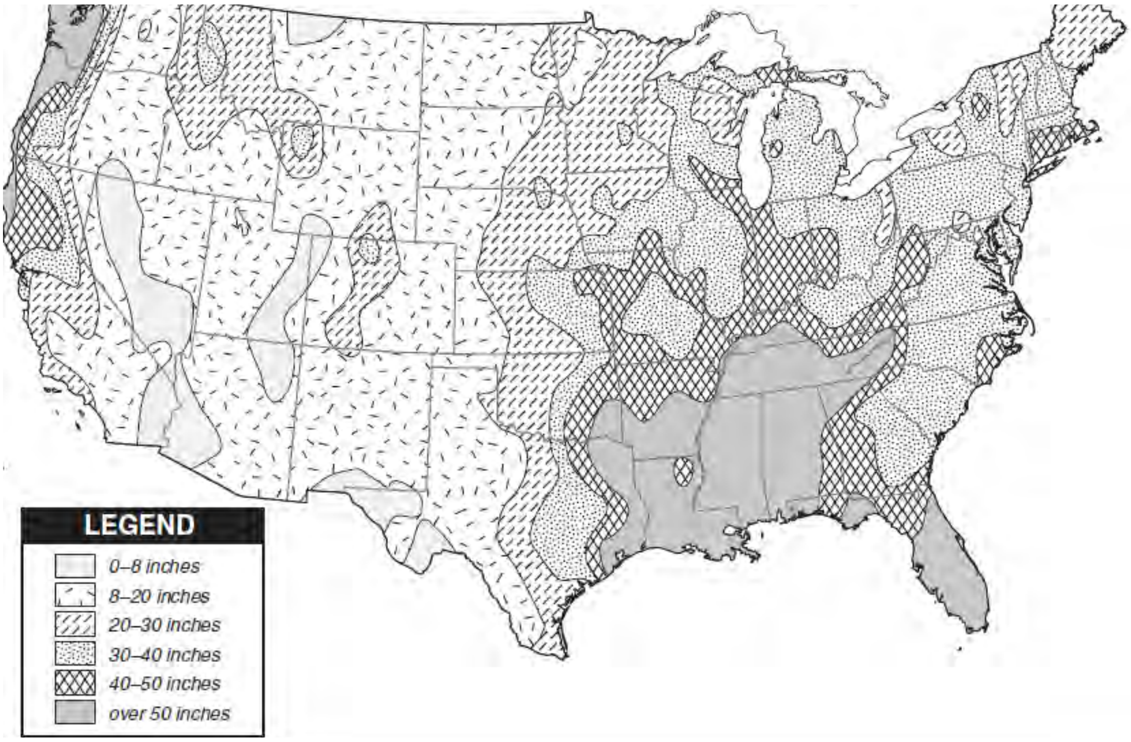


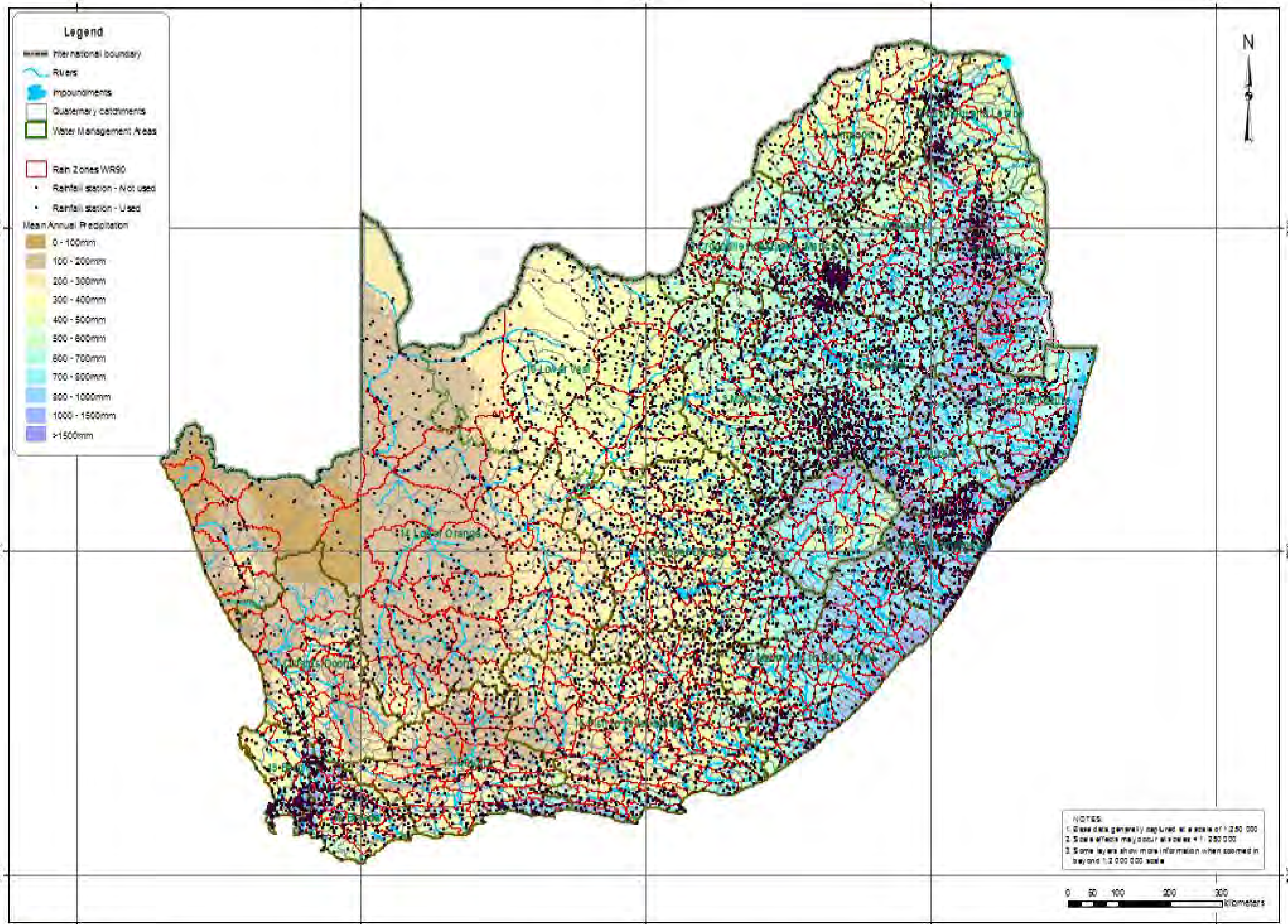
Figure 2. 3: MAP of the U.S.A (Scholastic inc., 2013)

2.2.3 Rainfall and Hydropower potential in South Africa

South Africa is a dry, semi-arid country with an average rainfall of about 500 mm annually which is fairly low compared to other continents and countries within southern Africa (Karanitsch, 2011). Therefore, hydroelectric potential and hydro resource are limited (Olivier, 1986).

The larger rainfall amounts occur in the summer months between November and February (Cretat *et al.,* 2010) although South African rainfall remains quite variable throughout the year.

The two major river systems in the country are the Orange River which flows westward partly bordering Namibia and the Limpopo River which flows eastward and forms part of the border with Zimbabwe and Botswana (Karanitsch, 2011). Figure 2. 4 depicts the unevenly distributed mean annual precipitation trends of South Africa and the locations of rainfall stations. Areas in dark blue identify regions of high precipitation in the country.



Water Research Commission

Figure 2. 4: South African Rainfall

Water Resources of South Africa 2005

Location: ...\WR2005\data\gis maps\wr2005 maps\Figure 1 Rainfall_2005.mxd
Date: April 2008

It can be seen that the south-western, southern and eastern regions of SA provide the most suitable potential for hydropower development due the high rainfall regions resulting in perennial river flows (DME, 2003).

South Africa and certain Asian countries, face economic issues associated with the third world country classification. Asia possesses significant hydroelectric power potential when compared to South Africa (refer to Figure 2. 2). Although the Asian continent shows significant hydroelectric power potential, technical development is lower compared to the European and American continent. South Africa has significant hydropower potential in high rainfall regions identified in Figure 2. 4 however, capital has been invested in more pressing issues such as basic education and healthcare, housing, infrastructure and service delivery rather than technical development (Varun *et al.,* 2008). Electrification in rural areas is an issue common to all continents, specifically in Africa and Asia, due to difficult terrain, diminished funds and lack of urgency that exists in terms of development and improvement of living standards in rural areas (Varun *et al.,* 2008).

In an assessment done by the Department of Minerals and Energy called the "Baseline Study on Hydropower in South Africa" (Barta and Stephenson, 2002) there exists a significant potential for development for all scale of hydropower in the short and medium term as shown in Figure 2. 5. The high rainfall regions in Figure 2. 4 coincide with the zones of excellent hydroelectric potential in Figure 2. 5. The Eastern Cape, KwaZulu-Natal and Western Cape Province have the largest capabilities and resources for small scale hydro potential generation (< 10 MW).

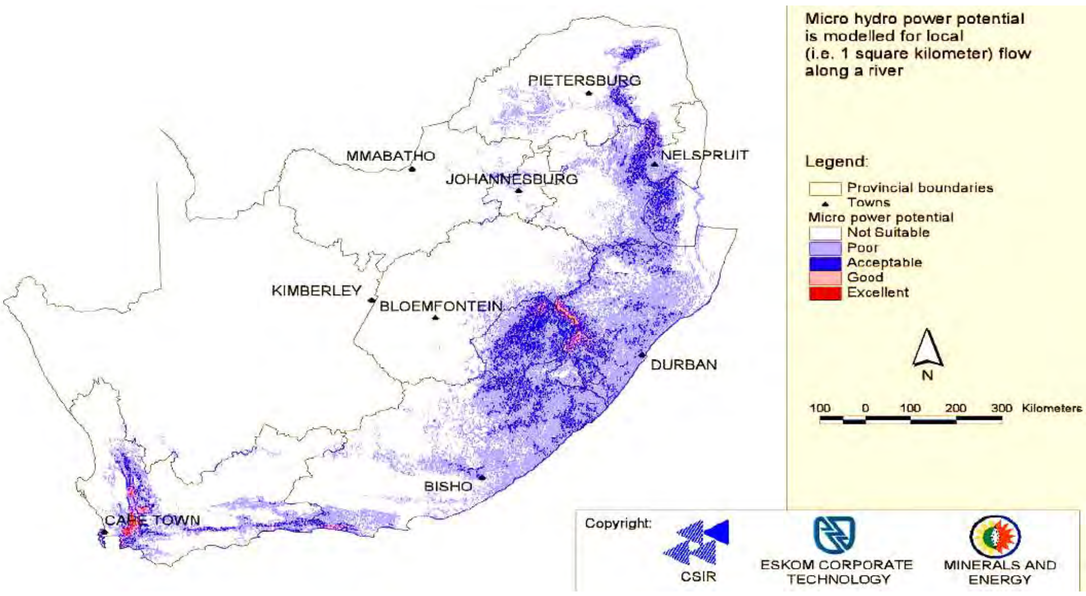


Figure 2. 5: Areas with micro hydro potential in South Africa (Barta and Stephenson, 2002)

Small schemes can either be stand-alone or a hybrid combination with other renewable energy sources. Table 2.1 shows the potential for small scale hydropower in South Africa. To date, approximately 40 MW of small hydropower is operating in South Africa (Kotze, 2011).

Table 2. 1: Small Hydro Power Potential in South Africa (After CaBEERE, 2002)

Small Hydro Power (< 10 MW)				
Category	**Type**	**Installed Capacity (MW)**	**Potential for Development**	
			Firmly Established (MW)	**Additional Long-term (MW)**
Small: 1- 10 MW	**Conventional**	25.70	27.00	20.00
	Transfers[4]	-	25.00	5.00
	Refurbishment	-	11.00	-
Mini: 100 kW- 1MW	**Conventional**	8.10	5.50	3.00
	Transfers	-	-	2.00
Micro: 20 kW- 100 kW	**Conventional**	0.10	0.40	0.50
	Transfers	-	-	3.30
Pico: ≤ 20 kW	**Conventional**	0.02	0.10	0.20
	Transfers	-	-	60.00

Two examples of small hydropower stations in South Africa are the Friedenheim hydropower station (2 MW) in Nelspruit which has been operating since 1988 and the Lydenburg hydro station (2.6 MW) in Mpumalanga which supplies electricity to the local municipality. The Friedenheim hydropower station has proved to be a commercial success with a payback period of the project after three years (Karanitsch, 2011). Table 2. 2 shows some conventional small hydro power stations in operation in South Africa.

[4] Transfer type schemes: interbasin transfer or transbasin diversion hydropower schemes such as pumped storage schemes (refer to Figure 2.7).

Table 2. 2: Conventional small-scale hydroelectric plants in operation in South Africa (after Karanitsch, 2011)

Small Hydro Electric Power Potential (conventional)	Capacity (MW)
Ceres	1.00
Densa	0.50
First Falls	6.00
Friedenheim	3.00
Glenwilliam	1.50
Hectorspruit	1.10
Kaapmuiden	0.75
Lydenburg	3.00
Malalane	1.00
Ncora	2.00
Piet Retief	1.00
Second Falls	11.00
Troske	0.50
Bethlehem	9.80
Total	***42.15***

2.3 Types of Hydropower schemes

2.3.1 Storage plants

Most of the hydropower facilities in South Africa are storage plants that use dams to store water to offset for seasonal fluctuations in water flow. Storage plants type of schemes can provide a constant supply of electricity throughout the year.

Water flows down a penstock which turns the turbine as shown in Figure 2. 6.

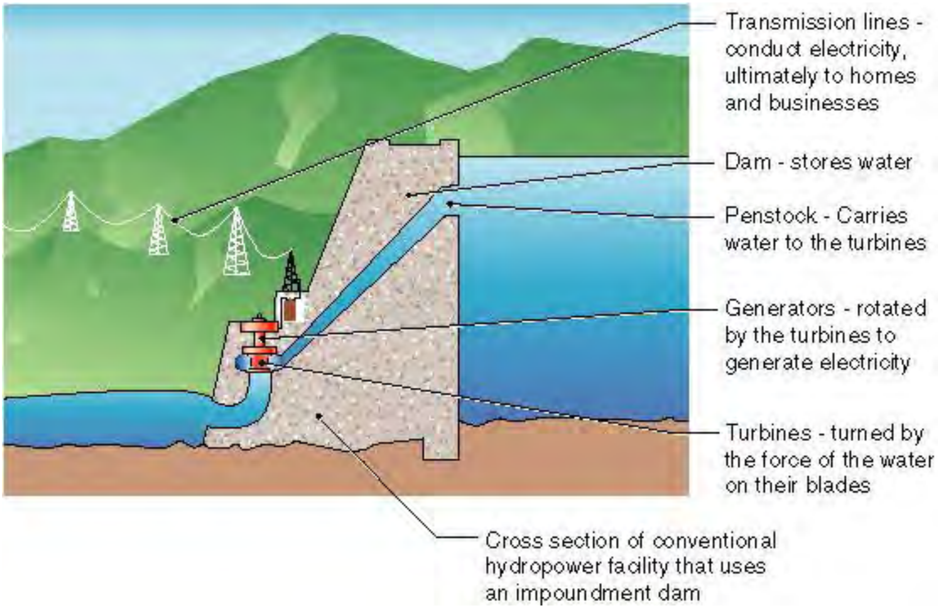


Figure 2. 6: Conventional Storage Plant (Idaho National Lab, 2012)

The produced power can be used locally or sent over transmission lines to populated centres (Campbell, 2012). Due to no fuel needed to generate power, the maintenance and operation of the dams and other infrastructure are the major on-going expense.

The dam has several functions in this type of scheme:

- Storage of water for irrigation
- Flood control
- Recreational activities

2.3.2 Pumped storage

This type of scheme “recycles” water after it initially produced electricity. Two reservoirs at different elevations “recycle” the water from the lower reservoir during times of low energy demand via pumps for times of peak energy use. Figure 2. 7 shows the basic operations of a pumped storage scheme.

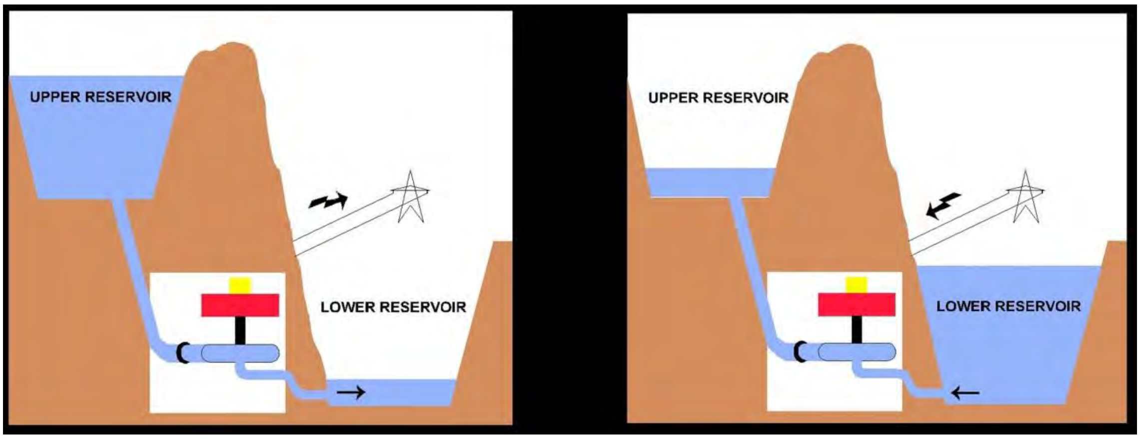


Figure 2. 7: Pump Storage Scheme (Eskom, 2011)

2.3.3 Run-of-river schemes

This type of scheme is a result of the turbine generating electricity according to the availability of water provided by the river (Pelikan, 2004). Due to the dependence of the varied flow of the river, generation ceases when the flow falls below an amount or minimum technical flow for the turbine (Pelikan, 2004; Penche, 2004). This type of scheme often requires supplemental power when in an isolated area due to irregular flow unless the demand is lower than the rated generated power of the scheme (Kosnik, 2010).

Small scale plants can be designed using large flow rates with low head or small flow rates with high head (Campbell, 2012). Diversion methods are examples of run-of-river schemes in which a portion of water is channelled by a canal or penstock for power generation. Figure 2. 8 is an example of a diversion hydropower scheme.

Figure 2. 8: Run-of-River Scheme (Idaho National Lab, 2012)

Low-head schemes are usually built in river valleys. Water can either be directed to the turbine intake via a short penstock as presented in Figure 2. 9. Hydraulic head can also be provided by the use of sector gates creating a small dam as shown in Figure 2. 10.

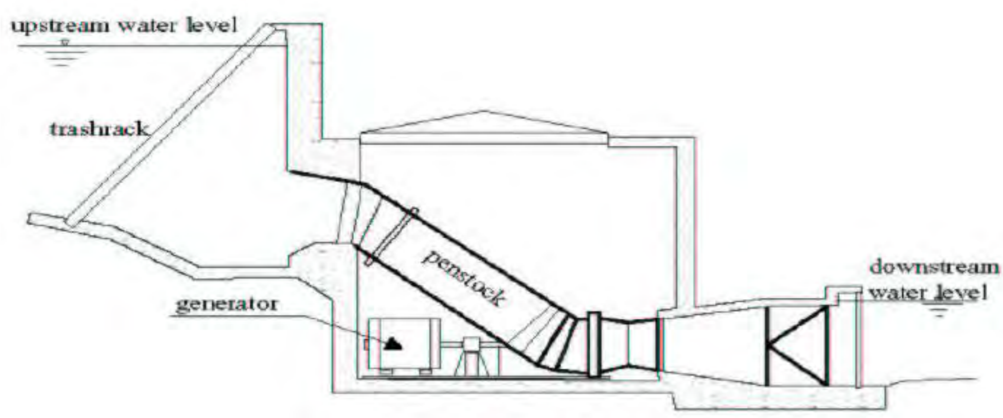


Figure 2. 9: Low head diversion scheme (Gulliver, 1991)

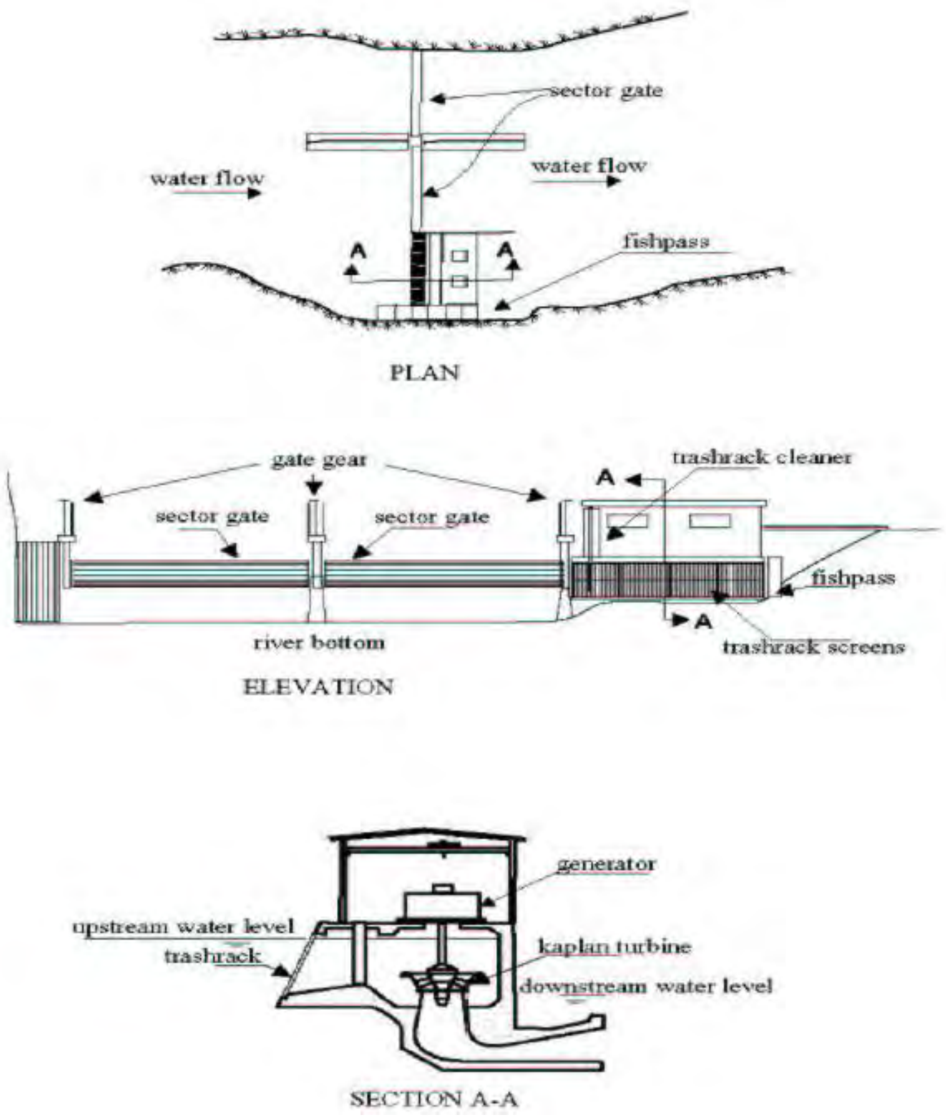


Figure 2. 10: head provision by use of sector gates (Gulliver, 1991)

Since many low-head projects seek to minimize infrastructure and costs, these types of projects are usually run-of-river and are designed to operate at optimal river levels but will cease to produce electricity when the river reaches its minimal flow (Campbell, 2012).

2.4 Small scale hydro generation ranges

Small scale hydropower generation typically refers to generating capabilities of less than 10 MW.

Although there is no international agreement on the definition of hydro sizes, different countries adopt different ranges and standards. For the purpose of definition, this thesis uses the following standards on hydro size presented in Table 2. 3. For simplicity and clarity, all schemes below 10 MW will be referred to as small scale schemes. Hydroelectric sites are also divided according to head as detailed in Table 2. 4.

Table 2. 3: Small Scale Scheme Classification (After Fritz, 1984)

Scheme	Range
Small scale	<10 MW
Mini scale	<1 MW
Micro scale	<100 kW
Pico scale	<20 kW

Table 2. 4: Small Scale Head Classification (After Fritz, 1984)

Low head	2-20 m
Medium head	20-150 m
High head	>150 m

2.5 Small scale hydro power station civil works and critical components

2.5.1 Intake structures

An intake structure is required in order to convey the water from the river to the power house and turbine (Van Vuuren *et al.,* 2011). The design of the intake structure is based on reducing the head losses, cost, maintenance and environmental impacts. Trash racks are utilised to limit the possibility of intake of foreign material which can damage the turbine.

2.5.2 Penstock diameter

This pipe structure is used to convey the water from the river under pressure from the intake of the powerhouse to the entrance of the turbine. Penstock diameter usually requires optimisation in order to reduce project costs as this component's costs increase exponentially according to length and diameter.

The economic diameter of the penstock for small hydro applications is done by utilising Equation 2.1 (Fritz, 1984).

$$\boldsymbol{D_e = C_1 C_2 {Q_0}^{0.43} {H_0}^{-0.24}} \qquad \text{Equation 2. 1}$$

Where:

D_e= economic diameter (m)

Q_o= design discharge of the penstock or plant (m^3/s)

H_o= design head of plant (m)

C_1= coefficient taking in to consideration the energy cost in the area.

C_1= 1.2 for areas where the energy cost is low

C_1= 1.3 for areas where the energy cost is medium

C_1= 1.4 for areas where the energy cost is high or no alternative source exists.

C_2= coefficient taking in to account the material for the penstock; 1 for steel penstocks,

1.05-1.1 for wood stave pipes, 0.90-0.95 for plastic pipes.

Gordon and Penman (1979) suggest the use of Equation 2.2 for estimating optimal diameter based on the design discharge.

$$\boldsymbol{d_p = 720\sqrt{Q_d}} \qquad \text{Equation 2. 2}$$

2.5.3 Penstock thickness

Penstock thickness increases as the diameter increases. This is due to the proportional relationship of their parameters. Equation 2.3 can be used to approximate the thickness of the penstock wall.

$$\boldsymbol{t_k = \frac{d_p.P_i}{2\sigma_{allow}}} \qquad \text{Equation 2. 3}$$

Where:

t_k= Thickness in mm

d_p= Diameter in mm

σ_{allow}= Allowable tensile strength (N/m^2)

P_i= Internal pressure (N/m^2)

2.5.4 Powerhouse

A turbine housing structure is required to protect the electromechanical equipment from weather effects. Powerhouse components include inlet valves, gates, turbine, generator and transformer if required (Van Vuuren *et al.,* 2011). Fritz (1984) developed a design chart to approximate the floor area for the electromechanical equipment based on discharge capacity and available head of the small hydro scheme. Reference to Pelton and Francis turbines are made in Figure 2.11 (discussed in Section 2.8.1: Turbines).

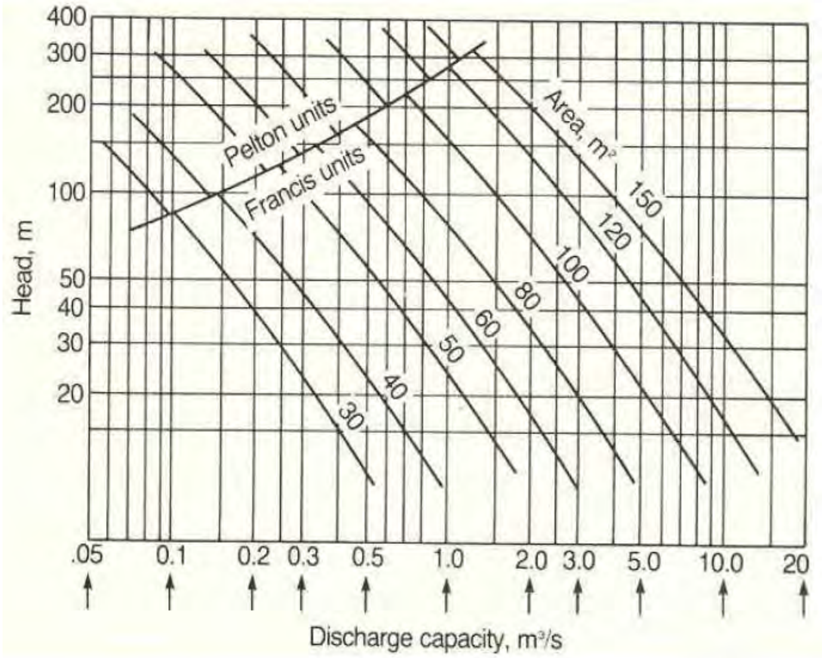


Figure 2. 11: Power House Floor Area (Fritz, 1984)

Sub-structures are also required in order to develop better approximations on the potential cost of a project. Gulliver (1991) suggests the use of formulae to approximate the volume of concrete which is based on the turbine throat diameter.

Gulliver (1991) states that the volume of concrete within a power houses substructure on competent rock foundation is given by Equation 2.4:

$$\boldsymbol{V = K(N + 0.5)d^{2.4}} \qquad \text{Equation 2. 4}$$

Where:

V= volume of concrete, m^3

N= number of units

d= turbine throat diameter (m)

K= 140 for vertical-axis Francis, Kaplan and Propeller units

K=130 for horizontal axis tube or bulb units

2.5.5 Outlet structures

The function of outlet structures is to return the water from the turbine back into the river. If the powerhouse is near the river, than direct conveyance is possible (Van Vuuren *et al.,* 2011). Exit velocities are crucial in order to limit sedimentation and erosion of the river banks. If exit velocities are high, than tailrace or canal structures must be designed and implemented. Figure 2. 12 depicts the general site layout needed for small-scale hydroelectric power generation.

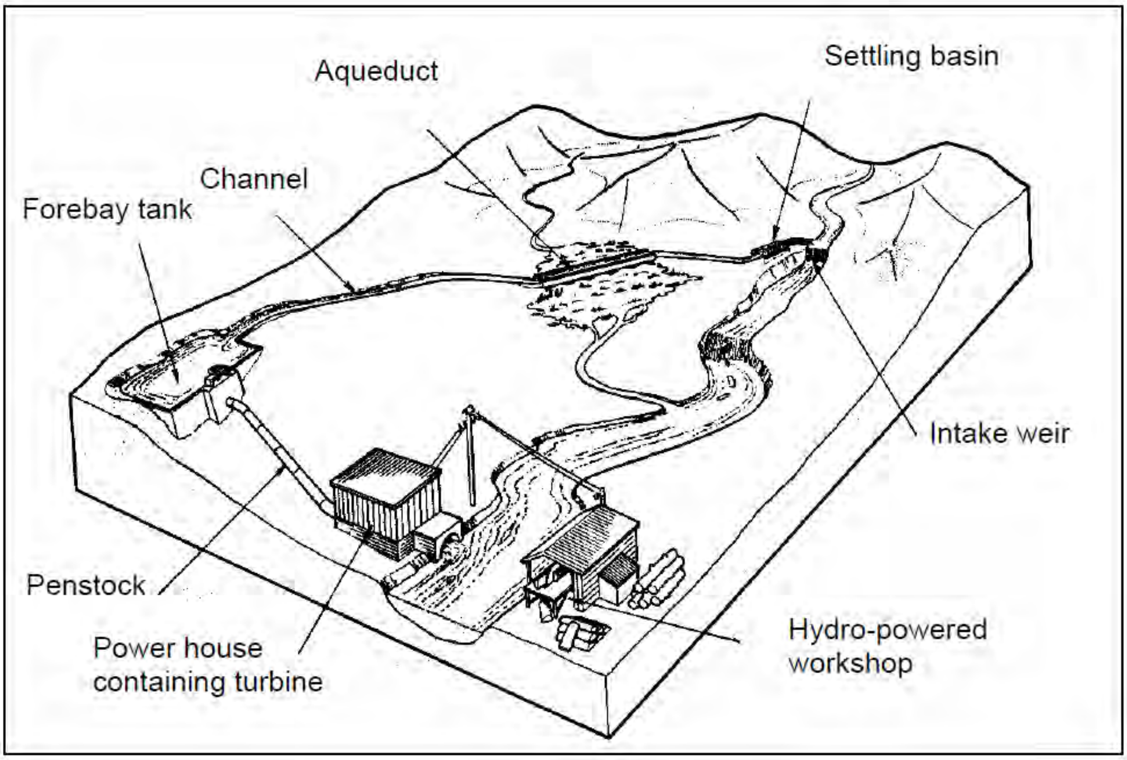


Figure 2. 12: Typical small hydro site layout (Nottingham Trent University, 2012)

2.6 Small - scale hydro generation examples

2.6.1 India

The first small-scale hydroelectric power plant in India was commissioned in 1897 and had a capacity of 130 kW (Varun *et al.,* 2008). Other examples of small-scale hydro schemes that are in still working order are: Shivasundaram in Mysore with a capacity of 2 MW built in 1902 and the Galogi in Mussoorie with capacity of 3 MW built in 1907.

The diversion scheme of the Karmi- III hydroelectric power plant, using the Saryu River, has a capacity of 50 kW and net head of 55 metres (Varun *et al.,* 2008). The Jakhna hydro power scheme located in the hilly area of Bhilanga possesses a net head of about 48 metres and utilises a design flow of 0.28 m^3/s (Varun *et al.,* 2008). The 100 kW scheme supplies a total population of approximately 260 families. Table 2. 5shows the payback period of the Karmi-III and Jakhna hydro scheme with carbon dioxide Green House Gas (GHG) equivalent emission avoidance:

Table 2. 5: Small Hydro Power Schemes, examples in India (after Vaarun *et al.*, 2008)

Scheme	Capacity (kW)	Renewable Energy (kWh/year)	Pay-back Period (years)	GHG (gCO_{2eq}/kWh)
Karmi-III	50	332880	2.71	74.88
Jakhna	100	665760	1.99	55.42

2.6.2 Africa

In Zimbabwe, the Svinurayi hydro-power scheme has an estimated output of 10 kW and was installed in the 1930's (Klunne, 2011). It is currently been used for powering shops and the sugar cane crusher and is utilised for lighting roads and schools of the local area.

The Tungu-Kabiri hydropower scheme (10 kW) in Kenya supplies approximately 200 households in the nearby community (Klunne, 2011). The schemes cost between 1920 $/kW to 6400 $/kW and were built and are maintained by the village residents it supplies (Klunne, 2011).

2.7 Environmental, Social and Barrier Issues Arising from Small -scale Hydro Generation

2.7.1 Environmental issues

Irrespective of the size of the development, authorisation is only awarded in terms of the National Water Act according the DWAF (DWAF, 2012).

Unlike conventional large hydro developments such as pump and water storage, which often require flooding of land upstream of the dammed structure which can significantly change the water quality, small scale hydro has no dam or appropriate structure hence in theory it should not affect the river's ecology.

Conventional hydro schemes usually adversely affect the fauna and flora of the surrounding area and can also have severe impacts on migratory fish species (Campbell, 2012).

Water in the reservoir has the potential to become stratified where the surface water becomes warmer and cooler water remains at the bottom isolated from oxygen. Due to the lack of oxygen at the bottom of the reservoir, metals can dissolve more easily from the surrounding rock which can be released downstream of the river which can become toxic (Campbell, 2012).

Most of the negative environmental impacts of small scale hydro developments can be mitigated by good design and efficient operating procedures. It should take into account the seasonal variations of flow in the river in order to mitigate its potential impacts on wildlife. Although not common for small scale hydro generation, a small damming structure can still adversely affect the water quality and alter the natural flow regime of that river. Low-head hydropower developments can affect the water quality, soils and groundwater as well as the native plant and animal species (DWAF, 2012).

Some of the common anthropogenic impacts that would occur during construction are:

- The impact on aquatic fauna and flora
- The impacts of river diversion, both temporary and permanent on the downstream channel characteristics
- Increased noise and vibration levels occurring during the construction and operational phases
- Visual impacts of the structure after construction
- The impact on residents in the area by altering the flow of water they receive, destroying land that they deem culturally significant, or altering the natural habitat in a way that they find unacceptable.

2.7.2 Potential social impacts of hydropower

Public participation is an important component in preparing the necessary documents for construction. The Public/affected parties' should be given the platform to voice their concerns over the project.

Some of the general areas of consideration are:

- The cultural heritage of the site.
- Potential public health threats resulting from changes in downstream flow regimes or changes in the water quality.
- Public acceptance by the community and affected parties to increase buy-in and reduce vandalism.
- Impacts on downstream agricultural activities.
- The balance between community upliftment and the preservation of traditional ways.

Eskom (2011) states that:

"For every 1 GWh saved, 0.99 kilo tonnes of CO_2 are avoided."

Despite all the possible negative environmental impacts, there is one major positive environmental consequence in the form of greenhouse gas emission reductions which indirectly affects wildlife, nature and the general public.

2.7.3 Barriers to the use of renewable energy in Africa

Although the contribution of African countries to GHG emissions is, on a per capita basis, significantly smaller than western countries such as United States of America, the effects of climate change are evident due to the unpredictable nature of weather patterns which poor Africans citizens are heavily dependent on for their rain fed agriculture (Karekezi *et al.,* 2003).

Renewable technologies such as small scale hydro power cannot solve Africa's entire energy needs but do offer a significant unexploited potential to enable African countries to meet their growing energy requirements. Although many national and international resources have been committed to develop, adapt and distribute renewable technology, this is often insubstantial and insignificant compared to what is actually needed by the energy sector. The major barriers to the adoption of renewable technology will be discussed namely: Policy and Legal Barriers, Technical Barriers and Financial Barriers.

Existing government policy should ideally form a platform in order to create and enable a framework, in which renewable technologies are acquired, distributed and to gather necessary resources both human and electromechanical. This can also encourage investment from the private sector (Sampa, 1994).

Most governments do not have a clear-cut policy on the development and promotion of RET's (Karekezi and Karottki, 1989). Limited policy support for renewables is further demonstrated by the low budgetary allocations to renewables in most countries.
The introduction of unfamiliar technologies such as RET's requires the development of technical skills. The importance of technical know-how in the increased utilisation of RET's has been recognised in the region, but in spite of efforts by governments, there is a continuing shortage of qualified personnel. Technical skills are a critical component in assessing and developing RET's.
Financing plays a major role in developing RET policies, Governments and private enterprises must therefore seek creative ways of financing RET projects.
High equipment cost due to importation fees also results in unstable funding measures whereas the components can be manufactured and assembled using local available resources.

2.7.4 Overcoming the barriers

2.7.4.1 Appropriate technology, Technology transfer and Building local capacity

With the dissemination of the new technologies, thought should be given to the existing technical knowledge and know how as this will form a platform for the new technology allowing improvement in existing development techniques and are likely to be more successful in implementation.

With increased financial support at national and international levels for such technologies, it may be possible for an African country to become a significant player in the global renewable energy industry.

Modest changes to university and colleges curricula, with emphasis on renewable technologies, will allow for an increase in skilled engineers familiar in renewable technologies, policy analyst and technicians.

2.7.4.2 Innovative financing mechanisms

Funding allocations for the renewable technologies should be made; which could be based on modest tax on fossil fuels as well as credit schemes. Due to the high capital cost associated with renewable technologies such as small scale hydro power, it is usually difficult in acquiring funds for the project. Based on experience, the initial stage is always the costly phase but with time, the project becomes self-sustainable in the financial sense.

The Clean Development Mechanism (CDM) is based on the reduction of GHG emissions of developing countries by means of the commitment, by ways of investments, by industrialised countries. The rationale is that it is less costly to reduce GHG emissions in developing countries.

South Africa recognises the challenges faced with its current primary form of power generation, i.e. greenhouse gases such as carbon dioxide. This issue was mentioned in the World Summit on Sustainable Development in 2002 in Johannesburg and as a result, the South African Government has made a commitment to promote renewable energy and recognises the global effort to mitigate greenhouse gas emissions (Department of Minerals and Energy, 2003).

A framework is being developed within which the renewable energy industry can operate, grow and contribute to the South African economy and global environment.

At the moment, renewables are slow in uptake as lack of renewable energy resource development as well as the low cost associated with the competing fossil fuel electricity generation exists.

The improvement in the uptake of renewables will be dependent on financial incentives offered which will have to come from the South African government as well as the private sector and international sources. Funding can be obtained from the Global Environment Facility and the Clean Development Mechanism to reduce greenhouse gas emissions as South Africa is sanctioned with the United Nations Framework Convention on Climate Change (1997) and the Kyoto Protocol (2002).

The government's medium-term target is 10 000 GWh renewable energy contribution to final energy consumption by 2013 from sources such as wind, solar and small-scale hydro developments. Financing for these developments is constrained due to higher priority national activities (Department of Minerals and Energy, 2003).

It is expected that the cost of coal-based generation will increase and new power generation capacity will increase therefore the South African funding would be recognised and increased. The changes are expected to make it feasible to make rapid progress towards the target over the period 2009 – 2014.

A sustainable development can be achieved with the implementation of renewable energy produced from natural sources such as small hydro schemes as it will be naturally available and insensitive to international crises.

"There is therefore a need for Government to create an enabling environment through the introduction of fiscal and financial support mechanisms within an appropriate legal and regulatory framework to allow renewable energy technologies to compete with fossil-based technologies" (Department of Minerals and Energy, 2003).

Renewable energy can contribute to the diversification of energy resources through the proper implementation of management and sufficient incentive programmes for sustainable development. Although renewables have higher investment costs, operation and maintenance is much lower than the conventional fossil-fuelled energy generation technologies.

2.8 Small scale hydropower station: electro -mechanical works

2.8.1 Turbines

This machinery converts the potential energy of the water into mechanical energy. The mechanism is done by one of two means:

- The water pressure can apply a force on the face of the runner blades which decrease as it progresses through the turbine (Pelikan, 2004). Turbines that operate in this manner are called reaction turbines. Francis and Kaplan turbines belong to this category.
- The water pressure is converted into kinetic energy before entering the runner. The energy is in the form of a high-speed jet that strikes the buckets which are mounted on the side of the runner (Pelikan, 2004). Turbines that operate in this manner are termed impulse turbines with the most common being the Pelton turbine.

The hydraulic power produced by the turbine is given as:

$$P_h = \rho Q . gH \ \text{(W)} \qquad \text{Equation 2. 5}$$

Where:

- ρQ= mass flow rate (kg/s)
- ρ= specific density of water (kg/m^3)
- Q= discharge (m^3/s)
- gH= specific hydraulic energy of machine (J/kg)
- g= gravitational acceleration (m/s^2)
- H= net head (m)

The mechanical output of the turbine is given by:

$$P_{mechanical} = P_h . \eta \qquad \text{Equation 2. 6}$$

Where:

- η= turbine efficiency

The hydraulic circuit diagram for the turbine system is as shown in Figure 2. 13:

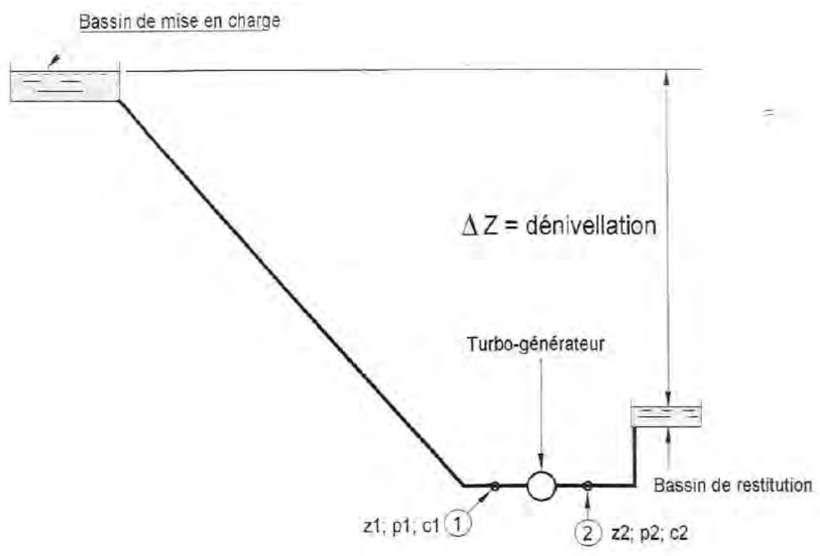


Figure 2. 13: Schematic view of a hydropower scheme and of the measurement sections of a circuit diagram (Pelikan, 2004)

The Equation governing the hydraulic energy is:

$$E = gH = \frac{1}{\rho}(p_1 - p_2) + \frac{1}{2}\left(c_1^2 - c_2^2\right) + g(z_1 - z_2) \qquad \text{Equation 2. 7}$$

Where:

- gH= specific hydraulic energy of the machine (J/kg)
- p_x= pressure in section x as shown in figure (Pa)
- c_x= water velocity in section x (m/s)
- z_x= elevation of the section x (m)

The subscripts 1 and 2 denote the upstream and downstream measurements respectively

Therefore the net head can be defined as:

$$H_n = {}^{E}/_{g} \text{ (m)} \qquad \text{Equation 2. 8}$$

2.8.1.1 Turbine types- Impulse:

Pelton turbines

The Pelton turbine is an impulse turbine. One or more jets impact a wheel which carries several buckets. The jets are produced as water passes through a nozzle with a needle valve for flow control. Typical usage is for heads from 60 m to over 1000 m. In the event of an emergency stop of the turbine the jets may be diverted by the deflector so that the buckets do not reach runaway speed and the needle valve can be gradually closed so as to prevent surge pressures from reaching dangerous levels (Penche, 2004). Figure 2. 14 shows a typical cross sectional configuration of the nozzle with deflector. The tangential component of the exit velocity is kept low since, otherwise the tangential component contributor to the rotation of the rotor is lost.

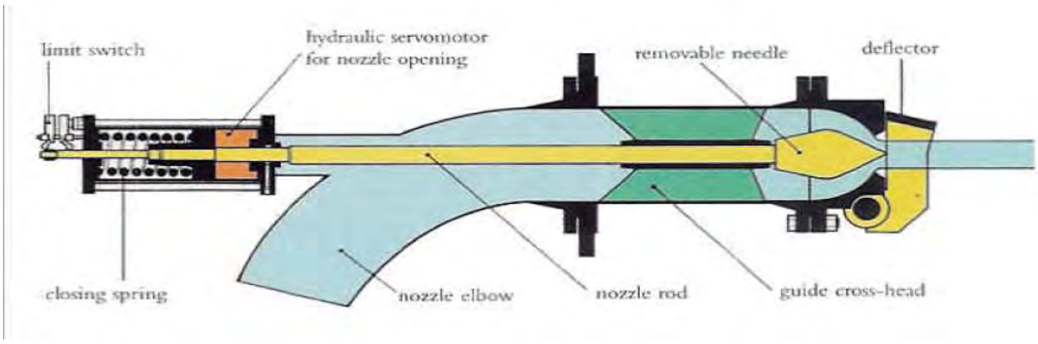


Figure 2. 14: Cross section of nozzle with deflector (Penche, 2004)

Based on maximum discharge for a one jet turbine, typical efficiency range from 30 % to 95 % and for multi jet turbines are from 10 % to 90 %.

Turgo turbines

Turgo turbines typically operate at hydraulic heads that range from 50- 250 m. The impulse turbine's buckets are shaped differently due to the water striking the plane of its runner at a 20° angle (Pelikan, 2004). Water enters the runner through one side of the runner disk and emerges from the other side as shown in Figure 2. 15. Typically, efficiencies range from 20- 95 % of maximal turgo turbine design flow (Pelikan, 2004).

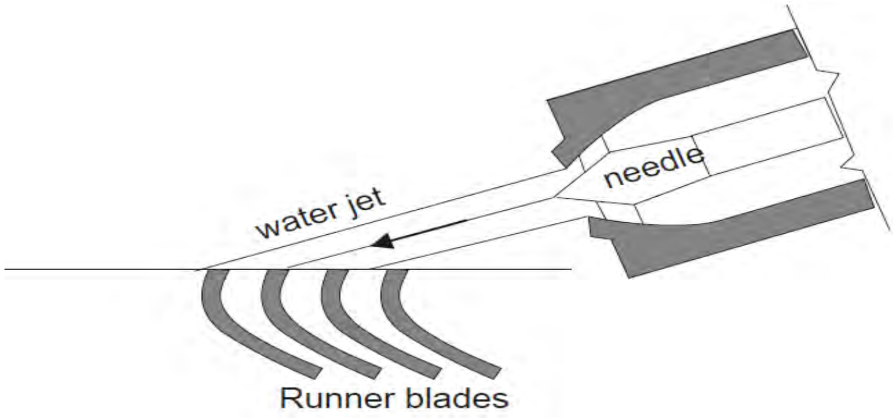


Figure 2. 15: Principle of Turgo turbine (Penche, 2004)

Cross-flow turbines

The cross - flow impulse turbine, commonly known as Banki-Michell, is used for a wide range of heads overlapping those of the Kaplan, Francis and Pelton as it can operate heads from 5-200 m.

Water enters the turbine as directed by one or more guide-vanes located upstream of the runner and crosses it twice before leaving the turbine (Penche, 2004; Paish, 2002). Figure 2. 16 depicts the principle of the cross – flow turbine.

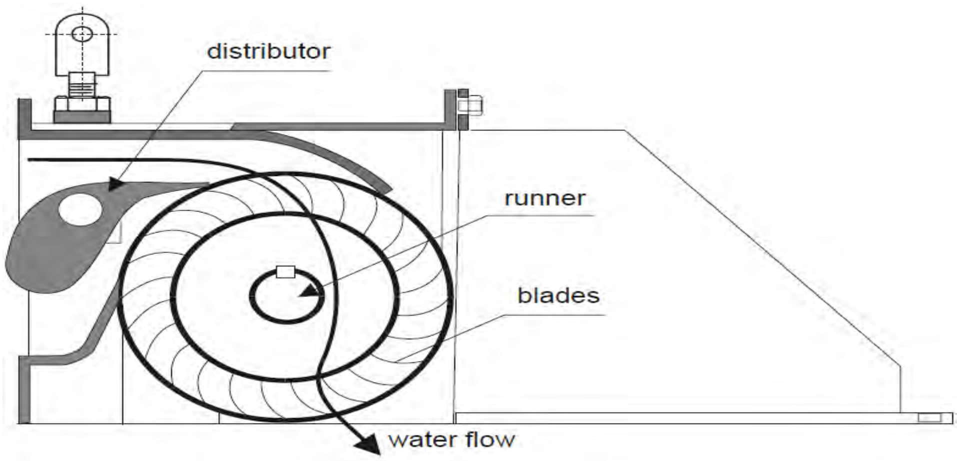


Figure 2. 16: Principle of a Cross-flow turbine (Penche, 2004)

Due to the cross – flow turbine's simplistic design, it is inexpensive and easy to repair in cases of runner breakage but does have a lower efficiency compared to the other turbines discussed in this study.

2.8.1.2 Turbine types- Reaction:

Francis turbines are reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. Francis turbines usual field of application is from 25 to 350 m head (Penche, 2004).

As with Peltons, Francis turbines (refer to Figure 2. 17) can have vertical or horizontal axis either of which is common in small – scale hydro due to the lower hydraulic head available allowing for easier configuration.

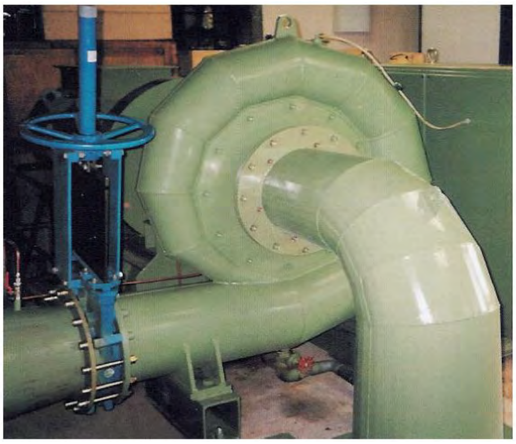


Figure 2. 17: Horizontal axis Francis turbine (Penche, 2004)

The reaction turbine configuration contains mobile guide vanes, as shown in Figure 2. 18, whose function it is to control the discharge going into the runner and adapts the inlet angle of the flow to the runner blades angles. They can be used to shut off the flow to the turbine in emergency situations such as load rejection.

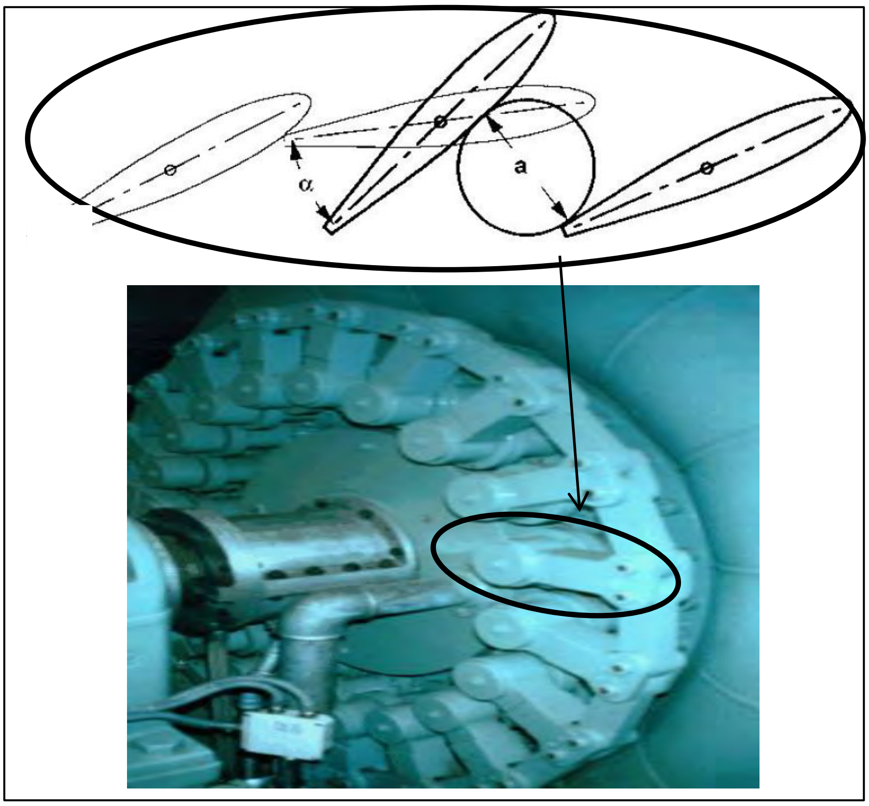


Figure 2. 18: Guide vane functioning principle with Francis turbine guide vane operating device (Penche, 2004)

Kaplan and Propeller turbines

Kaplan and propeller turbines are axial-flow reaction turbines; generally used for low heads from 2 to 40 m. The Kaplan turbine has adjustable runner blades and may or may not have adjustable guide- vanes. If both blades and guide-vanes are adjustable it is described as "double-regulated" as depicted in Figure 2. 19. If the guide-vanes are fixed it is "single-regulated". Fixed runner blade Kaplan turbines are called propeller turbines. Propeller turbines are used when both flow and head remain practically constant, which is a characteristic that makes them unusual in small hydropower schemes. The double regulation allows, at any time, for the adaptation of the runner and guide vanes coupling to any head or discharge variation. It is the most flexible Kaplan turbine that can work between 15 % and 80 % of the maximal design discharge. Single regulated Kaplan turbines allows a good adaptation to varying available flow but is less flexible in the case of important head variation (Pelikan, 2004). Single regulated Kaplan turbines can work between 30 % and 90 % of the maximum design discharge.

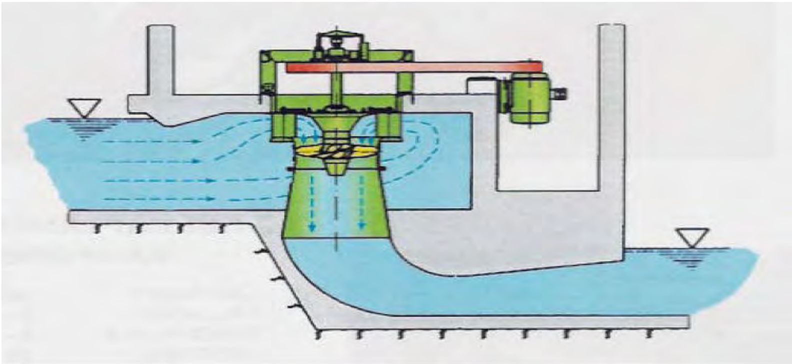


Figure 2. 19: Cross section of a double regulated Kaplan turbine (Penche, 2004)

Turbine selection is dependent on the following factors in order to reduce overall cost of a project:

• Range of discharges

• Net head

• Geomorphology of the terrain

• Environmental requirements (both visual and sonic)

• Labour cost

2.8.2 Specific speed

The specific speed of a turbine is defined by the equation:

$$n_{QE} = \frac{n.\sqrt{Q}}{E^{3/4}} \qquad \text{Equation 2. 9}$$

Where:

- Q= Discharge (m^3/s)
- E= specific hydraulic energy of machine (J/kg)
- n= rotational speed of the turbine (rev/s)

The lower the specific speed, the higher the corresponding head. Many studies have been carried out in order to correlate specific speed of the turbine to its net head (Pelikan, 2004). Generally the turbine manufacturers define the specific speed of their turbines. Some correlations are made graphically and by derived equations as in Table 2. 6 or utilising

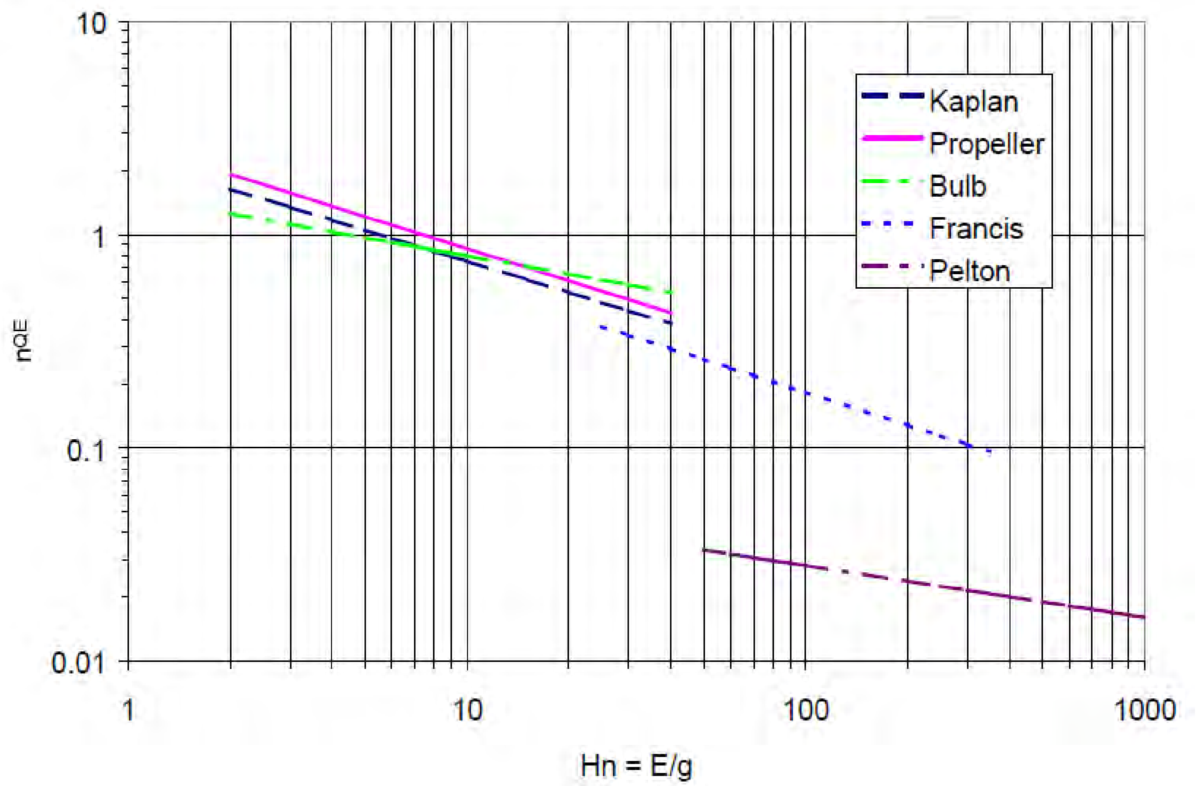


Figure 2. 20, specific speed as a function of net head.

Table 2. 6: Specific Speed of Turbine by Equation

Turbine	Specific Speed, n_{QE}=
Pelton (1 nozzle)	$\frac{0.0859}{H_n^{0.243}}$
Francis	$\frac{1.924}{H_n^{0.512}}$
Kaplan	$\frac{2.294}{H_n^{0.486}}$
Propeller	$\frac{2.716}{H_n^{0.5}}$
Bulb	$\frac{1.528}{H_n^{0.2837}}$

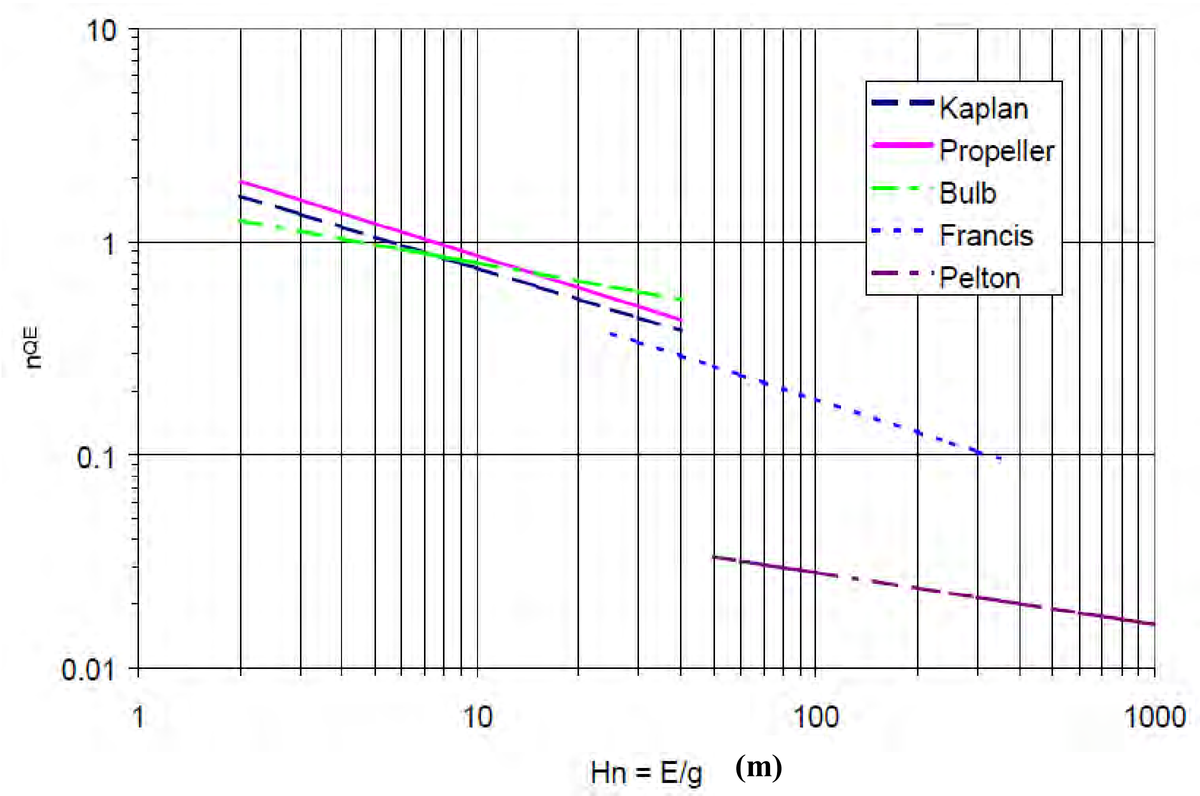


Figure 2. 20: Specific Speed as a function of net head (Paish, 2002)

With the specific speed of the turbine determined, the dimensions of the turbine can be estimated however manufacturer consultation is needed for final dimensions.

2.8.3 Preliminary design

Turbine design is a miscellaneous process with several factors such as rotational speed, specific speed and cavitation limits, amongst others. For all turbines, the initial step is to select a rotational speed.

For Pelton turbines:

With the runner speed known, the diameter can be estimated from the equations below:

$$D_1 = 0.68\frac{\sqrt{H_n}}{n} \quad \text{Equation 2. 10}$$

$$B_2 = 1.68\sqrt{\frac{Q}{n_{jet}}\frac{1}{\sqrt{H_n}}} \quad \text{Equation 2. 11}$$

$$D_e = 1.178\sqrt{\frac{Q}{n_{jet}}\frac{1}{\sqrt{gH}}} \quad \text{Equation 2. 12}$$

Where:

- n= is the rotational speed (t/s)
- n_{jet}= number of nozzles
- D_1 defined as the diameter of the circle describing the buckets centre line
- B_2 defined as the bucket width dependant on discharge and number of nozzles
- D_e defined as the nozzle diameter

As a rule the ratio $D_1/B_2 > 2.7$ if not than a new calculation with a lower rotational speed and/or more nozzles must be performed.

For Francis turbines:

Francis turbines cover a wide range of specific speeds from 0.05 to 0.33 which correspond to high head and low head respectively. The Francis cross section in Figure 2. 21shows reference diameters D_1, D_2 and D_3:

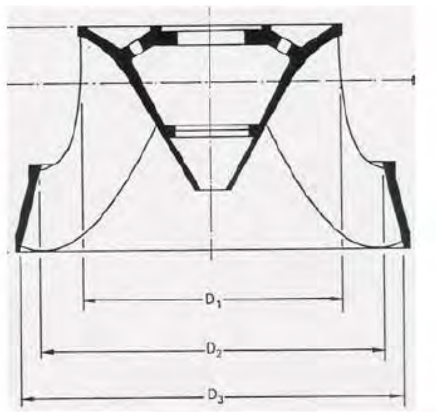


Figure 2. 21: Cross section of a Francis Runner (Paish, 2002)

The diameters can be found by using the equations below based on statistical studies:

$$\boldsymbol{D_3 = 84.5(0.31 + 2.488n_{QE})\frac{\sqrt{H_n}}{60.n}} \qquad \text{Equation 2. 13}$$

$$\boldsymbol{D_1 = \left(0.4 + \frac{0.095}{n_{QE}}\right) D_3} \qquad \text{Equation 2. 14}$$

$$\boldsymbol{D_2 = \frac{D_3}{0.96+0.3781n_{QE}}} \qquad \text{Equation 2. 15}$$

For n_{QE} >0.164 (where n_{QE} is as defined in Equation 2.9) otherwise D_1=D_2

Kaplan turbines:

Compared to the Francis and Pelton turbine, the Kaplan turbine exhibits much higher specific speeds. Refer to Figure 2. 22 and Equations 2.16 and 2.17:

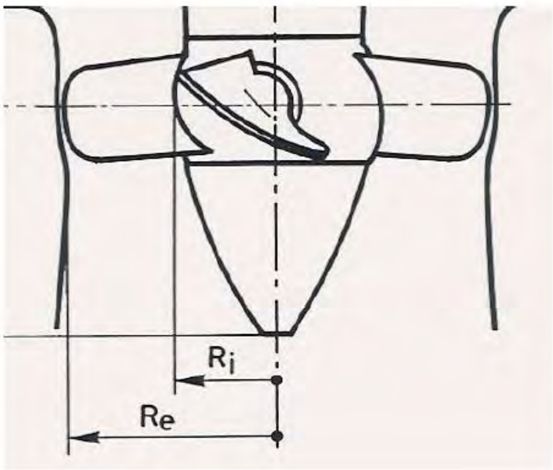


Figure 2. 22: Cross section of a Kaplan Turbine (Paish, 2002)

The outer and inner diameters can be determined from the equations below resulting in the outer and inner radii respectively:

$$\boldsymbol{D_e = 84.5(0.79 + 1.602.n_{QE})\frac{\sqrt{H_n}}{60.n}} \qquad \text{Equation 2. 16}$$

$$\boldsymbol{D_i = \left(0.25 + \frac{0.0951}{n_{QE}}\right).D_e} \qquad \text{Equation 2. 17}$$

Turbine selection will depend on the following criteria:

- Net head
- Range of discharges through the turbine
- Rotational speed
- Cavitation problems
- Cost

Net hydraulic head

The ratio of the specific hydraulic energy of the machine by the acceleration due to gravity is termed the net head. Table 2. 7 shows the net head range for the corresponding turbine. It can be seen that overlapping occurs i.e. several types of turbines can be used.

Table 2. 7: Range of heads for turbines Source: (After Gulliver and Roger, 1991)

Turbine Type	Ranges of Net Head, H_n, (m)
Kaplan and Propellor	$2 < H_n < 40$
Francis	$25 < H_n < 350$
Pelton	$50 < H_n < 1300$
Crossflow	$50 < H_n < 200$
Turgo	$50 < H_n < 250$

2.8.4 Discharge Considerations for Turbine selection

The flow regime is needed in order to determine the appropriate turbine. This can be obtained from the FDC.

The appropriate turbine can be determined based on the given rated flow and net head been plotted within the operational envelopes. It can be seen from Figure 2. 23 the overlapping occurs and either turbine can be selected in the event of the plot being within the operational envelope.

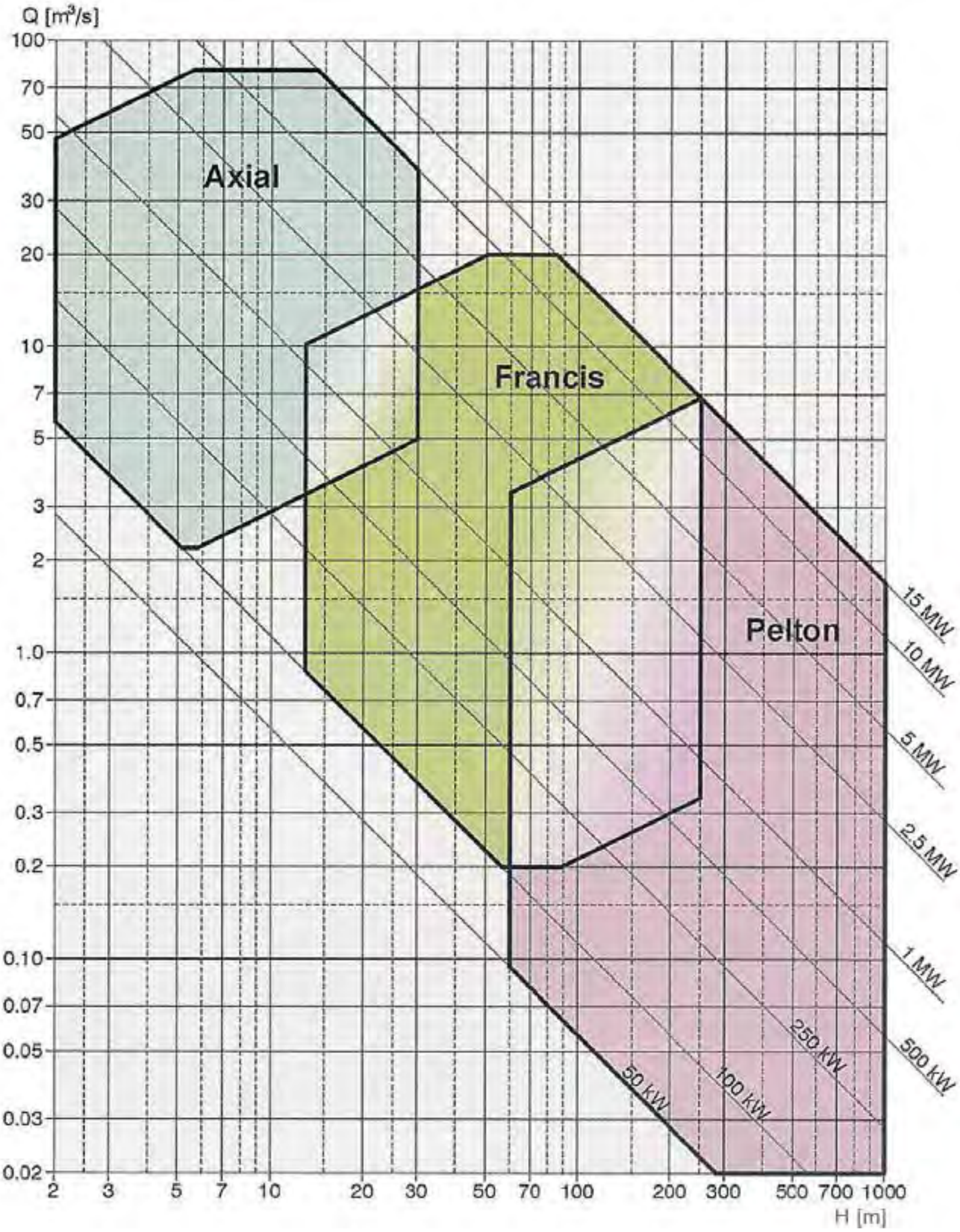


Figure 2. 23: Log scale net head and rated flow (Pelikan, 2004)

It is beneficial to install smaller turbines rather than one large turbine; the turbines can be sequentially started so that all the turbines except one will be operational at their nominal discharge and resulting in higher efficiency's. It also is beneficial to better facilitate the transport to site due to lower unit weight and volume (Penche, 2004).

Different turbines respond differently to the variations in flow and head as shown in Table 2. 8 and this combined with the FDC can allow for choice of the turbine type to be completed.

Table 2. 8: Head/Flow Variation Acceptance for Turbine (After Gulliver and Roger, 1991)

Turbine Type	Acceptance of flow variation	Acceptance of head variation
Pelton	High	Low
Francis	Medium	Low
Kaplan double regulated	High	High
Kaplan single regulated	High	Medium
Propeller	Low	Low

2.9 Turbine Efficiency Curve

Standard turbine efficiency curves have been developed for the model that includes the turbines discussed in this study:

- Kaplan (reaction turbine)
- Francis (reaction turbine)
- Propeller (reaction turbine)
- Pelton (impulse turbine)
- Turgo (impulse turbine)
- Cross-flow (generally classified as an impulse turbine).

Calculated efficiencies can be adjusted using the model worksheet provided in the RETScreen layout. The turbine selection is governed by the head and flow conditions of the site. The efficiency curves include a number of factors which are:

- Gross head less maximum hydraulic losses
- Runner diameter
- Turbine specific speed
- Manufacturer/design coefficient.

The efficiency equations are based on a number of manufacture efficiency curves for the turbines mentioned earlier. The efficiency equations are found in Appendix B. An example of a turbine efficiency curve showing the effects of using 2 turbines is shown in Figure 2. 24.

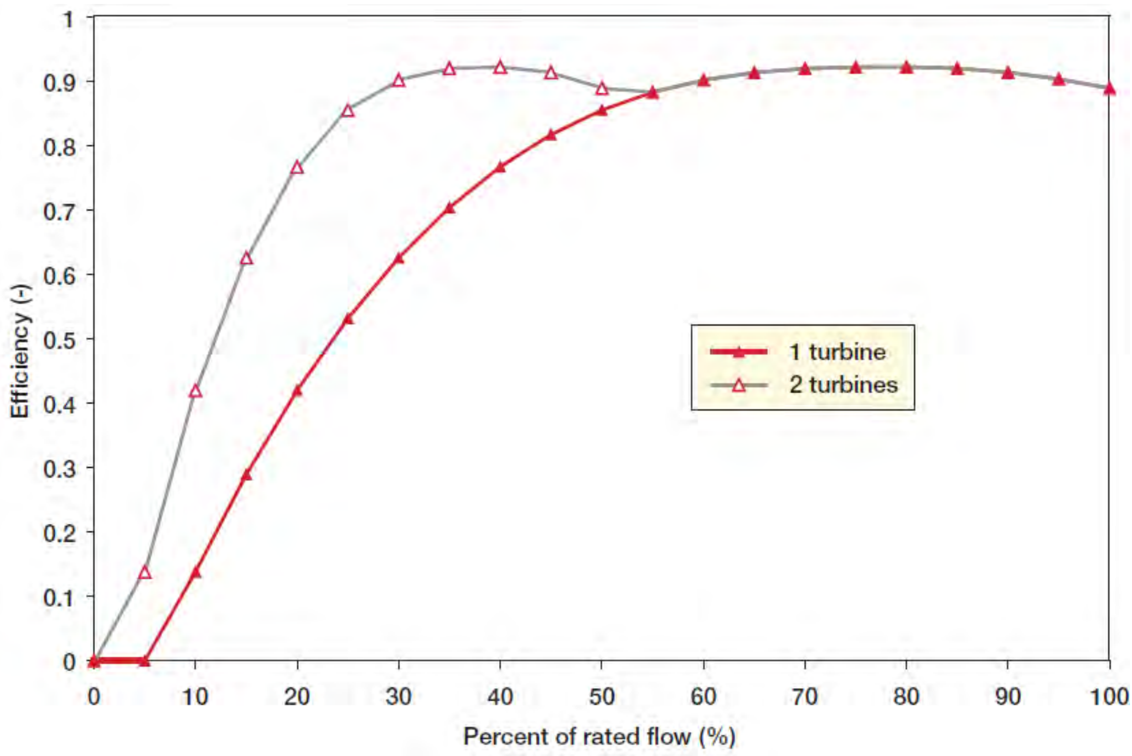


Figure 2. 24: Francis turbine calculated efficiency Curves (Kosnik, 2010)

Relative turbine efficiencies

An important difference of the various turbine types are their relative operating efficiencies which differ at design point and reduced flows. Figure 2. 25 shows the typical efficiency curves. The efficiency of the Francis turbine falls away sharply if it is run below half its normal flow. The fixed pitch propeller turbine perform very poorly except above 80 % of full flow, in contrast, the Pelton, Cross flow and Kaplan turbines retain very high efficiencies when running below design flow (Paish, 2002).

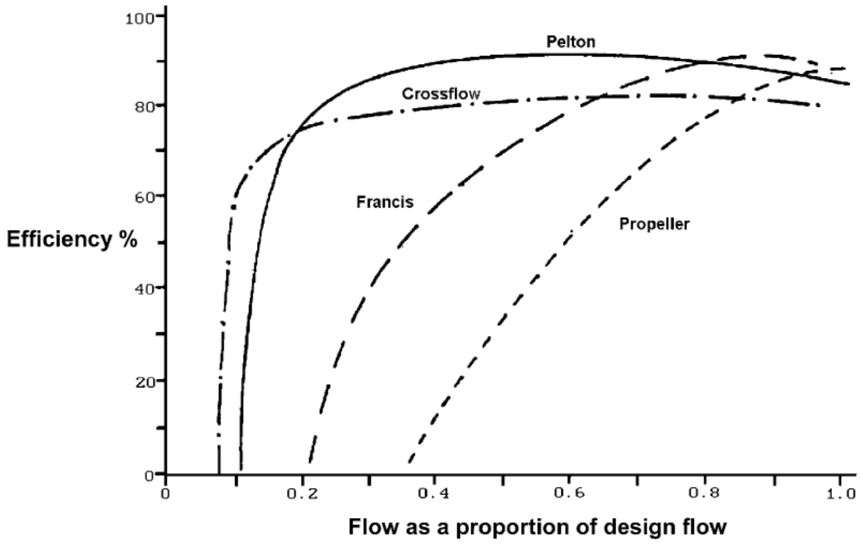


Figure 2. 25: Part – Flow Efficiencies (Paish, 2002)

2.10 Generators

Generators transform mechanical energy into electrical energy. Although most early hydroelectric systems were of the direct current variety to match early commercial electrical systems, nowadays only three-phase alternating current generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between.

Synchronous generators: They are equipped with a DC electric or permanent magnet excitation system (rotating or static) associated with a voltage regulator to control the output voltage before the generator is connected to the grid. They supply the reactive energy required by the power system when the generator is connected to the grid. Synchronous generators can run isolated from the grid and produce power since excitation is not grid-dependent (Kosnik, 2010).

Asynchronous generators: They are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. They draw their excitation current from the grid, absorbing reactive energy by their own magnetism. Adding a bank of capacitors can compensate for the absorbed reactive energy. They cannot generate when disconnected from the grid because are incapable of providing their own excitation current. However, they are used in very small stand-alone applications as a cheap solution when the required quality of the electricity supply is not very high (Kosnik, 2010).

2.11 Hydropower computations at a Small Scale Hydropower site

2.11.1 Hydropower Quantification

The basic data requirements for any hydropower potential project are given in the general power equation (Fritz, 1984):

$$\boldsymbol{P_{kW}} = \frac{\boldsymbol{\rho g Q H \eta}}{\boldsymbol{1000}} \qquad \text{Equation 2. 18}$$

Where:

P_{kW} = power output, kW

ρ= density of water, 1000 kg/m^3

g= gravitational acceleration constant, 9.81 m/s^2

Q= plant discharge, m^3/s

H= available head, m

η= plant efficiency in decimal form

Head and discharge of the river of interest are required in order to assess the hydropower power potential and development on site. In recent years, great improvements have been made in evaluating hydraulic head and discharge features with the aid of GIS (Geographic Information System) which digitally represent the geographic features such as elevation contours and RS (Remote Sensing) which are tools used for acquiring information at a particular site of interest. With the combination of the tools, an effective method of evaluation of hydropower aspects can be made and are widely used in such developments (Maidment, 2002). The tools can collectively aid the designer in highlighting hydropower potential sites such as run-of-river schemes and storage capacity dams and have been applied in the U.S.A (Hall *et al.,* 2004) and South Africa (Ballance *et al.,* 2000).

Availability of data, or lack of it, will yield a method of analysis in order to obtain the discharge of a river. This is mainly a function of whether the catchment is gauged or ungauged. Water balance techniques can be used successfully to establish surface runoff at large sites (Yates, 1997). A Flow Duration Curve (FDC) provides a means of determining the percentage of time a given discharge is equalled or exceeded over a defined period (Gulliver and Roger, 1991). A FDC can predict the availability and variability of discharge but does not simulate the actual flow sequence (Viessman Jr and Lewis, 2003). FDC's form the basis of sizing and selecting the hydromechanical equipment such as the turbine and civil works such as the penstock.

2.11.2 Development of the Flow Duration Curve

A Flow Duration Curve (FDC) illustrates the relationship between the frequency and magnitude of streamflow and is an important tool in analysing the ranges of river discharge *(*Castellarin *et al.,* 2004). Although easy to construct, FDC's become problematic when estimations need to be made at ungauged rivers or when large amounts of data are scarce. Several techniques are available for constructing FDC at ungauged sites but they vary in reliability (Castellarin *et al.,* 2004). For gauged sites the approach is much simpler as readings are merely recorded and relevant plots made. The Department of Water Affairs and Forestry (DWAF) maintain records of gauging stations located all over South Africa which can be obtained from their online database. The gauging stations location are shown in Figure 2.22 with the legend showing stations (red) in use and also those used to validate and form the database of Water Resources 2005 data and information (Middleton and Bailey, 2008). DWAF maintain streamgauge records of about 200 stations nationally as shown in Figure 2. 26.

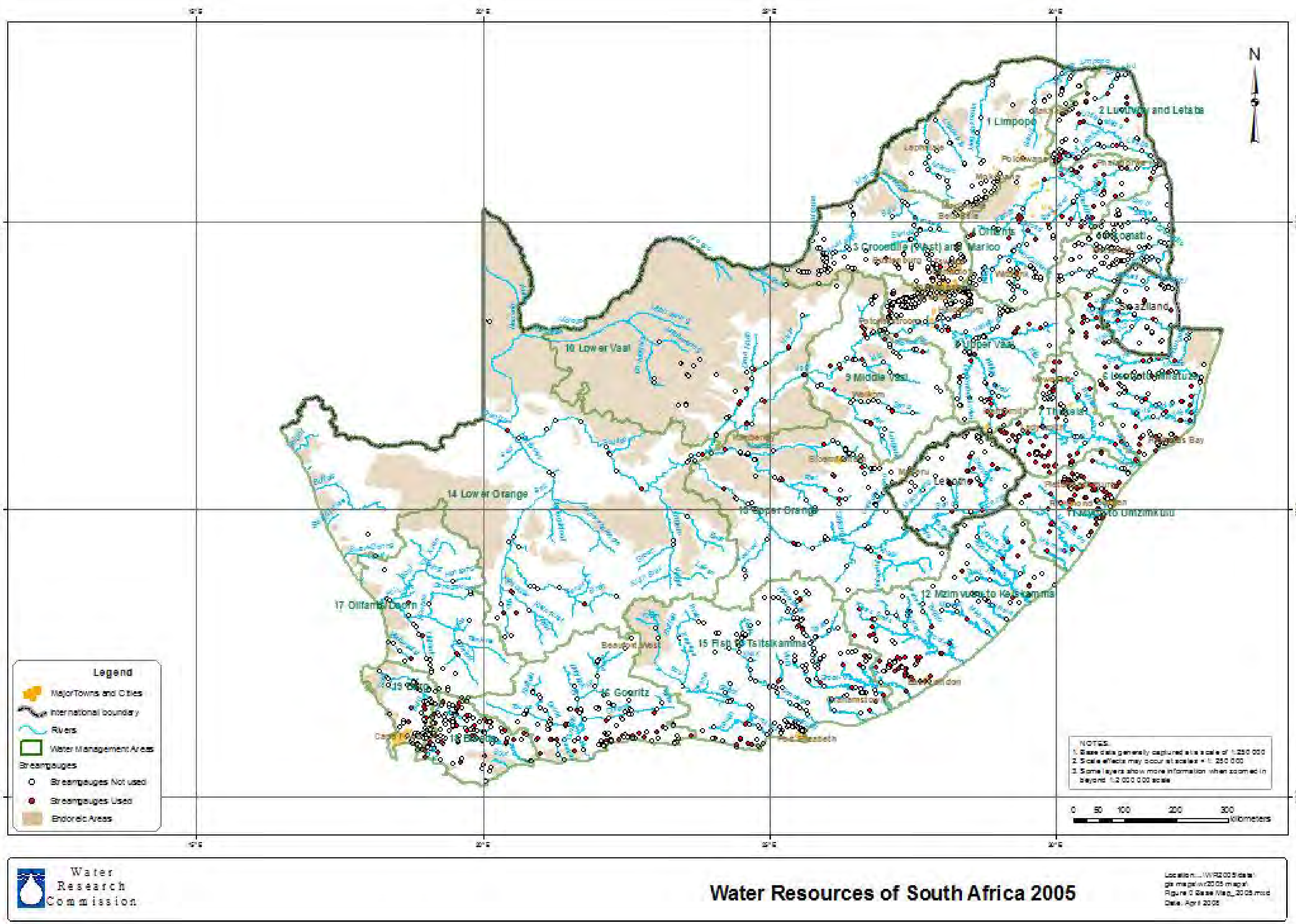


Figure 2. 26: WR2005 Streamgauges in South Africa (WR2005, 2005)

2.11.3 Regionalisation of Flow Duration Curve's

Regionalisation estimation techniques are aimed at the estimation of some particular low-flow characteristics or general flow measure applicable to any ungauged location in a specific region (Smakhtin *et al.,* 1998).

Regional FDC's are constructed by in two major steps:

1. Construction of non-dimensional 1-day FDC's for each flow gauge in a hydrologically homogenous region by dividing discharges from a curve by the mean daily flow and superposition of all individual FDC's in the region on one plot to calculate a composite regional non-dimensional FDC (Smakhtin *et al.,* 1998) HYMAS (Hydrological Modelling Application System) allows the user to establish these regional FDC's.
2. The actual required FDC for any ungauged site in the region is found by multiplying back the non-dimensional ordinates of a corresponding regional FDC by the estimate of mean daily flow which is calculated from the estimates of the Mean Annual Run-off (MAR) of the quaternary catchment (Smakhtin *et al.,* 1998).

This approach fits into two categories which distinguish between procedures that view FDC as the complement of the cumulative frequency distribution and procedures that do not make any connection between FDC and the probability theory (Castellarin *et al.,* 2004).

For the former category, the uses of stochastic models are used to represent FDC's and are performed as a suitable frequency distribution is chosen as the parent distribution for the region of interest. This is followed by the estimating the distribution parameters on a local basis for the gauged river within the study region. The regional regression models are then identified for predicting the distribution parameters at the ungauged site on the basis of geo-morphological and climatic characteristics of the site (Castellarin *et al.,* 2004).

2.11.4 Flow Estimation from patched/extended observed streamflow records

Spatial interpolation technique

Many time series data have gaps in the record which effectively shorten the record period (Smakhtin *et al.,* 1998). This implies that only a portion of the record is useable or nothing at all. In order to make the observed records useable, the data needs to be patched or extended. An algorithm is used that is based on twelve 1-day flow duration curves (one curve for each calendar month of the year).

Steps to employ technique:

1. Identify relevant source site(s) no more than 5 in the surrounding area of interest which is to be patched/extended

2. The sites are assigned weighted numbers (W_j =1-5) which is a result of the similarity of the site of interest and surrounding site's flow regimes
3. Tables of discharge are to be generated of each site and month of the year for 17 fixed percentage points of the flow duration curves i.e. DTQ_i =1-17 corresponding to 0.01, 0.1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99, 99.9 and 99.99 %
4. An estimate of streamflow on any day at the destination site[5] is then made by identifying the percentage point position on the duration curve table (for the relevant month) of the streamflows on the same day at the 'source' sites and reading off the flow value for the equivalent percentage point from the 'destination' sites duration curve table.
5. Each estimate of the 'destination' site flow value is then multiplied by the 'source' site weight and the sum of the values is divided by the sum of the weights
6. For 'source' streamflows lying between the 17 defined percentage points of the duration tables, logarithmic interpolation is used to define the position.

Limitations for this method are that due to the approach of creating representative 1-day flow duration curves for each month of the year which is dependent on the quality of streamflow records in South Africa (Smakhtin *et al.,* 1998). The accuracy and validity of the representative 1 – day FDC's are likely to decrease due to missing/gaps in the streamflow record which is currently one of the main issues experienced today. As well as been a lengthy task, without the use of specialist software such as HYMAS, the method does not allow for spatial resolution which is achieved through the use of the rainfall run-off models and is limited to the estimation at only present day conditions (Smakhtin *et al.,* 1998).

2.11.5 Transfer of Flow Duration Curve

Due to some hydropower sites of interest not having a gauging station in or near the region, adjustments are usually performed on the gauged location that is on the same river or a downstream river with a drainage area, DA, containing the sites watershed. The data from one or more gauges may then be adjusted to represent that of the site (Gulliver and Roger, 1991). Equation 2.19 is the common type of relation that is used to estimate flow-duration at a site (Gulliver and Roger, 1991).

$$Q_{site} = \left(\frac{DA_{site}}{DA_{gauge}}\right)^n Q_{gauge} \qquad \text{Equation 2. 19}$$

Where:

DA_{site}= drainage area of the power station site

DA_{gauge}= drainage area of the gauge

[5] Destination site is the record which is to be patched or extended

Q_{site}= discharge at site

Q_{gauge}= discharge at gauge

n= parameter where $0.6 < n < 1.2$ [6]

<u>Selection of n value:</u>

- If drainage area, DA, of the site is within 20 % of the DA of the gauged location i.e. $0.8 \leq \frac{DA_{site}}{DA_{gauge}} \leq 1.2$ than use n=1
- If DA of the site is within 50 % of the DA of the gauged locations, than considerations should be made for combining the two gauged locations (up/down stream) i.e. the site is between two gauged locations (Gulliver and Roger, 1991). Equation 2.20 can be applied if the above statement is true.

$$Q_{site} = \frac{(DA_{gauge1} - DA_{site})Q_{gauge1} + (DA_{site} - DA_{gauge2})Q_{gauge2}}{DA_{gauge1} - DA_{gauge2}} \qquad \text{Equation 2. 20}$$

2.11.6 Construction of Flow Duration Curves

A Flow Duration Curve (FDC) is a curve that describes the time availability of flow at a certain point in a river (Fritz, 1984). It is a plot of flow versus the percent of time that a river flow can be expected to be or exceeded and aids in preliminary design as a means of checking proposed site installations (Fritz, 1984). Figure 2. 27 shows an example of a FDC.

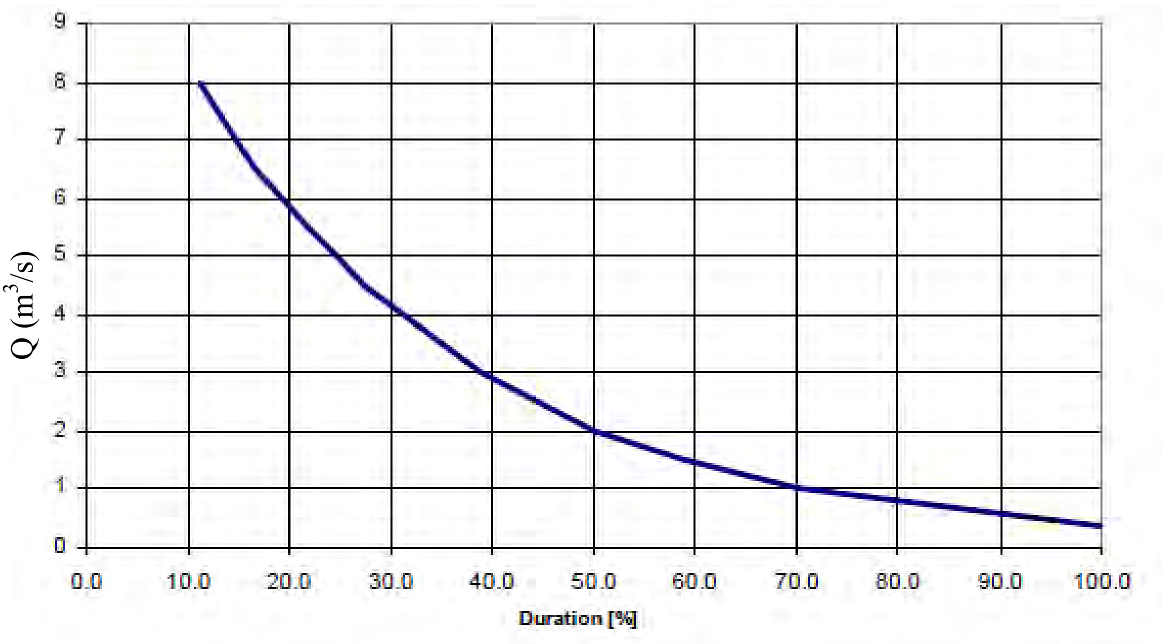


Figure 2. 27: FDC example (Penche, 2004)

[6] It should be noted that when n=1 than the above equation is merely a transfer by proportion of areas.

In order to develop a FDC a historic river hydrograph is required from site which shows the fluctuations of flow over time. The longer the hydrograph record implies that the design will be less sensitive to abnormal variations in flow. An example of a river hydrograph is shown in Figure 2. 28.

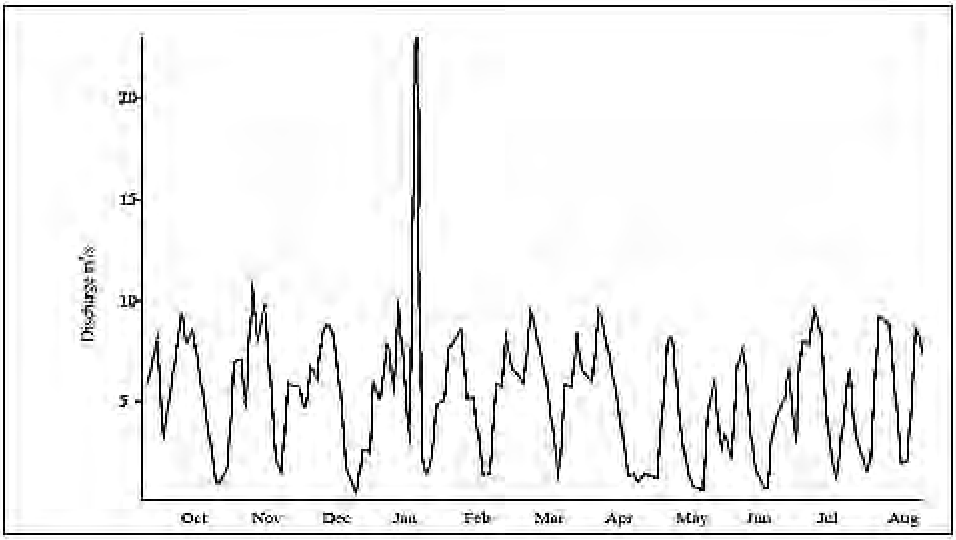


Figure 2. 28: Example of a River Hydrograph (Pelikan, 2004)

Two techniques are commonly used in order to construct the FDC:

Ranked Flow technique

The time series of flows is ranked-ordered according to magnitude of flow. Mean annual, monthly and weekly or daily flows may be used. The rank-ordered values are assigned order numbers, the largest starting with 1. The order numbers are then divided by the total number in the record and multiplied by 100 which represent the percent of time intervals (week, month, and day) that a particular mean flow has been equalled or exceeded during the period of record recognised. Flow is than plotted versus the respective percent exceedence (Fritz, 1984).

Class Interval technique

Each time series flow values are categorised into class intervals. The classes of flows range from highest to lowest value of flow in the time series. A tally is made of number of flows in each class and the number of values greater than each class can be determined. The number of values greater than each class is divided by the total number of flows to get the percent exceedence. This is plotted versus the upper class interval to get the flow-duration curve values. It should be noted that with the use of data other than the daily average flows, any flow averaging period is hidden due to the averaged values. For small hydro developments, the critical month periods should contain high-flow as well as the obvious low-flow months (Fritz, 1984).

Q_{50} index year can offer a good estimate of primary energy; Q_{20} and Q_{30} values are good starting flows for equipment sizing (Fritz, 1984).

The following factors control the FDC:

- Annual cycle of precipitation, potential evapotranspiration and actual evapotranspiration in the watershed
- Amount of rainfall that infiltrates and moves on subsurface flow paths into stream channels. Infiltration rates depend on the permeability and depth of the watershed soils
- Subsurface flow velocities and the storage capacity of subsurface aquifers.

Figure 2. 29 shows the factors that control the development of a FDC. The hydrological cycle is a complex process which governs rainfall, runoff, groundwater movement and streamflow discharge.

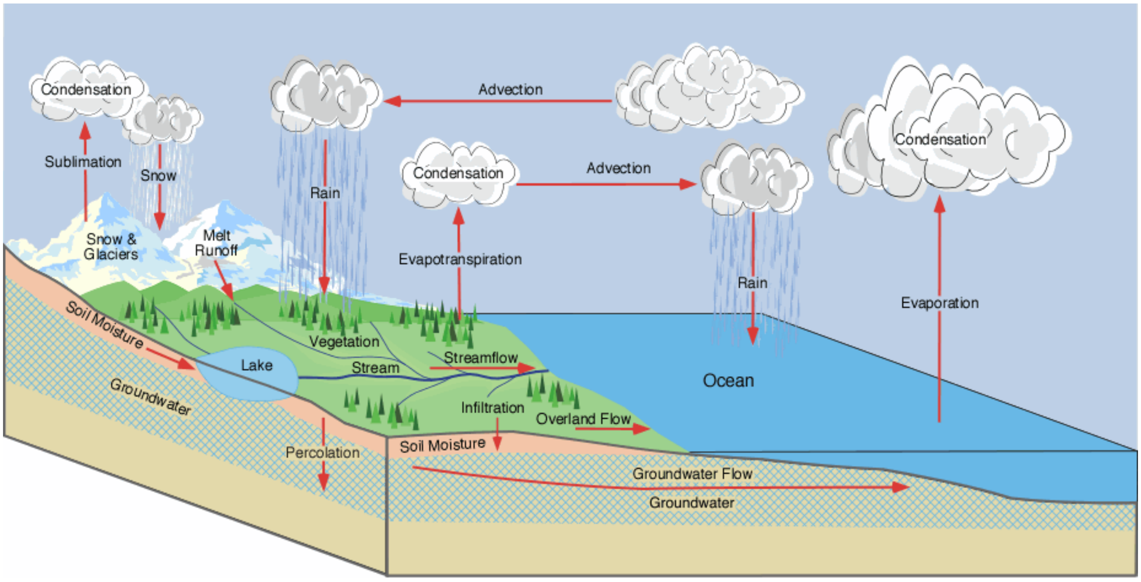


Figure 2. 29: The Hydrological Cycle (Pidwirny, 2009)

2.12 Flow Development and Computations using RETScreen

Residual flow

Due to environmental and ecological sensitivity, it is important that a minimum flow be maintained throughout the year. This is termed residual flow, Q_r, and results in a deduction in potential power output, plant capacity, firm capacity and renewable energy available.

Available flow

Available flow is found by deducting the residual flow and is defined as Q'_n (n=0, 5,…, 100):

$$Q_n' = max(Q_n - Q_r, 0)$$

Firm Flow

Q_{firm} is defined as the flow available *p* percent of the time where *p* is the percentage specified by the user.

Power availability as a function of flow

When the flow-dependent hydraulic losses and tailrace reduction are taken into account, it is possible to determine the actual power, P, available for the small hydro plant at any given flow, Q'n. The available power can be found by the equation:

$$P = \rho g Q'_n\left[H_g - \left(h_{hydr} + h_{tail}\right)\right] e_t e_g (1 - l_{trans})\left(1 - l_{para}\right) \quad \text{Equation 2. 21}$$

Where:

- ρ= density of water (1000 kg/m^3)
- g= acceleration due to gravity (9.81m/s^2)
- H_g= gross head (m)
- l_{trans}= transmission losses
- l_{para}= parasitic losses
- h_{hydr} and h_{tail} are hydraulic losses and tailrace effect respectively

And,

$$h_{hydr} = H_g l_{hydr,max} \frac{(Q'n)^2}{Q_{des}^2} \quad \text{Equation 2. 22}$$

Where $l_{hydr,max}$ is the maximum hydraulic lost and Q_{des} the design flow.

$$h_{tail} = h_{tail,max} \frac{(Q'n - Q_{des})^2}{(Q_{max} - Q_{des})^2} \quad \text{Equation 2. 23}$$

Where $h_{tail,max}$ is the maximum tailwater effect which is the maximum reduction in available gross head that occurs during times of high flows in the stream. Q_{max} is the maximum river flow.

Applicable only when river flow greater than design flow ($Q > Q_{des}$).

- e_t = turbine efficiency at flow Q'_n
- e_g= generator efficiency

Plant Capacity

P_{des} or plant capacity is calculated by the substitution of the design flow Q_{des} instead of the flow Q as:

$$P_{des} = \rho g Q_{des}\left[H_g - \left(h_{hydr} + h_{tail}\right)\right] e_{t,Q_{des}} e_g (1 - l_{trans})\left(1 - l_{para}\right) \qquad \text{Equation 2. 24}$$

Power-Duration Curve

The power-duration curve is defined as using available flow $Q'_0, Q'_5, \ldots, Q'_{100}$ in Equation 2.24 resulting in the available power $P_0, P_5, \ldots, P_{100}$. Due to the maximum flow that the turbine can use referred to as the design flow, the flow value used in Equation 2.24 is defined as:

$$Q_{n,used} = min(Q'_n, Q_{des})$$

Or

$$P_{PDC} = \rho g Q_{n,used}\left[H_g - \left(h_{hydr} + h_{tail}\right)\right] e_{t,\min(Q'_n, Q_{des}),} e_g (1 - l_{trans})\left(1 - l_{para}\right)$$

Equation 2. 25

An example of a power-duration curve is shown in the Figure 2. 30 with design flow of 3 m^3/s.

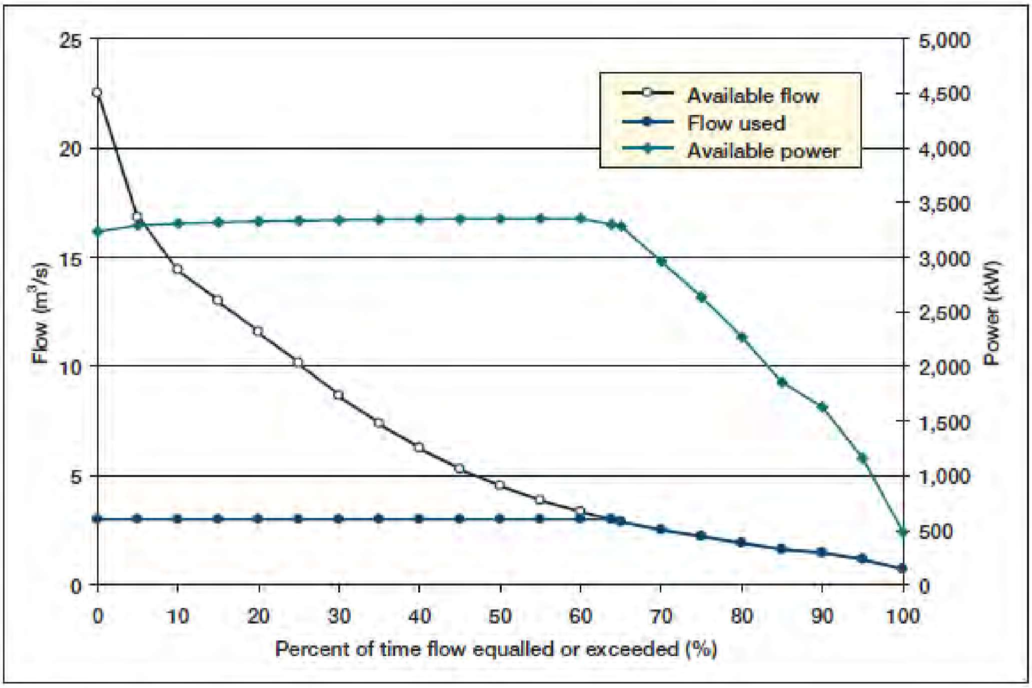


Figure 2. 30: Example of a Power-Duration Curve (Kosnik, 2010)

Renewable Energy Available

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 annual available energy, E_{avail} in kWh/yr, is therefore calculated from the values P (in kW) by:

$$E_{avail} = \sum_{k=1}^{20} \left(\frac{P_{5(k-1)} + P_{5k}}{2}\right) \frac{5}{100} 8760(1 - l_{dt}) \qquad \text{Equation 2. 26}$$

Where:

L_{dt}= annual downtime losses specified by the user

Typically, the decision to connect the plant to the grid or not is dependent on several factors such as distance to sub-station, cost per kilometre of transmission lines, existing structures etc. Table 2. 9 can be used as a connection classification according to the generating capabilities of the plant.

Table 2. 9: Grid Connection By Plant Generating Capabilities (after Brent, 2010)

Classification	Description
Small Hydro	1 - 15 MW; usually feeding into a grid
Mini-Hydro	Above 100 kW, but below 1 MW; either stand-alone or feeding into the grid
Micro-Hydro	From 5kW up to 100 kW; usually proving power for a small community or rural industry in remote areas away from the grid.

It is assumed that the grid is able to absorb all the energy produced by the small hydro plant for a central grid. It can be said that the renewable energy available will be delivered to the central grid and the renewable energy delivered, E_{dlvd}, is:

$$E_{dlvd} = E_{avail}$$

Small Hydro Plant Capacity Factor

The annual capacity factor K of the small hydro power plant is a measure of the available flow at the site and how efficiently is can be utilised. It is defined as the average output of the plant compared to its rated capacity:

$$K = \frac{E_{dlvd}}{8760 P_{des}}$$ Equation 2. 27

2.13 Rural Household Energy Demand Quantification

The energy sector in South Africa has both first and third world aspects, and produces and consumes over 60 % of electricity on the African continent (Madubansi and Shackleton, 2006).

Davis (1998) says that over three-quarters of South Africa's rural households use wood for cooking and thermal needs in addition to paraffin, candles and batteries as an energy source. The mean rural household size is about 6-7 people per household which is based on the 2007 national South African Census (Madubansi and Shackleton, 2006). Following South Africa's post-apartheid regime, the Government has implemented an electrification program as well as a free basic electricity allowance of 50 kWh per month as a means of poverty alleviation (Madubansi and Shackleton, 2006). Even though a substantial increase over the last 10 years in household electrification has occurred, many rural households still use wood for heating because they cannot afford the appliances and/or the monthly costs associated with electricity usage (Howells *et al.,* 2005; Davis, 1998).

According to Madubansi (2006), the free basic allowance is not adequate for the household's thermal needs. Table 2. 10 shows the energy demand of essential services carried out by Adam (2010).

Table 2. 10: Essential Services and their Energy Demand (after Adam, 2010)

Services	Average Power (kW)	Number of Devices	Estimated hours operation per day		Total kWh per day	
			Summer	Winter	Summer	Winter
Space Heating	0.75	1	0.0	5.0	0.0	3.8
Lighting	0.02	3	6.0	8.0	0.4	0.5
Hot Water (kettle/cooking)	3.00	1	0.5	0.5	1.5	1.5
Cooking	2.00	1	1.0	1.0	2.0	2.0
Warm Water (washing)	3.00	1	1.0	1.0	3.0	3.0
Refrigeration	0.15	1	12.0	8.0	1.8	1.2
Total Daily Consumption					8.7	11.9
Total Monthly Consumption					261	357

Based on the FBE and Table 2. 10, only 14 % to 19 % of electricity demands are met.

Most of the population of rural South Africa is located in areas that are far from electrical grid connections, therefore off grid renewable energy such as small hydro power can play a significant role in electrification of these areas (Madubansi and Shackleton, 2006).

A study performed by ScottishPower (2003) identified areas in South Africa that are not electrified shown as dark regions in Figure 2. 31:

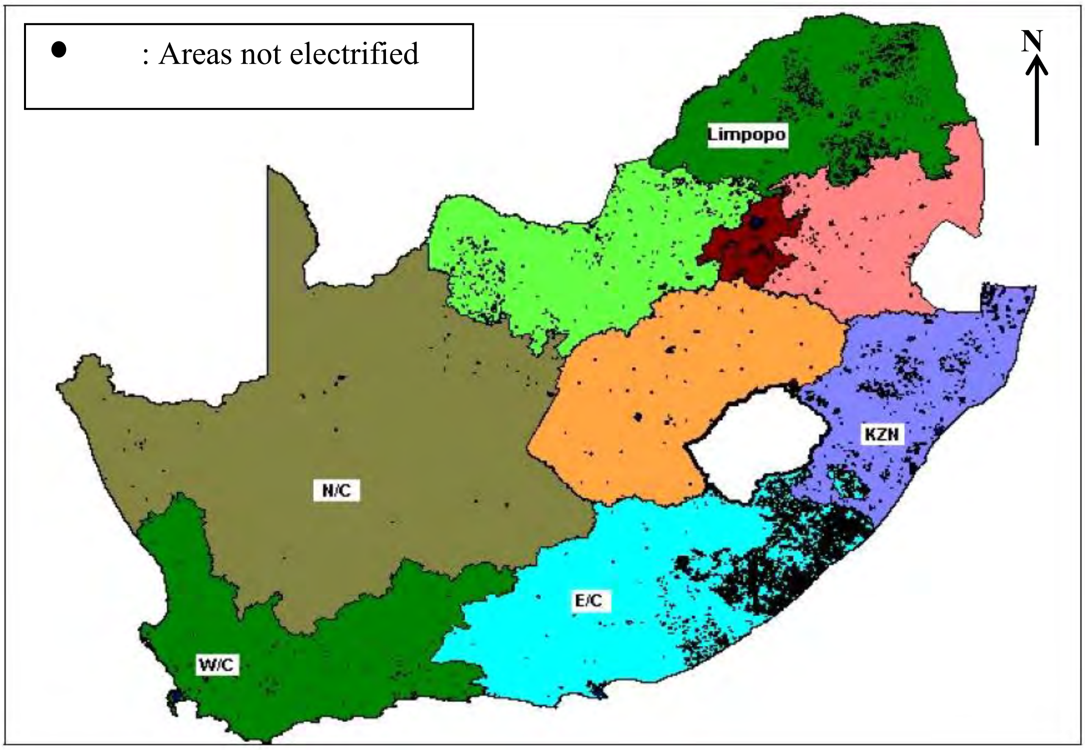


Figure 2. 31: Regions in SA not electrified identified using dark dots (ScottishPower plc, 2003)

Figure 2. 31, combined with Figure 2. 5 of hydroelectric potential in South Africa can offer a good starting point for site selection, i.e. excellent hydro potential and unelectrified rural areas in South Africa.

2.14 The Free Basic Electricity (FBE) policy

With the goal of "electrification for all", the South African Government realised that the increase in electrification would not necessarily result in an increase in electricity consumption amongst the poor due to affordability issues (Malzbender, 2005).

In 2001 the FBE policy was introduced by Eskom after suggestions made by the DME (Inglesi, 2010). It was argued that the average poor do not consume more than 50 kWh of electricity per month and therefore it is sufficient and offered free of charge.

Brent and Rogers (2010) found that the electrical demand of many households double soon after installation as they purchase stoves and refrigerators.

Solar Home System's (SHS's), which produces electricity for household use, is a project that the government has used to promote non-grid technologies as a clean energy source (Malzbender, 2005). The SA government currently awards a subsidy of R 3 500 for each installation per household which goes towards the capital cost (Mapako and Prasad, 2005). Due to claims of insufficient funds, an additional maintenance and service fee of R 58 per month and an upfront installation fee of R 100 have been implemented. R 40 of the R 58 maintenance and service fee is covered by the government (Malzbender, 2005) resulting in just R 18 per month payable by each household.

2.15 Economics of a Small Scale Hydropower Station

The power output of a turbine/generator is largely dependent on hydraulic head and flow rate, therefore a decrease in head will have to be compensated for by increasing the flow in order to produce the same amount of power (Campbell, 2012). The civil works and the electro-mechanical equipment of a project make up most of the cost and are dependent on flow rate and head (Campbell, 2012). Cost contribution of different works required at a small hydro project is shown in Figure 2. 32.

Economics in terms of job creation is also a product of implementing hydro schemes in rural areas. Not only does the community benefit from been electrifed and obtaining a higher quality of living, the economy also benefits from this new source of employment and income. It is estimated that at every 1 MW of hydropower installed capacity, two permanent jobs are established within the industry (CaBEERE, 2002).

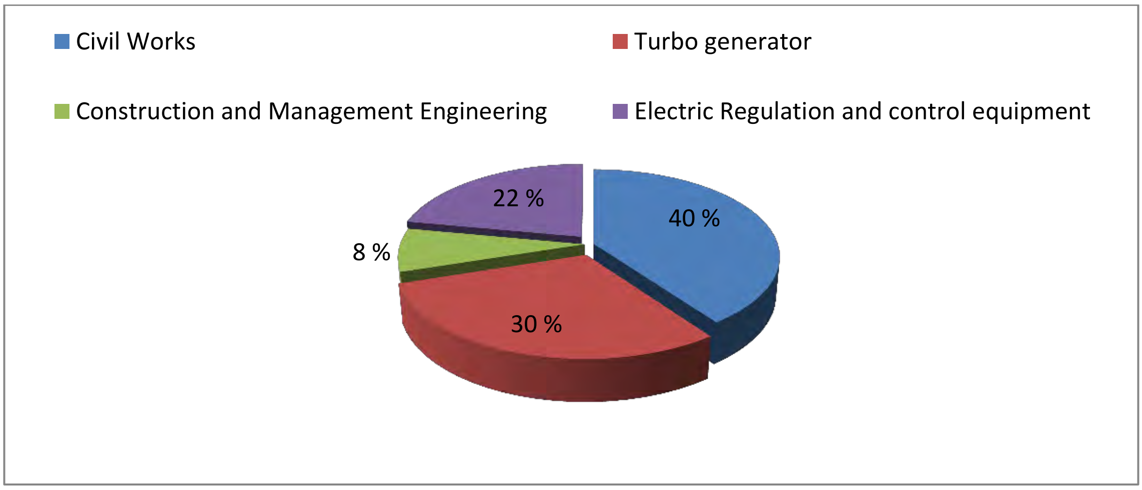


Figure 2. 32: Cost Contribution for small hydropower by components (After Ogayar and Vidal, 2009)

2.16.1 Formula based methods

Various formulas have been developed worldwide to approximate cost per kW of large and small hydro schemes. Generally, the larger the plant, the lower the cost per kW installed. Different equations are used depending on the capacity of the small hydro scheme.

Equipment costs formulae

In a recent study which involved 81 hydropower projects in 32 countries (Van Vuuren *et al.,* 2011), a trend relating the electromechanical cost to power output was performed Alvarado-Ancieta (2009). The electromechanical costs include costs of turbines, valves, cooling and drainage systems, generators, control and auxiliary equipment. Equation 2.28 was created with the use of a number of curves and graphs for different turbines (Alvarado-Ancieta 2009).

$$C_{em} = 9.742(10^{-6}P)^{0.7634}.(10^{6}) \qquad \text{Equation 2. 28}$$

Where:

C_{em}= cost of electromechanical equipment as defined above, (ZAR[7])

P= installed capacity, (W)

Alvarado-Ancienta (2009) claims an error range of 5 % to 10 % which should allow for better costing estimation.

Another electromechanical formula which is based on North American experience is applicable for power plants below 5 MW capacity and is given by Equation 2.29.

$$K_{us} = K\left(\frac{P^{0.7}}{H^{0.35}}\right) \qquad \text{Equation 2. 29}$$

Where:

K_{us}= cost of electromechanical equipment. (USD in 1987)

K= 9000

P= plant Capacity (kW),

H= head, (m)

Gulliver and Gordon (1991) recommend that the equation is appropriate for plant capacities in the range of 50- 40,000 kW and head range of 4-100 m.

[7] ZAR= South African Rand

For small hydropower projects below 1.5 MW capacity, GTZ (1980) recommend the use of Equation 2.30.

$$C = 48{,}000(P/H)^{0.53} \qquad \text{Equation 2. 30}$$

Where:

C= cost of machinery (DM[8] 1980)

P and H are as above according to North American Experience.

Many barriers exist to the uptake of renewables due to the lack and in some cases absence of reliable data on cost performance (IRENA, 2012). Cost estimation is a crucial aspect in establishing the performance and benefits of hydropower. The IRENA (2012) study was published with the aim of aiding individuals and the government in decision making on renewable power generation and is based on updated studies on hydropower projects around the world.

A simplified cost analysis can reveal several aspects of the project such as installed cost, fixed and variable cost, operation and maintenance etc. As what is termed the "Levelised Cost of Electricity" or LCOE (IRENA, 2012). The LCOE is the price of electricity required for a project where revenues would equal costs, including making a return on the capital invested equal to the discount rate. The Equation 2.31 shows the LCOE:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \text{Equation 2. 31}$$

Where:

I_t= investment expenditures in the year t

M_t= operations and maintenance expenditures in the year t

F_t= fuel expenditures in the year t

E_t= electricity generation in the year t

r= discount rate (Assumed at 7 %)

n= economic life of the system (Assumed to be 40 years)

[8] DM= Deutschmark

An electricity price above 0.1 USD/kWh LCOE would yield a greater return on capital while a price below it would yield a lower return on capital or loss (IRENA, 2012). The LCOE is a widely used measure of renewable energy and is robust and simple to determine.

Figure 2. 33 shows installed capital cost for small hydro in developing countries which was developed through an IRENA survey which highlights similar cost bands.

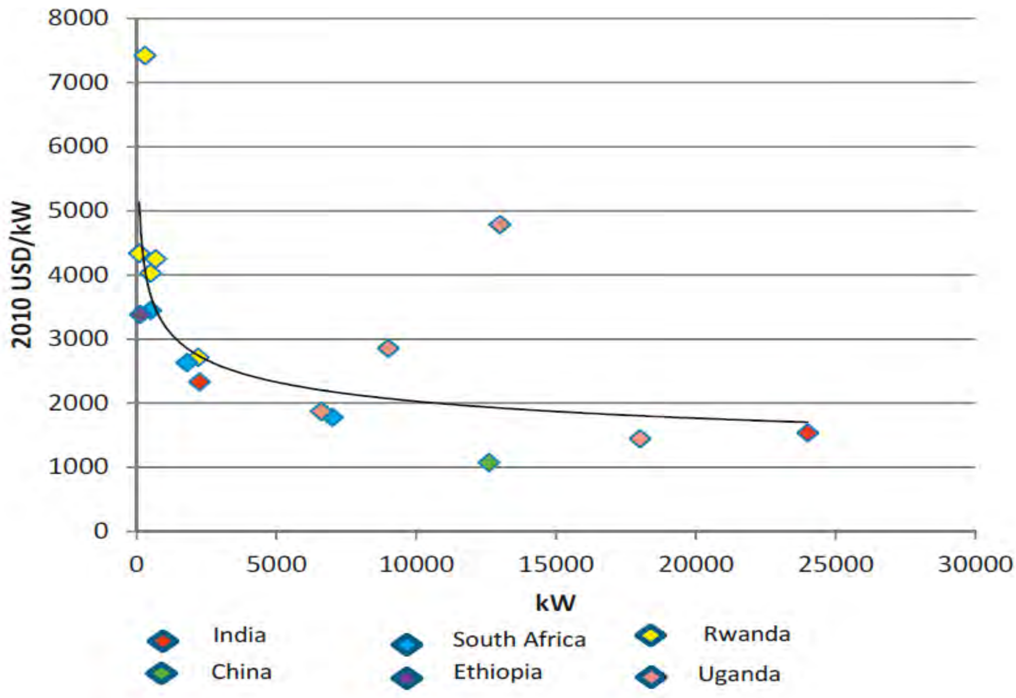


Figure 2. 33: Investment cost as a function of installed capacity and turbine head (IRENA, 2012)

The typical design lifespan for small hydropower plants is 40 years however this value could be even lower according to the integrity of the overall design and construction methods (IRENA, 2012).

Rehabilitation of old decommissioned hydropower stations could also be an economic option as the reduced O&M[9] costs and the higher output after refurbishment can have the effect of lowering investment costs for refurbishment (IRENA, 2012).

Figure 2. 34 shows the investment cost of small hydropower projects for each represented country. Depending on the local materials and resources available, cost bands will show the effects of the site's site-specific considerations of small hydropower.

[9] O&M= Operation & Maintenance

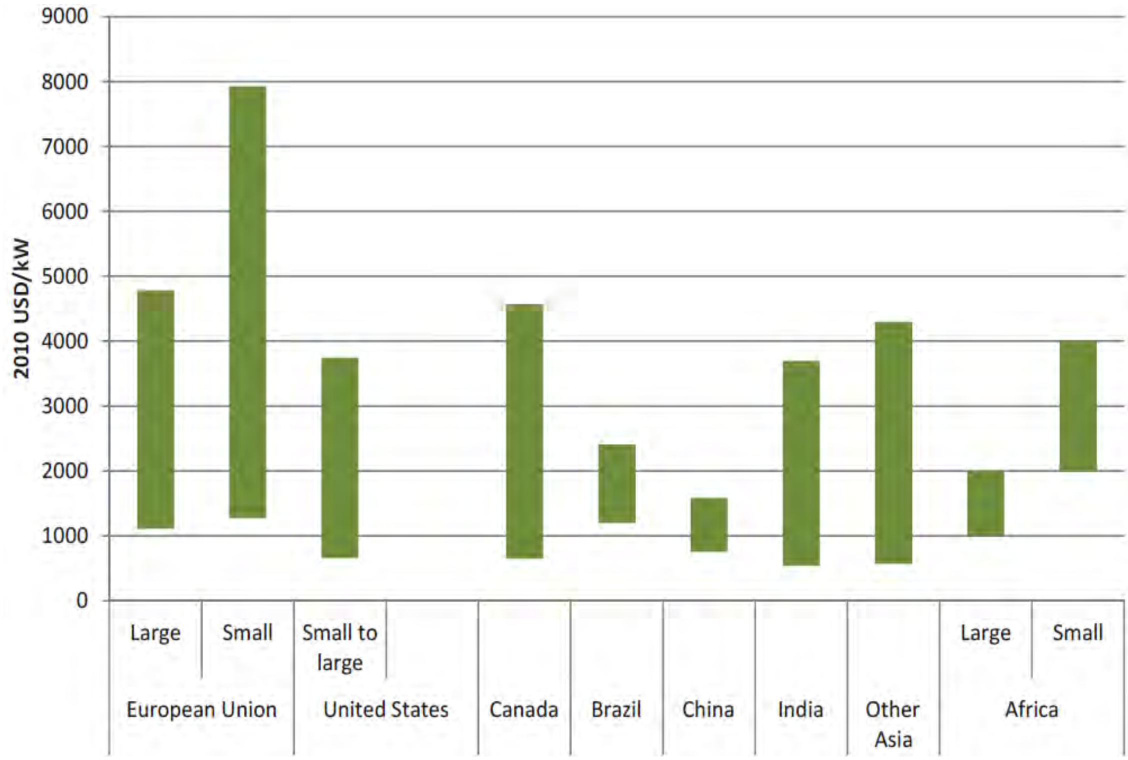


Figure 2. 34: Total installed hydropower cost ranges by country (IRENA, 2012)

Average Investment Costs and Annual Operations and Maintenance Costs

According to IRENA (2012), typical small hydropower projects cost between USD[10] 1300/kW to around USD 8000/kW. The Operation and Maintenance (O&M) expense is usually expressed as a percentage of the investment cost per kW. O&M cost range from 1 % to 6 % for small hydropower projects (IRENA, 2012). This does not include major replacements of mechanical equipment or penstocks as these components usually have design lives of 30 and 50 years respectively (IRENA, 2012).

2.16.2 The Levelised Cost of Electricity

The Levelised Cost of Electricity (LCOE) value is site dependent and is generally low for hydropower production (refer to Table 2. 11). The LCOE for refurbishments/upgrades range from USD 0.01/kWh for additional capacity at an existing project to 0.05/kWh for more expensive upgrades assuming 10 % capital cost (IRENA, 2012).

For small hydropower projects, based on real world projects in developing countries, the LCOE ranges from 0.02 $/kWh - 0.10 $/kWh.

[10] USD= United States Dollars

Table 2. 11: Estimated Operation and Maintenance cost and LCOE for small hydro and refurbishment schemes (After IRENA, 2012)

	Installed Cost (USD/kW)	O&M cost (% per year of installed costs)	LCOE (2012 USD/kWh)
Small Hydro	1300 - 8000	1 - 4	0.02 - 0.27
Refurbishments/upgrades	500 - 1000	1 - 6	0.01 - 0.05

The electro-mechanical equipment costs tend to be higher in small scale schemes than for large-scale projects, contributing from 18 percent to as much as 50 percent of the total costs. This relationship can be seen in Figure 2. 35 and shows the different contribution of items such as civil works, infrastructure and equipment for schemes that range from 0.1 MW to 24 MW. The smaller schemes (0.1 MW to 7 MW) tend to have higher civil works cost contribution (approximately 40 % – 60 %) with moderate equipment cost contribution (20 % – 40 %) while the larger projects (> 7 MW) tend to have equipment cost contribution dominate total cost of the project. For projects in remote or difficult to access locations, infrastructure and logistical costs can dominate total costs (IRENA, 2012).

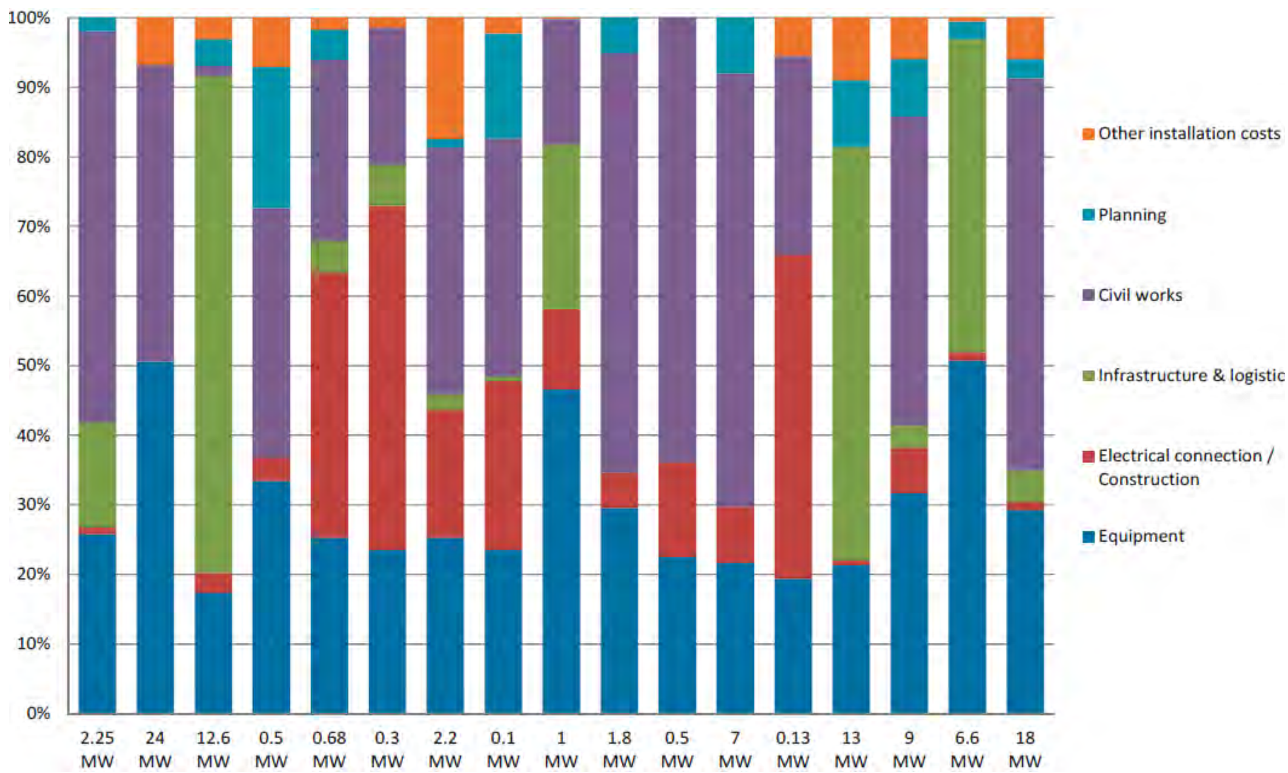


Figure 2. 35: Cost breakdown for small hydro projects in developing countries (IRENA, 2012)

3. RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the research methodology for this study. The areas of interest, i.e. the sites selected for study, the study design, procedure, methods of analysis and the sampling of population are described in this chapter. The tools used to collect the data and methods of measuring the viability of the results are also described herein.

Several complex models for streamflow quantification have been developed due to advances in science which allow accurate streamflow predictions to be made. Streamflow quantification is a necessary step in assessing the energy potential of rivers. The magnitude of the river's flow, combined with hydraulic head parameters, determines the extent of power generation. Assessing the natural stream water energy from long duration river flow records can be performed relatively easy but can be complicated for ungauged sites. The accuracy and level of the hydrological analysis is important for determining the cost effectiveness of a hydroelectric power scheme.

Some complex model's (regionalisation and spatial interpolation) require large data requirements from several nearby streamflow gauging stations therefore it was opted to select the streamgauges with available streamflow data. A study performed by Eskom and the DME in 2002 identified regions as excellent hydropotential opportunity in South Africa which allowed the streamflow gauges with available data to be highlighted. The simpler RETscreen model uses readily available data and was used to address the aims and objectives of this study. Quantifying flow at ungauged sites using spatial interpolation or regionalisation was beyond the scope of this study. The large data requirements of the complex models are necessary in the case of ungauged locations, where hydro generating potential have not yet been performed.

The available head and flow of the stream, the capacity and energy output could be determined using design programmes. Hydrological data analysis assisted by specialised hydrologic software estimates the flow available for energy development and is the first crucial component of a hydropower project.

Demand quantification was assessed using the FBE policy as a base case for electricity demand of the community. By evaluating the population density and the power requirements of the community, the percentage of this power that the scheme can supply can be determined.

A literature review was performed to assess the relevant information and computer programs associated with small-scale hydropower. Integrated Geographical Information System (GIS) for the planning and design of small hydropower plants was collected and assessed.

RETScreen enables the user to facilitate project development in various renewable energy and energy efficiency projects. This includes the assessment of the hydropotential which is based on the flow-duration curves, quantifying the CO_2 emissions avoided and the capacity of the hydro power plant and assessing the pay-back period of various renewable technologies.

3.2 Research Approach and Design

The power potential and the electricity demand by the community was estimated using available streamflow data, power-duration curves and quantifying the renewable energy the small-scale hydropower scheme could potentially produce. This study aimed to investigate the current status of rural electrification in South Africa and the process of assessing costs of small hydro schemes and also the electrical needs of people.

To meet the aims of the study the following was performed:

1. The primary rivers in South Africa that are in close proximity to rural communities were identified.
2. An evaluation of the streamflow gauges and hydraulic head in the region of the river and the community was performed
3. Relevant government subsidised policies currently in place that promote the use of small-scale hydropower were reviewed.
4. An evaluation of the population density of the community and potential demand using the FBE policy as a base case for electricity demand was carried out.
5. An assessment of the FBE allowance to determine basic energy demand requirements and to simulate higher electrical demand by the community was performed.
6. An investigation into the socio-economic and environmental issues in implementing a system in a community was carried out.
7. Cost functions and experience in other countries for small scale hydropower systems was investigated.
8. Developmental study of the small hydro scheme using RETScreen was performed and the model was evaluated at each site selected in terms of power potential, feasibility, GHG emission mitigation and the percentage demand met.

3.3 Data Collection and Preliminary Site Selection

Barta (2002) found that of the 1650 MW installed capacity of the current existing hydropower schemes (<10 MW) in South Africa, an additional 1650MW capacity can be developed in the rural areas of Eastern Cape, KwaZulu-Natal and Western Cape. Therefore the site selection was confined to these three provinces. Streamflow gauges and the study sites were chosen based on the availability of streamflow data, moderate to high flow requirements and the availability of flow during dry seasons. The data acquired from the DWAF hydrological database (DWAF, 2012) can be found in Appendix A. Each value is followed by a key which describes the integrity of the data. This data was not altered as the readings should convey a lower flow volume due to some of the data been incomplete for that month. The resulting power potential should be conservative estimates due to this incomplete data. The accuracy of the lower flow volumes are not a critical parameter because the aim of this investigation was to validate/negate the use of SSHEPS[11] and assess the FBE in policy and economic transfer therefore calculations are based on mean monthly flows.

The rural communities and their respective populations were estimated from population density maps (given as persons per square kilometre) and by using Google Earth version 6.2 (2012) to visually identify housing structures. This was performed to validate the existence of a community. Either scattered housing structures or large community centres were found during this assessment. The populations/communities chosen are based on their proximity to the scheme's site as these communities will initially benefit from a small hydro scheme as it will be feasible for logistical reasons (expansion of the new grid). The sites provide a case study for the use and affects (ecological, if any) of such schemes before further development.

The parameters and technical factors that govern the viability of a small hydro station are discussed here. Flow charts are provided after each sub-section in order to highlight the important steps taken in estimating the parameters.

3.3.1 Site Selection

The study was defined to be restricted by data availability of primary rivers in South Africa. KwaZulu-Natal, Eastern Cape and Western Cape Provinces were evaluated for the existence of a community that will benefit from the small hydro power scheme. A study performed by the Department of Minerals and Energy (DME) and Eskom in 2002 (Barta, 2002) identified regions of excellent hydropower potential (refer to Figure 2.1). This enabled a search criterion for this study to be formed. Hydropower potential comprises 3 main factors namely: (1) moderate to high rainfall in the region resulting in streamflow, (2) Close contour intervals resulting in valley systems and (3) a river network. Figure 2.26 was overlaid with primary rivers in South Africa in order to show potential un-electrified communities in close proximity to river networks. Figure 3. 1 shows primary rivers and un-electrified regions in South Africa. The dark regions show places that are not electrified in South Africa as of 2002 and it will be assumed that these regions and the final sites selected remain un-electrified.

[11] SSHEPS - Small Scale Hydro Electric Power Station

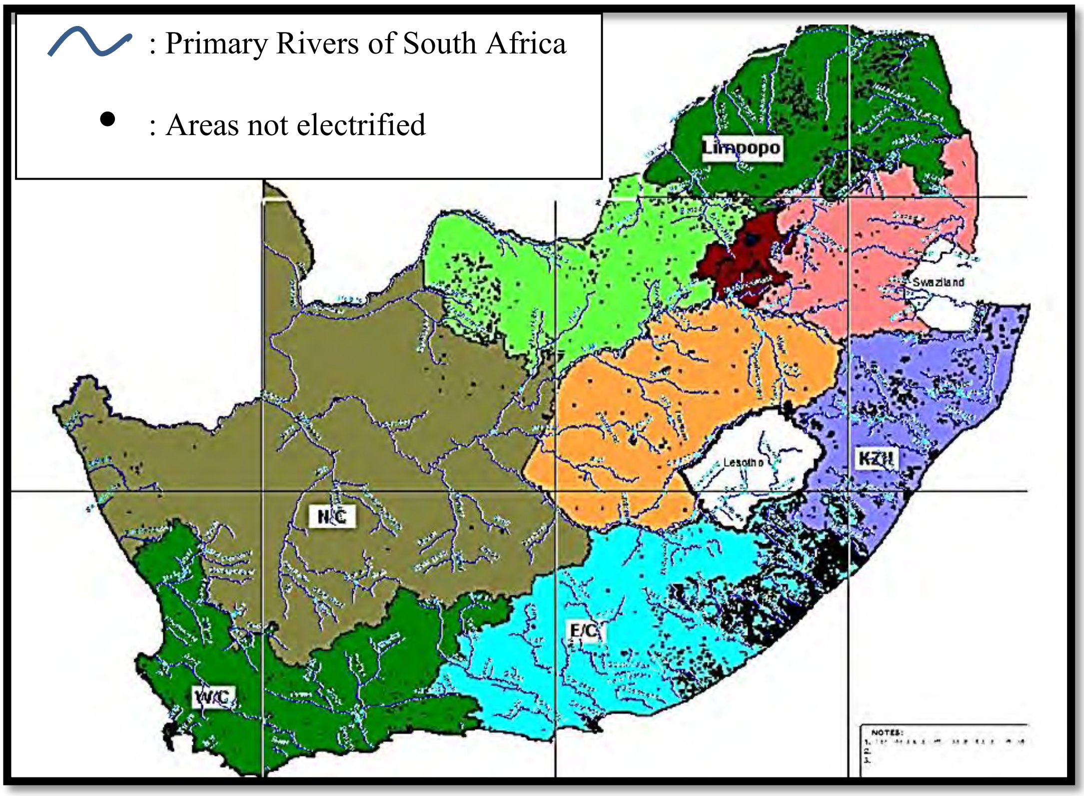


Figure 3. 1: Primary Rivers and Unelectrified regions in South Africa (Barta, 2002)

Unelectrified communities in close proximity to a river network and streamflow gauges were identified and their population density (people/km^2) evaluated. The evaluation of the hydraulic head along the river was performed near the community and streamflow gauge. Figure 3. 2 – 3.7 show the rivers selected, identified communities and possible hydraulic head configurations for the sites under study.

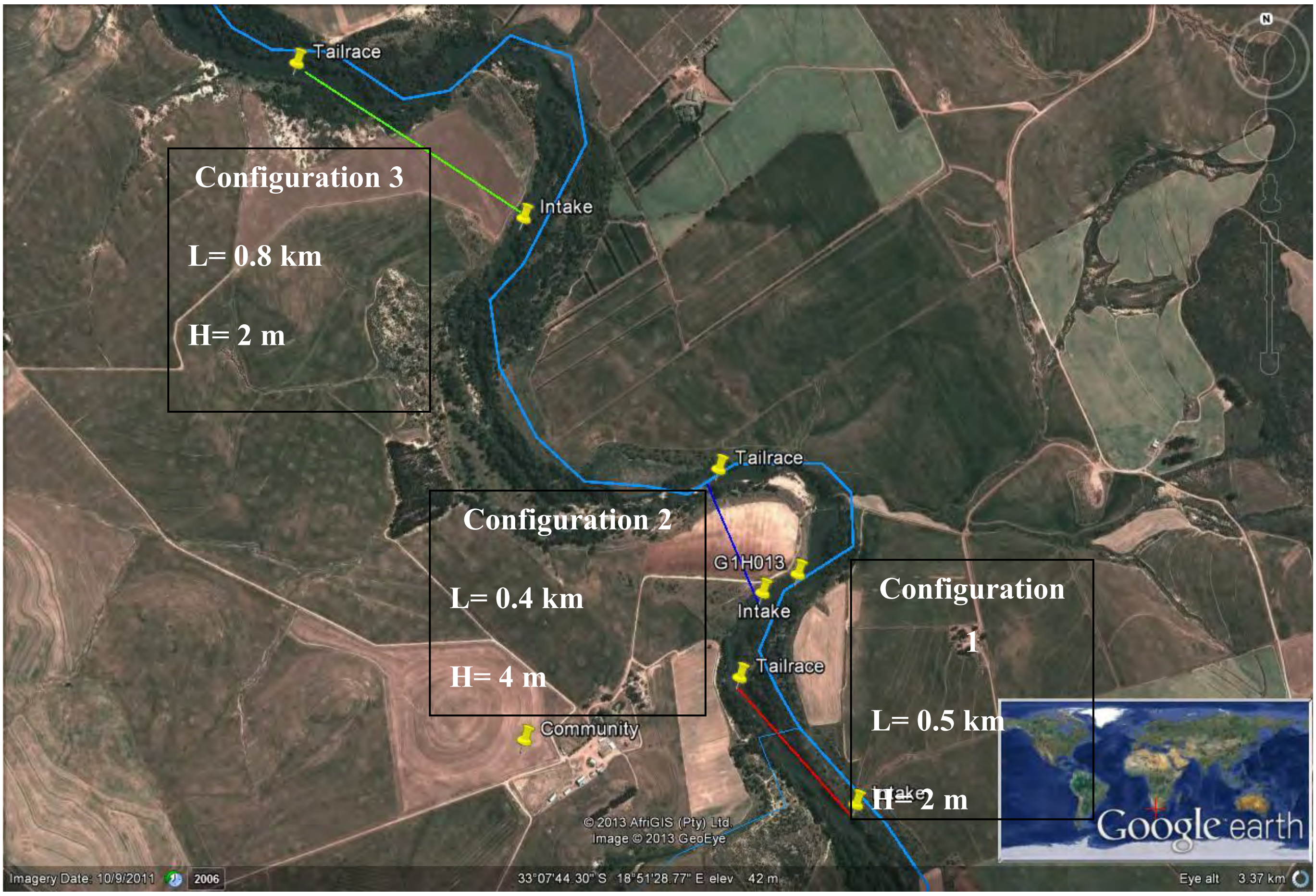


Figure 3. 2: Preliminary placement of site 1, Berg River

Figure 3. 2 shows three potential configurations with varying hydraulic head near streamflow gauge G1H013. Despite configuration 1 been closer to the community, configuration 2 was selected for further quantification due to a greater difference in hydraulic head. Configuration 3 was considered to be too far from the community and could result in increased cost of the hydro scheme due difficult terrain and logistics. The lower head configurations (1 and 3) would also result in less hydroelectric power production based from the Power Equation 2.18.

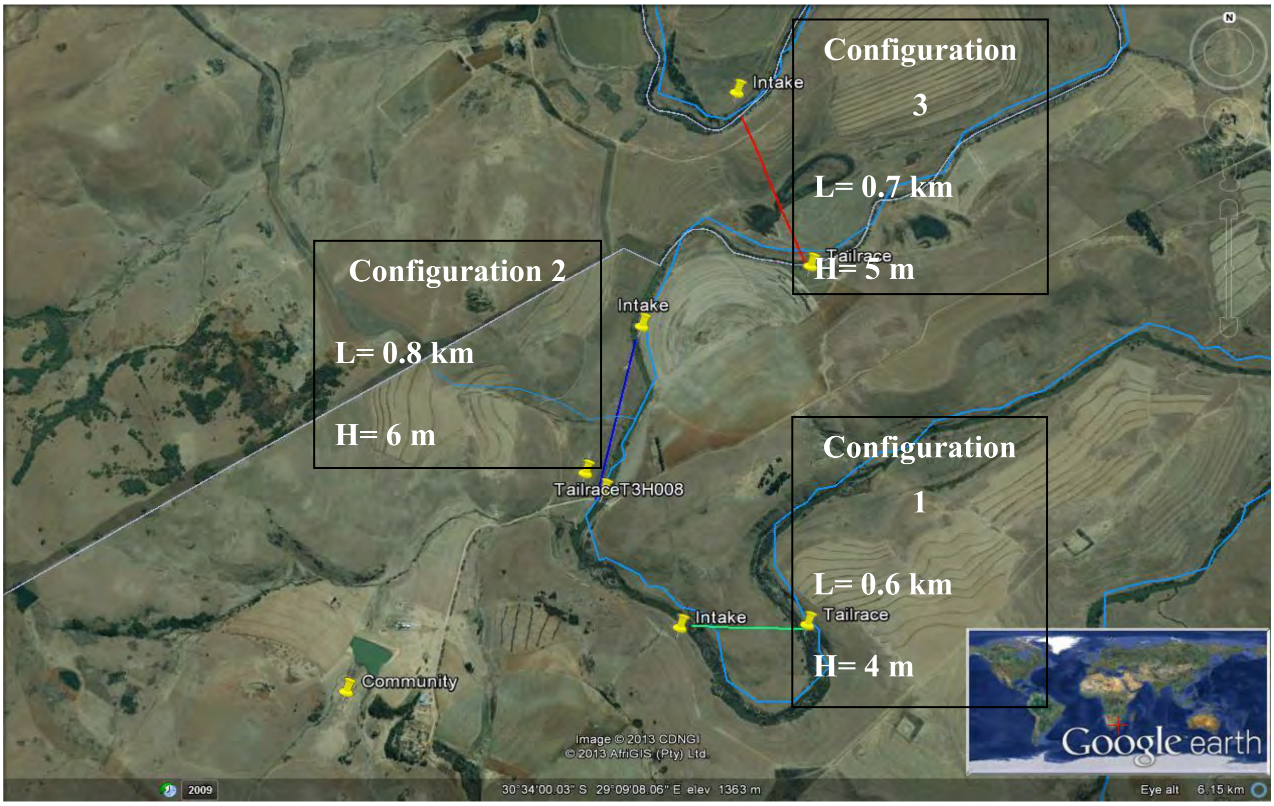


Figure 3. 3: Preliminary placement of site 2, Mzimvubu River

Figure 3. 3 shows a small farming community with three potential configurations of the small hydro scheme. Although an assumption of the regions under investigation was said to be un-electrified, the community identified here is likely to be semi-electrified due to the agricultural processes performed in the farmland. Configuration 1 and 2 were both found to be ideal for site set-up and found to be approximately equal distance to the community. Configuration 2 was selected for the study as it possesses a greater hydraulic head compared to configuration 1. Configuration 1 and 3 would of resulted in less hydroelectric power produced from the scheme as well as configuration 3 determined to be too far for a feasible development to be undertaken.

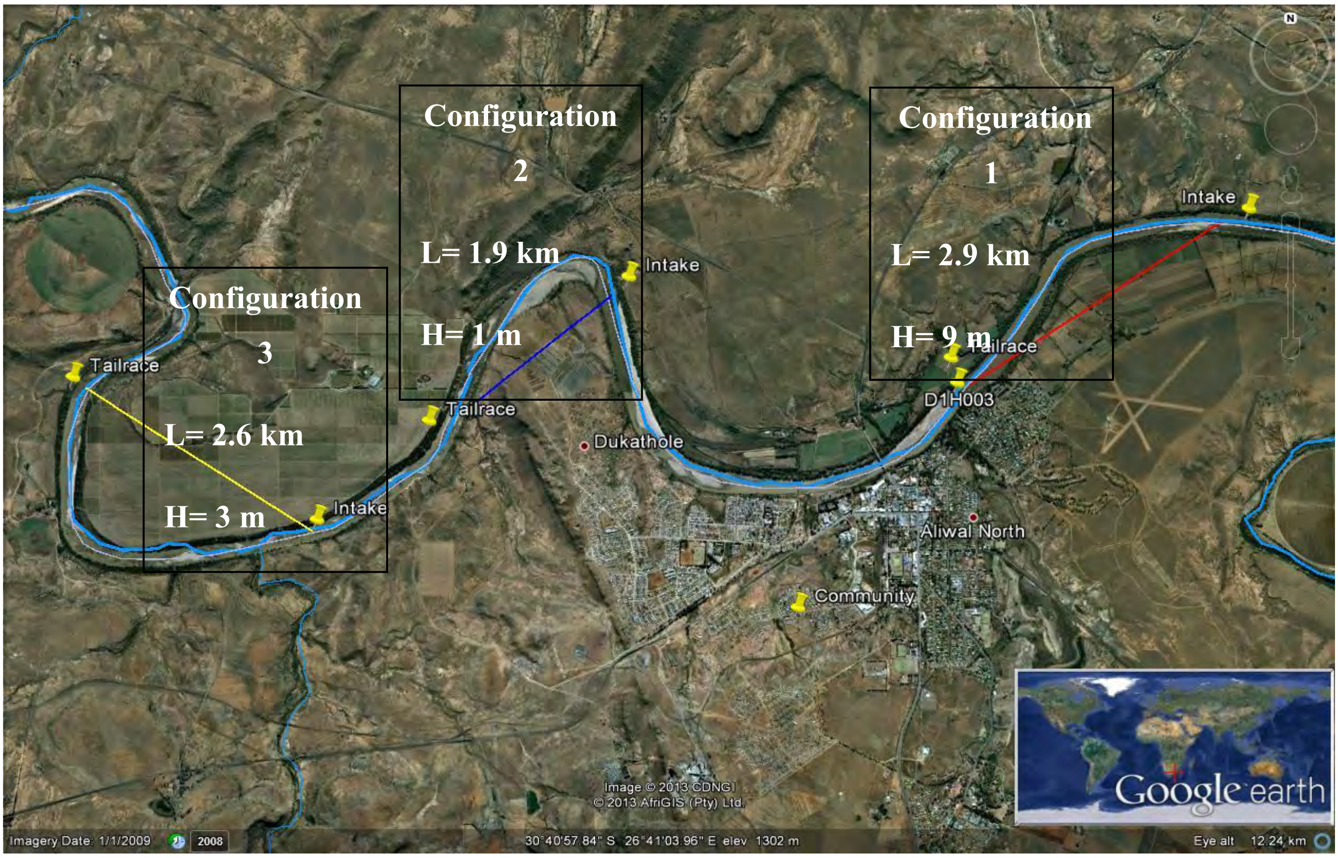


Figure 3. 4: Preliminary placement of site 3, Orange River

Figure 3. 4 shows a large community along the Orange River. Of the three possible configurations, configuration 1 was selected for this sites study as it offers a greater hydraulic head compared to the other 2 configurations and is closer to the community. Configurations 1 and 3 would result in less hydroelectric power produced by the scheme which makes the scheme uneconomical when compared to the hydropotential offered by configuration 1.

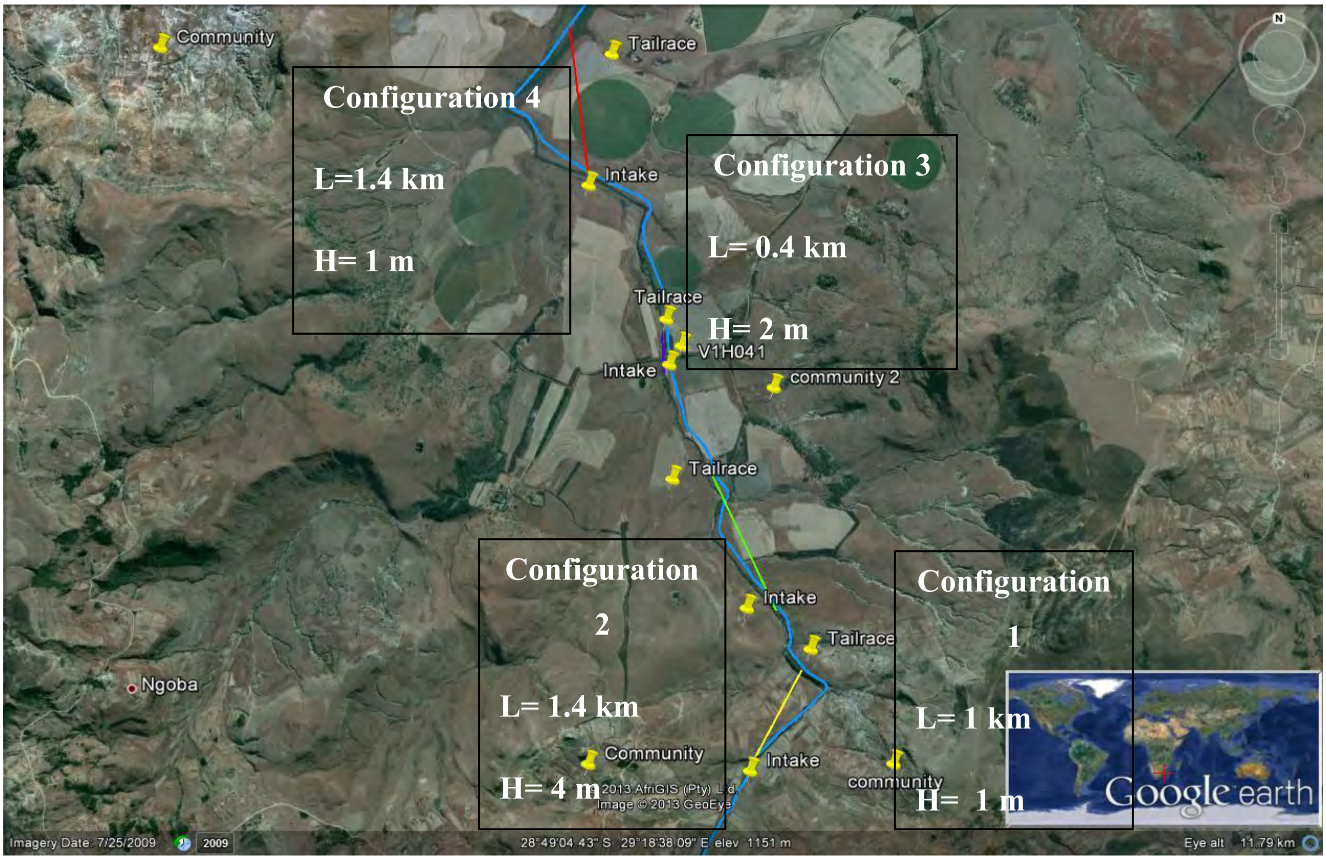


Figure 3. 5: Preliminar placement of site 4, Mlambonja River

Figure 3. 5 shows four potential configurations with 4 potential communities. Configuration 1 was dismissed as the split required in the potential power generated would cause a greater expense to the scheme due to a higher transmission and distribution cost between the adjacent communities. Configuration 2 was also dismissed due to no community present close to the potential scheme. Configuration 4 was dismissed due to the great distance and difficult terrain that may be encountered during transmission of the electricity generated. Configuration 3 was selected for investigation due to the close proximity of the community to the scheme.

Configuration 3 would offer a greater hydroelectric power output compared to configurations 1 and 4. Although configuration 2 possesses a larger hydraulic head, the length of the channel/tunnel required is far longer than that of configuration 3 which could make this set – up more expensive and uneconomical.

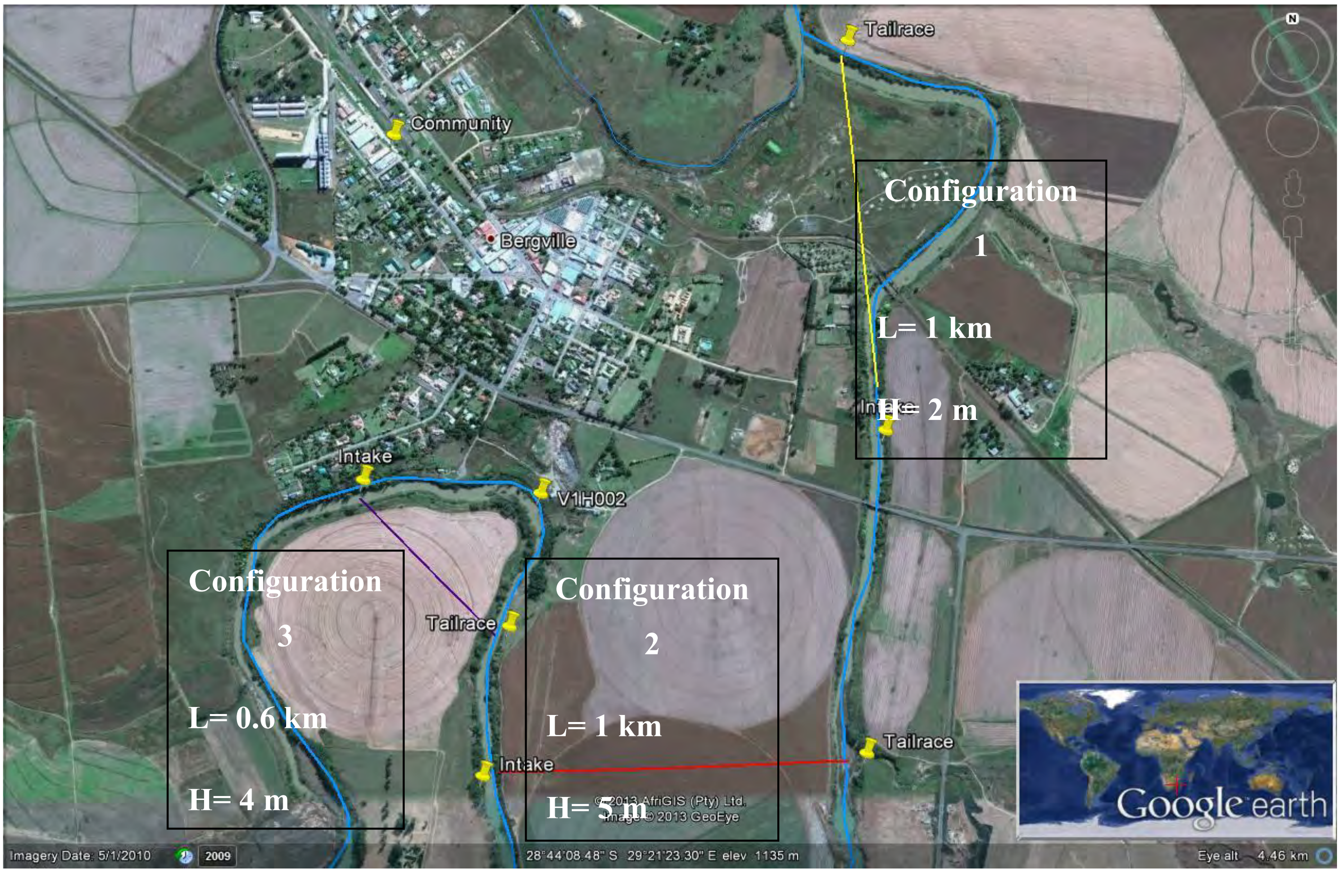


Figure 3. 6: Preliminary placement of site 5, Thukela River

Figure 3. 6 shows a medium sized community located in the town of Bergville. It is likely that this area is semi-electrified hence the potential scheme can supplement the community's electricity needs. Configuration 2 was dismissed as it is located a greater distance (1.7 km) from the demand centre compared to the other two configurations. Configuration 1 and 3 are located closer to the community at 1.2 km and 1 km respectively but in order to achieve a desirable hydraulic head at configuration 1 a longer penstock/channel is required. Configuration 3 was selected for this site's investigation as it is closer to the demand centre and requires a shorter penstock/channel (0.5 km) thus reducing construction cost.

Although configuration 2 possesses a greater hydraulic head compared to 1 and 3, the channel/penstock length and distance to town centre makes this set – up uneconomical.

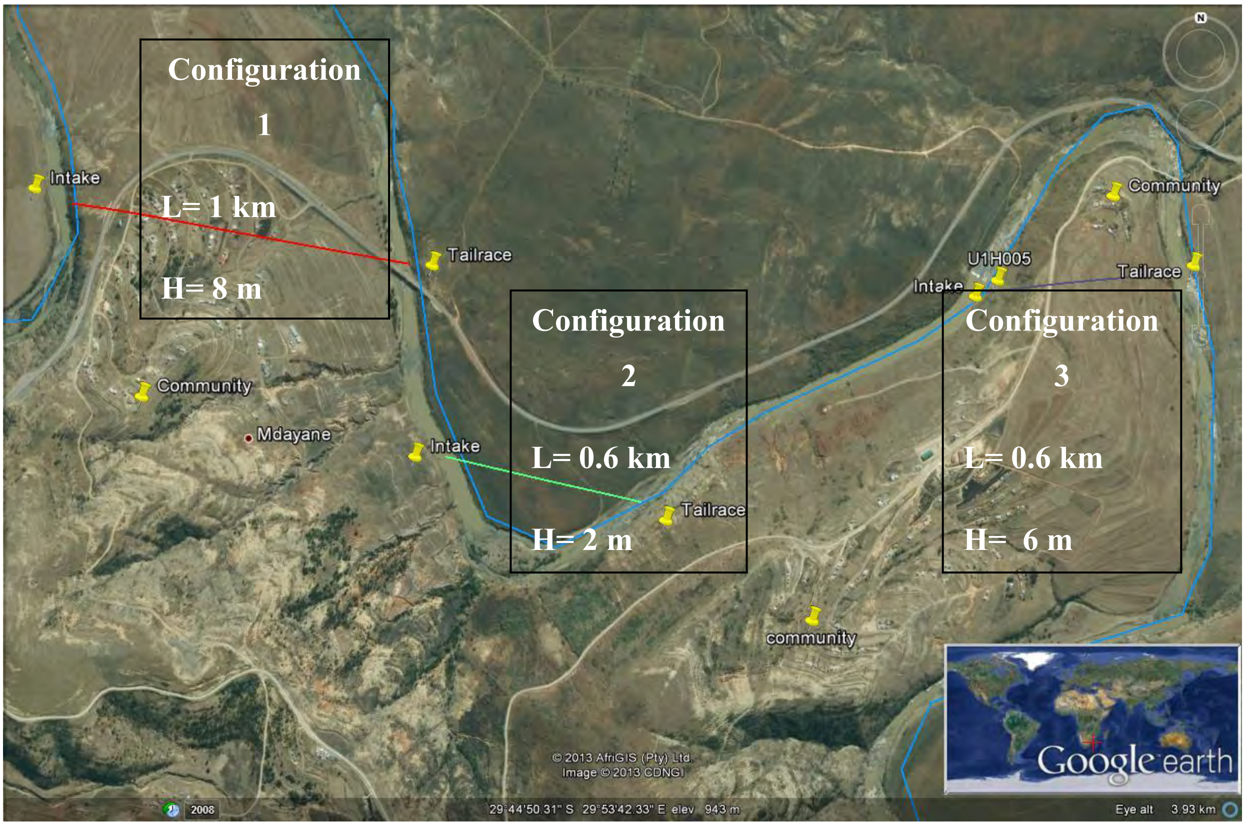


Figure 3. 7: Preliminary placement of site 6, Mkomazi River

Figure 3. 7 shows three potential configurations with three potential communities. In order to achieve a desirable head greater than 5 m, the length of the channel/penstock requires an extensive length (1 km) which makes it uneconomical in configuration 1. Configuration 2 possesses hydraulic head of 2 m but will require expensive transmission distribution due to the difficult terrain. Configuration 3 was selected for this sites investigation as it possesses good hydraulic head (6 m) resulting in a higher power potential and is closer to the demand centre compared to the configuration 1 and 2.

Table 3.1 presents the sites chosen and their locations for investigation. By inspection of the streamflow gauges, optimal hydraulic head for each scheme and an electricity demand centre/community, it was possible to select the sites for the study due to their excellent hydropotential according to Barta (2002) and the close proximity to a "community". Table 3. 2 provides a brief description of the case study sites.

Table 3. 1: Chosen Sites for Study and Assessment

Province	River	Streamgauge	Location (dd:mm:ss)		Quaternary Catchment
			Latitude	*Longitude*	
KZN	**Mkomazi**	U1H005	29°44'39.12"	29°54'20.88"	U10E
	Thukela	V1H002	28°44'15.00"	29°21'9.00"	V11J
	Mlambonja	V1H041	28°48'42.12"	29°18'42.84"	V11H
Eastern Cape	**Orange**	D1H003	30°40'46.92"	26°42'45.00"	D14A
	Mzimvubu	T3H008	30°34'14.88"	29°9'2.16"	T31J
Western Cape	**Berg**	G1H013	33°7'58.08"	18°5'42.84"	G10J

Table 3. 2: Site Description

Site	MAP (mm)	MAR (mm)	Land cover	Population Density (people/km^2)
1. G1H013	450	15	predominately dryland agriculture with temperate and transitional forest and scrub type	150
3. T3H008	750	150	temperate and transitional forest and scrub type	250
4. D1H003	550	35	False Karoo types	250
5. V1H041	650	1250	False grassveld type	150
6. V1H002	750	150	False grassveld type	350
7. U1H005	900	200	False grassveld type	250

3.3.2 Streamflow Data

With the scope of site selection defined in Section 3.3.1, the selected regions were investigated to determine the streamflow gauges available for assessment. The locations of the streamflow gauges selected for study are shown in Figure 3. 15 and the co-ordinates are provided in Section 3.3.1 (refer to Table 3.1). The DWAF online database was used to obtain streamflows for the selected river gauging stations. The streamflow data provided by DWAF is provided in Appendix A. The mean flow for each month of the year for the case study sites under consideration is provided in Figures 3.8 to 3.13 –River Hydrographs. The average monthly flow for the case studies, which shows the availability of flow throughout the year, is shown in Figure 3. 14.

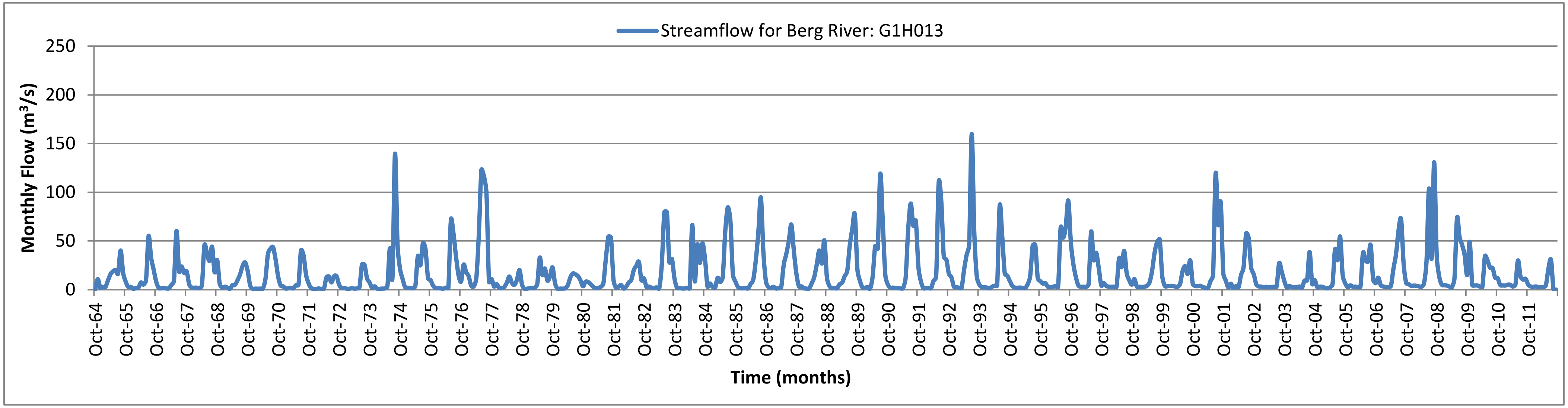


Figure 3. 8: Berg River Hydrograph, Western Cape

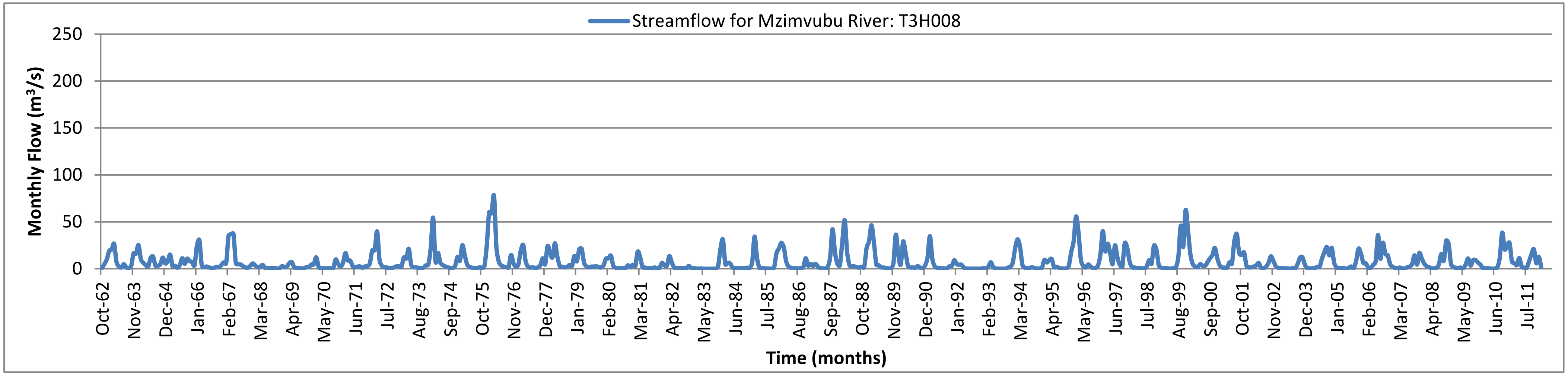


Figure 3. 9: Mzimvubu River Hydrograph, Eastern Cape

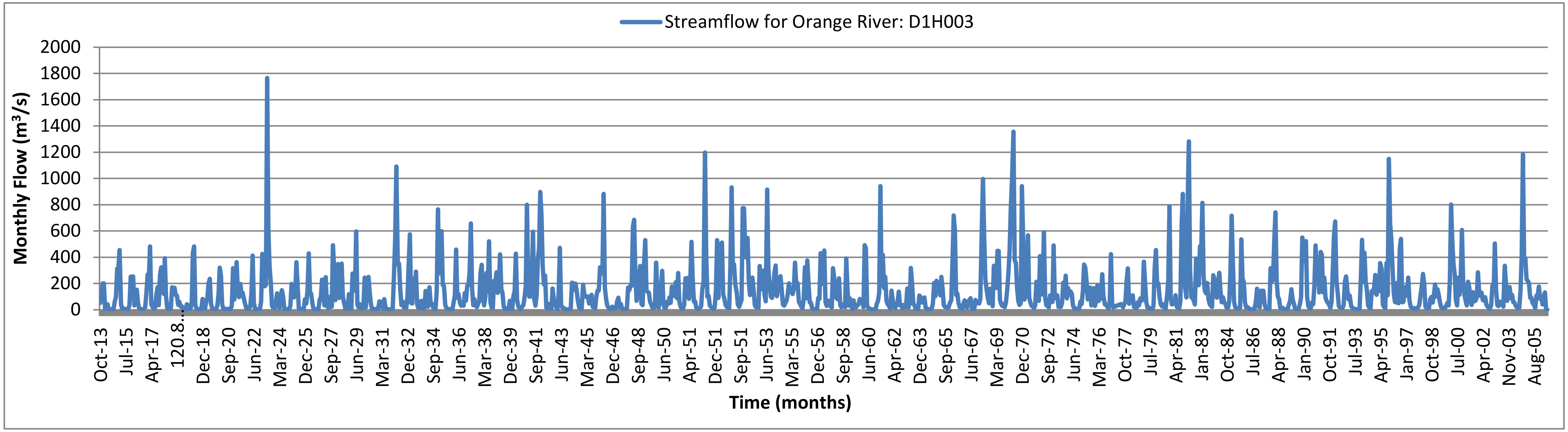


Figure 3. 10: Orange River Hydrograph, Eastern Cape

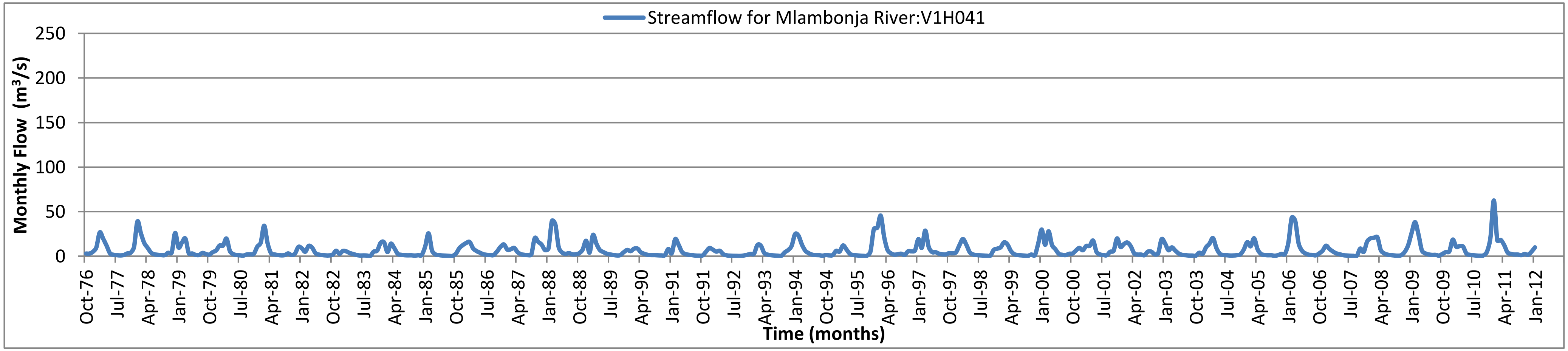


Figure 3. 11: Mlambonja River Hydrograph, KwaZulu-Natal

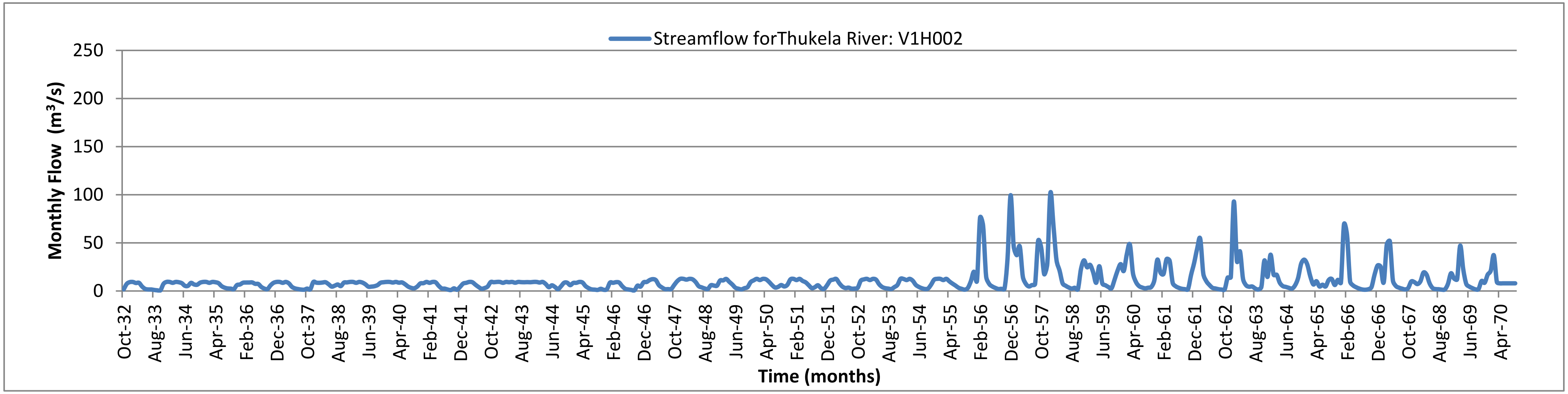


Figure 3. 12: Thukela River Hydrograph, KwaZulu-Natal

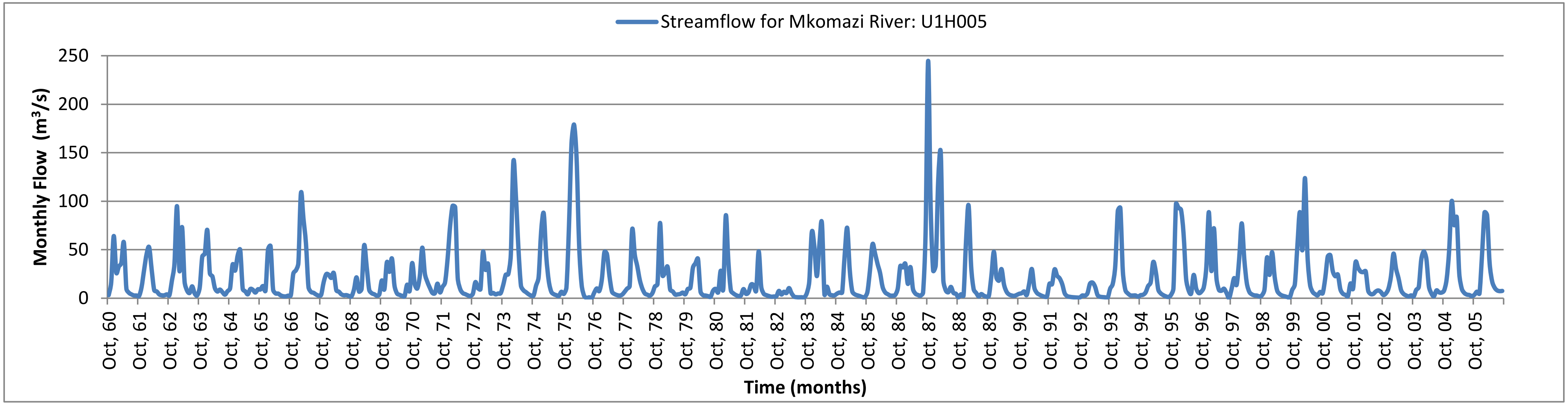


Figure 3. 13: Mkomazi River Hydrograph, KwaZulu-Natal

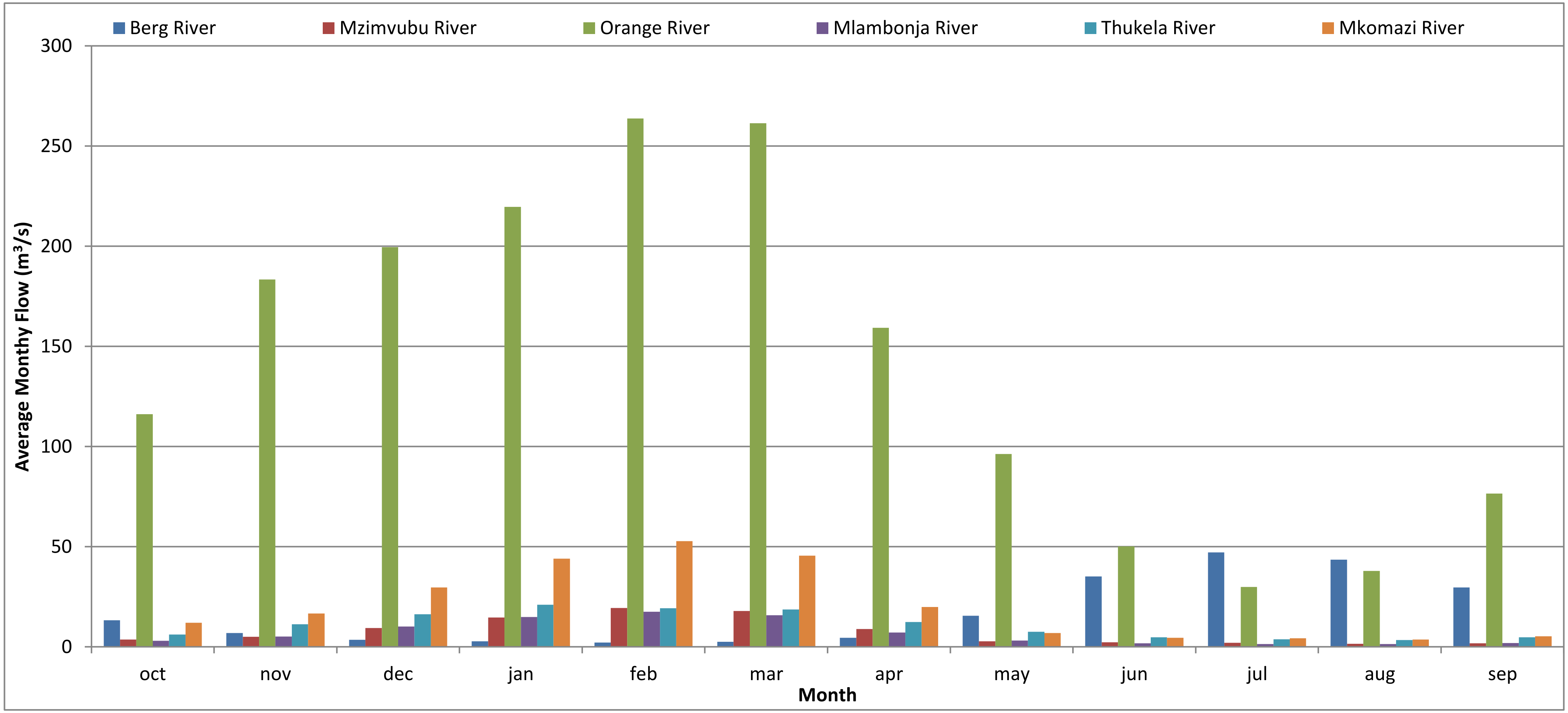


Figure 3. 14: Average Monthly Flow

3.3.3 Head Determination

Google Earth (GE) was used to determine hydraulic head at each site of interest. Figure 3. 15 shows all major primary rivers of South Africa and the location of streamflow gauges that were used in the study. The proposed sites were then evaluated for maximum head capabilities by assessing elevation. Due to GE's sample interval of 90 m, all heights in between these points are estimations. The decision to use an altitude filler was made which allows for better elevation profiling at altitudes below 10 km. The altitude filler uses a web service that takes Digital Elevation Models (DEM's) and uploads it into GE's altitude data and has a higher resolution, datum and interpolation method. The difference in elevations between GE and the altitude filler are well within error tolerances hence GE elevations could have still been used for quantification.

Either a channel or penstock would be used to convey a portion of the streamflow to the turbine house. Once possible intake and tailrace placements were decided, the water conveyance system was routed in order to show the elevation profile between the intake and tailrace for the SSHEPS. The difference in elevation between these two points is defined as hydraulic head [H] and was used for calculation of potential power output of the small hydro system.

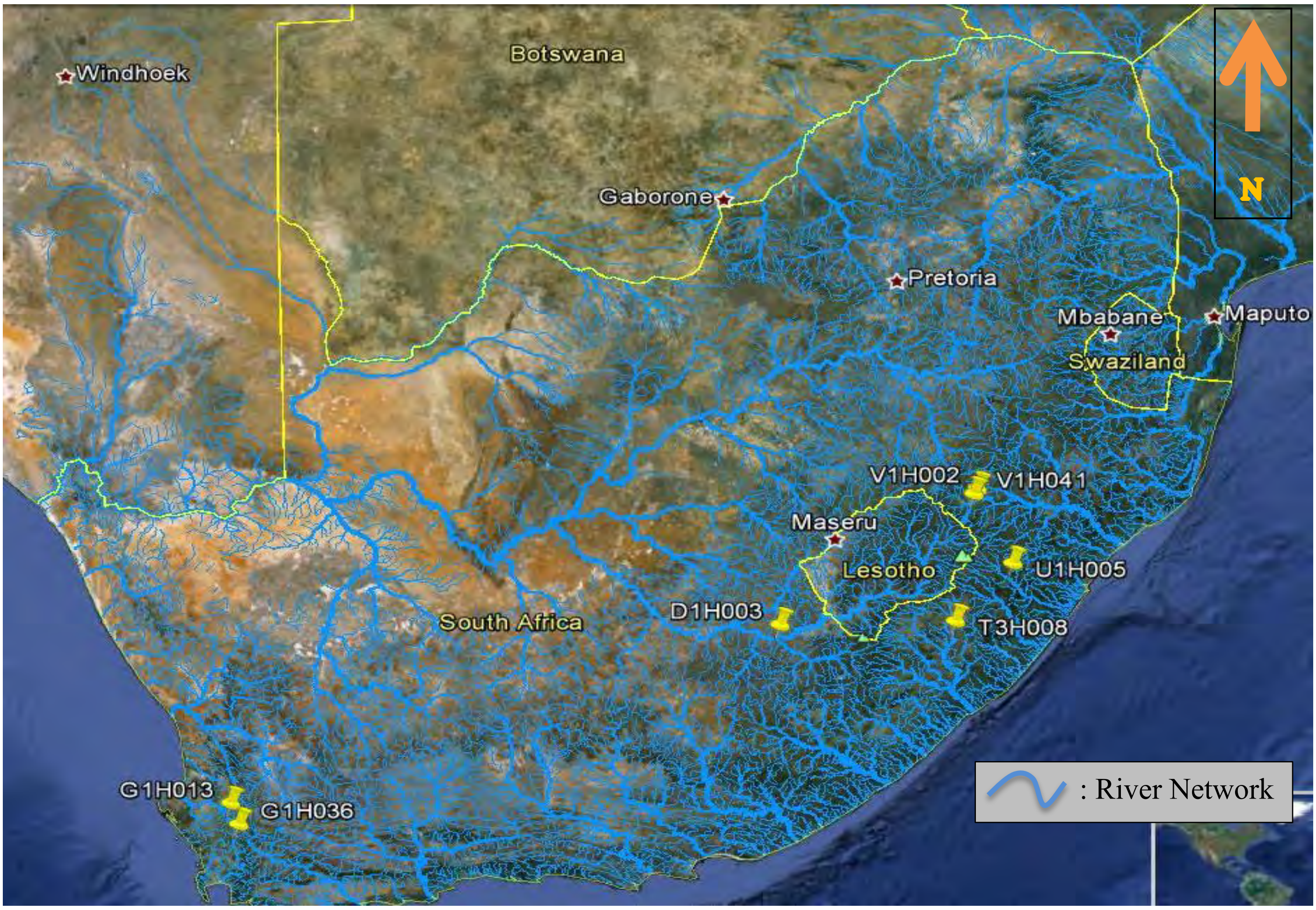


Figure 3. 15: South African River System and Site selection for hydropower development (Google Earth, 2012)

Figure 2. 16 to Figure 2. 22

show the placement of the intake structure and tailrace of the sites and the elevation profiles which allowed head to be quantified. Intake structures were selected to be placed upstream of the conveyance system (higher elevation) with the tailrace situated downstream of the conveyance system after the powerhouse/turbine.

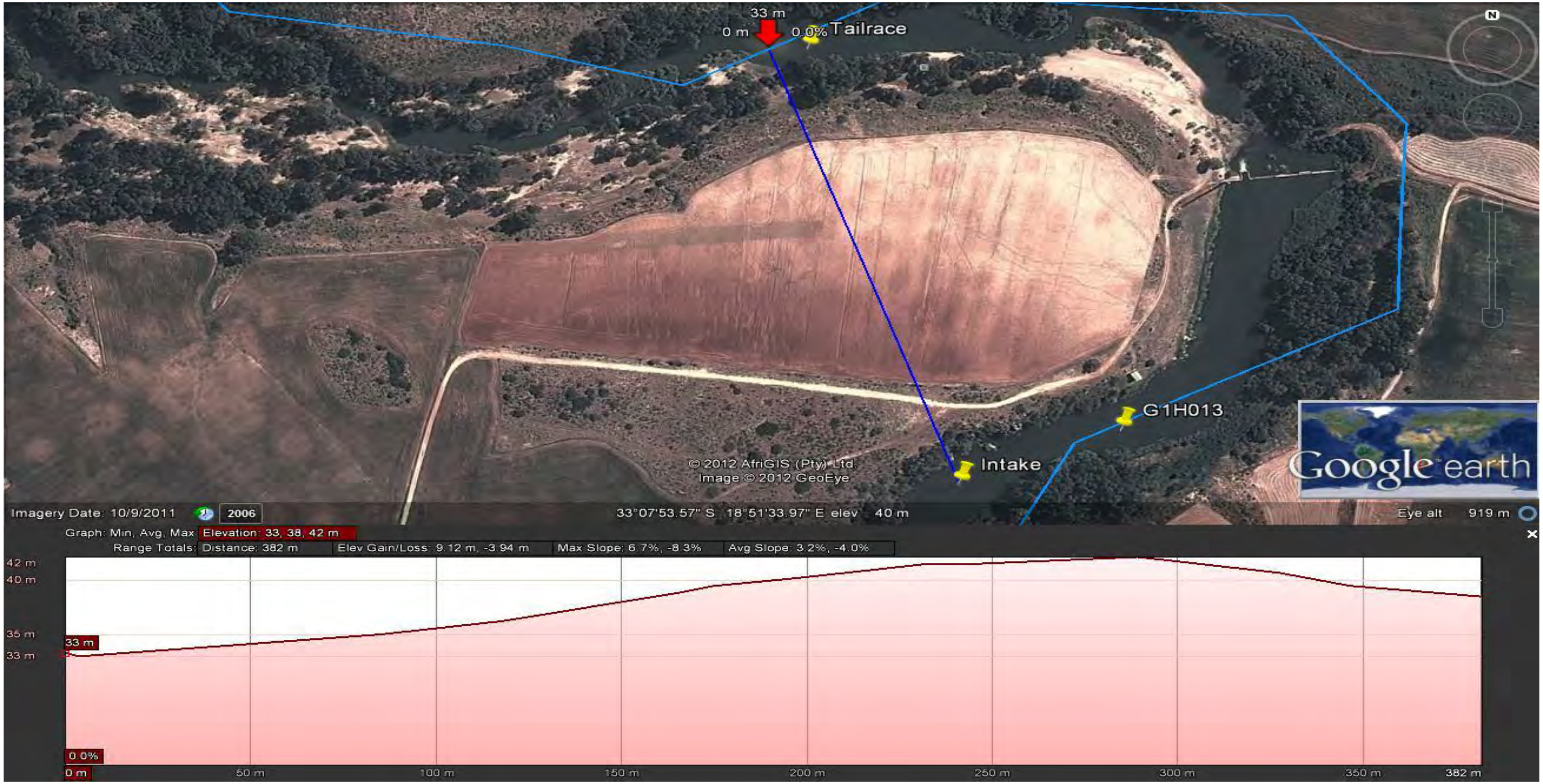


Figure 3. 16: Berg River Elevation Profile, Western Cape

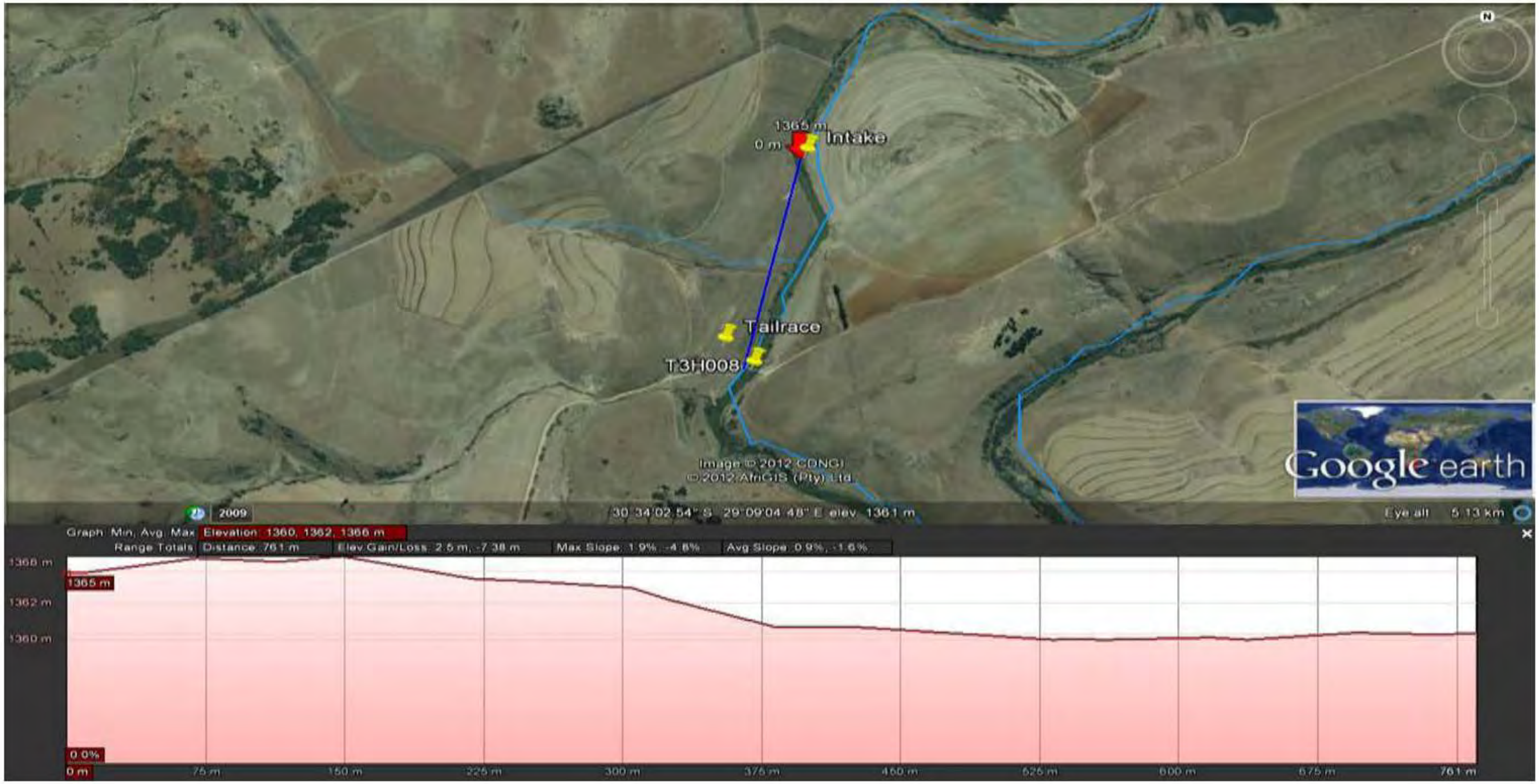


Figure 3. 17: Mzimvubu River Elevation Profile, Eastern Cape

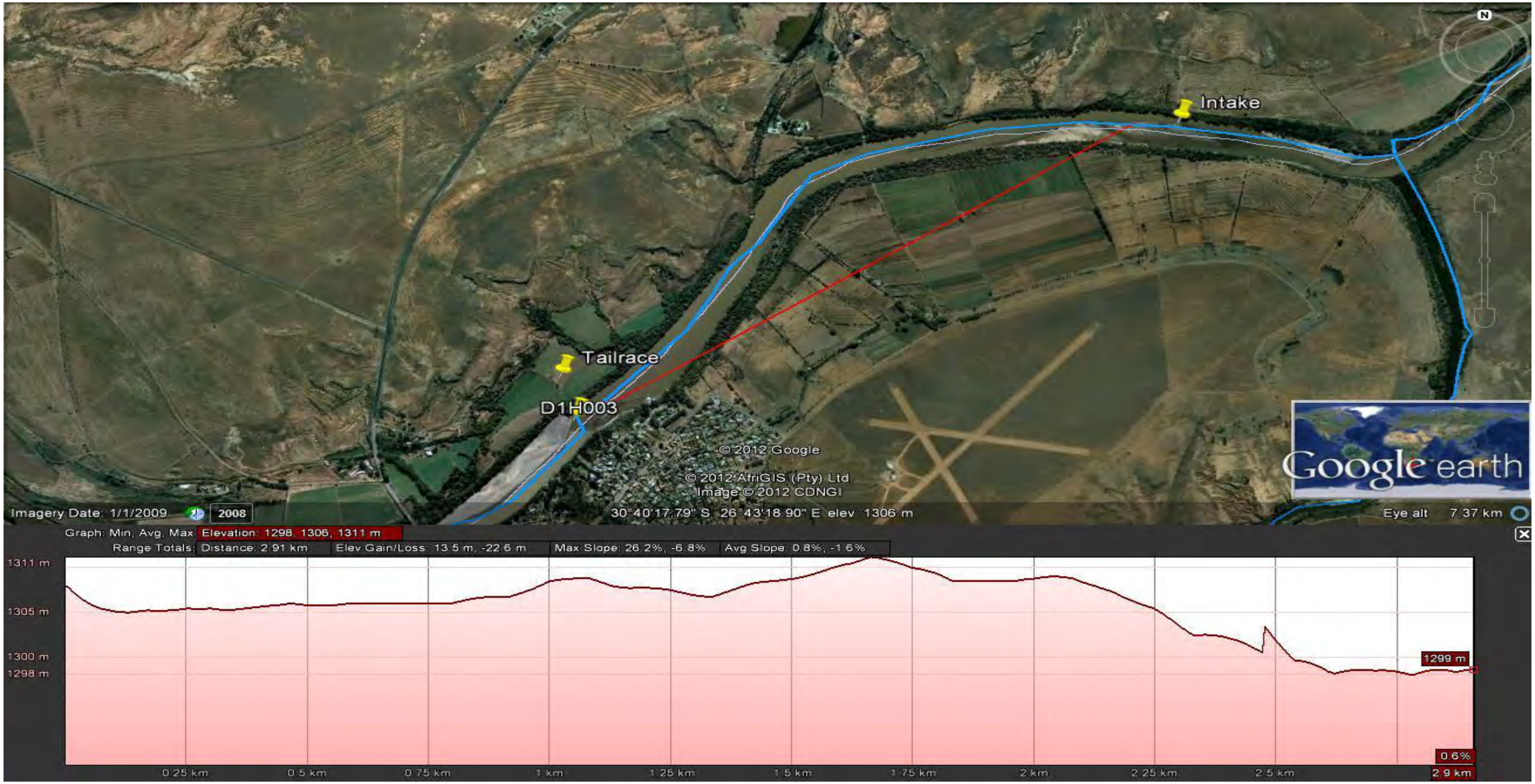


Figure 3. 18: Orange River Elevation Profile, Eastern Cape

Figure 3. 19: Mlambonja River Elevation Profile, KwaZulu-Natal

Figure 3. 19: Thukela River Elevation Profile, KwaZulu-Natal

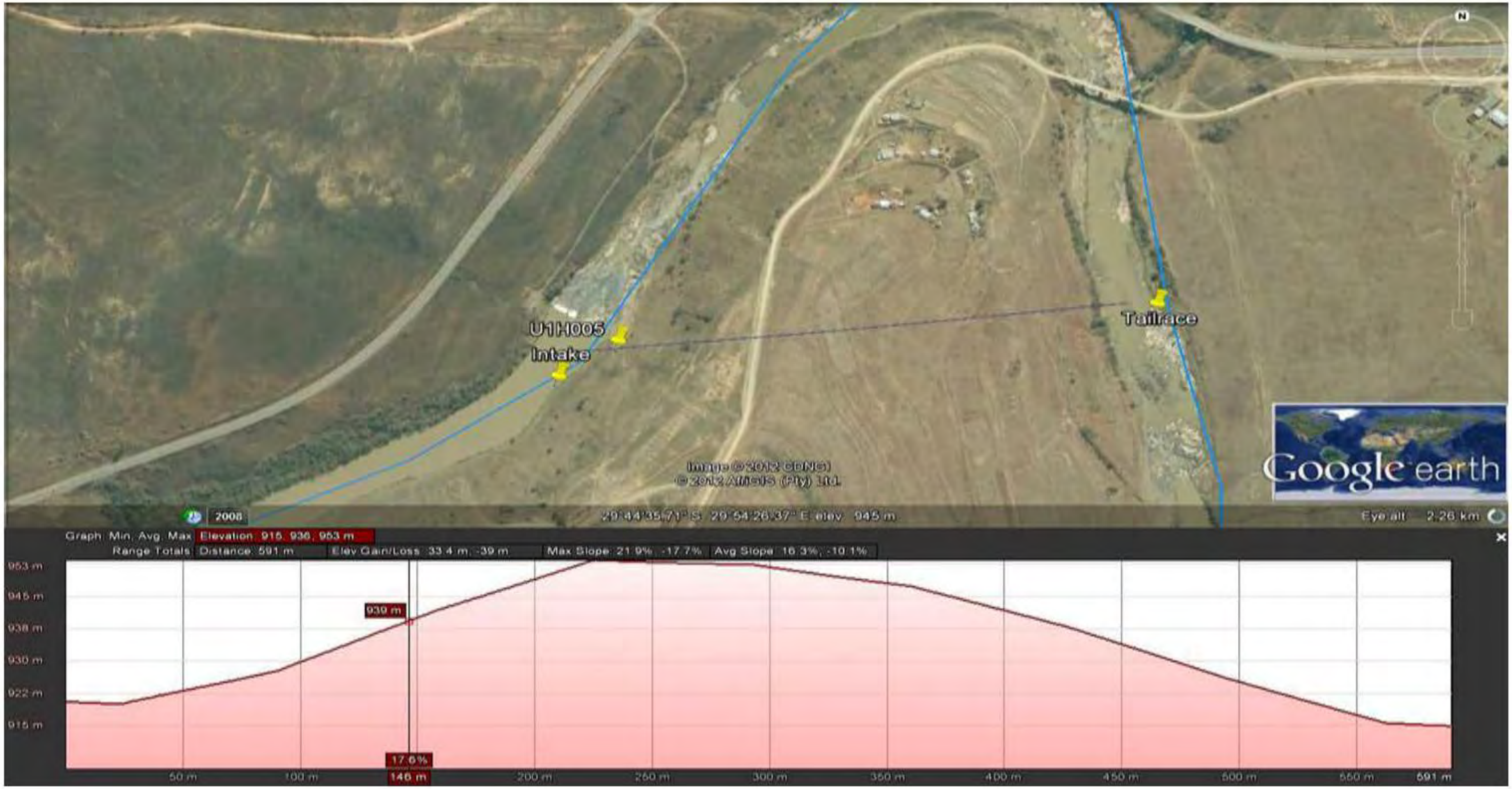


Figure 3. 20: Mkomazi River Elevation Profile, KwaZulu-Natal

3.3.4 Flow Duration Curves Development

The Flow Duration Curve's (FDC's) for each site was constructed following the procedures outlined in Chapter 2.10.2 through to Chapter 2.10.6. Once the FDC's (using an adjusted discharge value to take residual flow into account) where developed, an 85 % system efficiency was selected to take into account any uncertainties from flow construction and hydraulic head profiling using Google Earth (refer to Section 3.3.3) as well as to include any miscellaneous losses, for example due to friction, resulting from the small hydro system. An additional adjustment to the discharge value (subtracting residual flow) was performed to safeguard the environment and turbine. During the dry season, when streamflow is low, a minimum flow should remain in the river as the fluctuation of river flow is necessary for fauna and flora species. If SSHEPS is allowed to draw all the water for generation, it can lead to draining of the river and if this flow is below the minimum flow requirements for the turbine, mechanical damage to the turbine may result. During the dry season when the flow drops to the residual flow value (selected between the 95th and 100th percentile from the FDC) power generation ceases.

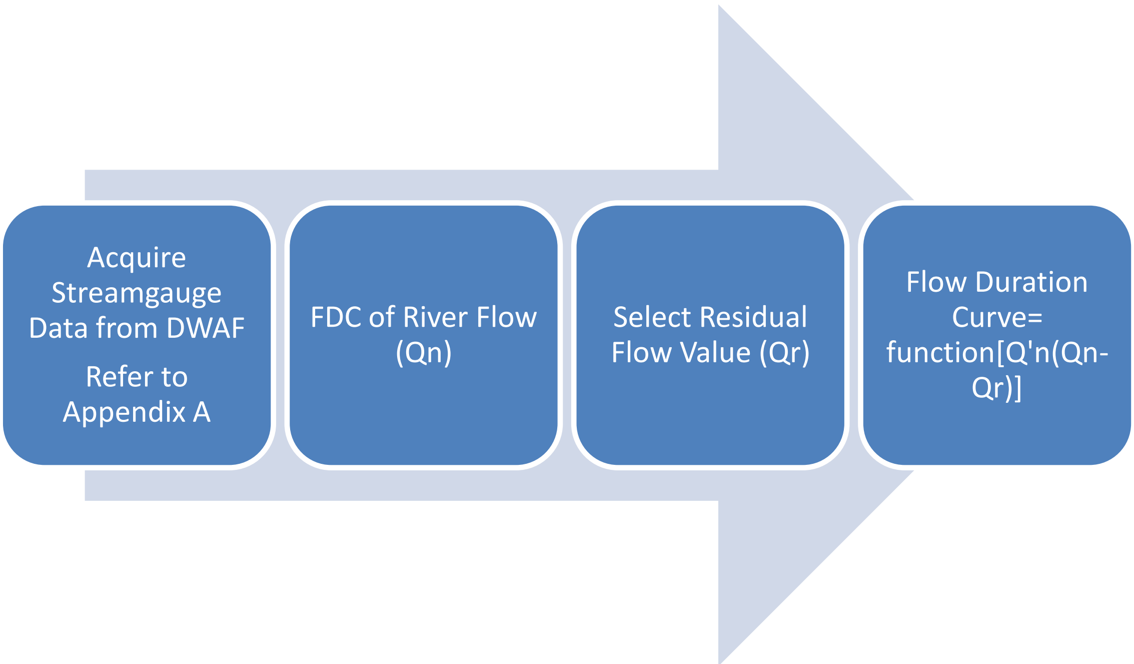


Figure 3. 21: FDC Development Flow Chart

3.3.5 Turbine Selection and Efficiency

With FDC's for each site constructed, the appropriate turbine was selected.

The turbine was selected based on the design flow and the rated head of the small hydro scheme. Figure 2.19 was used in order to select the appropriate turbine. The hydraulic head for all six sites was determined to be low head schemes according to Table 2.6 therefore Kaplan turbines (Reaction) were selected for efficiency curve quantification. Using the RETScreen Turbine Efficiency formulae (refer to Appendix B) the peak efficiency of the Kaplan turbine was found using the respective site's design flow and hydraulic head. The Turbine efficiency curve was plotted against percentage exceedence which shows the performance of the scheme at different expected flows and hence its response or performance to this change in flow.

The following equations for Kaplan turbines were used in this study for the development of the turbine efficiency curve:

$$n_q = kh^{-0.5} \qquad \text{Equation B.2}$$

Where:

n_q= specific speed based on flow

k= 800 for Kaplan turbines

h= rated head on turbine (m)

With the specific speed determined, the specific speed adjustment to peak efficiency could be determined by Equation B.11:

$$\hat{}e_{nq} = \left\{ {(n_q - 170)}/{700} \right\}^2 \qquad \text{Equation B.11}$$

Runner size adjustment to peak efficiency was found using Equation B.12:

$$\hat{}e_d = \left(0.095 + \hat{}e_{nq}\right)(1 - 0.789d^{-0.2}) \qquad \text{Equation B.12}$$

The Kaplan turbine's peak efficiency was found using Equation B.13:

$$e_p = \left(0.905 - \hat{}e_{nq} + \hat{}e_d\right) - 0.0305 + 0.005R_m \qquad \text{Equation B.13}$$

Where $2.8<R_m<4.5$ is the design coefficient.

The peak efficiency of the Kaplan turbine and the efficiency above and below peak efficiency was determined using Equation B.14 and B.15 respectively:

$$Q_{peak} = 0.75Q_{design} \qquad \text{Equation B.14}$$

And
$$e_q = \left[1 - 3.5\left({Q_p - Q}/{Q_p} \right)^6\right] e_p \qquad \text{Equation B.15}$$

Power as a function of available flow was quantified considering hydraulic losses and tailrace effects of the schemes. Plant capacity as a function of design flow and respective turbine efficiency was then quantified.

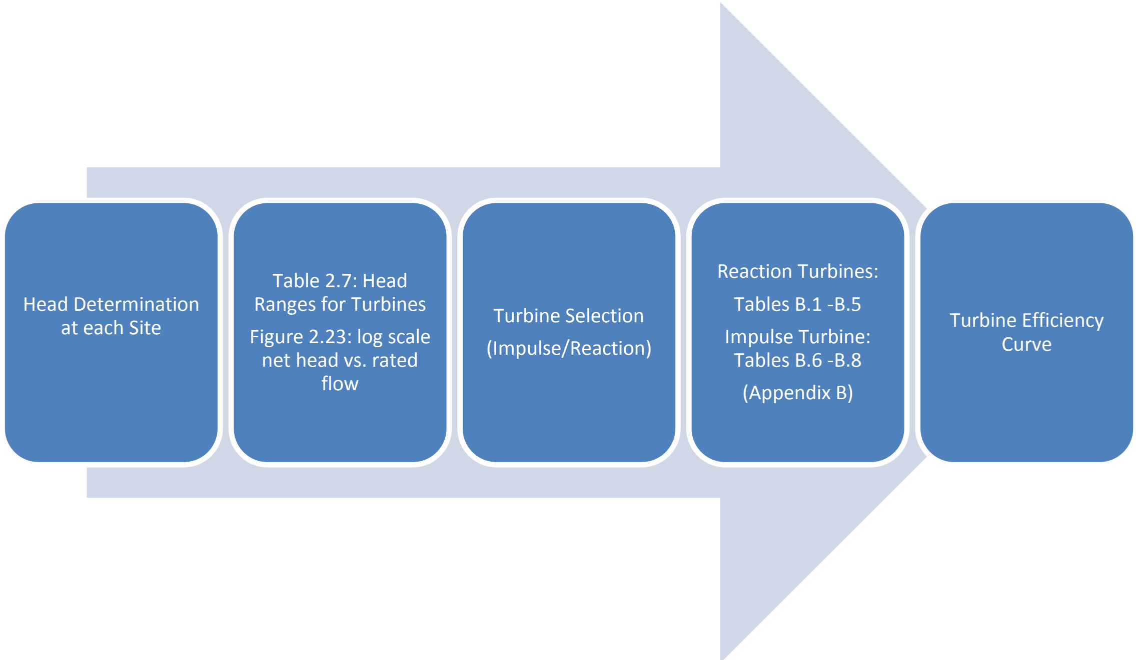


Figure 3. 22: Turbine Efficiency Curve Flow Chart

3.3.6 Power Duration Curve development

Power Duration Curve's (PDC's) show the response of the plants power output as a function of its flow [$Q_{n,used}$]. PDC's were developed by considering the function and Equation 2.25.

$$Q_{n,used} = \min(Q'n, Q_{des})$$

And,

$$P_{PDC} = \rho g Q_{n,used}\left[H_g - \left(h_{hydr} + h_{tail}\right)\right] e_{t,\min(Q'_{n},Q_{des}),} e_g (1 - l_{trans})(1 - l_{para})$$

Equation 2. 32

The value of $Q_{n,used}$ was set to use the minimum value between design flow [Q_{des}] and available flow [Q'n]. This was performed so that the scheme's turbine does not exceed the permitted flow used during power generation which can lead to damage of the electromechanical equipment and harm the rivers ecology. In Equation 2.25, parasitic losses [l_{para}] and transmission losses [l_{trans}] were set to zero as they could not be quantified at this stage of development and would be a small percentage of power loss of the entire hydro scheme. Although not considering the losses lead to a higher power output, this is not critical as miscellaneous losses were considered during FDC construction as outlined in Section 3.3.4.

The renewable energy available to the community was assessed by quantifying the area under the PDC which is given by Equation 2.26 assuming zero downtime losses [L_{dt}] as this value is negligible and dependent on the plants performance or the times where energy production ceases as Operation and Maintenance (O&M) are performed.

$$E_{avail} = \sum_{k=1}^{20} \left(\frac{P_{5(k-1)}+P_{5k}}{2}\right) \frac{5}{100} 8760(1-l_{dt}) \qquad \text{Equation 2. 33}$$

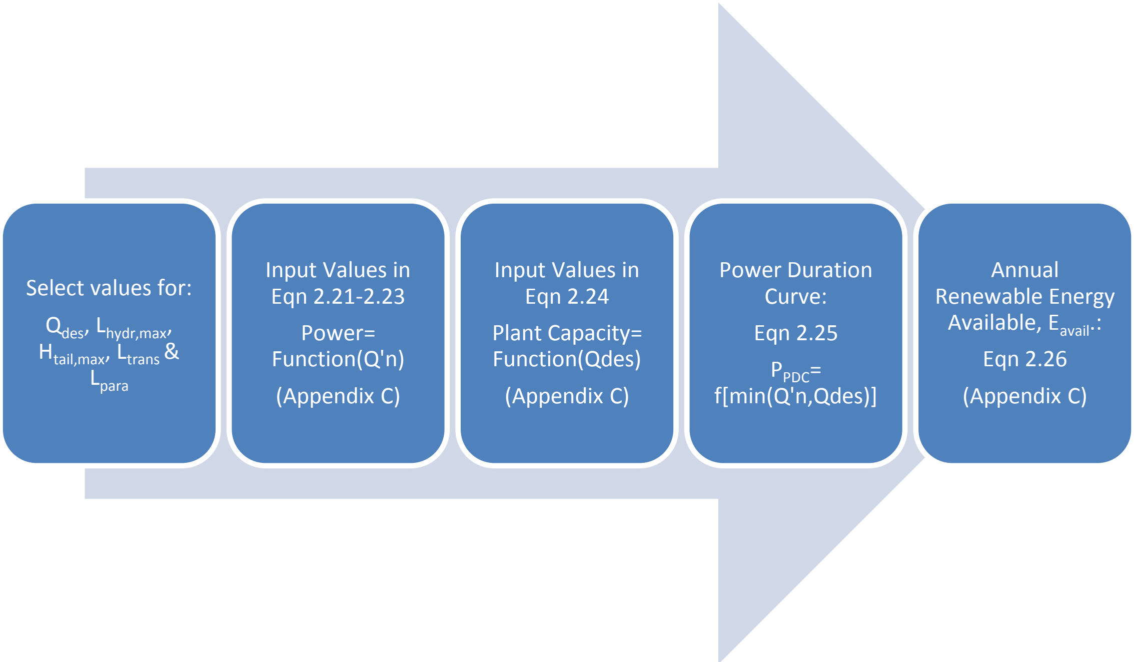


Figure 3. 23: PDC and Annual Renewable Energy Determination flow Chart

3.3.7 Demand Quantification

The electrical demand figure in rural households is difficult to determine without site specific surveys and this demand figure varies due to different demographics.

The Free Basic Electricity (FBE) policy states that 50 kWh/month of electricity should be available for all households in South Africa. With only about 50 % of rural areas electrified (refer to Figure 1.3) this electricity allowance figure was used as a basis for initial demand. Due to claims by Madubansi (2006) and Adam (2010) that this electricity demand figure is too low to meet basic heating needs in a household, the demand figure was adjusted in order to arrive at reasonable allowances which could be expected: 50, 70, 100 and 120 kWh/month per household. The adequacy of the actual FBE policy allowance to meet basic heating needs is out of the scope of this research.

The aim and justification of this adjustment is to simulate different demand quantities and to evaluate how the SSHEPS responds to higher electricity demand. This also has the effect of simulating a community's growing electricity needs.

With annual renewable energy determined (Equation 2.33), the potential number of houses supplied could be quantified by using:

$$\frac{E_{available}}{Annual\ allowance\ per\ household}$$

The potential number of houses supplied could then be compared to the quantified demand of the community which was assessed by using the population density map given in people/km^2 and assuming an approximate area perimeter of 10 km^2 and average household occupancy of 6 for all the communities. Table 3.3 shows the approximate number of houses within each site of this study.

Table 3. 3: household supply summary

<table>
<tr><th>Site</th><th>Population Density (people/km^2)</th><th>Assumed Perimeter (km^2)</th><th>Assumed average household occupancy</th><th>Number of houses</th></tr>
<tr><td>1. G1H013</td><td>150</td><td rowspan="6">10</td><td rowspan="6">6</td><td>250</td></tr>
<tr><td>2. T3H008</td><td>250</td><td>417</td></tr>
<tr><td>3. D1H003</td><td>250</td><td>417</td></tr>
<tr><td>4. V1H041</td><td>150</td><td>250</td></tr>
<tr><td>5. V1H002</td><td>350</td><td>583</td></tr>
<tr><td>6. U1H005</td><td>250</td><td>417</td></tr>
</table>

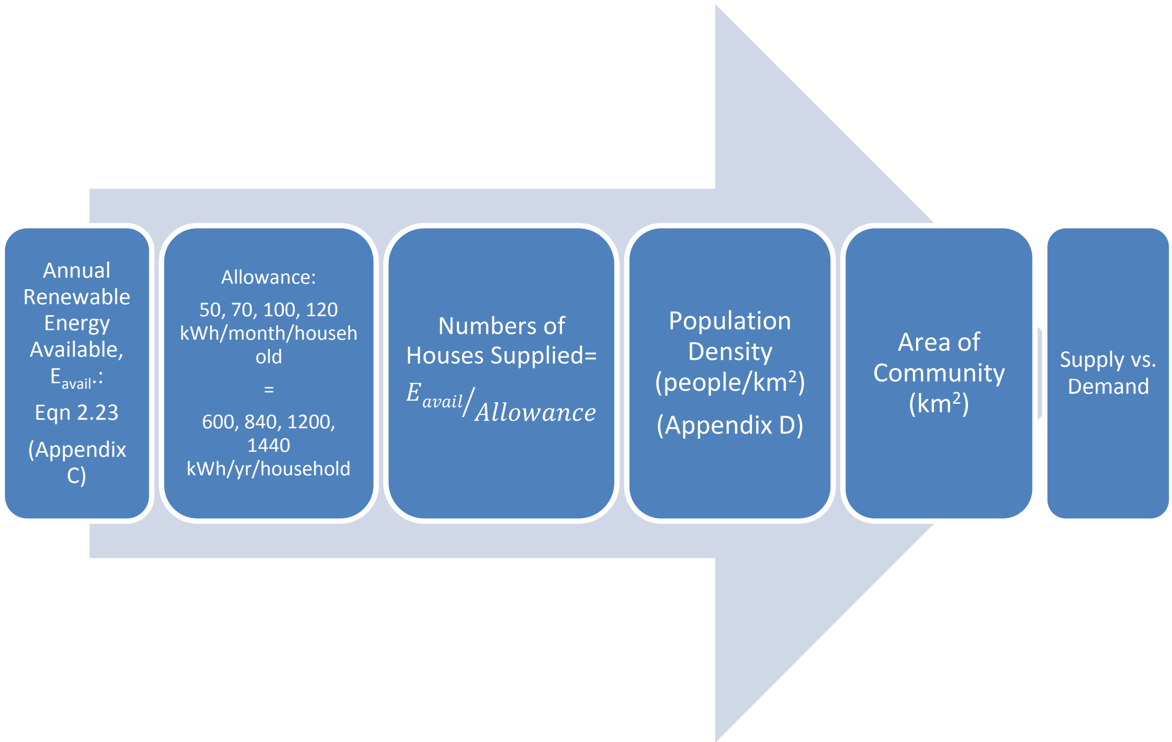


Figure 3. 24: Demand Met Flow Chart

3.3.8 Electromechanical cost contribution

Although this study mentions several costing functions to determine electromechanical costs, it was decided to use the cost functions [Equation 2.25] developed by Alvarodo-Ancieta (2009), which considers examples from 32 countries on small hydropower, as well as the function considering the majority of the electromechanical costs of a scheme. The costs of the turbines, valves, cooling and drainage systems, generators, control and auxiliary equipment is included in the cost function. The formula was developed with the use of a number of curves and graphs for different turbines and Alvarodo- Ancieta (2009) claims an error range between 5 - 10 percent, which allows for better costing estimation.

3.3.9 Civil works cost contribution

Civil works cost contribution was determined by subtracting electromechanical equipment costs from the overall cost of a small scheme. Once the electromechanical cost function was determined, an assumption of the total percentage contribution was made and set at 52 percent. By simple subtraction, the remaining 48 percent was assumed to be the civil works cost contribution (refer to Figure 2.27).

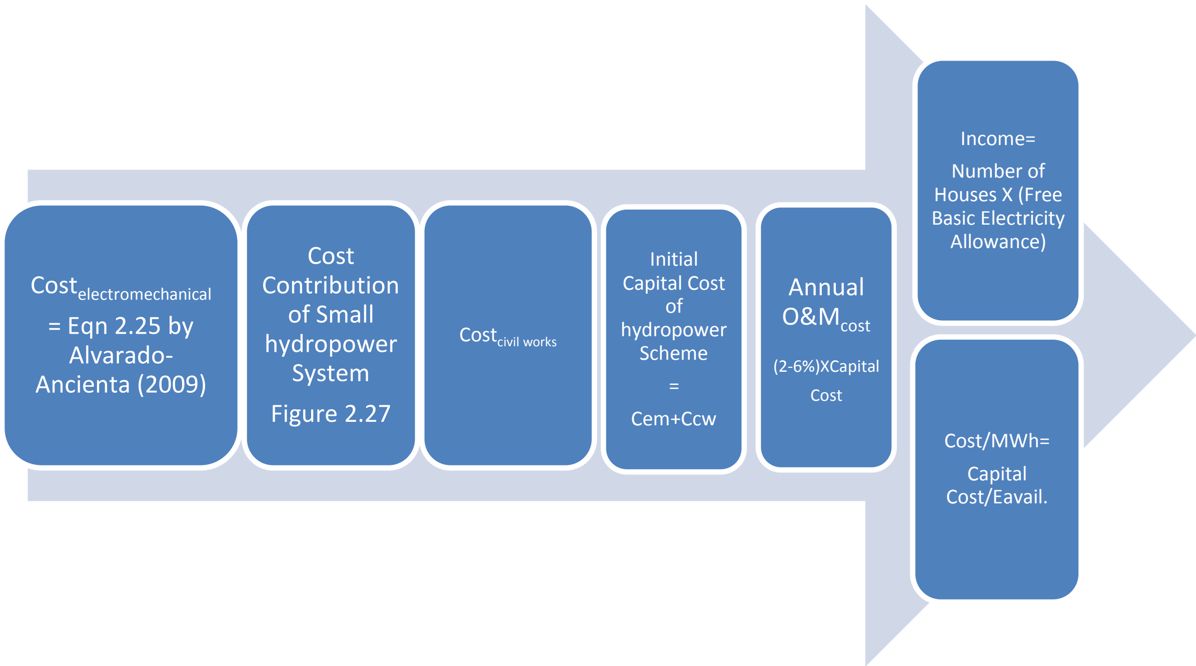


Figure 3. 25: Economics Flow Chart

3.4 Selection and implementation of appropriate method of analysis

Several methods of determining the FDC of ungauged regions have been discussed in Sections 2.10.2 – 2.10.5. Regionalisation, spatial interpolation and transfer of FDC were unnecessary due to the sites selected been gauged and information available. The computations required to perform some of the above mentioned methods are complex with large data input requirements, which in some cases are missing or incomplete. The analysis used in this study inputs low resolution (mean monthly flow) time series data which is not critical as the flow ranking process using the long duration flow sets results in 20 values (flows at 5 %, 10 %,…, 100 % exceedence). The 20 values obtained are indifferent of the size of the streamflow records. Searcy (1959) suggests the use of 25 years or more of chronological time series data for FDC construction. Table 3.4 shows the length of streamgauge data used.

Table 3. 4: Streamgauge length of record

Site/Streamgauge	Length of record (years)	
1. G1H013	1964 - 2012	48
2. T3H008	1963 – 2012	49
3. D1H003	1914 – 2012	98
4. V1H041	1977 – 2012	35
5. V1H002	1933 – 1970	37
6. U1H005	1960 - 2006	46

Based on Searcy (1959), the length of the time series was adequate for quantification and FDC construction, therefore the simple method of analysis was selected.

Spread sheets were formulated and used to manipulate and present the data. The data tables included site specific characteristics of each scheme such as DWAF streamflow data, head profiles from GE, residual flow and miscellaneous losses of each system. The results obtained from applying the simple RETscreen model were then tabulated. Each component of the small scale hydro production such as turbine efficiency curve development, annual renewable energy production and economic quantifications were than implemented. Appendix C and E presents the spread sheets used for small scale hydro generation and feasibility determination.

3.5 Data quality and potential

The accuracy of the results was dependent on the streamflow data used for analysis which was based on mean monthly flows. The elevation profiles obtained using GE was estimated hence an altitude filler was used to obtain higher resolution hydraulic head. Due to the use of these parameters (streamflow and Hydraulic head) the results quantified are reasonable approximates that should convey conservative values for decision and observation/conclusion making.

In some instances the streamgauge records are incomplete or missing, hence patched data was used. The length of the records which start at year 1914/1964 (refer to Table 3. 4) to the present day were sufficient for analysis based on Searcy (1959) who recommends a minimum record of 25 years.

The demand of electricity quantified, which the community is likely to possess, was approximated using population density maps which generalises the area where, in some cases, there is no population present in the area of interest.

The use of the monthly average flows instead of higher resolution daily streamflows is not ideal but is satisfactory at this preliminary design stage of the schemes. Due to the nature of the costing functions used, approximations are always made in order to arrive at final cost of the schemes. The costing functions developed considered other case studies from other countries including South Africa and should predict a reasonable cost band range for the schemes. Variations should arise due to exchange rates, raw materials costs, inflation etc.

3.6 Limitations and Uncertainty

This study looks at implementing a small hydroelectric power system in rural areas where streamflow data is available. The sites chosen in this study, which were selected based on previous studies performed by the DME and Eskom in 2002 (Barta, 2002), were identified as areas of excellent hydro potential and availability of streamflow data. Mean Annual Precipitation for South Africa was used to confirm the regions as excellent hydro potential.

Rivers were identified in the hydropotential regions as shown in Figure 2.1. Further investigation and final sites were found to be in areas that have inconsistent local electricity demand. Some sites contain small scattered communities of electrified towns and villages and some have low cost/traditional dwellings that are semi-electrified. In order to deal with demand computation of all the sites, population density maps [people/km^2] were utilised which provides the necessary parameters to assess the electricity demand. By assuming occupancy level at 6 people per household and dividing the population density by this assumption (after assuming the area perimeter of the community at 10 km^2) an approximate value of the potential number of houses that is in the “community” was quantified.

This study looks at how much free basic electricity (and multiples of this value) can the potential SSHEPS generate to supply the nearby “community” which is simply the demand quantified per square kilometre of population density based on the FBE policy.

The methodology can be applied to sites in need of additional or general power supply. The main objectives of this thesis aim to examine and explain the costs, socio-economic benefits and requirements for modelling a small hydropower scheme in South Africa for basic electrical needs in rural areas.

Based on the cost ranges defined in Chapter 2. 14, the small hydro plant should cost between USD 1300/kW to USD 8000/kW. With all assumptions made and the plants design parameters defined, the schemes should fall in this range, failing to will reaffirm the barriers to implementing such a system. The costs involved with Solar Home System’s (SHS’s) will be transferred to Small hydro schemes in order to check the potential for this system to succeed in terms of income obtainable for capital costs.

4. RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results for the potential power generation of the sites identified in this study. In order to determine the energy available for the year at each site, monthly averaged FDC's are constructed, considering the residual flow, which is said to be the 100th percentile of the river's flow. With the construction of FDC's it was possible to select the optimal design flow value and its corresponding percent exceedence for further quantifications. The value of design flow should be sufficient for power generating opportunity in that it should possess an occurrence greater that 50 percent [$Q_d > Q_{50}$].

The selection of the turbine was carried out based on head elevation which results in the turbine efficiency curves. Using the power equations at normal river and design flows, the energy available at each site was determined resulting in Power Duration Curves (PDC's).

Finally, the financial assessment, costing of schemes, plant capacity factors and CO_2 emission avoidance were carried out.

4.1.1 Flow Duration Curve's

From the streamgauge data collected for the sites under study, the river flows were ranked in descending order with the largest flow assigned to rank 1. After all the flows were ranked (m= 1, 2,…, n) and the percentiles for each flow quantified [(rank m/rank n)x100], the 100th percentile flow was selected as the residual flow value and is shown in Table 4.1.

Table 4. 1: Residual Flow Summary

Site/Streamgauge	River	Q_r (m^3/s)
1. G1H013	Berg	0.63
2. T3H008	Mzimvubu	0.01
3. D1H003	Orange	1.50
4. V1H041	Mlambonja	0.36
5. V1H002	Thukela	0.72
6. U1H005	Mkomazi	0.16

DWAF (2012) states that low - head hydropower developments can affect the water quality, soil, groundwater and the native plant and animal species. Therefore, the consideration of residual flow is crucial for safeguarding the environment despite small-scale hydroelectric power generation been considered environmentally neutral according to Karanitsch (2011).

Appendix A contains the ranked flows. The FDC's at each site are constructed and presented in Figures 4.1 to 4.6.

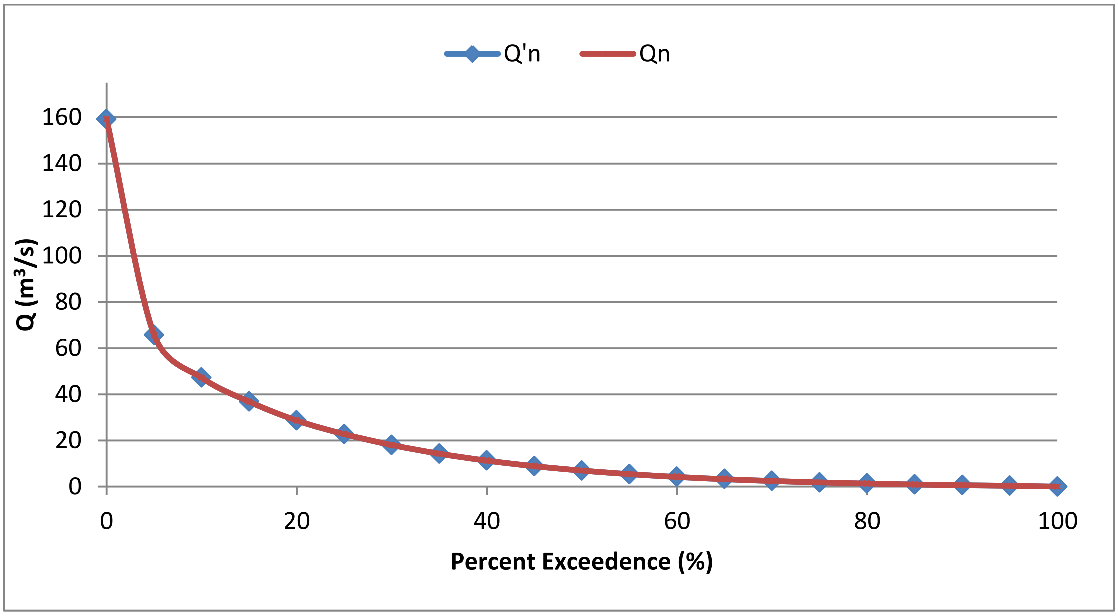


Figure 4. 1: FDC for Site 1, gauge G1H013

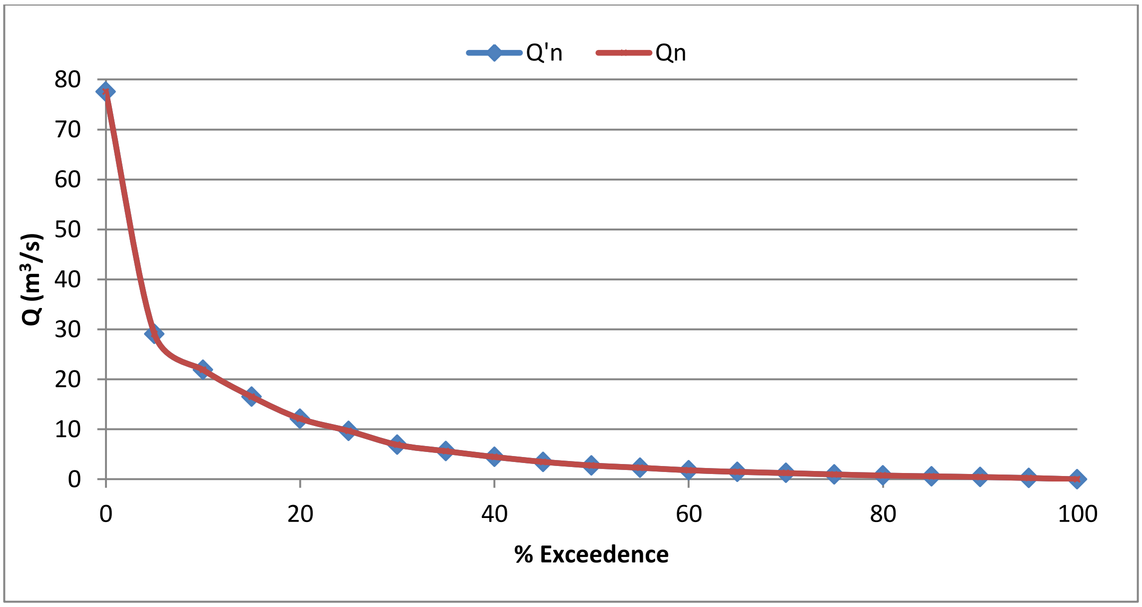


Figure 4. 2: FDC for Site 2, gauge T3H008

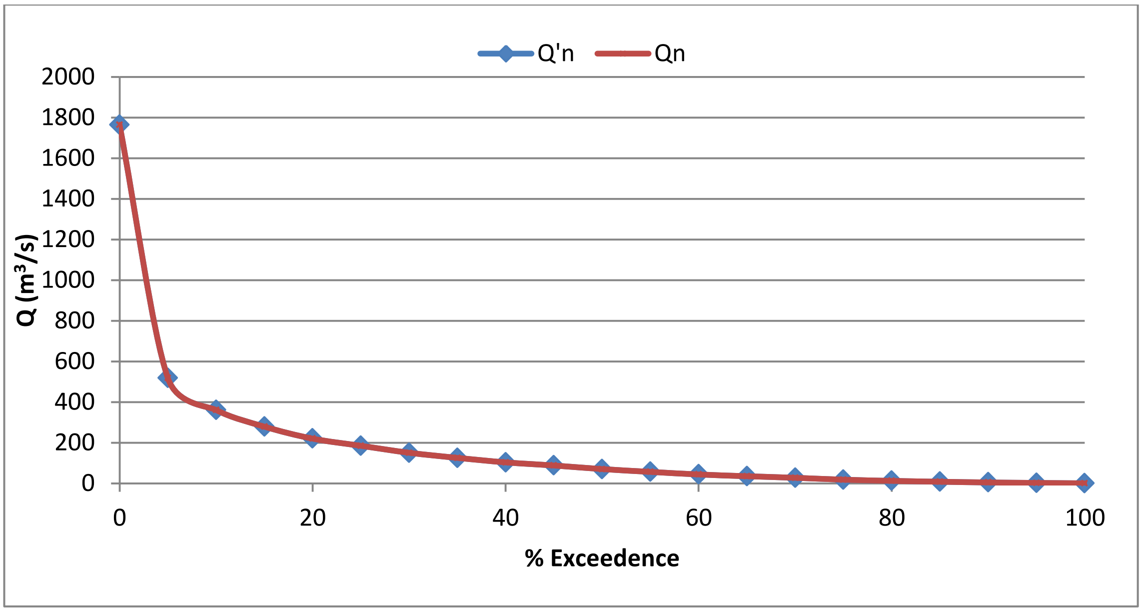


Figure 4. 3: FDC for Site 3, gauge D1H003

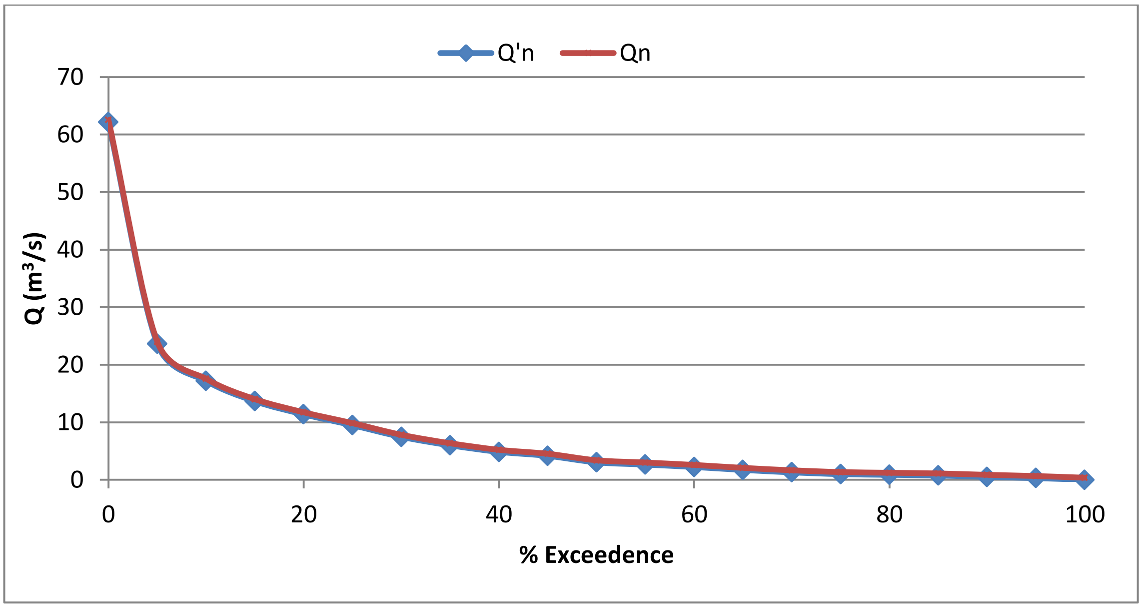


Figure 4. 4: FDC for Site 4, gauge V1H041

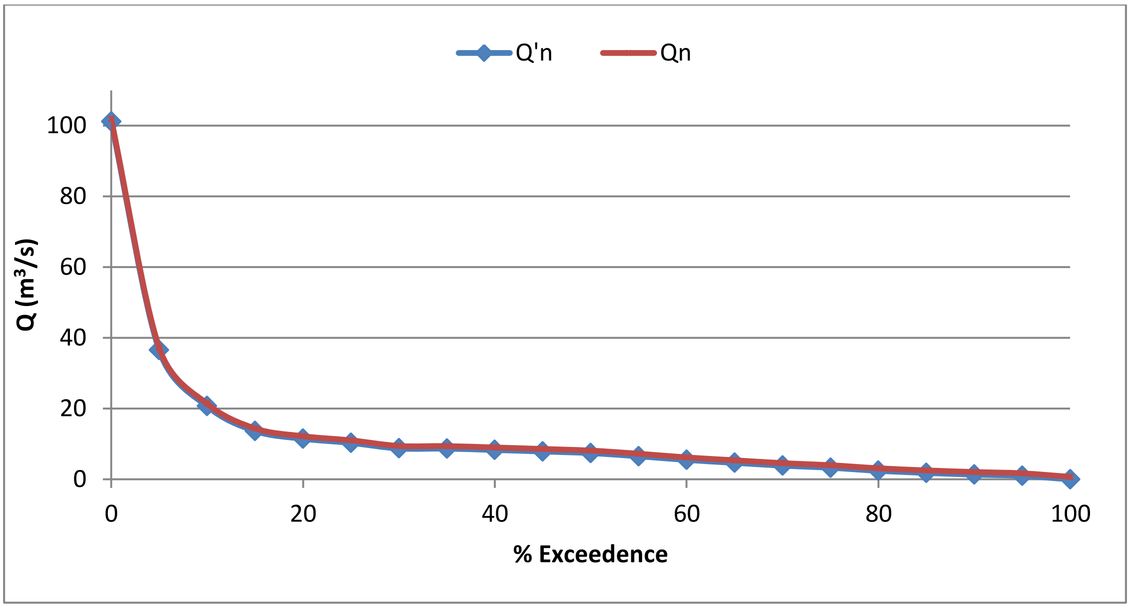


Figure 4. 5: FDC for Site 5, gauge V1H002

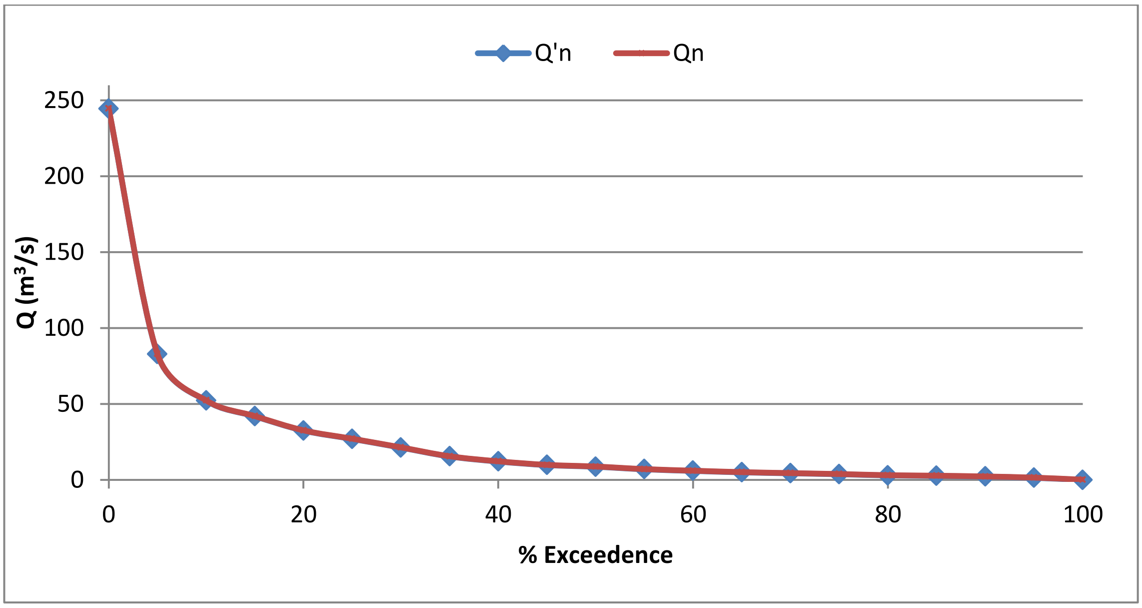


Figure 4. 6: FDC for Site 6, gauge U1H005

The ranked flow technique was utilised, as outlined in Section 2.10.6, to construct FDC's as shown in Figures 4.1 to 4.6. Unlike the river hydrograph's shown in Figure 3. 8 to Figure 3. 13, which depicts the change in flow with time (Pelikan, 2004), the FDC shows the probability of a certain flow occurring or exceeded (Fritz, 1984). The smaller intensity flows are a more common occurrence in the FDC which corresponds to a higher percent exceedence (20 - 100 %) which is due to the disproportionate relationship. The higher streamflow recorded corresponding to a lower percent exceedence (< 20 %) is an occurrence due to the high summer rainfall months between November and February where high flooding is likely to occur (Cretat *et al.,* 2010). Table 4.2 summarises the selected design flows with the corresponding percent exceedence and hydraulic head at each site.

Table 4. 2: Design Flow, Percent Exceedence and Gross Head

Site Number - Streamgauge	Q_{des} (m^3/s)	Percent Exceedence	H_g (m)
1 - G1H013	3	70	4
2 - T3H008	3	60	6
3 - D1H003	10	80	9
4 - V1H041	3	60	2
5 - V1H002	3	80	4
6 - U1H005	3	80	6

A daily time step for FDC construction provides a more accurate relationship of river flow over the course of a day, however monthly mean flows were sufficient for the scope of this study. The six sites selected for study have more than the minimum required chronological streamflow time series data of 25 years which is sufficient for analysis according to Searcy (1959).

After the design has been investigated for feasibility, daily averages should be used to check the variances from a monthly to a daily time step. Regionalisation and Spatial interpolation mentioned earlier require numerous input parameters from several gauges in order to arrive at FDC's. The simple RETscreen model utilised in this study was sufficient for analysis at this stage.

4.1.2 Turbine Selection and Efficiency Curve:

From the head ranges given in Table 2. 7, all the schemes under study were determined to be low head schemes and hence Kaplan Turbines were selected according to Gulliver and Roger (1991). The Turbine Efficiency Curves were developed using the equations found in Appendix B. Figures 4.7 to 4.12 show the Turbine Efficiency Curve for all sites under study.

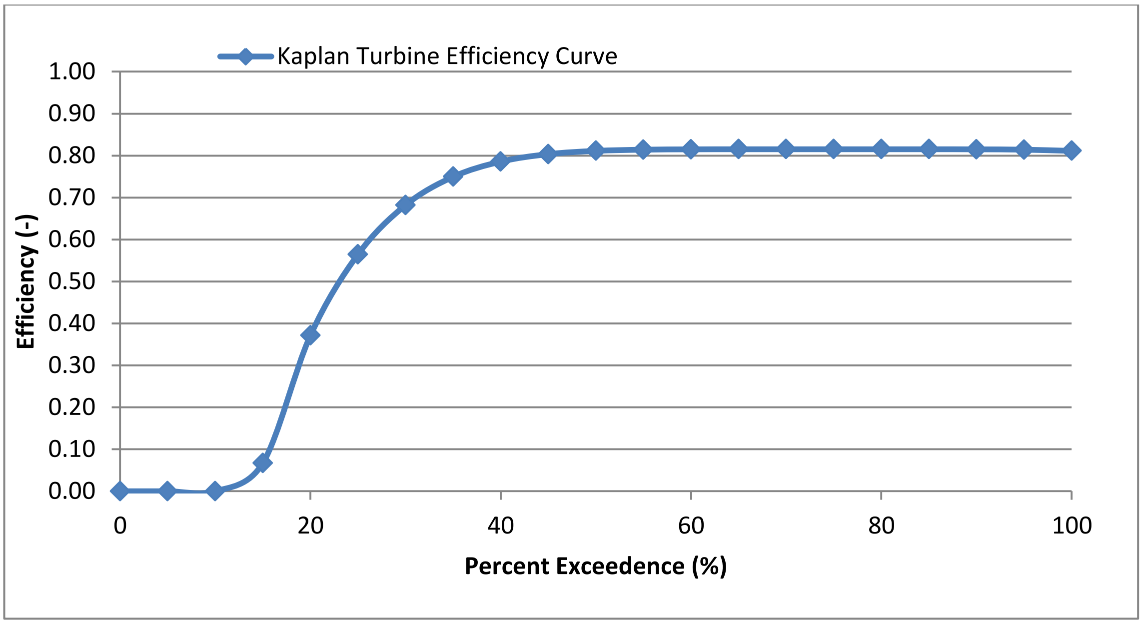


Figure 4. 7: Turbine Efficiency Curve for Site 1, gauge G1H013

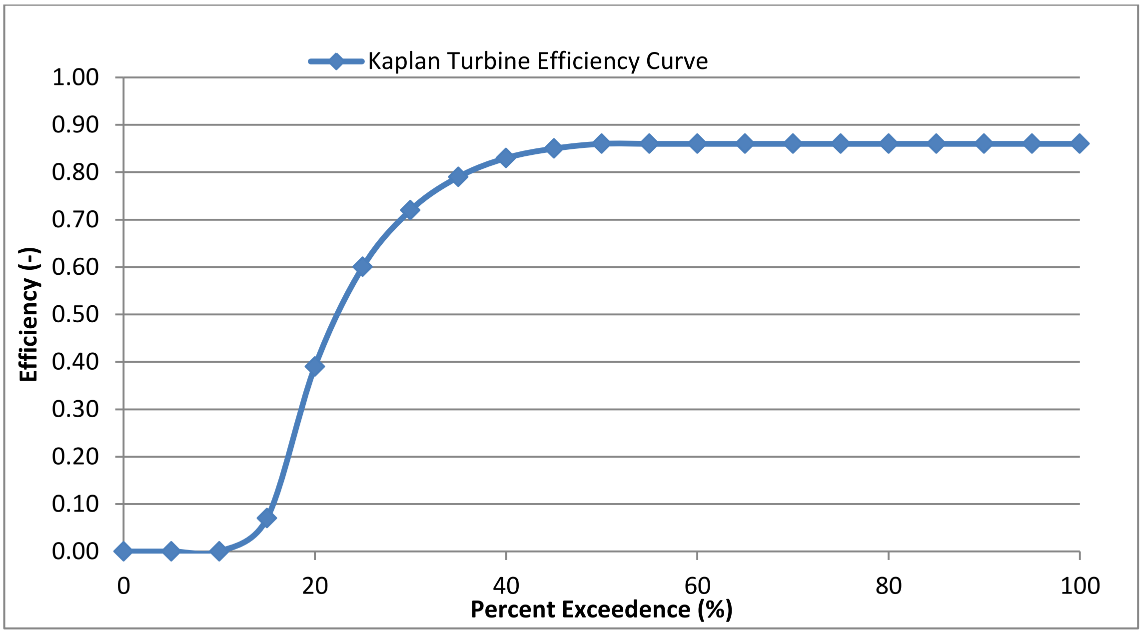


Figure 4. 8: Turbine Efficiency Curve for Site 2, gauge T3H008

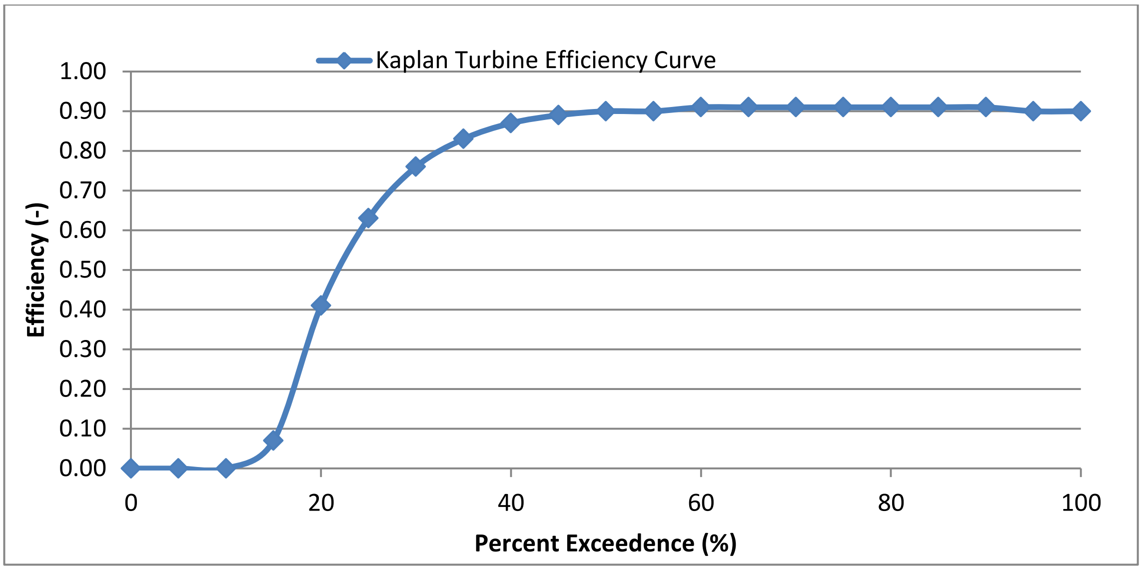


Figure 4. 9: Turbine Efficiency Curve for Site 3, gauge D1H003

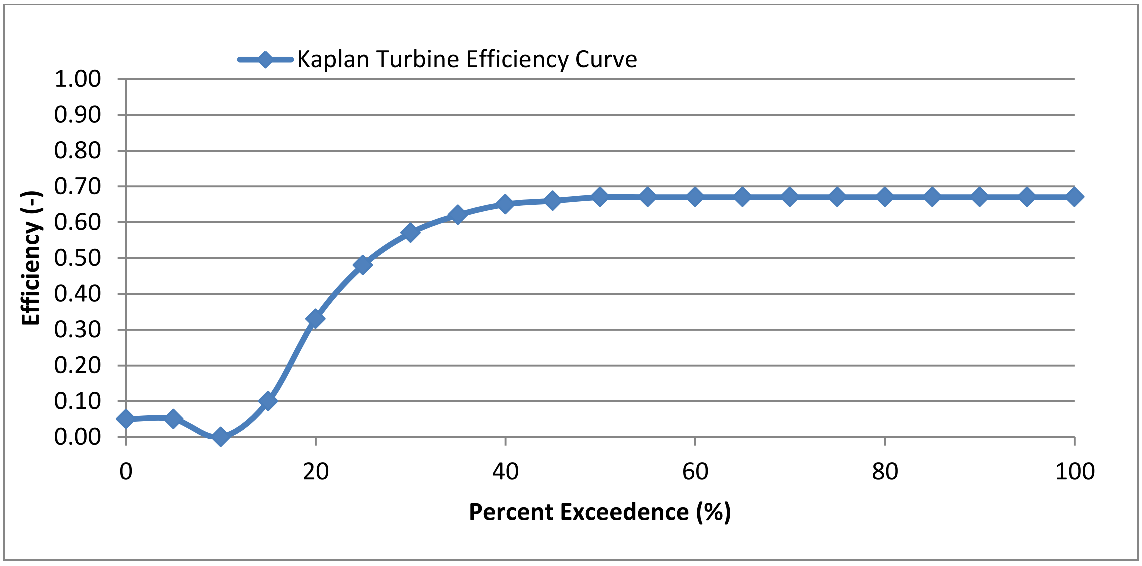


Figure 4. 10: Turbine Efficiency Curve for Site 4, gauge V1H041

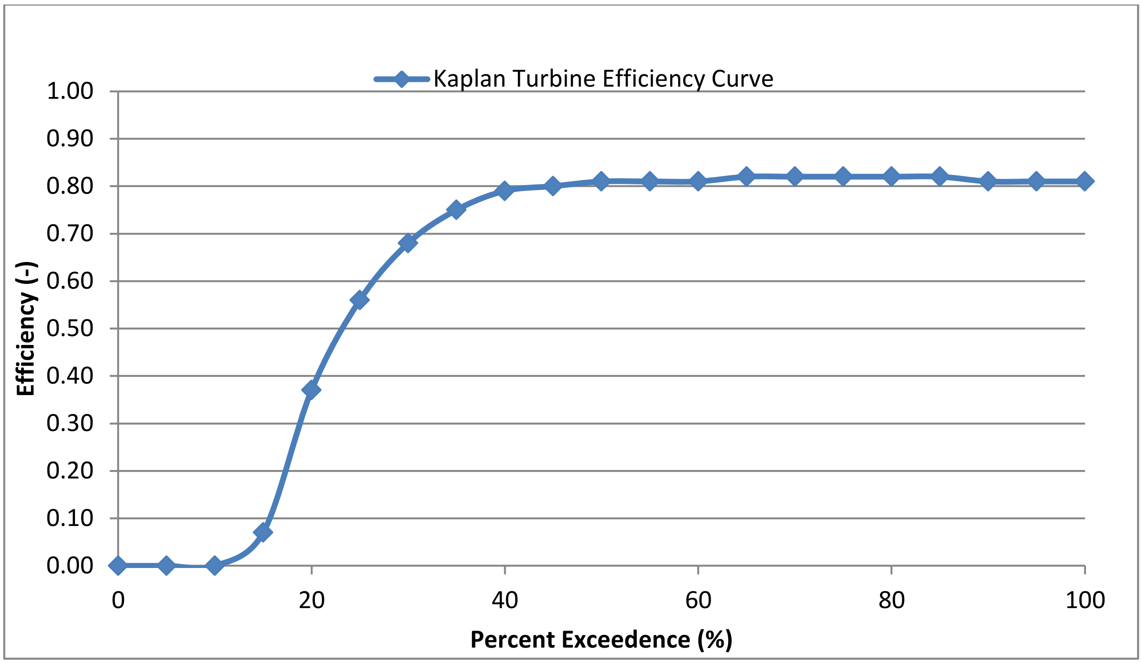


Figure 4. 11: Turbine Efficiency Curve for Site 5, gauge V1H002

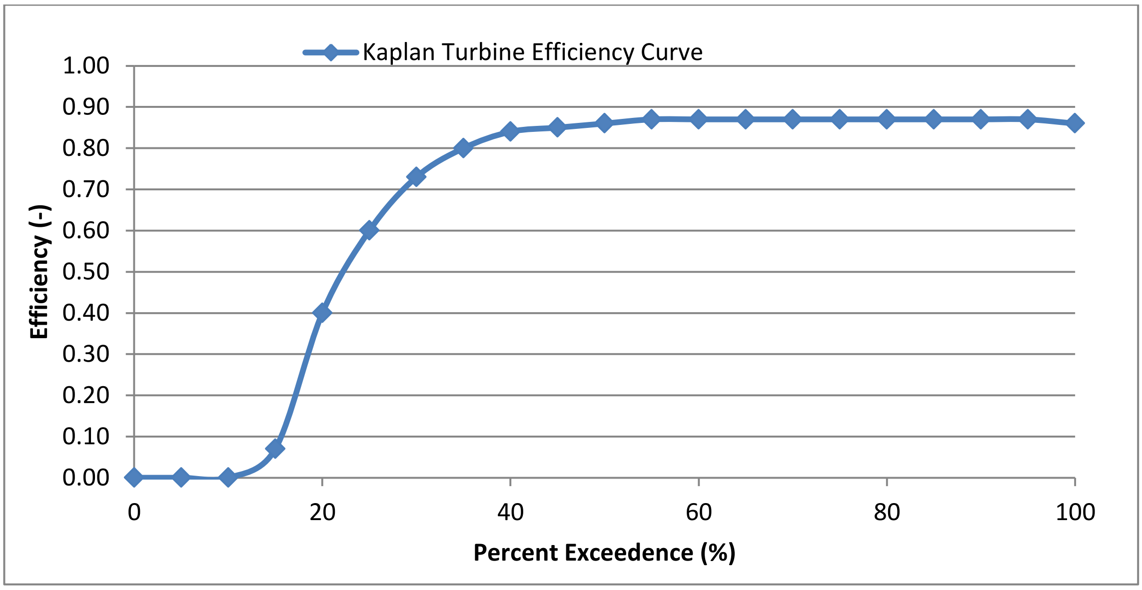


Figure 4. 12: Turbine Efficiency Curve for Site 6, gauge U1H005

The efficiency of the Kaplan turbine is a function of the design flow and hydraulic head and has a working range between 2 – 40 metres (Penche, 2004). All the case study's efficiencies are above 80 % except site 4 (gauge V1H041). Pelikan (2004) states that single regulated Kaplan turbines can work between 15 – 100 percent of the maximum design discharge. Therefore, due to the hydraulic head and streamflow been lower compared to the other sites, site 4's efficiency is reduced resulting in less than normal hydro-electricity production.

4.1.3 Power Duration Curve and Renewable Energy

In assessing the renewable energy available by each scheme, Power Duration Curve's (PDC's) were constructed. PDC's used here utilise a flow in accordance to the function:

$$Q_{n,used} = min(Q'_n, Q_{des})$$

Power generation decreases at flows below Q_{design} occur and eventually ceases when the river flow drops close to the residual flow (Q_r) (Kosnik, 2010).

The area under each graph is the renewable energy available by each scheme for a year (Kosnik, 2010). The PDC's are shown in Figures 4.13 to 4.18.

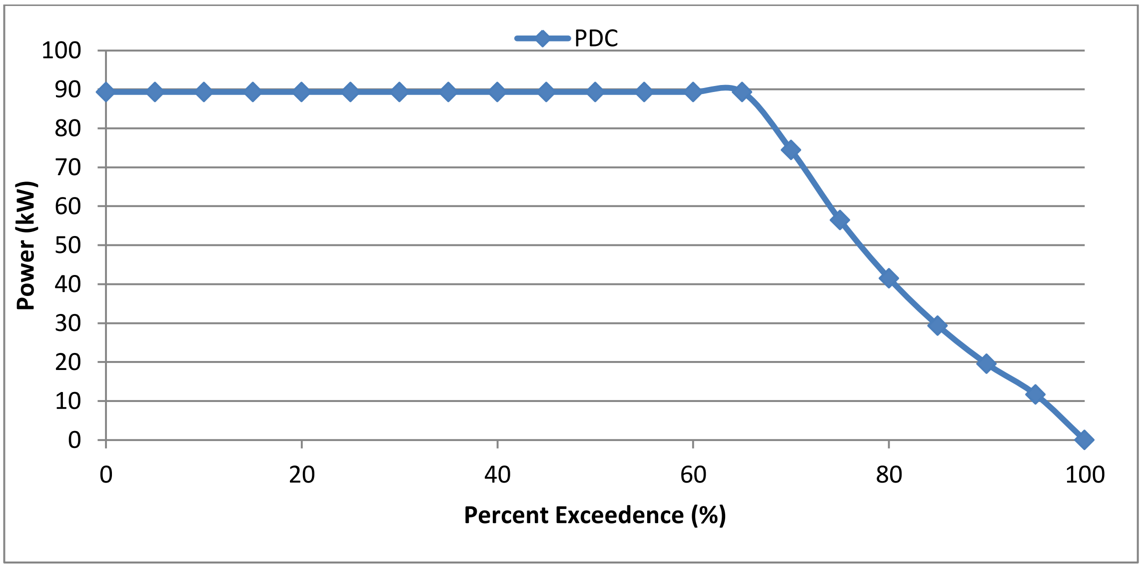


Figure 4. 13: PDC Site 1, Berg River

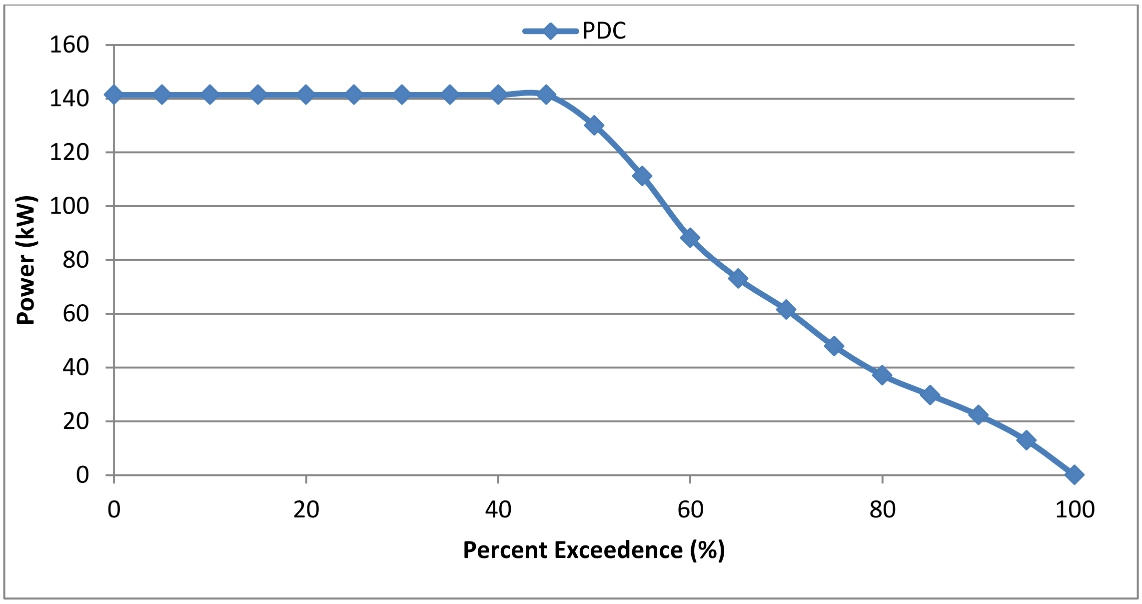


Figure 4. 14: PDC Site 2, Mzimvubu River

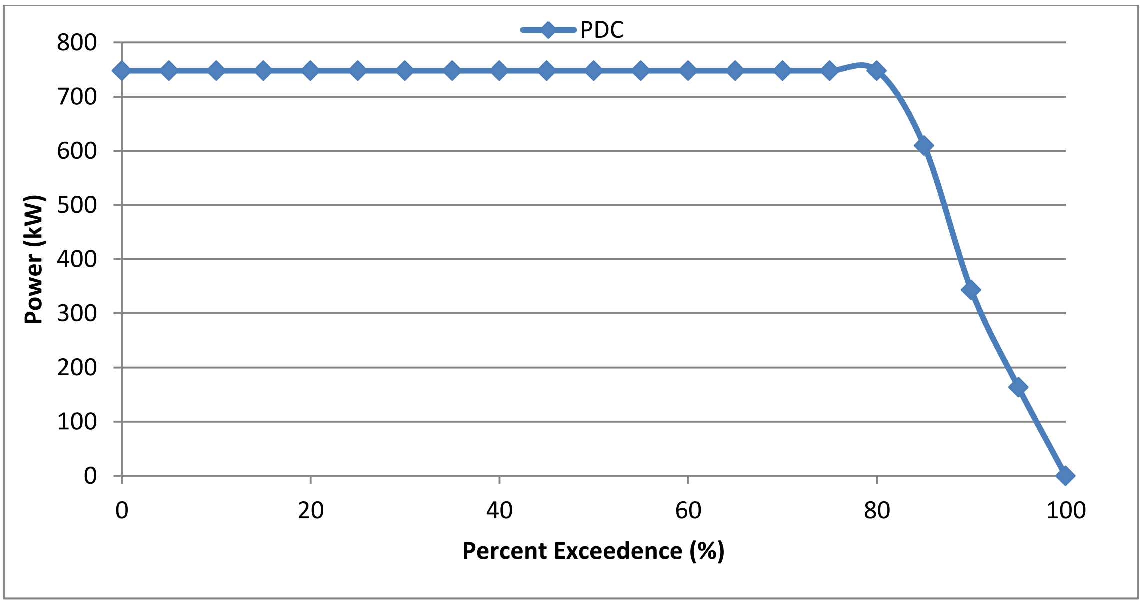


Figure 4. 15: PDC Site 3, Orange River

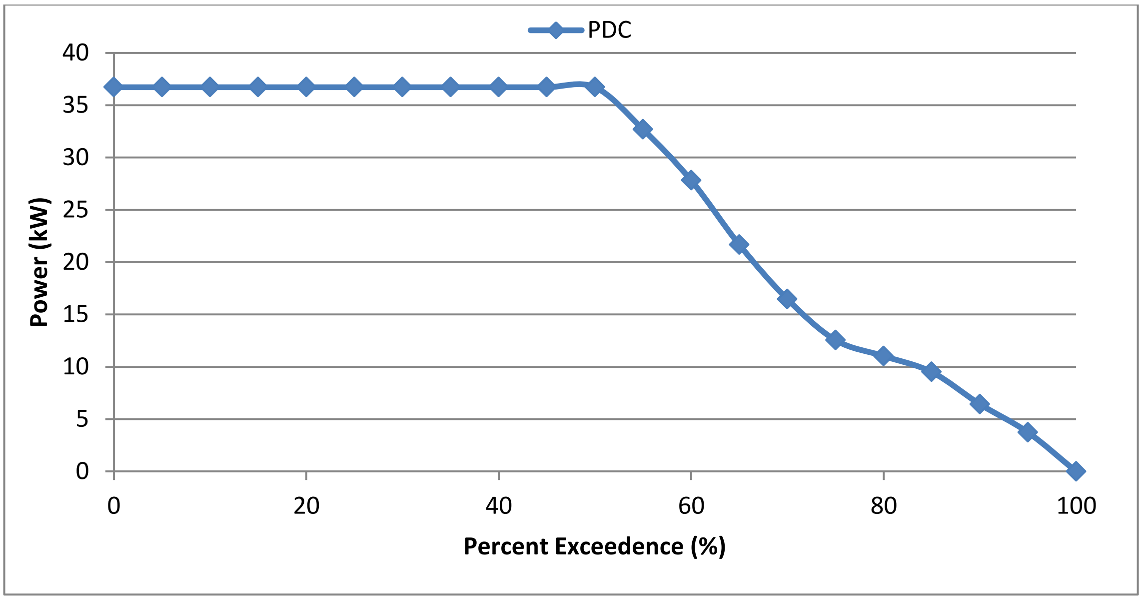


Figure 4. 16: PDC Site 4, Mlambonja River

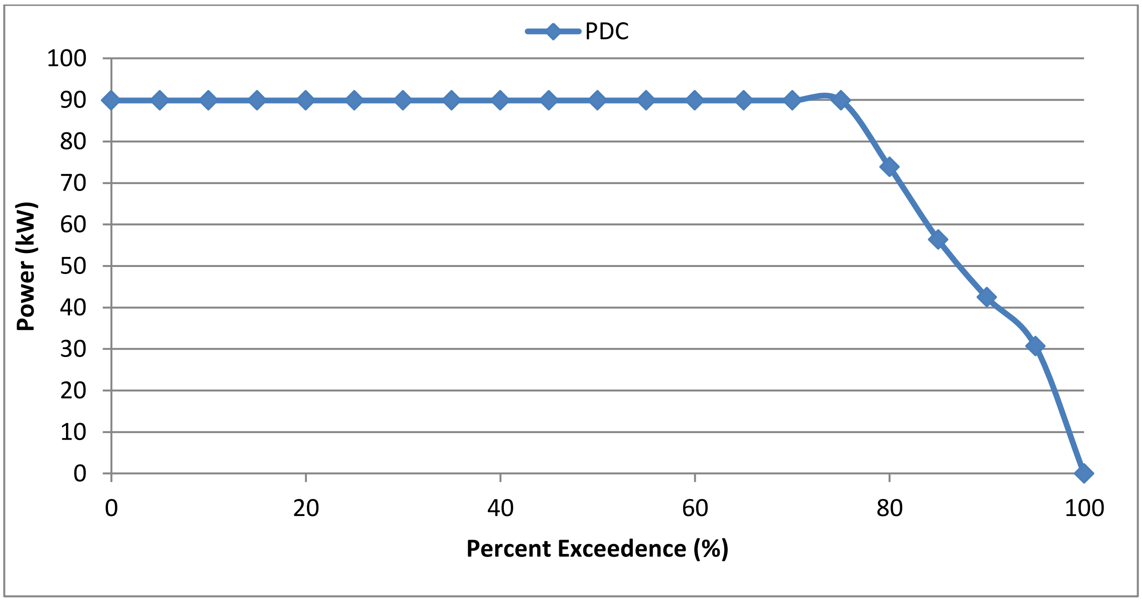


Figure 4. 17: PDC Site 5, Thukela River

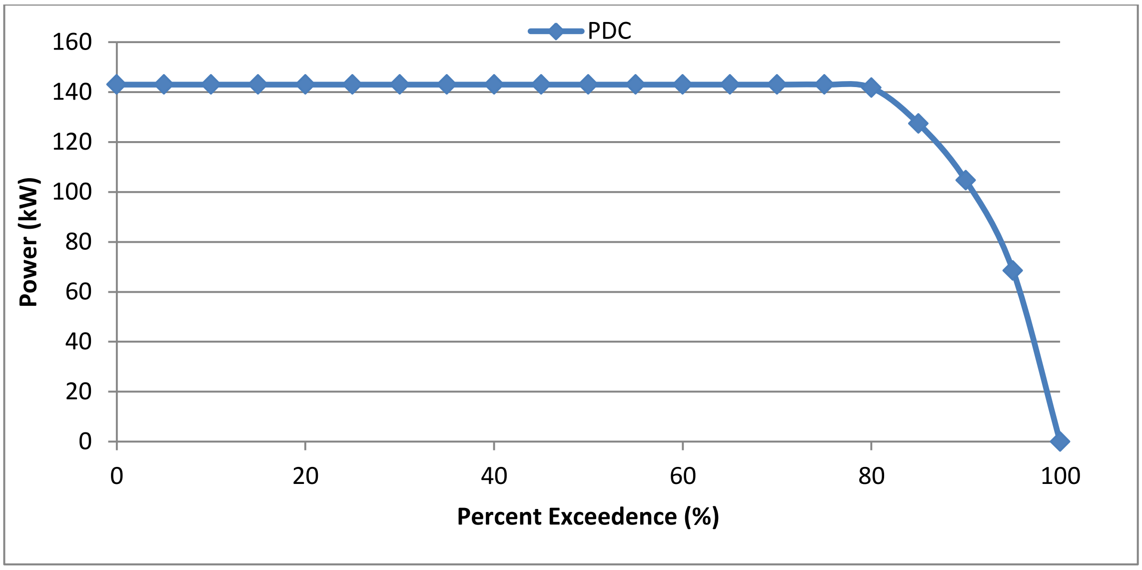


Figure 4. 18: PDC Site 6, Mkomazi River

From Equation 2.26, the annual renewable energy available by each scheme was quantified and is shown in table 4.3.

Table 4. 3: Annual Renewable Energy

Site	Capacity (kW)	Renewable Energy Available, E_{avail} (MWh/year)
1. G1H013	89	650
2. T3H008	141	888
3. D1H003	748	6058
4. V1H041	36	239
5. V1H002	90	719
6. U1H005	143	1196

According to Brent (2010) (refer to Table 2.9), the classification of the schemes below 100 kW are termed micro-hydro systems which could be used for powering a small community in remote areas. Capacities between 100 kW – 1 MW are termed micro-hydro systems and can be a stand-alone or directly fed into the grid (Brent, 2010). The schemes in table 4.3 can be used for supplemental electricity needs in the case of semi-electrified communities, providing additional power needs, or can supply electricity directly to the community.

The FDC's and PDC's, as constructed Figures 4.1 to 4.6 and Figures 4.18 to 4.18 respectively, were plotted on the same Y-axis and included residual flow and percent exceedence on the X-axis. This was performed for comparison purposes of the graphs parameters. Figures 4.19 to 4.24 show the parameter comparison graphs.

The available flow far outweighs the utilised flow during high flows however as the flow rate drops/approaches residual flow, power generation decreases. Power generation ceases when the river flow drops below a predetermined value set by the user, i.e. when the flow reaches/falls below the residual flow value (Kosnik, 2010). This is performed in order to protect the river's ecology and also prevent damage to the turbine by cavitation (DWAF, 2012). Lower flows usually occur in the dry season (June to September) whilst higher flows are common in the wet season (October to May)[12], although rainfall in South Africa remains variable throughout the year (Cretat *et al.,* 2010).

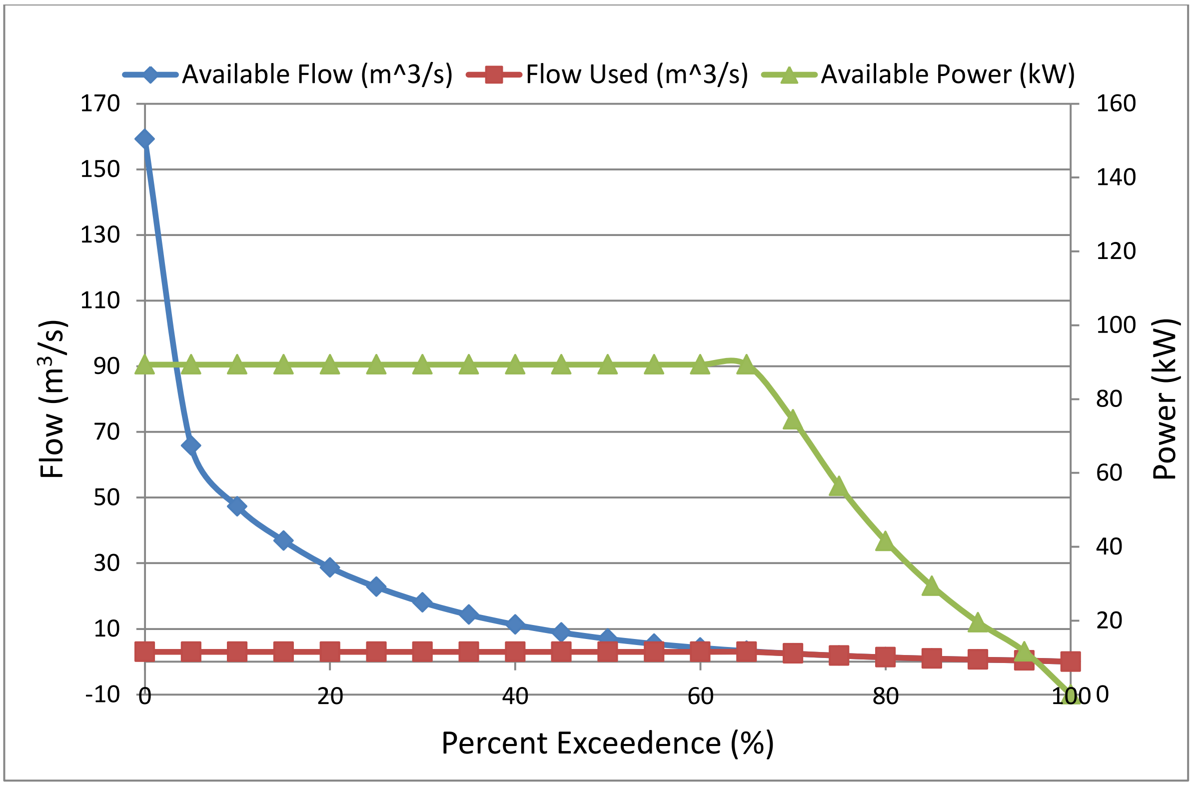


Figure 4. 19: Available Power Site 1

[12] According to www.southafrica.info/climate

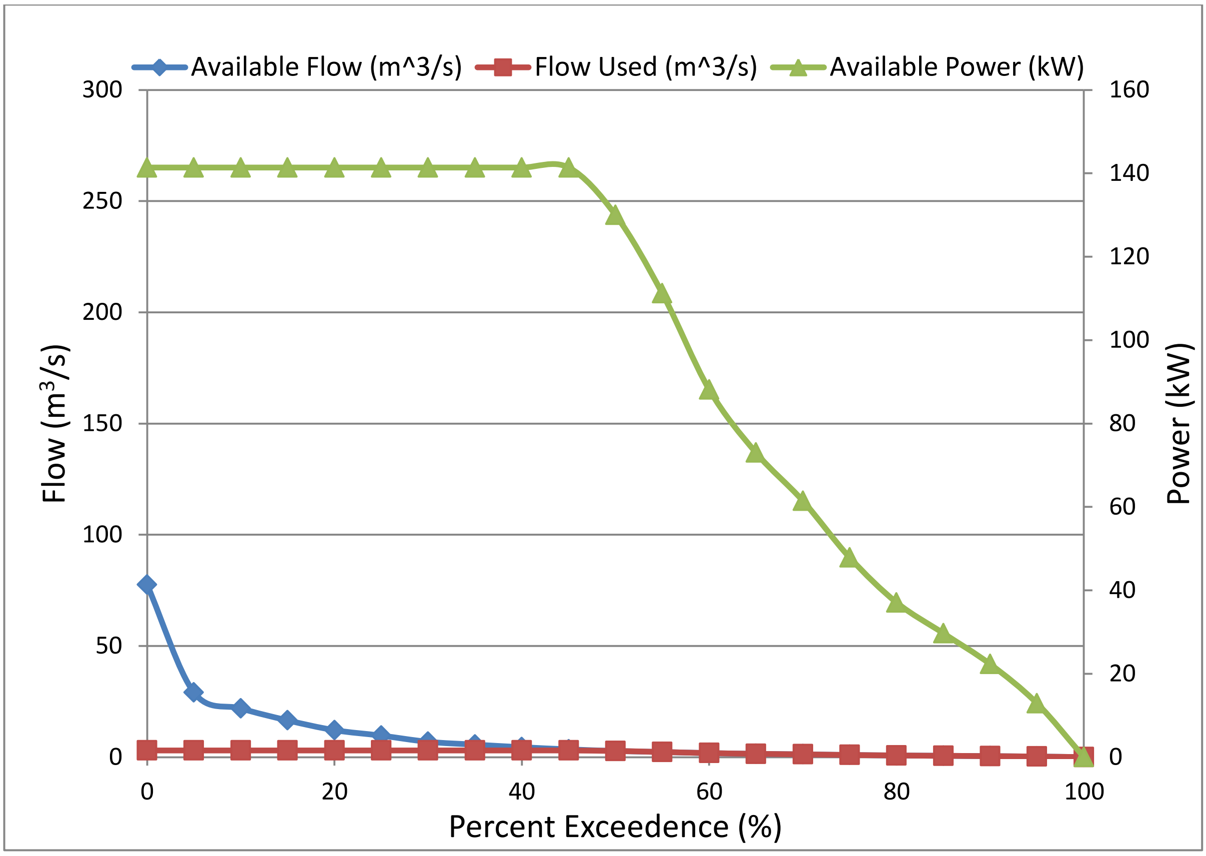


Figure 4. 20: Available Power Site 2

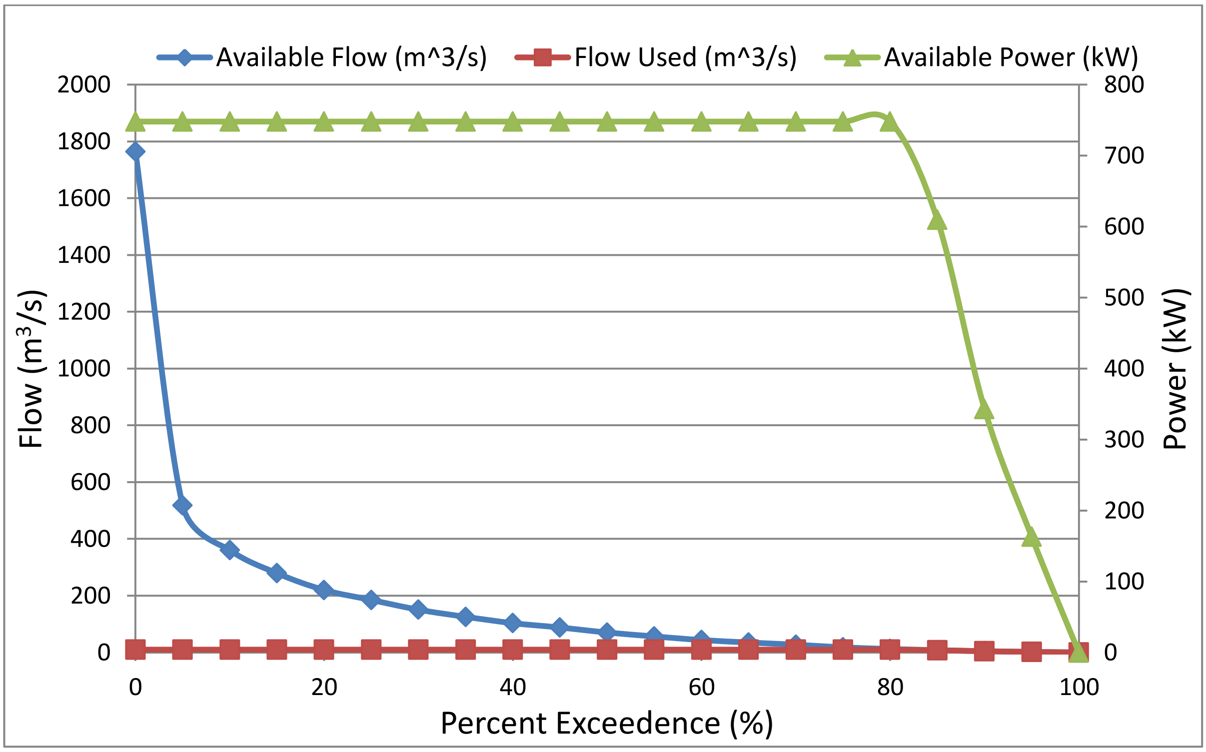


Figure 4. 21: Available Power Site 3

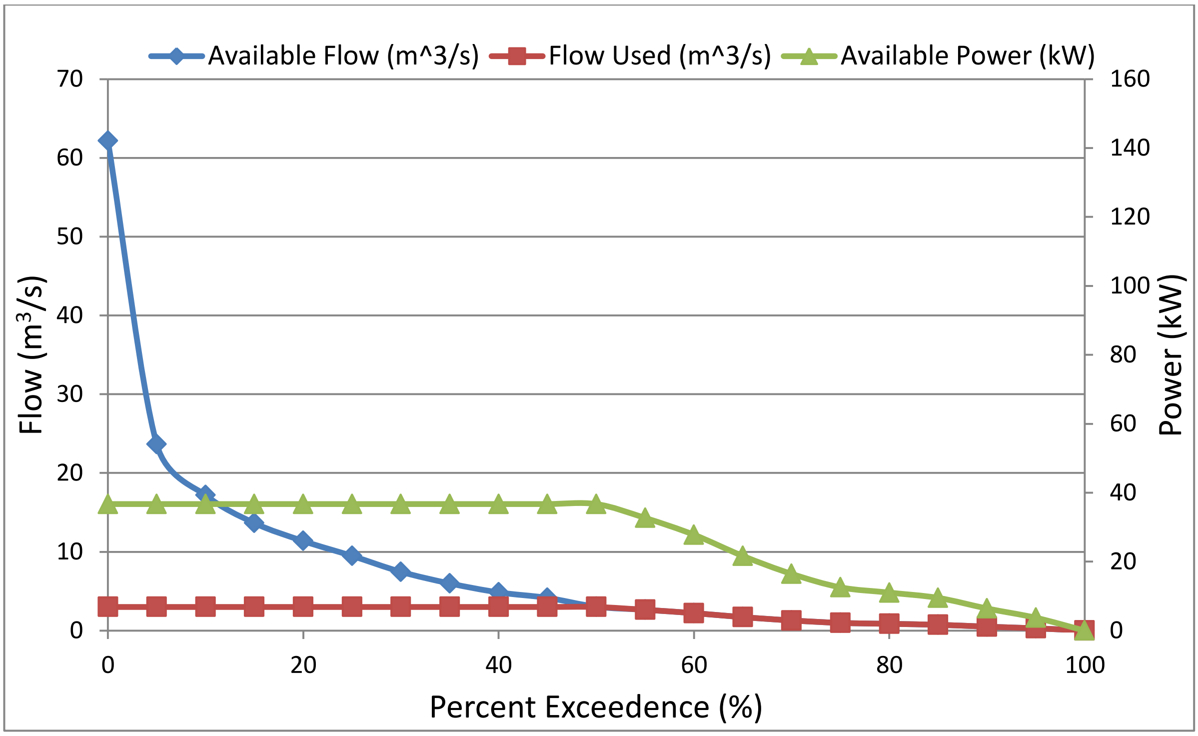


Figure 4. 22: Available Power Site 4

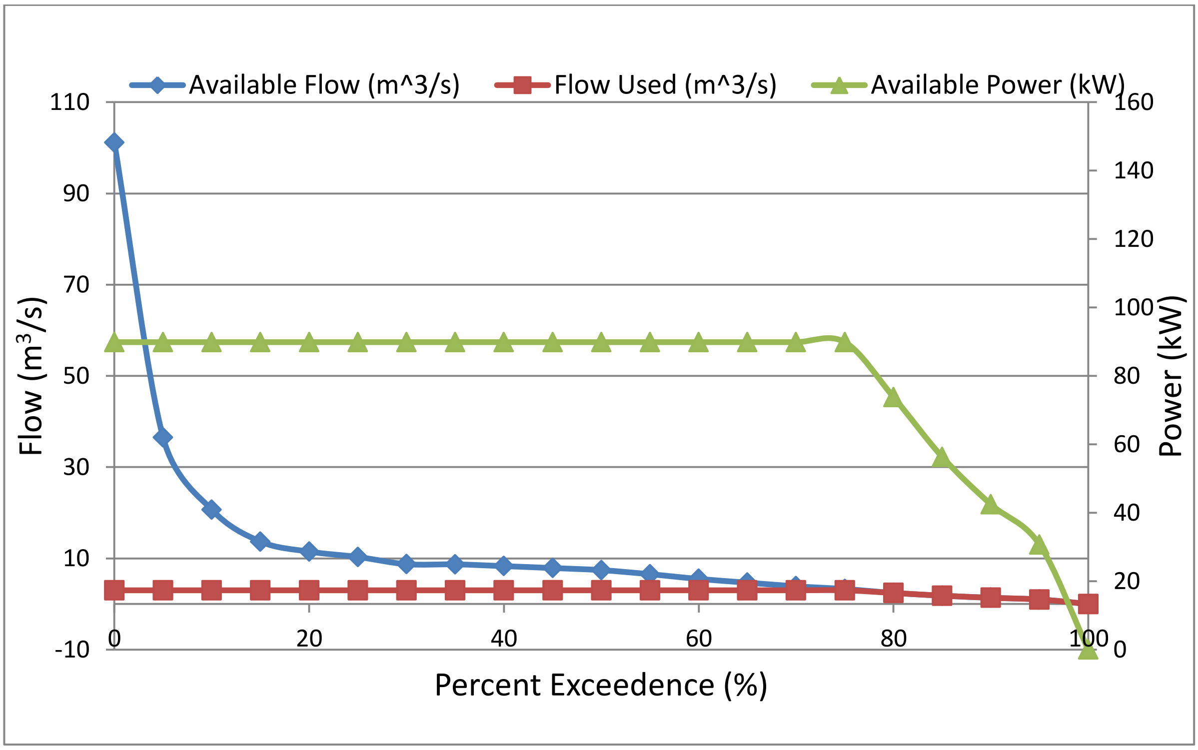


Figure 4. 23: Available Power Site 5

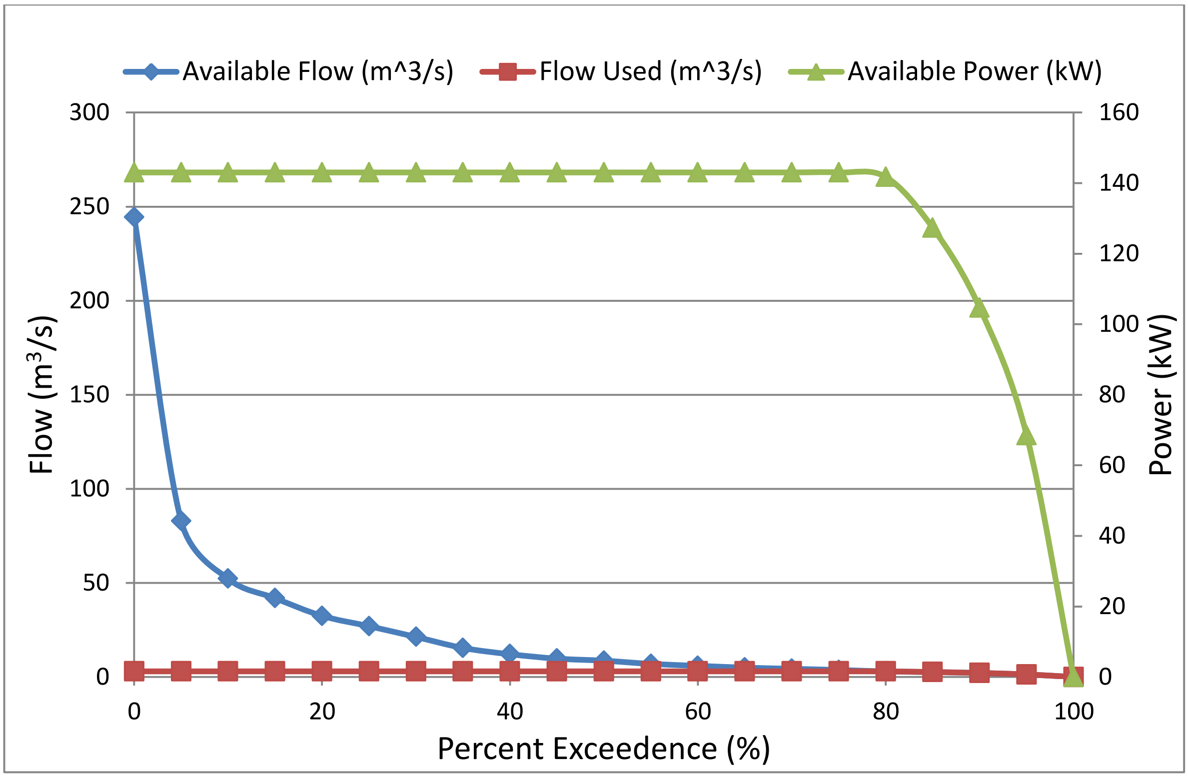


Figure 4. 24: Available Power Site 6

4.1.4 Free Basic Electricity allowance supply

In analysing the power supply available at each scheme, the factors presented in Table 4. 4 are used to check the number of houses that can be supplied by each scheme.

Table 4. 4: Power Allowance per Household

kWh/month/household	kWh/year/household
50	600
70	840
100	1200
120	1440

With more provisions made for the allowance (a higher allowance set per household), fewer houses will be supplied with electricity generated from the schemes. This is due to the disproportionate relationship that exists between available renewable energy and electricity demand of the community. The schemes are capable of producing a limited quantity of renewable energy per year and unless the parameters (design flow and hydraulic head) are increased to increase power production, the community has to divide and distribute the available energy from the scheme.

Table 4.5 shows the number of houses supplied according to the allowances made.

Table 4. 5: Allowance used and Possible Houses Supplied

Site	Allowance (kWh/year/hh)	Houses Supplied
1 Gauge G1H013 Berg River	600	1083
	840	773
	1200	541
	1440	451
2 Gauge T3H008 Mzimvubu River	600	1480
	840	1057
	1200	740
	1440	616
3 Gauge D1H003 Orange River	600	10097
	840	7212
	1200	5048
	1440	4207
4 Gauge V1H041 Mlambonja River	600	398
	840	284
	1200	199
	1440	165
5 Gauge V1H002 Thukela River	600	1198
	840	855
	1200	599
	1440	499
6 Gauge U1H005 Mkomazi River	600	1993
	840	1423
	1200	996
	1440	830

50 kWh/month per household is said to be sufficient for the average poor/rural household in South Africa (Inglesi, 2010). Using different variances of the allowance, considering all the sites in this study, the following range of the number of houses supplied was observed:

The minimum number of houses supplied using the maximum allowance of 1440 kWh/year/household occurs at site 4 and is approximately 170 houses.

The maximum number of houses supplied, using the minimum allowance of 600 kWh/year/household, occurs at site 3 and supplies approximately 10 100 houses.

By comparing the number of houses within each community to the number of houses supplied by the schemes, it can be seen that supply far outweighs the demand for the upper and lower limit of allowance (see Table 4.6). Depending on the percent availability of flow, all households will be able to utilise the power generated from its respective scheme.

Table 4. 6: Summary of Supply

Site	Quantified No. Households in Community	Maximum no. of houses supplied @ 600 kWh/year/hh	Minimum no. of houses supplied @ 1440 kWh/year/hh
1. G1H013	250	1083	451
2. T3H008	417	1480	616
3. D1H003	417	10097	4207
4. V1H041	250	398	165
5. V1H002	583	1198	499
6. U1H005	417	1193	830

Many combinations and options are available depending on the allowance made and size of the communities near these sites under consideration. Brent and Rogers (2010) found that electrical demand of many households double soon after installation. To allow for the increase in electricity demand of the community, the allowance per household will be increased and the hydropower system retrofitted to a smart - grid system in order to maintain the communities' electricity requirements.

It can be said that, based on the quantifications performed at the small schemes of interest, small scale hydro electricity supply to nearby communities in rural settings can offer a credible solution.

4.1.5 Financial Analysis

Solar Home System's (SHS's) costing was used to check the financial viability for policy and subsidy transfer to small hydro power schemes. SHS's promote the use of non-grid clean energy (Malzbender, 2005) and the South African government currently subsidises R 3 500 for each installation per household which contributes towards capital costs (Mapako and Prasad, 2005).

An additional R 58 per month for maintenance and services was financed into the funding of each installation due to claims of insufficient funds (Malzbender, 2005). The R 58 per month was used as an opportunity for income payable by each household in the community and was defined as income in this study. Therefore, assuming a 40 year design life for each scheme, the total money received could be quantified by multiplying the number of households in each community by the subsidy (R 3500) and income (R58) payable per annum.

The costing formula developed by Alvarado- Ancieta (2009) (refer to Equation 2.28) was used to estimate the electro-mechanical cost, in rands, and based on the total contribution of each component. The civil works costs were determined according to Figure 2.31 by Ogayar and Vidal (2009). The Operations and Maintenance (O&M) cost per annum was assumed to be 6 percent of the total electromechanical and civil works cost (IRENA, 2012).

The income per kilowatt-hour and cost per kilowatt-hour could be determined by dividing income and cost of each scheme by the total Renewable Energy Delivered (refer to Equation 2.26). Subtraction of the income/cost per kilowatt-hour values resulted in the additional subsidy required for the schemes to be financially viable.

It should be noted that the annual income for each scheme is calculated only at the 50 kWh allowance and R 58 payable income per household per month since there were no cost values available for the higher value FBE allowance. Therefore the income per kilowatt hour for each site remains at a fixed value as can be seen in Table 4.7.

Table 4. 7: Financial Summary

Site	C_{em} (Rands/R)	C_{cw} (Rands/R)	$C_{O\&M}$ (@ 6 % of total cost) (Rands/R)	Cost/kWh		Income/kWh		Additional Subsidy Required	
				R	*$*	*R*	*$*	*R*	*$*
1-G1H013	1.54 million	1.42 million	178000	4.83	0.55	1.31	0.15	3.52	0.40
2- T3H008	2.18 million	2.02 million	252500	5.02	0.57	1.31	0.15	3.71	0.42
3- D1H003	7.80 million	7.20 million	900600	2.63	0.30	1.31	0.15	1.32	0.15
4- V1H041	782000	722000	90200	6.67	0.76	1.31	0.15	5.36	0.61
5- V1H002	1.55 million	1.43 million	180000	4.39	0.50	1.31	0.15	3.08	0.35
6- U1H005	2.21 million	2.04 million	255000	3.76	0.43	1.31	0.15	2.45	0.28

It can be seen from Table 4. 7 that the costs per kilowatt-hour for the schemes are higher than the income obtainable based on the SHS subsidy and income mechanism. According to IRENA (2012) the cost for small schemes in developing countries range from 0.02 - 0.10 $/kWh (0.18 – 0.88 R/kWh). From Table 4.7 it can be seen that the schemes under consideration are significantly higher ranging from 0.2 - 0.66 USD/kWh. This could be due to the over – estimation of the cost of electromechanical equipment and therefore the civil works cost in the costing function formula.

An average kilowatt hour of electricity purchased from a municipality is 97 cents (Eskom, 201). The cost/kWh for the schemes in Table 4.7 are significantly higher than that of conventional coal fired power stations. This is due to factors such as economies of scale and the large start-up cost required for renewables which disfavour the up-take of renewable small – hydro schemes.

Figures 4.25 to 4.30 of the Cumulative Cash Flow show how long it will take to pay off the system and begin generating a profit for each site, based on the income from the community and the subsidy transfer of SHS which is assumed payable by the South African government. The total cost functions of each scheme can be found in Appendix E, it shows the cost/income per annum over the assumed 40 year design life of the schemes. Due to the initial start – up cost, the finanical viability of the schemes suggest no viability. Although the schemes show high risk of investment, there is no need for external resource aquiring such as that of procuring coal for coal fired powerstations. The clean, renewable property of small – scale hydro does not require additional resources for power production besides regular maintenance and services.

It should be noted that the major expenses such as turbine replacment, penstock/channel repairs/replacment and payment to employees were not considered. Replacment of the civil and electromechanical equipment usually occurs every 10-30 years or longer if maintenance is routinely performed.

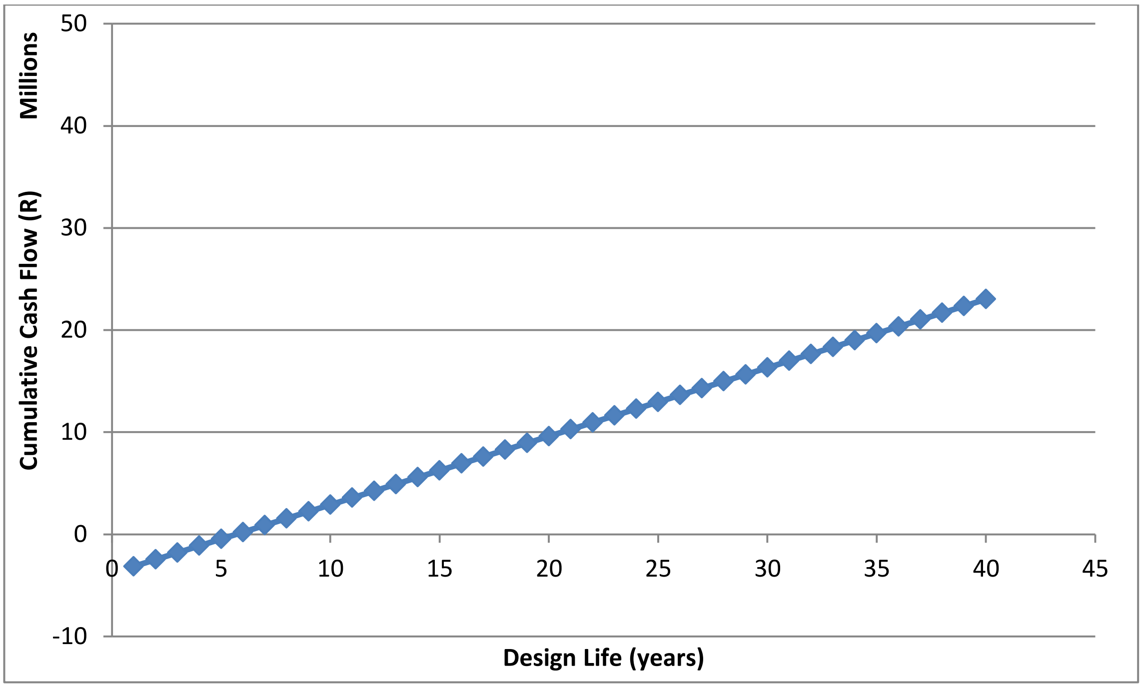


Figure 4. 25: Cumulative Cash Flow for Site 1

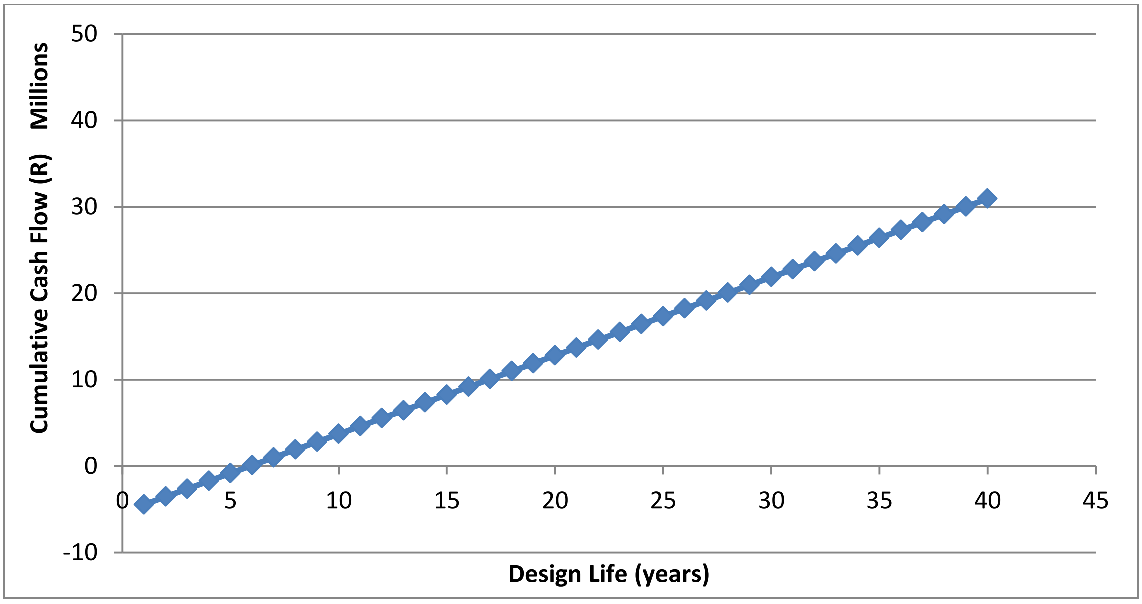


Figure 4. 26: Cumulative Cash Flow for Site 2

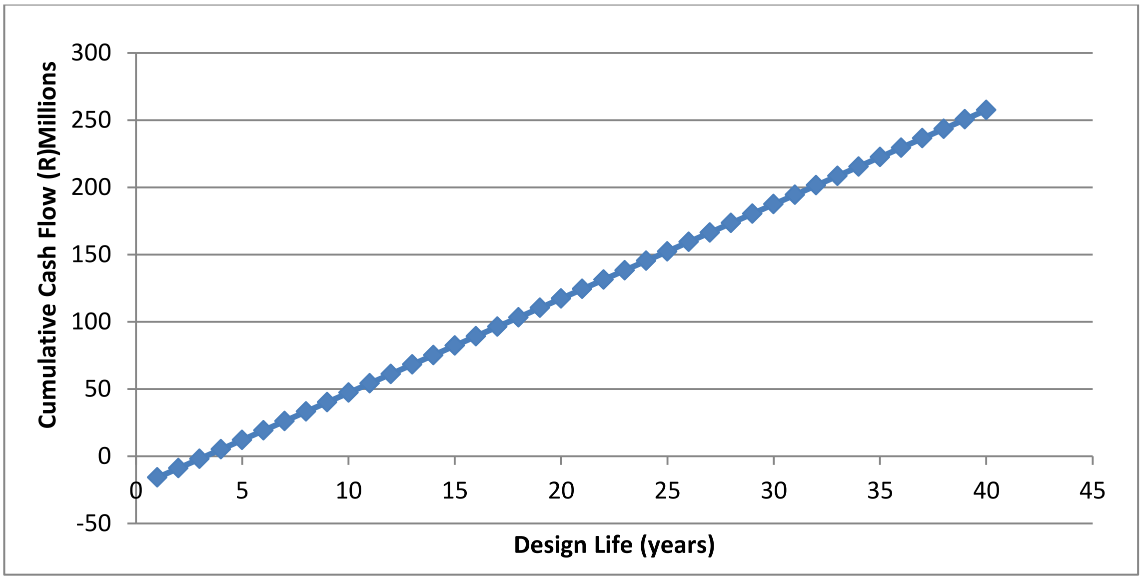


Figure 4. 27: Cumulative Cash Flow for Site 3

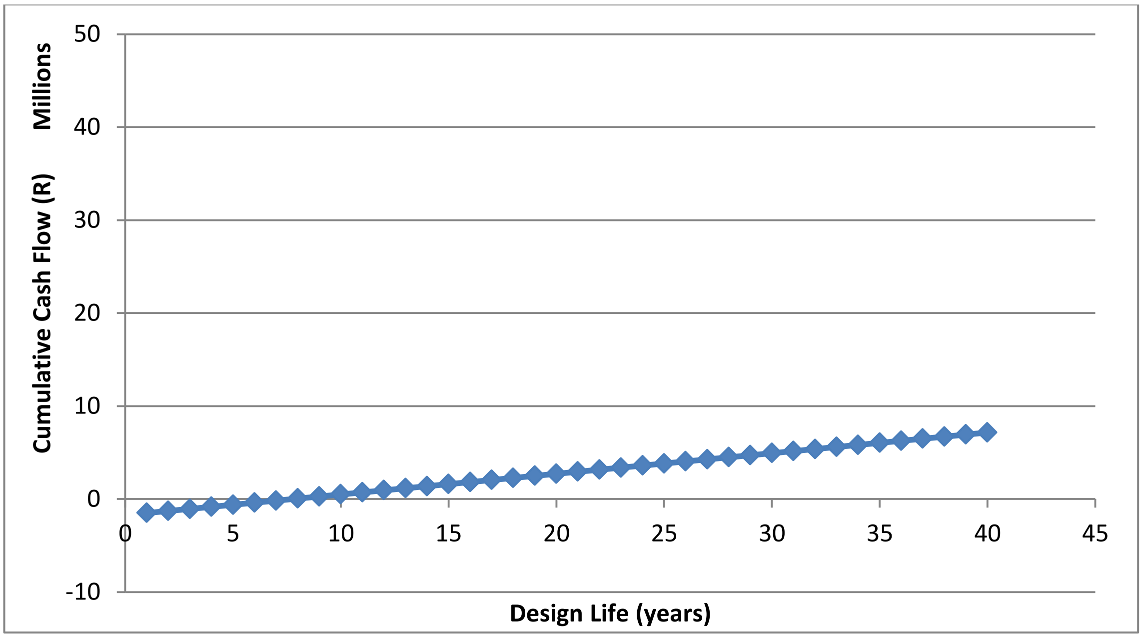


Figure 4. 28: Cumulative Cash Flow for Site 4

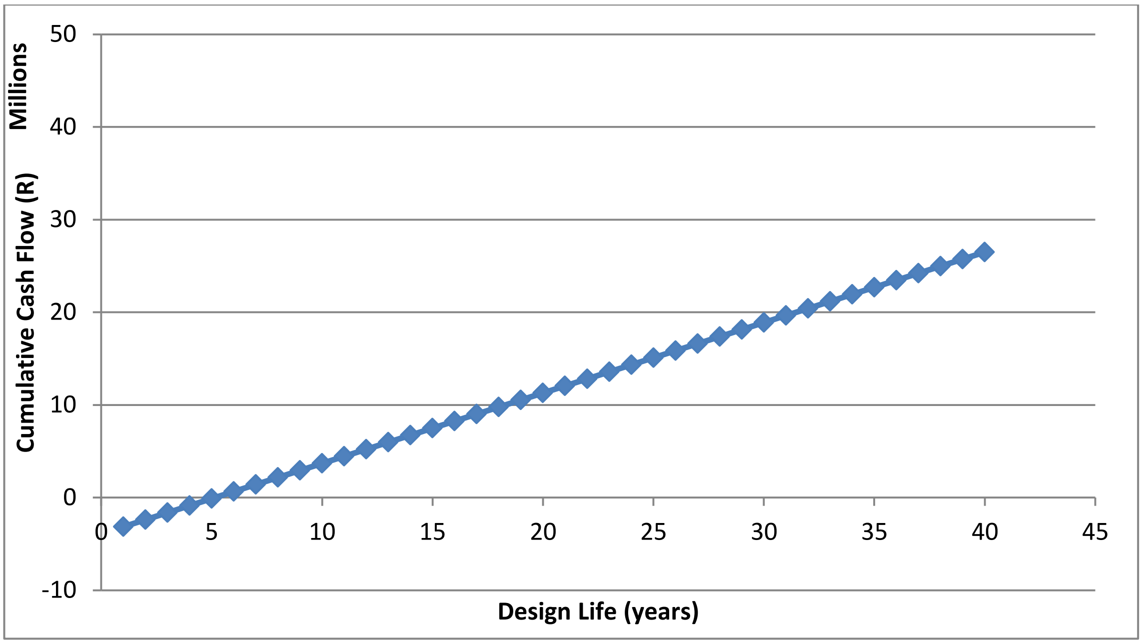


Figure 4. 29: Cumulative Cash Flow for Site 5

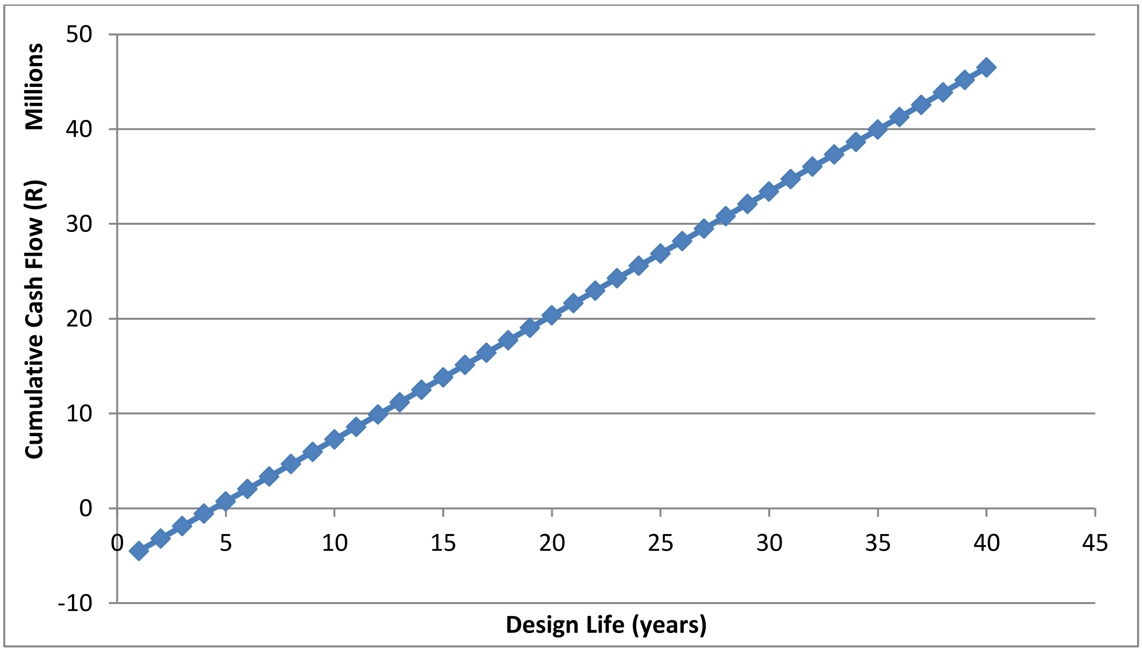


Figure 4. 30: Cumulative Cash Flow for Site 6

From the cumulative cash flow graphs, the schemes can be paid off within 4- 8 years after construction is completed. This compares well and makes small hydro very competitive in terms of cost recovery and construction time schedule as compared to the Friedenheim power station (2 MW) which recovered all its cost after three years of service. The Levelised Cost of Electricity for each scheme is presented in Appendix E. it can be seen that the initial LCOE in the schemes early design life is low but soon becomes favourable as the systems amortize their costs.

4.1.6 CO_2 Emission Avoidance Analysis and Plant Capacity Factor

Table 4.8 shows how much CO_2 emissions are avoided due to the clean energy produced from the hydro schemes.

Table 4. 8: tonnes CO_2 Emission Avoidance

Site	Tonnes CO_2 Emission Avoided per year
1	643
2	879
3	5998
4	237
5	712
6	1184

Small scale hydroelectric power generation is one of the cleanest energy sources and the GHG emission avoidance from this small-scale technology can be viewed as being beneficial to the community and to the environment. The Clean Development Mechanism (CDM) could be utilised for investment into the technology as it promotes the reduction of GHG emissions in developing countries (DME, 2003).

The Plant Capacity Factor, K, is a measure of how efficiently the hydro scheme utilises the available flow at site. Table 4.8 shows the K values for the different sites under consideration:

Table 4. 9: Small Hydro Power Plant Capacity Factor

Site	Plant Capacity Factor, K (%)
1	83
2	72
3	92
4	74
5	91
6	95

Due to the selection of the design flow and its respective percent exceedence, scheme 2 shows the lowest capacity at 72 % while scheme 6 shows the highest at 95 %. With optimisation carried out the K values can be adjusted in favour of increasing plant capacity and generating capabilities.

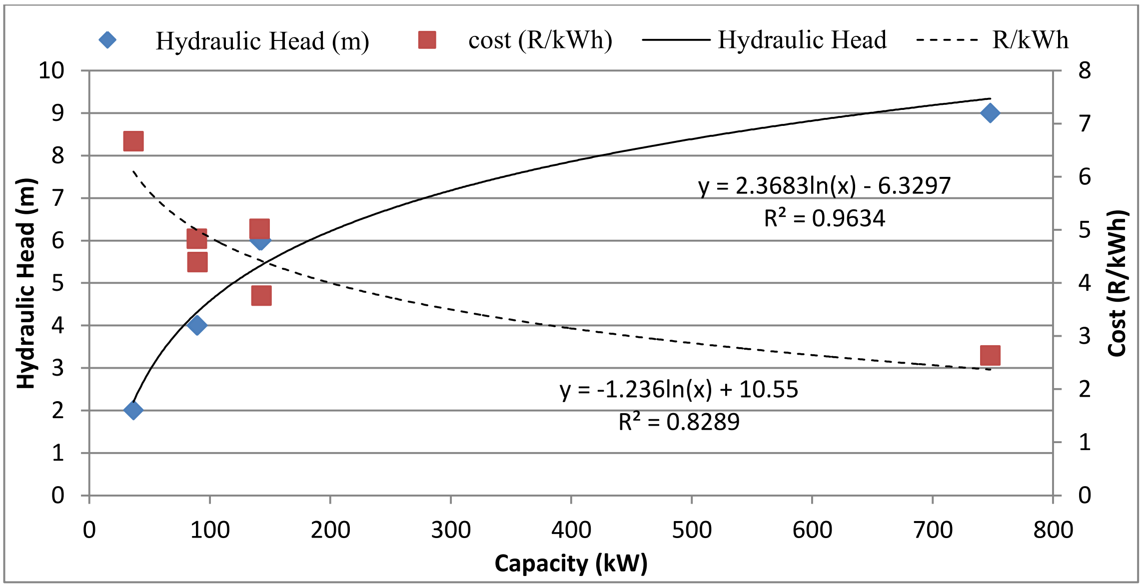
The results in this chapter show that with proper design and implementation of small hydroelectric power system, rural electrification is a possibility in terms of socio-economic and power generating aspects.

4.1.7 Generalisation of Case Studies

The costing formula is only as accurate as the input parameters of capacity and the hydraulic head of the small – scale hydroelectric scheme. Despite the best efforts to accurately predict the cost of a scheme, the cost of electromechanical equipment, civil works construction costs and the operation and maintenance change in monetary value with time.

To generalise results of this study and predict the cost of other schemes in using capacity and hydraulic head as variable parameters, Figure 4. 31 was developed. The equations shown in Figure 4. 31can be applied to other case studies of similar design flow rate in order to predict potential costs of the scheme. Due to most schemes in this study utilizing the same design flow of 3 m^3/s, except scheme 3 which utilizes a design flow rate of 10 m^3/s due to higher river flows experienced in the Orange River, Figure 4.31 allows a simplified means of costing other schemes of similar design flow rate. The simplification of Figure 4.31 is supported by Equations 2.24 - 2.26 and plant capacity is dependent on the design flow as an input parameter. The greater the design flow the greater the potential power production of the scheme which results in greater cost of the scheme.

Figure 4. 31: Site Generalisation



5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Small - scale hydroelectric power potential in South Africa exists in several provinces, namely the Eastern Cape, Western Cape and KwaZulu-Natal regions which have a high hydro electrical potential. Despite this abundance of hydroelectric potential, many rural villages in South Africa are still without electricity. The schemes considered in this study can offer the nearby load centres power between 60 to 80 percent of the year with short falls occurring during the dry season due to low streamflow. The renewable energy developed also adds to the renewable energy target of 10 000 GWh which the South African government has set to achieve by the year 2013 as a means of reducing GHG emissions.

The aim of this study was to investigate and formulate an appropriate methodology that can be used for estimating the power potential of small hydropower schemes and its economic potential in South Africa using available technology and data. This was done with the aid of the Department of Water and Forestry hydrological database as well as Water Resources 2005 in conjunction with ArcGIS with which streamflow data, population densities of the identified communities and river network information could be extracted. RETscreen was used to perform the preliminary design and financial analysis. No construction and development limitations were imposed on the site regions such as environmental protection policies and restrictions, because small hydro is environmentally neutral.

Although monthly stream flow averages were used instead of daily flow frequencies, the data was obtained from onsite streamflow gauges which were sufficient for technical hydropower potential at this preliminary stage. This methodology for hydropower potential determination was applied to all 6 sites in South Africa. The hydraulic head, flow and hydropower potential were summarised and presented in tables and maps for each site.

The Free Basic Electricity policy has the potential to be a positive mechanism that can improve the quality of life for South Africans living without electricity. Energy demand requirements were determined with the use of the FBE policy in order to assess the nature of electricity supply to the community. It is still unclear as to what the allowance of free electricity should be therefore several electricity allowances were used in this study.

The results of this study showed that the whole community could potentially benefit from the small - scale hydropower scheme and the schemes can be paid off and begin generating a profit within 4 to 8 years of implementation. Although the schemes can supply electricity to the communities 60 to 80 percent of the time, hybrid systems such as a smart grid with solar photovoltaic panels can compensate for the shortfall. Smart – grid systems allow for an efficient renewable solution resulting in fewer problems experienced or frustration caused to the community due to the lack of electricity availability during seasons of low streamflow.

The cost functions used in this study allowed the quantification of the civil and electro-mechanical works and could be generalised in order to assess cost at different locations in South Africa using hydraulic head and hydropower plant capacity as the variable parameters. Although the cost of the schemes are higher by an average of 0.43 R/kWh than that of the IRENA (2012) study, the results showed that costing functions can predict approximate small – scale hydroelectric power scheme cost of similar design flow, as shown in Figure 4.31, in South Africa.

Small hydroelectric power generation may not always make economic sense due to the large start-up capital costs and the lack of clear cut policies and frameworks; Small hydro is a good technical solution combined with smart – grid properties. Small – scale hydro could be a feasible option, in terms of off-grid/isolated communities near rivers with good hydroelectric power potential, if extending the national grid is found to be more expensive due to difficult terrain.

This study looked at performing technical and feasibility checks in developing small hydro schemes for rural electrification.

The results of this study provide a good foundation for future work in the estimation of hydropower potential in South Africa and will hopefully be a stepping stone to better estimation of both technical and exploitable hydropower potential for South Africa.

Although it is unlikely that the existing hydropower potential in South Africa will ever be fully exploited, small decentralised hydro power stations could play a role in supplying electricity to rural areas. Refurbishments/upgrades can be performed on decommissioned stations which should have a low ecological impact and may be good from an economic stance.

5.2 Recommendations

Un-electrified communities within these zones of good hydro potential need to be identified and electrical loads calculated in order to assess how much of the community demand for power can be met from a proposed scheme with its limitations of available flow and head.

A database in which hydropotential regions as well as the parameters needed to perform preliminary design works is needed in South Africa. At the moment, several databases and hydro sources have to be compiled in order to check design feasibility and potential which can become tedious and time consuming.

It is necessary to apply the methodology to all catchments in the future, in order to estimate the technical hydropower potential for the whole country, using best available data as well as with the aid of complex software, for ungauged rivers, such as HYMAS. Using patched/extended daily discharge series would be optimal in order to use the best available discharge simulations.

River network calculations can be performed along the length of the network, cumulating the head along the channel and computing generating capabilities of river networks in South Africa. DEM's are needed for all catchments in South Africa which aid in calculating hydropotential in a more efficient and systematic approach.

Daily time steps can be compared to the monthly average time steps used in this study and comparisons/relationships identified.

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APPENDICES

- Appendix A: DWAF Streamgauge data
- Appendix B: Turbine Efficiency Formulae
- Appendix C: Power and Available Energy
- Appendix D: Population Density, Rivers and Streamgauges of South Africa
- Appendix E: Financials
- Appendix F: Electrical Units of Measure and Exchange Rate

Appendix A

DWAF Streamgauge data

Key for streamflow value:

Good	&
Above rating	+
Estimated data	E
Calculated data	*
Greater than	m
Less than	M
Incomplete/Missing/Non-existing	#

Table A. 1

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Sum
G1H013	*10^6 (Mm^3/month)												
1963/1964	#	#	#	#	#	#	#	#	#	#	#	#	#
1964/1965	#	27.8	5.17	7.32	6.69	24.1	40.7	48.9	51.6	42.2	104	44.4	#
1965/1966	21.3	7.13	7.5	2.02 #	4.22	4.84 #	19.0 #	13.3	24.6	142	85.1	53.3	384 #
1966/1967	21.3	4.3	3.64	4.43	3.05	3.31	13	23.5	156 #	48.1	61.6	44	386 #
1967/1968	48.2	13.7	5.45	5.11	5.17	3.62	11.2	118	97.0 #	76.3 #	114	46.1	544 #
1968/1969	78.9	15.9	4.64	7.62	5.36	1.80 #	11.6	12.5	24.8	40.3	62.4	72.3	338 #
1969/1970	50	10.9	1.95	2.62	2.31	2.67	2.69	28.2	95.2	109	113	80	499
1970/1971	35	10.7	8.63	2.8	3.55	4.38	3.23	11.7	12.6	104	91.2	39.4	327
1971/1972	16.6	3.93	2.21	1.85	2.95	1.78	1.64	32.1	34.8	19.2	35.7 #	35.5	188 #
1972/1973	13.3	4.16	4.36	2.41	2.2	3.79	2.51	3.27	5.58	66.6	66.2	29.9	204
1973/1974	18.6	4.56	8.65	2.41	2.19	2.7	3.08	8.77	110m	32.8	361	120	675m
1974/1975	54.6	28.1	6.27	4.96	4.57	3.49	9.40 #	89	64.7	124 #	108m#	30.5	528m#
1975/1976	25.3	10.3	3.85	3.59	3.16	2.46 #	5.13	4.66	185m	150	89	38.5	521m#
1976/1977	21.2	66.4	46.5	35.4	10.3	8.5	30.3	148	318	302	256	20.6 #	1264 #
1977/1978	#	8.39 #	14.2	5.06	4.45	6.87	18.1	34.8	18.1	12.8	26.2 #	51.9	#
1978/1979	35	13	1.91	2.4	3.9	4.42	4.14	15.3	85.3	39.1	56	24.1	285
1979/1980	59.1	16.6	1.99	2.65	2.56	3.59	11.3	32	43	40.8	36.1	24.7	274
1980/1981	8.93	20.8	20.2	14.5	7.44	3.87	4.56	7.32	15.7	83.1	141	138	465
1981/1982	25.9	4.79	7.69	12	2.74	7.79	19.1	26	52	63.4	73.6	24.8	320
1982/1983	29.8	6.62	8.08	4.92	4.72	5.73	3.35	66.1	206	206	72.7	81.7	696
1983/1984	29.8	4.73	4.29	2.91	2.96	5.06	3.72	172	22	120	70.9	123	561
1984/1985	82.5	8.03	16.3	7.46	5.22	31.3	19.9	33.1	156	219	184	40.1 #	803 #
1985/1986	21.2 #	6.71	3.49 #	3.48	4.2	3.23	15.3	26.3	77.4	151	245	99.4	656 #
1986/1987	21.5	6.35	4.87	7.31	2.85	3.85	6.19	65.8	94.5	129	173	102	617
1987/1988	41.6	8.53	8.6	3.63	2.64 #	2.91	16.6	33.2	66.9	104	69.5	131	490 #
1988/1989	31.8	9.3	3.67	4.08	3.61	14.2	18.7	35.9	49.4	118	162	199	650
1989/1990	53.8	23.4	5.54	4.23	7.09	2.71	34.6	116	109	308	177	38.1	880
1990/1991	13.4	4.86	5.33	4.41	3.83	3.2	4.11	32.8	161	229	170	183	815
1991/1992	61.2	21.8	4.07	3.88	4.66	3.94	24.1	34.2	285	237	87.6	80.3	847
1992/1993	42.4 #	32.7	7.63	6.14	5.22	4.57	53.2	92.7	121	414	154	34.7	969 #
1993/1994	13.4	6.24	6.13	5.32	3.43	7.52	10.4	10.8	223	142	43.1	37	508
1994/1995	22.7	9.54	5.46	4.91	5.43	4.59	4.33	14	35.6	117	119	30.2	373
1995/1996	22.4 #	16.1	17.1	7.32	6.64	7.42	9.37	7.2	165	138	167	237	801 #
1996/1997	127	68	33	10.7	7.54	7.62	7.25	14.4	154	79.3	98	57	664
1997/1998	10.9	17.1	9.55	7.86	7.47	7.7	7.7	83.4	59.6	103	43.6	24.9	382
1998/1999	13.2	28.2	7.85	7.68	7.05	7.85	10.1	19.6	50.2	99.4	127	133	511
1999/2000	35.2	9.79	8.88	9.78	9.95	8.16	7.47	14.8	49.4	62.4	41.6	78	336
2000/2001	15.4	9.55	9.21	10.1	6.26	5.3	4.48	23.2	39.2	309	172	232	835
2001/2002	44.6	23.9	5.54	15.6	4.19	9.14	5.79	39.1	59.6	149	137	58.1	552
2002/2003	41	14	8.49	7.89	6.55	7.39	5.96	6.75	7.65	8.15	70.2	47.8	232
2003/2004	23.5	5.79	9.08	7.27	5.99	6.05	8.23	4.98	24.2	25	100	15	235
2004/2005	25.4	6.23	7.71	7.48	4.78	3.32	6.04	13.7	107	78.4	141	38.7	440
2005/2006	17	6.35	11.2	7.58	7.88	6.64	7.78	97.3	77.3	74.8	119	26.8	460
2006/2007	16.9	31.8	11.8	8.25	7.11	6.57	9.82	56	94.3+#	158	187	68.7	656+#
2007/2008	17.7	14.4	10	10.6	10.1	8.54	7.64	16.1	75.2	269	82.2	339	860
2008/2009	91.8	34.9	13	11.8	10.7	8.2	6.27	29.6	190	140	119	91.9	746
2009/2010	39	127	12.3	11	11	8.05	7.54	89	78.3	58.3	57.6	31.8	530
2010/2011	30.5	12.2	11.1	10.8	13.2	12.8	8.06	13.5	77.5	34.7	26.6	28.7	280
2011/2012	13.6	8.26	7.31	8.33	6.74	6.82	6.67	11.9	56.4	78.6	#	#	#

Table A. 2

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Sum
T3H008	*10^6 (Mm^3/month)												
1962/1963	1.69 #	12.8 #	26.1	49.7	53.3	68.7 #	18.3	5.58 #	3.98 #	12.5	3.93	2.12	259 #
1963/1964	7.47	42.6	41.7	65.4	26.1	16.2	9.87	5.63	30.2	33.5 #	8.23 #	8.2	295 #
1964/1965	12.6	30.9 #	14.7	19.9	39	7.19	8.19	2.8	10.5	29	13.6	27.8	216 #
1965/1966	21.5	17.9	9	63.1	79	8.97	4.71	6.16	3.53	2.34	2.09	5.41	224
1966/1967	3.64	10.1	17.5	14.7	90.8	95.5	96.8	15.2	12.3	11.6	6.96	3.39	378
1967/1968	3.1	8.73	14.7 #	8.79	3.85	6	10.6	2.29	1.81	1.68	1.96	1.93	65.5 #
1968/1969	0.57	1.56	7.29	4.42	6.91	16	18.3	3.15	2.6	1.51	1.19	0.934	64.4
1969/1970	4.69	4.66	11.6	12.3	31.6	4.99	1.1	1.62	1.07	1.31	1.36	2.15	78.4
1970/1971	25.7	12.9	6.13	16.3	43	23.3	22.2	7.09	3.85	5.97	6.31	2.52	175
1971/1972	6.31	6.89	14.3	50.6	51.4	103	23.7	7.61	3.91	3.45	2.09	1.74	275
1972/1973	3.98	6.74 #	6.72	5.46	31.6	28.3	55.1	10.4	4.48	3.63	2.69	1.45	161 #
1973/1974	2.86	9.35	11.2	56.4	141+#	19.1 #	43.8	16.2	10.1	6.35	4.08	2.32	322+#
1974/1975	2.12	7.11 #	32.6	21.8	65	36.9 #	11.3	4.79	2.98	2.33	1.79	3.59	192 #
1975/1976	3.02	5.24	62.4 #	156+	153+	201+	58	18.8	9.15	6.02	4.37	4.08	681+#
1976/1977	38.1	15.2	5.25	11.7	50.2	65.6	20.4	5.12	3.21	3.63	2.57	3.48	224
1977/1978	9.29	28.9 #	12.3 #	62.6	44.2	31.2	70.4	33.8	7.44	5.69	3.74	5.04	315 #
1978/1979	10.5	7.2	34.9 #	20.4 #	53.7	55.1	15.9	6.22	3.86	6.01	5.97	6.82	227 #
1979/1980	4.31	3.63	9.67	28	28.7	36.1	7.67	2.79	2.23	1.94	1.68	2.07	129
1980/1981	9.52	4.19	11.1	7.13 #	47.1	32.1	4.45	3.4	1.92	1.33	1.45	3.4	127 #
1981/1982	1.21	2.96	16.2	9.05	8.07	35.3	17.1	3.09 #	2.14 #	2.27	1.15	1.74	100 #
1982/1983	0.716	7.72	1.32	1.53	0.726	0.347	0.675	0.016	0	0.016	0.118	0	13.2
1983/1984	0.425	6.52	55.1	80.4	12.2	16.4	14.4	2.65	2.02	1.84	1.27	1.19	194
1984/1985	1.83	2.98	1.93	17.3	88.9	30	2.75	1.44	1.22	0.811	0.536	0.285	150
1985/1986	3.04	42.9	56	71.8 #	58.8	19.6	5.34	2.85	1.86	1.19	1	1.84	266 #
1986/1987	4.58	29	8.55	13.7	7.73 #	13.7 #	5.76	1.24	1.08	0.822 #	4.49	29.7+	120+#
1987/1988	109+	46.3	13.3	8.94 #	72.6+	134+#	45.9	9.25	7.06	6.47	3.68	3.52	460+#
1988/1989	5.39	3.6	57.3 #	75.5	120+#	73	11.2	9.78	3.93	3.42	1.92	0.925	366+#
1989/1990	0.725	14.2	94.1	38.7	11.6	75	44.7	7.62	3.43	3.55	2.61	7.4	304
1990/1991	2.54	1.42	8.87	30.3	90.1 #	26.6	6.29	2.66	1.89	1.53	0.837	0.657	174 #
1991/1992	6.77	7.75	23.4	12.9	11.2	11	2.55	0.583	0.462	0.328	0.226	0.327	77.5
1992/1993	0.171	0.525	1.32	0.99	5.86	18	4.23	0.88	0.311	0.238	0.19	0.101	32.8
1993/1994	3.22	5	16.3	56.8	81.2+	60.4	10.3	2.93	1.59	2.55	3.99	1.46	246+
1994/1995	0.628	0.84	2.54	24.3	17.4	23.4	26.8	4.29	5.4	2.37	1.06	0.665	110
1995/1996	1.05	7.45	45.7	75.4+	144	101+	24.5	6.56	3.44	11.7	5.9	1.62	428+
1996/1997	2.45	8.29	39.7	104+	48.2	69.4	43.6	12.6	64.6	31	11.1	5.28	441+
1997/1998	6.14	3.79	11.5	25.1	70.3	58.3	19.7	4.29	3.34	2.18	2.06	1.35	208
1998/1999	0.796	5.84	23.7	13.8	63.9	52.6	8.95	2.89	1.91	1.39	0.914	0.388	177
1999/2000	1.53	3.9	31.6	119+	60	162+	104	37.6	12.3	5.44 #	4.71	12.8 #	554+#
2000/2001	8.21	8.16	18	29	37.6	57.7	29	9.43	3.35	3.21	2.24	17.8	224
2001/2002	13.6	76.2	96.3	42.8	37.7	44.8	8.01	3.56	4.12	6.19	9.32	16	358
2002/2003	2.74	1.52	5.26	15.6	34.4	21.9	6.92	2.73	1.8	1.44	1.01	0.902	96.2
2003/2004	0.123	1.84	0.738	13.4	30.9	31.3	10.2	1.79	0.969	1.25	1.78	5.1	99.3
2004/2005	5.42	28.1	46.2	60.1	36.9	57.9	16.2	3.49	1.87	1.44	1.49	0.201	259
2005/2006	2.54	6.2	1.57	21.1	55.6	41.1	15.9	14.7	3.43	2.36	11	19	194
2006/2007	93.3	27.4	71.9	40.8	36.9	12.4	5.56	2.03	1.76	3.25	1.16	0.392	297
2007/2008	4.31	6.14	12.5	36.9	11.5	43.7	27.5	14	6.67	4.17	1.72	1.13	170
2008/2009	2.27	12	40.9	21.7	77.4	68.5	12.1	4.53	2.67	2.32	3.29	1.13	249
2009/2010	11.8	28.4	8.53	23.5	24	17.1	11.9	2.15	1.73	1.45	0.744	0.057	131
2010/2011	0.744	3.81	30.6	99.6	53.6	66	71.6	19.5	15.4	9.93	29.5	5.44	406
2011/2012	3.32	2.24	19.8	39.8	53.9	15	33.2	4.16	#	#	#	#	#

Table A. 3

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Sum
D1H003	*10^6 (Mm^3/month)												
1913/1914	#	#	#	3.36 #	16	44.1	107	11.4	8.84	8.58	13.8	10	#
1914/1915	158	250	810	814	1176	100	17.1	25.4	9.23	12.1	12.5	14.2	3399
1915/1916	99.7	650	357	659	82.2	349	394	136	16.4	10.8	8.55	8.41	2771
1916/1917	16.7	45.4	348	697	638	1251	110	43.5	16.1	38.7	289	440	3934
1917/1918	89.1	688	832	832	313	1013	259	30	14.2	11.9	26.4	444	4552
1918/1919	371	433	287	280	99.1	156	66.9	70	9.67	9.22	8.59	107	1898
1919/1920	11.6	89.3	28.1	104	1126	1249	94.9	22.7	11.7	8.61	8.39	10.2	2764
1920/1921	213	43.4	21.2	148	244	529	610	111	19.4	9.24	8.41	17.1	1973
1921/1922	75.2	306	827	676	104	23.7	10.8	8.34	14.6	9.59	11.2	17.7	2084
1922/1923	78.8	817	198	531	939	300	247	510	316	333	188	94.1	4552
1923/1924	14.6	44.5	22.5	60.9	321	1066	136	23.3	9.57	8.34	8.38	12.4	1728
1924/1925	157	1102	1015	463	490	4575	1576	847	540	79.3	36.6	27.6	10908
1925/1926	136	324	131	21.6	272	386	261	20.5	10	9.55	8.34	17.8	1598
1926/1927	75	509	384	241	303	938	467	23.7	11.7	11.1	13.8	8.29	2986
1927/1928	204	124	404	1112	345	313	129	12.9	8.51	8.37	8.34	8.07	2675
1928/1929	197	241	597	270	84.4	645	84.8	35	46.8	259	61.7	1275	3796
1929/1930	792	191	734	899	231	361	910	256	138	19.5	23.9	24.9	4579
1930/1931	306	17.5	15.5	715	574	375	1544	104	43.8	108	96.3	20.7	3919
1931/1932	43.4	633	50.6	447	646	343	109	10.7	11.1	9.25	8.34	23.2	2335
1932/1933	13	166	67.5	155	28.5	207	44.5	8.34	8.1	8.39	8.34	8.07	723
1933/1934	8.34	659	1362	2824	894	908	427	93	164	44.1	94.4	35.8	7513
1934/1935	251	889	1487	131	124	616	363	751	109	33.4	31.9	171	4957
1935/1936	27.6	180	24.4	370	209	58.1	440	103	122	39.8	13.3	8.56	1597
1936/1937	371	1979	716	1162	1548	485	472	99	30.9	19.1	13.2	12	6907
1937/1938	12.7	9.05	149	286	1185	236	308	133	80.2	122	79.4	329	2930
1938/1939	178	471	483	747	1704	430	86.8	207	79.3	50.8	111	171	4718
1939/1940	729	888	264	85.3	254	725	359	1348	153	40.2	33.9	571	5451
1940/1941	497	736	332	535	1092	409	323	55.7	18.2	23	13.1	14.4	4049
1941/1942	174	170	11.2	265	363	1107	199	69.8	25.9	12.9	59.4	87.8	2545
1942/1943	232	468	2070	536	256	260	636	1541	211	79.5	277	980	7547
1943/1944	1228	2322	1868	864	499	670	42.3	27.8	113	48.7	18.6	418	8120
1944/1945	189	130	50.7	10.3	329	1221	94.9	46.5	34.7	11	9.27	7.76	2135
1945/1946	8.96	6.62	24.6	534	523	391	516	353	160	42.2	19.9	6.76	2586
1946/1947	494	310	254	255	260	121	236	293	54.8	50.9	29.6	272	2630
1947/1948	373	378	840	715	770	2284	435	218	77.3	41.1	23.2	9.34	6165
1948/1949	61.7	41.3	23.3	30.3	170	236	51.6	114	30	9.65	8.19	10.1	786
1949/1950	22.4	437	383	479	470	1639	1773	723	175	349	612	864	7927
1950/1951	116	90.5	901	1373	374	352	339	153	102	37.1	29	65	3931
1951/1952	929	315	37.6	161	#	766	109	29.2	35.1	157	111	240	#

Table A.3 Continued

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Sum
D1H003	*10^6 (Mm^3/month)												
1952/1953	138	457	302	270	544	226	724	156	59.3	21	19.9	100	3018
1953/1954	621	446	630	211	569	1340	622	160	165	35.3	19.9	19.9	4840
1954/1955	36.5	70.8	410	548	3103 #	1076	257	271	80.4	57	26	14.3	5949 #
1955/1956	44.4	368	1374	233	930	1283	1328	300	218	91.2	53.5	37.7	6261
1956/1957	31	892	2414	880	894	497	341	99.1	54.7	120	192	2002	8416
1957/1958	2005	1272	1026	1416	555	288	539	633	378	82.8	52.3	43.5	8289
1958/1959	40.1	863	397	614	770	292	165	2374	793	512	262	232	7313
1959/1960	360	727	873	265	406	411	662	392	101	80.4	133	174	4585
1960/1961	314	518	351	417	306	399	927	524	524	154	113	59.4	4607
1961/1962	24.2	214	837	222	971	503	139	136	21.3	9.21	6.54	5.76	3089
1962/1963	14.1	232	211	1117	508	950	1170	152	72.8	181	172	65.8	4844
1963/1964	47.5	818	632	277	228	205	619	88.8	50	102	94.6	48.2 #	3210 #
1964/1965	1012	386	79.9 #	223	134	14.3	184	61.1	40.2	86.6	97.8	213	2532 #
1965/1966	150	189	48.7	1274	1212	74.1	37	23.4	10.5	4.02	4.26	5.66	3033
1966/1967	5.81	117	168	339	2438	481	1080	427	646	179	101	76.9	6058
1967/1968	16.8	376	191	66.4	29.8	93.6	150	356	81.7	97.9	24.7	94.8	1578
1968/1969	52.3	53.2	416	43.5	126	822	509	116	82.7	10.8	29.4	6.36	2267
1969/1970	281	243	142	191	242	38.8	14.6	8.35	7.69	9.19	24.5	113	1314
1970/1971	529	263	572	508	501	283	649	413	87.2	52.9	56.5	36	3951
1971/1972	43.4	125	190	967	1862	1567	291	316	131	51.6	15.4	9.23	5568
1972/1973	118	186	77.3	40.9	159 #	192 #	228	28.4	7.68	10.1	192	126	1365 #
1973/1974	153	120	210	1565	2581	1415	596	401	236	126	414	205	8022
1974/1975	69.6	868	584	428	1161	1159	205	114	74.4	112 #	48.8	143	4968 #
1975/1976	389	703	1149	2010	2556	3515	977	922	430	168	93.8	128	13040
1976/1977	2440	1402	200	265	973	1471	235	146	73.3	58.1	30.7	89	7383
1977/1978	554	353	175	1057	429	299	1525	246	86.9	67.5	47.6	282	5121
1978/1979	269	149	1266	226	280	283	54.8	61.3	54.4	142	535	405	3726
1979/1980	673	223	426	293	362	319	84.3	20.5	21.4	17.3	14.8	23.7	2478
1980/1981	162	112	362	891	833	578	204	225	436	82.3	320	424	4630
1981/1982	76.6 #	202	481	170	215	224	702	265	105	105	55.8	24.1	2625 #
1982/1983	176	1095	121	42.5	68.5	65.4	82.1	90.1	89.3	113	100	47.5	2090
1983/1984	107	171	587	815	115	142	198	283	58.6	29.2	24.9	145	2676
1984/1985	84.1	224	175	201	948	546	152	40	44.5	22.5	7.49	4.51	2449
1985/1986	79.9	842	1178	489	520	246	102	66.6	109	38.9	19	272	3960
1986/1987	580	2043	232	105	113	139	284	57.7	25.6	28.6	163	1640	5412
1987/1988	2284	715	411	241	2067	3321	806	244	230	183	101	1012	11615
1988/1989	487	483	1249	1143	2111	653	374	325	526	211	113	74.8	7750
1989/1990	53.4	683	586	308	239	561	728	367	146	246	148	118	4184
1990/1991	42	35.3	168	756	1854	938	154	43.6	34	27.1	15.8	35.2	4104
1991/1992	1390	606	552	142	42.8	54.8	31	12	9.01	7.79	9.25	29.9	2886
1992/1993	157	413	64.6	45	375	269	373	115	23.7	13	21.2	7.96	1878
1993/1994	818	559	608	1345	1923	576	256	207	35.4	23.1	33.9	14.5	6399
1994/1995	3.99	12.3	8.6	89.2	177	405	202	121	28.6	10.6	4.74	19.7	1082
1995/1996	106	246	1426	956	1100	1352	250	69.6	27.5	29.1	141	108	5812
1996/1997	466	1266	720	871	342	1141	1083	344	631	237	169	133	7403
1997/1998	97.3	32.1	154	762	1469	1739	570	349	68.1	40.7	35.7	30	5348
1998/1999	86.4	551	659	400	204 #	281	70.6	41.9	21.9	13.5	10.3	5.96	2346 #
1999/2000	4.11	24.4	615	1377	546	1126	555	388	82.9	43.1	25.3	367	5154
2000/2001	332	436	687	295	490	365	922	806	97.5	54	29	920	5433
2001/2002	284	2976	1706	1405	825	329	154	143	531	129	1212	1398	11093
2002/2003	148	154	399	452	273	634	177	58.4	30.4	21.4	29.4	20.6	2397
2003/2004	13.3	51.7	98.1	289	470	705	504	61.4	29	24.6	35.3	215	2497
2004/2005	250	142	288	501	262	406	296	147	51	30.1	35.5	33.2	2441
2005/2006	77.4	138	82.3	574	2075	1357	907	704	185	86.1	634	293	7113
2006/2007	688	1574+	531	308	186	84.9 #	#	#	#	#	#	#	# +
2007/2008	179 #	230	740	364	275	335	193	180	248	100	61.9	35.4	2940 #
2008/2009	22.5	99	475	369	1308	398	93.6	71.2	162	141	130	58.2	3328
2009/2010	868	510	173	291	449	226	294	151	141	79.2	44	21.4	3247
2010/2011	42.5	372	1069	3071	966	1013	599	568	529	237	236	130	8833
2011/2012	98	33.5	282	275	456	211	259	104	267	340	#	#	#

Table A. 4

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Sum
V1H041	*10^6 (Mm^3/month)												
1976/1977	#	#	#	25.5	69.2m	50.9	30.6	8.37	4.3	3.01	2.35	3.4	# m
1977/1978	7.96	10.1	26.7	101	67.1	38.4 #	24.2 #	10.3	5.62	4.1	3.15	3.26	302 #
1978/1979	10.1	10.3	67.6	25.3	39.9	51.2	8.63	8.04	3.9	3.48	9.61	6.4	245
1979/1980	4.72	11.9	17	31.2	31	51.4	15	6.05	3.42	2.55	2.03	5.35	182
1980/1981	5.62	7.26	28	39.5	88.8	38	8.87	5.34	3.61	2.51	3.27	8.09	239
1981/1982	3.48	7.64	27.2	22.9	13.1	30.1	24.9	8.71	4.77	3.21	2.39	2.38	151
1982/1983	4.65	16	7.24	15.4	14	9.15	6.54	3.41	2.11	2.36	2	1.18	84
1983/1984	13.5	16.4	38.9	40.5	12.1	36.5	23.5	6.95	4.18	2.91	2.54	2.64	201
1984/1985	1.95	2.88	3.67	28	66.5	16.7	5.42	3.24	2.18	1.7	1.15	1.06	134
1985/1986	7.74	23.6	32.3	38.5	41.4	22.9	15.1	10.2	5.9	4.05	3.25	3.45	209
1986/1987	14	27.2	34.2 #	19.1 #	20.2	24.1	11.7	5.91	4.08	3.11	5.5	52.5	222 #
1987/1988	41.9	33.8	17.9	22.5 #	102	92.7	25.6	10.7	7.09	8.79	5.6	5.83	375 #
1988/1989	8.93	19.6 #	44.9	10.5 #	62	36.3	18.1	12.2	7.52	5.26	3.5	2.28	231 #
1989/1990	3.4	11.8	18.3 #	14.8 #	21.9	22.2	11.2	7.01	3.98	3.13	3.09	2.57	123 #
1990/1991	2.38	3.23	21.1	8.63 #	49.8 #	33.1	12.3	6.37	4.18	2.99	1.92	1.72	148 #
1991/1992	2.34 #	13.1	23.9	19.1m	13.5m	15.9	6.22	2.61	1.7	1.26 #	1.12	0.934	102m#
1992/1993	2.07	4.09m	6.76	7.09	32.5	30.6m	9.16	4.69	2.94	2.14	1.55	1.43	105m
1993/1994	11.4	18.1	30.4	64.4	59.5	33.6	15.9	8.79	4.59	3.22	2.95	1.69	255
1994/1995	3.22	2.49	3.39	15.7	13.5	31.3	19.6	6.97	3.44	2.48	1.65	1.14	105
1995/1996	1.59	13.5	78.8	82.8	118	56.1	18	8.47	4.53	5.98	7.25	3.71	399
1996/1997	14.4	14.3	16.9	49.7	24.4	74.5	27.4	12.1	11.8	7.49	5.69	5.4	264
1997/1998	8.98	8.72	11.7	32.5	49.9	33.3	11.5	5.17	3.26	2.56	2.01	1.47	171
1998/1999	1.68	18.3	22	25.8	40.3	34.3	15.4	6.02	3.43	2.53	1.85	1.24	173
1999/2000	5	3.02	37.6	77.6	33.2	72.4	32.8	20.3	6.93	4.23	3.14	7.17	303
2000/2001	8.06	16.7	24.2	17.4	29.9	30.1	45.5	12.5	5.35	3.45	2.92	13	209
2001/2002	15.9	51.8	27.1	35.4	39.8	29.1	8.35	4.93	4.9	2.96	13.3	13.3	247
2002/2003	5.43	8.53	49.2	37.3 #	17.5 #	25.7	16.5	7.85	4.02	2.92	2.08	1.96	179 #
2003/2004	1.43	10.1	7.4	26.3	36.8	52.7	23.9	7.02	3.64	2.84	2.07	2.23	177
2004/2005	2.98	5.52	19.4	41	28.8	52.2	20.7	6.89	3.78	2.74	2.84	1.45	188
2005/2006	3.1	6.88	6.3	38.7 #	112	103	37.5	15.9	8.19	4.43	3.76	2.59	343 #
2006/2007	8.09	16.1	30.6	21.3	13.8	8.35	5.87	2.98	2.16	1.55	1.2	1.22	113
2007/2008	22.2	12.6	42.3	51.9	53.6	55.1	17.5	8.3	4.59	3.08	2.21	1.61	275
2008/2009	3.24	12.8	32.3	68	99.2	63.1	16.5	8.35	5.16	3.92	4	1.86	319
2009/2010	6.8	12.2	13.8	48.3	27.7	29.4	28.1	7.61	4.15	2.84	1.96	1.55	184
2010/2011	2.66	13.3	53.4	162	46.1	47.5	32.7	10.9	6.94	5.08	4.92	3.01	389
2011/2012	6.45	4.24	13.2	25.8	#	#	#	#	#	#	#	#	#

Table A. 5

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Sum*
V1H002	**10^6 (Mm^3/month)*												
1932/1933	4.66	19.3m	24.0m	24.4m	21.6m	22.1m	12.2m	5.84	4.27	4.19	2.85	1.90	147m
1933/1934	1.87	19.2m	24.5m	24.50	22.10	24.50	23.70	21.1m	14.10	13.9m	22.0m	17.80	229m
1934/1935	16.9m	22.5m	24.50	24.50	22.10	24.50	23.70	21.2m	13.20	9.05	6.97	6.51	216m
1935/1936	5.03	15.9m	17.6m	22.3m	22.90	23.0m	23.2m	19.4m	19.0m	11.00	6.56	5.14	191m
1936/1937	15.2m	22.1m	24.5m	24.50	22.10	24.50	20.7m	11.30	7.09	5.38	3.99	3.63	185m
1937/1938	6.50	4.72m	24.3m	22.5m	22.10	22.90	23.7m	18.30	11.9m	14.4m	17.6m	13.30	202m
1938/1939	22.7m	23.2m	24.50	24.50	22.10	24.50	22.90	18.3m	11.70	11.9m	13.00	16.0m	235m
1939/1940	22.3m	23.7m	24.50	24.4m	22.90	24.50	22.5m	23.2m	18.30	12.00	8.54	7.40m	234m
1940/1941	12.20	20.5m	21.1m	24.50	22.10	24.50	23.40	13.90	7.00	6.41	3.90	2.67	182m
1941/1942	7.22	3.47m	11.3m	20.1m	22.10	24.50	23.7m	17.10	11.00	6.28	8.10	12.10	167m
1942/1943	24.2m	23.70	24.50	24.50	22.10	24.50	23.70	24.50	22.40	24.5m	23.9m	23.70	286m
1943/1944	24.0m	23.70	24.50	24.50	22.90	24.50	18.80	10.30	15.4m	11.00	5.04	12.9m	218m
1944/1945	22.2m	22.5m	15.8m	21.8m	22.10	24.50	23.0m	13.40	7.84	4.47	3.80	3.01	184m
1945/1946	5.93	3.27	5.16	22.6m	22.10	23.9m	22.8m	13.1m	6.06	4.23	2.92	1.91	134m
1946/1947	14.50	11.8m	23.5m	24.4m	29.6m	32.0m	29.30	15.80	9.56	5.12	5.22	5.28	206m
1947/1948	16.3m	26.6m	32.80	32.80	30.70	32.80	31.50	24.30	13.10	9.84	6.84	5.50	263m
1948/1949	15.6m	14.7m	14.4m	28.4m	28.6m	32.6m	24.90	17.50	8.96	6.22	4.48	7.70	204m
1949/1950	10.60	24.0m	28.8m	32.80	29.6m	32.80	31.60	24.80	16.00	9.44	11.3m	16.1m	268m
1950/1951	12.3m	16.7m	31.30	32.80	29.60	32.80	27.2 #	#	#	#	#	#	# m
1951/1952	#	5.83 #	15.8m	28.1m	30.70	32.5m	20.8m	11.90	8.14	9.11	6.46	6.66	# m
1952/1953	8.66m	27.7m	31.3m	32.80	29.60	32.80	30.60	18.40	10.90	7.73	6.58	5.39	243m
1953/1954	10.6m	16.5m	32.8m	32.5m	29.60	32.80	27.70	16.5m	11.10	7.53	5.44	6.70m	230m
1954/1955	17.2m	30.6m	32.80	32.80	29.60	32.80	25.9m	19.90	14.60	8.73	5.92	3.76	255m
1955/1956	8.20	26.40	52.00	27.50	197.00	176.00	39.30	19.20	12.40	8.41	5.40	6.03	578.00
1956/1957	5.97	88.90	258.00	121.00	96.50	120.00	38.60	19.20	12.30	16.10	18.80	135.00	931.00
1957/1958	117.00	45.10	74.20	264.00	177.00	83.80	55.50	20.80	14.20	9.58	6.48	8.74	876.00
1958/1959	4.78	58.80	82.70	64.00	70.50	50.30	22.30	66.90	20.30	15.60	10.70	7.48	474.00
1959/1960	30.70	55.50	72.50	54.10	99.30	125.00	48.20	24.20	13.30	9.50	7.34	8.94	549.00
1960/1961	10.90	28.70	84.60	49.70	46.00	86.00	81.40	22.00	12.70	8.62	6.04	5.09	442.00
1961/1962	4.97	43.20	75.20	114.00	141.00	46.90	26.50	16.40	8.70	6.84	4.90	3.92	493.00
1962/1963	4.42	36.60	37.40	241.00	80.50	107.00	32.50	15.50	11.60	12.20	6.80	4.15	590.00
1963/1964	11.10	82.40	37.90	97.90	44.00	43.90	22.60	13.40	11.10	8.54	6.52	15.20	394.00
1964/1965	35.0 #	73.50	84.50	71.50	39.20	17.70	26.50	12.20	17.00	12.30	29.50	32.50	451 #
1965/1966	16.2 #	30.1 #	22.40	179.00	151.00	26.10	15.00	10.10	6.59	4.15	3.49	4.91	470 #
1966/1967	10.40	43.80	68.80	65.3 #	23.3 #	125.00	134.00	28.60	13.40	9.03	6.38	4.42	533 #
1967/1968	7.96	25.60	24.10	18.70	26.10	49.70	44.30	20.80	7.96	5.27	4.84	3.66	239.00
1968/1969	4.43	19.10	47.80	33.60	31.50	122.00	58.70	19.00	11.90	7.75	4.52	5.29	366.00
1969/1970	27.0m	22.30	44.1m#	54.80	96.50	24.40	#	#	#	#	#	#	# m

Table A. 6

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Sum
U1H005	*10^6 (Mm^3/month)												
1960	8.11	42.6	166	68.3	84.9	94	149	25.3	14.5	10.1	7.27	7.09#	677.00#
1961	5.68	29.4	75.3	118	136	75.9	21.4	18	9.95	7.69	7.64	10.1	516
1962	7.66	47.1	91.5	246	72.1	190	44.7	20.1	13.8	31.6	12.4	7.46	784
1963	28.7	111	119	182	66.8	58.5	26.7	17.7	22.9	15.8	9.39	18.8	678
1964	26.2	89.9	73.8	114		24.8	18.4	10.2	24.4	22.4	15	23.7	572
1965	23.2	32.4	20	130	139	23.2	12.7	12.2	7.56	5.16	4.71	6.74	417
1966	7.22	65.6	74.1	94	280	213	146	29.8	16.7	14.3	9.74	6.86	957
1967	8.68	42.6	63.9	62.6	54.1	67.10#	21.30#	17.5	10.3	7.78	8.06	5.95	370.00#
1968	4.79	23.3	55.6	17.3	25	141	84.5	22.5	13.3	10.4	6.94	9.83	414
1969	47.4	23.7	96.1	70.4	106	33.7	12.6	8.9	6.24	5.46	36	19.4	466
1970	93.9	38.1	25.7	58.3	135	66.1	43.6	27.5	13.8	13.5	38.8	15.3	570
1971	30.4	42.2	105	193	247	243	54.7	24.2	13.7	10.7	7.53	5.76	978
1972	11.8	42.9	26.7	23.9	124	75.7	91.60#	13.10#	14	10.1	12.5	13.4	459.00#
1973	35.3	62.7	64.3	116.00#	364	274	134	33.8	21.2	16	10.6	6.98 1	138.00#
1974	6.98	33.9	56.5	179	227	113	46.2	17.1	10.6	7.97	5.94	17	722
1975	11.5	28.9	193	413	464.00+	375.00+	144	35.7	5.96	0.62	2.36	0.43#	1675.00#
1976	#	#	19.30#	50.70#	123	118	59.4	17.5	11.1	8.27	6.93	9.31	#
1977	17	25.8	32.6	184	117	85.5	48.60#	25.7	12.5	9.23	6.81	13.6	577.00#
1978	31.8	38	201	60.3	68	83.5	23.2	18.1	9.5	10.1	11.3	14.9	569
1979	10.3	24.8	27.8	81.4	93.1	105	17.60#	8.04	6.99	5.41	3.8	20.1	404.00#
1980	24.8	15.8	73.40#	25.10#	221	99.1	20.8	12.8	8.3	5.86	7.37	24.3	539.00#
1981	11.5	15.9	36.2	34.5	19.6	125	30.4	11.9	8.18	5.85	3.86	4.52#	308.00#
1982	5.14	19.4	9.75	17.1	13.7	27	13.2	4.25	2.6	2.34	2.46	2.25	119
1983	12.5	44.2	176	138	58.9	143	201	10.40#	30.7	10.6	7.84	7.47	842.00#
1984	12.2	15.2	15.3	114	188.00#	76.2	18.3	10.3	7.59	5.56	2.98#	2.91	469.00#
1985	16.6	73.90#	144.00#	120	91.7	67.4	30	15.60#	10.8	7.1	6.74	8.72	592.00#
1986	25.9	85.8	82.2	91.8	38.1	83.2	24.60#	12	8.51	6.71	15	177.00+	651.00#
1987	634	245.00#	73.4	88.3	316.00+	388	49	20.4	15.8	30.1	14.2	11.70 1	885.00#
1988	2.35#	#	6.72#	154	248	85.8	24.1	14	4.65	10.9	6.68	4.24	#
1989	5.72	58.9	124	55.3	46.7	77.80#	36.50#	17.4	9.88	7.27	6.14	8.53	454.00#
1990	11.7	13.3	17.90#	8.54#	40.50#	78	27.8	14.2	9.45	6.23	3.97	4.69	236.00#
1991	38.8	37.2	77	60.10m	53	37.9	12.9	5.52	3.65	2.7	2.14	1.66	333.00m
1992	1.9	7.22	6.49	13.00m	38.70m	41.70m	30.80m	8.14	3.93	2.88	2.35	1.42	159.00m
1993	25.8	38.1	86.5	233	241.00m	70.8	21.5	12.5	7.44	7.09	7.25	3.93	756.00m
1994	7.9	9.14	15.5	32.60#	42.3	96.5	71.3	22.9	12.7	8	4.91	3.17	327.00#
1995	8.39	26.5	252	241.00+	236	172	52.3	20.7	12.4	62.1	25.8	13.60 1	124.00+
1996	17.2	29.3	83.3	230	72.6	187	54	22	19.9	25.3	13.7	0.42#	754.00#
1997	25.00#	53.6	36.20#	106	200	105	40.4	16.9	10.2	7.55	6.91	4.73	611.00#
1998	7.69	22.9	109	62.20#	123	58	20.5	11	6.99	5.06	3.07	2.35	432.00#
1999	22.7	37.20m	139	230	129	321	114	36.1	17.1	10.9	7.55	16.60 1	081.00m
2000	13	53	111	115	72	58.6	63.1	23.6	11.9	8.84	5.67	39.3	576
2001	25.1	96.3	81.2	71.3	69.6	71.8	19.8	11	11.3	17.8	20.6	16.5	512
2002	8.35	12.7	25.3	58.4	119	79	53	21.6	11.3	7.29	4.72	7.45	408
2003	4.89	22.3	30.2	104	125	105	31.6	12.5	5.25	#	# #	14.90#	#
2004	20.3	49.8	127	259	195	216	66.2	25.3	14	9.6	8.39	5.44	996
2005	9.07	17.4	12.3	115	229	#	#	#		#	# #	#	#

Appendix B

Turbine Efficiency Formulae

Table B. 1 (Kosnik, 2011)

FRANCIS, KAPLAN AND PROPELLOR TURBINES (REACTION TURBINES):	
Reaction turbine runner size (d)	$d = kQ_d^{0.473}$ Equation B. 1 Where: d= runner throat diameter in m k= 0.46 for d<1.8 = 0.41 for d $\geq$ 1.8 Q_d= design flow (m^3/s)
Specific speed (n_q)	$n_q = kh^{-0.5}$ Equation B. 2 where: n_q= specific speed based on flow k= 800 for propeller and Kaplan turbines = 600 for Francis turbines h= rated head on turbine in m (gross head less maximum hydraulic losses)

Table B. 2 (Kosnik, 2011)

FRANCIS TURBINES:	
Specific speed adjustment to peak efficiency ($\hat{}e_{nq}$)	$\hat{}e_{nq} = \{(n_q - 56)/256\}^2$ Equation B. 3
Runner size adjustment to peak efficiency ($\hat{}e_d$)	$\hat{}e_d = (0.081 + \hat{}e_{nq})(1 - 0.789d^{-0.2})$ Equation B. 4
Turbine peak efficiency (e_p)	$e_p = (0.919 - \hat{}e_{nq} + \hat{}e_d) - 0.0305 + 0.005\ R_m$ Equation B. 5 Where: R_m = Turbine manufacture/design coefficient (2.8-4.5)
Peak efficiency flow (Q_p)	$Q_p = 0.65\ Q_d\ n_q^{0.05}$ Equation B. 6
Efficiencies at flows below peak efficiency flow (e_q)	$e_q = \left\{1 - \left[1.25\left(\frac{(Q_p - Q)}{Q_p}\right)^{(3.94 - 0.0195 n_q)}\right]\right\} e_p$ Equation B. 7
Drop in efficiency at full load ($\hat{}e_p$)	$\hat{}e_p = 0.0072\ n_q^{0.4}$ Equation B. 8
Efficiency at full load (e_r)	$e_r = (1 - \hat{}e_p)\ e_p$ Equation B. 9
Efficiencies at flows above peak efficiency flow (e_q)	$e_q = e_p - \left[\left(\frac{Q - Q_p}{Q_d - Q_p}\right)^2 (e_p - e_r)\right]$ Equation B. 10

Table B. 3 (Kosnik, 2011)

KAPLAN & PROPELLOR TURBINES:	
Specific speed adjustment to peak efficiency ($\hat{}e_{nq}$)	$\hat{}e_{nq} = \{(n_q - 170)/700\}^2$ Equation B. 11
Runner size adjustment to peak efficiency ($\hat{}e_d$)	$\hat{}e_d = (0.095 + \hat{}e_{nq})(1 - 0.789d^{-0.2})$ Equation B. 12
Turbine peak efficiency (e_p)	$e_p = (0.905 - \hat{}e_{nq} + \hat{}e_d) - 0.0305 + 0.005\ R_m$ Equation B. 13 Where: R_m = Turbine manufacture/design coefficient (2.8-4.5)

Table B. 4 (Kosnik, 2011)

KAPLAN TURBINES:	
Peak efficiency flow (Q_p)	$Q_p = 0.75\ Q_d$ Equation B. 14
Efficiency at flows above and below peak efficiency flow (e_q)	$e_q = \left[1 - 3.5\left(\frac{Q_p - Q}{Q_p}\right)^6\right] e_p$ Equation B. 15

Table B. 5 (Kosnik, 2011)

PROPELLOR TURBINES:	
Peak Efficiency flow (Q_p)	$Q_p = Q_d$ Equation B. 16
Efficiencies at flows below peak efficiency flow (e_q)	$e_q = \left[1 - 1.25\left(\frac{Q_p - Q}{Q_p}\right)^{1.13}\right] e_p$ Equation B. 17

Table B. 6 (Kosnik, 2011)

PELTON TURBINES:	
Rotational speed (n)	$n = 31\left(h\,\frac{Q_d}{j}\right)^{0.5}$ Equation B. 18
Outside diameter of runner (d)	$d = \frac{49.4\,h^{0.5}\,j^{0.02}}{n}$ Equation B. 19
Turbine peak efficiency (e_p)	$e_p = 0.864\;d^{0.04}$ Equation B. 20
Peak efficiency flow (Q_p)	$Q_p = (0.662 + 0.001j)\,Q_d$ Equation B. 21
Efficiency at flows above and below peak efficiency flow (e_q)	$e_q = \left[1 - \left\{(1.31 + 0.025j)\left\lvert\left(\frac{Q_p - Q}{Q_p}\right)\right\rvert^{(5.6+0.4j)}\right\}\right] e_p$ Equation B. 22

Table B. 7 (Kosnik, 2011)

TURGO TURBINES:	
Efficiency (e_q)	Pelton efficiency minus 0.03

Table B. 8 (Kosnik, 2011)

CROSS-FLOW TURBINES:	
Peak efficiency flow (Q_p)	$Q_p = Q_d$ Equation B. 23
Efficiency (e_q)	$e_q = 0.79 - 0.15\left(\frac{Q_d - Q}{Q_p}\right) - 1.37\left(\frac{Q_d - Q}{Q_p}\right)^{14}$ Equation B. 24

Appendix C

Power and Available Energy

Site 1: G1H013

Table C. 1

% Exceedence	Hhydra (m)	Hhydra (m)	Lhydr,max (m)	Q'n (m^3/s)	Qdes (m^3/s)	Qmax (m^3/s)	Htail,max (m)	Htail (m)	et	eg	Ltrans	Lpara
0.00	0.50	563.00	0.05	159.17	3	159.80	1	1.00	0.00	0.98	0	0
5.00	0.50	96.10		65.76				0.16	0.00			
10.00	0.50	49.57		47.23				0.08	0.00			
15.00	0.50	30.11		36.81				0.05	0.07			
20.00	0.50	18.26		28.66				0.03	0.37			
25.00	0.50	11.51		22.76				0.02	0.56			
30.00	0.50	7.24		18.05				0.01	0.68			
35.00	0.50	4.54		14.29				0.01	0.75			
40.00	0.50	2.83		11.28				0.00	0.79			
45.00	0.50	1.75		8.88				0.00	0.80			
50.00	0.50	1.08		6.96				0.00	0.81			
55.00	0.50	0.66		5.43				0.00	0.81			
60.00	0.39	0.39		4.21				0.00	0.81			
65.00	0.23	0.23		3.24				0.00	0.82			
70.00	0.13	0.13		2.46				0.00	0.82			
75.00	0.07	0.07		1.84				0.00	0.82			
80.00	0.04	0.04		1.34				0.00	0.82			
85.00	0.02	0.02		0.94				0.00	0.82			
90.00	0.01	0.01		0.63				0.00	0.81			
95.00	0.00	0.00		0.37				0.00	0.81			
100.00	0.00	0.00		0.00				0.00	0.81			

Table C. 2

% Exceedence	Power f(Qdes,et,des) (W)
0.00	89337
5.00	89337
10.00	89337
15.00	89337
20.00	89337
25.00	89337
30.00	89337
35.00	89337
40.00	89337
45.00	89337
50.00	89337
55.00	89337
60.00	89337
65.00	89337
70.00	89337
75.00	89337
80.00	89337
85.00	89337
90.00	89337
95.00	89337
100.00	89337

Table C. 3

% Exceedence	Qn,used=min(Q'n,Qdes) (m^3/s)	et,des	et,Q'n	et,used	Hhydra (m)	Htail (m)	P (kW)
0.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
5.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
10.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
15.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
20.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
25.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
30.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
35.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
40.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
45.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
50.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
55.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
60.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
65.0	3.0	0.8	0.0	0.8	0.2	0.0	89.3
70.0	2.5	0.0	0.8	0.8	0.1	0.0	74.5
75.0	1.8	0.0	0.8	0.8	0.1	0.0	56.5
80.0	1.3	0.0	0.8	0.8	0.0	0.0	41.5
85.0	0.9	0.0	0.8	0.8	0.0	0.0	29.4
90.0	0.6	0.0	0.8	0.8	0.0	0.0	19.6
95.0	0.4	0.0	0.8	0.8	0.0	0.0	11.7
100.0	0.0	0.0	0.8	0.8	0.0	0.0	0.0

Table C. 4

% Exceedence	Ldt	P (kW)		
		0		Eavail (kWh/yr)
0.00	0	89.34		19564.77
5.00		89.34		39129.54
10.00		89.34		39129.54
15.00		89.34		39129.54
20.00		89.34		39129.54
25.00		89.34		39129.54
30.00		89.34		39129.54
35.00		89.34		39129.54
40.00		89.34		39129.54
45.00		89.34		39129.54
50.00		89.34		39129.54
55.00		89.34		39129.54
60.00		89.34		39129.54
65.00		89.34		39129.54
70.00		74.45		35869.73
75.00		56.46		28669.68
80.00		41.55		21463.47
85.00		29.38		15533.98
90.00		19.56		10718.50
95.00		11.66		6837.15
100.00		0		2553.87
			Total=	649895.10

Site 2: T3H008

Table C. 5

% Exceedence	Hhydra (m)	Hhydra (m)	Lhydr,max (m)	Q (m^3/s)	Qdes (m^3/s)	Qmax (m^3/s)	Htail,max (m)	Htail (m)	et	eg	Ltrans	Lpara
0.00	0.50	844.50	0.05	159.17	3	77.59	1	4.38	0.00	0.98	0	0
5.00	0.50	144.15		65.76				0.71	0.00			
10.00	0.50	74.36		47.23				0.35	0.00			
15.00	0.50	45.17		36.81				0.21	0.07			
20.00	0.50	27.39		28.66				0.12	0.39			
25.00	0.50	17.27		22.76				0.07	0.60			
30.00	0.50	10.86		18.05				0.04	0.72			
35.00	0.50	6.80		14.29				0.02	0.79			
40.00	0.50	4.24		11.28				0.01	0.83			
45.00	0.50	2.63		8.88				0.01	0.85			
50.00	0.50	1.62		6.96				0.00	0.86			
55.00	0.50	0.98		5.43				0.00	0.86			
60.00	0.50	0.59		4.21				0.00	0.86			
65.00	0.35	0.35		3.24				0.00	0.86			
70.00	0.20	0.20		2.46				0.00	0.86			
75.00	0.11	0.11		1.84				0.00	0.86			
80.00	0.06	0.06		1.34				0.00	0.86			
85.00	0.03	0.03		0.94				0.00	0.86			
90.00	0.01	0.01		0.63				0.00	0.86			
95.00	0.00	0.00		0.37				0.00	0.86			
100.00	0.00	0.00		0.00				0.00	0.86			

Table C. 6

% Exceedence	Power f(Qdes,et,des) (W)
0.00	141380.54
5.00	141380.54
10.00	141380.54
15.00	141380.54
20.00	141380.54
25.00	141380.54
30.00	141380.54
35.00	141380.54
40.00	141380.54
45.00	141380.54
50.00	141380.54
55.00	141380.54
60.00	141380.54
65.00	141380.54
70.00	141380.54
75.00	141380.54
80.00	141380.54
85.00	141380.54
90.00	141380.54
95.00	141380.54
100.00	141380.54

Table C. 7

% Exceedence	Qn,used=min(Q'n,Qdes) (m^3/s)	et,des	et,Q'n	et,used	Hhydra (m)	Htail (m)	P (kW)
0.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
5.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
10.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
15.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
20.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
25.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
30.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
35.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
40.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
45.0	3.0	0.9	0.0	0.9	0.3	0.0	141.4
50.0	2.8	0.0	0.9	0.9	0.3	0.0	130.0
55.0	2.3	0.0	0.9	0.9	0.2	0.0	111.2
60.0	1.8	0.0	0.9	0.9	0.1	0.0	88.2
65.0	1.5	0.0	0.9	0.9	0.1	0.0	73.0
70.0	1.3	0.0	0.9	0.9	0.1	0.0	61.5
75.0	1.0	0.0	0.9	0.9	0.0	0.0	47.9
80.0	0.8	0.0	0.9	0.9	0.0	0.0	37.1
85.0	0.6	0.0	0.9	0.9	0.0	0.0	29.7
90.0	0.5	0.0	0.9	0.9	0.0	0.0	22.3
95.0	0.3	0.0	0.9	0.9	0.0	0.0	12.9
100.0	0.0	0.0	0.9	0.9	0.0	0.0	0.0

Table C. 8

% Exceedence	Ldt	P (kW)		
		0		Eavail (kWh/yr)
0.00	0.00	141.38		30962.34
5.00		141.38		61924.68
10.00		141.38		61924.68
15.00		141.38		61924.68
20.00		141.38		61924.68
25.00		141.38		61924.68
30.00		141.38		61924.68
35.00		141.38		61924.68
40.00		141.38		61924.68
45.00		141.38		61924.68
50.00		130.02		59437.72
55.00		111.19		52826.85
60.00		88.15		43656.54
65.00		73.00		35291.64
70.00		61.47		29447.41
75.00		47.86		23942.52
80.00		37.08		18602.96
85.00		29.70		14625.51
90.00		22.29		11386.56
95.00		12.89		7705.28
100.00		0.00		2822.94
			Total=	888030.37

Site 3: D1H003

Table C. 9

% Exceedence	Hhydra (m)	Hhydra (m)	Lhydr,max (m)	Q (m^3/s)	Qdes (m^3/s)	Qmax (m^3/s)	Htail,max (m)	Htail (m)	et	eg
0.0	0.5	114.0	0.1	159.2	10.0	1766.0	1.0	0.0	0.0	1.0
5.0	0.5	19.5		65.8				0.0	0.0	
10.0	0.5	10.0		47.2				0.0	0.0	
15.0	0.5	6.1		36.8				0.0	0.1	
20.0	0.5	3.7		28.7				0.0	0.4	
25.0	0.5	2.3		22.8				0.0	0.6	
30.0	0.5	1.5		18.0				0.0	0.8	
35.0	0.5	0.9		14.3				0.0	0.8	
40.0	0.5	0.6		11.3				0.0	0.9	
45.0	0.4	0.4		8.9				0.0	0.9	
50.0	0.2	0.2		7.0				0.0	0.9	
55.0	0.1	0.1		5.4				0.0	0.9	
60.0	0.1	0.1		4.2				0.0	0.9	
65.0	0.0	0.0		3.2				0.0	0.9	
70.0	0.0	0.0		2.5				0.0	0.9	
75.0	0.0	0.0		1.8				0.0	0.9	
80.0	0.0	0.0		1.3				0.0	0.9	
85.0	0.0	0.0		0.9				0.0	0.9	
90.0	0.0	0.0		0.6				0.0	0.9	
95.0	0.0	0.0		0.4				0.0	0.9	
100.0	0.0	0.0		0.0				0.0	0.9	

Table C. 10

% Exceedence	Power f(Qdes,et,des) (W)
0.00	748001.71
5.00	748001.71
10.00	748001.71
15.00	748001.71
20.00	748001.71
25.00	748001.71
30.00	748001.71
35.00	748001.71
40.00	748001.71
45.00	748001.71
50.00	748001.71
55.00	748001.71
60.00	748001.71
65.00	748001.71
70.00	748001.71
75.00	748001.71
80.00	748001.71
85.00	748001.71
90.00	748001.71
95.00	748001.71
100.00	748001.71

Table C. 11

% Exceedence	Qn,used=min(Q'	et,des	et,Q'n	et,used	Hhydra	Htail	P (kW)
0.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
5.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
10.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
15.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
20.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
25.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
30.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
35.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
40.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
45.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
50.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
55.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
60.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
65.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
70.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
75.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
80.0	10.0	0.9	0.0	0.9	0.5	0.0	748.0
85.0	8.0	0.0	0.9	0.9	0.3	0.0	609.7
90.0	4.4	0.0	0.9	0.9	0.1	0.0	343.1
95.0	2.1	0.0	0.9	0.9	0.0	0.0	163.2
100.0	0.0	0.0	0.9	0.9	0.0	0.0	0.0

Table C. 12

% Exceedence	Ldt	P (kW)		
		0		Eavail (kWh/yr)
0.00	0	748.00		163812.37
5.00		748.00		327624.75
10.00		748.00		327624.75
15.00		748.00		327624.75
20.00		748.00		327624.75
25.00		748.00		327624.75
30.00		748.00		327624.75
35.00		748.00		327624.75
40.00		748.00		327624.75
45.00		748.00		327624.75
50.00		748.00		327624.75
55.00		748.00		327624.75
60.00		748.00		327624.75
65.00		748.00		327624.75
70.00		748.00		327624.75
75.00		748.00		327624.75
80.00		748.00		327624.75
85.00		609.74		297345.30
90.00		343.09		208669.41
95.00		163.17		110870.66
100.00		0.00		35734.18
			Total=	6058427.906

Site 4: V1H041

Table C. 13

% Exceedence	Hhydra (m)	Hhydra (m)	Lhydr,max (m)	Q (m^3/s)	Qdes (m^3/s)	Qmax (m^3/s)	Htail,max (m)	Htail (m)		et	eg
0.00	0.5	281.50	0.05	159.17	3	62.53	1	6.97		0.05	0.98
5.00	0.5	48.05		65.76				1.13		0.05	
10.00	0.5	24.79		47.23				0.56		0.00	
15.00	0.5	15.06		36.81				0.33		0.10	
20.00	0.5	9.13		28.66				0.19		0.33	
25.00	0.5	5.76		22.76				0.11		0.48	
30.00	0.5	3.62		18.05				0.06		0.57	
35.00	0.5	2.27		14.29				0.04		0.62	
40.00	0.5	1.41		11.28				0.02		0.65	
45.00	0.5	0.88		8.88				0.01		0.66	
50.00	0.5	0.54		6.96				0.00		0.67	
55.00	0.328126669	0.33		5.43				0.00		0.67	
60.00	0.197161477	0.20		4.21				0.00		0.67	
65.00	0.116406528	0.12		3.24				0.00		0.67	
70.00	0.067112531	0.07		2.46				0.00		0.67	
75.00	0.037436136	0.04		1.84				0.00		0.67	
80.00	0.019914903	0.02		1.34				0.00		0.67	
85.00	0.00986181	0.01		0.94				0.00		0.67	
90.00	0.004345165	0.00		0.63				0.00		0.67	
95.00	0.001541064	0.00		0.37				0.00		0.67	
100.00	0	0.00		0.00				0.00		0.67	

Table C. 3

% Exceedence	Power f(Qdes,et,des) (W)
0.00	36715.10
5.00	36715.10
10.00	36715.10
15.00	36715.10
20.00	36715.10
25.00	36715.10
30.00	36715.10
35.00	36715.10
40.00	36715.10
45.00	36715.10
50.00	36715.10
55.00	36715.10
60.00	36715.10
65.00	36715.10
70.00	36715.10
75.00	36715.10
80.00	36715.10
85.00	36715.10
90.00	36715.10
95.00	36715.10
100.00	36715.10

Table C. 4

% Exceedence	Qn,used=min(Q'n,Qdes) (m^3/s)	et,des	et,Q'n	et,used	Hhydra (m)	Htail (m)	P (kW)
0.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
5.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
10.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
15.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
20.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
25.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
30.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
35.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
40.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
45.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
50.0	3.0	0.7	0.0	0.7	0.1	0.0	36.7
55.0	2.6	0.0	0.7	0.7	0.1	0.0	32.7
60.0	2.2	0.0	0.7	0.7	0.1	0.0	27.8
65.0	1.7	0.0	0.7	0.7	0.0	0.0	21.7
70.0	1.3	0.0	0.7	0.7	0.0	0.0	16.5
75.0	1.0	0.0	0.7	0.7	0.0	0.0	12.6
80.0	0.9	0.0	0.7	0.7	0.0	0.0	11.0
85.0	0.7	0.0	0.7	0.7	0.0	0.0	9.5
90.0	0.5	0.0	0.7	0.7	0.0	0.0	6.4
95.0	0.3	0.0	0.7	0.7	0.0	0.0	3.7
100.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0

Table C. 16

% Exceedence	Ldt	P (kW)		
		0.00		Eavail (kWh/yr)
0.00	0.00	36.72		8040.61
5.00		36.72		16081.21
10.00		36.72		16081.21
15.00		36.72		16081.21
20.00		36.72		16081.21
25.00		36.72		16081.21
30.00		36.72		16081.21
35.00		36.72		16081.21
40.00		36.72		16081.21
45.00		36.72		16081.21
50.00		36.72		16081.21
55.00		32.69		15200.22
60.00		27.81		13250.79
65.00		21.67		10836.03
70.00		16.46		8349.11
75.00		12.55		6352.74
80.00		11.03		5163.21
85.00		9.50		4494.59
90.00		6.43		3487.28
95.00		3.73		2224.34
100.00		0.00		816.93
			Total=	239028.00

Site 5: V1H002

Table C. 5

% Exceedence	Hhydra (m)	Hhydra (m)	Lhydr,max (m)	Q (m^3/s)	Qdes (m^3/s)	Qmax (m^3/s)	Htail,max (m)	Htail (m)	et	eg
0.00	0.5	563.00	0.05	159.17	3	101.85	1	2.533	0.00	0.98
5.00	0.5	96.10		65.76				0.409	0.00	
10.00	0.5	49.57		47.23				0.203	0.00	
15.00	0.5	30.11		36.81				0.119	0.07	
20.00	0.5	18.26		28.66				0.068	0.37	
25.00	0.5	11.51		22.76				0.041	0.56	
30.00	0.5	7.24		18.05				0.024	0.68	
35.00	0.5	4.54		14.29				0.013	0.75	
40.00	0.5	2.83		11.28				0.007	0.79	
45.00	0.5	1.75		8.88				0.004	0.80	
50.00	0.5	1.08		6.96				0.002	0.81	
55.00	0.5	0.66		5.43				0.001	0.81	
60.00	0.39	0.39		4.21				0.000	0.81	
65.00	0.23	0.23		3.24				0.000	0.82	
70.00	0.13	0.13		2.46				0.000	0.82	
75.00	0.07	0.07		1.84				0.000	0.82	
80.00	0.04	0.04		1.34				0.000	0.82	
85.00	0.02	0.02		0.94				0.000	0.82	
90.00	0.01	0.01		0.63				0.001	0.81	
95.00	0.00	0.00		0.37				0.001	0.81	
100.00	0	0.00		0.00				0.001	0.81	

Table C. 18

% Exceedence	Power f(Qdes,et,des) (W)
0.00	89869.80
5.00	89869.80
10.00	89869.80
15.00	89869.80
20.00	89869.80
25.00	89869.80
30.00	89869.80
35.00	89869.80
40.00	89869.80
45.00	89869.80
50.00	89869.80
55.00	89869.80
60.00	89869.80
65.00	89869.80
70.00	89869.80
75.00	89869.80
80.00	89869.80
85.00	89869.80
90.00	89869.80
95.00	89869.80
100.00	89869.80

Table C. 19

% Exceedence	Qn,used=min(Q'n,Qdes) (m^3/s)	et,des	et,Q'n	et,used	Hhydra (m)	Htail (m)	P (kW)
0.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
5.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
10.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
15.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
20.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
25.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
30.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
35.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
40.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
45.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
50.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
55.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
60.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
65.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
70.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
75.0	3.0	0.8	0.0	0.8	0.2	0.0	89.9
80.0	2.4	0.0	0.8	0.8	0.1	0.0	73.8
85.0	1.8	0.0	0.8	0.8	0.1	0.0	56.3
90.0	1.4	0.0	0.8	0.8	0.0	0.0	42.4
95.0	1.0	0.0	0.8	0.8	0.0	0.0	30.7
100.0	0.0	0.0	0.8	0.8	0.0	0.0	0.0

Table C. 60

% Exceeden	Ldt	P (kW)		
		0.00		Eavail (kWh/yr)
0.00	0.00	89.87		19681.49
5.00		89.87		39362.97
10.00		89.87		39362.97
15.00		89.87		39362.97
20.00		89.87		39362.97
25.00		89.87		39362.97
30.00		89.87		39362.97
35.00		89.87		39362.97
40.00		89.87		39362.97
45.00		89.87		39362.97
50.00		89.87		39362.97
55.00		89.87		39362.97
60.00		89.87		39362.97
65.00		89.87		39362.97
70.00		89.87		39362.97
75.00		89.87		39362.97
80.00		73.83		35849.61
85.00		56.33		28504.90
90.00		42.44		21631.49
95.00		30.67		16010.58
100.00		0.00		6715.87
			Total=	718838.54

Site 6: U1H005

Table C. 21

% Exceedence	Hhydra (m)	Hhydra (m)	Lhydr,max (m)	Q (m^3/s)	Qdes (m^3/s)	Qmax (m^3/s)	Htail,max (m)	Htail (m)	et	eg
0.00	0.5	844.50	0.05	159.17	3	244.60	1	0.42	0.00	0.98
5.00	0.5	144.15		65.76				0.07	0.00	
10.00	0.5	74.36		47.23				0.03	0.00	
15.00	0.5	45.17		36.81				0.02	0.07	
20.00	0.5	27.39		28.66				0.01	0.40	
25.00	0.5	17.27		22.76				0.01	0.60	
30.00	0.5	10.86		18.05				0.00	0.73	
35.00	0.5	6.80		14.29				0.00	0.80	
40.00	0.5	4.24		11.28				0.00	0.84	
45.00	0.5	2.63		8.88				0.00	0.85	
50.00	0.5	1.62		6.96				0.00	0.86	
55.00	0.5	0.98		5.43				0.00	0.87	
60.00	0.5	0.59		4.21				0.00	0.87	
65.00	0.35	0.35		3.24				0.00	0.87	
70.00	0.20	0.20		2.46				0.00	0.87	
75.00	0.11	0.11		1.84				0.00	0.87	
80.00	0.06	0.06		1.34				0.00	0.87	
85.00	0.03	0.03		0.94				0.00	0.87	
90.00	0.01	0.01		0.63				0.00	0.87	
95.00	0.00	0.00		0.37				0.00	0.87	
100.00	0	0.00		0.00				0.00	0.86	

Table C. 22

% Exceedence	Power f(Qdes,et,des) (W)
0.00	143024.50
5.00	143024.50
10.00	143024.50
15.00	143024.50
20.00	143024.50
25.00	143024.50
30.00	143024.50
35.00	143024.50
40.00	143024.50
45.00	143024.50
50.00	143024.50
55.00	143024.50
60.00	143024.50
65.00	143024.50
70.00	143024.50
75.00	143024.50
80.00	143024.50
85.00	143024.50
90.00	143024.50
95.00	143024.50
100.00	143024.50

Table C. 7

% Exceedence	Qn,used=min(Q'n,Qdes) (m^3/s)	et,des	et,Q'n	et,used	Hhydra (m)	Htail (m)	P (kW)
0.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
5.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
10.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
15.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
20.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
25.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
30.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
35.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
40.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
45.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
50.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
55.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
60.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
65.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
70.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
75.0	3.0	0.9	0.0	0.9	0.3	0.0	143.0
80.0	3.0	0.0	0.9	0.9	0.3	0.0	141.7
85.0	2.6	0.0	0.9	0.9	0.2	0.0	127.4
90.0	2.1	0.0	0.9	0.9	0.2	0.0	104.7
95.0	1.4	0.0	0.9	0.9	0.1	0.0	68.5
100.0	0.0	0.0	0.9	0.9	0.0	0.0	0.0

Table C. 8

% Exceedence	Ldt	P (kW)		
		0		Eavail (kWh/yr)
0.00	0	143.02		31322.37
5.00		143.02		62644.73
10.00		143.02		62644.73
15.00		143.02		62644.73
20.00		143.02		62644.73
25.00		143.02		62644.73
30.00		143.02		62644.73
35.00		143.02		62644.73
40.00		143.02		62644.73
45.00		143.02		62644.73
50.00		143.02		62644.73
55.00		143.02		62644.73
60.00		143.02		62644.73
65.00		143.02		62644.73
70.00		143.02		62644.73
75.00		143.02		62644.73
80.00		141.74		62363.99
85.00		127.36		58932.57
90.00		104.66		50811.77
95.00		68.52		37926.86
100.00		0		15006.04
			Total=	1196034.59

Appendix D

Population Density, Rivers and Streamgauges of South Africa

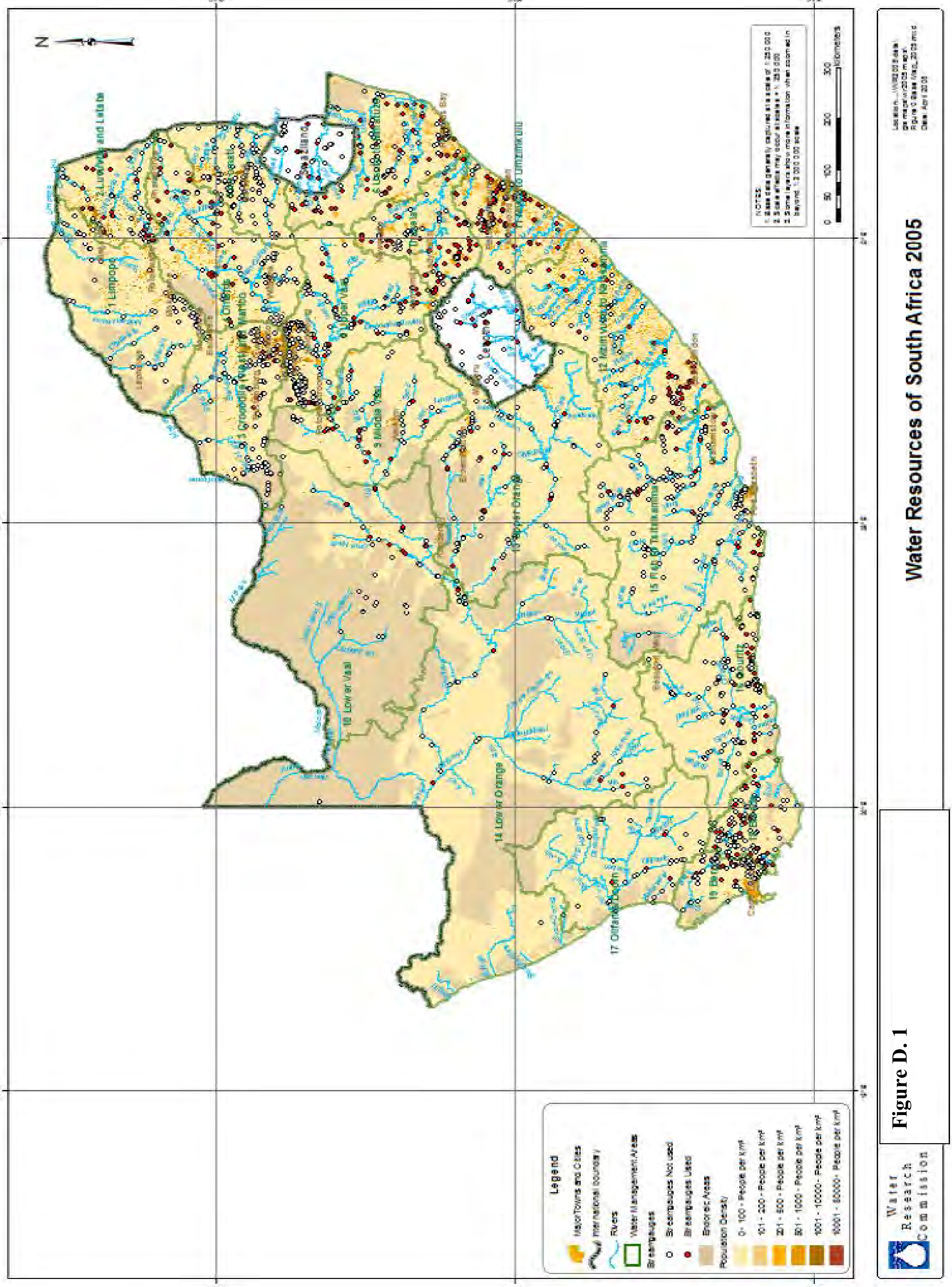
Water Resources of South Africa 2005
Legend
Major Towns and Cities
International boundary
Rivers
Water Management Areas
Streamgauges
Streamgauges Not used
Streamgauges Used
Endoreic Areas
Population Density
Water Research Commission

Figure D. 1

Appendix E

Financials

Site 1: G1H013

Table E. 1

Year	Cost/Income ($)	Cumulative Cash ($)	Numerator	Denominator	LCOE (USD/kWh)
1	-358784.36	-358784.36	335312.48	607378.59	0.55
2	76607.82	-282176.54	246463.92	567643.55	0.43
3	76607.82	-205568.72	167805.31	530507.99	0.32
4	76607.82	-128960.91	98383.66	495801.86	0.20
5	76607.82	-52353.09	37327.03	463366.22	0.08
6	76607.82	24254.72	16161.95	433052.54	0.04
7	76607.82	100862.54	62812.12	404722.00	0.16
8	76607.82	177470.36	103289.36	378244.86	0.27
9	76607.82	254078.17	138201.69	353499.87	0.39
10	76607.82	330685.99	168103.99	330373.71	0.51
11	76607.82	407293.81	193502.35	308760.48	0.63
12	76607.82	483901.62	214858.11	288561.20	0.74
13	76607.82	560509.44	232591.49	269683.36	0.86
14	76607.82	637117.25	247085.06	252040.52	0.98
15	76607.82	713725.07	258686.81	235551.89	1.10
16	76607.82	790332.89	267713.09	220141.95	1.22
17	76607.82	866940.70	274451.22	205740.14	1.33
18	76607.82	943548.52	279161.96	192280.51	1.45
19	76607.82	1020156.33	282081.73	179701.41	1.57
20	76607.82	1096764.15	283424.70	167945.24	1.69
21	76607.82	1173371.97	283384.69	156958.17	1.81
22	76607.82	1249979.78	282136.89	146689.88	1.92
23	76607.82	1326587.60	279839.52	137093.35	2.04
24	76607.82	1403195.41	276635.23	128124.62	2.16
25	76607.82	1479803.23	272652.53	119742.64	2.28
26	76607.82	1556411.05	268006.97	111909.01	2.39
27	76607.82	1633018.86	262802.33	104587.86	2.51
28	76607.82	1709626.68	257131.63	97745.66	2.63
29	76607.82	1786234.49	251078.15	91351.08	2.75
30	76607.82	1862842.31	244716.22	85374.85	2.87
31	76607.82	1939450.13	238112.12	79789.58	2.98
32	76607.82	2016057.94	231324.76	74569.70	3.10
33	76607.82	2092665.76	224406.38	69691.30	3.22
34	76607.82	2169273.57	217403.18	65132.06	3.34
35	76607.82	2245881.39	210355.85	60871.08	3.46
36	76607.82	2322489.21	203300.15	56888.86	3.57
37	76607.82	2399097.02	196267.34	53167.16	3.69
38	76607.82	2475704.84	189284.61	49688.94	3.81
39	76607.82	2552312.65	182375.52	46438.26	3.93
40	76607.82	2628920.47	175560.31	43400.24	4.05

Site 2: T3H008

Table E. 2

Years	Cost/Income ($)	Cumulative Cash ($)	Numerator	Denominator	LCOE (USD/kWh)
1	-509359.26	-509359.26	476036.69	829934.92	0.57
2	103596.91	-405762.35	354408.55	775640.12	0.46
3	103596.91	-302165.44	246657.01	724897.30	0.34
4	103596.91	-198568.53	151486.98	677474.12	0.22
5	103596.91	-94971.63	67713.46	633153.38	0.11
6	103596.91	8625.28	5747.39	591732.13	0.01
7	103596.91	112222.19	69886.34	553020.68	0.13
8	103596.91	215819.10	125608.68	516841.76	0.24
9	103596.91	319416.01	173741.14	483029.68	0.36
10	103596.91	423012.92	215038.32	451429.61	0.48
11	103596.91	526609.82	250188.53	421896.83	0.59
12	103596.91	630206.73	279819.33	394296.10	0.71
13	103596.91	733803.64	304502.42	368501.03	0.83
14	103596.91	837400.55	324758.37	344393.49	0.94
15	103596.91	940997.46	341060.78	321863.07	1.06
16	103596.91	1044594.37	353840.25	300806.61	1.18
17	103596.91	1148191.28	363487.95	281127.67	1.29
18	103596.91	1251788.18	370358.95	262736.14	1.41
19	103596.91	1355385.09	374775.27	245547.80	1.53
20	103596.91	1458982.00	377028.67	229483.92	1.64
21	103596.91	1562578.91	377383.26	214470.96	1.76
22	103596.91	1666175.82	376077.82	200440.15	1.88
23	103596.91	1769772.73	373328.04	187327.24	1.99
24	103596.91	1873369.63	369328.49	175072.19	2.11
25	103596.91	1976966.54	364254.46	163618.86	2.23
26	103596.91	2080563.45	358263.65	152914.83	2.34
27	103596.91	2184160.36	351497.73	142911.05	2.46
28	103596.91	2287757.27	344083.75	133561.73	2.58
29	103596.91	2391354.18	336135.48	124824.05	2.69
30	103596.91	2494951.09	327754.53	116657.99	2.81
31	103596.91	2598547.99	319031.55	109026.16	2.93
32	103596.91	2702144.90	310047.15	101893.61	3.04
33	103596.91	2805741.81	300872.88	95227.67	3.16
34	103596.91	2909338.72	291572.02	88997.82	3.28
35	103596.91	3012935.63	282200.41	83175.53	3.39
36	103596.91	3116532.54	272807.10	77734.14	3.51
37	103596.91	3220129.44	263435.05	72648.73	3.63
38	103596.91	3323726.35	254121.67	67896.01	3.74
39	103596.91	3427323.26	244899.41	63454.22	3.86
40	103596.91	3530920.17	235796.19	59303.01	3.98

Site 3: D1H003

Table E. 3

Years	Cost/Income ($)	Cumulative Cash ($)	Numerator	Denominator	LCOE (USD/kWh)
1	-1816996.07	-1816996.07	1698127.17	5662082.15	0.30
2	800621.30	-1016374.78	887741.09	5291665.57	0.17
3	800621.30	-215753.48	176119.11	4945481.84	0.04
4	800621.30	584867.82	446192.86	4621945.64	0.10
5	800621.30	1385489.11	987834.59	4319575.37	0.23
6	800621.30	2186110.41	1456697.67	4036986.32	0.36
7	800621.30	2986731.70	1859986.40	3772884.41	0.49
8	800621.30	3787353.00	2204273.93	3526060.20	0.63
9	800621.30	4587974.29	2495554.03	3295383.36	0.76
10	800621.30	5388595.59	2739288.75	3079797.54	0.89
11	800621.30	6189216.88	2940452.36	2878315.46	1.02
12	800621.30	6989838.18	3103571.74	2690014.44	1.15
13	800621.30	7790459.47	3232763.71	2514032.19	1.29
14	800621.30	8591080.77	3331769.24	2349562.80	1.42
15	800621.30	9391702.07	3403985.03	2195853.08	1.55
16	800621.30	10192323.36	3452492.55	2052199.14	1.68
17	800621.30	10992944.66	3480084.75	1917943.12	1.81
18	800621.30	11793565.95	3489290.61	1792470.21	1.95
19	800621.30	12594187.25	3482397.72	1675205.80	2.08
20	800621.30	13394808.54	3461473.07	1565612.90	2.21
21	800621.30	14195429.84	3428382.08	1463189.62	2.34
22	800621.30	14996051.13	3384806.17	1367466.94	2.48
23	800621.30	15796672.43	3332258.82	1278006.48	2.61
24	800621.30	16597293.72	3272100.36	1194398.58	2.74
25	800621.30	17397915.02	3205551.53	1116260.36	2.87
26	800621.30	18198536.32	3133705.93	1043233.98	3.00
27	800621.30	18999157.61	3057541.41	974985.03	3.14
28	800621.30	19799778.91	2977930.55	911200.96	3.27
29	800621.30	20600400.20	2895650.25	851589.68	3.40
30	800621.30	21401021.50	2811390.50	795878.21	3.53
31	800621.30	22201642.79	2725762.44	743811.41	3.66
32	800621.30	23002264.09	2639305.72	695150.85	3.80
33	800621.30	23802885.38	2552495.25	649673.69	3.93
34	800621.30	24603506.68	2465747.32	607171.67	4.06
35	800621.30	25404127.97	2379425.29	567450.16	4.19
36	800621.30	26204749.27	2293844.70	530327.26	4.33
37	800621.30	27005370.57	2209277.99	495632.95	4.46
38	800621.30	27805991.86	2125958.78	463208.36	4.59
39	800621.30	28606613.16	2044085.76	432905.01	4.72
40	800621.30	29407234.45	1963826.32	404584.12	4.85

Site 4: V1H041

Table E. 4

Years	Cost/Income ($)	Cumulative Cash ($)	Numerator	Denominator	LCOE (USD/kWh)
1	-171677.49	-171677.49	160446.25	223390.65	0.72
2	25344.68	-146332.81	127812.75	208776.31	0.61
3	25344.68	-120988.13	98762.36	195118.05	0.51
4	25344.68	-95643.45	72965.93	182353.31	0.40
5	25344.68	-70298.78	50122.06	170423.66	0.29
6	25344.68	-44954.10	29954.81	159274.45	0.19
7	25344.68	-19609.42	12211.76	148854.62	0.08
8	25344.68	5735.26	3337.97	139116.47	0.02
9	25344.68	31079.94	16905.43	130015.39	0.13
10	25344.68	56424.62	28683.42	121509.71	0.24
11	25344.68	81769.30	38848.01	113560.48	0.34
12	25344.68	107113.98	47559.89	106131.29	0.45
13	25344.68	132458.66	54965.63	99188.12	0.55
14	25344.68	157803.34	61198.85	92699.18	0.66
15	25344.68	183148.02	66381.27	86634.75	0.77
16	25344.68	208492.70	70623.69	80967.05	0.87
17	25344.68	233837.37	74026.92	75670.14	0.98
18	25344.68	259182.05	76682.62	70719.76	1.08
19	25344.68	284526.73	78674.01	66093.23	1.19
20	25344.68	309871.41	80076.66	61769.38	1.30
21	25344.68	335216.09	80959.07	57728.39	1.40
22	25344.68	360560.77	81383.31	53951.77	1.51
23	25344.68	385905.45	81405.55	50422.21	1.61
24	25344.68	411250.13	81076.57	47123.56	1.72
25	25344.68	436594.81	80442.23	44040.71	1.83
26	25344.68	461939.49	79543.90	41159.54	1.93
27	25344.68	487284.17	78418.82	38466.86	2.04
28	25344.68	512628.85	77100.51	35950.34	2.14
29	25344.68	537973.52	75619.07	33598.45	2.25
30	25344.68	563318.20	74001.49	31400.42	2.36
31	25344.68	588662.88	72271.91	29346.19	2.46
32	25344.68	614007.56	70451.92	27426.34	2.57
33	25344.68	639352.24	68560.75	25632.10	2.67
34	25344.68	664696.92	66615.49	23955.23	2.78
35	25344.68	690041.60	64631.32	22388.06	2.89
36	25344.68	715386.28	62621.66	20923.42	2.99
37	25344.68	740730.96	60598.34	19554.60	3.10
38	25344.68	766075.64	58571.74	18275.33	3.20
39	25344.68	791420.32	56550.94	17079.75	3.31
40	25344.68	816765.00	54543.88	15962.38	3.42

Site 5: V1H002

Table E. 5

Years	Cost/Income ($)	Cumulative Cash ($)	Numerator	Denominator	LCOE (USD/kWh)
1	-360417.21	-360417.21	336838.51	671811.72	0.50
2	86796.66	-273620.54	238990.78	627861.42	0.38
3	86796.66	-186823.88	152503.94	586786.37	0.26
4	86796.66	-100027.22	76310.29	548398.48	0.14
5	86796.66	-13230.56	9433.21	512521.94	0.02
6	86796.66	73566.10	49020.20	478992.47	0.10
7	86796.66	160362.76	99865.87	447656.51	0.22
8	86796.66	247159.43	143849.04	418370.57	0.34
9	86796.66	333956.09	181649.98	391000.54	0.46
10	86796.66	420752.75	213889.36	365421.06	0.59
11	86796.66	507549.41	241133.07	341515.01	0.71
12	86796.66	594346.07	263896.76	319172.91	0.83
13	86796.66	681142.73	282650.02	298292.44	0.95
14	86796.66	767939.39	297820.14	278777.98	1.07
15	86796.66	854736.06	309795.68	260540.17	1.19
16	86796.66	941532.72	318929.71	243495.48	1.31
17	86796.66	1028329.38	325542.75	227565.87	1.43
18	86796.66	1115126.04	329925.56	212678.38	1.55
19	86796.66	1201922.70	332341.64	198764.85	1.67
20	86796.66	1288719.36	333029.57	185761.54	1.79
21	86796.66	1375516.03	332205.12	173608.91	1.91
22	86796.66	1462312.69	330063.23	162251.32	2.03
23	86796.66	1549109.35	326779.79	151636.75	2.16
24	86796.66	1635906.01	322513.34	141716.59	2.28
25	86796.66	1722702.67	317406.55	132445.41	2.40
26	86796.66	1809499.33	311587.63	123780.76	2.52
27	86796.66	1896296.00	305171.61	115682.95	2.64
28	86796.66	1983092.66	298261.52	108114.91	2.76
29	86796.66	2069889.32	290949.47	101041.97	2.88
30	86796.66	2156685.98	283317.62	94431.75	3.00
31	86796.66	2243482.64	275439.11	88253.97	3.12
32	86796.66	2330279.30	267378.88	82480.34	3.24
33	86796.66	2417075.97	259194.41	77084.43	3.36
34	86796.66	2503872.63	250936.47	72041.53	3.48
35	86796.66	2590669.29	242649.70	67328.53	3.60
36	86796.66	2677465.95	234373.21	62923.86	3.72
37	86796.66	2764262.61	226141.11	58807.35	3.85
38	86796.66	2851059.27	217983.03	54960.14	3.97
39	86796.66	2937855.94	209924.52	51364.61	4.09
40	86796.66	3024652.60	201987.45	48004.31	4.21

Site 6: U1H005

Table E. 6

year	Cost/Income ($)	Cumulative Cash ($)	Numerator	Denominator	LCOE (USD/kWh)
1	-513874.52	-513874.52	480256.56	1117789.33	0.43
2	149272.82	-364601.71	318457.25	1044662.93	0.30
3	149272.82	-215328.89	175772.52	976320.49	0.18
4	149272.82	-66056.07	50393.86	912449.06	0.06
5	149272.82	83216.74	59332.39	852756.13	0.07
6	149272.82	232489.56	154917.61	796968.35	0.19
7	149272.82	381762.37	237742.42	744830.23	0.32
8	149272.82	531035.19	309067.32	696103.02	0.44
9	149272.82	680308.01	370042.48	650563.57	0.57
10	149272.82	829580.82	421716.82	608003.33	0.69
11	149272.82	978853.64	465046.31	568227.42	0.82
12	149272.82	1128126.45	500901.64	531053.66	0.94
13	149272.82	1277399.27	530075.28	496311.83	1.07
14	149272.82	1426672.08	553288.03	463842.83	1.19
15	149272.82	1575944.90	571194.96	433497.97	1.32
16	149272.82	1725217.72	584390.93	405138.29	1.44
17	149272.82	1874490.53	593415.70	378633.92	1.57
18	149272.82	2023763.35	598758.55	353863.48	1.69
19	149272.82	2173036.16	600862.61	330713.53	1.82
20	149272.82	2322308.98	600128.77	309078.06	1.94
21	149272.82	2471581.80	596919.35	288858.00	2.07
22	149272.82	2620854.61	591561.39	269960.75	2.19
23	149272.82	2770127.43	584349.75	252299.77	2.32
24	149272.82	2919400.24	575549.89	235794.18	2.44
25	149272.82	3068673.06	565400.49	220368.39	2.57
26	149272.82	3217945.87	554115.78	205951.77	2.69
27	149272.82	3367218.69	541887.74	192478.29	2.82
28	149272.82	3516491.51	528888.10	179886.25	2.94
29	149272.82	3665764.32	515270.15	168117.99	3.06
30	149272.82	3815037.14	501170.43	157119.62	3.19
31	149272.82	3964309.95	486710.25	146840.76	3.31
32	149272.82	4113582.77	471997.13	137234.36	3.44
33	149272.82	4262855.58	457126.03	128256.41	3.56
34	149272.82	4412128.40	442180.62	119865.80	3.69
35	149272.82	4561401.22	427234.24	112024.11	3.81
36	149272.82	4710674.03	412351.00	104695.43	3.94
37	149272.82	4859946.85	397586.61	97846.20	4.06
38	149272.82	5009219.66	382989.20	91445.05	4.19
39	149272.82	5158492.48	368600.12	85462.66	4.31
40	149272.82	5307765.30	354454.59	79871.65	4.44

Appendix F

Electrical Units of Measure and Exchange Rate

Table F. 1

<table>
<tr><th colspan="3">Power:</th></tr>
<tr><td>Megawatt (MW)</td><td>A unit of power</td><td>One Megawatt is equal to 1000 kilowatts or 1000 000 Watts</td></tr>
</table>

Table F. 2

<table>
<tr><th colspan="3">Energy:</th></tr>
<tr><td>Kilowatt-hour (kWh)</td><td rowspan="4">A unit of energy consumption.</td><td>One kilowatt hours is equal to 3.6 Mega Joules (MJ) or about 859.86 Kilocalories (kcals)</td></tr>
<tr><td>Megawatt hour (MWh)</td><td>One Megawatt hour is the amount of energy consumed in one hour at a rate of on Megawatt.</td></tr>
<tr><td>Gigawatt hour (GWh)</td><td>One Gigawatt hour is equal to 1000 Megawatt hour.</td></tr>
<tr><td>Terawatt hour (TWh)</td><td>One Terawatt hour is equal to 1000 Gigawatt hour.</td></tr>
</table>

Exchange Rate Used

1 United States Dollar = 8.76 South African Rands

(According to www.likeforex.com as of 24/09/12)