UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

A FEASIBILITY AND IMPLEMENTATION MODEL OF SMALL-SCALE HYDROPOWER DEVELOPMENT FOR RURAL ELECTRIFICATION IN SOUTH AFRICA

GIDEON JOHANNES BONTHUYS

A FEASIBILITY AND IMPLEMENTATION MODEL OF SMALL-SCALE HYDROPOWER DEVELOPMENT FOR RURAL ELECTRIFICATION IN SOUTH AFRICA

GIDEON JOHANNES BONTHUYS

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OF ENGINEERING (WATER RESOURCE ENGINEERING)

in the

FACULTY OF ENGINEERING, BUILT-ENVIRONMENT AND INFORMATION TECHNOLOGY

University of Pretoria

January 2016

DISSERTATION SUMMARY

A FEASIBILITY AND IMPLEMENTATION MODEL OF SMALL-SCALE HYDROPOWER DEVELOPMENT FOR RURAL ELECTRIFICATION IN SOUTH AFRICA

GIDEON JOHANNES BONTHUYS

Supervisor:	Mr Marco van Dijk
Department:	Civil Engineering
University:	University of Pretoria
Degree:	Master of Engineering (Water Resource Engineering)

Small scale hydropower used to play a very important role in the provision of energy to urban and rural areas of South Africa. The national electricity grid however, expanded and offered cheap, coal generated electricity and a large number of hydropower systems were decommissioned. Unfortunately, large numbers of households and communities will not be connected to the national electricity grid for the foreseeable future due to high cost of transmission and distribution systems to remote communities, the relatively low electricity demand within rural communities and the current expenditure on upgrading and constructing of new coal fired power stations. Today, small hydropower projects are the most commonly used option to supply electricity to isolated or rural communities throughout the world including countries such as Nepal, India, Peru and China.

It was hypothesized that it is technically possible to provide small-scale hydropower (SSHP) installations for rural electrification in South Africa, and that for specific configurations of penstock diameter, penstock length and transmission line lengths, SSHP installations are more feasible for rural electrification than local or national electricity grid extension or even other energy sources such as diesel generators.

The objective of the study was to identify potential sites for the development of feasible small-scale hydropower plants within the OR Tambo District Municipality in the Eastern Cape, and the uMzinyathi District Municipality in Kwa-Zulu Natal, South Africa. The objective was the development of a feasibility and implementation model to assist in designing and financially evaluating small-scale hydropower plants for several similarly identified potential small-scale hydropower installations in South Africa.

The implementation model describes steps to be followed in identifying a technically possible and feasible opportunity to develop a small-scale hydropower site for rural electrification, and categorises them into three different sections, namely Site Selection, SSHP and Cost Assesment, which combine to form the implementation model. Continuous referral from the subsequent sections of the study back to the implementation model provides a comprehensiveness to the model which allows for a sustainable implementation of the SSHP project from the conceptual phase to the commissioning of the plant.

Several designed small-scale hydropower plants were economically evaluated on Net Present Value, Internal Rate of Return, Levelised Cost of Energy, Financial Payback Period and Capital Cost Comparison (CCCR). It was observed that a low levelised cost is not always associated with a low CCCR and vice versa. The levelised cost of small-scale hydropower is lowered by developing sites with shorter penstock lengths for higher elevation differences, to obtain a higher head while minimizing penstock lengths and capital costs. From the financial analysis of several designed installations, generic formulae for costing a small-scale hydropower plant were developed. By keeping specific variables constant, design charts for technically executable and financially feasible small-scale hydropower plants were developed by assuming constant penstock diameters, penstock lengths and potential head available.

The outcome of this study proved the initial hypothesis. From the feasibility analysis and developed design charts it was concluded that the levelised cost of small-scale hydropower projects indicate that the cost of small-scale hydropower for low energy generation is high compared to the levelised cost of grid connected electricity supply. However, the remoteness of small-scale hydropower for rural electrification and the cost of infrastructure to connect remote rural communities to the local or national electricity grid provides a low CCCR and renders technically implementable small-scale hydropower projects for rural electrification feasible on this basis.

DECLARATION

I, the undersigned hereby declare that:

I understand what plagiarism is and I am aware of the University's policy in this regard;

The work contained in this project report is my own original work;

I did not refer to work of current or previous students, lecture notes, handbooks or any other study material without proper referencing;

I have not allowed anyone to copy any part of my project report;

I have not previously in its entirety or in part submitted this project report at any university for a degree.

Disclaimer:

The work presented in this report is that of the student alone. Students were encouraged to take ownership of their projects and to develop and execute their experiments with limited guidance and assistance. The content of the research does not necessarily represent the views of the supervisor or any staff member of the University of Pretoria, Department of Civil Engineering. The supervisor did not read or edit the final report and is not responsible for any technical inaccuracies, statements or errors. The conclusions and recommendations given in the report are also not necessarily that of the supervisor, sponsors or companies involved in the research.

____

Gideon Johannes Bonthuys

25075170

ACKNOWLEDGEMENT

I wish to express my appreciation to the following organisations and persons who made this dissertation possible:

- This dissertation was completed in conjunction with the Water Research Commission, the uMzinyathi District Municipality within the KwaZulu-Natal Province and the OR Tambo District Municipality within the Eastern Cape Province of South Africa. The opinions expressed are those of the author and do not necessarily represent the policy of the Water Research Commission.
- The Water Research Commission for financial support during the course of the study.
- The uMzinyathi District Municipality for allowing access to their data and for permitting research within their municipality.
- The OR Tambo District Municipality for allowing access to their data and for permitting research within their municipality.
- The following persons are gratefully acknowledged for their guidance and assistance during the course of the study:
    - Mr. M. van Dijk
    - Ms. I. Loots
    - Ms. B. Scharfetter
    - Mr. B. Barta
    - Ms. A. van Dyk
    - Me. C. Dedekind
    - Mr. J. Bhagwan
- Mr. W. Smit from BDE Consulting Engineers for the electrical designs of the proposed SSHP projects and for assistance with costing of the electrical designs.
- My wife, family, friends and colleagues for their patience, encouragement and support during the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	– Alternating current
AG	– Asynchronous generators
ARE	– Alliance for Rural Electrification
BA	– Basic assessment
BOQ	– Bill of quantities
CC	– Construction costs
CCCR	– Capital Cost Comparison Ratio
CDM	– Clean development mechanism
CER	– Credits for emission reduction
CSIR	– Council for Scientific and Industrial Research
CWC	– Civil Works cost
DC	– Direct current
DM	– District Municipality
DME	– Department of Minerals and Energy
DOE	– Department of Energy
DWS	– Department of Water and Sanitation
EC	– Equipment costs
EDNA	– Elevation Derivatives for National Applications
EIA	– Environmental impact assessment
ESHA	– European Small Hydropower Association
ESMAP	– Energy Sector Management Assistance Program
ESP	– Electricity Service Provider
EU	– European Union
EUMB	– Energy Utilization Management Bureau
EV1	– Extreme Value Type 1
FEY	– Future Energy Yorkshire
GA	– General Authorisation
GIS	– Geographic Information System
GSU	– Generator step-up
HDPE	– High-density polyethylene

HV	– High voltage
ICC	– Initial capital costs
IEA	– International Energy Agency
IFC	– International Finance Corporation
IMP	– Integrated method for power analysis
INEP	– Integrated national electrification programme
INL	– Idaho National Laboratory
IRR	– Internal rate of return
LM	– Local Municipality
LP3	– Log Pearson Type 3
LV	– Low voltage
MPPT	– Maximum Power Point Tracking
MRR	– Modified Run-off-River
NEMA	– National Environmental Management Act
NERSA	– National Energy Regulator of South Africa
NPV	– Net present value
O&M	– Operations and Maintenance
OMC	– Operating and Maintenance cost
PAT	– Pump as turbine
PET	– Polyethylene terephthalate
PRV	– Pressure reducing valve
PV	– Photovoltaic
PVC	– Polyvinyl chloride
RETs	– Renewable-energy and Energy-efficient Technologies
ROD	– Record of decision
RPM	– Revolutions per minute
RR	– Run-off-River
SANRAL	– South African National Roads Agency Limited
SG	– Synchronous generators
SHP	– Small hydropower
SSHP	– Small-scale Hydropower
TVP	– Transient voltage protection

UPD	– Utility Programs for Drainage
USAID	– United States Agency for International Development
VHP	– Virtual Hydropower Prospector
WB	– Water Board
WSP	– Water Services Provider
WUA	– Weighted usable area
WWTP	– Wastewater treatment plant

1 INTRODUCTION

1.1 BACKGROUND

The major role that access to energy services plays in economic development is generally recognised. However, the linkages between the provision of energy and poverty alleviation through economic development are not fully understood and it can be argued that this lack of understanding contributes to the relatively slow pace of energisation of the African continent (Szewczuk, 2010). The South African Government is committed to universal access to electricity across South Africa.

With 80% of the urban areas and 45% rural areas electrified the emphasis of the South African Electrification Programme is shifting from the urban to the rural areas of South Africa. Feasible grid electricity is being extended as far as is possible into the rural areas. However, large numbers of households and communities will not be connected to the national electricity grid for the foreseeable future due to high cost of transmission and distribution systems to remote communities, the relatively low electricity demand within rural communities and the current expenditure on upgrading and constructing of new coal fired power stations.

Alternative, energy technologies will need to be developed and implemented to ensure that the South African Government's objective of universal access of energy & electricity to all its citizens is achieved (Szewczuk, 2010). Also, many low-income households make use of 'traditional' forms of energy such as dung, paraffin, wood, kerosene and coal. Many negative consequences arise from the use of these forms of energy such as respiratory problems from combusting coal, denuding of the environment from collecting and burning wood and other health hazards associated with these forms of energy.

Few would disagree that one of the most significant differences between the developing nations of the world and those in which people enjoy healthy, productive lives is the establishment and widespread use of effective electric power systems. In South Africa various programmes have been implemented over the years to provide more households with electricity. An overview of the evolution of electrification in South Africa is shown in Figure 1-1.

Small scale hydropower used to play a very important role in the provision of energy to urban and rural areas of South Africa. In South Africa, the concept of generating electricity using water turbines was first suggested in 1879 for lighting purposes in Cape Town (Barta, 2002) and Pretoria by using small scale hydropower schemes. The national electricity grid however, expanded and offered cheap, coal generated electricity and a large number of hydropower systems were decommissioned. The South African Renewable Energy Database (Muller, 1999), developed by the CSIR, did investigate the available renewable energy resources in the country, including the potential for hydropower with the results graphically depicted in Figure 1-2.

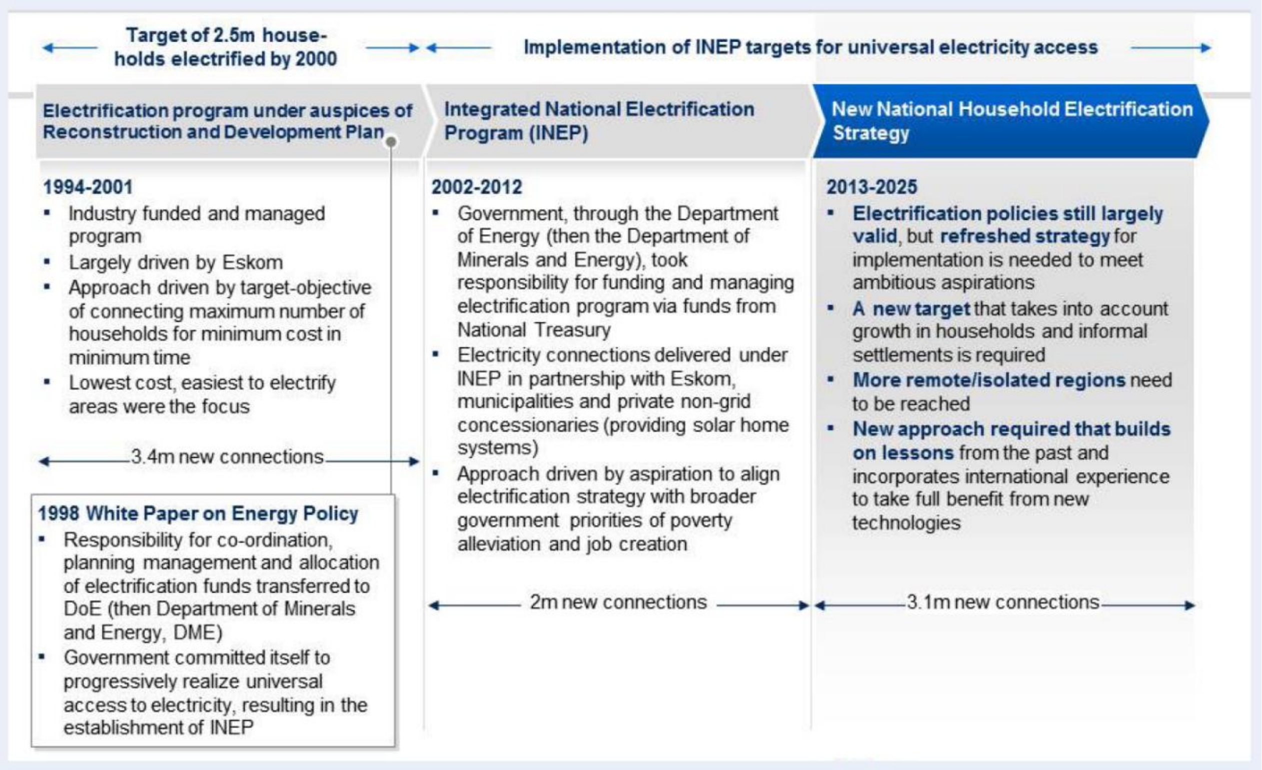


Figure 1-1 - Evolution of electrification in South Africa (IFC, 2013)

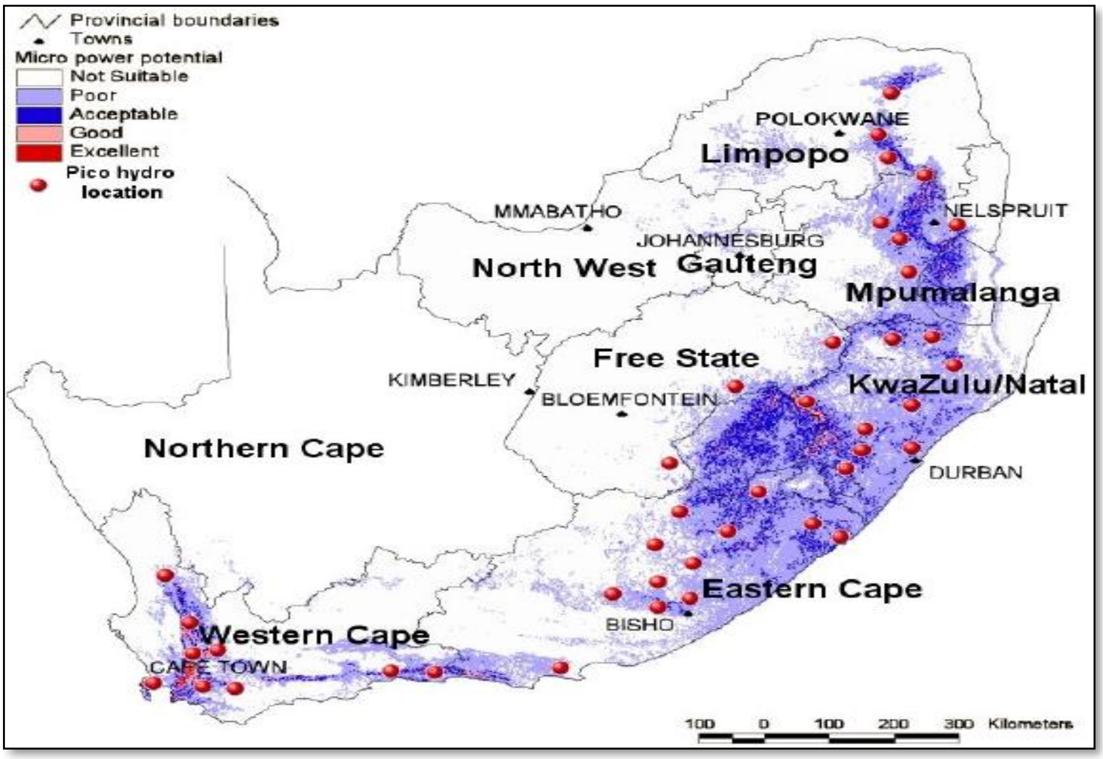


Figure 1-2 - Potential for small hydropower in South Africa (Muller, 1999)

Hydropower has since evolved and has several diverse applications. Today, small hydropower projects are the most commonly used option to supply electricity to isolated or rural communities throughout the world including countries such as Nepal, India, Peru and China.

An 'African Hydropower Database', with a section focusing on South African hydropower installations has been developed by Jonker Klunne (2015). Figure 1-3 was retrieved from the database and shows all planned, existing and decommissioned sites in the country, as well as various potential sites.

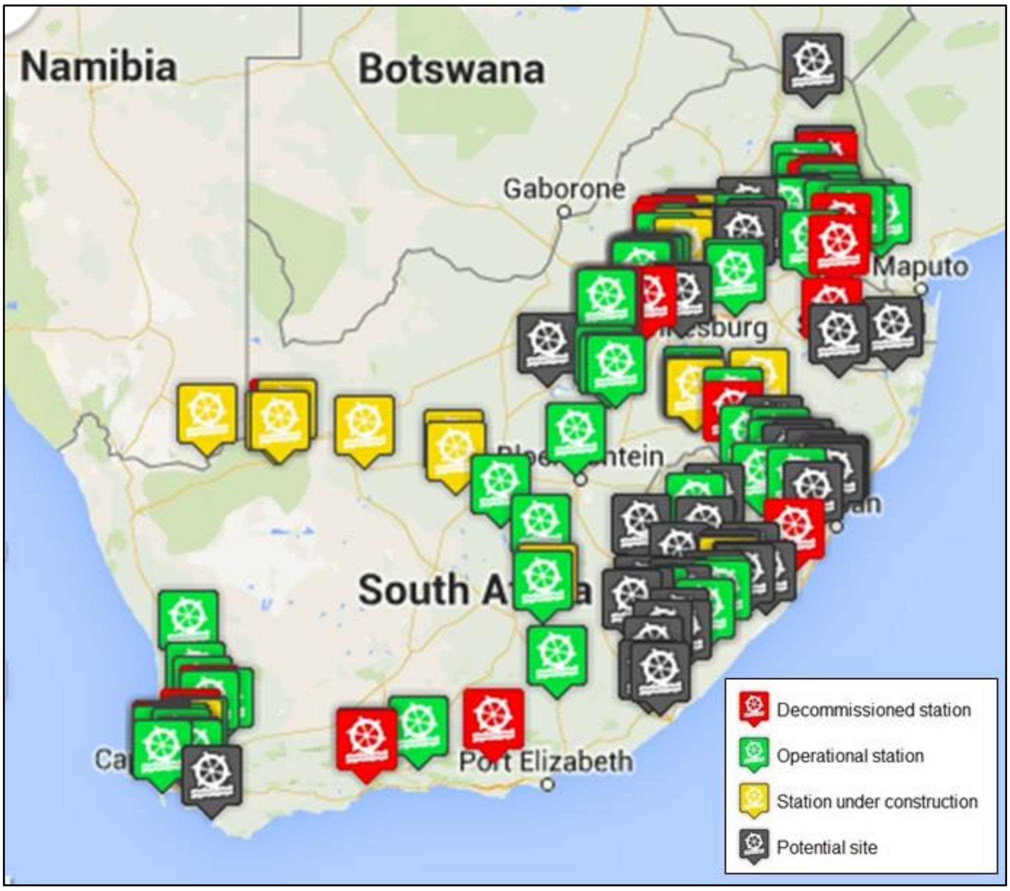


Figure 1-3 - South African map indicating existing and potential hydropower sites (Jonker Klunne, 2015)

Hydropower is not only a renewable source of energy, but it is non-polluting. A high efficiency of energy conversion means that small- scale hydropower plants produce about 60-80 % of the total energy consumed into power output. Therefore, small-scale hydropower would be a suitable option to generate electricity in rural areas. But, the uncertainty of the feasibility of such plants in comparison to alternative or existing energy resources has played a major role in the choice of the most applicable solution. Also, the legislation and policies in place with respect to renewable energy still seem to have considered small-scale hydropower as a less favourable option in South Africa.

Furthermore, water-scarcity in South Africa has threatened the viability of hydropower as a renewable source of energy. Even so, only a fraction of the potential available for hydropower has been exploited and the lack of explicit models on the sustainable generation and supply of energy using small-scale hydropower for South Africa challenges the criteria for selection. There is also a general lack of awareness of the prospects small-scale hydropower offers amongst local stakeholders. Small hydropower can play a critical role in providing energy access to remote areas in South Africa as stand-alone isolated mini-grids (Van Dijk, Van Vuuren, Bhagwan and Loots 2014)

1.2 HYPOTHESIS

It is hypothesized that it is technically possible to provide small-scale hydropower installations for rural electrification in South Africa, and that for specific configurations of small-scale hydropower (SSHP) penstock diameter, penstock length and transmission line lengths, SSHP installations are more feasible for rural electrification than local or national electricity grid extension.

1.3 OBJECTIVES OF STUDY

The objective of the study was to identify potential sites for the development of feasible small-scale hydropower plants within the OR Tambo District Municipality (DM) in the Eastern Cape, and the uMzinyathi District Municipality (DM) in Kwa-Zulu Natal, South Africa. The objective includes designing and financially evaluating small-scale hydropower plants for several similarly identified potential sites and incorporating said designs and financial evaluations into a feasibility study to develop a model for evaluating technically possible small-scale hydropower installations in South Africa.

1.4 SCOPE OF THE STUDY

The study entailed the identification and development of potential sites for feasible small-scale hydropower plants within the OR Tambo DM in the Eastern Cape, and the uMzinyathi DM in Kwa-Zulu Natal, South Africa. The study focussed on plants with a generating capacity of less than 100 kW, to serve rural communities which were previously not connected to the local or national electricity grid due to their remoteness. The scope of the study involved designing and developing potential sites within the South African legal and regulatory framework and economic situation, financially evaluating such designs in a feasibility study and developing a model for feasible small-scale hydropower plants in South Africa. In short the scope of the study can be summarised with the following five (5) points:

- Identifying potential sites within the OR Tambo and uMzinyathi DM's
- Designing and developing several similarly identified potential sites
- Financially evaluating designs in a feasibility study
- Developing a feasibility model and matrix
- Developing an implementation model

1.5 METHODOLOGY

STEP 1: Potential sites for small-scale hydropower were identified within the OR Tambo and uMzinyathi DM's. Potential sites with an energy generating potential of less than 100 kW were identified by evaluating different sections of rivers within the OR Tambo and uMzinyathi DM's service areas with regard to available head and flow. Available head was calculated and evaluated by means of the Google Earth Application's elevation tool as well as physical altimeter readings on site. Available flow was calculated by statistical means using historic flow data records accessible from the Department of Water and Sanitation (DWS) hydrology database.

STEP 2: Site Selection Criteria was set up based on the technical possibility, locality, demographics, existing electricity infrastructure, environmental and socio-economic aspects of potential SSHP sites. Site Selection Criteria was for a pre-feasibility study to identify feasible potential SSHP sites.

STEP 3: Several similar sites were identified and visited. Potential small-scale hydropower plants for several visited sites were designed with the objective of physically developing six (6) of the sites. Designed sites were analysed on financially with regards to cost, including initial capital and construction cost, life-cycle and maintenance cost, and with regards to benefits, i.e. saving on electricity costs or providing otherwise lacking electricity to rural communities.

STEP 4: From the financial evaluations of the sites, a feasibility study was conducted on the implementation of small-scale hydropower for the electrification of remote rural communities in lieu of supplying new infrastructure to connect said communities to the local and national electricity grid.

STEP 5: By standardizing the turbine and turbine room to a containerised unit, and by varying penstock lengths and transmission line lengths, a feasibility matrix for different specific values of power generated was developed for small-scale hydropower within the South African framework.

1.6 ORGANIZATION OF THE REPORT

The report consists of the following chapters and appendices:

- Chapter 1 presents an introduction to the report. It provides background information to the purpose, the hypothesis, scope and methodology for the study.
- Chapter 2 serves as a literature review focussing on the various technicalities relating to the generation of power by means of hydro turbines. These aspects include the theory of hydropower, different hydropower options, the civil, mechanical, electrical and electronic equipment that is contained within a hydropower design and installation. The literature review continues with an overview of various different international examples of small-scale

hydropower as well as potential site selection and evaluation techniques and software. In close the literature review discuses the feasibility of small-scale hydropower from previous studies and policies/licensing and regulatory aspects of small scale hydropower.

- Chapter 3 explains the potential site selection process undertaken, the potential sites visited and their power generating potential, as well as the final sites selected for design and development.
- Chapter 4 details the designs of the selected potential small-scale hydropower sites, including the intake structure, penstock, power house and the tailrace.
- Chapter 5 contains a description and results of the financial analysis and life-cycle cost analysis of the various designed small-scale hydropower plants, including cost analysis, financial payback period and SSHP benefit analysis.
- Chapter 6 entails the feasibility study undertaken on the different designs for the identified small-scale hydropower plants within the OR Tambo and uMzinyathi DM's.
- Chapter 7 contains a description and the results of the feasibility analysis development design charts for the evaluation of new potential sites for small-scale hydropower within the South African framework. This includes various aspects such as turbine cost, length of penstock, transmission lines and mini-grid, legislative and regulatory costs and the number of households provided with a specific amount of electricity per annum.
- Chapter 8 serves as a conclusion to the study, including recommendations for the development of small-scale hydropower plants and general recommendations for further research on the topic.
- Chapter 9 lists the references used in the study.

2 LITERATURE REVIEW

2.1 THEORY OF HYDROPOWER

Hydropower, hydraulic power or water power is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes (Carrasco, 2011)

In theory hydropower works much like any ordinary coal fired power station where a power source is used to turn a propeller-like piece called a turbine, which then turns a metal shaft in an electric generator, producing electricity. In a coal fired power station steam is used to turn the turbine blades, whereas in a hydropower setup falling or flowing water is used to turn the turbine. The different components involved in a conventional hydropower setup is discussed and explained in more detail in section 2.2.3. Figure 2-1 illustrates the basic or a simplified theory of the components of a conventional hydropower setup.

The main difference between these two methods of electricity generation is that unlike with the coal fired power station where fossil fuels are consumed in the process with no means of replenishing it. With hydropower generation the natural resource, water, is not consumed thus making a source of renewable energy. The advantages of hydropower as a renewable energy source as well as other advantages of the technology is discussed in section 2.1.2.

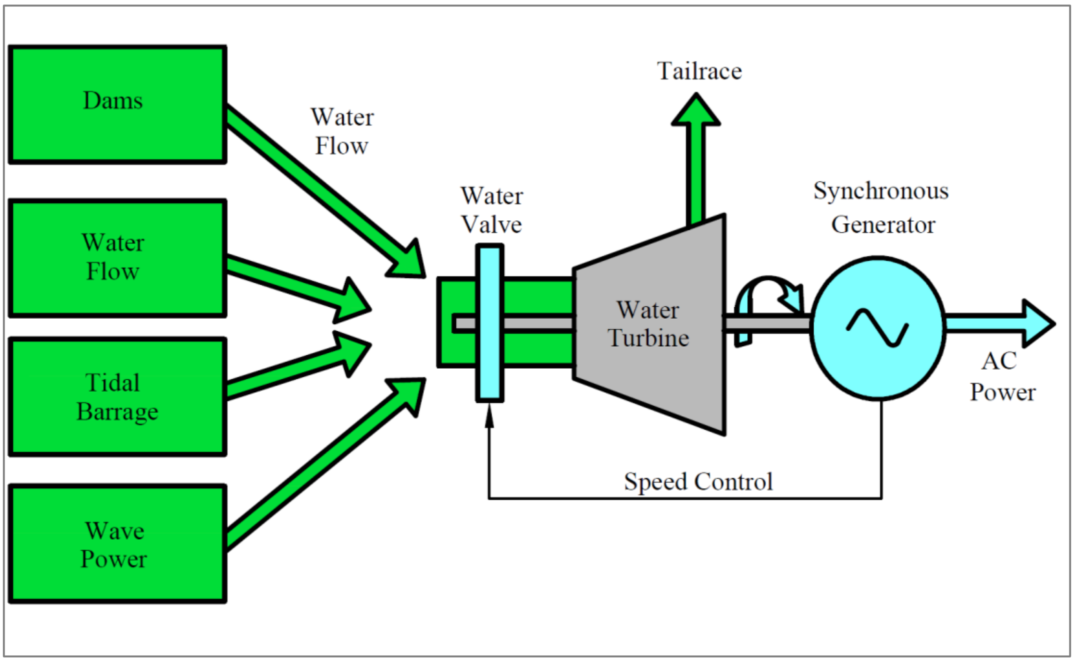


Figure 2-1 - Basic Hydropower Setup Schematic

As stated above the basic theory of hydropower is that hydro turbines converts the water pressure of the falling or flowing water into mechanical shaft rotation from the turbine to power an electric generator or some other form of electricity generating machinery. The basic mathematical relationship is that the potential power output is directly proportional to the flow through the turbine and the pressure head available. This can be stated as follows:

$$P = \eta \rho g Q H$$

Equation 2-1

Where:

P = Mechanical power output (W)

η = Hydraulic efficiency of the turbine (%)

ρ = Density of water (kg/m^3)

g = Gravitational acceleration (9.81 m/s^2)

Q = Flow rate through the turbine (m^3/s)

H = Effective pressure head across the turbine (m)

For kinetic hydro turbines the energy available to capture at a site for power generation is a function of the stream power, which varies with the cube of the velocity. The power flux or power per unit time and area, of a current or stream is given by:

$$P = \eta \frac{1}{2} \rho V^3$$

Equation 2-2

Where:

P = Power flux (kW/m^2)

η = Hydraulic efficiency of the turbine (%)

ρ = Density of water (kg/m^3)

V = current/stream velocity (m/s)

Hydroelectric facilities generate 16% of the electric power worldwide. There are however some more developed countries which have a higher utilization of hydroelectric power. Norway gets 99% of its electric power from water, Brazil 84% and Canada 58%. Germany only generates 4% of its total electric energy generation from water. This 4% of Germany's electricity provided by hydroelectric power, comes from about 120 large (>1 MW) systems, producing more than 3800 MW. Apart from the large systems there are almost 5000 small (<1 MW) hydropower plants active in Germany (Wagner and Mathur, 2011). The focus of this study will be primarily on small hydropower plants.

2.1.1 Hydropower Options

2.1.1.1 Conventional Types of Hydropower

2.1.1.1.1 Storage Schemes

The most common or most conventional type of hydropower system is a storage scheme, also referred to as a hydroelectric dam (Figure 2-2). It is essentially a mechanical gateway that can control how often and how much water can be released, providing power when needed, for base load, or to meet a fluctuating demand or a peak load.

Water is collected in a reservoir and when power is needed released through a spillway gate through the penstock and passed through the turbine and generator to produce electricity. The amount of power that can be produced is directly proportion to the head and flow available (Equation 2-1), put simply the higher the dam is and the higher the rate of release of water, the more power you can generate.

Advantages of a hydroelectric dam is that it is a source of clean renewable energy. In conventional storage schemes or hydroelectric dams the body of water can also be used for alternative purposes such as agricultural irrigation or recreational purposes such as water sports, and in some cases the structures itself become tourist attractions. Hydroelectric power stations that uses dams however has the disadvantage that large areas of land are submerged. This loss of land and damage to the ecosystem is a disadvantage. The availability of this hydropower is also restricted to hilly or foothill areas due to the availability of flow and head required. This, often remote areas, require additional investment in terms of installing long transmission lines which also inevitably leads to transmission losses (Wagner and Mathur, 2011).

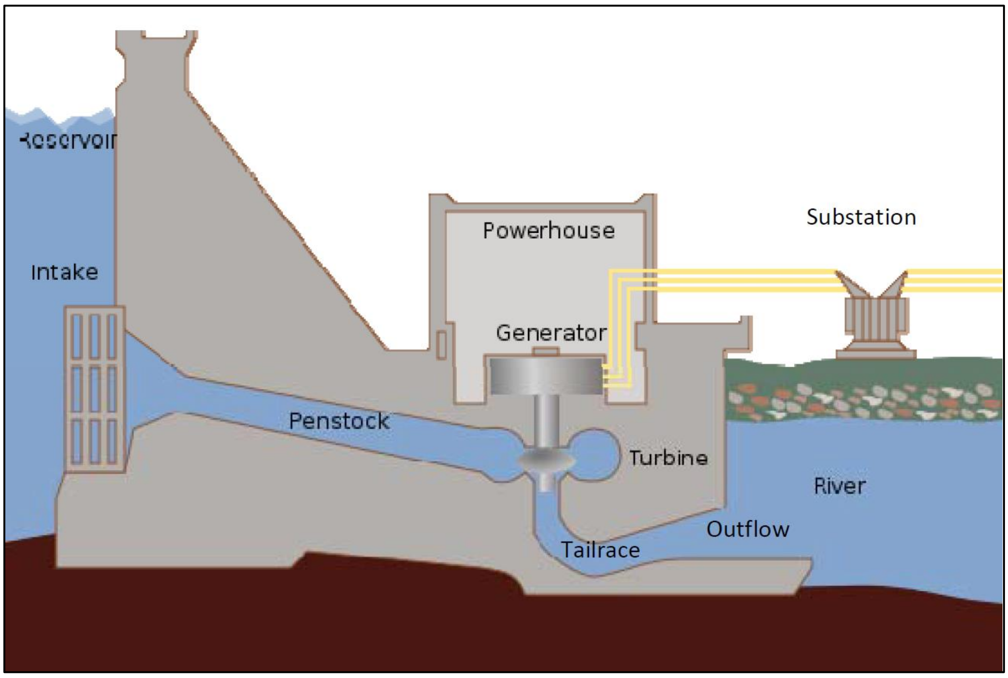


Figure 2-2 – Storage Scheme Hydropower Plant Schematic (US EPA, 2013)

Due to the significantly large nature of a conventional storage scheme hydropower plant, and the construction costs involved in the execution of such a project, it is not deemed feasible and is not considered for purpose of this project and for rural electrification in South Africa. There are however several larger hydropower schemes on existing storage schemes in South Africa, with several more having potential to be developed as hydropower schemes. It is important to note that there are existing storage schemes and infrastructure that can be utilized in the development of hydropower but has not yet been exploited.

2.1.1.1.2 Run-of-rivers schemes

Run-of-river hydroelectricity is a type of hydroelectric generation whereby the natural flow and elevation drop of a river are used to generate electricity (Carrasco, 2011). In such schemes some or most of the rivers flow is diverted through a pipe or tunnel to electricity-generating turbines. In most cases a small dam or weir is needed upstream of the penstock, to ensure enough water is able to be fed through the penstock to the lower-elevation turbines. A run-of-river system can also be described as a dam with a short penstock which directs the water to the turbines, using the natural flow of the river with very little alteration to the terrain stream channel at the site and little impoundment of the water.

Run-of-river projects are dramatically different in design and appearance from conventional storage scheme projects. In traditional storage schemes or hydro dams large quantities of water are stored in reservoirs/dam, in most cases necessitating the flooding of large tracts of land, which might often include rural villages. The benefit of run-off-rivers schemes is that large storage and flooding of large tracts of land is not necessary. For this reason the run-off-rivers schemes are seen to be more environmentally-friendly. Figure 2-3 illustrates a conventional run-off-river hydropower plant. The disadvantage of run-of-river schemes is that it is highly dependent on the river run-off which might not always match the power demand.

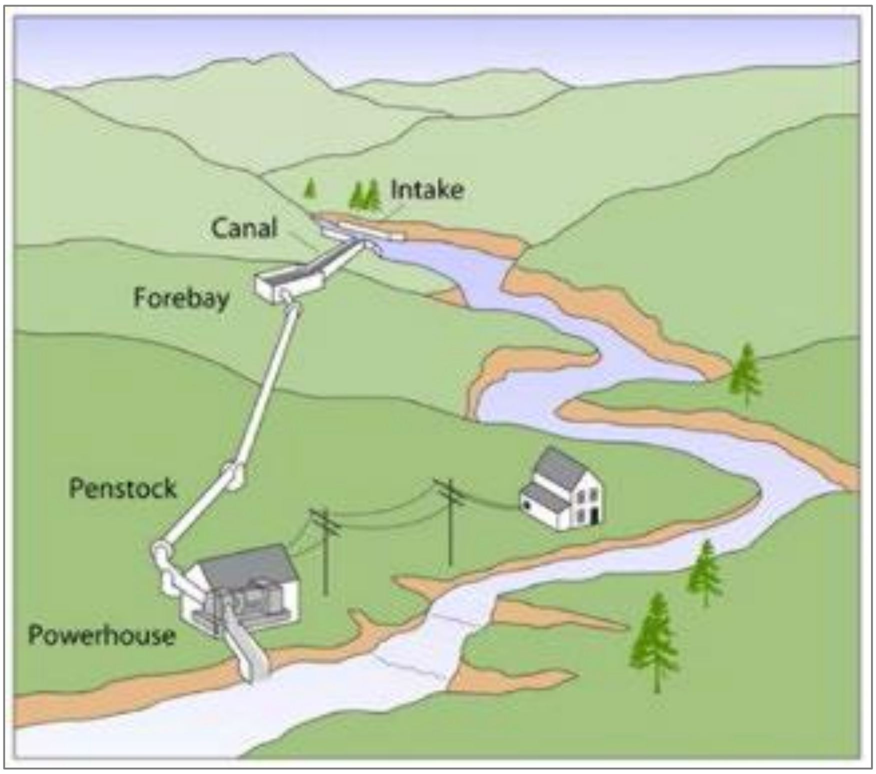


Figure 2-3 - Typical Run-off-river scheme (Wade, Wade and Milton, 2015)

2.1.1.1.3 Pumped storage schemes

This method of hydroelectric power generation stores energy in the form of water. Water is pumped from a lower reservoir to a higher reservoir using low-cost off-peak electric power to run the pumps during periods of low energy demand such as night times. The water is then run down through the turbines to produce power to meet peak demands. Although more energy is used in pumping the water to the higher reservoir than is gained from the hydropower generation through the turbines, making the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest.

However, some recent projects have utilised hybrid systems where pumped storage is combined with a renewable energy, like wind power, with high generation randomisation (Beuno and Carta, 2006).

A pumped storage system may be economical because it flattens out load variations on the power grid, permitting thermal power stations such as coal-fired plants and nuclear power plants and renewable energy power plants that provide base-load electricity to continue operating at peak efficiency (Base load power plants), while reducing the need for "peaking" power plants that use costly fuels. However, capital costs for purpose-built hydro-storage are high (Carrasco, 2011).

A major advantage of a pumped hydropower scheme is that the system can help control network frequency and provide reserve generation during peak times. Coal fired power plants and other thermal plants cannot respond to changes in electrical demand as quickly as hydroelectric plants can. Thus pumped storage schemes can help prevent frequency and voltage instability. An example of a pumped storage scheme in South Africa is the Ingula Pumped Storage Scheme (Figure 2-4). Upon completion it will be Eskom's third pumped storage scheme with an output of 1 332 MW, mostly used during peak-demand periods. The station will be fully operational at the end of 2015 (Eskom, 2015).

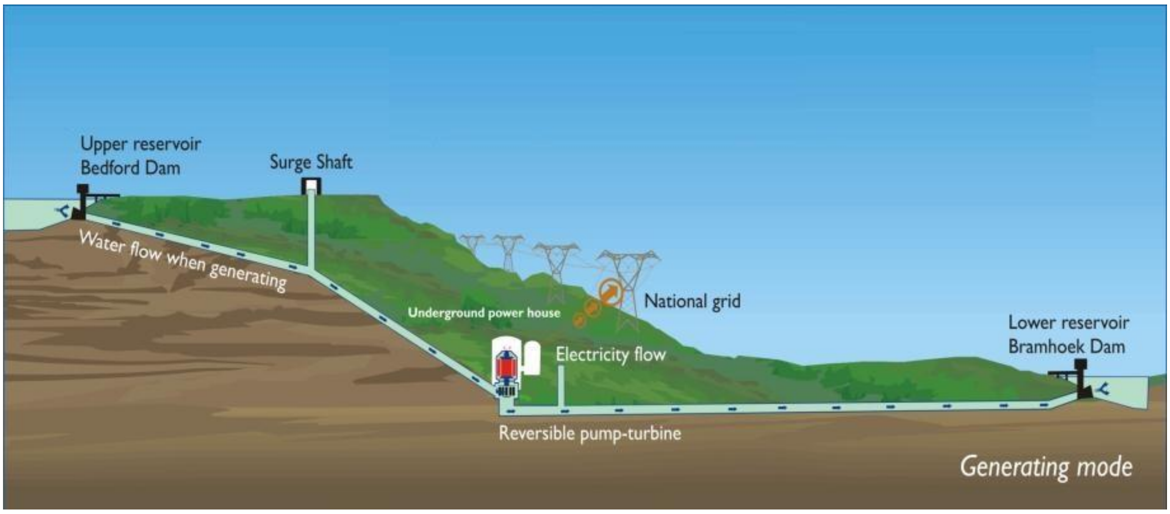


Figure 2-4 - Ingula Pumped Storage Scheme (Eskom, 2015)

2.1.1.2 Unconventional Hydropower Opportunities

Apart from the conventional hydropower plants there are several other hydropower opportunities, discussed below:

- **Hydropower from the flow in irrigation canals** – These schemes work much the same as river-run-off schemes with the difference being that water from the irrigation canal is used to operate the turbine and not water from a natural river or stream. Water can either be diverted or turbines place in the main stream of the canal (Figure 2-5). It is important to note that in these schemes the main purpose of the canal remains irrigation supply and water transfer and the hydropower development should not inhibit the main purpose of the canal.

Figure 2-5 - Hydrovolts turbine installed in the Roza Canal in Oregon (Colorado Energy Office, 2007)

- **Hydropower potential at flow gauging weirs or diversion weirs** – Weirs are essentially small dams or reservoirs. A level difference exists at weirs, which lends an available head, which along with the flow over the weir can be used to operate a turbine and generate electricity. Since hydropower generation relies both on available head and flow, not all weirs will have equal power generating potential, and sites needs to be evaluated on the frequency of certain flow rates.
- **Hydropower from outflow of wastewater treatment plants (WWTP) -** Wastewater outfalls may provide hydroelectric power opportunities if a significant elevation drop is available. Large municipalities, such as City of Tshwane, with large wastewater treatment plants may have the necessary available head and flow rate to produce a significant amount of power. Hydropower plants at a WWTP has the options of being constructed either upstream or downstream of the plant, with the latter having less civil works (trash screens, silt traps etc.) but the disadvantage of less available head for electric power generation.
- **Utilizing the large industrial outflows for energy generation –** The potential for hydropower generation at these industries works on the same principle as the WWTP. A lot of industries like breweries, universities and even ESKOM, uses great volumes of water each and every day. These high flows along with potential available head can be used to generate hydroelectric power.
- **Conduit Hydropower -** Conduit hydropower uses a conduit (pipe or canal) that exists for another purpose, such as municipal water supply or irrigation (Van Vuuren, Van Dijk, Loots, Barta and Scharfetter, 2014). Excess pressure in the pipeline that otherwise would have to be mechanically reduced by pressure reduction valves (PRV) is utilised to generate electrical

power. Bloemwater in Bloemfontein, South Africa, has installed a 96 kW crossflow (Banki) turbine at the outlet of the Caledon-Bloemfontein pipeline to Brandkop reservoir which meets the electricity demands of Bloemwater's head office situated next to the Brandkop reservoir (Van Dijk, Kgwale, Bhagwan and Loots, 2015).

- **Ocean power plants**

  The following different options were identified (Wagner and Mathur, 2011).
  - Tidal power plant
  - Wave power plant
  - Oceanic heat power plant
  - Current power plant
  - Osmotic power plant

With the exception of tidal power plants, and some pilot plants based on some of the other possibilities, the generation of electricity in ocean power plants is still in a stage of technical development (Wagner and Mathur, 2011).

2.1.2 Advantages of Hydropower

Other than the advantages of hydropower discussed with the different hydropower options, hydropower has the following advantages over other forms of energy production in terms of economic, social, and environmental impacts:

- Hydropower is a form of clean renewable and sustainable energy as it makes use of the energy in water due to flow and available head, without actually consuming the water itself or emitting any atmospheric pollutants such as carbon dioxide, sulphurous oxides, nitrous oxides or particulates such as ash (Frey and Linke, 2002).

  Nowadays hydropower electricity in the European Union, both large and small scale represents according to the White Paper (European Commission, 1997), 13% of the total electricity generated, so reducing the CO_2 emissions by more than 67 million tons a year (Penche, 1998).
- Hydropower schemes often have very long operational lifetimes (50 years or more) and high efficiency levels (70% to 90%) (BHA, 2005). A hydropower plant in Darjeeling, India, was installed in 1897 and is still in operation (Wagner and Mathur, 2011).
- Operating costs per annum can be as low as 1% of the initial investment costs (Oud, 2002). Cost of generation of hydropower plants is virtually free from inflationary effects after the initial installation (Wagner and Mathur, 2011).

- Hydropower schemes often have more than one purpose. Hydropower through water storage can help with flood control and supply water for irrigation or consumption, and dams constructed for hydropower can also be used for recreational purposes (Frey and Linke, 2002). Storage based hydro schemes often provide benefits in addition to power generation, such as irrigation, flood control, drinking water supply, navigation, recreation, tourism etc. (Wagner and Mathur, 2011).
- The location of most the small hydropower projects in remote regions may lead to the development of rural areas. This advantage is very important in a developing country such as South Africa. It is however important to note that this development does not encroach on the cultural heritage of specific sites. A balance between the upliftment of the community and the perseverance of the traditional ways of life must be found.

2.2 HYDROPOWER DESIGN

2.2.1 Site Selection

Identifying potential small scale hydropower sites involves both a technical and feasibility component. A specific site might have tremendous technical potential for hydropower, but might be unfeasible to develop a small scale rural electrification facility. All sites must be technically feasible and should first be evaluated on this grounds.

Since there is control over the hydraulic efficiency of the turbine, defined by the system's design, and since the density of water and gravitational acceleration is relatively constant, the only two variables which we cannot control at any specific site is the flow rate and pressure head across the turbine. Potential sites for small scale hydropower generation therefor have to be identified and evaluated in terms of there available flow and head at any specific site.

The use of Geographic Information System (GIS) as assessment tool for hydropower has led to a leap forward in the strengthening of the evaluation of the power potential of water streams (Punys, Dumbraukas, Kvaraciejus and Vyciene, 2011). However for a reliable assessment of real SHP site's feasibility, site specific "on the ground" surveying is needed. But the assessment can be greatly facilitated using GIS techniques that involve the spatial variability of catchment characteristics (Punys et al., 2011).

2.2.2 Software – Objectives and types of software

There exists comercial software assessment tools with computing algorithms for SHP site development, from countries in which hydropower is highly developed. The main aim of these software tools is to find a rapid and reasonably accurate means of predicting the energy output of a particular potential hydropower scheme within a specific river or stream (Punys et al., 2011). As discussed earlier this is done by evaluating a specific site in terms of the available flow and head.

The software tools available for evaluating or identifying potential small-scale hydropower sites can be grouped into two (2) categories, conventional software tools and GIS-based assessment tools. The next two (2) sections discusses and describes internationally available examples of different software tools available to assist in the identification and assessment of small-scale hydropower projects.

2.2.2.1 Conventional software tools

2.2.2.1.1 HydroHELP

The HydroHELP series of programs has been developed to allow engineers to obtain an initial assessment of a hydro-electric site, with a minimum of site data (IEA, 2008). The programs do not include any hydrologic or financial analysis.

There are presently 6 programs in the series, four for developments with surface power plants and two for underground plants as shown in Table 2-1.

Table 2-1 - HydroHELP series of programs (IEA, 2008)

Program No.	Program	Development	Application
1	HydroHELP 1.6	Surface power plants	Turbine selection
2	HydroHELP 2.6		Franci turbine powered developments
3	HydroHELP 3.6		Impulse turbine powered developments
4	HydroHELP 4.6		Kaplan turbine powered developments
5	HydroHELP 5.4	Underground plants	Pump as turbine (PAT) powered developments
6	HydroHELP 6.4		Francis turbine powered developments

The assessment by the user for surface power plants starts in program no.1, which determines the most suitable turbine for the flow, head and number of units desired in the power plant. The user then proceeds to the next program, either program 2,3 or 4, based on the type of unit selected in the first program. Typical input data would be length of pipeline, whether buried or above ground, length of tunnel, crest length of dam, headwater and tailwater elevations. The programs calculate all basic structure dimensions, from wave heights and the corresponding average rip-rap size on the dam, to the capacity of the powerhouse crane, governor open-close times, and provide a chart on suitability for isolated operation. Programs 5 and 6 are for underground plants and are similar to programs 2, 3 and 4 (IEA, 2008).

The HydroHELP tool is an assessment tool and identification on the different sites to assess must still be done by different means such as physical surveying or GIS-based programs. The programs have been successfully tested on several projects of varying capacity and head, from small hydro sites, to very large mega-projects (IEA, 2008). Figure 2-6 shows an example of the HydroHELP interface.

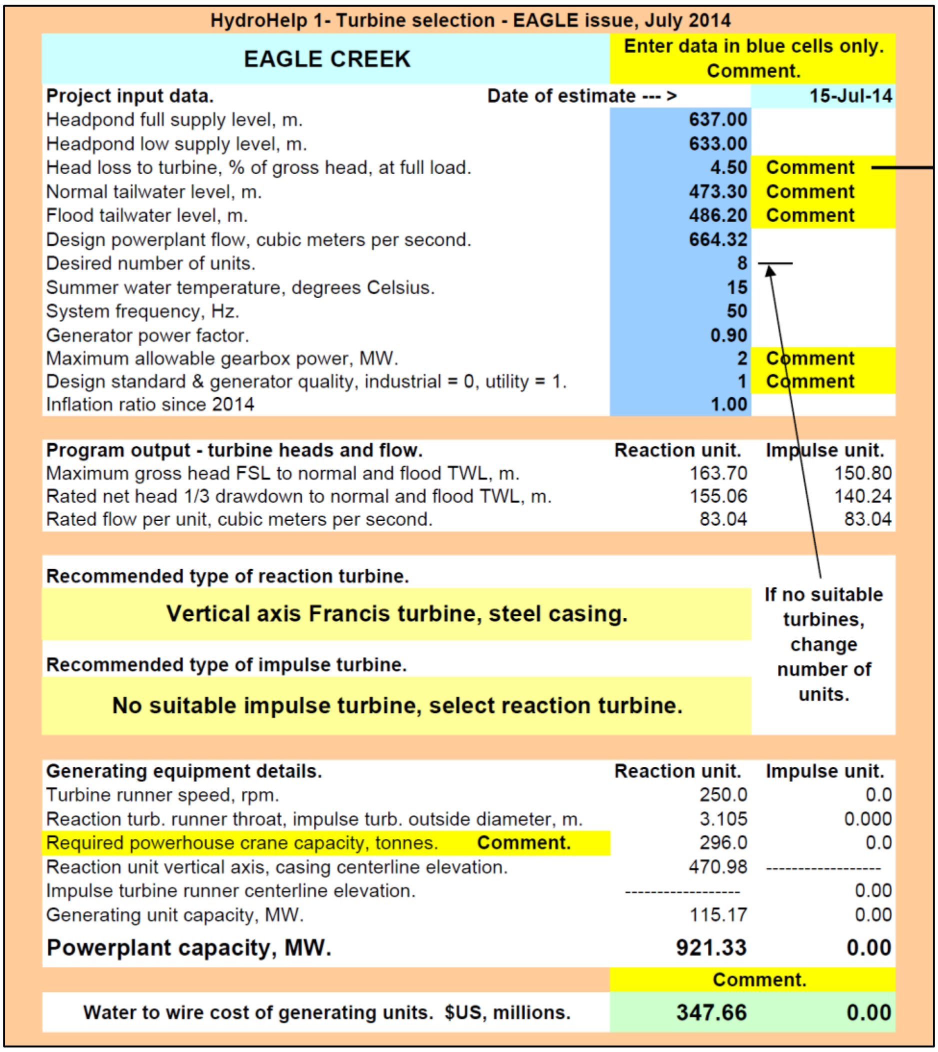
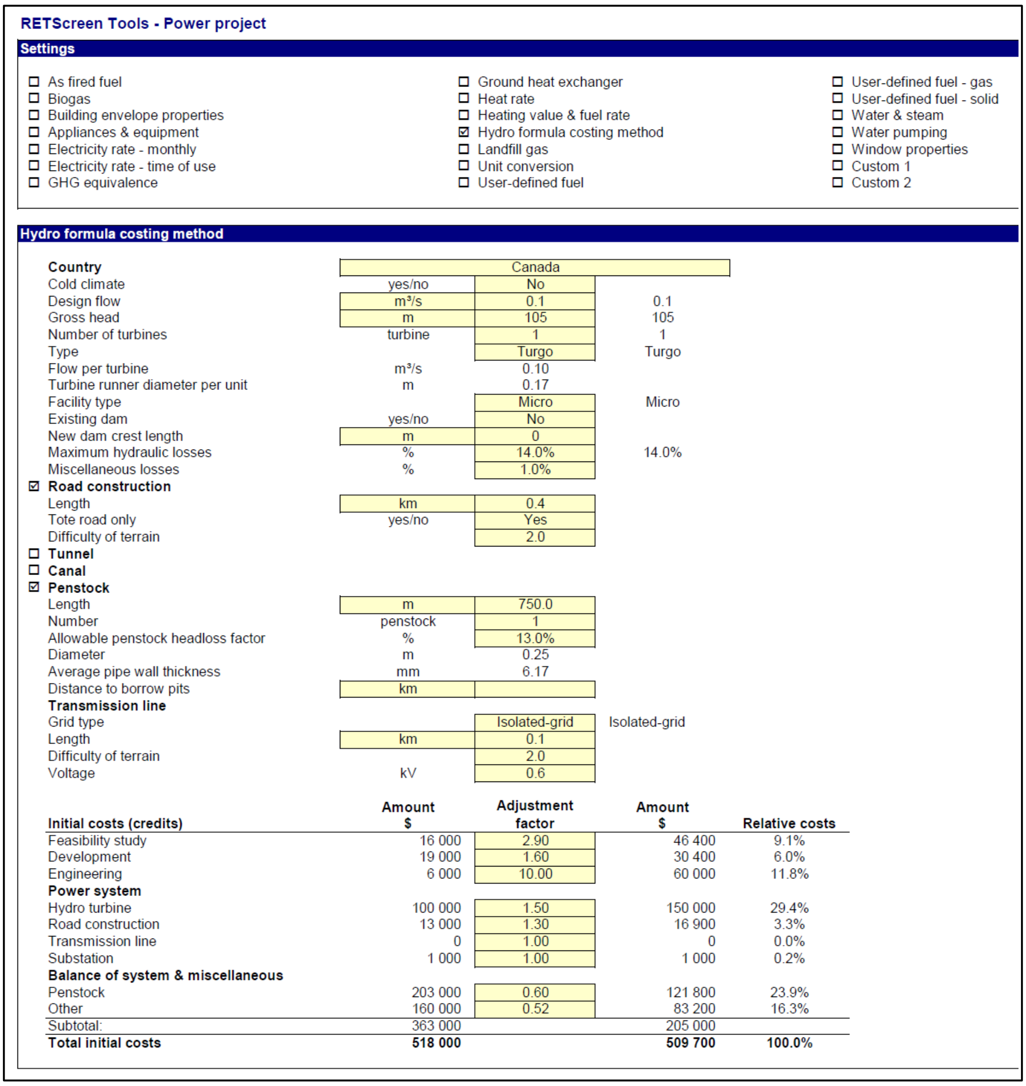


Figure 2-6 - HydroHELP 1.6 Interface extract example

2.2.2.1.2 RETScreen

The RETScreen International Clean Energy Project Analysis Software can be used to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs) (IEA, 2008). The software is capable of evaluating central-grid, isolated-grid and off-grid hydro projects, ranging in size from multi-turbine large systems to single-turbine micro hydro systems. It is an Excel-based clean energy project analysis software tool that helps to determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects. The RETScreen tool is an assessment tool only and identification of potential sites to assess must still be done by different means such as physical surveying or GIS-based programs. Figure 2-7 shows an example of the RETScreen interface.



RETScreen Tools - Power project

Settings

☐ As fired fuel	☐ Ground heat exchanger	☐ User-defined fuel - gas
☐ Biogas	☐ Heat rate	☐ User-defined fuel - solid
☐ Building envelope properties	☐ Heating value & fuel rate	☐ Water & steam
☐ Appliances & equipment	☑ Hydro formula costing method	☐ Water pumping
☐ Electricity rate - monthly	☐ Landfill gas	☐ Window properties
☐ Electricity rate - time of use	☐ Unit conversion	☐ Custom 1
☐ GHG equivalence	☐ User-defined fuel	☐ Custom 2

Hydro formula costing method

Country	Canada		
Cold climate	yes/no	No	
Design flow	m³/s	0.1	0.1
Gross head	m	105	105
Number of turbines	turbine	1	1
Type		Turgo	Turgo
Flow per turbine	m³/s	0.10	
Turbine runner diameter per unit	m	0.17	
Facility type		Micro	Micro
Existing dam	yes/no	No	
New dam crest length	m	0	
Maximum hydraulic losses	%	14.0%	14.0%
Miscellaneous losses	%	1.0%	
☑ **Road construction**			
Length	km	0.4	
Tote road only	yes/no	Yes	
Difficulty of terrain		2.0	
☐ **Tunnel**			
☐ **Canal**			
☑ **Penstock**			
Length	m	750.0	
Number	penstock	1	
Allowable penstock headloss factor	%	13.0%	
Diameter	m	0.25	
Average pipe wall thickness	mm	6.17	
Distance to borrow pits	km		
Transmission line			
Grid type		Isolated-grid	Isolated-grid
Length	km	0.1	
Difficulty of terrain		2.0	
Voltage	kV	0.6	

Initial costs (credits)	**Amount $**	**Adjustment factor**	**Amount $**	**Relative costs**
Feasibility study	16 000	2.90	46 400	9.1%
Development	19 000	1.60	30 400	6.0%
Engineering	6 000	10.00	60 000	11.8%
Power system				
Hydro turbine	100 000	1.50	150 000	29.4%
Road construction	13 000	1.30	16 900	3.3%
Transmission line	0	1.00	0	0.0%
Substation	1 000	1.00	1 000	0.2%
Balance of system & miscellaneous				
Penstock	203 000	0.60	121 800	23.9%
Other	160 000	0.52	83 200	16.3%
Subtotal:	363 000		205 000	
Total initial costs	**518 000**		**509 700**	**100.0%**

Figure 2-7 - RETScreen interface extract example

2.2.2.1.3 PEACH

The peach assessment software tool is not freeware, but for sale by the French consulting firm ISL of Paris and Montpelier.

The user is led through six distinct steps which take the user through all the necessary procedures in designing, building and commissioning a small hydro scheme and analysing the financial returns expected. The six (6) steps are as follows:

1. Site Data Definition,
2. Project Creation,
3. Project Design,
4. Plant Design,
5. Economic and Financial Analysis,
6. Report.

The output characteristics of the software is Power curve and main results, Construction costs, Bill of quantities, Cost flows and Yearly cash flow, Economic analysis with graphic results as well as Financial analysis with graphic results.

2.2.2.1.4 Integrated method for power analysis (IMP)

The integrated method for power analysis (IMP) is a convenient tool for evaluating small-scale hydroelectric power sites (Punys et al., 2011). The tool can be used for evaluating all aspects of an ungauged hydro site including a power study, development of a flood frequency curve and fish habitat analysis. Figure 2-8 shows an example of the IMP interface.

The IMP consists of the following features (IEA, 2008):

- A Flood Frequency Analysis Model that uses topographic information specific to the site to generate the flood frequency curve.
- A Watershed Model that will generate a continuous hourly or daily time series of streamflow for an ungauged site based on daily precipitation, maximum and minimum temperature and a description of the basin.
- A Hydroelectric Power Simulation Model that determines the daily energy output for a run-of-river or reservoir storage site based on selected generation facilities and the hydrologic daily time series generated by the Watershed Model. An optimization routine performs a sensitivity analysis on the results of a simulation and provides an estimate of the optimal installed capacity from economic data.
- A Fish Habitat Analysis Model to help determine the weighted usable area (WUA) of one or more types of fish in a particular stream cross-section at a particular flow. Weighed usable area is the area available in a stream for fish to inhabit, and is a function of discharge and fish preference.

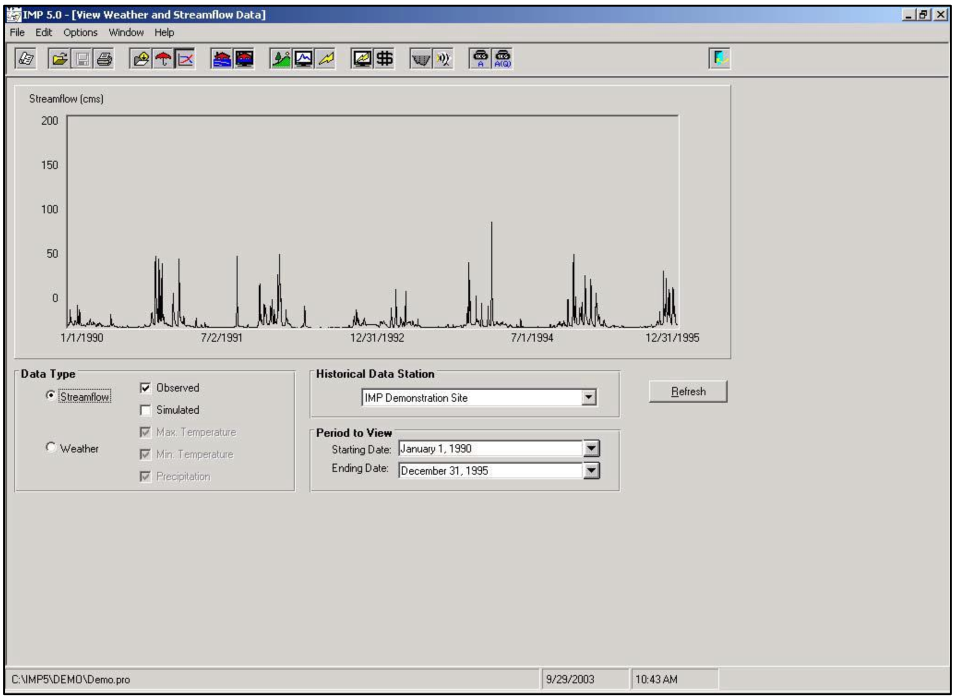


Figure 2-8 - IMP interface extract example - Weather and Streamflow Data Screen - Streamflow (Natural Resources Canada, 2004)

2.2.2.2 GIS-based assessment tools

A geographic information system (GIS) in a general sense describes any information that integrates, stores, edits and displays geographic information. The first known use of the term "geographic information system" was by Roger Tomlinson in the year 1968 in his paper "A Geographic Information System for Regional Planning" (ESRI, 2012).

GIS is a broad term that can refer to a number of different technologies, processes, and methods. For the purposes of this study the focus is mainly on the GIS applications related to engineering and planning.

From all the various techniques and technologies of GIS the most important for the focus of this study is the data capturing and a spatial slope analysis.

There are numerous different data capture techniques, the following are some of the more common techniques:

- Data can be entered manually.
- Existing data printed on paper or PET film maps can be digitized or scanned to produce digital data.
- Survey data can be directly entered into a GIS from digital data collection systems on survey instruments.

- Remotely sensed data from camera, digital scanner or LIDAR sensors attached to aircraft and satellite platforms.
- Digital data from photo interpretation of aerial photographs (Google Earth).

Slope is defined as the steepness or gradient of a unit of terrain, usually measured as an angle in degrees or as a percentage for hydraulic and hydrological applications. Slopes in terrain analysis are derived from neighbourhood operations using elevation values of a cell's adjacent neighbours (Chang, 2008), i.e. the difference in elevation from two adjacent cells in a terrain model is used to calculate the slope. A terrain model of a stream or river system might consist out of cross-sections at different intervals down the reach of the system. The slope within a river system is of great use for identifying hydropower potential. A high slope value means a high elevation difference over a short length of river. This is both advantages on a technical as well as feasibility level. Technically a higher difference in elevation results in more head for power generation, and the steeper slope means a shorter penstock length which lends to a financially more feasible site.

The following paragraphs discuss two (2) comercially available GIS-based identification and assessment tools for small hydropower potential plants.

2.2.2.2.1 Virtual Hydropower Prospector

The Virtual Hydropower Prospector (VHP) is a web-based geographic information system (GIS) application for displaying U.S. water energy resource sites and feasible, potential hydropower projects on hydrologic region maps. The VHP application is designed to assist users in locating and assessing natural stream water energy resources in the United States. It was developed as part of the Small Hydropower Resource Assessment and Technology Development Project conducted at the Idaho National Laboratory (INL) in support of the U.S. Department of Energy Wind and Hydropower Technologies Program (IEA, 2008). The water energy resource sites displayed by this tool were identified and their gross potential power was estimated as described in Water Energy Resources of the United States with Emphasis on Low Head/Low Power Resources (U.S. Department of Energy, 2004).

The total potential power generated from a stream reach was calculated using the hydraulic head and estimated annual mean flow rates at the inlet and outlet of the reach (U.S. Department of Energy, 2004). The calculation of the annual mean flow rates was done with a method similar to the Rational Method (SANRAL, 2013), incorporating the area of the catchment, mean annual precipitation etc. The hydraulic head associated with each stream reach was obtained using the elevation data in the Elevation Derivatives for National Applications (EDNA) dataset. The EDNA dataset provides elevations for the upstream and downstream end of the reach, the difference in these elevations are the hydraulic head for the flow in the reach. Because of the method of calculating flow, Runoff from the local catchment within the different reaches adds hydraulic heads to the system reaching from the total reach hydraulic head to zero depending on where the runoff entered the stream (U.S. Department of Energy, 2004). To account for this, the following equation was used to calculate the power potential of the reach (U.S. Department of Energy, 2004):

$$P = 0.0847\left[Q_i \times H + \left(\frac{Q_0 - Q_i}{2}\right) \times H\right]$$

Equation 2-3

And, $H = z_i - z_0$

Equation 2-4

Where

P = power in kilowatts

Q_i = flow rate at the upstream end of the stream reach in cubic feet per second

Q_o = flow rate at the downstream end of the stream reach in cubic feet per second

H = hydraulic head in feet

z_i = elevation at the upstream end of the stream reach in feet

z_o = elevation at the downstream end of the stream reach in feet.

**US customary units are used in the formula as it is a method only applicable to the US, SI units must be applied in developing a similar method for the South Africa framework*

The VHP and its use is intended to provide the user with a broad overview of energy potential within a water resource within a specific area, in order to perform preliminary, development feasibility assessment of particular sites of interest. Actual on site measurements must be taken to verify information presented by VHP and assess true feasibility of different sites under investigation (IEA, 2008).

VHP is only for application in the US, but there is definitely potential for developing such a database for South Africa.

2.2.2.2.2 Remote Small Hydro Reconnaissance Methodology

The Remote Small Hydro Reconnaissance Methodology was initially applied as a test case in Northern Ontario in Canada, but has since become applicable to all region of the world. IT is intended to provide a basis for systematically identifying small hydro sites that could potentially supply power and to remote communities on an economically feasible scale (IEA, 2008).

The methodology involves a series of screenings done with the aid of a GIS program called MapInfo, with the purpose of identifying sites that are capable of supplying specific remote communities with power that is more cost efficient than the current supply (IEA, 2008). This correlates very closely to the scope of this study.

The power potential of each identified potential site is assessed theoretically and compared to the requirements of its surrounding communities. The energy requirements of each remote community as well as the cost of the current source of energy compared to the cost of hydropower is reviewed within the Remote Small Hydro Reconnaissance Methodology. The methodology reviews the sites and identifies sites based on the capability of supplying power economically to surrounding communities (IEA, 2008).

The methodology has the following two (2) phases:

1. Phase 1 – Identify potential sites within feasible transmission line distances from remote communities.
2. Phase 2 – Sites identified in phase 1 are evaluated based on their potential for offsetting all or part of the respective community's current energy costs.

2.2.3 Components of a hydropower scheme

2.2.3.1 Civil Components

2.2.3.1.1 Storage

The dam is a fundamental element in conventional hydraulic schemes, where it is used to create a reservoir to store water and to develop head (Penche, 1998). The basic mathematical relationship of hydropower generation, as previously stated, is that the potential power output is directly proportional to the flow through the turbine and the pressure head available. In hydropower plants, dams are used to store (pressure available head) and divert flow into the conveyance system and to the turbine.

Dams are associated with significant environmental and social impacts, and the high cost of dams and their appurtenances immediately flags the unfeasibility for using dams in small hydro schemes. However, where reservoirs/dams have been constructed for other purposes such as irrigation, water supply/reticulation to a city, flood control etc. hydropower plants can be constructed as an additional benefit.

2.2.3.1.2 Stilling Basins, Forebay Tanks, Settling Basins and Intakes

In some cases of flooding, especially with large installation on large dams, while passing over the spillway, water can summon up huge powers and this can cause damage downstream that becomes hard to control. The function of the stilling basin is to reduce this danger (Wagner and Mathur, 2011). These structures are mainly for large installations. Due to the fact that this study is focussing on small-scale hydropower, stilling basins will not be discussed in detail in the document.

With run-off river schemes, which are more likely to be incorporated as small-hydropower schemes, there is a chance of a significant amount of debris larger than 0.5 mm being diverted from the river/stream, into the conveyance channel/canal and ultimately into the penstock and turbines. Most turbines, but Francis and Pelton turbines in particular, are highly susceptible to debris. Even small erosion damage on the runner seals can lead to high leakages and excessive thrust loading on the thrust bearing which might cause severe damage to the turbine (Leyland, 2014). The turbine being such an expensive component in the system and also the main drive behind the power generation, makes this an important issue to consider. This issue is resolved through silt/settling basins and forebay tanks.

To remove the above-mentioned material and debris, the water flow must be slowed down and sediment and silt allowed to settle. This is done in the settling basin. Particles settle on the basin floor where the deposits can be periodically flushed out to make room for further deposition (Harvey, 1993). The flow in the system is slowed down at the settling basins by essentially increasing the flow area. By increasing the flow area at a constant flow, the velocity of the water flow is decreased. This is achieved with the settling basin being wider and deeper than the channel flow. There are typically five (5) important principles to follow in preliminary settling basin designs, (Harvey, 1993):

1. Basin large enough to cause settlement, but still economically feasible.
2. Allow easy flushing at sufficiently frequent intervals.
3. Water removed by flushing must not cause any damage when re-entering the system.
4. Turbulence, which causes flow separation, must be avoided (i.e. sharp bends and corners).
5. Sufficient capacity to have a long operation window.

The principles above also ring true for forebay tanks. The position of the settling basin should be on relatively straight portions of the conveyance channel/canal. Some sources refer to the preferable location of the settling basin being after the headrace (Rodriguez and Sanchez, 2011). There are several different terminologies for the headrace channel/canal or conveyance channel etc. The simplest explanation of the location of the settling basin is that the basin must be situated as close upstream to the intake or penstock as possible. This is to eliminate any extra sediment entering the system after the settling basin. For this reason also the bottom level of the crest weir of the settling basin, should preferably be higher the high flow level of the river/stream at the same section/chainage, to avoid in the inflow of water still containing sediment, during high flow periods.

The design of the settling basin therefor essentially becomes a question of the length and width of the basin, with a feasible collection depth below the settling depth of the basin. The two governing equations are as follows (Rodriguez and Sanchez, 2011) as indicated in Figure 2-9:

1) $L_d = \frac{V_h}{V_d} \times d_d \times f$

Equation 2-5

Where:

L_d = settling length of floating particle (m)

V_h = horizontal speed oat which water should enter basin ($0.2 < V_h < 0.4$ m/s is recommended)

V_d = settling speed of particle (m/s)

d_d = setting depth (not more than 1.00 m recommended)

f = factor of safety for settling length ($2 < f < 3$ recommended)

2) $W = \frac{Q}{V_h \times d_d}$

Equation 2-6

Where:

W = width of settling basin (m)

Q = flow (m^3/s)

V_h = horizontal speed oat which water should enter basin ($0.2 < V_h < 0.4$ m/s is recommended)

d_d = setting depth (not more than 1.00 m recommended)

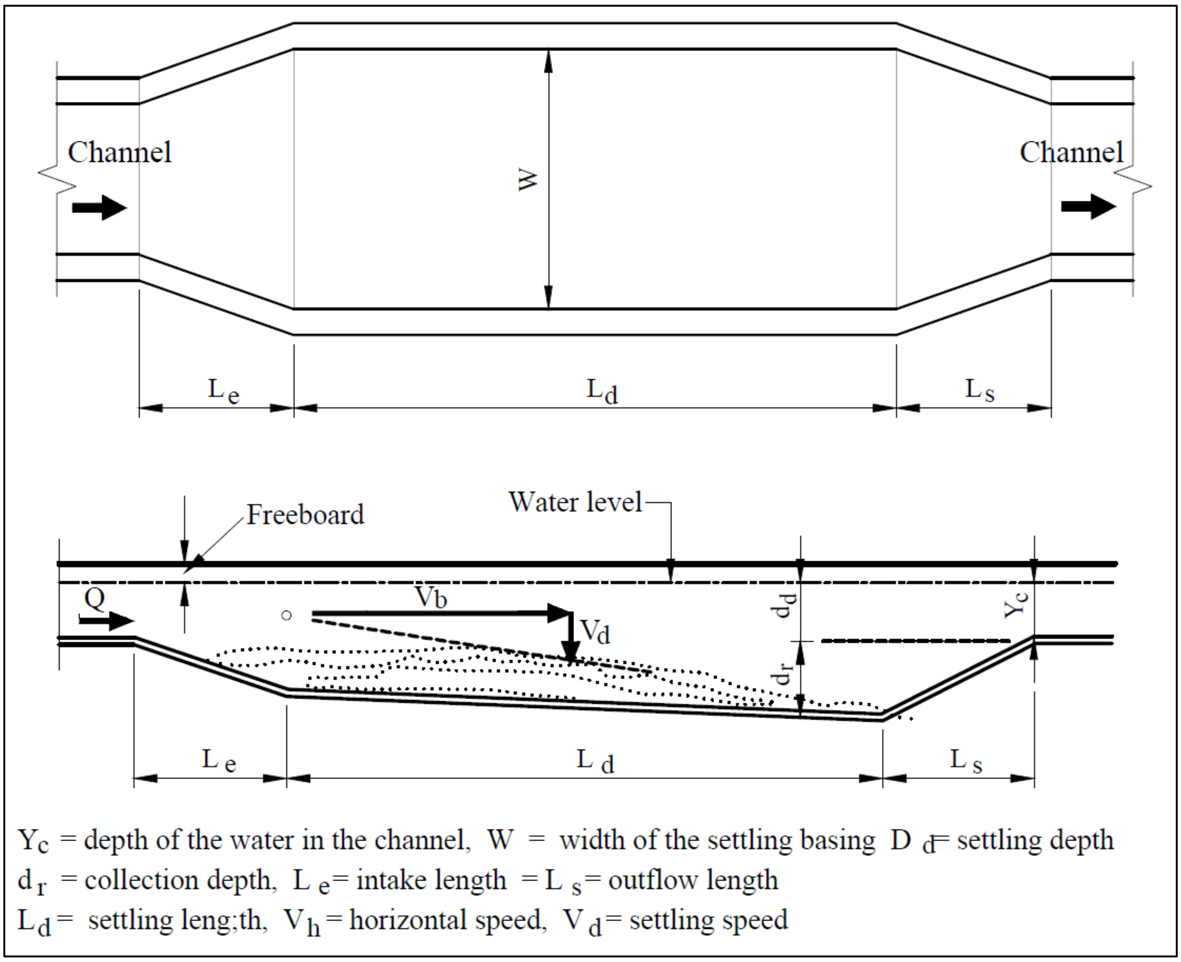


Figure 2-9 - Diagram of a settling basin (Rodriguez and Sanchez, 2011)

Figure 2-10 shows an aerial photograph of the Tone diversion weir settling basin in China.

Figure 2-10 - Tone Diversion Weir settling basin (Google Earth Image)

A forebay tank (Figure 2-11 and Figure 2-12) is used where the silt basin is immediately upstream of the penstock and water enters the penstock directly from the silt basin. The design of the forebay tank is similar to the silt basin, except that the exit portion is replaced with a trash rack and penstock entrance area (Harvey, 1993). The wall dividing the forebay tank and the silt basin is called the dividing wall and must be about 200 mm higher that the collection depth (Figure 2-11) (Harvey, 1993). The spacing on the trash rack will be discussed under the relevant section for trash screens and racks. In designing the forebay tank it is important to bear in mind that the penstock must be fully submerged. Submergence is discussed in detail in the section on intakes.

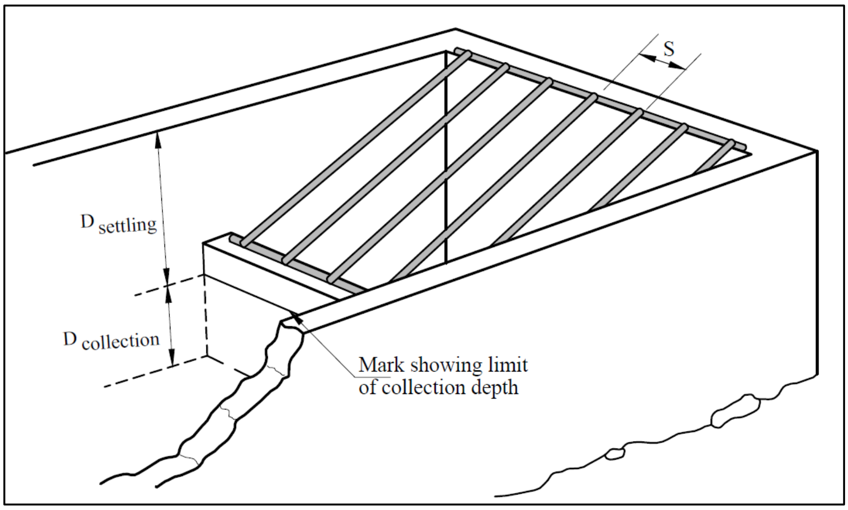


Figure 2-11 - Forebay tank with collection depth and settling depth (Harvey, 1993)

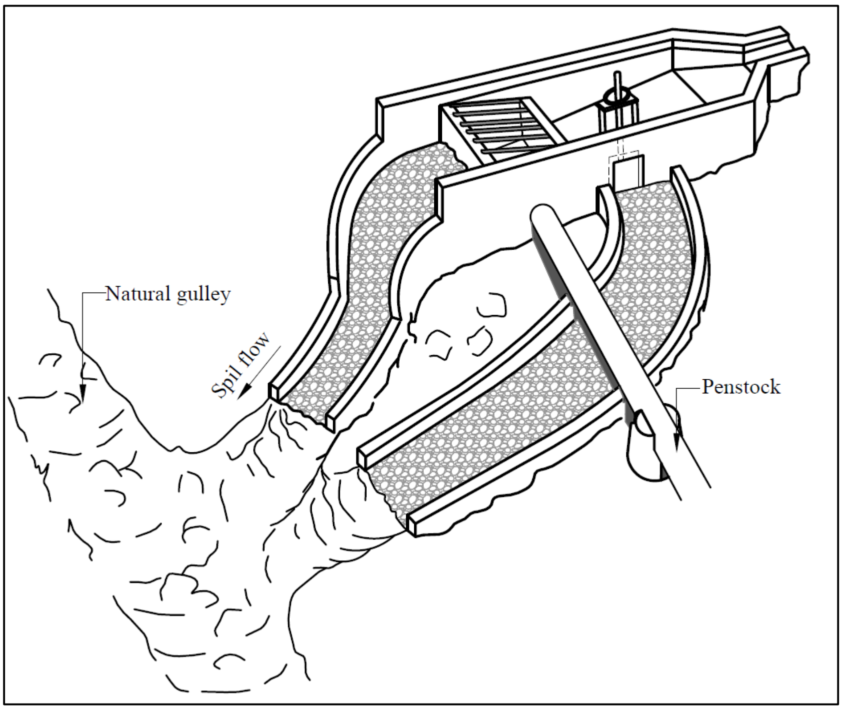


Figure 2-12 - Forebay tank position relative to silt basin and penstock (Harvey, 1993)

In a hydropower system intakes are the transitions between free surface flow, such as canals or streams, and closed conduit flow i.e. tunnels and/or penstocks (Gulliver, 1991). Intake structures consists of trash screens and sediment traps, fish protection facilities etc. and a flow constriction to bring water into the penstock. The screens, traps and fish protection facilities is discuss later in the document under the section on auxiliary components. The intake depth, horizontal location and other structure relative to the intake are of concern and the hydraulics regarding intakes can become very complex. It is proposed that hydraulic model studies are conducted, to verify and improve the design where practical and feasible.

A practical design aspect of intakes is that the trash rack is normally designed as slanted at 15 degrees (Gulliver, 1991) off the vertical, so that trash will move to the surface from where it can be raked and removed during routine maintenance.

Intakes can also be described a structures designed to capture the volume of water required for generating power, for the purpose of this study, and/or other uses (Rodriguez, 2011). From this definition intakes are no longer limited to transitions between free surface flow and closed conduits, but also includes transitions from normal stream flow into conveyance channels. In both cases though good intake design is important because bad intake design is commonly the major reason for loss of power generation (Leyland, 2014). Intakes are the “Achilles heel” of small hydropower schemes and they are often the greatest single cause of failure to generate (Leyland, 2014)

In most cases of small hydropower schemes and/or low head power schemes water is captured a weir or gauging station, where a relatively constant depth of water is present upstream of the weir. This damming of the natural stream lends the available head necessary for power generation. There are predominantly to main types of intake upstream of a weir structure, a side intake or a direct intake. The latter being where the intake is almost perpendicular to the flow of the stream/river (Figure 2-14)

Where it is not practical or feasible to have the powerhouse close to the intake or water extraction point on the river/stream, a long headrace might be needed which can consist out of a channel, penstock or combination of both. Where a combination of the channel and penstock is used there will effectively be two (2) intakes, one for water from the stream to the channel and one for water from the channel to the penstock (closed conduit). The principles of design are essentially the same with the addition of the consideration for submergence for the transition from open channel flow to closed conduit. This aspect is discussed at a later stage in die document.

The first aspect to consider is the position of your intake, i.e. height above streambed, distance from the weir, side or direct intake. With a side intake (Figure 2-13) it is important for the intake mouth to be place some distance from the weir in order to allow sediment and debris built up downstream of the mouth that can be cleaned during low flow conditions. Where a direct intake (Figure 2-14) will automatically stay clear of blockage by encouraging debris to flow through the intake rather than collect at the intake mouth. Thus in the case of a direct intake a settling basin will be required to clear the water of sediment and debris in the headrace before entering the penstock (Harvey, 1993).

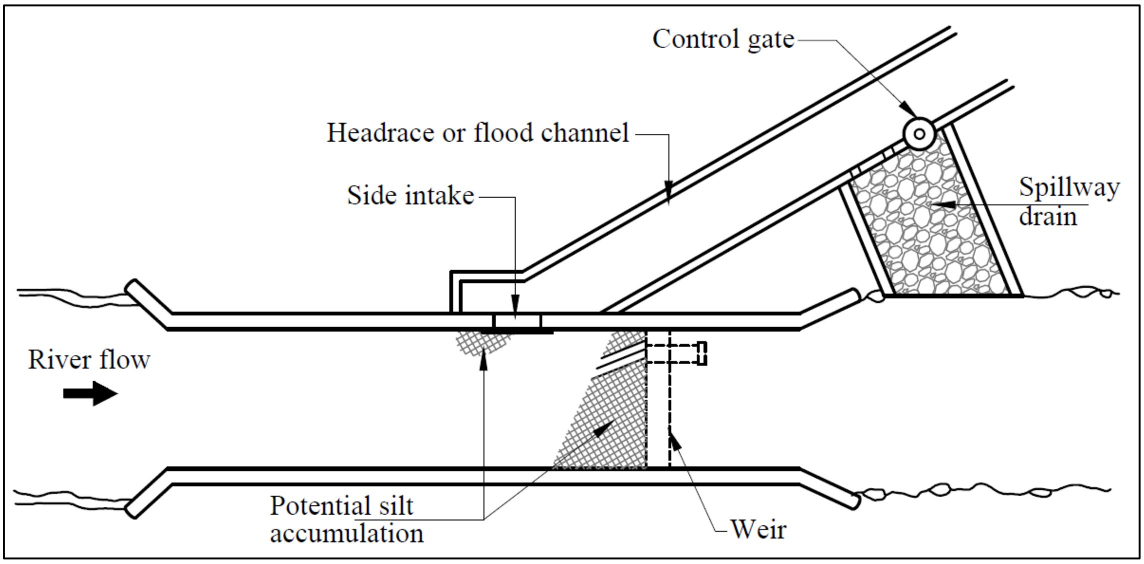


Figure 2-13 - Side Intake Example (Harvey, 1993)

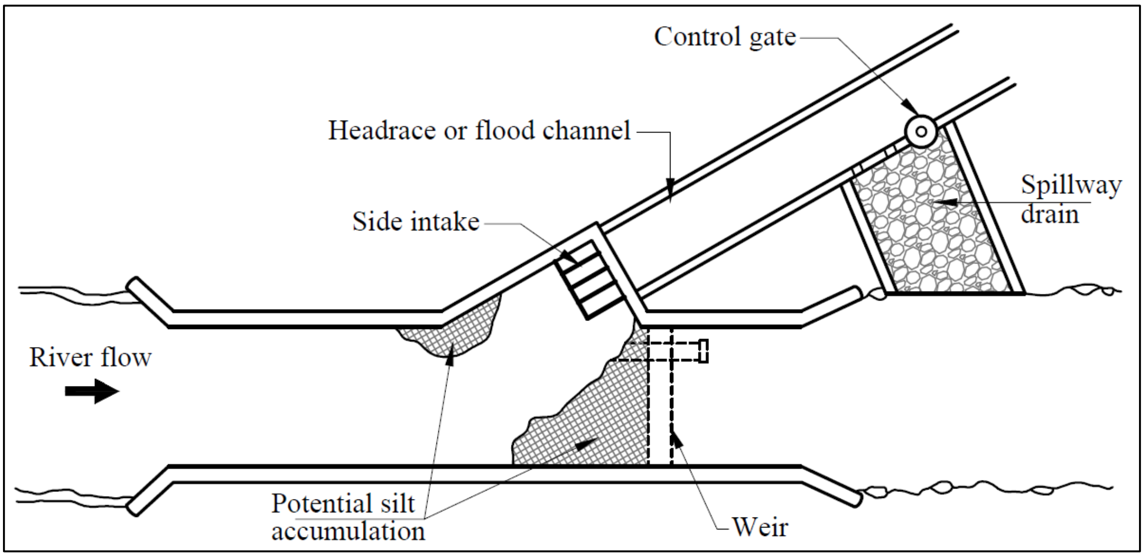


Figure 2-14 - Direct Intake Example (Harvey, 1993)

The direct and side intakes behave according to the orifice discharge equation (Harvey, 1993). The equation is as follows:

$$Q = A_i \times V_i = A_i \times c_d \times \sqrt{2g(h_r - h_h)}$$

Equation 2-7

Where:

Q = flow through the intake (m^3/s)

A_i = cross-sectional area of the intake (m^2)

V_i = velocity of water passing through the intake (m/s)

c_d = coefficient of discharge of the intake orifice

g = gravitational acceleration (m/s^2)

h_r = head of river water upstream (m)

h_h = depth of water in headrace channel (m)

An alternative to side intakes and direct intakes, which are all vertical face intakes, is a streambed intake (Figure 2-15). The streambed intake is in some cases also referred to as a Tyrolean intake or submerged weirs (Rodriguez, 2011). Characteristics of the streambed intake is as follows:

- The intake aperture is located on the bottom of the river (riverbed must be prepared to be resistant to corrosion)
- Headrace channel is embedded in the river/stream
- It may or may not have a weir
- Weir is very low, therefor increase in upstream head during rainy season is normal
- Must be located in straight section
- Slopes of river must be greater than 4% with no change in direction
- Free passage for debris, settling basin necessary in most cases. Stones and larger rocks pass on own river, but sand and small gravel enter the system and must be removed with a settling basin with manual or automatic flushing (Leyland, 2014)

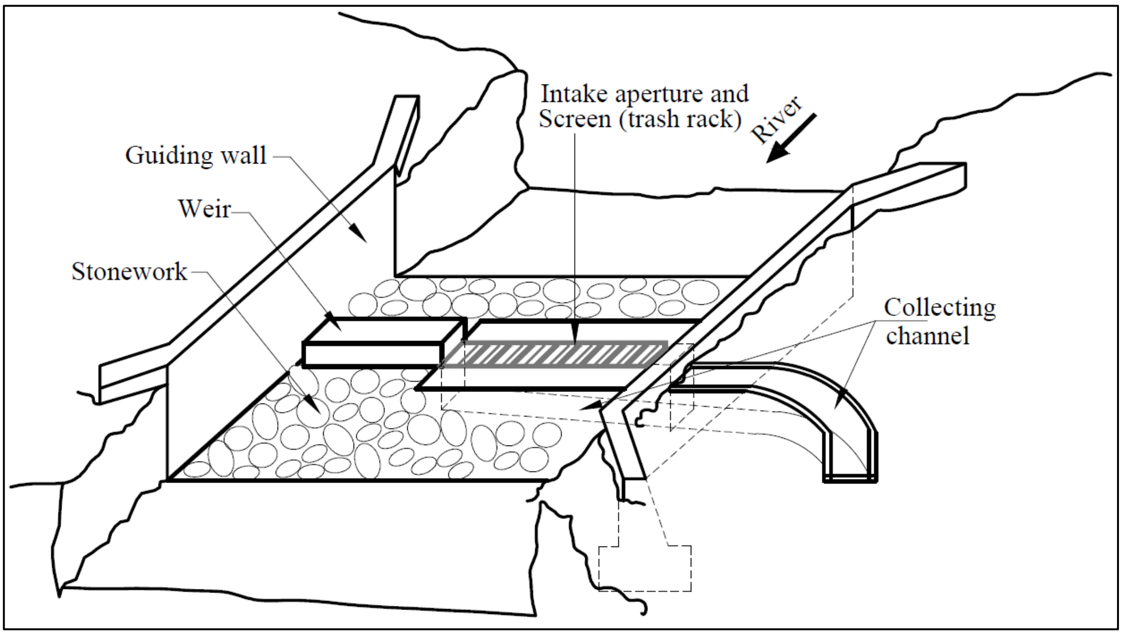


Figure 2-15 - Riverbed intake/Tyrolean intake (Rodrigeuz and Sanchez, 2011)

The design of the dimensions, length and width of the screen, of a Tyrolean or streambed intake can be found in Lauterjung and Schimdt (1989).

Another intake alternative when flows are below 5 m^3/s, is a "Coanda" intake screen (Figure 2-16 and Figure 2-17). The Coanda screen uses the Coanda effect that makes water "stick" to a curved surface (Leyland, 2011). Substantially clean water can be diverted using a Coanda screen, and might in same cases eliminate the need for a settling basin altogether. Because the screen is on the downstream side of the weir, damage due to large rocks, boulders or debris is also greatly reduced, due to these objects tending to leap over the screen instead of hitting them. The Design Guidance for Coanda-Effect Screens (Wahl, 2003) is available from the United States Bureau of Reclamation online at http://www.usbr.gov/.

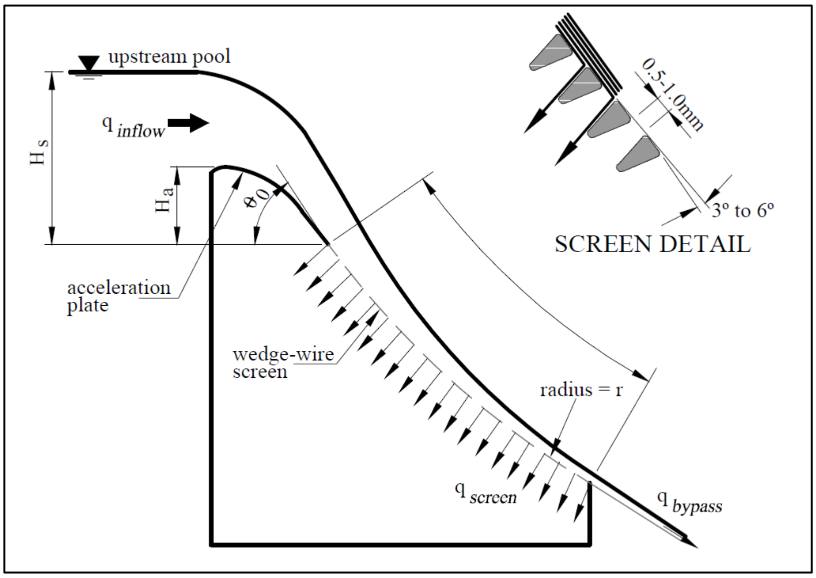


Figure 2-16 - Features, typical arrangement, and design parameters for Coanda screens (Wahl, 2003)

Figure 2-17 - Montgomery Creek intake – Coanda Screen - Shasta County, California, USA (Wahl, 2003)

In all the above cases of intakes, it is imperative to install a bypass in the system to ensure that maintenance and cleaning of the intakes will be possible. The bypass will be discussed under the section of auxiliary components of the system.

With intakes from channels, streams or dams directly into the penstock, the most important design aspect to consider is submergence and free surface vortices. Free surface vortices are a highly organized flow phenomenon that occurs due to the residual angular momentum in the flow at a closed-conduit intake (Gulliver, 1991).

Hydro turbines are designed to work with a relatively uniform flow approach profile. If approaching flow is not uniform the turbine will not operate at its maximum capacity. Unbalanced loading on the turbine blades due to non-uniform flow will also increase the necessary maintenance and shorten the expected useful life of the turbine. Therefore hydraulic turbines are designed with the requirement that the flow in the penstock be straight and uniform. This is especially difficult with very short penstocks. Free surface vortices have been found to cause flow reductions, vibrations, surging etc (Gulliver, 1991). All of which reduce the uniformity of the approach flow in the penstock. We refer to this issue as the quality of approach flow. It will be further discussed within the section concerning turbine selection.

The parameters that influence the occurrence of intake vortices are (Gulliver, 1991):

- Arrangement – Vertically arranged intake have a much higher tendency for vortices forming than horizontally arranged intakes. Inverted vertical intakes have a similar tendency as horizontal intakes.
- Submergence – i.e. S/D, a greater submergence will reduce the tendency for vortex formation.
- Intake Froude Number – Ratio of the inertial to the viscous forces in the water column.
- Approach circulation – If flow enters at an angle it has an overall swirl which will tighten up and form a vortex as it enters the intake.

The submergence needed to prevent free surface vortices forming can be determined by using the following formula:

$$S = 0.725 \times V \times D^{1/2}$$

Equation 2-8

Where:

S = submergence to the roof of the gate section (intake) (m)

D = diameter of the penstock or height of the gate (m)

V = velocity at the gate for the design flow (m/s)

To isolate penstocks for cleaning and maintenance and inspection purposes, or to cut off the flow in the case of a burst or problems occurring at the power station, a gate or valve is normally installed at the intake. Valves and gates will be discussed in further detail in the section on auxiliary parts of the hydropower system.

The head loss through trash racks and intakes is a function of the velocity head and is determined by the following formula:

$$h_L = K_t \frac{V_t^2}{2g} + K_i \frac{V^2}{2g}$$

Equation 2-9

Where:

h_L = head loss (m)

K_t = head loss coefficient for trash racks (m)

K_i = head loss coefficient for intakes (m)

V_t = velocity approaching trash racks (m/s)

V = velocity of flow in penstock/tunnel or channel downstream from inlet (m/s)

Idel'chik has compiled an extensive amount of information on head-loss coefficients at intakes and trash racks which is given in Figure 2-18 and Figure 2-19 (Idel'chik, 1986).

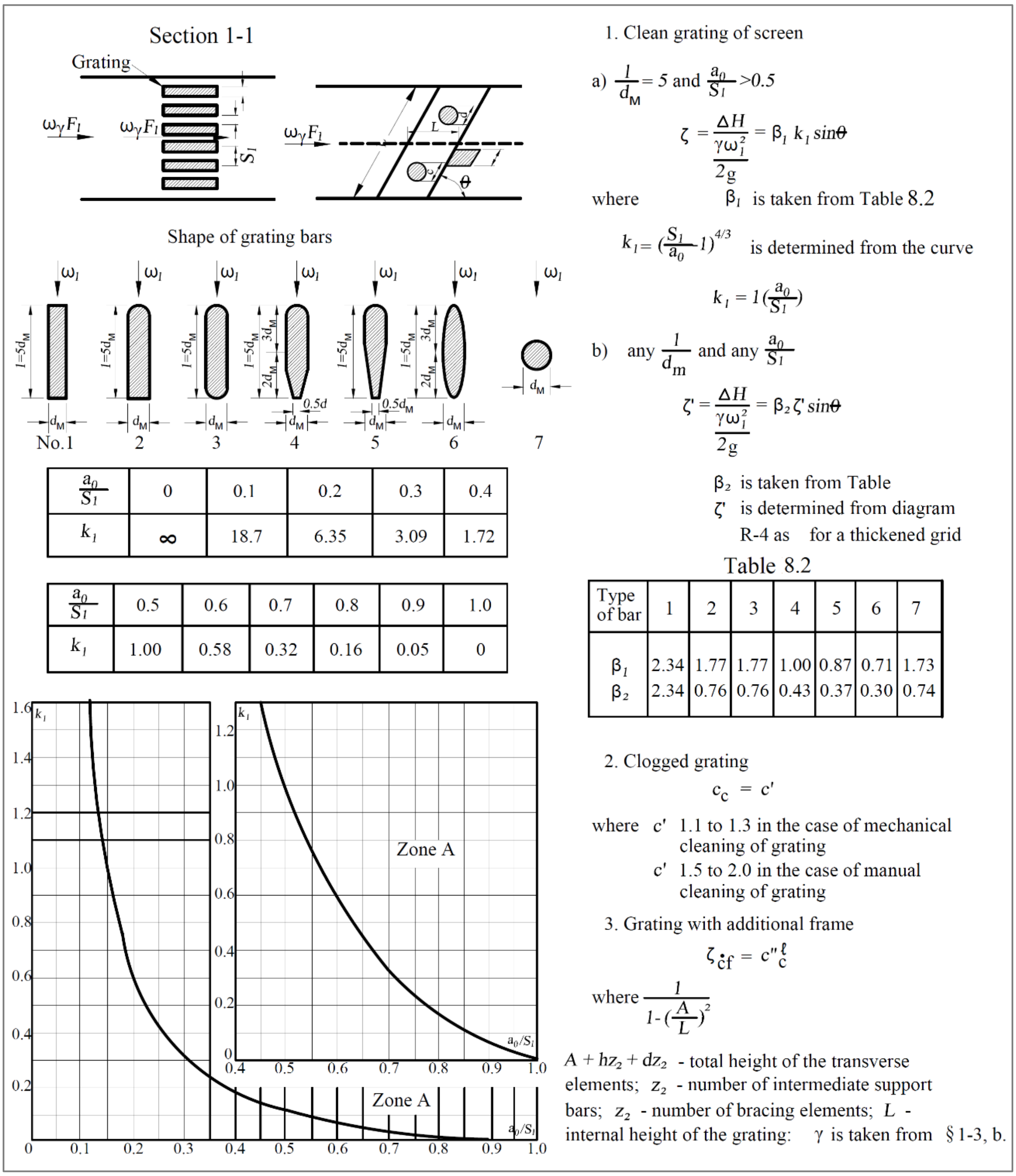


Figure 2-18 - Bar grating losses (Idel'chik, 1986)

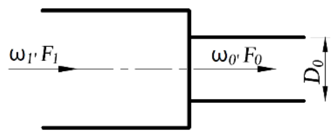
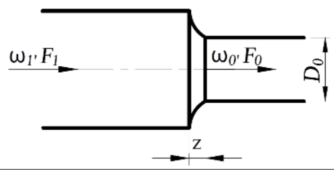
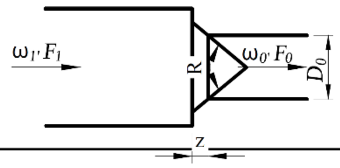
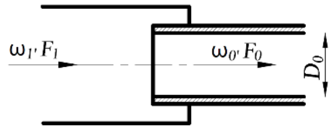
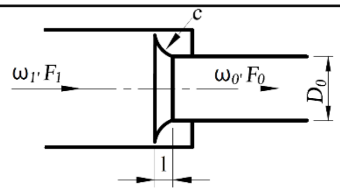
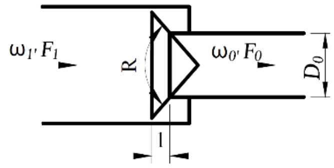
Inlet condition	Diagram	Resistance coefficient $\zeta = \frac{\Delta H}{\frac{\gamma \omega_0^2}{2g}}$
A. Inlet section in the end wall $(\frac{b}{D_h} = 0)$: $D_h = \frac{F_0}{\Pi_0}$: Π_0 = perimeter		
Inlet edge blunt		$\zeta = 0{,}5\ (1 = \frac{F_0}{F_2})$
Inlet edge rounded		$\zeta = \zeta\ (1 = \frac{F_0}{F_2})$ where ζ is determined from the curve $\zeta = 1(\frac{b}{D_h})$ on diagram 3-3 (curve c)
Inlet edge beveled		$\zeta = \zeta\ (1 = \frac{F_0}{F_2})$ where ζ is determined from the curve $\zeta = 1\ (a \bullet \frac{1}{D_h})$ on diagram 3-6
B. Inlet edge moved forward relative to the end wall $(\frac{b}{D_h} > 0)$		
Inlet edge sharp or thick		$\zeta = \zeta\ (1 = \frac{F_0}{F_2})$ where ζ is determined from the curves $\zeta = 1\ (\frac{}{D_h} \cdot \frac{b}{D_h})$ on diagram 3-1
Inlet edge rounded		$\zeta = \zeta\ (1 = \frac{F_0}{F_2})$ where ζ is determined from the curves $\zeta = 1\ (\frac{r}{D_h})$ on diagram 3-3 (curves a and c)
Inlet edge beveled		$\zeta = \zeta\ (1 = \frac{F_0}{F_2})$ where ζ is determined from the curve $\zeta = 1\ (a \bullet \frac{1}{D_h})$ on diagram 3-5: is taken from 1-3,b

Figure 2-19 - Various inlets with sudden contractions (Idel'chik, 1986)

2.2.3.1.3 Canals

It is not always that the most practical or optimum location for the powerhouse is within the river or close to the dam/reservoir. For this reason water most often needs to be conveyed by means of conveyance channels/canals to the preferable intake location. Many authors refer to this conveyance channel or tunnel as the headrace. When the headrace takes the form of a long channel it is also sometimes referred to as the “diversion channel” or “power canal” (Gulliver, 1991).

The design of a canal for the head race, or a diversion channel, is a trade-off between the cost of excavation and lining of the canal against the loss in profit and power cost lost (Gulliver, 1991). Canals can be constructed by simply excavating or digging a trench if the ground is suitable, or if the ground is unsuitable or unstable, by using a lining. Canals can be lined with anything from masonry linings to stone pitching, concrete or high-density polyethylene linings, examples shown in Figure 2-20.

The first step in canal design is to determine the dimensions and shape of the canal needed to carry the design flow needed to operate the turbine. Secondly the head losses in the canals must be low enough to ensure sufficient available head for the turbine to operate. Available head and flow is the main elements governing the operation of the turbine, which in turn governs the electric power generation. Therefor the two canal/channel elements for design is as follows (Rodriguez, 2011):

1. Geometric elements in accordance with the cross-section (Flow) (Figure 2-21)
2. Hydraulic characteristics of the channel (Head loss) (Figure 2-22)

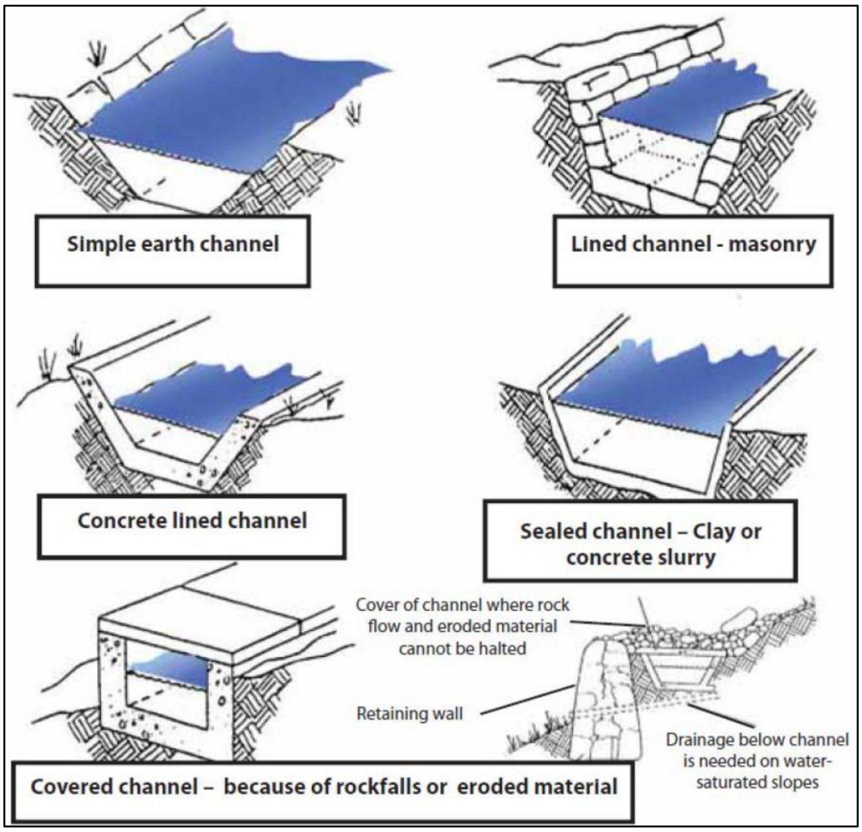


Figure 2-20 - Examples of headrace channels (Jorde and Hartmann, 2009)

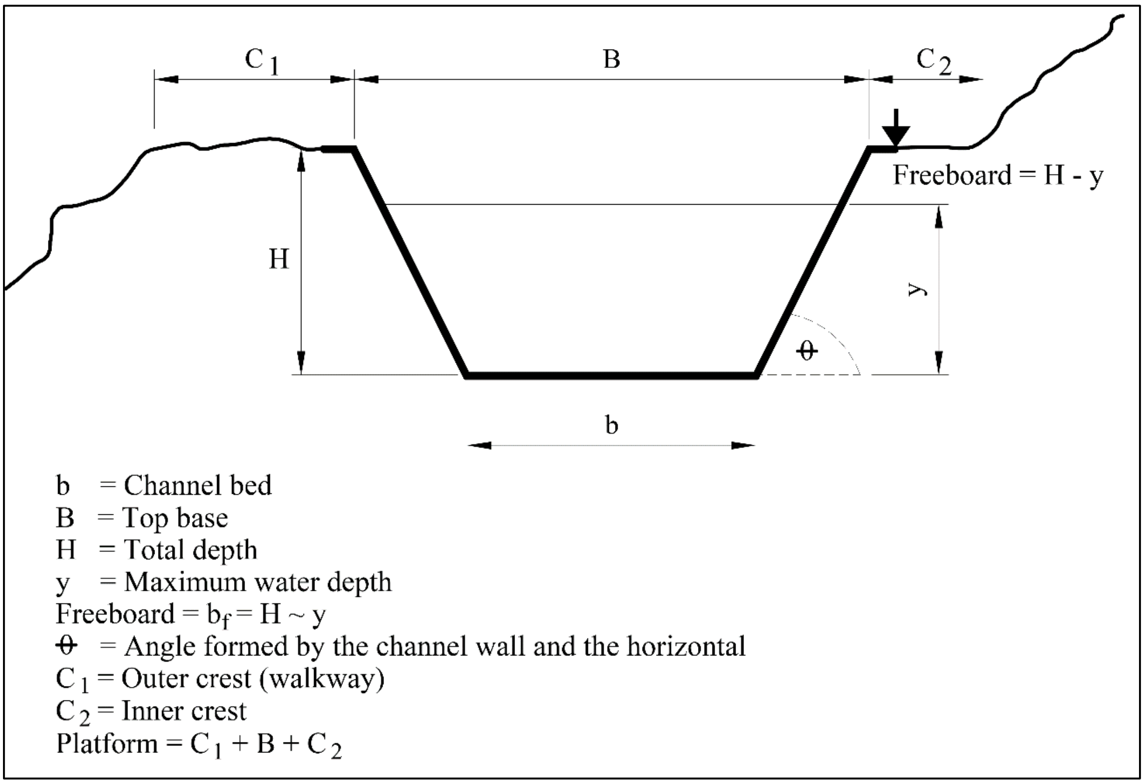


Figure 2-21 - Geometric elements of a channel section (Rodrigeuz, 2011)

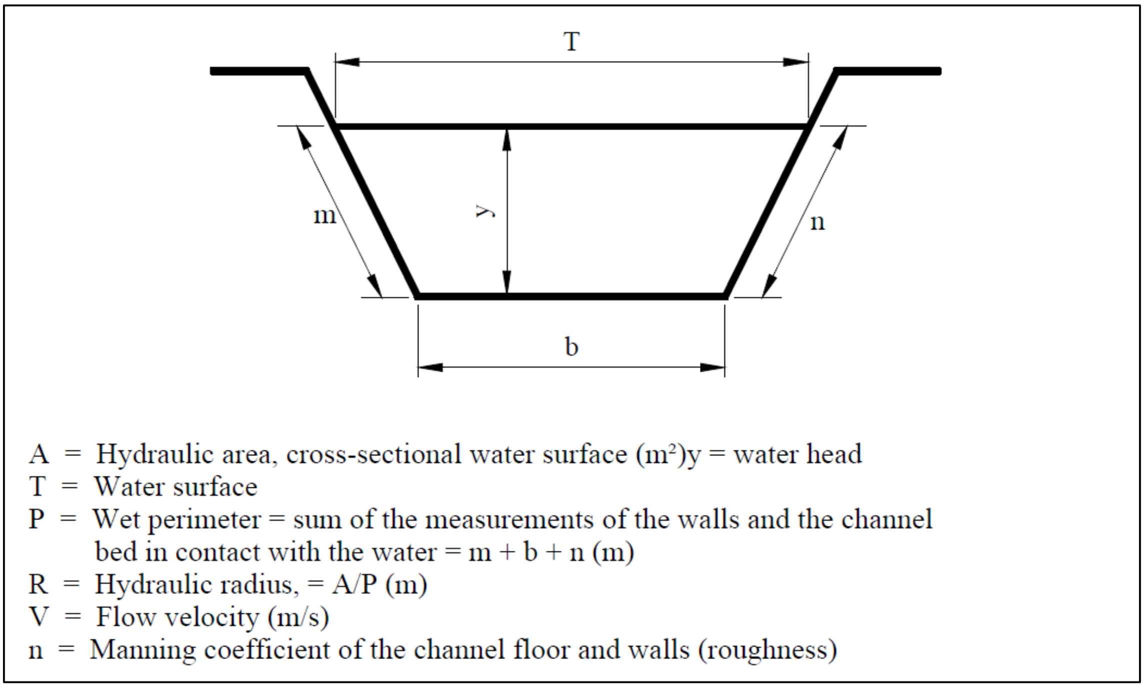


Figure 2-22 - Hydraulic characteristics of a channel (Rodrigeuz, 2011)

With regards to the flow in the canal, the action of the flowing water made from soil (unlined) will cause the walls to collapse inwards, unless the sides are sloped gently and the width is relatively large compared to the depth of the canal. The advantage of the lining is that the canal can be much narrower and accommodate the same flow. Excessively fast flows will erode the canal, where excessively slow flows will cause silt deposition which changes the geometric and hydraulic characteristics of the canal and decreases efficiency (Harvey, 1993). For concrete lined canals with a flow depth lower than 300 mm the flow velocity should not exceed 1.5 m/s, whereas for concrete lined canals with a flow depth lower than 1.00 m the flow velocity should not exceed 2.0 m/s (Rodriguez, 2011).

There are 2 basic formulas for the design of a conveyance channel/canal. The formulas are as flows:

1. Continuity formula

$$Q = V \times A$$

Equation 2-10

Where:

Q = flow (m^3/s)

A = area of the cross-section of the channel (m^2)

V = velocity of the water (m/s)

2. Manning formula

$$Q = \frac{1}{n} \times \frac{A^{5/3}}{P^{2/3}} \times S^{\frac{1}{2}}$$

Equation 2-11

Where:

Q = flow (m^3/s)

n = Manning coefficient of the lining or natural material (examples in Table 2-2)

A = area of the cross-section of the channel (m^2)

P = wetted perimeter the cross-sectional area of flow (m)

S = channel slope (gradient m/m)

Table 2-2 - Typical Manning roughness values (Brunner, 2010)

Type of Channel and Description		Minimum	Normal	Maximum
Natural Streams				
Main Channels	Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
	Same as above, but more stones and weeds	0.030	0.035	0.040
	Clean, winding, some pools and shoals	0.033	0.040	0.045
	Same as above, but more stones and weeds	0.035	0.045	0.050
	Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
	Same as "d" but more stones	0.045	0.050	0.060
	Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
	Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150
Lined or Built-Up Channels				
Concrete	Trowel finish	0.011	0.013	0.015
	Float finish	0.013	0.015	0.016
	Finished, with gravel bottom	0.015	0.017	0.020
	Unfinished	0.014	0.017	0.020
	Gunite, good section	0.010	0.019	0.023
	Gunite, wavy section	0.018	0.022	0.025
	On good excavated rock	0.017	0.020	
	On irregular excavated rock	0.022	0.027	

The design of the conveyance channel/canal will be governed by the following five principles, which needed to be adhered to achieve the optimum design (Harvey, 1993):

1. The velocity must be high enough to prevent the settlement of solids and silt
2. The velocity must be low enough to avoid erosion of channel bottom and sides lopes – if impossible use lining i.e. concrete lined channels
3. Head loss due to the channel must be minimised (best hydraulic cross-section)
4. The channel must be durable and reliable – withstand storm runoff, rock falls, unusually high flows etc.
5. The channel must have the minimum possible and practical material cost, construction cost and maintenance cost.

2.2.3.1.4 Penstock/Tunnels

A penstock is the conduit that is used to carry water from the supply sources to the turbine. This conveyance is usually from a canal or a reservoir. Other than tunnels and canals which are not pressurised, penstocks can be either pressurised or non-pressurised (Gulliver, 1991). Penstocks can be constructed from various materials i.e. concrete or steel pipes, fibreglass, woodstave pipe etc. Penstocks are also usually equipped with gate systems for controlling the flow (Wagner and Mathur, 2011).

Tunnels can also be used to convey water from the intake to the turbine (Gulliver, 1991). A typical layout of a tunnel-penstock is shown in Figure 2-23.

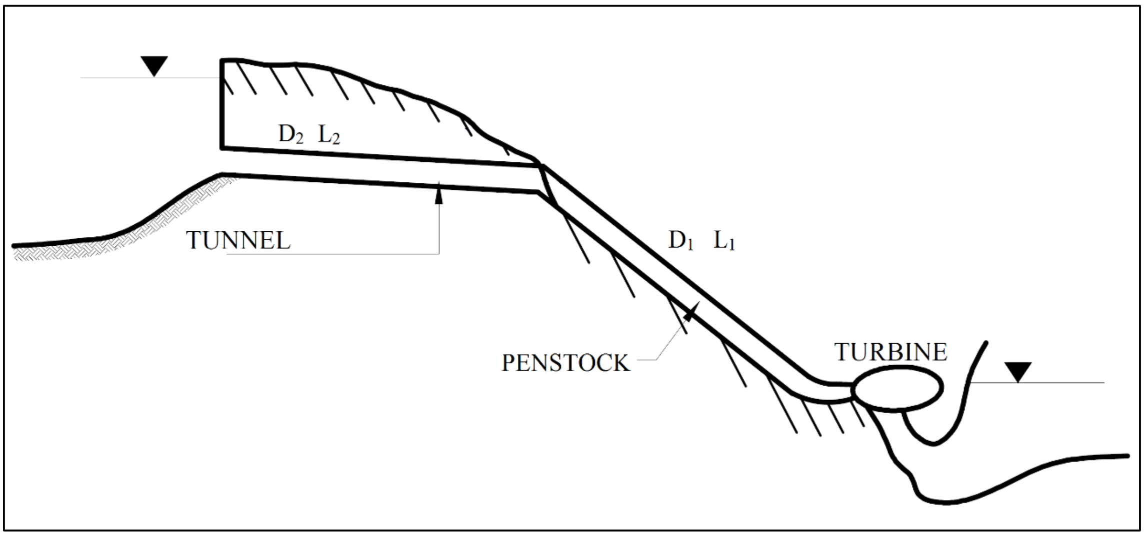


Figure 2-23 - Typical layout showing tunnel and penstock (Gulliver, 1991)

There are three (3) important factors, with regards to feasibility, to consider in the preliminary design of the penstock (Warnick, 1984):

1. Head loss through the penstock
2. Safe thickness of the penstock shell
3. The economical size of the penstock.

A fourth consideration will be the route of the penstock.

The head loss through the penstock is depicted by the Equation 2-12. The higher the energy losses/head loss in the penstock, the less head is available for power generation as per Equation 2-1.

$$h_f = \frac{\lambda L V^2}{2gD}$$

Equation 2-12

Where:

h_f =friction loss/Head loss (m)

λ = friction factor

L = length of penstock/pipe length (m)

V = flow velocity (m/s)

g = gravitational acceleration (m/s^2)

D = pipe internal diameter (m)

Common techniques for reducing penstock head losses are lining the penstock, increases the diameter or construction a second penstock parallel to the first (Gulliver, 2011)

The acceptable minimum thickness of the penstock is governed by a safety factor of the Ultimate tensile strength of the pipe/penstock material over the total pressure head at a certain point in the system. The safety factor equation as per Micro-Hydro Design Manual (Harvey, 1993), is as follows:

$$S = \frac{t_{effective} \times \sigma_{UT}}{5 \times h_{total} \times 10^3 \times D}$$

Equation 2-13

Where:

S = safety factor

$t_{effective}$ = effective thickness (m)

In the case of steel pipes there will be welded or rolling defects. The effective thickness is there for less than the nominal thickness of the pipe. If the pipe is PVC a correction factor needs to be applied for low temperatures.

σ_{UT} = ultimate tensile strength (N/m^2)

h_{total} = total static pressure head (m)

D = internal diameter of pipe/penstock (m)

With:

$$h_{total} = h_{gross} + h_{surge}$$

Equation 2-14

And,

$$h_{surge} = \frac{a'V}{g}$$

Equation 2-15

Where:

h_{surge} = surge head (m)

V = velocity in pipe/penstock (m/s)

g = gravitational acceleration (m/s^2)

And,

$$a' = \frac{a}{\sqrt{1+\left(\frac{K\times D}{E\times t}\right)}}$$

Equation 2-16

Where:

a = wave celerity (m/s)

K = bulk modulus of elasticity of the liquid (N/m^2)

D = internal diameter of pipe/penstock (m)

t = thickness (m)

E = Young's Modulus (N/m^2)

The recommendation of Harvey is that the penstock option be rejected if the safety factor is below 3.5. It is further stated in the Micro-Hydro Design Manual (Harvey, 1993), that if good operating conditions and well trained operators are in place and equipped, that a safety factor as low as 2.5 can be acceptable. This safety factor can be further lowered or raised according to the level acceptable risk within the design of the system.

The economical size of the penstock is not the same for every project and depends on various factors such as the cost of material, the value of power generated, the flow and available head required, the length of the penstock etc. The most economical size of the penstock can also be confirmed by doing a sensitivity analysis and comparing all the different hydraulically and structurally adequate options.

It is of value to take note of the different components to consider when doing a sensitivity analysis to obtain the most economical penstock size.

Some time and effort is spent on the review of the penstock design due to the fact that friction head losses in the penstock reduces the available head for power generation. Also due to the increasing cost of greater diameter pipes to reduce friction losses versus the reduction in safety factor with a greater diameter makes the design of the penstock almost a feasibility issue which is best resolved with a sensitivity analysis.

2.2.3.1.5 Surge Chambers

Due to variations in the operation of hydropower plants with changes in flow demand, energy demand, flooding events etc. there exists variation on the turbine loading. Sudden changes on turbine loading can negatively influence the operation, maintenance cost and useful service life of such a turbine.

The role of a surge chamber is to limit the change in pressure by providing buffer space for the storage or supply of water in the case of a sudden increase or decrease in turbine loading (Wagner and Mathur, 2011). Where operational procedures are not adhere to or in the event of power failures or malfunction, and valves are suddenly opened, pressures can drop suddenly and cause cavitation. In turn a suddenly closure of a valve can increase pressures to the extent of pipe burst. These effects are largely referred to as water hammer, which is the pressure surge or wave caused when the water in motion is forced to stop or change direction suddenly, i.e. with sudden valve closures.

In these events surge chambers can regulate the swaying of water. When a valve is opened, the surge chamber can feed water into the system to avoid the interruption of water head. When a valve is shut the surge chamber regulates the pressure by taking water into the empty space above the previous water level. The practise and mechanism of surge chambers on hydropower systems are principally the same as for surge chambers in large water pump systems.

Extensive study of the effect of water hammer, pressure systems and surge chambers has been done by Stephenson (2002). Water hammer following the tripping of pumps can lead to overpressures, which may either require excessive pipe wall thickness or some form of water hammer protection, (Stephenson, 2002). For the benefit of this study the tripping of pumps can be substituted by the sudden failure of turbines or valve closures.

Most simply put, the volume, or more importantly, the height of surge chambers (open surge tanks) should be such that rise/fall of water in the chamber can accommodate the pressure transients caused by sudden valve closures or turbine failures. This fluctuating level of water in the surge chamber limit the change in pressure by preventing sudden pressure drops or spikes which might cause either cavitation or pipe bursts.

2.2.3.1.6 Powerhouse/Turbine Room

Powerhouses for hydropower plants usually consist of the superstructure and the substructure. The superstructure provides protective housing for the generator and control equipment as well as structural support for cranes for installation and maintenance purposes. The substructure (foundation) of the powerhouse has the main purpose of supporting all the mechanical, electrical and auxiliary components of the plant. Hydro turbine and generator components of the power plant have substantial weight and it is imperative that the foundation of the powerhouse is designed as such to adequately handle to loads it is subjected to. A separate control room is included in the powerhouse. This isolates the control systems from generator noise and provides a clean and comfortable environment for the operators (Warnick, 1984).

Conventional powerhouse can differ in many different ways, ranging from powerhouses connected directly to dams or reservoirs to other located a distance from the reservoir with penstocks carrying water from the intake to the turbine in the powerhouse. The setup of the electrical and mechanical components within the powerhouse will also differ from setups where the shaft of the turbine and the generator is vertical and flow is normal to the turbine units to horizontal generator setups with flow in line with the turbine units. This setup will be discussed further within the mechanical and electrical sections of the literature review. In most cases dimension that govern the powerhouse is furnished by the turbine and generator manufacturers.

Each development might require special considerations of the location and size of the powerhouse to accommodate the geology and topography at the site, and to gain the most economic construction of the plant. A typical setup of a reaction turbine powerhouse is show in Figure 2-24 with an example of a powerhouse shown in Figure 2-25.

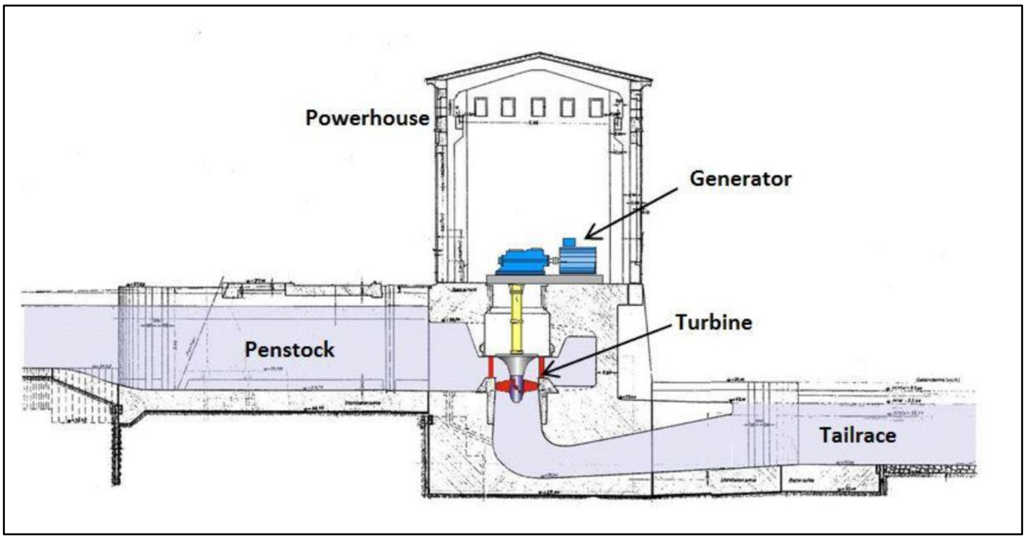


Figure 2-24 - Reaction turbine powerhouse (Colorado Energy Office, 2007)

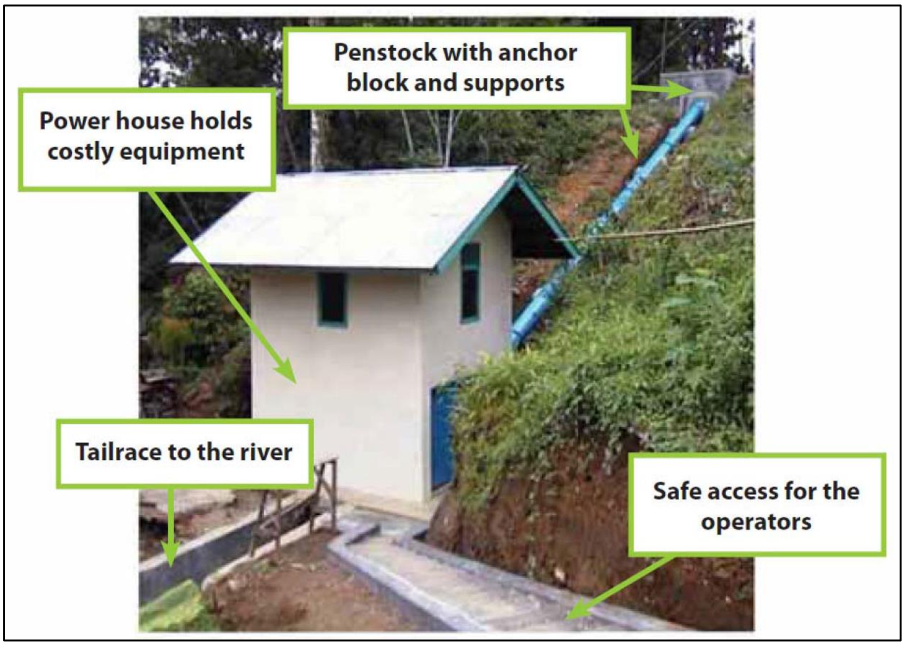


Figure 2-25 - Example of a powerhouse (Jorde and Hartmann, 2009)

2.2.3.1.7 Tailrace

The tailrace is the downstream part of the system where the diverted or impounded water re-enters the river (Wagner and Mathur, 2011). It is a channel or canal that allows the water to flow back to the stream after it has passed through the turbine (Natural Resources Canada, 2004). The Tailrace, or discharge structure, is located downstream of the turbine and takes the water discharged from the turbine back to the watercourse (Colorado Energy Office, 2007) as shown in Figure 2-26.

Reaction turbines (Kaplan, Propeller, or Francis) will require a draft tube (Figure 2-27 and Figure 2-28) to be incorporated into the tailrace. A draft tube is simply an outlet pipe from the turbine that must be submerged in water on the tailrace side. This is achieved by maintaining tailwater with a concrete structure or by setting the bottom of the draft tube below the downstream water surface. The reaction turbines take advantage of the suction provided by the draft tube and water level on the downstream side of the turbine. Alternatively, impulse turbines (Pelton, Turgo and Crossflow) will discharge into the open air and do not require a set tailwater elevation or a draft tube (Colorado Energy Office, 2007).

Figure 2-26 - Powerhouse with clear tailrace

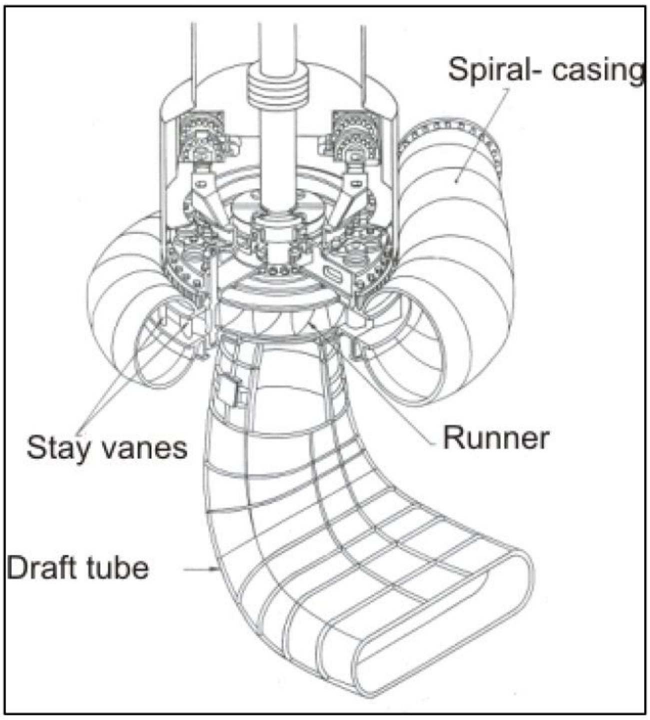


Figure 2-27 - Typical draft tube

Figure 2-28 - Bulb turbines and draft tubes - Sebec Hydropower plant (Swiftriverhydro, 2015)

De Siervo and De Leva have developed empirical relationships and experience curves to make preliminary determinations for draft tube design based in the turbine discharge diameter, D_3, and specific speed, N_S, for both Francis and Kaplan turbines (De Siervo and De Leva, 1976, 1977 and 1978).

There are four (4) main considerations for the location of the tailrace, or more specifically where the tailrace allows the water to re-enter the river or stream (DoE EUMB, 2009). The considerations are as follows:

1. Flood Water Level – The tailrace channel should be preferably placed above the expected flood water level to avoid the inundation of water into the powerhouse and sedimentation of the tailrace.
2. Existence of Riverbed Fluctuation at Tailrace – If fluctuations of the riverbed is expected care must be taken to avoid sedimentation in front of the tailrace.
3. Possibility of Scouring – Select a location where protective measures of the river/streambed can be easily implemented.
4. Flow Direction of River Water – Tailrace must, whenever possible discharge in the same direction as to which the river flows.

Similarly to the design of the head race or conveyance channel/canal, the design of the tailrace is trade-off between excavation and lining costs versus the lost power cost of the channel head losses. In many cases the tailrace is so short that the head losses are negligible and not include in the head loss calculations (Gulliver, 1991).

Figure 2-29 and Figure 2-30 show the typical layouts of tailraces for both impulse and reaction turbines. Take note of the difference in water levels at the entrance and exit of the tailrace with impulse and reaction turbines.

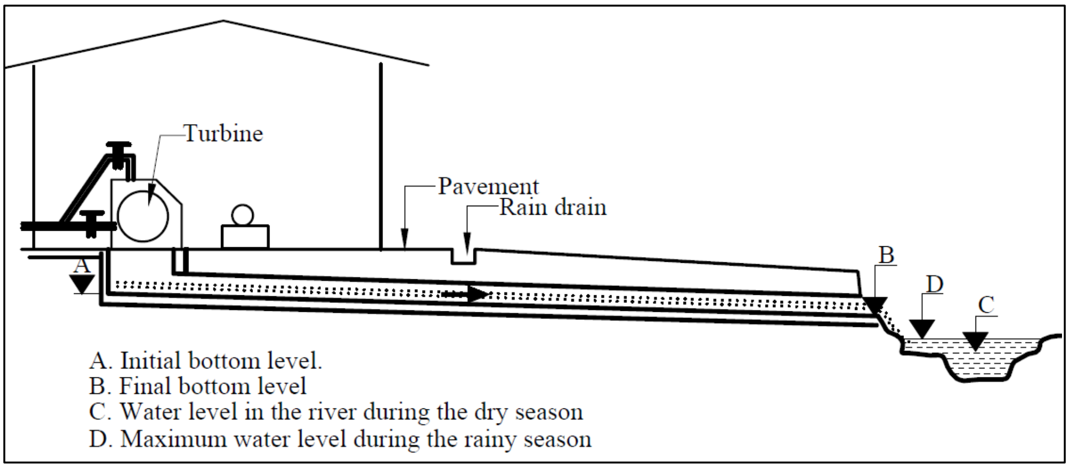


Figure 2-29 - Location of tailrace channel for pelton type turbines (Rodriguez and Sanchez, 2011)

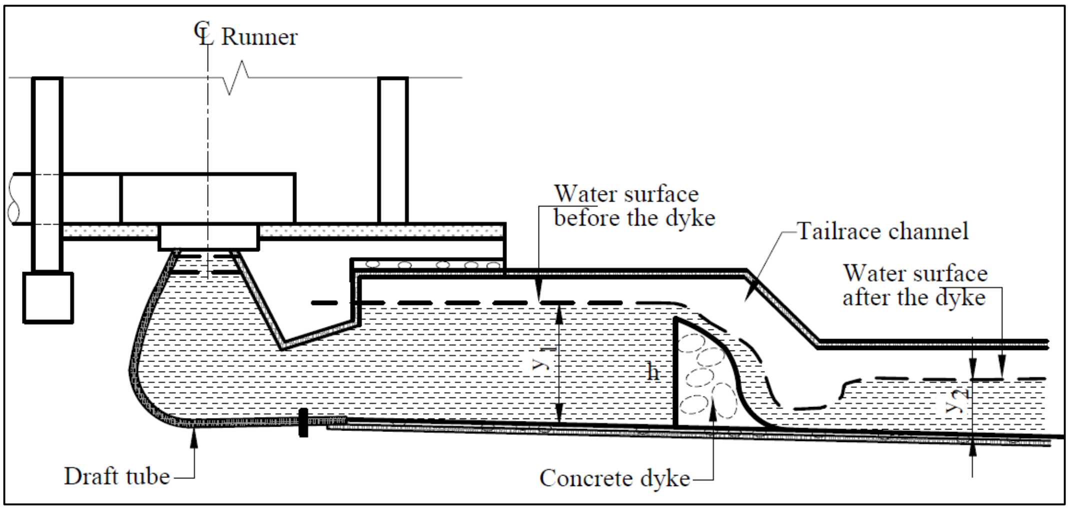


Figure 2-30 - Profile of the tailrace channel for an axial turbine (Rodriguez and Sanchez, 2011)

For impulse turbines the technical specifications for the design of the tailrace are the same as for the headrace/conveyance channel. For reaction turbines, the technical specifications or the tailrace also depends on the following characteristics seen in Figure 2-30 (Rodriguez and Sanchez, 2011):

- Hydraulic characteristics of the draft tube
- Height of dyke
- Slope before and after dyke

2.2.3.2 Mechanical Components

The typical electro-mechanical components of a micro hydropower plant include (Figure 2-31):

- Turbine
- Mechanical transmission/gear (drive system)
- Generator
- Turbine controller and power cabinet
- Transformers and transmission/distribution lines
- House connections of users

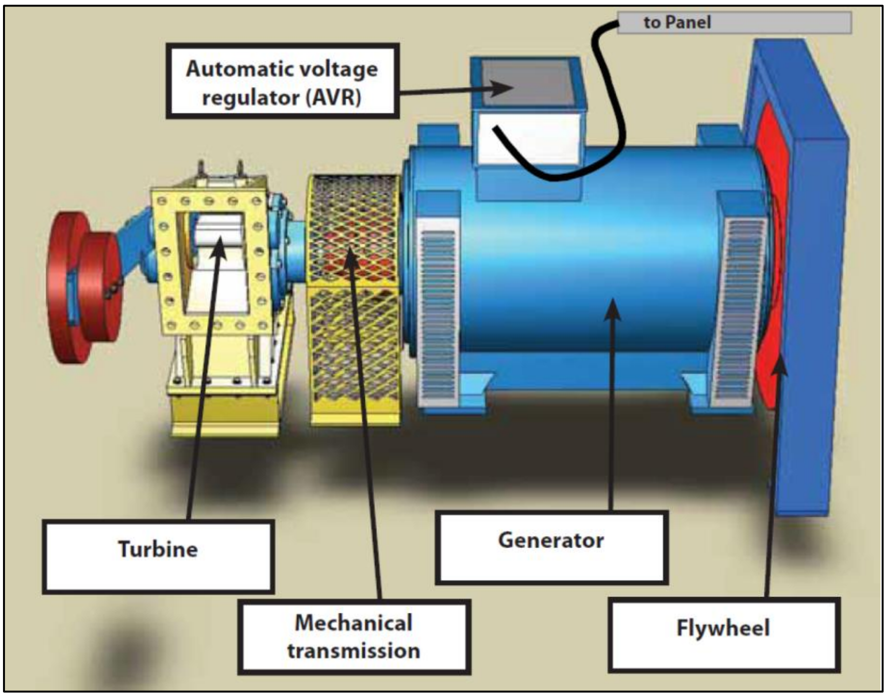


Figure 2-31 - Basic electro-mechanical components of a micro hydropower plant (Jorde and Hartmann, 2009)

2.2.3.2.1 *Hydraulic turbines*

The turbine is the heart of any hydropower plant, considering that it is the turbine which converts the power of the flowing water into rotation of a shaft, which in turn through a generator is capable of producing electricity (Wagner and Mathur, 2011).

Large turbine units have been developed with efficiencies of up to 96% (Gulliver, 1991). Smaller turbines have been relatively more expensive than large turbine when considering the cost per installed capacity of the turbine. However as early as the early 90's, Gulliver in his Hydropower Engineering Handbook (Gulliver, 1991), states that the "recent" escalation of energy cost has made small site economically feasible and has expanded the market for small turbines. The increase in energy cost also justified the extra cost for smaller turbines. Gulliver also comments on the increasing need for turbines in less-developed countries where hydropower has become an attractive source of alternative energy. Due to computer-aided design (CAD) tools, standardized turbine designs can be move up or down to a custom turbine design for the design flow and head requirements at any given site. For this reason it is important to understand the basic turbine hydrodynamics to be able to select the appropriate turbine for current situations and also to be able to evaluate existing turbines for future developments.

The basic equations for turbines as similar to the basic equations for pumps, with the difference being that in turbines the flow is the exact reverse from the flow in pumps. This means that the inflow velocity in the Euler equation for turbines is the outflow velocity in the Euler equation for pumps and visa versa.

The Euler equation states that the torque on the runner of a turbine (or pump) can be found through the conservation of radial momentum (Guliver, 1991). The torque on the runner is the difference between the rate of angular momentum entering and the rate of angular momentum exiting the turbine. With reference to Figure 2-32 this can be written as follows:

$$T = \rho Q(r_1 V_1 cos\alpha_1 - r_2 V_2 cos\alpha_2)$$

Equation 2-17

Where:

T = torque on the runner (N.m)

ρ = fluid density (kg/m^3)

Q = volumetric flow rate (m^3/s)

r_1 = outer radius of turbine blade (m)

r_2 = inner radius of turbine blade (m)

V_1 = velocity entering (m/s)

V_2 = velocity exiting (m/s)

Euler's equation can also be written in terms of energy transferred from the water to the shaft as follows (Hussain, 2009):

$$E = \frac{(u_1 V_{1w} - u_2 V_{2w})}{g}$$

Equation 2-18

Where:

E = energy transferred (m)

u_1 = peripheral velocity of the turbine blade at entry (m/s)

u_2 = peripheral velocity of the turbine blade at exit (m/s)

V_{1w} = velocity of whirl at entry (m/s)

V_{2w} = velocity of whirl at exit (m/s)

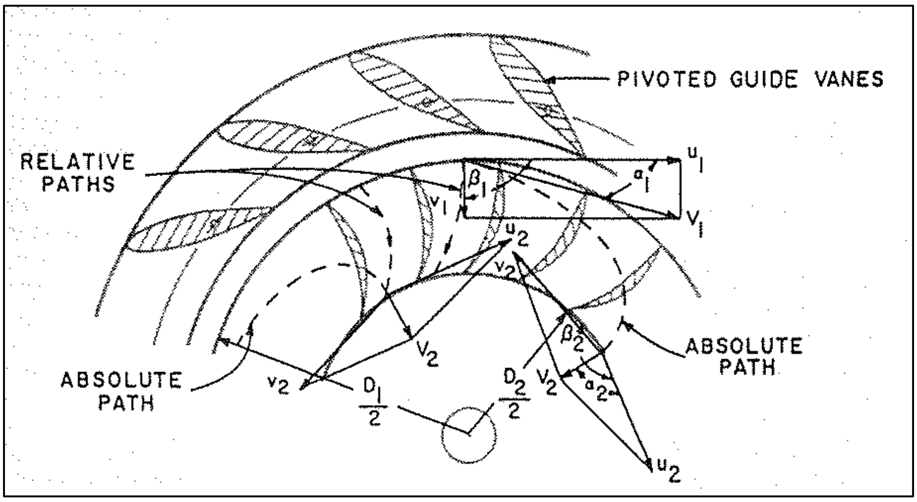


Figure 2-32 - Definition sketch for radial flow turbine runner (Gulliver, 1991)

The energy equation in a rotating frame of reference, such as a radial flow turbine runner, is as follows (Gulliver, 1991):

$$\left[\frac{p_1}{\gamma} + z_1 + \frac{v_1^2 - u_1^2}{2g}\right] - \left[\frac{p_2}{\gamma} + z_2 + \frac{v_2^2 - u_2^2}{2g}\right] = H_L$$

Equation 2-19

Other important basic definitions or equations for hydraulic turbines are power developed as seen in Equation 2-1 and efficiency as follows:

$$\eta_h = \frac{H_u}{H}$$

Equation 2-20

Where:

η_h = efficiency of the turbine (%)

H_u = head utilized (m)

H = net head over turbine (m)

Similarity laws have been developed for characterizing turbine performance of units of different size and type. They provide a means of predicting performance based on the performance of models or the performance of units of design similar to those that have already been built. The power outputs, speeds, and flow characteristics are proportional and they tend to have equal efficiencies. These similarity laws were developed and presented in a series of formulas that defines what are called the turbine constants. (Warnick, 1984). As stated above, these turbine constants, i.e. unit speed, unit discharge, unit power and specific speed can be used to performance of units of design similar to those that have already been built. The turbine constants are as follows (Warnick, 1984):

- Speed Ratio : $k_u = \frac{D_3 N}{60(2gH)^{0.50}}$

Equation 2-21

- Unit Speed : $N_u = \frac{DN}{H^{0.5}}$

Equation 2-22

- Unit Flow/Discharge : $Q_u = \frac{Q}{D^2 H^{0.5}}$

Equation 2-23

- Unit Power : $P_u = \frac{P}{D^2 H^{1.5}}$

Equation 2-24

- Specific Speed : $N_s = \frac{NP^{0.5}}{H^{1.25}}$

Equation 2-25

Where:

D = runner diameter (m)

N = shaft rotational speed (rpm)

g = gravitational acceleration (m/s^2)

H = net head (m)

Q = discharge (m^3/s)

P = power (W)

There are three major criteria for classifying turbines for hydropower plants:

- Direction of flow – Water passes through turbines in different flow paths, according to these paths turbines can be classified into four (4) types (Figure 2-33).
  a. Axial flow turbines – Flow is parallel to axis of rotation of blades, ex. Kaplan and Propeller turbines.
  b. Radial flow turbines – Flow is in plane perpendicular to axis of rotation of blades, ex. Pelton turbines.
  c. Mixed flow turbines – Flow has a significant component of both axial and radial flow, most common turbines in practise, ex. Francis turbines

d. Cross flow turbines – Water runs through the blade ring of the turbine wheel and gives energy twice, both on entering and leaving the blade ring. Ex. Banki or Ossberger turbines

- Pressure change of water – Based on the change of water pressure as it passes through the rotor (turbines wheel) of the turbine, and classified into two (2) groups (Figure 2-33)

a. Impulse turbines – available head is converted into kinetic energy before entering the runner. The kinetic energy of the water impinges on the bucket shaped vanes of the rotor and gets converted into the rotational movement of the shaft. All the power is extracted from the flow at atmospheric pressure. Ex. Pelton turbine.

b. Reaction turbines – Reaction turbines are classified according to the variation in flow direction through the runner. The flow enters and exists the runner at different radii. The change in fluid velocity and the reduction in pressure caused by the difference in radii, causes a reaction on the turbine blades, hence reaction turbines. In reaction turbines the runner is completely submerged. Reaction turbines are low head high flow rate machines.

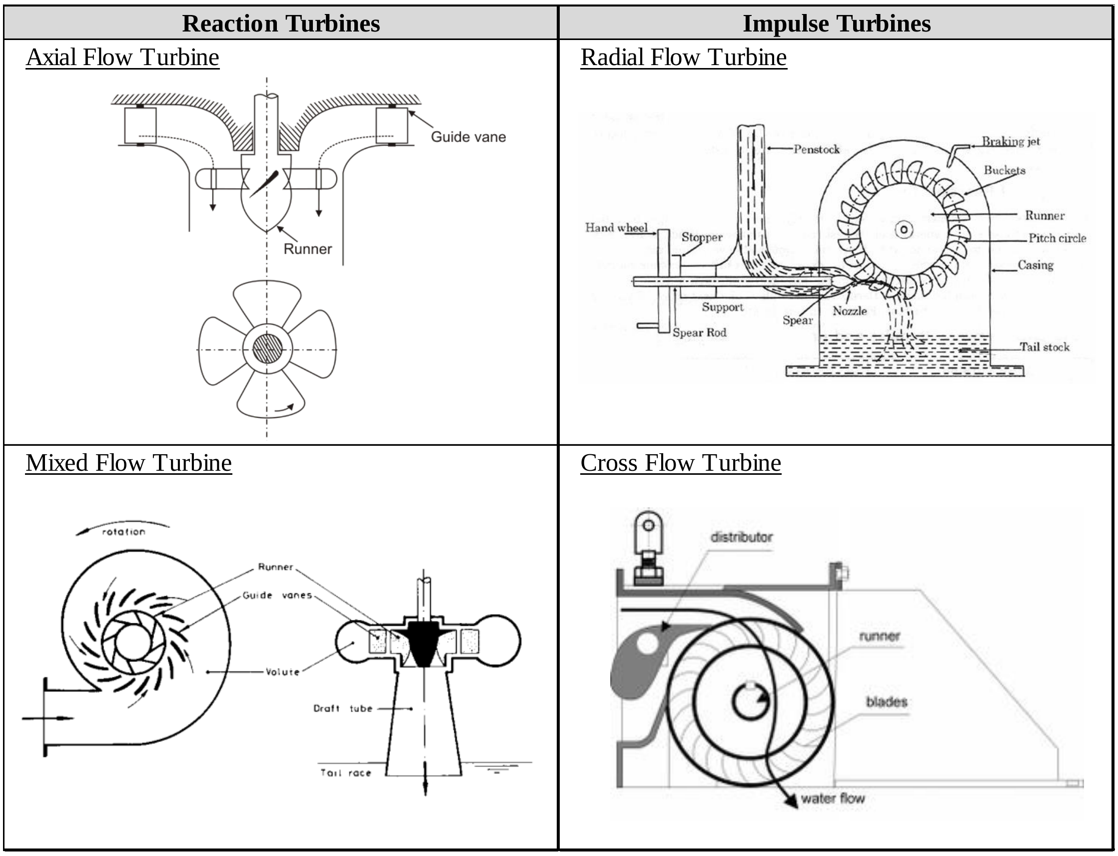


Figure 2-33 – Classification of Turbines

- Shape and orientation of turbine – Categorised by their installation or orientation into three categories.

a. Bulb turbines – axis of flow through turbine orientated nearly horizontal and generator contain in bulb shaped case. Generator partially surrounded by water.
b. Vertical turbines – axis of flow through turbine orientated nearly vertical and generator above the water current.
c. Straflo turbines –Advanced bulb turbine. The rotor blades are fixed to a ring that activates the generator.

The sections below gives an explanation as well as typical operating regions and typical installations of several of the most common turbines in the field of hydropower generation.

The mechanical design of the turbines used does not form part of the study as selection diagrams was used for the determination of the appropriate turbines to be used.

2.2.3.2.1.1 Francis Turbine (Reaction)

The Francis turbine is a radial and mixed flow reaction turbine named after James B. Francis. Energy available from water is transferred to a shaft by means of a rotating runner. The torque from the shaft can in turn be used to drive the electric motor.

Within a Francis turbine the flow is contained within a spiral casing called the volute (Husain, 2009). The volute channels water into the runner and has a decreasing area to maintain uniform velocity to the stationary vanes. The water passes through both a set of fixed vanes and then adjustable vanes before entering the runner. The cross-sectional areas between the adjustable guide vanes can be changed to vary flow when the turbine is only under partially working loads. The water enters the runner at a large radius and leaves at a smaller radius. As previously mentioned the reaction of the water in the runner results in torque being generated by the turbine which can then be used to generate electricity with the electric generator. After the runner the water leaves the turbine through the draft tube. It produces a negative pressure at the turbine exit and thus increases the head over the turbine, resulting in a higher potential to generate power (Hussain, 2009). Figure 2-34 show the main components of a Francis turbine.

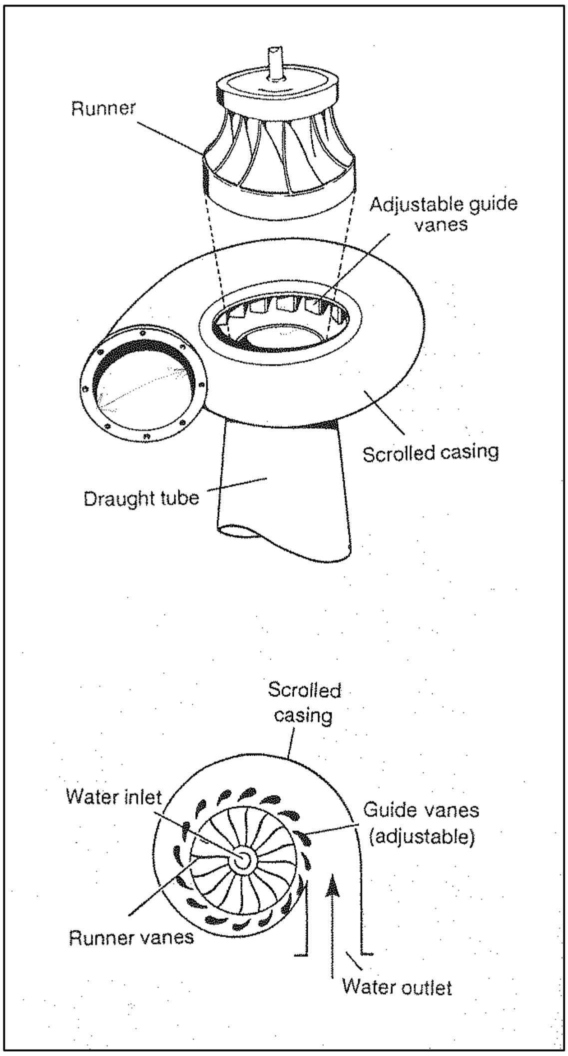


Figure 2-34 - Francis Turbine (Harvey, 1993)

The Francis turbine is most suitable for medium to high flow and medium to high head installations, but can be used for almost all available heads. The following is examples of advantages of the Francis Turbine over the Pelton wheel/turbine, as well as disadvantages of the Francis Turbine over the Pelton wheel/turbine (electricalengineeringtutorials.com).

Advantages of Francis Turbine:

- The variation in the operating head can be more easily controlled in Francis turbine than in Pelton wheel turbine
- The operating head can be utilized even when the variation in the tail water level is relatively large when compared to the total load
- The size of the runner, generator and power house required is small and economical if the Francis turbine is used instead of Pelton wheel for the same power generation.
- The mechanical efficiency of the pelton wheel decreases faster with wear than Francis turbine

Disadvantages of Francis Turbine:

- Water which is not clean can cause very rapid wear in high head Francis turbine and can quickly reduce overall efficiency of the turbine by several percentage.
- The inspection and overhaul of a Francis Turbine is much more difficult job than that of the equivalent Pelton turbine.
- Cavitation is an ever present danger in Francis Turbine as well as in all the reaction turbines. The raising of the power house floor level to reduce the danger of flooding may be followed by the endless cavitation troubles.
- Usually below 60% load, the Pelton wheel have much better efficiency than the Francis turbine of lower specific speeds.
- The water hammer effect with the Francis turbine is more troublesome than the Pelton turbine.

2.2.3.2.1.2 Kaplan Turbine (Reaction)

Kaplan turbines are low head, high flow rate turbines. The Kaplan turbine has a spiral casing and guide vanes similar to the Francis turbine. The flow enters the runner through guide vanes which can be set to a required angle to accommodate changes in power needs. The guide vanes ring is in a plane perpendicular to the shaft and thus the flow is radial. The runner is further downstream from the vanes, the water turns through 90 degrees to the runner into an axial direction (Hussain, 2009).

The basic Kaplan turbine/propeller turbine (Figure 2-35) consists of a propeller (similar to ships propeller) fitted inside a continuation of the penstock tube, with its shaft taken out where the tube changes direction (Harvey, 1993).

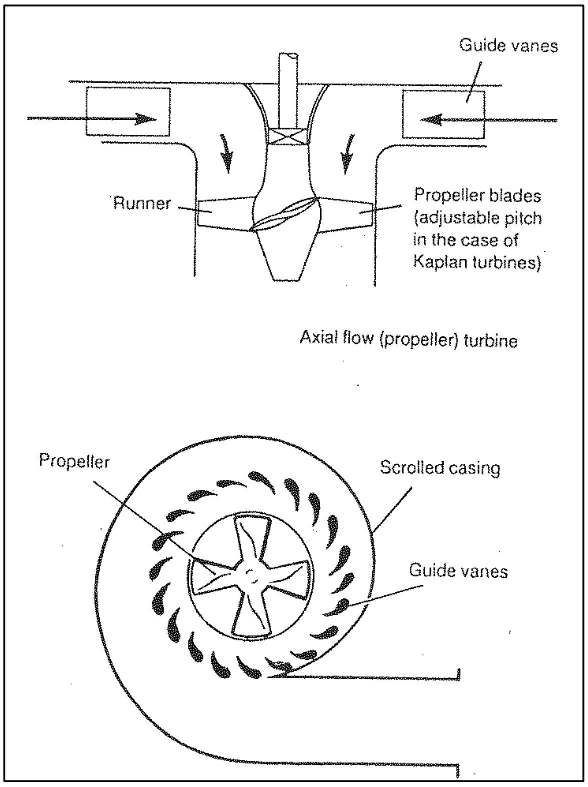


Figure 2-35 - Propeller and Kaplan Turbines (Harvey, 1993)

With Kaplan or Propeller turbines there is a large difference in radii between the hub and the tip of the blades.

The Kaplan turbine is suitable for low to medium flow and low to medium head installation. The advantages (Electrical Engineering Tutorials, 2015) of the Kaplan turbine are as follows.

Advantages of Kaplan Turbine:

- It is more compact in construction and smaller in size for the same power developed
- Its part load operating efficiency is considerably high. The efficiency curve of Kaplan turbine remains flat over the whole load range
- The frictional losses passing through the blades considerably lower due to small number of blades used in Kaplan Turbine

2.2.3.2.1.3 Hydrodynamic screw type turbine (Archimedean principle) (Reaction)

Screw-type turbines are based on the principle of an Archimedes screw pump in reverse that operates by utilising the hydrostatic pressure difference across the blades (Williamson, Stark and Booker, 2012). Screw-type turbines are used in low-head, high-flow applications (International Energy Agency, 2010).

A study done by Future Energy Yorkshire indicated that in terms of capital cost the Archimedes' screw turned out 22 percent cheaper than an equivalent Kaplan turbine (FEY, 2012). It is also reported that screw type turbines are less harmful to fish. A schematic view of a screw type turbine installation is shown in Figure 2-36.

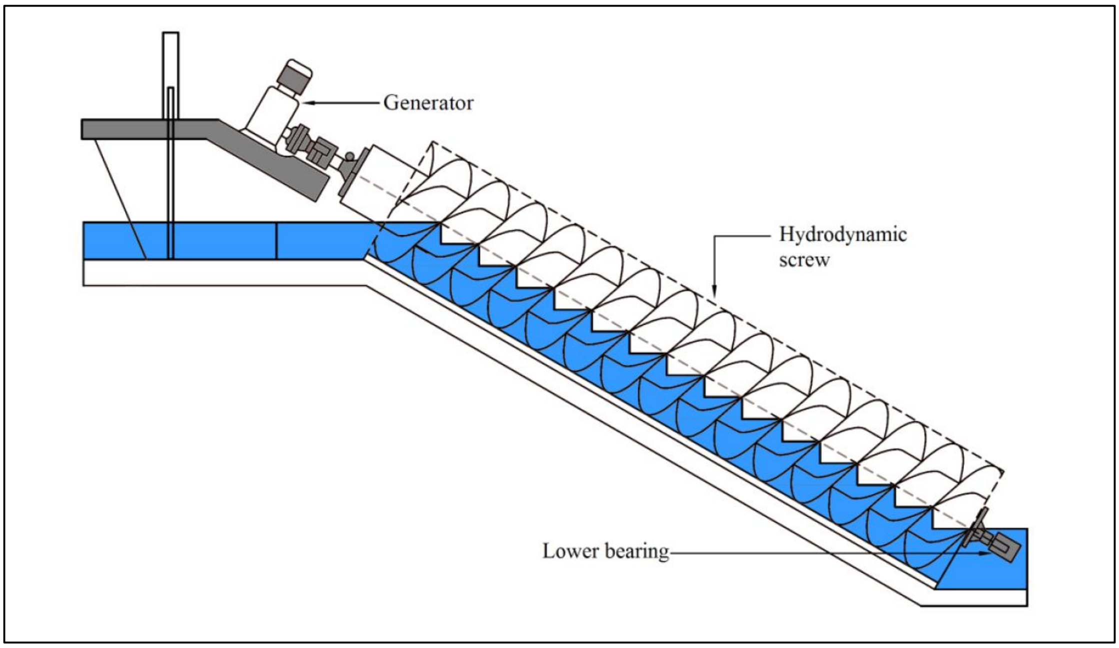


Figure 2-36 - Screw type turbine design (Bouk, 2011)

2.2.3.2.1.4 Vortex turbines (Reaction)

The vortex power plant (Figure 2-37) is a type of micro hydropower plant capable of producing energy using a low hydraulic head. The design is based on a round basin with a central drain (Loots et al., 2015) The water passes through a straight inlet and then passes tangentially into the round basin. A large vortex is formed over the center bottom drain of the basin and a turbine then withdraws the rotational energy from the vortex, which is converted into electric energy by means of a generator (Zotlöterer, 2013)

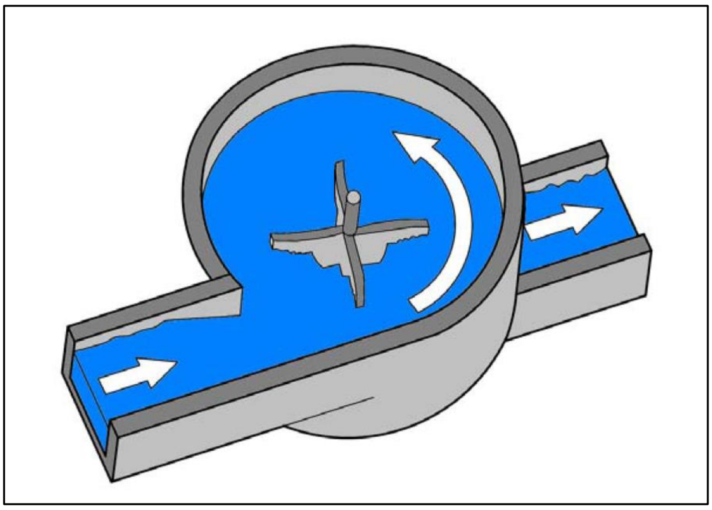


Figure 2-37 - Vortex type turbine installation in a river (Zotlöterer, 2013)

2.2.3.2.1.5 Siphon turbines (Reaction)

These turbines have propeller blades, similar to the blades found in Kaplan turbines. The blades are connected to a turbine shaft that turns a generator. The turbine only starts operating after 30-60 seconds, during which the generator acts as an electromotor that pumps water into the siphon until it is primed, there after it starts functioning as a generator (Figure 2-38) (Mavel, 2013).

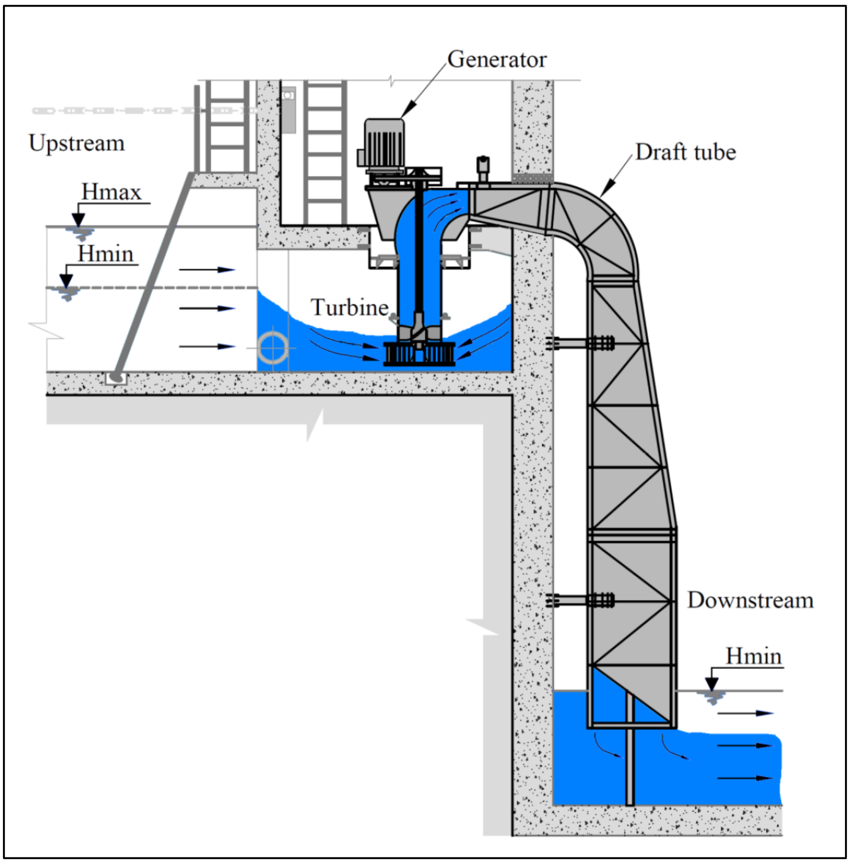
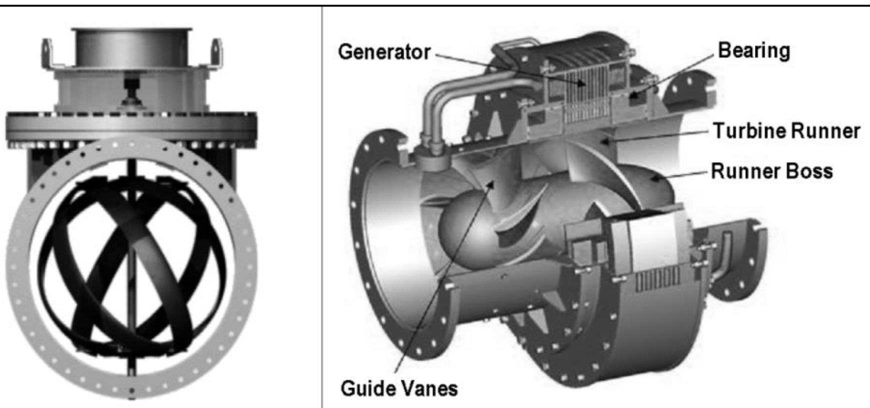


Figure 2-38 - Siphon turbine (Mavel, 2013)

2.2.3.2.1.6 Inline turbines (Reaction)

Recently the development and use of inline turbines has increased (loots et al., 2015). These turbines include spherical and ring turbines (Figure 2-39) do not need a bypass and are installed directly in the primary conduit of a pressurised system. These turbines can typically generate between 1 kW and 100 kW and are therefore applicable in pico- and micro-hydropower installations (Kanagy, 2011; International Energy Agency, 2010).



(a) Spherical turbine (Kanagy, 2011)
(b) Ring turbine (International Energy Agency, 2010)

Figure 2-39 - Examples of inline turbines

2.2.3.2.1.7 Pump as turbine (PAT) (Reaction)

There has been much research done on pumps used as hydraulic turbines. The pumps are reverse-engineered i.e. a standard centrifugal pump is run in reverse to act as a turbine. This is a very attractive option in developing countries as pumps are mass-produced and therefore more readily available and cheaper than turbines (Williams, 2003). However, PATs generally operate at lower efficiencies than conventional turbines, especially at partial flows (Loots et al., 2015)

Williams, Smith, Bird and Howard at the Nottingham Trent University Micro-Hydro Centre (Williams et al, 1998) have been involved with the design and installation of various PAT schemes. The university demonstration scheme at a farm in Yorkshire has been running since 1991. The pumps are now mass-produced and as a result, have the following advantages for micro-hydropower compared with purpose-made turbines (Loots et al., 2015):

- Low cost
- Available in a number of standard sizes
- Short delivery time
- Spare parts such as seals and bearings are easily available
- Easy installation – uses standard pipe fittings
- Standard pump motor can be used as a generator

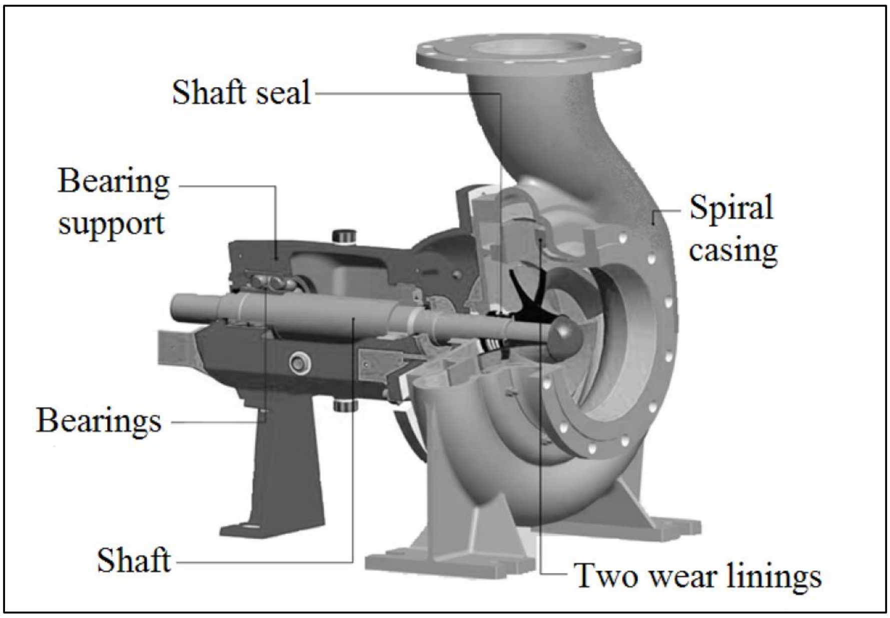


Figure 2-40 - An example of a pump as turbine (Mellacher and Fiedler, 2013)

2.2.3.2.1.8 Pelton Turbine (Impulse)

The Pelton turbine is an impulse turbine, operating by the impact of a water jet hitting the runner blades (Rodriguez and Sanchez, 2011). Water with high head from the penstock is accelerated through the nozzle of the Pelton turbine, turning the high head into velocity and discharging at a high speed in the form of a jet at atmospheric pressure. The jet strikes the buckets of the Pelton Turbine which is attached to the runner (Hussain, 2009), which in turn turns the shaft connected to the electric generator. The kinetic energy from the water jet is lost to the buckets, and water with relatively low speed falls into the tailrace or lower reservoir. Tailrace must be set to avoid submergence of the Pelton turbine/Pelton wheel during flooded conditions (Hussain, 2009).

If higher running speeds or a smaller runner/Pelton wheel is required the following can be implemented on the Pelton turbine (Harvey, 1993):

- Increased number of jets – more jets will allow smaller runner for a given flow and hence an increased rotational speed.
- Twin runners – two runners can be used side by side on the same shaft or on either end of the generator on the same shaft (take care to run twin runners on either side of generator on same shaft but in different directions). Allow plenty space to avoid splash interference.

The Pelton turbine has a spear rod or nozzle spear which controls the water to the turbine (Figure 2-41).

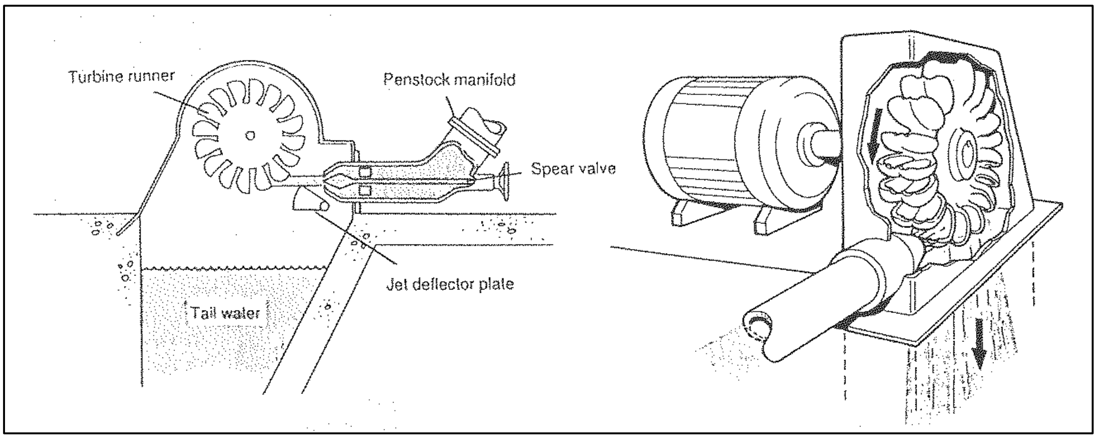


Figure 2-41 - Single jet Pelton wheel (Harvey, 1993)

The Pelton turbine is most suitable for low flow and high head installations. Advantages of the Pelton wheel/turbine is that it has a high overall efficiency, it is easily assembled, operates at low discharge, has a flat efficiency curve and can be operated in silted water.

Disadvantages of the Pelton wheel/turbine is the decrease in efficiency with time, the components of the Pelton wheel/turbine are large in size and a variation in the operating head is very difficult to control. An example of a Pelton turbine is presented in Figure 2-42.

Figure 2-42 - Example of a Pelton turbine (IREM)

2.2.3.2.1.9 Cross-Flow Turbine (Impulse)

This is an impulse turbine that spins as a result of the impact of the water jet on its blades. The runner is shaped like a drum formed by a group of blades welded onto two parallel discs (Rodriguez and Sanchez, 2011). Cross-flow turbines have often been used in micro hydroelectric schemes, because they require simpler manufacturing facilities than are required for other types of turbine (Rodriguez and Sanchez, 2011).

A cross-flow turbine (also called a Banki or Mitchell turbine) always has its runner shaft horizontal to the ground. In operation the nozzle directs the water jet to the full length of the runner. The water strikes the blades and imparts most of its kinetic energy, then it passes through the runner and strikes the blade again at exit and imparts a smaller amount of energy before leaving the turbine (Harvey, 1993). An example of a cross-flow turbine is presented in Figure 2-43.

Figure 2-43 - Example of a cross-flow/Banki turbine (IREM)

Because of the symmetry of the cross-flow turbine, the runner length can theoretically be increased to any value without changing the hydraulic characteristics of the turbine. Hence, doubling the runner length merely doubles the power output at the same speed. The lower the head, the longer the runner becomes, and conversely on high heads the cross-flow runner tends to be compact (Harvey, 1993). The selection and design of runner diameter depends on the flow conditions. A larger flow through the turbine requires a larger diameter runner and a lower flow through the turbine requires a smaller diameter runner (Khan and Badshah, 2014).

There are practical limits in both cases. If the blades are too long the flex of the blade will lead to fatigue failure. With short runners efficiency losses at edge of the runner become considerable.

The cross-flow turbine is suitable for a design, and is efficient, over a wide range of heads and power ratings. This along with the fact that it lends itself easily to simple fabrication and maintenance, makes it a very suitable turbine for consideration in hydropower projects in developing countries.

The dimensions of interest in sizing a cross-flow turbine is as follows:

- Runner length (L_{runner})
- Runner diameter (D_{runner})
- Jet thickness (t_{jet})

The width of the rectangular jet orifice is always the length of the runner. The second cross-sectional dimension, the thickness, is designed for optimum performance.

2.2.3.2.1.10 HydroEngines (Impulse)

HydroEngine turbines are constructed with two shafts connected to blades moving in an elliptical path between the shafts with the power transfer in the linear motion portion of blade travel. Water enters the turbine and gets directed to the first, and subsequently the second, set of blades by guide vanes (Natal Energy, 2013), as shown in Figure 2-44. HydroEngine turbines are similar to a cross-flow turbine in that water passes through the blades twice. The turbines are used in similar circumstances as a Kaplan turbine, except where Kaplan turbines often require sub-surface installation to avoid cavitation on the blades. There is no cavitation potential with the hydroEngine™.

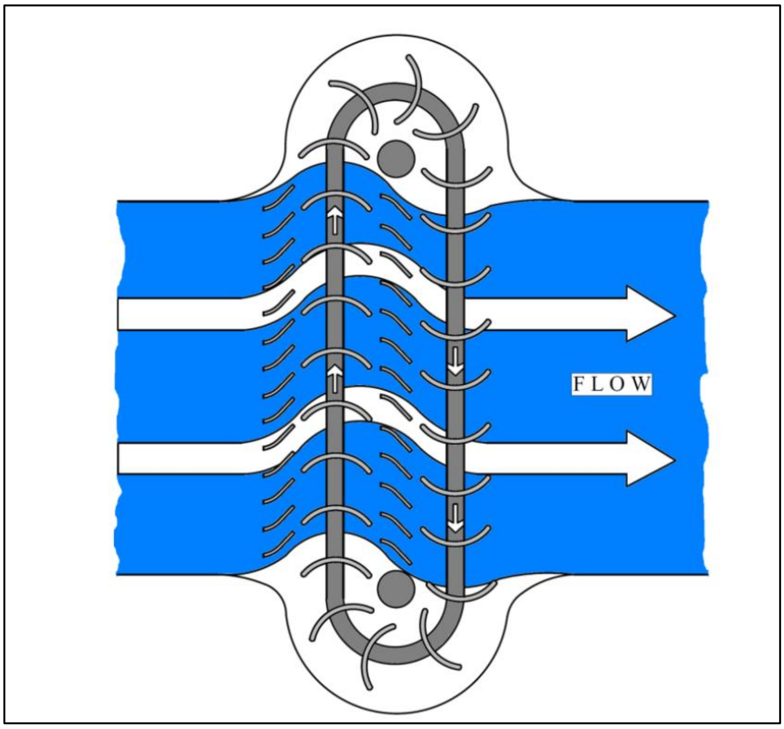


Figure 2-44 - Working philosophy of a HydroEngine turbine (Natel Energy, 2013)

2.2.3.2.1.11 Water wheels (Impulse)

For many years water wheels have been used as the traditional method for generating hydropower in small quantities. They are less efficient than turbines, yet remain a practical option in certain cases, as they are simple to control, easy to construct and maintain and are aesthetically pleasing (Natural Resources Canada, 2004).

Three main variations exist for water wheels each with its optimal applications:

- The Undershot wheel is vertically mounted on top of the water surface. The wheel is turned by the water flowing underneath the wheel. Figure 2-45 is a schematic of an undershot wheel.

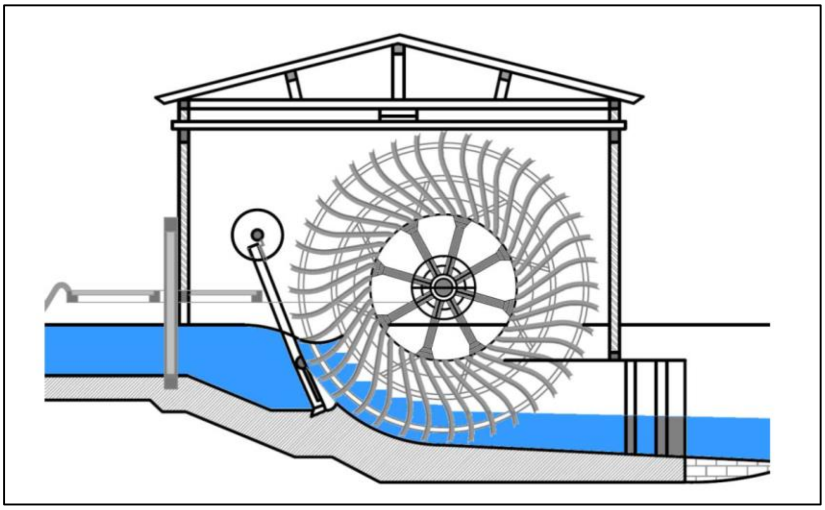


Figure 2-45 - Undershot wheel (Muller, 2004)

- The Breastshot wheel receives energy from falling water which hits the blades at the centre height of the wheel. A breastshot wheel is shown in Figure 2-46.

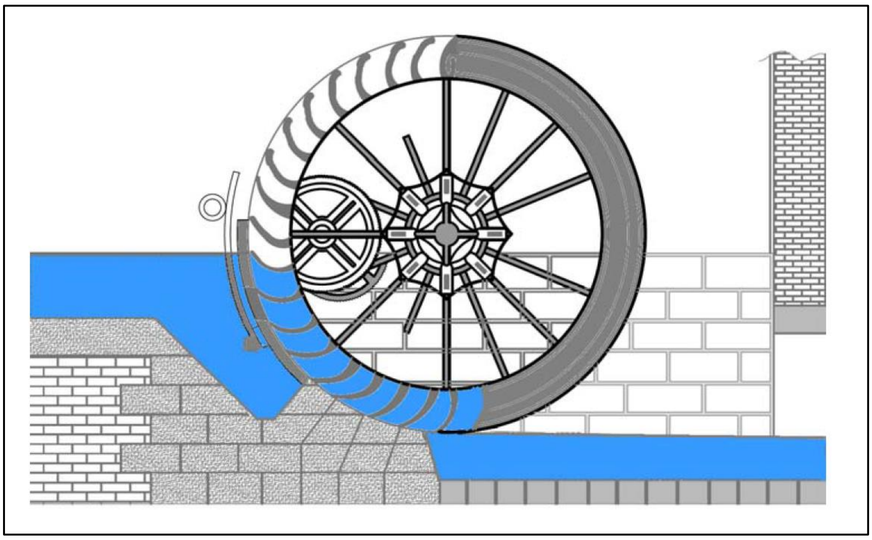


Figure 2-46 - Breastshot wheel (Muller, 2004)

- An Overshot wheel works in much the same manner as the breastshot wheel, only with the water striking the blades near the top of the wheel. Such an installation is shown in Figure 2-47.

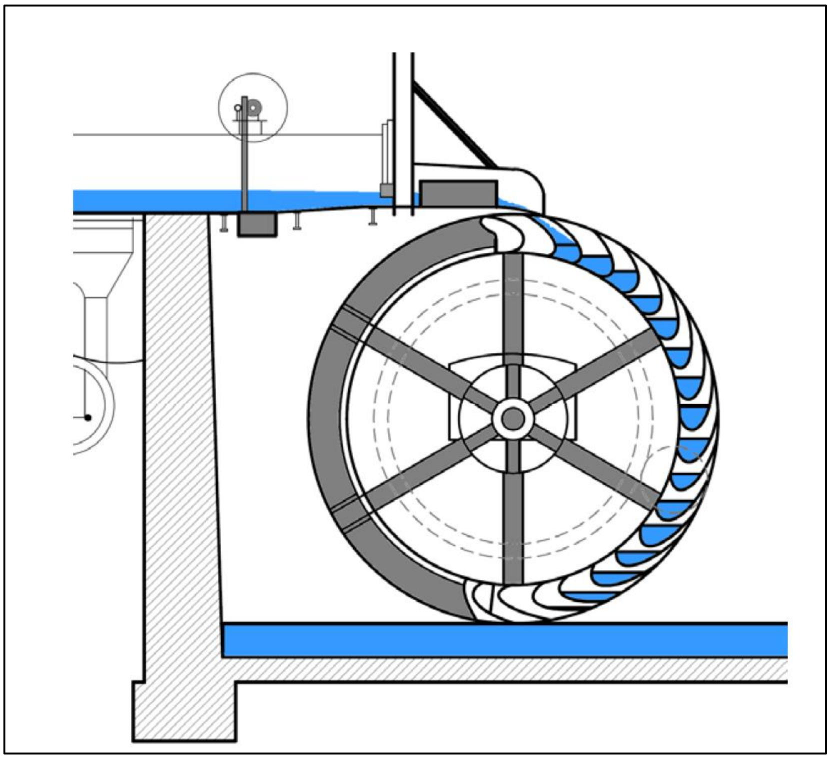


Figure 2-47 - Overshot wheel (Muller, 2004)

2.2.3.2.1.12 Hydrokinetic turbines (Kinetic)

Hydrokinetic turbines generate electricity using the kinetic energy of the water in low head applications, instead of the potential energy due to hydraulic head, as in high pressure applications (Loots et al., 2015). These devices do not require dams or diversions but capture energy from moving water (Kumar, Schei, Ahenkorah, Caceres Rodfriguez, Devernay, Freitas, Hall, Killingveit and Liu, 2011).

Two basic rotors are most commonly used. The Darrieus and Open Savonius rotors are shown in Figure 2-48. Most other hydrokinetic rotors work in a similar manner. These rotors can be placed horizontal or vertically (Loots et al., 2015).

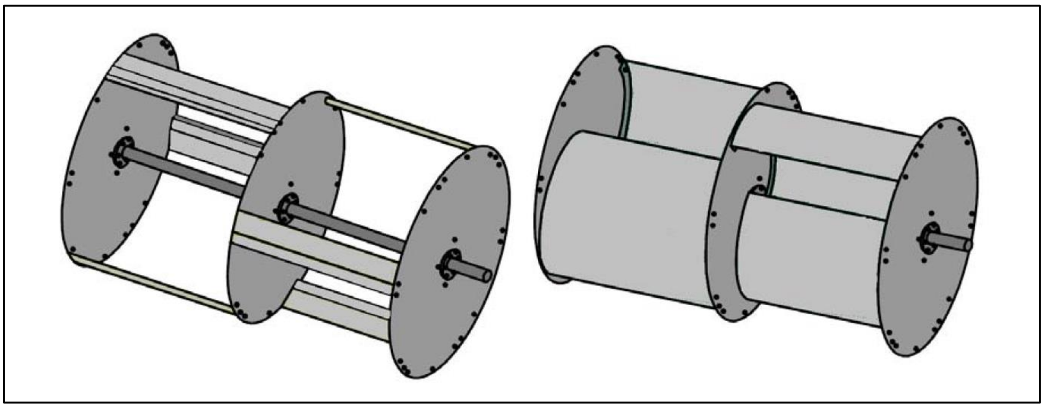


Figure 2-48 - Darrieus (left) and Open Savonius (right) rotors (Hydrovolts, 2011)

2.2.3.2.2 Turbine operating ranges and efficiency

The efficiency of a turbines is subject to the type of turbine and the water flow or flow rate of the water. Pelton and Kaplan turbines has a high efficiency over a wide range of flows, Francis turbines a bit less so and Propeller and Crossflow turbines have a distinct optimum, as can be seen from Figure 2-49 (Wagner and Mathur, 2011).

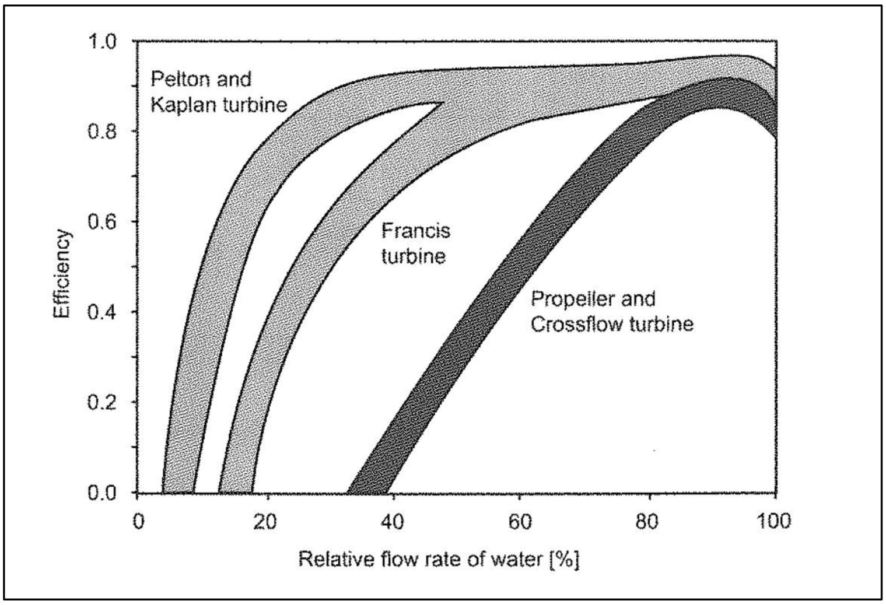


Figure 2-49 - Typical efficiency curves for different turbine types (Wagner and Mathur, 2011)

It is important to note that the maximum efficiency of all turbines are in the range of 90%. It is also important to note that this maximum efficiency is not at the maximum flow (Wagner and Mathur, 2011).

Figure 2-50 can be used to preliminary determine the most suitable turbines for any specific application (Loots, Van Dijk, Barta, Van Vuuren and Bhagwan, 2015). Figure 2-50 illustrates the following with regards to the operating ranges for several of the different types of turbines:

- The Pelton turbine is suitable for low flow and high head installations

- The Francis turbine is suitable for medium to high flow and medium to high head installations
- The Kaplan turbine is suitable for low to medium flow and low to medium head installation

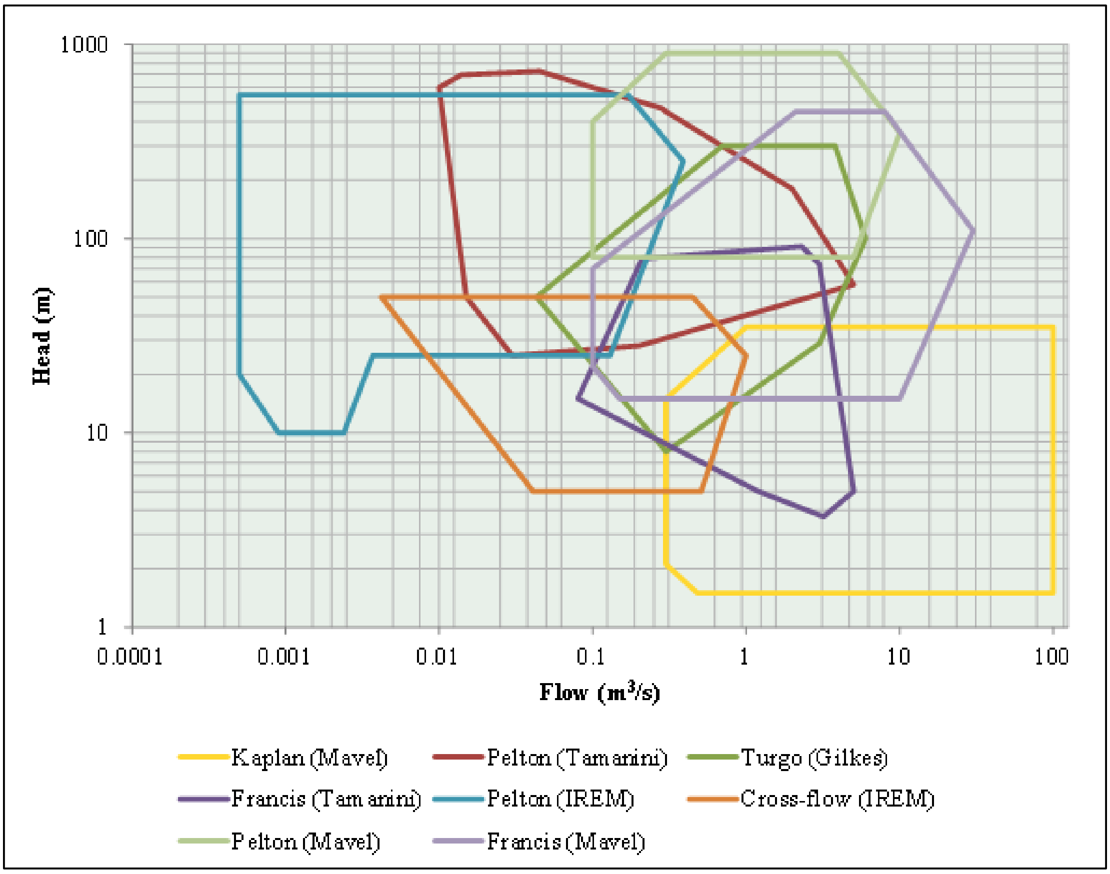


Figure 2-50 - Operation areas for hydro turbines (Loots et al., 2015)

The suitable impulse turbines (Table 2-3) and reaction turbines (Table 2-4) for low head hydropower applications are shown in the following tables.

Table 2-3 - Impulse turbines suitable for low head hydropower (Loots et al., 2015)

Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power output (kW)
Pelton	Powerspout	0.008-0.01	3-100	<1.6
Cross-flow (Banki)	IREM	0.01-1.0	5-60	<100
	Ossberger	0.04-13	2.5-200	15-3000
	Wasserkraft Volk	1.5-150	Not given	<2 000
hydroEngine™	Natel Energy	1.1-12	<6	20-500
Hydrodynamic (Archimedean) Screw	Andritz	<10	<10	<500
	Hydro Coil	<10	4-20	2-8
	3 Helix Power	0.2-10	1-10	1.4-700
Waterwheel	Hydrowatt	0.1-5	1-10	1.5-200
	Steffturbine (Walter Reist)	<0.4	2.5-5	10

Table 2-4 - Reaction turbines suitable for low head hydropower (Loots et al., 2015)

Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power output (kW)
Kaplan (Propeller and bulb included)	Ossberger	1.5 - 60	1.5 - 20	20 - 3 500
	Mavel	0.3-150	1.5 - 35	30 - 20 000
	Voith	Not given	3 - 95.0	100 - 400000
	Energy systems & Design	0.03-0.06	0.5 - 3.0	0.09 - 1
	Power Pal	0.04-0.13	1.5	0.1 - 1
	Wasserkraft	Not given	1 - 40	Not given
	Gugler	0.2 - 50	1 - 100	3 - 10 000
	Alstom	0.3-150	2 - 30.0	< 130 000
	Voith	2-30.0	Not given	1000 - 80 000
	Voith(Minihydro)	1-14.0	2 -10.0	Not given
	Tamanini	1.0 - 15	5 - 20	50 - 2 000
	Hydrolink	Not given	1.5 - 25	Not given
Hydrokinetic	Alternate Hydro	>0.8 M/s	>0.6	1 - 4.0
	New Energy Corporation	2.4 - 3 m/s	Not given	5 - 25.0
	Alden	<2.6	25	Not given
	Hydrovolts	1.5 - 3 m/s	0.15	1.5 - 12
Vortex	Zotlöterer	0.05-20	0.7 - 2	0.5 - 160
Francis	Wasserkraft Volk	Not given	<300	< 20 000
	Mavel	0.1 - 30	15 - 440	20 - 30 000
	Gilkes	0,05 - 40	<400	< 20 000
	Voith	Not given	3 - 95	5 - 1000 000
	Gugler	0.03 - 25	2 - 500	3 - 10 000
	Tamanini	0.2 - 10	15 - 300	20 - 5 000
	Hydrolink	Not given	20 - 120	Not given
	Newmills Engineering.ltd.	Not given	10 - 350	1 - 820
	Kössler	0.8 - 60	15 - 250	500 - 15 000
Siphon	Mavel	0.15 - 4.5	1.5 - 6	1 - 180
Inline	Kawasaki Ring	0.14 - 2.8	3 - 30.0	20 - 500
	Hydro E - kids (Toshiba)	0.1 - 3.5	2 - 15.0	5 - 200
	Lucidpipe Spherical	1 - 5.6	0.5 - 10	14 - 100
Pump as turbine	Andritz	0.03 - 6	3 - 80	310 000
	Voith	Not given	0 - 700	10 - 500 000
	Varspeed Hydro	0.007 - 0.4	20 - 150	1 - 350
	Cornell	<0.42	<120	Not given

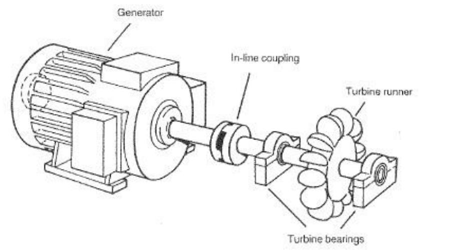
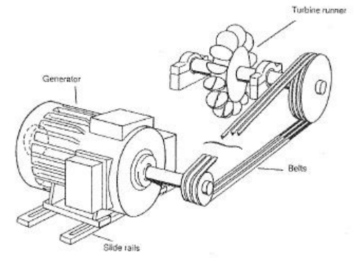
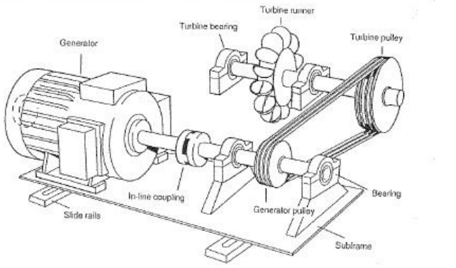
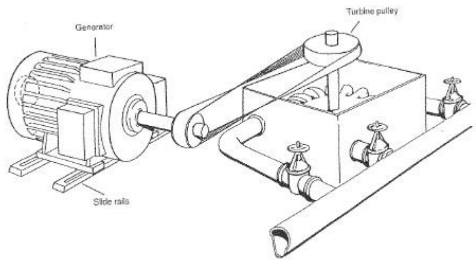
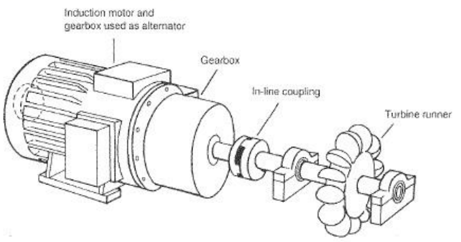
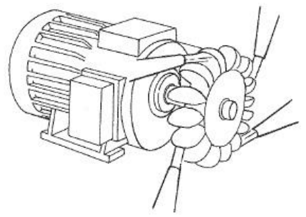
2.2.3.2.3 Drive System

The function of the drive system is to transmit power, in the form of mechanical energy, from the turbine to the generator at the correct speed for the generator and in a suitable direction. Drive systems comprises of the generator shaft, turbine shaft, the bearings which support those shafts and any other components to change the speed and orientation of the shafts for the correct speed and suitable direction. Figure 2-51 shows an example of a belt driven cross-flow turbine.

In direct drive systems the shafts of the turbine and generator are connected directly. This is a relatively cheap and efficient drive system, but can only be used if the angular velocities of the turbine and generators shafts are approximately equal (Muhammad and Karimov, 2010). Wedge belts and pulleys can be effective in micro-hydropower systems and a sprocket pulley in a micro hydropower system of power less than 3 kW. Gearboxes as drives are used at relatively large systems (Muhammad and Karimov, 2010). Table 2-5 shows several different possible arrangements for a drive system.

Figure 2-51 - Example of belt driven cross-flow turbine at Bloemwater, Bloemfontein, South Africa

Table 2-5 - Different drive arrangements (Harvey, 1993)

1) Direct coupled drive system 	2) Wedge belt drive system 
3) Wedge belt drive system with extra bearings 	4) Quarter turn belt drive 
5) Direct coupled turbine and geared motor used as alternator 	6) Turbine rotor mounted on generator shaft 

2.2.3.3 Electrical Components

2.2.3.3.1 Electric Generator

Hydroelectric generators are salient pole machines and have relatively slow operating speeds, in the range of 80-1000 rpm. This is in contrast to the cylindrical rotor machines commonly used at fossil-fuel plants, which operate at speeds up to 3,600 rpm.

Hydroelectric generators consists out of several major components. The Stator is the static part of the electric generator and consists of the stator foundation support members, a stator frame, stator core, and the stator windings. The stator core consists of thin sheet steel laminations stacked on top of one another. This is also referred to as the stator coil. When the rotor is rotated, a voltage is induced in the stator coil. At any instant, the magnitude of the voltage is proportional to the rate at which the magnetic field encircled by the coil is changing with time—i.e., the rate at which the magnetic field is passing the two sides of the coil.

The Rotor contains magnetic fields which are established by the exciter. When the rotor is turned it induces current in the stator. The changing polarity within a typical AC generator produces the alternating characteristics of the current. The central shaft of the rotor is coupled to the mechanical prime mover, which in the case of a hydroelectric generator would be the turbine. The generator shaft is typically bolted directly to the turbine shaft and conveys the mechanical power from the turbine to the generator rotor. The generator is normally designed with the shaft as short as possible, in order to reduce vibrations and minimize cost (Clemen, 1999).

Hydro generators are provided with a mechanical friction braking system. This system helps stop the generator's rotation after the unit is tripped off-line. Mechanical friction brakes usually are applied when the unit rotation has slowed to less than 25 percent of the operating speed. Stopping the unit at this point avoids wear on the thrust bearing. Hydro generators have thrust bearings located either at the top or bottom of the generator to support the rotating weight of the machine (Clemen, 1999).

There are mainly three (3) different types used in hydropower systems. Synchronous generators (SG), asynchronous generators (AG) and Direct Current generators (DC). In synchronous generators the rotor field and the magnetic field of the stator's currents are rotating synchronously. If the stator's rotational angular velocity is constant then the stator currents frequency is constant. In asynchronous generators the rotational angular velocities are usually different (Muhammad and Karimov, 2010). 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 (Penche, 1998)

Synchronous generators equipped with a Direct Current excitation system (rotating or static) associated with a voltage regulator, to provide voltage, frequency and phase angle control before the generator is connected to the grid. Synchronous generators also supply the reactive energy required by the power system when the generator is tied into the grid. Synchronous generators can run isolated from the grid and produce power since excitation is not dependent of the grid (Penche, 1998).

Before connecting it to the mains by the turbine rotation, the synchronous generator is started after which the turbine is gradually accelerated to synchronise the generator with the mains, regulating the voltage, frequency and rotating sense. When the generator reaches a velocity close to synchronous, the exciter regulates its field coils current so the generator voltage is identical to the mains voltage (Penche, 1998).

When the synchronous generator is connected to an isolated net, the voltage controller maintains a predefined constant voltage, independent of the load. The controller maintains the reactive power at a pre-defined level if it is connected to the main supply (Penche, 1998).

Asynchronous generators are simple squirrel-cage induction motors with no possibility of voltage regulation and running at a speed directly related to system frequency. Asynchronous generators receives or draws their excitation current from the grid. Adding a bank of capacitors can compensate for the absorbed reactive energy. Asynchronous generators are incapable of providing their own excitation current and therefor cannot generate electricity when they are not connected to a grid With an asynchronous generator the mains supply defines the frequency of the stator rotating flux and hence the synchronous speed above which the rotor shaft must be driven (Penche, 1998).

On start-up, the turbine is accelerated up to 90-95% of the synchronous speed of the generator, when a velocity relay close the main line switch. The generator passes immediately to hyper-synchronism and the driving and resisting torque are balanced in the area of stable operation (Penche, 1998).

Direct current generators are only used for special applications or local power generation. The DC generators have one main advantage over AC generators in the sense that the DC generators can charge batteries directly. The DC generators are basically AC generators whose output voltage is switched properly to ensure that the voltage is always in a single direction with its multitude changing (Muhammad and Karimov, 2010). These generators are more reliable and universal than AC generators but are more expensive, especially with rotors in the form of squirrel cages (Muhammad and Karimov, 2010).

The type of DC generator is characterized by the manner in which the field excitation is provided. In general the method employed to connect field and armature windings are classified into two (2) groups.

1. Separately excited generators – has field exciter terminals, external DC voltage source that produces a separate magnetic field winding for the magnetizing of the generator.
2. Self excited field generators – produces a magnetic field by itself without DC sources from an external. The electromotive force that is produced by the generator at the armature winding is supplied to a field winding instead of DC source from outside of the generator.

In micro-hydropower systems mainly synchronous generators are used (Muhammad and Karimov, 2010). In both the books Small Hydroelectric Engineering Practices (Leyland, 2014) and Introduction to Hydro Energy Systems (Wagner and Mathur, 2011), mention is only made of synchronous generators for hydroelectric power generation. Synchronous generators are currently used for generating hydro electric electricity in general. DC generators are no longer used in hydroelectric plants (Rodriguez and Sanchez, 2011).

2.2.3.3.2 Transformers

The transformers in any electrical system acts as the interface between the electrical generator and the power transmission systems or transmission lines. The electrical generators and transmission system components are designed to operate at specific voltage levels. The transformer's function is to convert electrical power from one voltage level to another, permitting the power to be transmitted between system components operating at different voltage levels (Clemen, 1999).

At hydroelectric plants, large transformers perform the primary task of delivering power produced by the generators to the transmission system. The voltage of the generated middle or low voltage electricity by generator, is increased into very high voltage electricity. High voltage is preferred for the transmitting of power over long distances as technical losses are reduced (Walter and Mathur, 2011)

Transformers fall into two categories: liquid-immersed transformers, which are normally used for power transfer rates greater than 10 MVA and voltages higher than 34.5 kV, and dry transformers, which are normally used for power transfer rates less than or equal to 10 MVA and voltages below 34.5 kV. Liquid immersed transformers also may be used for power transfer rates less than 10 MVA and voltages below 34.5 kV, if they are located outdoors. Liquid-immersed transformers are seldom utilized indoors because of the associated fire hazard (Clemen, 1999).

The transformer that transmits the power produced by the hydropower plant to the transmission system or utility network is commonly called the generator step-up (GSU). In order to perform this task, the transformer must convert the low voltage at which the generator produces power to a level that matches the transmission system.

Transformers are also used at hydroelectric plants in the plant electrical auxiliary systems, which typically require from one to six percent of the unit MVA rating. Electrical auxiliaries include unit auxiliaries (systems, such as the excitation system or governor oil pressure system, that are directly associated with individual units) and station auxiliaries (systems associated with operating the station as a whole, such as a sump pump drainage system). Transformers used for plant electrical auxiliaries today are usually dry-type transformers (Clemen, 1999).

2.2.3.3.3 *Control of hydroelectric plants*

Electrical appliances for both domestic and industrial purposes, powered from hydroelectric plants, require a steady electricity supply. This means that the frequency and voltage must be as constant as possible (Rodriguez and Sanchez, 2011). Depending on the different appliances, there may exist different tolerances to variations in frequency and voltage.

There are two main ways of generating electricity with constant frequency and voltage. The first way is to regulate the flow of water into the turbine so that only the required quantity of water needed to produce the required quantity of energy enters the turbine (Rodriguez and Sanchez, 2011). The second way is to always generate electricity at full capacity or full load, part of the energy is then used to meet the demand and the surplus goes to a ballast load. A ballast load might be a group of resistances that limit the amount of current by heating either air or water (Rodriguez and Sanchez, 2011).

The flow controllers are most often used in large plants. Hydraulic-mechanical governors are designed to detect minimum variations in demand though frequency sensors. These sensors transmit orders to valves of guide vanes which will open or shut and so maintain a constant frequency. The electronic load controller diverts excess electricity to a power dissipation system. Electronic load controllers are currently used in mini, micro and pico hydroelectric plants, mainly due to the lower cost involved in this type of load controller (Rodriguez and Sanchez, 2011).

The two most common controls are speed governors and electronic load controllers. Speed governors regulate the speed of the generator by controlling the flow through the turbine. This is accomplished by extending or retracting the servo-motor's rod to the required position. Electronic load controllers manage decreased loads by switching to a pre-set resistance to maintain system frequency (ESHA, 2004).

The installed turbines can supply the electricity to either a stand-alone islanded system or connected to the grid as shown in Figure 2-52 and Figure 2-53.

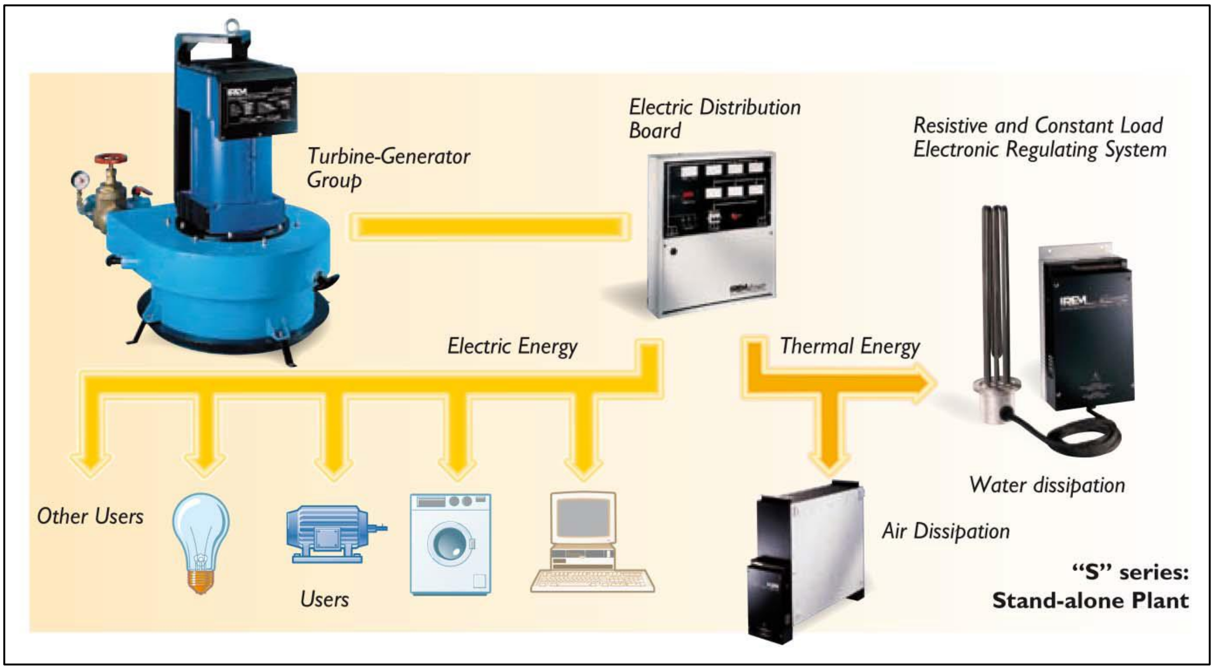


Figure 2-52 - Stand-alone (islanded) plant (Courtesy of IREM)

Figure 2-53 - Grid connected plant (Courtesy of IREM)

The typical installation which will be used for a rural electrification system is a stand-alone plant linked to a mini-grid.

Governors and other controls help ensure that the generator constantly spins at its correct speed. The most common types of governors for small hydro systems accomplish this by managing the load on the generator. As illustration, consider a hydro system without a governor. When the load is increased on the generator by switching something on, it will cause the generator to work harder. If the system did not have a governor, it would slow down, resulting in a lowering of both the voltage and the frequency. Similarly suddenly removing a load by switching something off would cause the generator to speed up, increasing voltage and frequency.

If the entire load was to be suddenly removed the generator would "freewheel," and run at a very high speed. By progressively increasing the load would eventually slow the generator until it reached the exact speed ensuring the correct voltage and frequency. As long this "perfect" load (Design load) is maintained, the power output will be correct.

Turbines are designed for a certain net head and discharge. Any deviation from these parameters must be compensated for by opening or closing the control devices, such as the wicket-gates, vanes, spear nozzles or valves, to keep either the outlet power, the level of the water surface in the intake, or the turbine discharge constant.

In schemes connected to an isolated network, the parameter that needs to be controlled is the turbine speed, which controls the frequency. In an off grid system, if the generator becomes overloaded the turbine slows-down therefore an increase of the flow of water is needed to ensure the turbine does not stall. If there is not enough water to do this then either some of the load must be removed or the turbine will have to be shut down. Conversely if the load decreases then the flow to the turbine is decreased or it can be kept constant and the extra energy can be dumped into an electric ballast load connected to the generator terminals.

The extra ballast load would typically be in the form of electronic regulators which would dissipate the energy. Normally sufficient resistors are installed to take the full generating load. These are usually modular parts and can be connected together to provide the dissipating capability. These could be air cooled or water dissipation resistances (based on the size of resistors required), see example shown in Figure 2-54.

Figure 2-54 - Resistor for water dissipation (IREM)

The regulator keeps the voltage and frequency stable, as the absorption of the energy produced by the turbine-generator group remains constant.

The electric control boards, Figure 2-55, provide the electric operation parameters of the plant. This could be a single phase or three phase control board fitted with instruments, alarms and protective devices.

Figure 2-55 - Electric control board (IREM)

The electric control board generally consists of a cabinet in which the different devices are contained. In the three-phase control board there is a voltmeter, a digital frequency-meter there are six ammeters, 3 of them indicating the input current on each phase and the other 3 the current drawn by the consumers.

In the three-phase control board, there is a three-phase circuit breaker and three electronic voltage relays, each of them being connected between one phase and neutral.

2.2.3.3.4 Governing

Electrical equipment within the hydropower plant is designed to operate at a specific voltage and frequency. Operation at any other frequency than the designed, can cause serious damage to the electrical components of the system or plant.

As described in ESHA (2004) in the first approach, speed (frequency) regulation is normally accomplished through flow control; once a gate opening is calculated, the actuator gives the necessary instruction to the servomotor, which results in an extension or retraction of the servo's rod. To ensure that the rod actually reaches the calculated position, feedback is provided to the electronic actuator. These devices are called "speed governors”.

In the second approach it is assumed that, at full load, constant head and flow, the turbine will operate at design speed, so maintaining full load from the generator; this will run at a constant speed. If the load decreases the turbine will tend to increase its speed. An electronic sensor, measuring the frequency, detects the deviation and a reliable and inexpensive electronic load governor, switches on pre-set resistance and so maintains the system frequency accurately.

The controllers that follow the first approach do not have any power limit. The Electronic Load Governors, working according to the second approach rarely exceed 100 kW capacity which is typical for the micro installations.

A governor is a combination of devices and mechanisms, which detect speed deviation and convert it into a change in servomotor position. A speed-sensing element detects the deviation from the set point; this deviation signal is converted and amplified to excite an actuator, hydraulic or electric, that controls the water flow to the turbine. In a Francis turbine, where there is a reduction in water flow you need to rotate the wicketgates. For this, a powerful governor is required to overcome the hydraulic and frictional forces and to maintain the wicket-gates in a partially closed position or to close them completely.

Several types of governors are available varying from old fashioned purely mechanical to mechanical-hydraulic to electrical-hydraulic and mechanical-electrical. The purely mechanical governor is used with fairly small turbines, because its control valve is easy to operate and does not require a big effort.

In a modern electrical-hydraulic governor a sensor located on the generator shaft continuously senses the turbine speed. The input is fed into a summing junction, where it is compared to a speed reference. If the speed sensor signal differs from the reference signal, it emits an error signal (positive or negative) that, once amplified, is sent to the servomotor so this can act in the required sense. All these regulation systems operate by continuously adjusting the wicket-gates position back and forth. In electrical hydraulic governors the degree of sophistication is much greater, so that the adjustment can be proportional, integral and derivative giving a minimum variation in the controlling process.

An asynchronous generator connected to a stable electric grid, does not need any controller, because its frequency is controlled by the mains. Notwithstanding this, when the generator is disconnected from the mains the turbine accelerates up to runaway speed of the turbine. The generator has to be designed to withstand this speed long enough until the water flow is closed by the controlling system (guide vanes or valve).

To ensure the control of the turbine speed by regulating the water flow, certain inertia of the rotating components is required. Additional inertia can be provided by a flywheel as shown in Figure 2-56 on the turbine, or the generator shaft. When the main switch disconnects the generator, the power excess accelerates the flywheel; later, when the switch reconnects the load, the deceleration of this inertia flywheel supplies additional power that helps to minimise speed variation (ESHA, 2004).

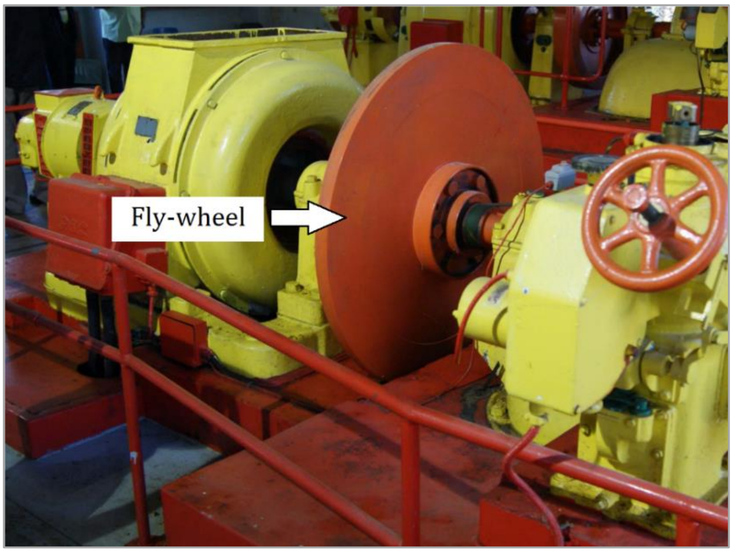


Figure 2-56 - Example of a fly-wheel

The frequency of a synchronous generator, is determined by the speed of the generator and the number of poles. For example, a four pole generator generates two cycles per revolution of its shaft. To generate 50Hz (cycles per second) as is the norm in South Africa, it must run at 25 rev/s, or 1500 rev/min (RPM) (Harvey, 1993). If the speed increases or decreases, the frequency generated also increases or decreases. Some control of generator speed is there for needed.

As the speed of the generator is determined by the turbine, the speed of the turbine must be regulated. This is done by the governing device. The governing device controls the speed of the turbine in response to changing external electrical loads place on the generator (Harvey, 1993).

The different approaches to governing can be classified into two categories, conventional and non-conventional governing systems. Most conventional governing system requires sophisticated equipment and components from industrialized countries and are not always available in developing countries. Non-conventional approaches are usually only used in small to micro hydropower systems and relies heavily on proper manipulation of the hydraulic turbine or the load. Output is thus of lower quality but still adequate to satisfy most end users (Harvey, 1993)

The different conventional and non-conventional governing system are summarised and described below (Harvey, 1993):

A. Conventional governing systems

Oil pressure governor – oil kept under pressure by a pump is used to drive a piston/servomotor which in turn moves the flow/control mechanisms ensuring varied flow to the turbine and thus varied power generation as the load imposed on the generator varies. Figure 2-57 illustrates the operation of an oil pressure governing system.

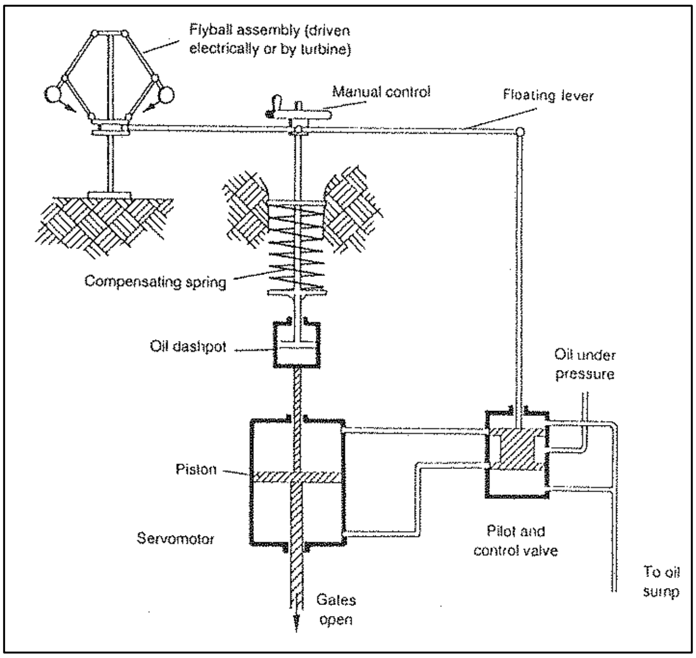


Figure 2-57 - Hydraulic mechanical governor (oil pressure governing system) (Harvey, 1993)

Mechanical governor – mechanical governors typically incorporate a flyball arrangement driven by the turbine shaft. The output form this assembly is used directly to drive the jet deflector on Turgo or Pelton wheels.

Load controller – a load controller is an electronic device that maintains a constant electrical load on the generator. This permits the use of a turbine without a flow control mechanism. Flow through the turbine is set at constant value. The load controller maintains a constant load by supplying a secondary ballast load with the power not required by the user load. Figure 2-58 describes the operation of a ballast load.

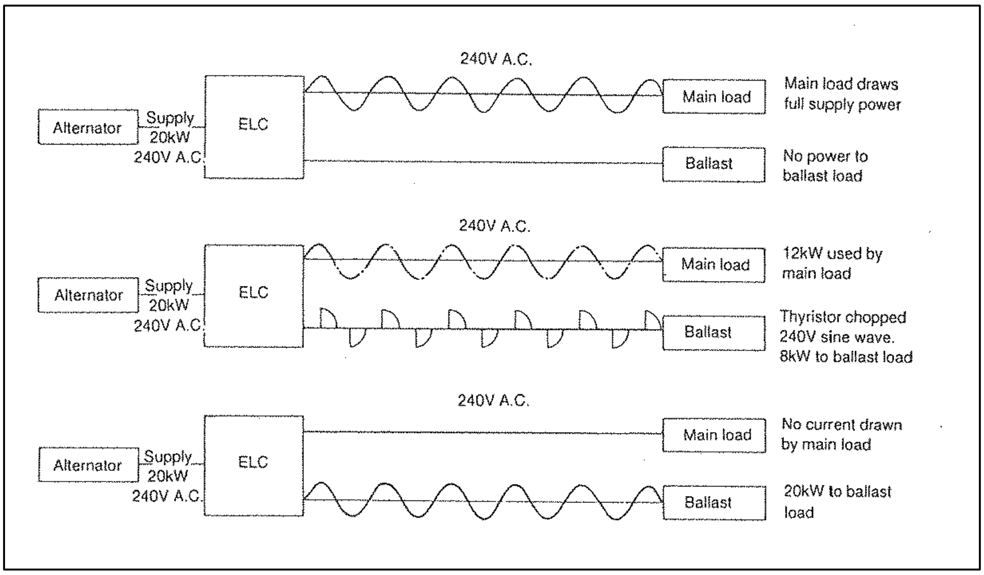


Figure 2-58 - Electronic Load Controller (ELC) (Harvey, 1993)

Induction generator controller – when a load controller is used to govern the speed of a turbine/generator an automatic voltage regulator will also be required. In the case of an induction generator, there are induction generator controllers which combines the speed control and the voltage regulator. This is only for induction generators and not normally used synchronous generators.

B. Non-conventional governing systems

Constant load – Only permits the use of a fixed load, such as the lighting for a rural village. This is the simplest method of ensuring a constant frequency and voltage. No switches need to be included in the system. The turbine is used as the switch. When the turbine valve is opened sufficiently wide to obtain the nominal frequency and voltage, the power will switch on. When closed again, the power will switch off. Where more than one fixed load will be used (i.e. water heater, lights), switches can be incorporated into the design, as long as one constant load is run at time. The turbine cannot supply both the fixed load on a water heater and a different fixed load of lights at the same time when using a constant load governing system.

Manual control – with manual control, the relative constant frequency has to be maintained manually by the operator. This is done by either adjusting the flow of water to the turbine or the total load imposed on the generator.

Flow modification requires a flow regulating valve which increases or decrease the flow to the turbine as fluctuations in the voltage frequency is observed. Small deviations from the nominal frequencies with have little to no adverse effect on the plant or the load.

Load modification works on the same principle of an automatic load controller. If the flow into the turbine remains constant the load imposed on the generator also needs to remain constant to keep the nominal frequency the same. This requires a ballast load also connected to the generator, to be increased or decreased as the user load varies. The ballast load can vary from being heating elements in air or water, to being a series of light bulbs.

2.2.3.3.5 Transmission

The electricity produced by the power generating equipment of the hydropower plant is transmitted to the users via a transmission and distribution system (Rodriguez and Sanchez, 2011). There are two types of transmission lines of energy: these are overhead and underground (Muhammad and Karimov, 2010). The most common way of transporting electricity from the powerhouse to homes is via overhead lines (Natural Resources Canada, 2004).

The size and type of electric conductor cables required depends on the amount of electrical power to be transmitted and the length of the power transmission line from the powerhouse to the house connections or users. For most micro-hydropower systems, power lines would be single-phase systems (Natural Resources Canada, 2004). The main design criteria to consider are as follows (Harvey, 1993):

- The maximum allowable voltage variation from no load to full load.
- The maximum economic power loss.
- Protection from lightning and other damage.
- Structural stability in high winds (Overhead lines).
- Safety for people living and working near the lines.

The allowable volt drop is a very critical design parameter. The figure used in the UK is 6%, meaning the allowable volt drop on a 240V supply is 14V. In order to avoid the delivered voltage being to low it might me sensible to raise the generated voltage at the powerhouse as much as possible (Harvey, 1993). The alternators in hydropower plants does not like high voltage because in increases field power and therefor heating which can cause failure. It is best to specify normal plus 10% as a maximum on new alternators. Power house lights often have a problem when the voltage is more than 4% above the normal rated value of the light bulb, and coils and transformers have a shorter life on voltages more than 4% above rated (Harvey, 1993). In turn motors start to draw more current and run hotter at low voltage and bulb brightness also changes at low voltages. Harvey (1993) suggests to run alternators at 4% higher than nominal voltage of motors and bulbs and design line losses to give drops between 4% and 11% depending on economics.

When connecting a small plant to a rural distribution line, care must be taken not to push the voltage to high when the plant output is at a maximum and the load on the line is light. In such a case the unit might need to operate under excited and import reactive power when the output is high and the local load is low. Vice versa the unit might need to operate over-excited when the output is low and the load on the line is high. If the generator needs to import a large amount of reactive power the excitation might go so low that pole slipping might occur (Leyland, 2014).

High voltage (HV) transmission system can transport electric energy over longer distances with fewer losses than low (LV) or medium voltage systems. The higher the voltage the fewer the losses in the system (Rodriguez and Sanchez, 2011). If transformers are used to step up voltage form low to high values, the current in the conductors and cables are smaller. The lower cost is offset by the cost of two transformers, one to step up and one to step down voltage before end users (Harvey, 1993).

LV lines are more easily erected and maintained by local users. In general it is found tat LV liens are more economic than HV lines for transmission distances less than 1.5 km (Harvey, 1993). In Micro schemes (>100 kW) electricity can be transmitted over even greater distances by LV lines, yet then the danger remains that the voltage may drop too low, due to losses, for the use by end users of the power generated (Harvey, 1993). This can be avoided by increasing cable size which will in turn increase costs.

The most common way of transporting electricity from the powerhouse to homes is via overhead lines. Yet underground power line might need to be considered due to environment and geographical conditions. Underground lines costs considerably more than overhead lines but may be safer. The advantages and disadvantages of overhead lines compared to underground lines as detailed by Harvey (1993) is as follows:

- Overhead transmission lines
    - Advantages
        - Less expensive
        - Air used as insulation
        - Installations are simple and cheap
        - Uninsulated cable is readily available
    - Disadvantages
        - Exposed to lightning – Trees in vicinity if lines to be cleared
        - Poles have infinite life and needs replacement – i.e. every 15 years
        - Less efficient than underground lines for a given conductor size.
- Underground transmission lines
    - Advantages
        - Runs without maintenance until insulating material deteriorates, i.e. 50 years
    - Disadvantages
        - Expensive
        - Needs to be insulated
        - Needs protection against ground movement, ploughing, developments etc.

All electrical works must follow national and local electrical codes and should be undertaken only by qualified and certified professionals (Natural Resources Canada, 2004).

The choice of conductor material is usually between aluminium and copper and is dictated by local availability and cost. Copper is a stringer conductor material. The advantage of a stringer material is that poles can be spaced out more widely, which saves on pole costs. Pole price also depends on local availability and local conditions. In transmission lines over 500 m length cost of poles can become significant (Harvey, 1993).

2.2.3.4 Auxiliary Components

In addition to the structural, mechanical and electrical parts of a hydropower plant, there are several parts that neither directly take part in power generation nor constitute any structural element of the plant. The use of these parts are however very important to the operation of the plant. These auxiliary parts of the hydropower plant are discussed in more detail below.

2.2.3.4.1 Screens/Screening Grill

The first device faced by the stream of water moving towards the turbine is a grill (Wagner and Mathur, 2011). As discussed within the section concerning the intakes and intake structures of the hydropower plant, the function of the screen or screening grill, is to protect living species or water life as well as protect the turbine from hazardous elements.

The screen or grill prevents fish or any animal as well as any solid (wood, debris, ice) that are larger than the holes in the grill, from entering the system. If no such screening is present, the entry of such items or material into the turbine, might cause damages to the turbine blades (Wagner and Mathur, 2011).

The addition of a grill or screen (Figure 2-59) into the system, causes additional friction losses in the system as discussed in section 2.2.3.1.1 and displayed in Figure 2-18. While the grill “collects” items that are larger than the gaps in the grill it also causes additional resistance to the flow which negatively influences the performance of the hydropower plant (Wagner and Mathur, 2011). In the case of a grill or screen added to a hydropower system, there must be a cleaning process (Figure 2-60) or method present, in order to prevent unnecessary head losses due to friction caused by a build up of debris or material at the intake screen or grid.

Figure 2-59 - Intake grill/screen with debris – First Falls Hydropower Plant, Mthatha River

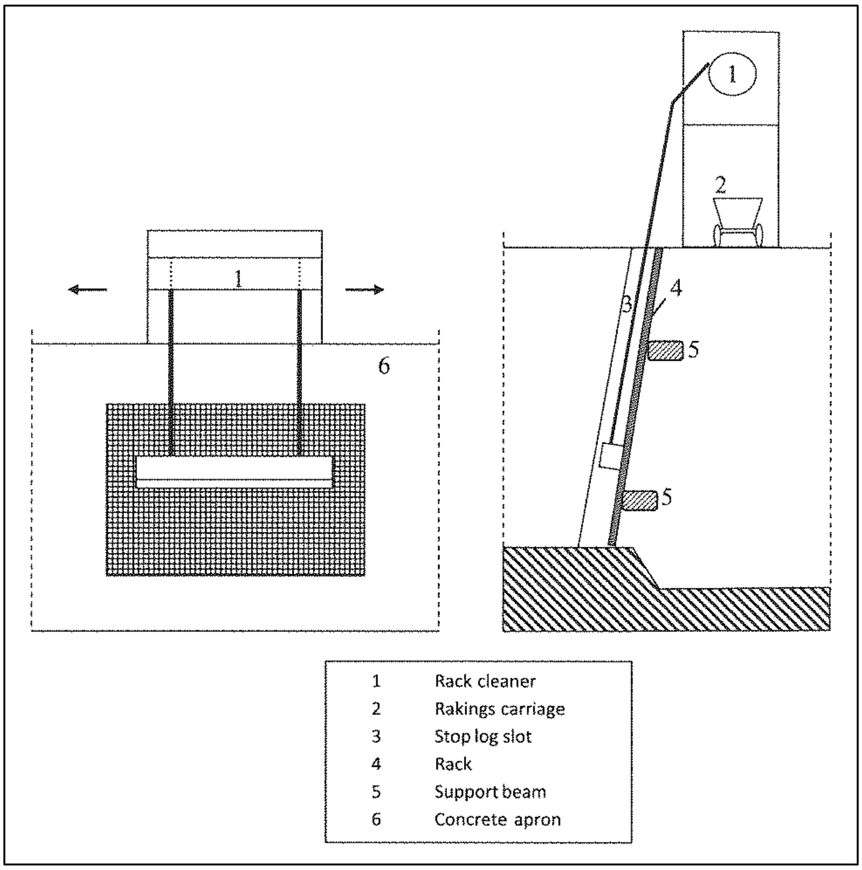


Figure 2-60 - Grill cleaning machine (Wagner and Mathur, 2011)

2.2.3.4.2 Control Gate

Control gates, as the name states, functions with the control of the system as described in section 2.2.3.3.3. Control gates regulate the mount of water flow into the turbine. Where flow controllers are used to control the hydroelectric plant, the control gates can be opened and closed according to the amount of flow needed in the system for energy generation within the capacity of the turbine and motor. Control gates for small scale hydropower schemes are relatively small and therefor mostly manually operated, which makes it unfeasible to use as a flow controller for the control of hydroelectric plants. Electronic load controllers coupled with ballast loads or a power dissipating system are mostly used in small scale hydropower projects.

Control gates are normally vertically lifting type gates (Figure 2-61), and in the case of large dams normally carry a heavy weight and large size and can only be lifted by help of large motors mounted on the top portion of the dam (Wagner and Mathur, 2011). As the gates are in constant contact with corrosive conditions, the material of the control gate of a hydropower plant is important, and for this reason also regular maintenance needs to be done on control gates (Wagner and Mathur, 2011).

Figure 2-61 - Sluice Control Gate (Penstock) (wemvalves.com)

2.2.3.4.3 Control and Shut-Off Valves

As with control gates, the function of control valves has been discussed in the section under the control of hydroelectric power plants. Control valves can also act as shut-off valves or separate shut-off valves could be installed into the system for interrupting the flow of water during operation. This can be necessary for safety issues concerning the bottom water, for draining the turbine if the turbine needs repair or service, as well as in a pumped storage scheme, when switching between turbine working and pump working (Wagner and Mathur, 2011).

There are three main types of shut-off valves, Ball valves, Throttle valves and Turn valves. In large power plants, moving the ball valve or throttle valve is achieved with the help of electric motors and a hydraulic or pneumatic system (Wagner and Mathur, 2011), or as explained in the section under control of hydroelectric power plants, by the electronic load controllers.

2.2.3.4.4 Fish Passes

Where a dam or weir is constructed in a river section for infrastructure for a hydropower plant, the blocking of the water prevents water living animals from going from one side of the obstruction to the other. In order to enable the water animals to pass through these hydropower plants from upstream to downstream and vice versa, fish passes are provided (Wagner and Mathur, 2011).

The aim of a fish passage facility is to attract migrants to a specified point in the river, downstream of the obstruction, and then to induce them, or even make them, pass upstream. This is achieved either by opening a waterway or else by trapping them in a tank and lifting them upstream (Wang, 2008).

The water velocities in the fishway or fish pass must be of such a magnitude which is compatible with the swimming capacity of the species concerned (Wang, 2008). Alternate deflectors within a pool type fish pass help to keep the velocity of the water stream relatively low so that the fish can survive while passing through them (Wagner and Mathur, 2011).

There are several different types of fish passes as described by the British Environmental Agency Fish Pass Manual and categorised under the following main groups (Armstrong, Aprahamian, Fewings, Gough, Reader and Varallo, 2004):

- Pool Passes
- Baffle fishways
- Active Fish Elevators

2.3 RURAL ELECTRIFICATION

2.3.1 Basics of Rural Electrification

Rural electrification is the provision of long term, reliable and satisfactory electricity service to households in remote, rural communities via grid or decentralized/centralized, renewable/non-renewable energy resources supply. Many consider electrification as a fundamental strategy for poverty alleviation in terms of financial, energy and sustainable developments (Bagdadee, 2014).

However, rural electrification is not only a technical issue but a multidimensional aspect that is affected by several factors, such as politics, economic development and culture (Bagdadee, 2014).

2.3.2 Social and Economic benefits of Rural Electrification

The following list of 51 indicators of social and economic benefits demonstrates that rural electrification, as part of a rural development program, can introduce immediate and tangible benefits to the rural population, especially the rural poor (Cecelski and Glatt, 1982).

1. *Irrigation systems utilizing electric system equipment, tube wells, etc., allowing for multiple cropping.*
2. *Property formulated livestock and poultry feeds prepared in small mills.*
3. *Automated poultry processing/breeding systems.*
4. *Refrigeration of perishable farm agricultural products and utilization of milk coolers.*
5. *Electrically powered grain drying, processing, storage systems and fumigation.*
6. *Conservation of export quality timber (electricity replaces wood for cooking and heating).*
7. *Fish farms in areas where pumps are required.*
8. *Working through his Cooperative provides farmer with some degree of leverage in the marketplace.*
9. *Agriculture employment opportunities are generated.*
10. *Electrically powered handicraft industries allowing for varied and increased production. (Cottage or home produced items can be made during off peak seasons of agricultural cycles).*
11. *Employment opportunities, especially for women, in commercial non-agricultural industries. (Due to electricity, women with reduced homemaking chores are able to earn much needed extra income either on full-time or part-time basis).*
12. *Market/stores utilizing refrigeration. Decrease in spoilage of perishables, especially in tropical areas.*
13. *Development of small industries to meet created demand for simple electric appliances.*
14. *Development of industries supplying poles, cross arms, insulators, hardware, meters and transformers for electric distribution systems.*
15. *Employment opportunities created by Cooperatives, contractors, National*
16. *Electrification Administration, auditing and accounting firms.*
17. *Limited school facilities utilized for night classes.*
18. *Community facilities such as libraries opened in evenings.*
19. *Wider use of audio visual equipment and materials in schools and adult education programs.*
20. *Allows for home economics training for women utilizing sewing machines and home appliances.*
21. *Women's routine home chores eased, which allows for daughters to be freer to attend school.*
22. *Lighted outdoor athletic facilities such as basketball courts allows for community recreation. (Too hot in tropical countries to participate during daytime.)*

23. *Teachers are more productive and better prepared due to home lighting.*
24. *Students academically improve. Homework better prepared.*
25. *Refrigeration of medical supplies by clinics and hospitals.*
26. *Use of sterilizers and electrical detection equipment in rural clinics.*
27. *Reliable source of power for hospitals and operating rooms.*
28. *Home electrical appliances allow for sanitary preparation of food and water. Electric pumps provide potable water.*
29. *Home refrigeration prevents spoilage of perishable foods and reduces health hazards.*
30. *Restaurants utilizing electrical appliances and refrigeration reduce health hazards.*
31. *Correlation of home lighting and decrease in population growth rate.*
32. *Increased security due to night lighting. Crime rate decreases.*
33. *Lighted homes provide social benefit. Utilization of radio and television for education, entertainment and leisure.*
34. *Appliances such as irons, hot plates, simple washing machines reduce work burden for women.*
35. *New home construction and improvement results from electrification.*
36. *Cooperatives provide outlet for community and national participation by rural population. Provides experience in management and democratic decision-making.*
37. *Improved and increased craft production in addition to economic benefits, enhances the cultural and aesthetic values that craftsmen and crafts tradition mean to a nation (national pride).*
38. *Cooperative institution, organization and facilities utilized for members' services (Better Family Living) such as family planning, crafts, and home economics.*
39. *Change in social well being. Index of satisfaction with one's current situation improves. New confidence.*
40. *Keeps the economic proceeds of a region invested locally.*
41. *Accelerates the monetization of the rural society.*
42. *Stems rural migration to cities and improves rural-urban balance.*
43. *Increased rural economic activity absorbs expanding rural labour force.*
44. *Decentralizes economic activity.*
45. *Rural population participating in a "self-problem solving" climate rather than a "depending on the government" climate.*
46. *Increased net tax revenues to government.*
47. *Levelling of ethnic differences.*
48. *Improved citizens-government relationship.*
49. *Reduced socioeconomic imbalance in the population.*

50. *Expanded communications system to entire population. Government able to communicate with its citizens.*
51. *Reduced foreign exchange expenditures for kerosene and oil used for lighting, cooking and heating. (A central generator is a much more efficient method for supplying energy, rather than each household purchasing fuel.)*

2.4 MINI GRIDS IN RURAL ELECTRIFICATION

Centralized power generation has been the dominant approach to electrification in developed countries over the last century since the development of improved generation technologies such as large-scale steam turbines, the introduction of transformers and high voltage lines using alternating current.

A similar centralized approach has been followed in many developing countries. In post WW2 Africa, for example, centralised electricity generation was seen as a precondition for development, with the delivery of electricity and infrastructure paving the way for economic growth.

This approach overlooked constraints such as a dispersed population, low purchasing power and limited potential for load growth (Kirubi, Jacobson, Kammen and Mills, 2009).

Since the 1980 s the approach has evolved, supported by studies that have consistently shown that electricity in itself cannot bring rural development, and that inequity in access is prevalent where supply had been achieved.

Despite success in increasing rural energy access in some developing countries, rural energy access remains a major challenge in many countries, with more than 1.5 billion people worldwide are without access to electricity. Around 80% of these people live in rural areas and a large proportion are in Africa. By 2030, the number of people without electricity is likely to remain similar to the present day due to population growth (IEA, 2009).

Interest in decentralized or off-grid energy generation has grown over the last twenty years as developing countries continue to grapple with the challenge of increasing rural energy access.

The implementation of decentralized energy systems depends upon the extent of decentralization. At village decentralization, the system is managed by local participation and energy is supplied to meet the local needs. In few cases, the excess power may be supplied to the grid. On the other hand it is also possible to have industry level decentralization, in which case the power generated as a by-product of industrial process is used mainly to cater to its own needs with any surplus being fed into the grid. The extent of decentralization also determines whether the system operates in either grid-connected or stand-alone mode.

The focus of this study is on stand-alone systems. Stand-alone systems produce power independently of the utility grid. These are more suitable for remotest locations where the grid cannot penetrate. Stand-alone systems comprise the majority of photovoltaic installations in remote regions of the world because they are often the most cost-effective choice for applications far from the utility grid. Examples are lighthouses and other remote stations, auxiliary power units for emergency services or military applications and small remote villages. The stand-alone systems suffer from innate disadvantages like low capacity factor, excessive battery costs and finite capacity to store electricity forcing to discard extra energy generated (Kaundinya, Balachandra and Ravindranath, 2009).

The important features of stand-alone systems are as follows.

- In stand-alone energy systems, the operational capacity is matched to the demand.
- The needs of the local region assume maximum priority.
- These systems are ideal for remote locations where the system is required to operate at low plant load factors.
- Operation is mostly seasonal, as the typical stand-alone systems are usually based on renewable energy technologies like solar PV, which is not available throughout the year and small hydro which is linked to the runoff cycles.
- This does not exert pressure on biomass and other renewable energy sources as it requires fewer resources for small-scale applications.
- These systems are not connected to the utility grid as a result of which they need batteries for storage of electricity produced during off-peak demand periods, leading to extra battery and storage costs, or else the excess power generated has to be thrown away.

There are many opportunities and challenges and these will vary between the different business model approaches that can be adopted to implement a rural electrification scheme. Table 2-6 below summarises some of the advantages and disadvantages.

Table 2-6 - Advantages and disadvantages of different mini-grid business models (World Bank 2008; USAID/ARE, 2011)

Model	Advantages	Disadvantages
Community	Increase ownership which improves maintenance.	Communities may lack technical and business skills (e.g. design and installation; tariff setting), leading to higher costs to bring these in.
	Can be more efficient than bureaucratic utilities.	Governance of systems needs to be well managed.
Private	Greater efficiency.	Lack upfront financial support in most cases.
	May have capacity to offer better operation and management services.	Often difficult to find enough experienced companies, so often schemes are run by smaller companies with less capacity.
	May be better able to navigate political interference.	
Utility	Responsibility lies with an experienced organisation.	Liberalisation means that they are market driven, so may not prioritise decentralised systems in rural areas.
	Often good links to policy so have better access to legal systems.	Often inefficient and bankrupt
	Their scale means that they may have better access to spare parts and maintenance.	Often driven by political agendas.
Hybrid	Combine the advantages of the models above, such as the technical expertise of a utility and the financial expertise of the private sector.	Differences in the management systems of each entity can increase transaction costs.

2.5 LEGISLATION AND REGULATION

Electricity generated for "islanded use" is completely independent of municipal- or Eskom distribution networks (South Africa, 2006). Islanded use, in turn can be applied for non-commercial purposes, i.e. for "own use", or for commercial purposes, i.e. for non-grid electrification.

The Department of Energy's (DoE's) "Non-Grid Electrification Policy Guidelines" (DoE, 2012) guides the implementation of the latter. The main objective of the policy guidelines is to guide the provision of non-grid electrification to households as part of the Integrated National Electrification Programme, or INEP (DoE, 2012).

Through a tendering process initiated in 1999, the DoE procured six (6) private sector concessionaires in 2002 to provide energy services, and specifically solar home systems, to remote rural areas as part of the INEP. These concessionaires were allocated exclusive rights to provide off-grid electrification to particular geographic areas (DoE, 2012). The concessionaire programme has generally not been successful with only three concessions being operational in 2011. Administrative delays between programme phases and lack of commitment by Government to provide long-term subsidies were some of the challenges faced by the Concessionaires

In lieu of the South African Government's objective to achieve universal access by 2025, the DoE initiated the "New Households Electrification Strategy" in June 2013, which has inter alia:

- Extended the roll-out of the INEP non-grid electrification programme to other areas that fall outside of the concession areas. This roll-out can be initiated and facilitated by Municipalities making application for non-grid electrification in their respective areas to the DoE (DoE, 2012, DoE, 2013); and
- Explicitly included "other possible technologies based on cost-effective options in order to address current and future backlogs" (DoE, 2013).

For hydropower generated from installations positioned within water and sanitation infrastructure, or water resources, this option would be applicable where:

- the potential for hydropower exists,
- there is no electricity network connection and
- "The proposed non-grid system's area of supply is not within 2 km from a grid line; falls outside the 3-year grid plans of an electricity distribution utility and is included in the Municipal IDP." (DoE, 2012).

Case-by-case contracting and funding models would need to be developed, in order to determine the feasibility of such a project, specifically for hydropower projects operated by Water Boards (WBs) or Water Services Providers (WSPs.)

Utilising South Africa's natural water resources in remote areas of the country to generate hydropower, without actually consuming any of the water, could potentially provide rural communities with access to basic electricity. Table 2-7 summarise the current legislative and regulatory requirements.

Electricity generated for islanded use, and used for non-commercial purposes does not require a NERSA electricity generation licence. Electricity generated for commercial purposes, requires a NERSA electricity generation licence (South Africa, 2006).

Table 2-7 - Electricity generated for islanded use (Adapted from Scharfetter, 2015)

	Commercial use	Non-commercial use
NERSA Generation Licence	Yes	No
Local electricity utility involvement	Applications to the DoE for non grid electrification through the INEP to be done by the local municipality	Good practice to inform
Proof of land ownership/ permission to use land	Needed for NERSA licensing requirements	Good practice to have
Environmental ROD	Needed for NERSA licensing requirements (show proof of appointment of EIA consultant, indicate Public Participation Process that is being followed, DEA approval of scoping report) Amendment to existing EIA or BA required for Brownfield's development (pers.comms. legal opinion) Yes, if required by NEMA Record of Decision (ROD) required based on a Basic Assessment (GN544) or full EIA (GN545) Opinion of Environmental professional needed if none required	Yes, if required by NEMA
Water Use licence	Needed for NERSA licensing requirements Yes, if required by National Water Act Legal opinion if none is required	Yes, if required by Water Act
Water allocation confirmation.	If conduit hydropower, WSP must confirm that water is available and hydropower generation will not affect security of supply	If conduit hydropower, WSP must confirm that water is available and hydropower generation will not affect security of supply

2.6 FEASIBILITY OF SMALL-SCALE HYDROPOWER PLANTS

As discussed in the previous section, a project or site can have the technical possibility to be developed as a small-scale hydropower plant and not be feasible. A site however cannot be feasible to be developed for small-scale hydropower if no technical possibility exists. For the purposes of the study it is preliminarily proposed that a project of site will be feasible to develop for small-scale hydropower to serve a community, if it is more expensive to provided infrastructure to connect said community to an existing grid with existing operating cost. Existing literature on the topic was reviewed to compare feasibility criteria of different studies in different countries as well as initial capital costs (ICC), construction costs (CC) and operating and maintenance costs (OMC) in different studies within different countries.

In the "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants" (Hall, 2006), the site development criteria that were used to estimate project hydropower potential were:

1. Project location – optimal based on hydraulic head capture
2. Penstock length
    a. Low power project – optimal based on capturing 90% of hydraulic head captured with longest, typical penstock length based on existing low power plants in the region.
    b. Small hydro project – optimal based on capturing 90% of hydraulic head captured.
3. Flow rate – lesser of:
    a. Half the stream reach flow rate.
    b. Flow rate required to produce an annual average power of 30 MWh using hydraulic head corresponding to optimal small hydro penstock.

The above mentioned study made certain assumptions which are conservative and can be improved on. The penstock was assumed parallel to the stream for all projects, where a transverse penstock in some cases may capture more hydraulic head over a shorter penstock length. Flow rates have also been limited to that required to produce 30 MWh because of the focus of this study. For the study at hand only sites with a generating potential of less than 1 MW will be considered.

The "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants" (Hall, 2006) feasibility criteria that were used to identify feasible potential project sites addressed the following aspects:

- Land use and environmental sensitivities
- Prior development
- Site access

- Load and transmission proximity

Specifically, the feasibility criteria applied to each water energy resource site were (Hall, 2006):

- Hydropower potential ≥10 kWh
- Does not lie within a zone in which development is excluded by federal law or policy
- Does not lie within a zone that makes development highly unlikely because of land use designations
- Does not coincide with an existing hydroelectric plant
- Is within 1.6 km of a road
- Is within 1.6 km of part of the power infrastructure (power plant, power line, or substation) OR is within a typical distance from a populated area for plants of the same power class in the region.

This gives a good indication of feasibility criteria, however for the purpose of the study distances might vary due to differences in construction and material costs in South Africa compared with that in the US.

Zhang, Smith and Zhang (2012) developed a small hydro costs reference model to identify key cost drivers for small hydro generation through cost analyse and review. Small Hydro Plants (SHP) analysed were classified with the following system (Zhang et al., 2012):

- Small hydro site classification by existing facilities
  - New sites
  - Existing sites
  - Restoration/expansion sites
- Small hydro classification by hydraulic head
  - Low head (2–25 m): Axial Flow (Af) Kaplan/Propeller, Cross-Flow, Francis
  - Medium head (25–70 m): conventional Kaplan/Propeller, Francis
  - High head (>70 m): Francis, Turgo, Pelton
- Small hydro classification by project design scheme
  - Water diversion scheme.
  - Dam-toe schemes
  - Siphon intake scheme.
  - River-based or canal-based scheme
  - Pipeline integrated scheme.

Zhang et al. (2012) investigated SHP, as classified with the system above, according to different empirical cost equations from different sources and as well as initial capital cost (ICC) equations and equipment cost (EC) equations from different sources. The different reviewed equations are discussed below.

In 2001 Papantonis developed cost estimate formulae based on European data (Papantonis, 2001). More recently Aggidis, Luchinskaya, Rothchild and Howard (2010) developed cost estimate equations (for overall plant and electromechanical equipment) for hydro sites in the north-western region of the UK. The equations of Aggidis are as follows (Zhang et al., 2012):

- Overall Plant Cost
  - $C_P = 25000\left(P/_{H^{0.35}}\right)^{0.65}$, for heads between 2 – 30 m

Equation 2-26

  - $C_P = 45500\left(P/_{H^{0.3}}\right)^{0.6}$, for heads between 30 – 200 m

Equation 2-27

- Electromechanical Equipment Cost
  - $C_{EM} = 12000\left(P/_{H^{0.2}}\right)^{0.56}$

Equation 2-28

Where P is in the range of 25–990 kW, and C_P and C_{EM} are in 2008 British pounds (£).

Based on Spanish data Ogayar and Vidal (2009) developed the following cost equations for electromechanical equipment, for different types of turbines used (Zhang et al., 2012):

- Pelton – $COST = 17.693 \times P^{-0.3644725} \times H^{-0.281735}$

Equation 2-29

- Francis – $COST = 25.698 \times P^{-0.560135} \times H^{-0.127243}$

Equation 2-30

- Kaplan – $COST = 33.236 \times P^{-0.58338} \times H^{-0.113901}$

Equation 2-31

Where cost is provided on a per-kilowatt basis in Euro (€)

Total initial project costs are between US $1800 and $8000 per kW for a head range of 2.3–13.5 m, and between $1000 and $3000 per kW for a head range of 27 –350 m according to a World Bank report (Zhang et al., 2012).

The cost equations/equations in the literature suggest that the following equation (of "three parameter power") should be assumed for regression of SHP initial capital cost (ICC) (Zhang et al., 2012):

$$ICC(\$) = aH^bP^c$$

Equation 2-32

Where:

H = head (m)

P = Plant Capacity (kW)

a,b and c = parameters to be determined by regression analysis

Based on the empirical cost equations found in the literature, the equation stated above can also be used for regression analysis for the calculation of for electromechanical cost (Zhang et al., 2012).

According to Zhang, Smith and Zhang (2012) the ICC difference is as high as $1500–2500/kW for low-head small hydro, Based on the cost data obtained from Canadian project experience.

For a complete comparison between different small-scale hydropower potential site options a full life-cycle cost analysis can be done. For the purposes of the study different potential sites are not compared as much as the development of a SHP for rural electrification in lieu of supplying infrastructure for connection to the existing local or national electricity gird.

A life-cycle of a hydropower project can be divided into the following stages (Zhang et al., 2012):

1. Development and construction stage
2. O&M stage
3. End-of-life stage.

Figure 2-62 lists the cost items during the life-cycle of a typical SHP.

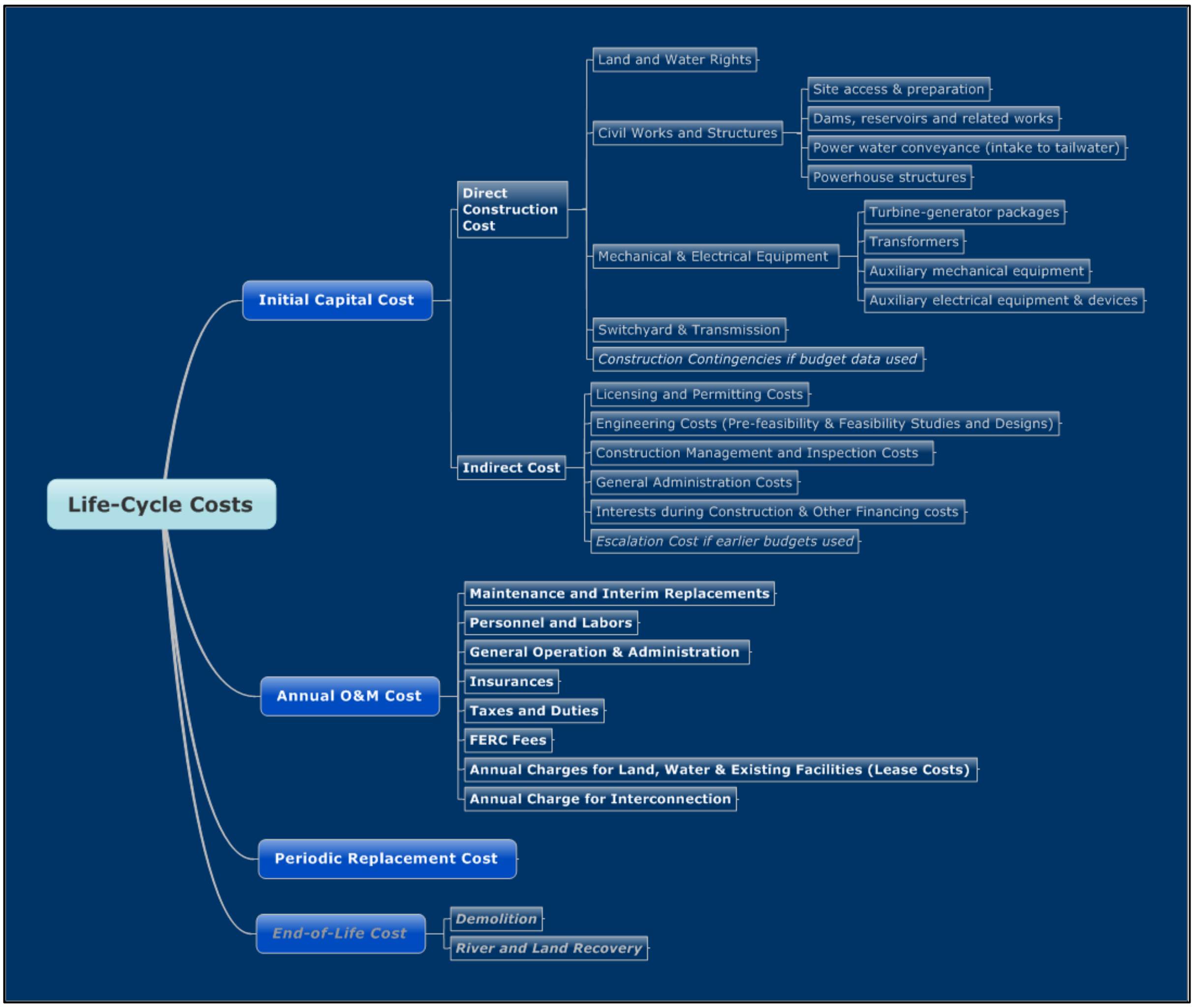


Figure 2-62 - Life-cycle costs of a hydro project (Zhang et al., 2012)

2.7 EXAMPLES/CASE STUDIES OF SMALL-SCALE HYDROPOWER PLANTS UTILIZED FOR RURAL ELECTRIFICATION

2.7.1 International examples of hydropower for Rural Electrification

During the 1900 s, many small hydropower stations which have been previously shutdown, were reactivated. There are almost 5000 small (>1 MW) hydropower systems in operation in Germany (Wagner and Mathur, 2011).

The World Hydropower Atlas 2000, published by the International Journal of Hydropower and Dams, reported that the world's technically feasible hydro potential is estimated at 14 370TWh/year, which equated to 100 per cent of the global electricity demand in 2002. The economically feasible proportion of that was considered to be 8080TWh/year in 2002. The hydropower potential exploited in 1999 was 2650TWh/year, providing 19 per cent of the planet's electricity from an installed capacity of 674 GW (Paish, 2002).

The first small-scale hydropower plant (SHP) in Greece was installed in Glafcos in 1927. This plants has benn operational for more than 85 years. In 2012 the produced energy from SHP in Greece was 586 GWh and the installed capacity of SHP is 213 MW, according to the statistics of the Operator of Electricity Market in Greece. This represented approximately 10% of the installed capacity from renewable energy sources in 2012 (Kougias, Patsialis, Zafirakou and Theodossiou 2014).

In Europe Hydropower provides about 17 per cent of EU electricity supply. Small hydro provides over 8 GW of capacity and there is an estimated 18 GW of further small hydro potential, including refurbishment projects (Paish, 2002). Small-scale hydropower had a negative development from the 1950's until about 1980 and many Small-scale hydropower plants were shut down because of age and competition from newer, larger plants. The increasing interest in renewable energy production has led to a growing focus on Small-scale hydropower (Kougias et al., 2014). In 2006 there were nearly 21,000 Small-scale hydropower plants operating in the EU-27. The installed capacity was more than 13,000 MW and the total electricity generation from Small-scale hydropower plants was more than 46,000 GWh. This means that in 2006 approximately 1.2% of the total electricity and 9% of the renewable energy in EU-27 came from Small-scale hydropower plants (Kougias et al., 2014).

Internationally, small hydro is considered to be the best proven of all renewable energy technologies, ideal for the electrification of remote communities, assisting in peak supply, and can be used to balance out variations present in wind and solar power production (Loots, Van Dijk, Van Vuuren, Bhagwan and Kurtz, 2014).

2.7.1.1 Latin America

Areas in Latin America and the Caribbean appear to be implementing a large amount of small hydropower schemes, as can be seen in Table 2-8.

Hydropower schemes developed under Kyoto Protocol's lean development mechanism (CDM) in these areas earn emission reduction credits (CER), which are each equivalent to one tonne of CO_2. These credits obtained can be traded and sold (ARE, 2014).

Table 2-8 - Latin America hydropower use (ARE, 2014)

Country	Population (million)	Rural population (%)	Electricity access (%)	Electrical capacity (MW)	Electricity generation (GWh/year)	Installed Hydropower capacity (MW)	Hydropower generation (GWh/year)
Argentina	40.41	8	97	33 810	128 922	10 045	39 920
Belize	0.34	48	85	144	388	53	250
Bolivia	9.92	33	78	1 459	6 085	477	3 876
Brazil	190.75	13	99	117 134	532 872	82 458	403 250
Chile	17.11	11	99	17 530	62 429	5 991	23 871
Colombia	46.29	25	94	14 424	64 230	9 718	38 714
Costa Rica	4.66	36	99	3 108	9 704	1 682	7 262
Cuba	11.25	25	97	6 240	17 387	64	>80
Dominica	0.07	33	95	27	89	6	32
Dominican Rep.	9.93	31	93	3 394	14 580	540	1 383
Ecuador	14.46	33	93	5 090	20 544	2 242	9 170
El Salvador	6.00	36	86	1 312	5 763	472	2 079
French Guiana	0.23	24	..	284	838	129	..
Grenada	0.11	61	97	49	224	-	-
Guadeloupe	0.50	2	..	..	..	10	21
Guatemala	14.39	51	81	1 477	8 147	891	3 752
Haiti	9.99	48	39	267	687	61	300
Honduras	7.60	48	70	1 722	7 127	531	3 081
Jamaica	2.89	48	92	872	5 001	22	152
Mexico	113.42	23	98	61 155	291 544	11 542	35 796
Nicaragua	5.79	43	72	895	3 781	105	326
Panama	3.52	25	88	2 391	7 858	1 351	3 971
Peru	29.07	23	86	8 556	12 975	3 453	20 038
Puerto Rico	3.69	1	100	5 840	22 558	100	133
St. Lucia	0.18	72	98	76	341	-	-
St. Vincent & the Grenadines	0.12	51	..	49	139	6	17
Uruguay	3.35	8	98	2 683	9 890	1 538	8 050

2.7.1.2 Nepal - Example of run-of-river scheme

Throughout the world there are numerous examples of small scale hydropower plants utilized for rural electrification. In China there are more than 100 000 small scale hydropower plants. It is recognised that micro and small hydropower is a mature, viable and clean alternative energy technology, especially for remote and rural areas that not only brings light into people’s lives in the locality, but also ensures energy and water security to population, makes people economically more stable, reduces the physical workload, in particular for women, enables the mechanisation of rural industries, has potential to lessen the use of conventional energy and its negative impacts and saves fauna and flora.

An example of a small scale hydropower plant in Nepal used for rural electrification is shown in Figure 2-63 to Figure 2-66 . This plant, Karamdanda micro hydro project has a capacity of 17 kW and benefits 179 households. The electricity is mainly used for lighting in the evenings.

Figure 2-63 - Turbine Room

Figure 2-64 - Intake collecting water from stream

Figure 2-65 - Penstock supplying water to turbine room

Figure 2-66 - All the components of the hydropower plant in the turbine room (Turbine, generator, electrical control panel and ballast load)

2.7.1.3 Dominican Republic - Example of Small Scale Hydropower (SSHP) for rural electrification

The village of El Limón is located in the arid southwest mountains of the Dominican Republic (DR), two hours west of Santo Domingo. Most of the income within the village is generated from agricultural activity. Electrification of the area like many villages was not a priority, however a regional workshop on very small hydropower systems presented by the EcoPartners Project (a Cornell University affiliate), in cooperation with ADESJO which is a regional community development organization in the nearby city of San Juan de Ocoa. The system described here was designed to address the limited water resource available. Technical support was provided by EcoPartners, logistic support by ADESJO, and labour by the community. The project was officially commissioned in April 1999 although portions of the village had begun receiving power earlier. As of yet, a total of 56 households now receive electricity and a few more will be added later.

A 2.5 kW micro-hydropower plant was built along an irrigation pipeline to harness the excess energy in the water as it descends the final kilometre of a 6 km PVC pipeline. A low cost 240-V induction motor, with an appropriate electronic load controller, is used as a generator to supply single-phase power to the mini-grid. The distribution system transmits the power about 600 m to the village and distributes it around the village, supplying homes as far as about 1 km from the village centre as can be seen in Figure 2-67. Because of the limited hydropower potential of the irrigation pipeline and the need to serve

60 households and to provide roughly 200 W of power to the school for lighting and the computer centre, the power available to each household is initially limited to no more than 35 W.

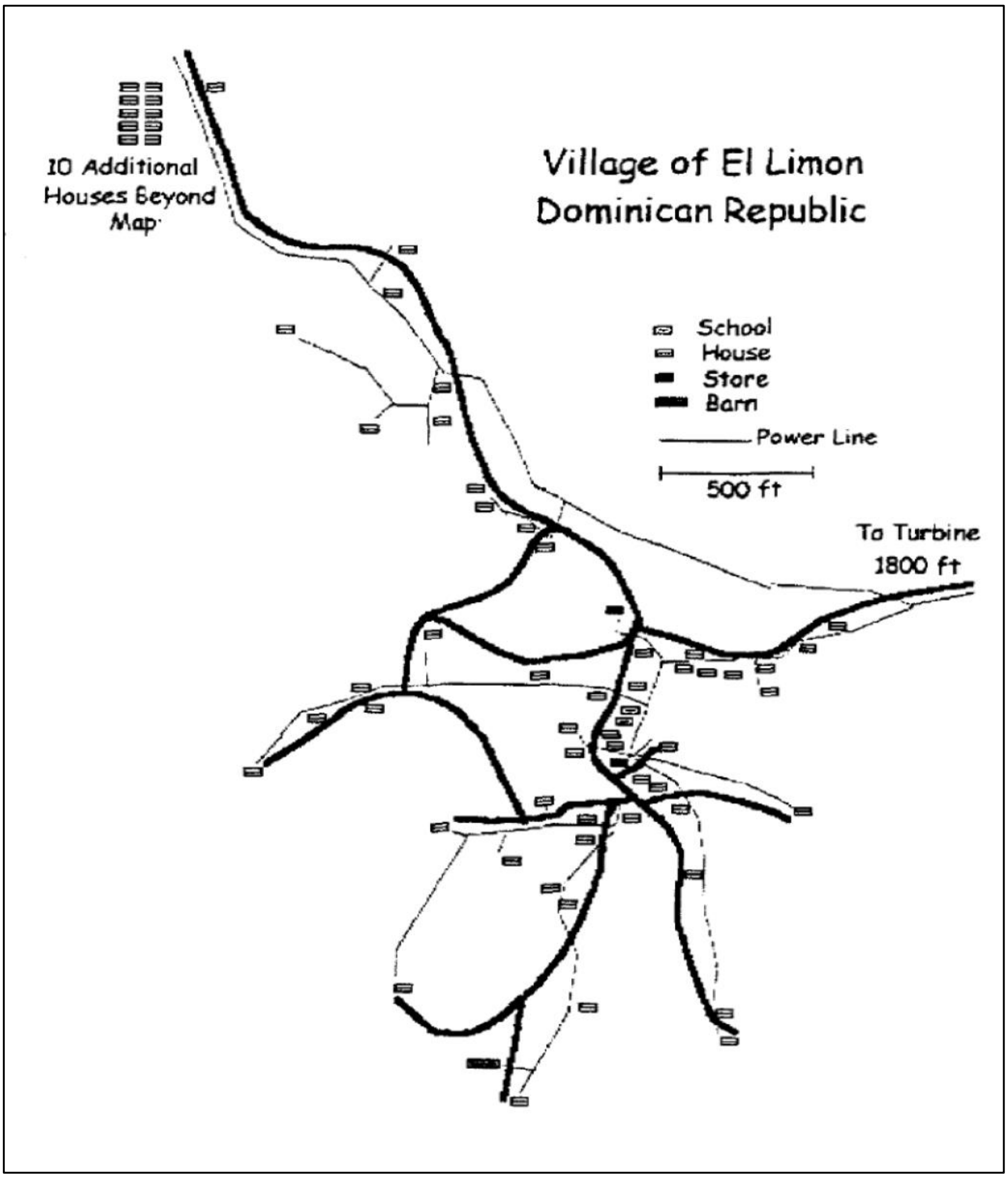


Figure 2-67 - Typical Layout of mini-grid supplying El Limon (ESMAP, 2000)

The Electricity Committee in this case set a monthly fee to cover regular maintenance such as cleaning filters, periodic turbine bearing replacement, lamp replacements and repairs. Residents were involved in every phase of construction and are already prepared to perform most of the maintenance and repairs themselves. The tariff is expected to be minimal, about $2 per month, approximately the same as that typically spent for kerosene for lamps. Because project costs were covered from various external sources, the monthly tariffs are expected to cover the cost of materials such as bulb replacement and turbine bearings and the cost of the plant operator. To ensure payment, the Electricity Committee has decided to require a written agreement with each household before installing the house wiring. At present, nearly 60 households (all in the village except for the four houses located outside the present service area) have access to electricity (ESMAP, 2000).

2.7.2 Examples of hydropower for Rural Electrification in Africa

Many countries in Africa do have a rich history of small scale hydropower, but over time large numbers of these stations have fallen in disrepair. Some because the national grid reached their location but others because of lack of maintenance or pure neglect (Jonker Klunne, 2009). In Tanzania, more than 16 small hydropower systems were installed by church missions in the 60's and 70's of last century that are still operating (Mtalo, 2005).

Jonker Klunne (2009) did a case study of small hydropower in Tanzania. The case study investigated three (3) isolated mini grids in Tanzania (Table 2-9) using small scale hydropower technology to serve a total of over 1100 households, 32 institutions and 84 commercial loads with electricity (Jonker Klunne, 2009). Jonker Klunne found that the implementation of hydro projects can be made more sustainable if attention is given to the non-technical issues right from the start.

Table 2-9 - Overview of the three hydro stations used in the Tanzania case study (Jonker Klunne, 2009)

Development	MATEMBWE	MAVANGA	LUGARAWA
Project location	Matembwe Village, Njombe District, Iringa Region	Mavanga Village, Ludewa District, Iringa Region	Mavanga Village, Ludewa District, Iringa Region
Implementers	CEFA, RC church-Njombe Diocese	German donors and RC church-Njombe Diocese	Swiss & German donors and RC church-Njombe Diocese
Project duration	Started in 1983 and commissioned in 1986	Stared in 1999, operational since 2002	Installed in 1979 single phase power, three phase in 1995
Area of distribution	Matembwe and Image	Mavanga and Mbugani	Lugarawa and Mdilidili
Source of water	UDEKA stream	MOLOMBOJI stream	LIFUNGULU stream
Installed capacity	150 kW	2 x 75 kW	140 kW
Application	Domestic uses in villages, commercial uses in Matembwe Village Company, social centres and light commercial loads	Domestic uses in villages, commercial applications in micro-enterprises and service institutions	Mission hospital and light load uses in villages
	Technical summary		
Intake level (masl)	1489.5	N/A	N/A
Tail race (masl)	1480	N/A	N/A
Gross head (m)	10	N/A	N/A
Net head (m)	9.5	N/A	8
Daily flow (m^3/sec)	0.4 – 1.7	N/A	2.542 (rated flow)
Flood flow (m^3/sec)	10	N/A	N/A
Catchment (km^2)	24.3	N/A	N/A
	Intake facility		
Intake weir	Concrete wall across the stream lying on the rock bed	Concrete wall across the stream lying on the rock bed	Concrete wall across the stream lying on the rock bed
Penstock	Steel pipe covered with concrete, 22m long	PVC pipe	Still pipe covered with concrete
Turbine type	Kaplan	Francis	Osserburg Crossflow
	Transmission and Distribution		
Transmission/ Distribution line	To village 4 and 5 km To mission 2 km Total transmission 13 km	6 km	3 km
Cables	Four wire overhead cable.	Four wire overhead cable	Four wire overhead cable
Transmitted voltage	10,000 V		10,000 V
Transformer	100 kVA		100 kVA
Metering	All loads	Only commercial loads	All loads
	Beneficiaries		
Households	280	570	309
Institutions	9	14	9
Commercial loads	20	46	18

Kaunda, Kimambo and Nielson compiled a paper on the Potential of Small-Scale Hydropower for Electricity Generation in Sub-Saharan Africa, including a summary of recorded small hydropower plants (SHP) potential in some selected Sub Sahara African countries as follows (Kaunda, Kimambo and Nielson, 2012):

- Malawi – SHP potential of 7.35 MW from 22 sites
- Tanzania – SHP potential of 185 MW from 85 sites
- Uganda – SHP potential of 210 MW from over 50 sites
- Mozambique – SHP potential of 1000 MW from over 60 sites
- Rwanda – over 333 potential micro-hydropower sites

- Ghana – total of 21 mini-hydropower sites had been identified with potential electricity output ranging from 4 kW to 325 kW
- Kenya – SHP potential of about 3000 MW

2.7.3 Examples of small-scale hydropower in South Africa

The gold mines at Pilgrims Rest in South Africa were power by two (2) hydro turbines as early as 1892, and in 1894 a 45 kW turbine was added to power the first electrical train (Eskom, 2009). A hydropower system with a 300 kW station on the slopes of Table Mountain, South Africa, was inaugurated in 1895 (Barta 2002).

In 1997, Prof D Stephenson from the University of the Witwatersrand, compiled a preliminary report on the Potential Hydro-Electric Sites in the former Transkei (part of the Eastern Cape) in South Africa. Stephenson identified 23 sites within generating capacities ranging from 50 kW to 300 MW (Stephenson, 1997)

2.7.3.1 Examples of small-scale hydropower opportunities in South Africa

An investigation on the available renewable energy resources in South Africa, including hydropower was developed by the CSIR (Muller 1999), and was detailed for the Eastern Cape region through a three-year investigative project entitled "Renewable energy sources for rural electrification in South Africa". The project had the primary objective of identifying commercially viable opportunities for rural electrification within the Eastern Cape Province of South Africa using wind, hydro and biomass powered energy systems. The outcomes of these studies with respect to the potential for small hydropower in South Africa and the Eastern Cape respectively are shown in Figure 2-68 and Figure 2-69 below.

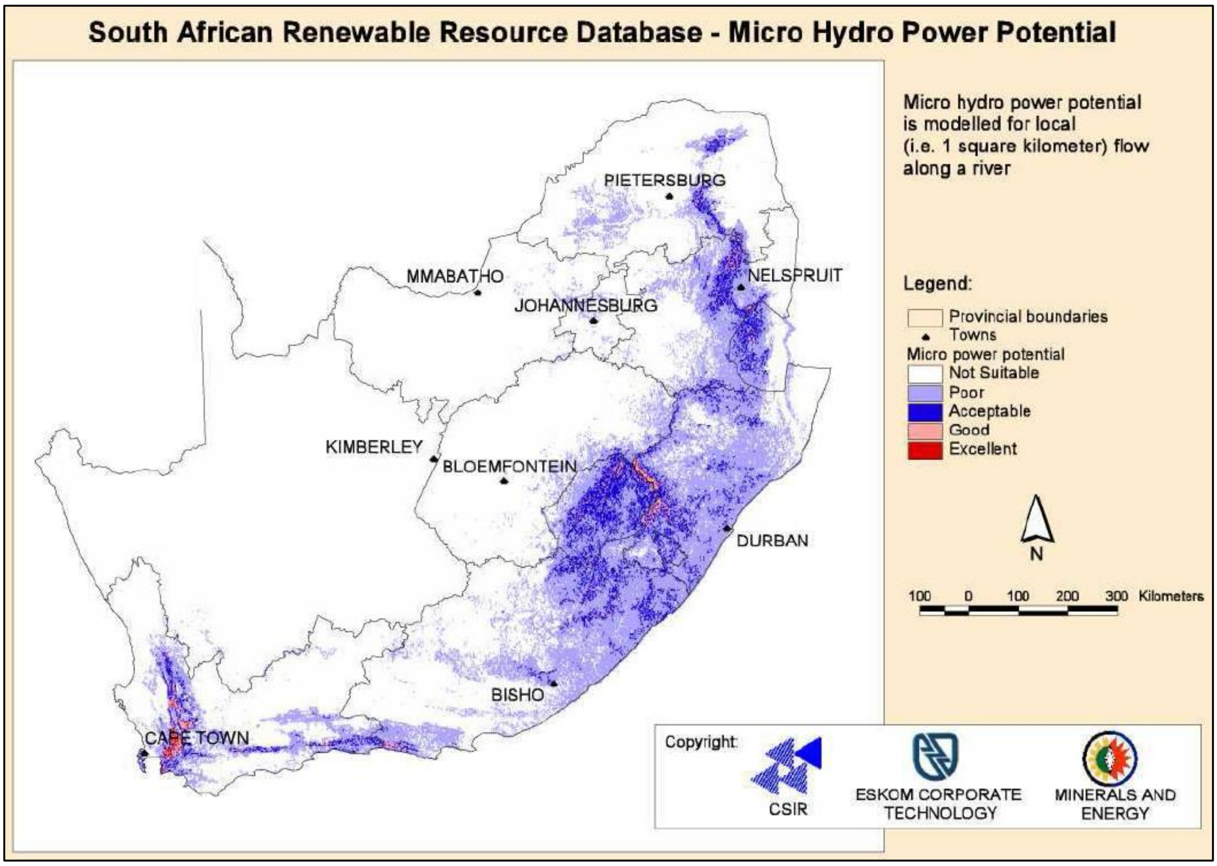


Figure 2-68 - Micro hydro potential South Africa (Muller, 1999)

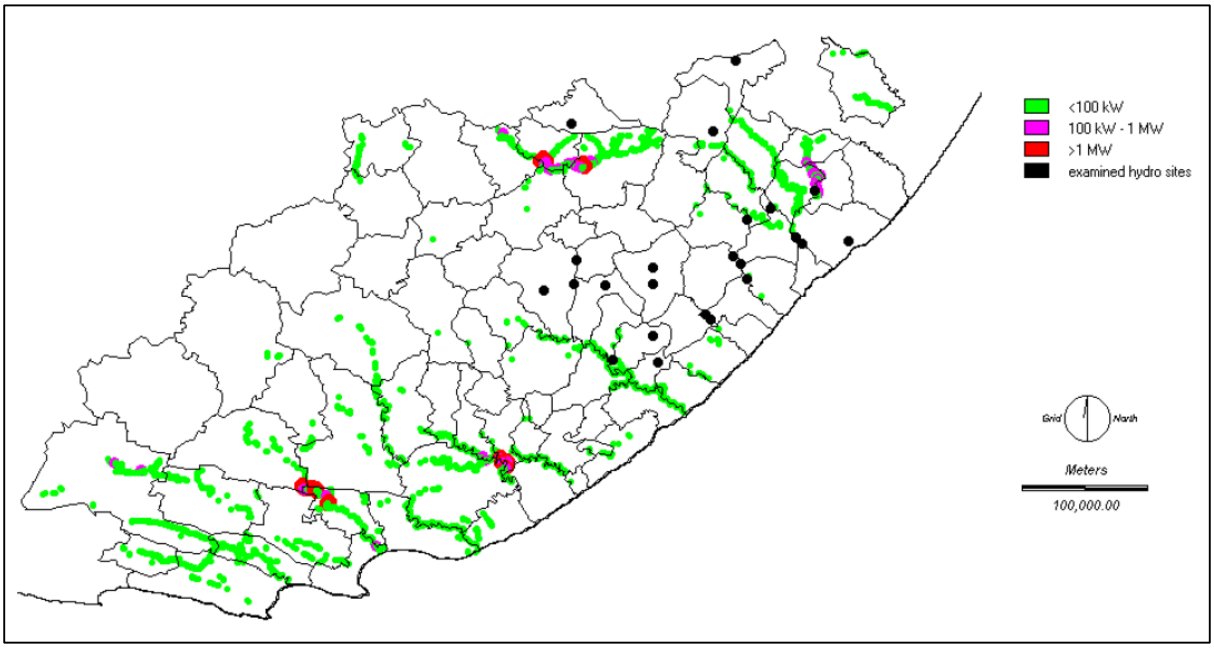


Figure 2-69 - Small hydro potential in the Eastern Cape (Szewczuk, Fellows & van der Linden 2000)

Barta (2002) investigated the installed capacities of hydropower in South Africa and the potential for new developments. He concluded that twice more the installed capacity of the present installed hydropower capacity below 10 MW can be developed in the rural areas of the Eastern Cape, Free State, KwaZulu Natal and Mpumalanga (Jonker Klune, 2009).

Recently initiatives have seen the light in a number of countries in Africa to revive the small hydro sector, particularly in Central Africa (Rwanda), East Africa (Kenya, Tanzania and Uganda) as well as Southern Africa (Malawi, Mozambique and Zimbabwe) new initiatives are focusing on implementing small hydropower projects. In South Africa the first new small hydro station in 20 years was opened in 2009, with more under development (Jonker Klunne, 2012).

2.7.4 Examples of Kinetic Turbine installations

Hydro Green Energy has developed a hydropower system by installing a hydrokinetic turbine which is located behind the turbine of the existing conventional hydropower plant on the Army Corps of Engineers' Lock and Dam No. 2 in Hastings, Minnesota. At the design point, the coefficient of performance for the Hasting hydrokinetic unit is 0.62, the highest in the hydrokinetic power industry at the point in time of commissioning. The Hastings hydrokinetic power station will produce a maximum of 1,454 MWh (100 kW per unit at 3.5 M/s) of electricity annually (Ortega-Achury, McAnally, Davis and Martin, 2010)

In The Yukon River at the Community of Ruby in Alaska, The Yukon River Inter-Tribal Watershed Council installed a 5 kW New Energy Encurrent turbine (Figure 2-70) for one month in 2008 to serve as a test case (Ortega-Achury et al., 2010). This installation represented the first hydrokinetic implementation in Alaska. Alaska has been highlighted as having large hydrokinetic potential due to the high energy costs and abundant river resources (New Energy Corporation, 2015). The community of Ruby has approximately 200 residents located on the Yukon River in central Alaska. Electricity for the community is currently being provided by diesel generators. A full year's supply of diesel is stored in a local tank farm. A pontoon boat was fabricated to house the EnCurrent Power Generation System (Figure 2-71).

Figure 2-70 - New Energy Encurrent Turbine (New Energy Corporation, 2015)

Figure 2-71 - Pontoon Boat with Encurrent Power Generation System (New Energy Corporation, 2015)

The Free Flow Power Corp proposed to install hydrokinetic turbines with a diameter of 3 m below the navigation depth at up to 55 sites along the Mississippi River. Each turbine would be able to generate roughly 1.6 MW of power which would then be transmitted ashore to the power grid or to industry sites (Ortega-Achury et al., 2010).

A Case Study of utilising the kinetic energy of flowing water of the Burinadi and Meghna Rivers of Bangladesh to generate hydroelectric power was done in 2012. The study showed the potential hydroelectric power generated from the Burinadi River as 21.1 MWh per annum and that from the Meghna River as 12.48 MWh per annum (Islam, Gupta, Masum, Karim and Rahman, 2013)

2.8 CONCLUSION

The basics of rural electrification were reviewed and numerous social and economic benefits were found ranging from levelling of ethnic difference to increased security due to home lighting.

From the basic theory of hydropower two governing equations for the generation of electricity by means of hydropower were found, the conventional available pressure head and flow equation and the kinetic hydro turbine equation. From the literature available it is clear that hydropower is a viable and efficient option for the generation of electrical energy and has various economic, social and environmental advantages. There are many different alternatives with regards to the different components of a hydropower scheme, which makes hydropower an attractive alternative to fossil fuel energies in many different scenarios or applications

Identifying potential small scale hydropower sites involves both a technical and feasibility component. A specific sites might have tremendous technical potential for hydropower, but might be unfeasible to develop on a small scale for rural electrification. A specific site however cannot be feasible without having the technical possibility of small scale hydropower. For this reason it is important to identify and evaluate potential sites on technical grounds first before evaluating the feasibility of such potential small scale hydropower sites. There exist commercially available software programs for identifying the hydropower potential of different areas or specific sites. The focus of the study is on Small-scale Hydropower.

There are several different hydropower schemes and configurations and alternatives for any specific site and these different schemes have different components contributing to the hydropower plant as a whole. Apart from the different options for hydropower schemes there also exist numerous different hydro turbines for different applications. The different turbines can be grouped into either reaction or impulse turbines. The decision of scheme, components and turbine will depend on the application, economic and social needs of the project.

There exist legislation and regulations in South Africa with regards to energy generation and distribution as well as water usage and environmental aspects of hydropower schemes which needs to be understood and complied with in the development of small-scale hydropower for rural electrification in South Africa.

Small-scale hydropower has been successfully implemented for rural electrification in several international settings. Within a South African framework, Small-scale Hydropower plants have existed since the early 1900's. The study aims to serve as a guide for SSHP development in South Africa as well as prove the feasibility of SSHP plants within a South African framework.

The following chapter focusses on identifying and selecting potential SSHP sites within the participating municipalities within the scope of the study.

3 IMPLEMENTATION MODEL

The following model was designed and constructed for the feasible implementation of a SSHP project for rural electrification in South Africa. The model can also be implemented on international projects by varying cost equations and currencies to project and country specific values.

The implementation model describes steps to be followed in identifying a technically possible and feasible opportunity to develop a SSHP site for rural electrification. The different sections within the model are described in detail in the relevant sections of the study based on research and designs of SSHP. The numbers in brackets in the implementation model refers to the relevant chapters within the study for the particular component of the model. Continuous referral from the subsequent sections of the study back to the implementation model provides a comprehensiveness to the model which allows for a sustainable implementation of the SSHP project from the conceptual phase to the commissioning of the plant.

Figure 3-1 to Figure 3-3 shows the three different sections, namely Site Selection, SSHP design and Costing, which combine to form the implementation model.

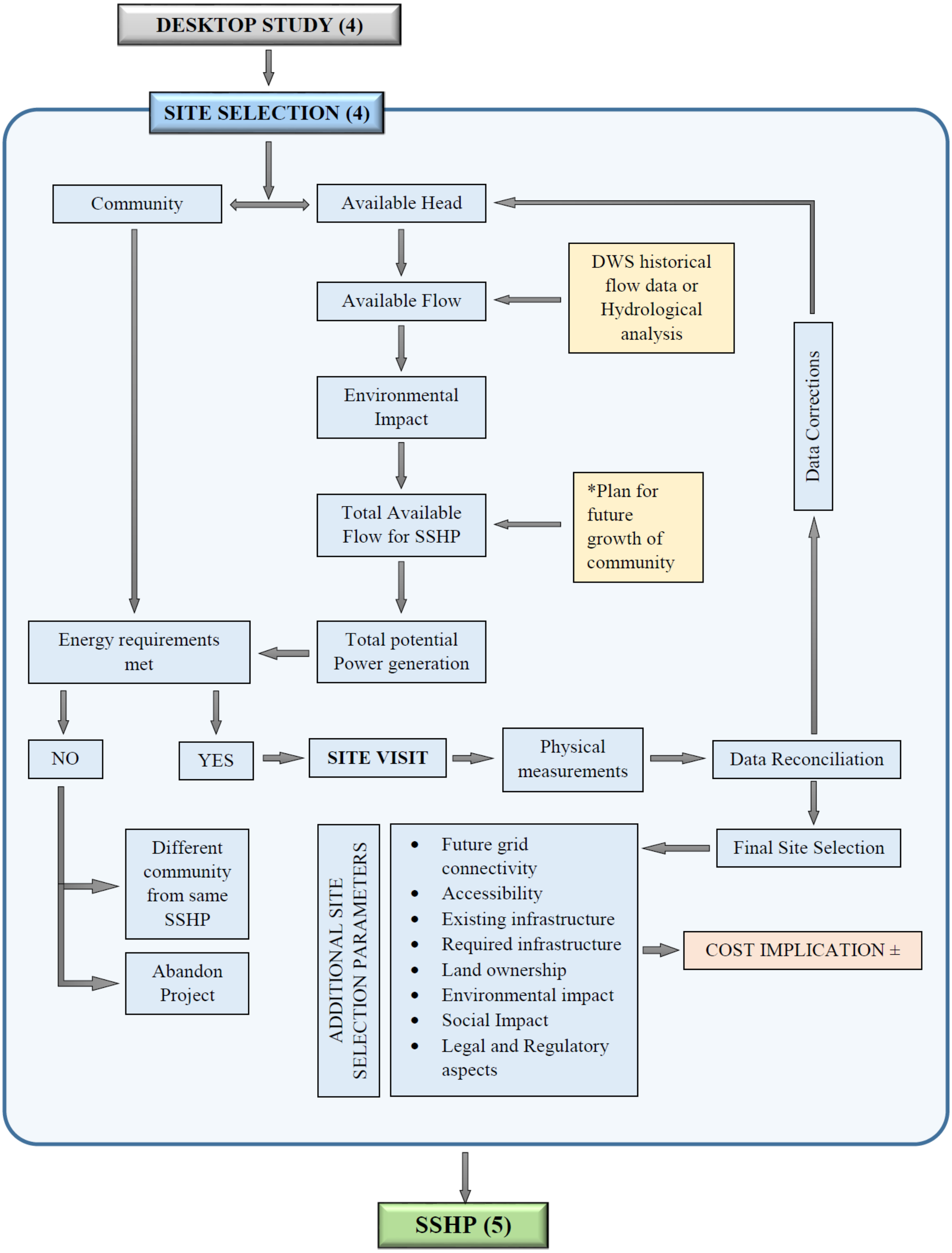


Figure 3-1 - Implementation Model - Site Selection

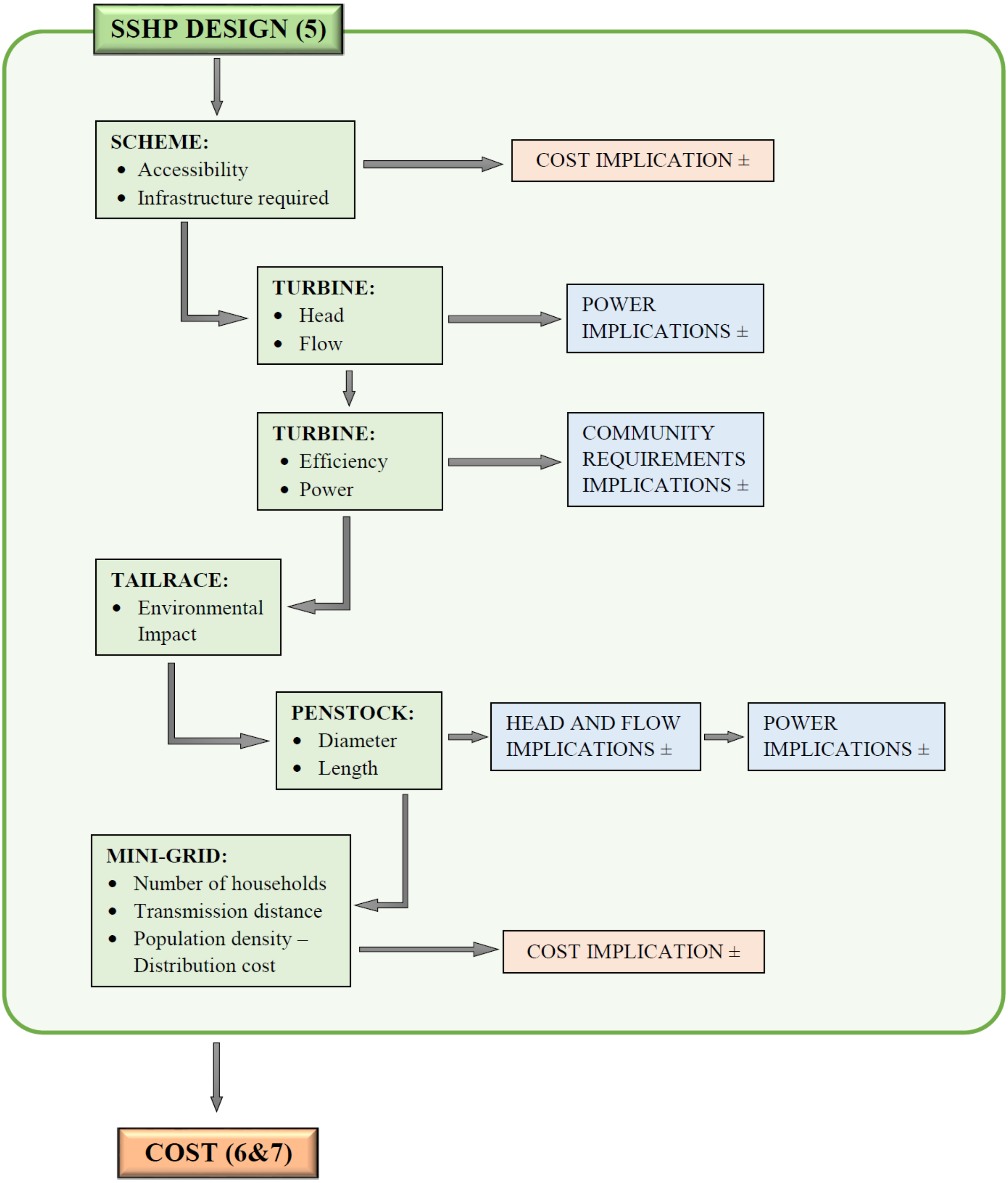


Figure 3-2 - Implementation Model – SSHP Design

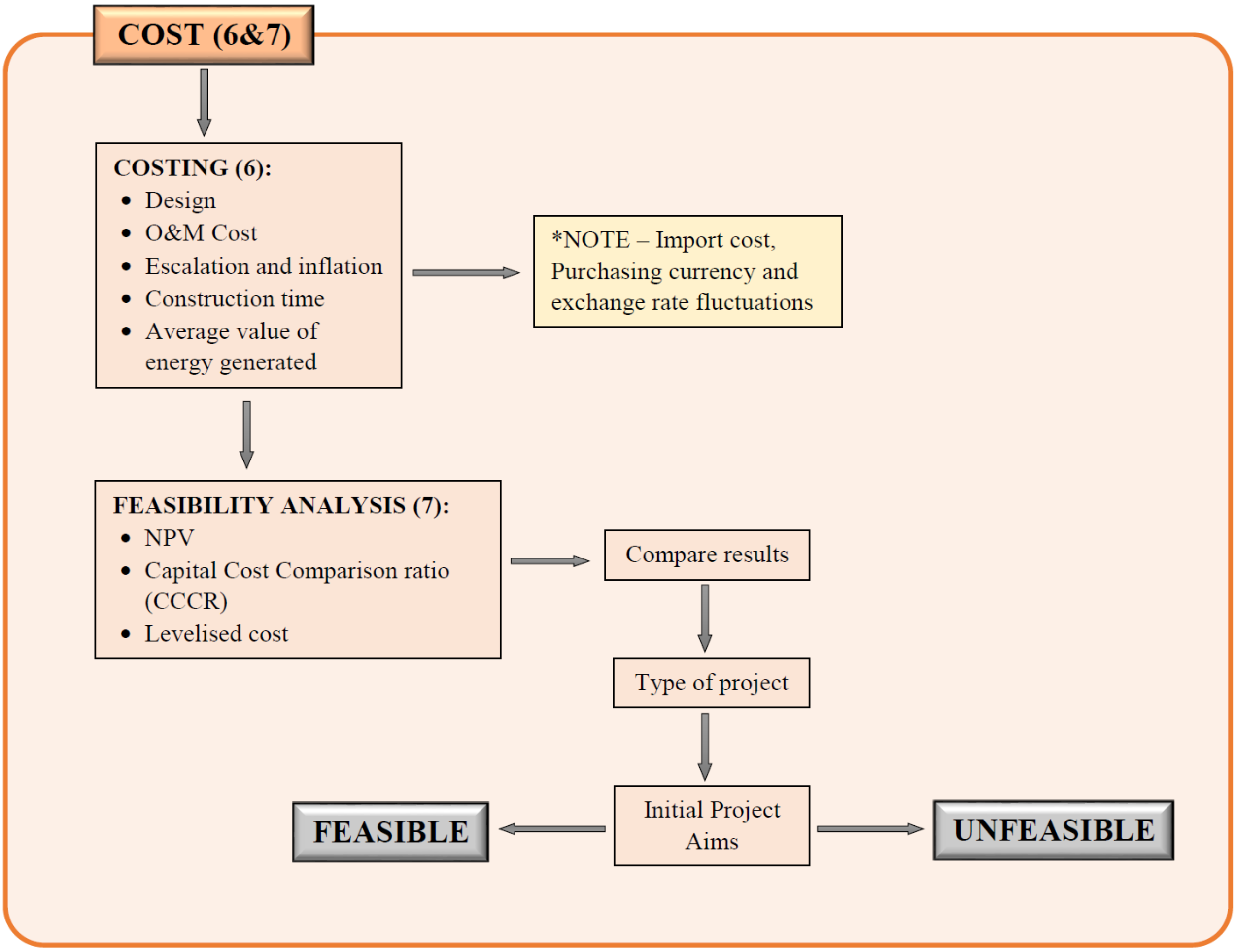


Figure 3-3 - Implementation Model - Costing

4 HYDROPOWER SITE SELECTION

This particular section of the report describes the steps and processes followed in the selection of the potential and implementable sites for developing small scale hydropower for rural electrification, as well as the various parameters and data used in selecting and refining the selection of the sites as shown in Figure 3-1.

4.1 SITE SELECTION PARAMETERS

As stated the main focus study is as follows:

> *The feasibility and technical possibility of providing small-hydropower installations for rural electrification in South Africa.*

From this focus all the aspects related to the selection of suitable sites can be categorised into three categories, which by definition sums up the purpose and expected outcome of the study. These three categories are as follows:

1. **Feasibility** – In simple terms, the two criteria to judge feasibility are cost required and value to be attained. In conduit hydropower projects, some may have a monetary value providing a fast payback period, while others have additional value, servicing remote sites with subsequent benefits (Barta, Van Dijk and Van Vuuren, 2011). The same is true for small-scale hydropower projects. The feasibility of the installation depends on the ability of providing electricity to an end user at a lower unit cost that it would cost the Electricity Service Provider to provide infrastructure to supply the end users with electricity, i.e. to provide and installation, within a remote community which is not grid connected, at a cost similar to what it would take ESKOM to provide the infrastructure to connect the remote community to the grid.
2. **Technical** – the technical ability to develop a site to generate electricity by means of a small scale hydropower plant depends mainly on the availability of flow and head. As discussed in the literature review different technologies are used for different combinations of head and flow available. The technical aspects are discussed in more detail in the sections below.
3. **Rural** – Rural in terms of the study will be classified as any community not connected the electricity grid and with no planning to be connected to the electricity grid in the near future. Rural will also include communities or individuals which are in close vicinity to the electrical grid yet cannot afford to purchase electricity from the Electricity Service Provider due to socio-economic reasons.

All the parameters investigated, as shown in Figure 3-1, or used for the selection of potential sites for the study is in one way or another related to the above mentioned three categories. Some sites might have the technical capacity to be developed but might be unfeasible due to large expenditure on infrastructure needed. Other sites might be feasible and technically possible yet contained within an urban area with a well established electrical grid and infrastructure.

As discussed in the literature review the two most important parameters for the selection of the potential sites are head and flow available, because without these the small scale hydropower generation is not possible. The head and flow available as well as all the other parameters used in the site selection process are discussed in detail in the sections below. Figure 4-1 graphically displays the site selection parameters flow (Q), head (h), penstock length (x), turbine selection (T), distance to nearest rural settlement (y), total population of rural settlement (n) and potential electricity generation (P).

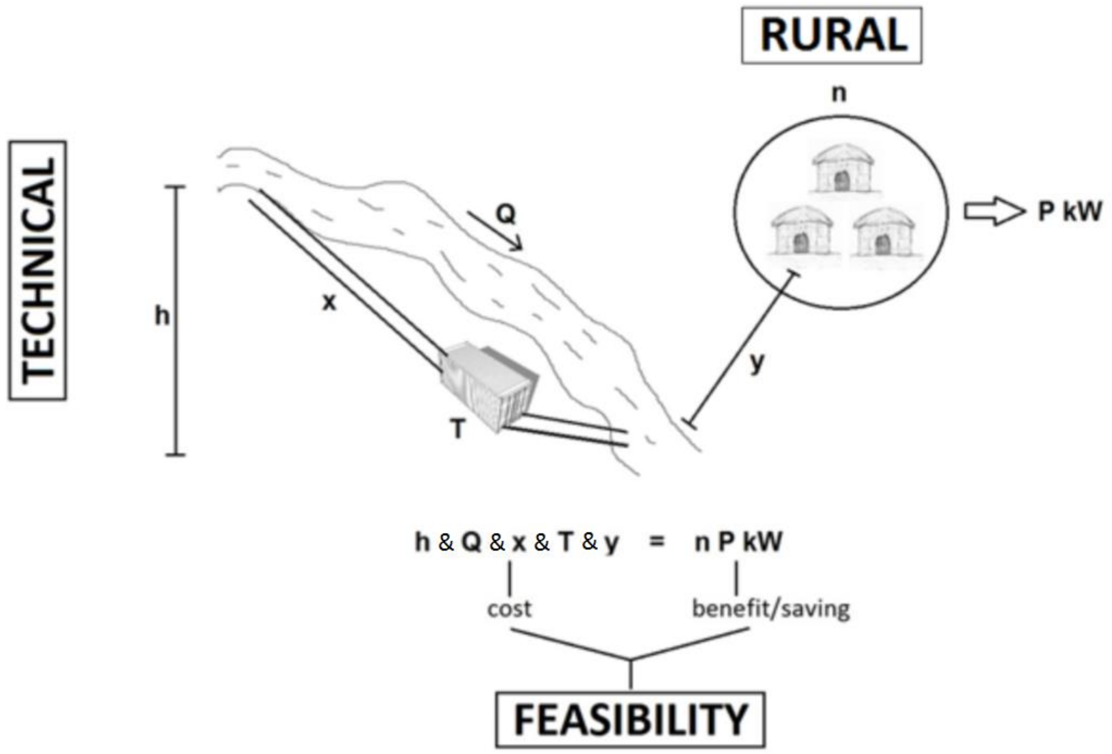


Figure 4-1 - Site selection parameters schematic

4.1.1 Potential Head

Potential head as determined preliminary per the elevation tool within the Google Earth application, and checked and confirmed with the physical site visits is one of the most important site selection parameters.

From the basic mathematical relationship that the potential power output is directly proportional to the flow through the turbine and the pressure head available, it is clear that for the same energy output, the higher your available head is the lower the flow needed for the same power generation. This is beneficial for two main reasons:

1. Less flow needs to be diverted from the river through the penstock, which minimises environmental impact on the flow within the river section.
2. The lower flow is needed through the turbine, the smaller the physical dimensions of the turbine (i.e. in the case of crossflow turbine) become and the lower the cost of the turbine becomes.

This tends to shift focus from sites with high flows towards sites with a higher height difference and more potential head.

4.1.2 Potential Flow

It must be noted that without flow through the turbine no electrical power will be generated. When selecting sites on flow, it is first and foremost important to select rivers or river section which do have flow within them, i.e. perennial rivers or streams.

It is important to provide an installation with as constant flow as possible to operate at maximum efficiency. It is important to know what flow rate can be constantly abstracted and rerouted through the small scale hydropower setup without adversely affecting the river system and in extreme cases run a river section dry. For this reason only rivers with an accurate historical flow data record were considered for potential sites. The amount of flow required with the available head for the generation of a specific required energy output is determined and discussed within the design of the different plant installations.

4.1.3 Nearest Rural Settlement

Apart form the population of the nearest rural settlement in proximity of the potential site, as discussed later in the document, the actual nearest rural settlement is also a parameter that needs to be assessed in the potential site selection.

In collaboration with the District Municipality and the different Local Municipalities it might become apparent that certain communities or settlements have had less infrastructure development in the past than others. These communities might be “due” for development and the DM might favour these above others. There might also be political reasons for favouring certain communities above others.

In the broader spectrum of the study and for the feasibility of providing the small scale hydropower plants for rural electrification, this is not a great issue. However for the construction of such a plant this parameter must be included.

4.1.4 Distance to nearest Rural Settlement

The closer the end users of the electricity is to the plant the shorter the electrical transmission line to the end users are and thus the more economically feasible the installation becomes.

For this reason preference was given to sites which are closer to the community. This however becomes issue of weighing the potential energy generation at a site against the cost of the transmission infrastructure. If the energy generation capacity of a site is much higher but further away from a community than another site which is closer but with a lower capacity a sensitivity analysis needs to be done to determine which of the sites would be more suitable. The optimum distance from a specific site for different plant capacities will be discussed in Section 10.

4.1.5 Population of Rural Settlement

As stated above, the population or the size of the rural settlement to be benefit from the plant installation is of importance as a site selection parameter in order to determine the demand on the potential site.

For a site with a high electricity generation potential it might not be a problem. However for a plant of moderate capacity with a large community as nearest settlement, it might become that the demand is higher than the plant capacity. For instance, your plant capacity is 50 kW and your demand or agreed demand is 5 kW per household. You can supply 10 households, but for more than 10 household your plant does not have sufficient capacity.

The goal will ultimately be to conceptualize a feasible small scale hydropower unit which can supply n amount of households with P amount of electricity when y distance from a potential site with H head available and Q flow. For the purpose of the study preference was given to sites which can supply the whole nearest settlement with an acceptable level of electricity.

4.1.6 Accessibility by vehicle

With using the Google Earth application for evaluating head differences within the desktop study done, it became necessary to verify available head by means of physical site visits. Although not an initial parameter for site identification (due to all sites being assumed equally accessible initially, and due to the small-scale of the installations), it becomes a crucial parameter for site selection.

During the site selection process, preference was given to sites accessible by vehicle, due to accessibility needed for the physical site visits and the construction phase of such an installation or plant.

Accessibility by a vehicle is also an important parameter once the sites are selected, for construction purposes. Sites only accessible by a 4x4 or 4WD vehicle becomes impractical once trucks need to off-load material for construction. Smaller sites which requires less or smaller infrastructure and which is accessible only by 4x4 vehicle or by foot might become feasible depending on the benefit gained from the small scale hydropower plant.

4.1.7 Electrical Grid Connected and Future Electrical Grid Connectivity

With the focus of the study being on the feasibility and technical possibility of providing small-hydropower installations for rural electrification in South Africa, communities or settlements connected to the electrical grid or with plans underway from the ESP to be connected to the grid in the near future were excluded from the potential site list.

Rural in terms of the study was classified as any community not connected to the electricity grid and with no planning to be connected to the electricity grid in the near future. Rural also includes communities or individuals which are in close vicinity to the electrical grid yet cannot afford to purchase electricity from the ESP due to socio-economic reasons.

In this regard, within the site selection process, preference was given to sites in close vicinity to settlements not connected to the electrical grid and with no plans underway from the ESP to be connected to the grid in the near future.

4.1.8 Existing Infrastructure

Existing infrastructure at a given site gives the benefit of saving on construction cost and makes a particular site more feasibility than a similar site without the infrastructure. With the added benefit of the existing infrastructure comes regulatory and legislative requirements from the owner of the existing infrastructure, this is discussed in the section below.

Existing infrastructure in both the uMzinyathi DM and the OR Tambo DM which might be beneficial to utilise within the study and the project are in the form of existing weirs. As discussed in the literature review, weirs are essentially small dams or reservoirs. A level difference exists at weirs, which provides an available head, which along with the flow over the weir can be used to operate a turbine and generate electricity. Hydropower generation relies both on available head and flow and thus not all weirs will have equal power generating potential, and sites needs to be evaluated on the frequency of certain flow rates.

All weirs within the rivers with an adequate and accurate flow data record within the uMzinyathi DM and the OR Tambo DM were seen as potential hydropower sites and included in the sites selected to be physically visited. Not all weirs visited provided an opportunity for small scale hydropower, either on the basis of to small a head difference or being within an urban and well established electricity grid area. Figure 4-2 and Figure 4-3 shows the difference between preliminary feasible and preliminary unfeasible sites.

Figure 4-2 - Tayside weir and gauging station - Existing infrastructure - Not feasible

Figure 4-3 - Rune Weir - Existing Infrastructure - Feasible

4.1.9 Infrastructure Required

This parameter is not as much a parameter for site selection as it is for site elimination. From the physical site visits as well as the desktop study at some identified sites, it can be seen that excessive infrastructure will be needed to make the hydropower plant technically possible. At some sites the river will need to be dammed by means of a weir to allow for the intake of water as well as function as additional available head. Some river sections become very wide at the upstream end of their highest height difference, this makes the construction of a weir difficult and expensive.

As discussed under the section of distance from the nearest settlement, the further from the settlement the SSHP plant is the more infrastructure is needed in the form of transmission lines. It is also known that theoretically any river with a bed slope will have a suitable head difference over a long enough section of river. However this can result in the need for very long and expensive penstocks which in turn increases friction losses and decreases available head.

Rivers carrying excessive silt material can cause problems to hydro turbines and additional infrastructure is needed in the system in terms of modified intake structures which could become expensive and render a site unfeasible.

As stated the parameter of infrastructure required was used in the potential site selection process not by identifying potential sites but by eliminating unfeasible sites which require extensive infrastructure development.

4.1.10 Land, Property and Infrastructure Owners

Where the land or property on which new infrastructure for the SSHP will be build, is not owned directly by the developer i.e. the DM or LM, an additional agreement with the land or property owners will have to be reached. For inline or conduit hydropower the same applies for the infrastructure owners.

Development rights on properties or land must also be obtained as a requirement for NERSA energy generation licenses. This is discussed further in section 5.1.

Sites which were the least affected by this parameter are seen as more feasible and practically implementable.

4.1.11 Environmental Impact

Due to the small scale of the hydropower plants and the fact that the generation of electrical energy by means of a hydro turbine is a non-consumptive use the environmental impacts of these installations are minimal.

To a degree the environmental impacts are limited to the construction period of the plant. A containerized unit was conceptualised. This allowed for assembly of site, leaving minimum civil works to be done on site in the form of small scale concrete works for foundations, and in some cases then penstock. This containerised unit is discussed in more detail in sections to follow.

For most sites identified the environmental effects will be the same and hence it is difficult to select a site on this parameter. An environmental effect that is quantifiable however is the amount of flow abstracted from the river and put through the hydro turbine. The impact being that the rivers or river section with the higher historical flow rate will be the least affected by the abstraction of water at a section, rerouting through the turbine and releasing into the river further downstream.

Sites with higher historical flow rate from accurate flow data records were given preference within the selection of sites to develop, bearing in mind that it is still possible to abstract and reroute very little flow when the available head is high enough.

4.1.12 Social Impact

The social impact parameter of the site selection process gave preference to rural settlements and communities which have either a school, clinic or community centre etc. which will be able to benefit from the rural electrification by means of small scale hydropower.

Based on the above mentioned criteria or parameters for the selection of potential sites, the initial sites from the desktop study were evaluated and several of the more suitable sites were visited physically during the months of January, February and March 2015.

4.2 PARTICIPATING MUNICIPALITIES

Two District Municipalities (DM's) have been included in this study; namely the uMzinyathi DM in KwaZulu-Natal and the OR Tambo DM in the Eastern Cape.

4.2.1 uMzinyathi District Municipality

The uMzinyathi District Municipality is one of the ten districts of the KwaZulu-Natal province in South Africa. The Municipality is bordered in the north by the aMajuba Municipality, in the west by the uThukela Municipality, in the south west by the uMgungundlovu Municipality, in the south east by the iLembe Municipality and in the east by uThungulu District Municipality. The district consists of four Local Municipalities, namely: eNdumeni, Nquthu, Msinga and uMvoti.

The extent of the uMzinyathi DM is illustrated in Figure 4-4.

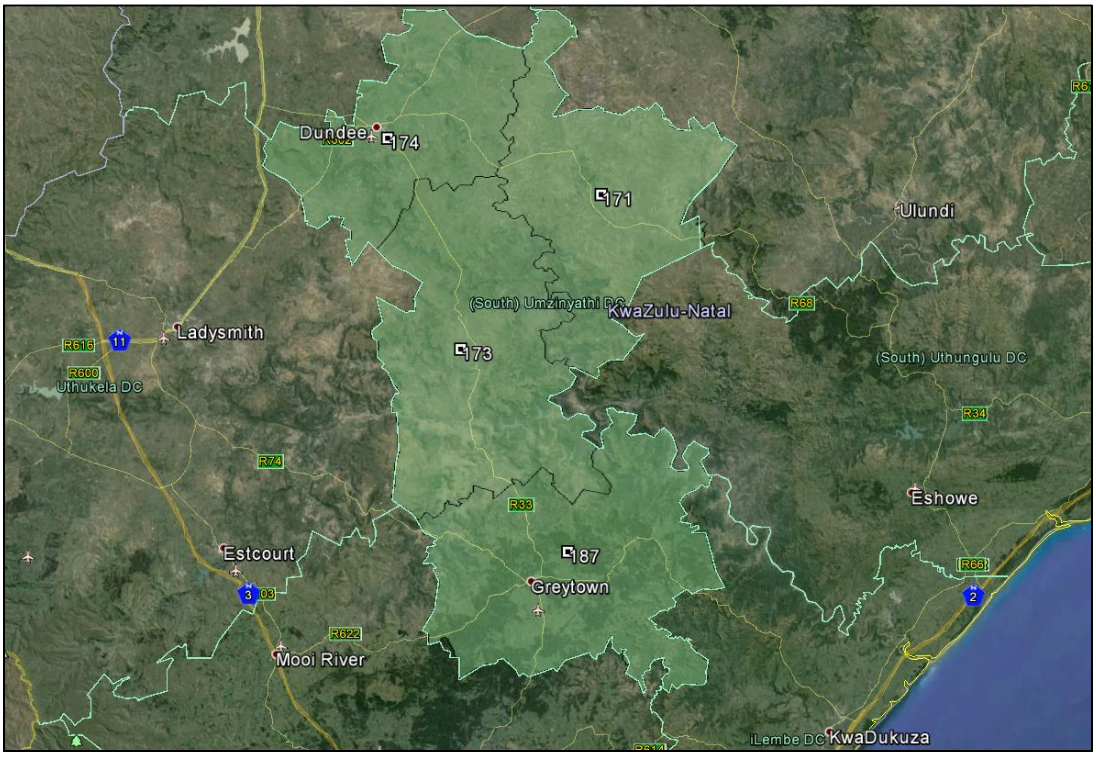


Figure 4-4 - uMzinyathi District Municipality boundaries

The uMzinyathi District Municipality comparative population figures indicates an increase from 480 088 in 2001 to 510 838 in 2011, contributing 5.0% in the entire province which is the same percentage as in 2011 due to population growth as seen in Table 4-1.

Table 4-1 - uMzinyathi District Municipality Comparative population and households figures by Local Municipalities for 2001 and 2011 (Statistics SA, Census 2001 and 2011)

Municipality	2001			2011		
	Population	%	Households	Population	%	Households
Endumeni	51 101	10.6	12 278	64 862	12.7	16 852
Nqutu	169 419	35.3	29 318	165 307	32.4	31 613
Msinga	167 274	34.8	32 505	177 577	34.8	37 723
Umvoti	92 294	19.2	19 669	103 093	20.2	27 282
Umzinyathi	**480 088**	**100.0**	**93 770**	**510 838**	**100.0**	**113 470**

Figure 4-5 illustrates access to electricity for lighting purposes in the district. As can be seen, the number of households without access to electricity has decreased as it was an average of 25.5% in 2001 and 48.9% in 2011.

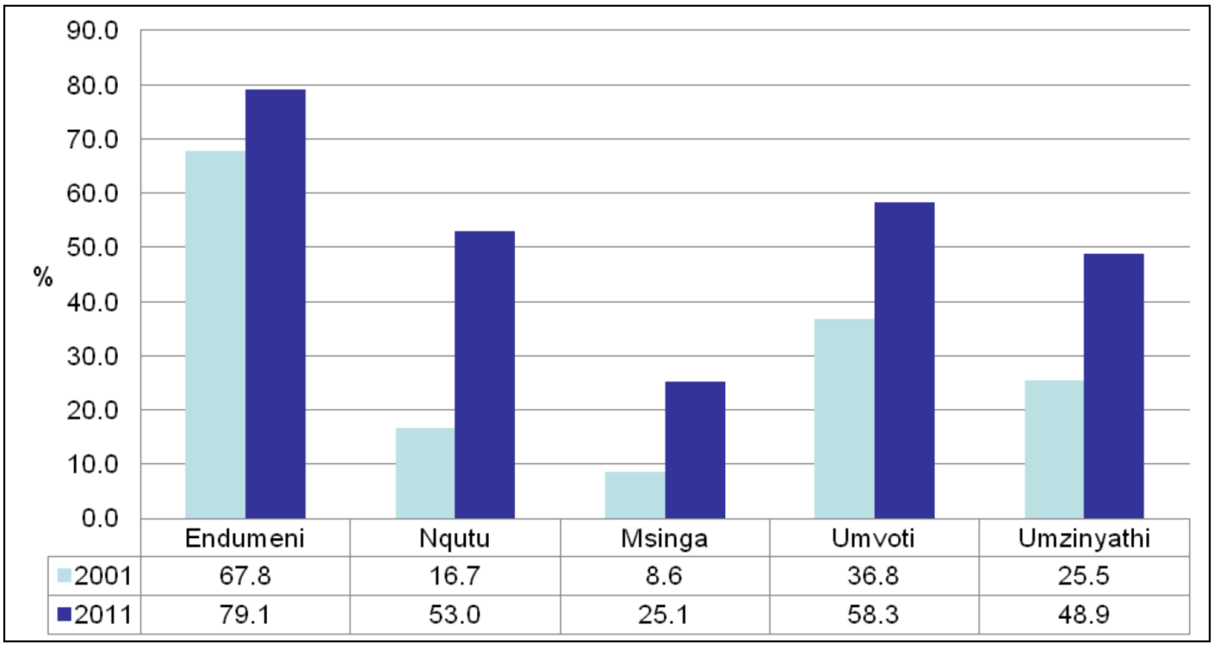


Figure 4-5 - Electricity provision for lighting

The provision of electricity within the district lies with Eskom and the local municipalities. The municipality is preparing a Electrification Master Plan which will provide a comprehensive approach in providing and managing electricity within the district. The bulk electricity network of uMzinyathi is depicted in Figure 4-6.

As can be seen from the information provided above there is a definite backlog of electricity in the uMzinyathi District Municipality.

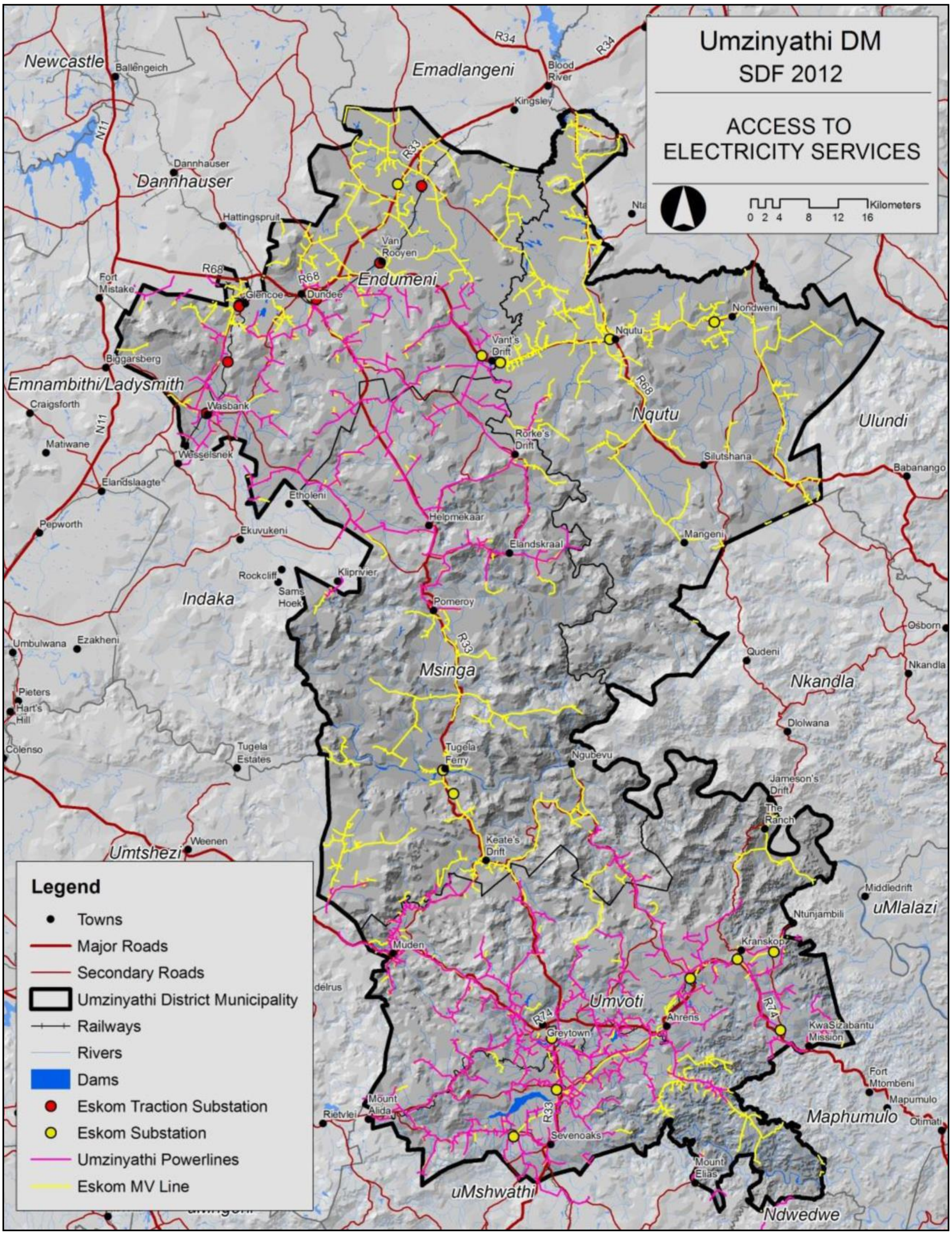


Figure 4-6 - uMzinyathi Bulk electricity network

4.2.2 OR Tambo District Municipality

OR Tambo District Municipality is one of the six district municipalities in the Eastern Cape Province. It covers about 80% of what used to be marginalised homeland in Transkei and is formed by five local municipalities: King Sabata Dalindyebo, Nyandeni, Mhlontlo, Port St Johns, and Ingquza Hill. The municipality is located to the east of the Eastern Cape Province, on the Indian Ocean coastline as depicted in Figure 4-7. Some of the larger cities/towns in this DM include: Flagstaff, Libode, Lusikisiki, Mqanduli, Mthatha (Umtata), Ngqeleni, Port St Johns, Qumbu and Tsolo.

Some demographic information:

- Population: 1 364 943
- Households: 298 229
- Population Growth: 0.52% p.a.
- Unemployment Rate: 44.10%

The provision of electricity is the sole responsibility of Eskom. The District Municipality is only involved in the planning process. With the exception of the King Sabata Dalindyebo Local Municipality, where 70% of the households have access to electricity for lighting, the other LMs in the District fell significantly below the Provincial average of 67% in 2007. Most of the households in these municipalities depended on candles and paraffin as their source of energy for lighting (see Table 4-2). This situation has now improved significantly (see Table 4-3).

Table 4-2 - Source of Energy for lighting (OR Tambo DM, 2013)

Municipality	**Electricity**		**Gas**		**Paraffin**		**Candles**		**Solar & others**	
	①	②	①	②	①	②	①	②	①	②
	%	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Eastern Cape	49.7	67.1	0.3	0.4	23.3	14.0	25.9	18.3	0.8	0.2
OR Tambo	28.1	49.6	0.3	0.2	12.1	8.0	58.4	41.6	1.2	0.5
Ingquza Hill	13.6	42.7	0.2	0.4	8.0	5.8	76.3	50.0	1.8	1.0
KSD	41.7	70.1	0.4	0.2	24.3	11.5	33.1	18.1	0.6	0.2
Mhlontlo	30.1	47.1	0.2	0.6	8.8	2.4	60.0	49.1	0.9	0.9
Nyandeni	32.2	58.4	0.2	0.2	11.5	19.7	55.0	21.7	1.0	0.0
Port St. John‟s	17.2	45.6	0.3	0.4	10.5	1.9	70.8	52.1	1.1	0.0

Note: ① - Census, 2001 in OR Tambo (2013)
② - RSS, 2006 in OR Tambo (2013)

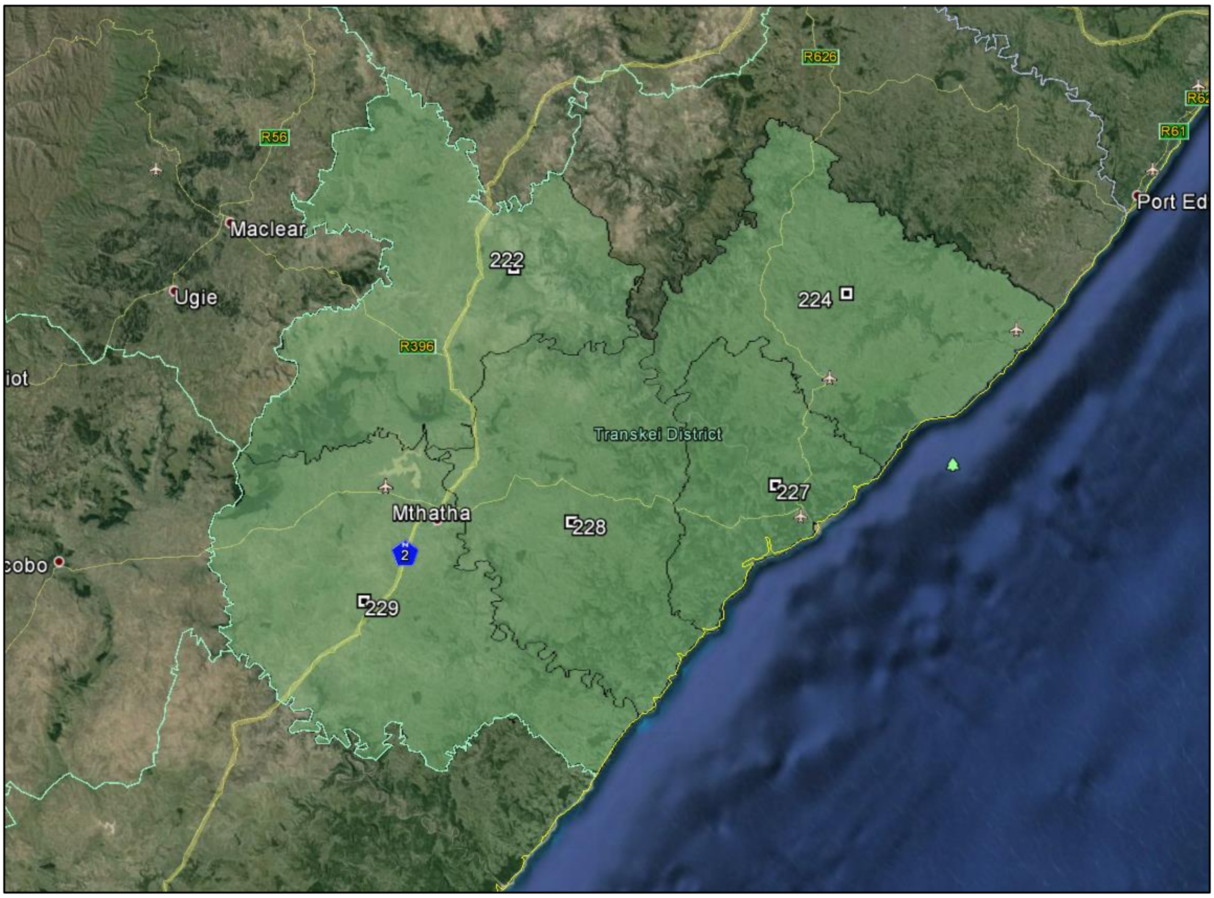


Figure 4-7 - OR Tambo District Municipality boundaries

The Census 2011 data revealed that local municipality with the most households with access to electricity for cooking is the Sabata Dalinyebo Local Municipality at a total of 60 464 households or 57.5% of the total households, see Table 4-3 In OR Tambo District Municipality a total of 209 288 households have access to electricity for lighting, which is 70.2% of the total households. The Port St Johns Local Municipality have the least access to lighting with a total of 21 504 households or 67.8% of the total households in that municipality having access.

Table 4-3 - Access to electricity 2011 (Stats SA Population census, 2011)

2011	Ngquza Hill LM	Port St Johns LM	Nyandeni LM	Mhlontlo LM	King Sabata Dalindyebo LM	OR Tambo DM
Electricity for lighting	35 317	21 504	43 760	31 525	77 182	209 288
Electricity for cooking	20 323	9 885	24 669	19 444	60 464	134 785
Electricity heating	10 680	5 406	9 583	6 519	20 888	53 076
Percentage of total households:						
Electricity for lighting	62.8 %	67.8 %	71.0 %	72.6 %	73.3 %	70.2 %
Electricity for cooking	36.2 %	31.2 %	40.0 %	44.8 %	57.5 %	45.2 %
Electricity heating	19.0 %	17.0 %	15.5 %	15.0 %	19.8 %	17.8 %

As can be seen from the information provided above there is a definite need for electricity in the OR Tambo District Municipality.

4.3 INITIAL SITE SELECTION DESKTOP STUDY

It is well known that the basic mathematical relationship of hydropower theory is that the potential power output is directly proportional to the flow through the turbine and the pressure head available. For the initial identification of potential sites for small scale hydropower generation within the OR Tambo and uMzinyathi District Municipalities, a desktop study was utilised. The focus of the desktop study was to preliminarily identify sites based solely on potential head available at different individually selected sites.

A Keyhole Markup language Zipped file (.kmz) for the rivers and river sections within the OR Tambo and uMzinyathi DM's was obtained from the Department of Water and Sanitation (DWS). This file contains the layout of all the rivers and streams within the different DM's. The different rivers and river sections within the OR Tambo and uMzinyathi DM's were investigated utilizing the Google Earth program. The elevation tool within Google Earth was used to identify height differences within the different rivers which would create head differences suitable for small scale hydropower generation.

Theoretically any river with a bed slope will have a suitable head difference over a long enough section of river. Although this is true for all rivers, not all sections of river are suitable for small scale hydropower generation. Specific parameters for eliminating certain sections of rivers or identified sites are discussed in more detail in the following sections. However the first step was to investigate solely on height differences which would create suitable potential head based on literature reviewed and sound engineering judgement.

A summary of the results of the desktop study and preliminary identified sites for both the OR Tambo and uMzinyathi District Municipalities are found in the sections below.

4.3.1 Preliminary Site Identification in uMzinyathi DM

Table 4-4, Table 4-5 and Figure 4-8 below shows a summary and the different locations of preliminary identified sites within the uMzinyathi District Municipality.

Table 4-4 - Preliminary Sites – Summary – uMzinyathi DM

Rivers investigated	1 – Buffels 2 – Hlimbitwa 3 – Mangeni 4 – Mooi 5 – Mvoti 6 – Ngwebini 7 – Nseleni 8 – Sampofu 9 – Thukela 10 – Wasbank
Potential sites	139
Lowest head	1 m
Highest head	50 m
Existing weirs	7

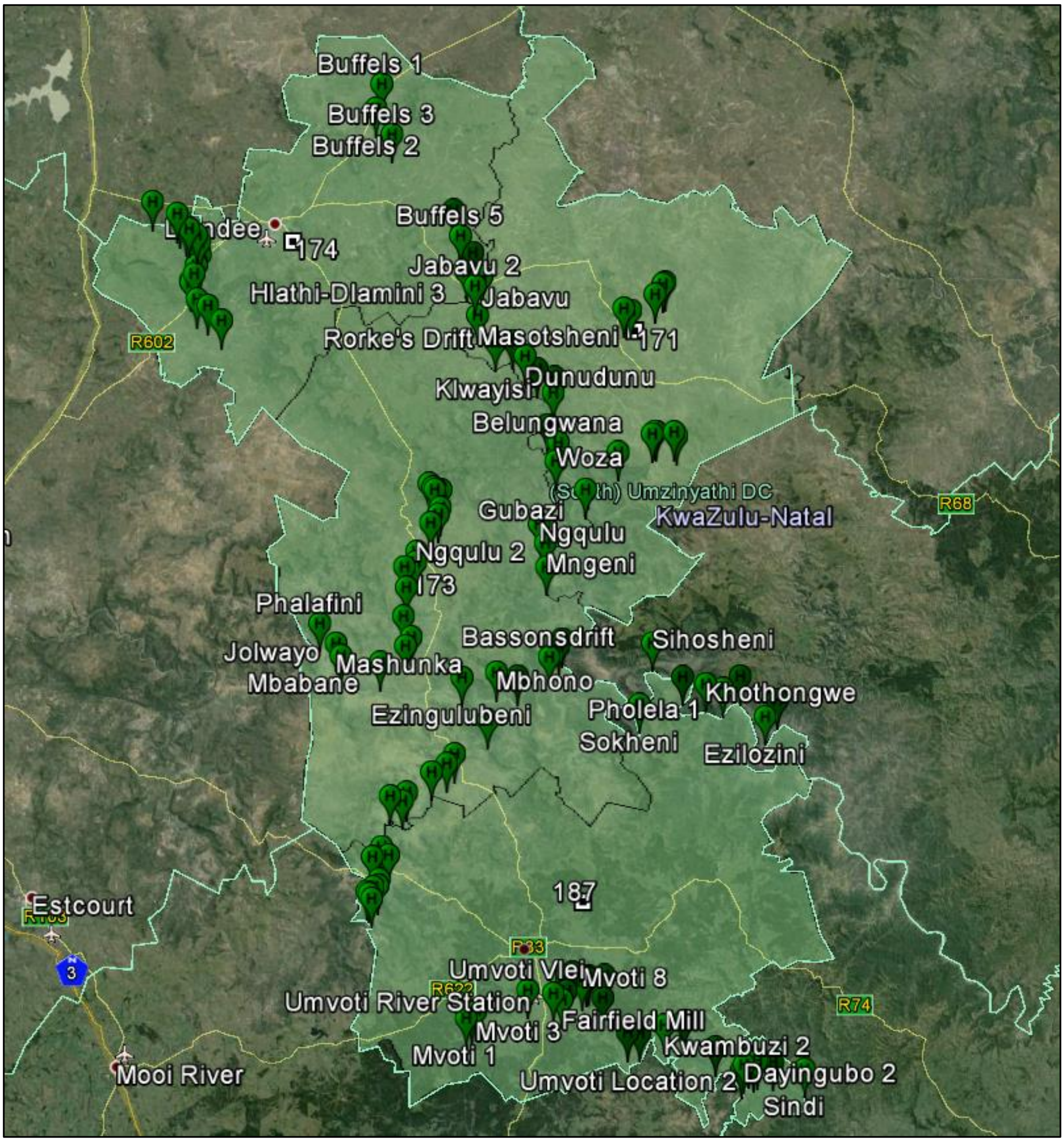


Figure 4-8 - Preliminary identified Site Locations - uMzinyathi

Table 4-5 - Preliminary Sites - Spreadsheet Abstract – uMzinyathi

No.	Local Municipality	River	Site	Co-ordinates		Potential Head (m)
				Lat	Long	
1	Endumeni - 174	Buffels	Vant's Drift	28° 14' 45.52"S	30° 30' 33.15"E	Gauging Station
2	Endumeni - 174	Buffels	Tayside	28° 03' 33.55"S	30° 22' 24.13"E	Weir
3	Endumeni - 174	Buffels	De Jagersdrift	28° 00' 37.58"S	30° 23' 39.15"E	Gauging Station
4	Endumeni - 174	Buffels	Buffels 1	28° 1'38.30"S	30°23'6.49"E	2
5	Endumeni - 174	Buffels	Buffels 2	28° 3'27.88"S	30°22'36.48"E	1
6	Endumeni - 174	Buffels	Buffels 3	28° 5'24.14"S	30°23'57.28"E	3
7	Endumeni - 174	Buffels	Buffels 4	28°11'5.12"S	30°29'8.53"E	26
8	Endumeni - 174	Buffels	Buffels 5	28°12'59.02"S	30°29'43.85"E	3
9	Endumeni - 174	Buffels	Hlathi-Dlamini	28°14'14.73"S	30°30'46.05"E	5
10	Endumeni - 174	Buffels	Hlathi-Dlamini 2	28°14'50.41"S	30°30'28.07"E	5
11	Endumeni - 174	Buffels	Hlathi-Dlamini 3	28°15'43.33"S	30°30'14.72"E	4
12	Nquthu - 171	Buffels	Jabavu	28°16'3.85"S	30°31'30.71"E	2
13	Nquthu - 171	Buffels	Jabavu 2	28°16'43.64"S	30°30'56.89"E	3
14	Nquthu - 171	Buffels	Masotsheni	28°18'55.83"S	30°31'9.39"E	3
15	Nquthu - 171	Buffels	Rorke's Drift 2	28°20'49.18"S	30°34'7.00"E	13
16	Nquthu - 171	Buffels	Rorke's Drift	28°20'56.94"S	30°32'39.90"E	2
17	Nquthu - 171	Buffels	Dunudunu	28°21'57.98"S	30°35'9.70"E	8
18	Nquthu - 171	Buffels	Goba	28°22'55.92"S	30°36'11.35"E	16
19	Nquthu - 171	Buffels	Mpandeni	28°23'32.83"S	30°37'38.38"E	16
20	Nquthu - 171	Buffels	Klwayisi	28°24'42.52"S	30°37'32.68"E	11

The complete list of sites identified within the uMzinyathi District Municipality is attached in Appendix A. The complete list attached also contains several additional parameters as discussed in the following sections.

4.3.2 Preliminary Site Identification in OR Tambo DM

Table 4-6, Table 4-7 and Figure 4-9 below shows a summary and the different locations of preliminary identified sites within the OR Tambo District Municipality.

Table 4-6 - Preliminary Sites – Summary - OR Tambo DM

Rivers investigated	1 – Cicira 2 – Corana 3 – Inxu 4 – iTsitsa 5 – KwaDlambu 6 – Mbhashe 7 – Mhlahlane 8 – Mngazana 9 – Mngazi 10 – Mntafufu 11 – Msikaba 12 – Mtakatye 13 – Mtentu 14 – Mthatha 15 – Mzimvubu 16 – Mzintlava 17 – Ngqungqu 18 – Thina 19 – Xura
Potential sites	178
Lowest head	1 m
Highest head	60 m
Existing weirs	9

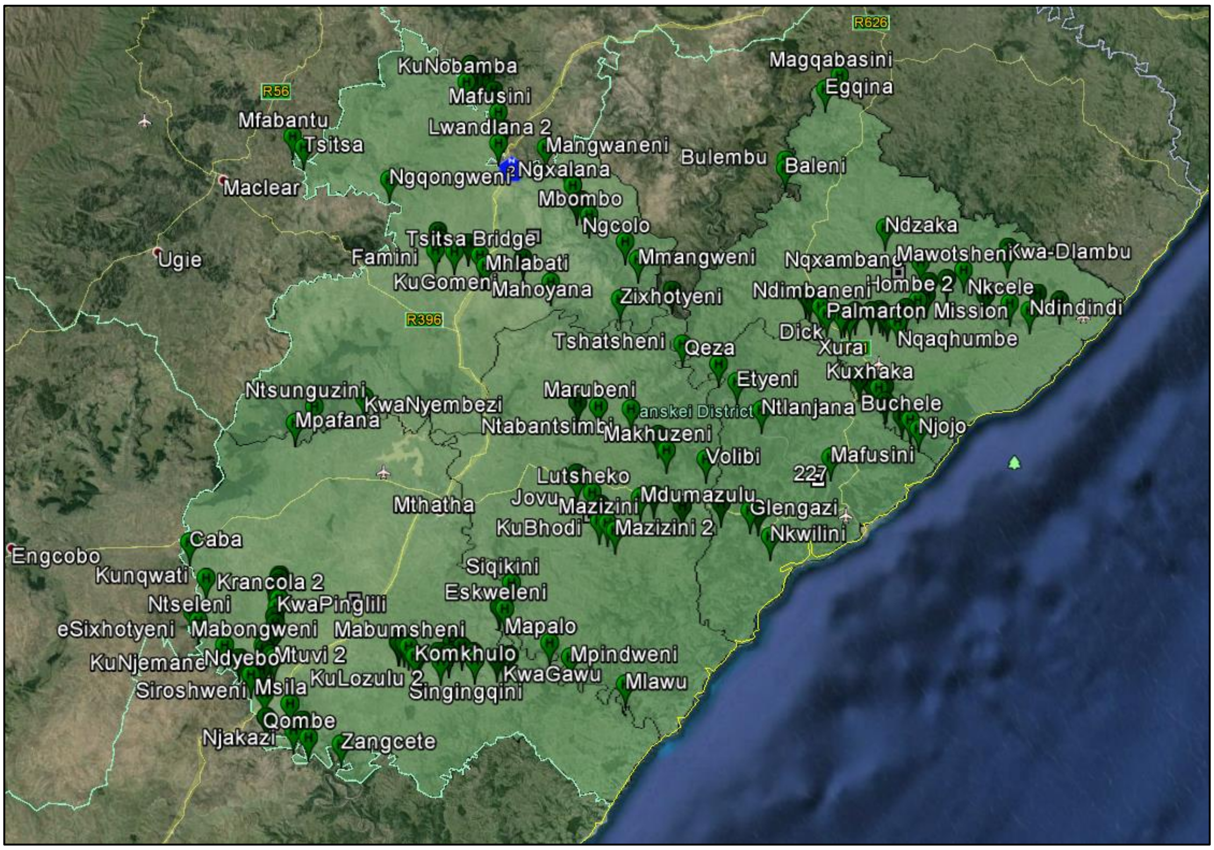


Figure 4-9 - Preliminary identified Site Locations - OR Tambo

Table 4-7 - Preliminary Sites - Spreadsheet Abstract - OR Tambo

No.	Local Municipality	River	Site	Co-ordinates		Potential Head (m)
				Lat	Long	
1	King Sabata Dalindyebo - 229	Cicira	Roode Heuvel	31°33'24.01"S	28°44'13.99"E	Gauging Station
2	Nyandeni - 228	Corana	Corana Dam	31°26'14.81"S	28°52'27.15"E	Gauging Station
3	Mhlontlo - 222	Inxu	St Augustine Mission	31°13'09.98"S	28°37'50.98"E	Gauging Station
4	Mhlontlo - 222	iTsitsa	Dudlaka	31°17'21.54"S	29°11'59.56"E	25
5	Mhlontlo - 222	iTsitsa	Zixhotyeni	31°18'18.71"S	29° 6'14.13"E	18
6	Mhlontlo - 222	iTsitsa	Laleni	31°14'29.53"S	28°55'25.83"E	14
7	Mhlontlo - 222	iTsitsa	KuGomeni	31°13'56.56"S	28°47'48.61"E	13
8	Mhlontlo - 222	iTsitsa	KuGomeni 2	31°13'6.75"S	28°49'19.61"E	13
9	Mhlontlo - 222	iTsitsa	Mdeni	31°11'58.04"S	28°45'56.55"E	12
10	Mhlontlo - 222	iTsitsa	Mhlabati	31°15'17.08"S	28°51'16.71"E	10
11	Mhlontlo - 222	iTsitsa	Tsitsa	31° 3'55.07"S	28°30'50.72"E	9
12	Mhlontlo - 222	iTsitsa	Mahoyana	31°16'45.22"S	28°58'31.16"E	8
13	Mhlontlo - 222	iTsitsa	Tsitsa Bridge	31°14'14.49"S	28°50'37.79"E	7
14	Mhlontlo - 222	iTsitsa	Mfabantu	31° 2'51.22"S	28°29'35.79"E	6
15	Mhlontlo - 222	iTsitsa	Famini	31°13'47.68"S	28°45'42.44"E	6
16	Mhlontlo - 222	iTsitsa	Malepelepe	31°12'40.49"S	28°46'6.50"E	5
17	Mhlontlo - 222	iTsitsa	Ngqongweni	31° 6'58.30"S	28°40'26.19"E	4
18	Mhlontlo - 222	iTsitsa	Xonkonxa	31°14'17.01"S	28°51'07.99"E	Weir
19	Mhlontlo - 222	iTsitsa	Xonkonxa	31°14'16.00"S	28°50'45.99"E	Gauging Station
20	Ingquza Hill - 224	KwaDlambu	Lupondo	31°17'3.71"S	29°52'48.75"E	26

The complete list of sites identified within the OR Tambo District Municipality is attached in Appendix A.

4.4 FLOW DATA RECORDS

Although the study investigates the potential for small scale hydropower throughout the whole OR Tambo and uMzinyathi DM's, the focus was shifted to rivers with records of flow data available. Without flow data available for a potential site on a river one could still estimate flows with theoretical modelling from hydrological and rainfall data and statistical methods, or deterministic and empirical methods for peak flow calculations. Not only does this need additional calculation time but it might also not be as accurate as an actual flow record as obtained by the gauging stations of the DWS. An accurate flow record is crucial in the design of the potential hydropower plant, as it will determine the amount of flow which can be routed through the turbine in order to generated energy.

Flood hydrology calculation will be done to determine flood lines and the position of the designed plants, however for the sizing of the turbine and for the feasibility calculations it is important to have an accurate flow record. Some gauging stations within the DM's may have an accurate monthly peak flows yet not accurate daily flow values. These monthly peaks will also be utilised in determining flood lines for the positioning of the designed plants.

From correspondence with the DWS, it was observed that there are eleven (11) gauging stations operational in the uMzinyathi DM and twenty-four (24) gauging stations operational in the OR Tambo DM. From these thirty-five (35) gauging stations, some do not have an accurate flow record and some are stations in dams which measure dam levels. The flow gauging stations within the OR Tambo and uMzinyathi DM's with an accurate flow record and applicable to the study are summarized in Table 4-8 and Table 4-9.

Table 4-8 - uMzinyathi DM - Gauging Stations

No.	River	Station	Co-ordinates		Accurate Record
			Lat	Long	
1	Buffels	V3H001 - Vant's Drift	-28.24598	30.50921	N/A
2	Buffels	V3H010 - Tayside	-28.05932	30.37337	Daily
3	Buffels	V3H006 - De Jagersdrift	-28.01044	30.39421	N/A
4	Hlimbitwa	U4H003 - Boschfontein	-29.00899	30.78866	Monthly
5	Mooi	V2H008 - Keate's Drift	-28.85983	30.49976	N/A
6	Mooi	V2H001 - Scheepersdaal	-29.03316	30.36004	Daily
7	Mvoti	U4H002 - Mistley	-29.16192	30.63000	Daily
8	Nseleni	U4H004 - Hermans Bridge	-29.01705	30.78060	Monthly
9	Thukela	V6H002 - Tugela Ferry	-28.75003	30.44222	Daily
10	Thukela	V6H007 - Impafana Loc.	-28.74623	30.37865	Daily
11	Wasbank	V6H003 - Kuikvlei	-28.30986	30.14781	Daily

Table 4-9 - OR Tambo DM - Gauging Stations

No.	River	Station		Co-ordinates		Accurate Record
				Lat	Long	
1	Cicira	T2H010 -	Roode Heuvel	-31.55667	28.73722	N/A
2	Corana	T2R003 -	Corana Dam	-31.43745	28.87421	N/A
3	Inxu	T3H014 -	St Augustine Mission	-31.21944	28.63083	N/A
4	iTsitsa	T3H006 -	Xonkonxa	-31.23806	28.85222	Daily
5	iTsitsa	T3H016 -	Xonkonxa	-31.23778	28.84611	N/A
6	Mbhashe	T1H015 -	Rara 34	-32.00056	28.58167	N/A
7	Mbhashe	T1H004 -	Bashee Bridge	-31.92028	28.44778	Daily
8	Mbhashe	T1H014 -	Rune	-31.85100	28.39269	Daily
9	Mbhashe	T1H013 -	Gxwali Bomvu	-31.79967	28.33303	Daily
10	Mhlahlane	T2R002 -	Mabeleni Dam	-31.44676	28.56245	N/A
11	Mngazi	T7H001 -	Mgwenyana Loc. 22	-31.55120	29.24380	Daily
12	Mntafufu	T6H001 -	Ntafufu Loc. 35	-31.49611	29.52881	Daily
13	Mthatha	T2H002 -	Norwood	-31.58444	28.78417	Daily
14	Mthatha	T2H007 -	Gate to Turbine	-31.58417	28.78500	Daily
15	Mthatha	T2H008 -	Umtata	-31.56889	28.76389	Daily
16	Mthatha	T2H009 -	Pipeline to P/Works	-31.55389	28.74500	Daily
17	Mthatha	T2R001 -	Umtata Dam	-31.55103	28.74100	N/A
18	Mthatha	T2H003 -	Kambi Forest Res.	-31.47052	28.61747	N/A
19	Mthatha	T2H001 -	Dumasi Loc 5	-31.68412	28.88359	N/A
20	Mzimvubu	T3H020 -	Nontela	-31.39550	29.26508	Daily
21	Mzintlava	T3H017 -	Ludiwana	-31.10428	29.39972	Daily
22	Thina	T3H005 -	Mahlungulu	-31.03181	28.88450	Daily
23	Xura	T6H005 -	Lusikisiki P/Works	-31.33444	29.52806	N/A
24	Xura	T6H004 -	Xura 27	-31.32778	29.52667	Daily

Statistical analysis examples of the flow records for the above mentioned gauging stations are shown and discussed in the following sections for the different DM's.

4.4.1 uMzinyathi DM Gauging Station Data Example

Figure 4-10, Figure 4-11 and Table 4-10 gives and example of gauging station data and flow statistics for one of the gauging stations used within the uMzinyathi DM.

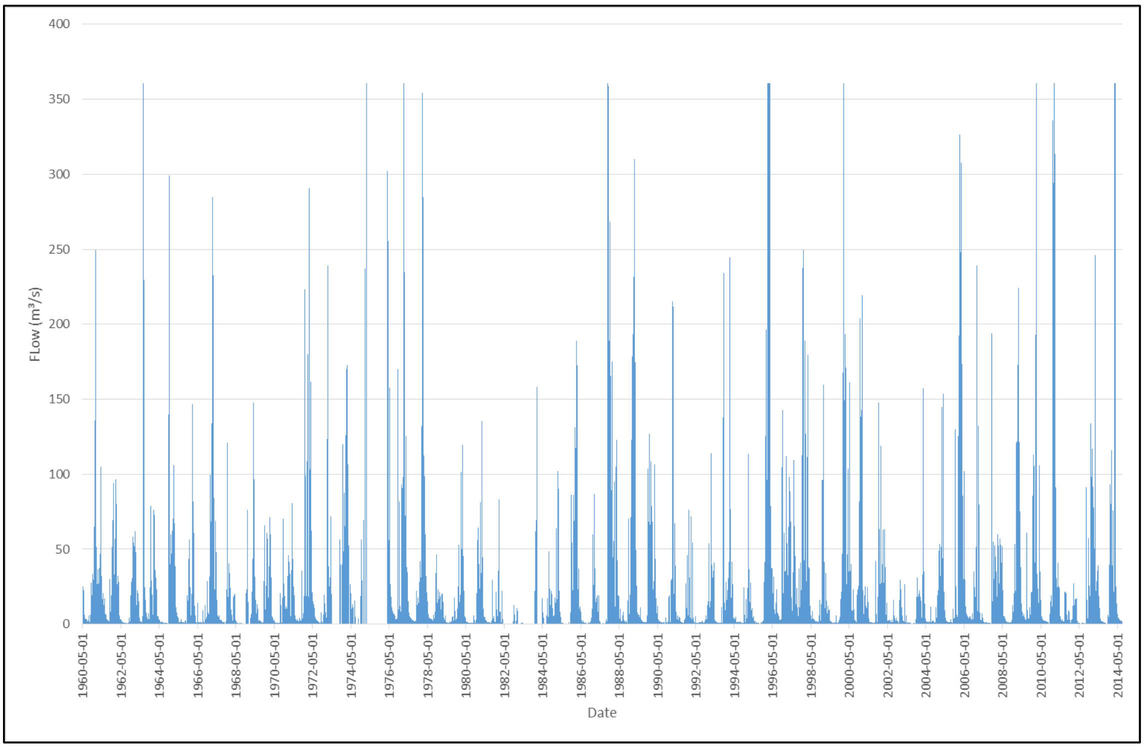


Figure 4-10 - V3H010 Flow Record

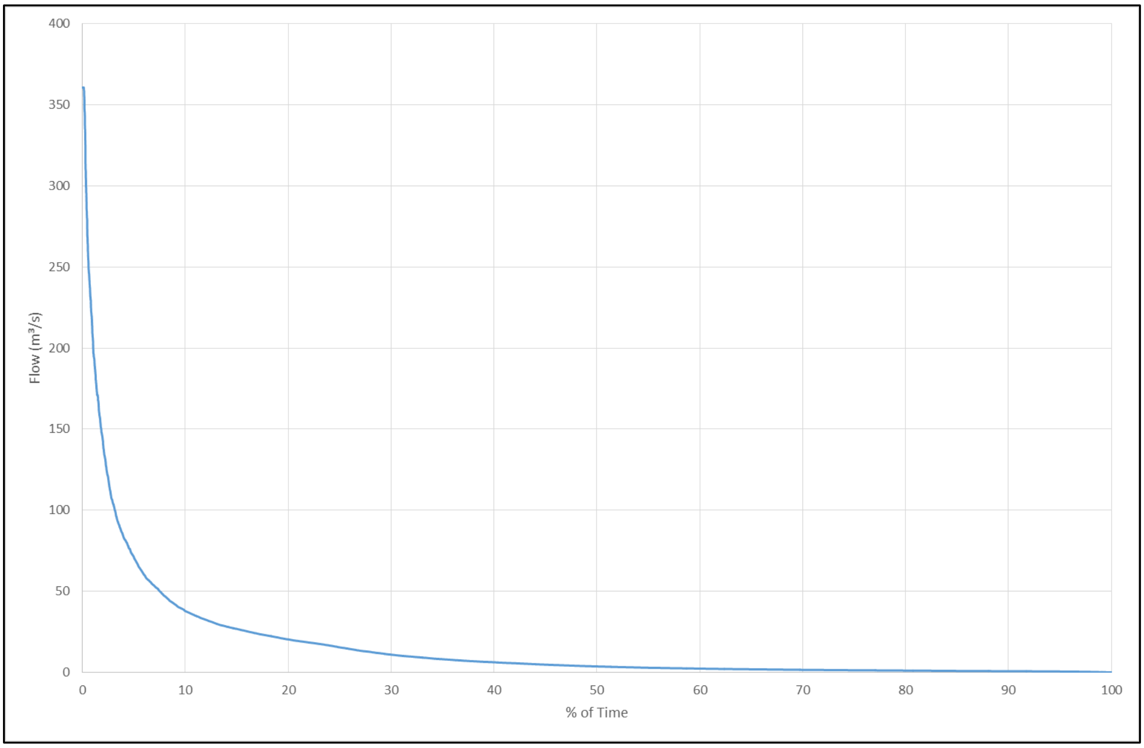


Figure 4-11 - V3H010 - Flow Duration Curve

Table 4-10 - V3H010 - Flow Statistics

Mean (m^3/s)	16.25
Standard Deviation (m^3/s)	37.15
Minimum (m^3/s)	-
Maximum (m^3/s)	360.73
Count	18 097
Confidence Level (95.0%) (m^3/s)	0.541

From the statistical analysis of the flow data record obtained from the DWS, it can be concluded with a 95% confidence level that the flow within the Buffels River at the V3H010 (Tayside) gauging station will be 0.541 m^3/s. The confidence level of flow and the amount of flow available for the small scale hydropower generation will be discussed in paragraph 4.1.

The complete data sets and statistical analyses for the flow gauging stations within the uMzinyathi DM is attached in Appendix B.

4.4.2 OR Tambo DM Gauging Station Data Example

Figure 4-12, Figure 4-13 and Table 4-11 gives and example of gauging station data and flow statistics for one of the gauging stations used within the uMzinyathi DM.

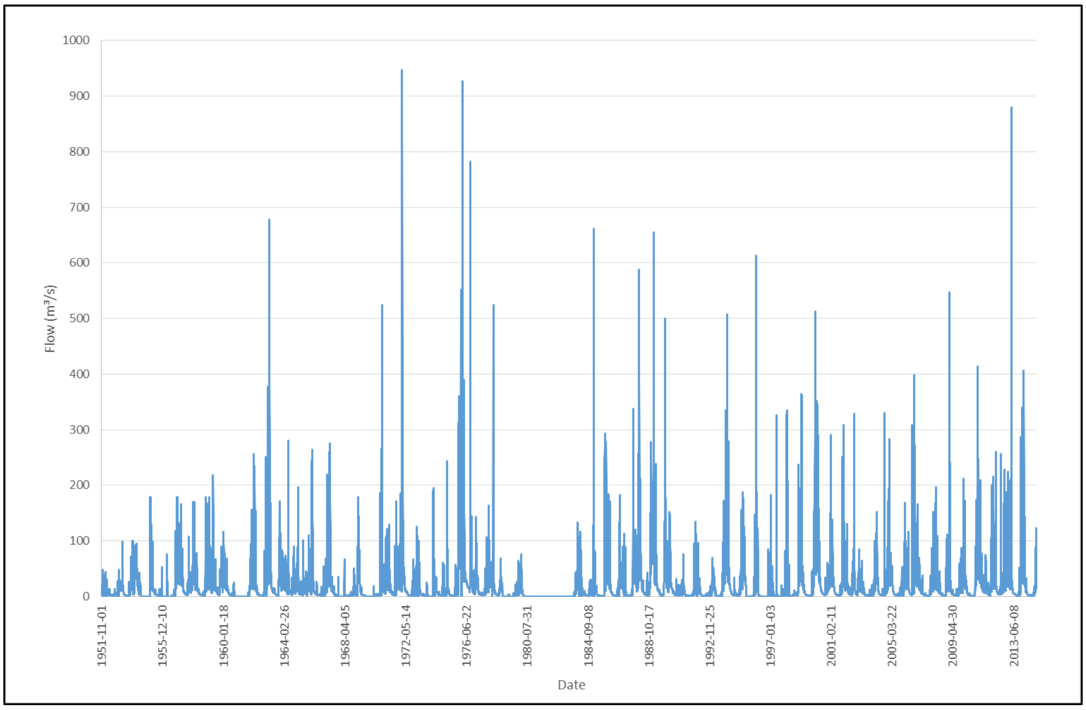


Figure 4-12 - T3H006 Flow Record

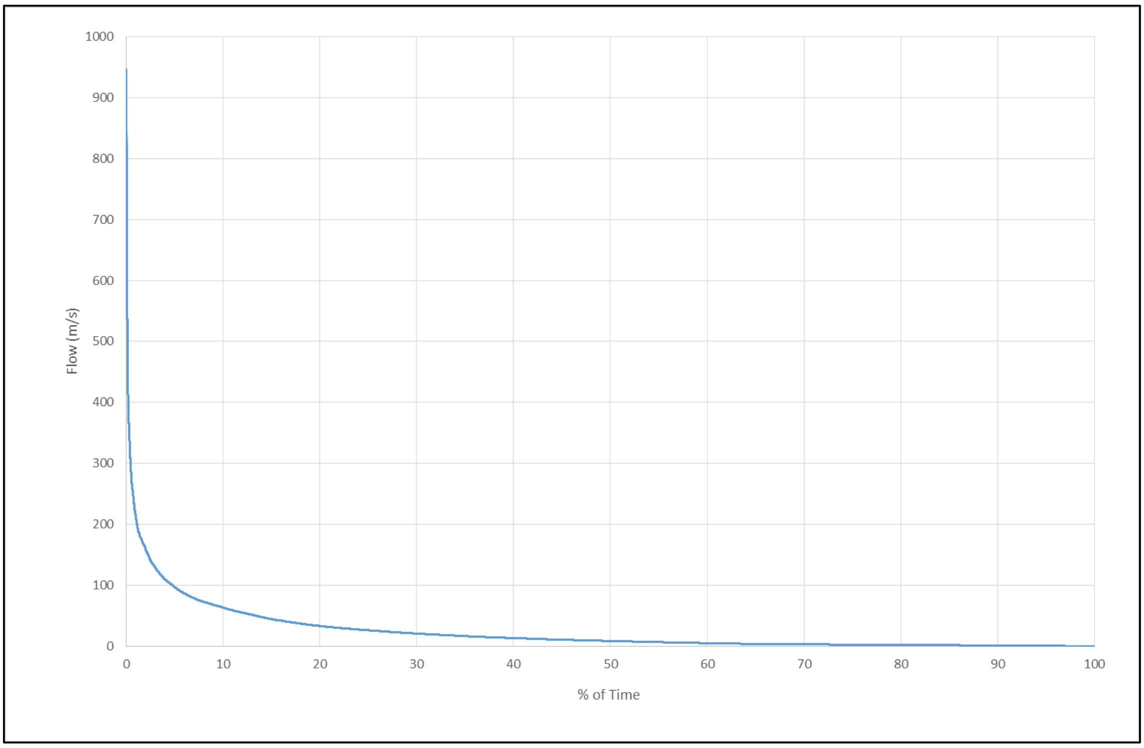


Figure 4-13 - T3H006 - Flow Duration Curve

Table 4-11 - T3H006 - Flow Statistics

Statistics	
Mean (m^3/s)	24.13
Standard Deviation (m^3/s)	46.51
Minimum (m^3/s)	-
Maximum (m^3/s)	946.77
Count	19 934
Confidence Level (95.0%) (m^3/s)	0.646

From the statistical analysis of the flow data record obtained from the DWS, it can be concluded with a 95% confidence level that the flow within the Tsitsa River at the T3H006 (Xonkonxa) gauging station will be 0.646 m^3/s. The confidence level of flow and the amount of flow available for the small scale hydropower generation will be discussed in paragraph 4.1.

The complete data sets and statistical analyses for the flow gauging stations within the OR Tambo DM is attached in Appendix B.

4.5 HYDROPOWER INSTALLATION TYPES

In the Literature Review (Paragraph 2.6), small-scale hydropower has been classified into five (5) different categories based on their design scheme. Within the scope of the study focus was placed on SSHP in either a Water Diversion Scheme or a River-based or canal-based scheme. The two schemes focussed on was further split into several subcategories, or hydropower installation types, as shown in Table 4-12.

Table 4-12 - Hydropower installation schemes and types

Scheme	Installation Type	Components					
		Intake	Channel	Tunnel	Penstock	Turbine Room	Tailrace
Water Diversion Scheme	Run-off-River 1 (RR1)	✔			✔	✔	✔
	Run-off-River 2 (RR2)	✔	✔		✔	✔	✔
	Run-off-River 3 (RR3)	✔	✔			✔	✔
	Modified Run-off-River 1 (MRR1)*	✔		✔	✔	✔	✔
	Modified Run-off-River 2 (MRR2)*	✔		✔		✔	✔
River-based or Canal-based scheme	Inline Kinetic Turbine (K1)	Inline Kinetic Turbine					

* *Modified Run-off-River Scheme incorporates directional drilling for tunnel construction*

For similar site conditions within the uMzinyathi DM and OR Tambo DM, it is proposed to develop a containerized unit for several similar site conditions, i.e. available head between 30 and 40 m and available flow between 100 and 200 l/s. Figure 4-14 below shows a draft design for a containerised turbine room unit. Such a unit minimises physical construction on site and therefor minimises the environmental impact of such an installation. The optimisation and final design of a containerised unit will be discussed in sections of the study.

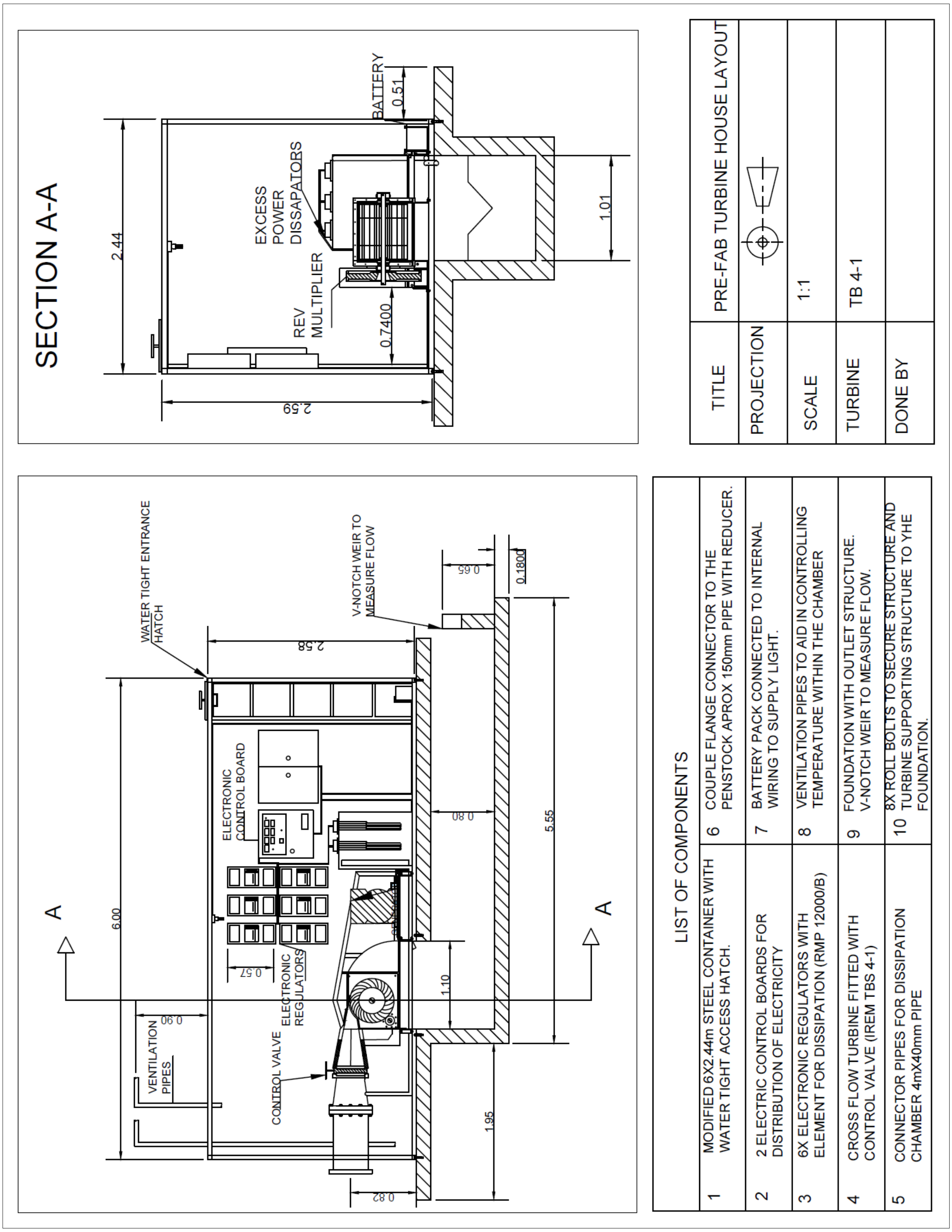


Figure 4-14 - Containerized Turbine RoomUnit

4.6 PHYSICAL SITE VISITS

The site selection parameters discussed, were used to evaluate the initial sites identified during the desktop study, and to identify and select several suitable sites to be visited in the uMzinyathi and OR Tambo District Municipalities summarized in Table 4-13.

Table 4-13 - Sites visited

No.	District Municipality	Local Municipality	River	Site	Co-ordinates	
					Lat	Long
1	uMzinyathi	Endumeni - 174	Buffels	Tayside	28°03'33.55"S	30°22'24.13"E
2	uMzinyathi	Endumeni - 174	Buffels	De Jagersdrift	28°00'37.58"S	30°23'39.15"E
3	uMzinyathi	Nquthu - 171	Buffels	Rorke's Drift	28°20'56.94"S	30°32'39.90"E
4	uMzinyathi	Nquthu - 171	Buffels	Dunudunu	28°21'57.98"S	30°35'09.70"E
5	uMzinyathi	Nquthu - 171	Buffels	Goba	28°22'55.92"S	30°36'11.35"E
6	uMzinyathi	Nquthu - 171	Buffels	Klwayisi	28°24'42.52"S	30°37'32.68"E
7	uMzinyathi	Nquthu - 171	Buffels	Woza	28°29'47.30"S	30°37'45.14"E
8	uMzinyathi	Nquthu - 171	Buffels	Mngeni	28°37'40.40"S	30°36'56.67"E
9	uMzinyathi	Nquthu - 171	Mangeni	Ntanyeni	28°27'47.32"S	30°45'55.31"E
10	uMzinyathi	Msinga - 173	Mooi	Dungamanzi	28°49'05.33"S	30°31'54.19"E
11	uMzinyathi	Msinga - 173	Thukela	Buffels	28°43'02.73"S	30°38'15.38"E
12	uMzinyathi	Msinga - 173	Thukela	Bassonsdrift 2	28°43'33.29"S	30°37'58.01"E
13	uMzinyathi	Msinga - 173	Thukela	Jolwayo	28°44'14.43"S	30°19'27.05"E
14	uMzinyathi	Umvoti - 187	Thukela	Sihosheni	28°43'20.99"S	30°45'56.04"E
15	OR Tambo	KSD - 229*	Mbhashe	eSixhotyeni	31°47'59.32"S	28°19'57.75"E
16	OR Tambo	KSD - 229*	Mbhashe	KuNjemane	31°51'04.64"S	28°23'34.55"E
17	OR Tambo	KSD - 229*	Mbhashe	KwaMiya	31°52'13.81"S	28°25'11.36"E
18	OR Tambo	KSD - 229*	Mbhashe	Siroshweni	31°55'27.84"S	28°28'02.32"E
19	OR Tambo	KSD - 229*	Mbhashe	Qombe	31°59'29.31"S	28°32'54.36"E
20	OR Tambo	Mhlontlo - 222	Thina	Lwandlana	31°01'54.35"S	28°53'02.01"E
21	OR Tambo	Mhlontlo - 223	Thina	Mnqunyana	31°04'15.50"S	28°57'59.87"E
22	OR Tambo	Mhlontlo - 222	Thina	Mpindweni 2	31°08'58.06"S	29°01'17.60"E
23	OR Tambo	Mhlontlo - 223	Thina	Kwa Madiba	31°11'38.62"S	29°03'18.18"E
24	OR Tambo	Mhlontlo - 222	iTsitsa	Tsitsa Falls	31°15'43.06"S	28°57'13.68"E
25	OR Tambo	KSD - 229	Mthatha	Siqikini	31°45'11.93"S	28°54'40.17"E
26	OR Tambo	KSD - 229	Mthatha	Dikeni	31°47'23.07"S	28°53'21.87"E
27	OR Tambo	KSD - 229	Mthatha	Eskweleni	31°47'35.94"S	28°53'58.12"E
28	OR Tambo	KSD - 229	Ngqungqu	Matyeni	31°51'05.01"S	28°49'22.65"E

*KSD – King Sabata Dalindyebo

Photographs taken at the various sites visited within the uMzinyathi and OR Tambo District Municipalities are shown and discussed in the following two (2) sections.

4.6.1 Pictorial overview of sites visited in uMzinyathi DM

Table 4-14 gives an overview of the potential sites visited within the uMzinyathi DM.

Table 4-14 - Potential Sites Visited - uMzinyathi

Tayside		
		
Statistics		**Comments**
Head:	2m	• Low potential head. • Existing weir structure in place. • Currently Eskom supplies power to nearest community. (Established grid). • Low feasibility of installing low head turbine unit.
Flow:	n/a	
Potential Power:	n/a	
Installation Type:	n/a	
De Jagersdrift		
		
Statistics		**Comments**
Head:	1m	• Low potential head available. • Visible debris could cause damage to structures and turbine due to excessive flooding. • Current gauging structure. • Low feasibility for low head turbine installation.
Flow:	n/a	
Potential Power:	n/a	
Installation Type:	n/a	

Rorke's Drift

Statistics	
Head:	2m
Flow:	0.465m^3/s
Potential Power:	7.85kW
Installation Type:	RR1

Comments

- Existing grid supplied by Eskom to the community.
- Low potential head in the river ± 2m available.
- Construction of a weir would be difficult due to the wide river.
- Excessive flooding has been seen to occur.

Dunudunu

Statistics	
Head:	8m
Flow:	0.465m^3/s
Potential Power:	31.38kW
Installation Type:	RR1

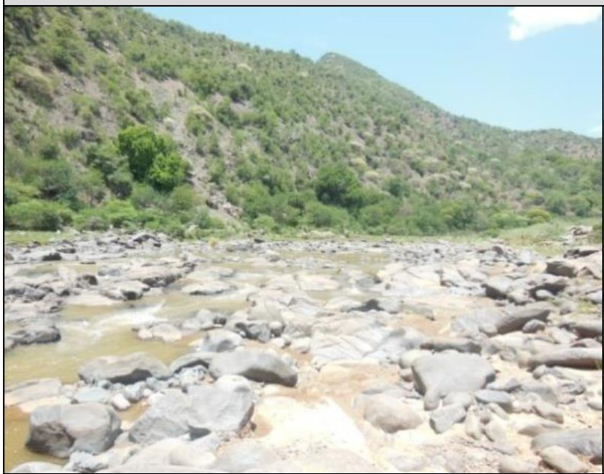
Comments

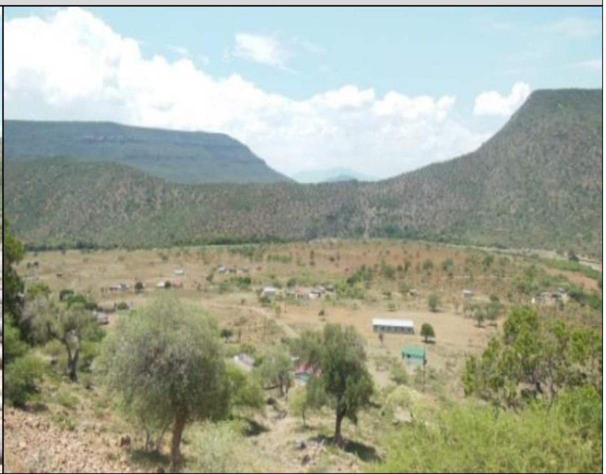
- Moderate potential head available
- Nearby community with minimal electricity supply.
- Wide river sections – Weir construction costly
- Reasonable damming upstream.
- Rock formation – Solid foundation

Goba

Statistics		**Comments**
Head:	4m	• Previous prediction of head found to be inaccurate. Only ± 4m potential head available.
Flow:	0.465m^3/s	• Existing electrical grid
Potential Power:	15.69kW	• Site located in nature reserve
Installation Type:	RR1	• Low feasibility for low head turbine.

Dungamanzi





Statistics		**Comments**
Head:	23m	• High head available
Flow:	0.38 m^3/s	• Run-off-river scheme could be utilized.
Potential Power:	80.60kW	• Current Eskom grid available to certain houses.
Installation Type:	MRR2	• Good opportunity for Research and feasibility case study after installation.

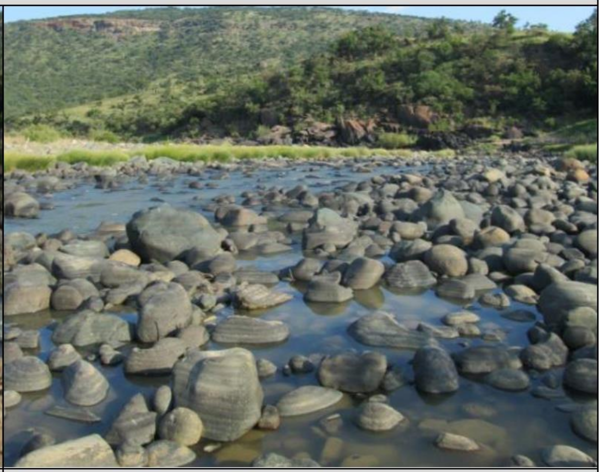
Ntanyeni

Statistics		**Comments**
Head:	38m	• 39m drop waterfall • Accessible site • Very low flow visible
Flow:	n/a	
Potential Power:	n/a	
Installation Type:	RR2	

Ntanyeni Weir

Statistics		**Comments**
Head:	7m	• Existing weir structure • ±7m potential head • Narrow banks downstream • Silted up weir • Low flow
Flow:	n/a	
Potential Power:	n/a	
Installation Type:	RR1	

Camp Buffalo

Statistics		Comments
Head:	8m	• 8-14m potential head • Narrowing downstream banks • No solid foundation visible
Flow:	0.465m^3/s	
Potential Power:	31.38kW	
Installation Type:	RR1	

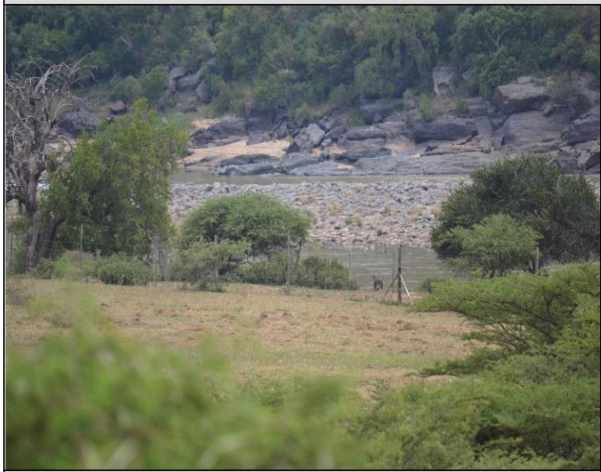
Woza

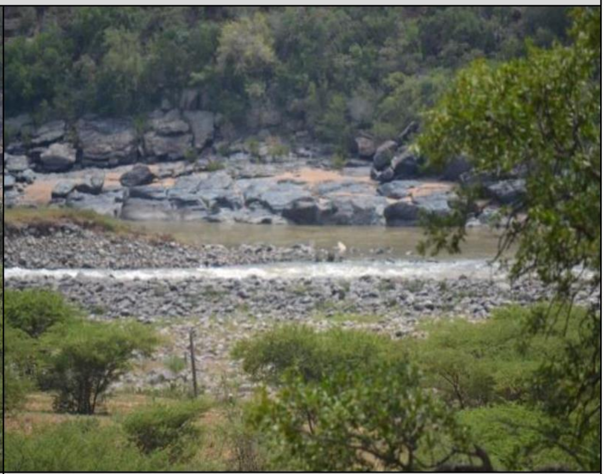

Statistics		Comments
Head:	13m	• 16m potential head • Widening downstream banks • Visible solid foundation for turbine room • Nearby homestead with no existing Eskom grid • Easily accessible
Flow:	0.465m^3/s	
Potential Power:	51kW	
Installation Type:	RR1	

Jolwayo

Statistics		**Comments**
Head:	12m	• Existing weir structure • Not easily accessible • High potential head
Flow:	$1.368 m^3/s$	
Potential Power:	138.50kW	
Installation Type:	RR1	

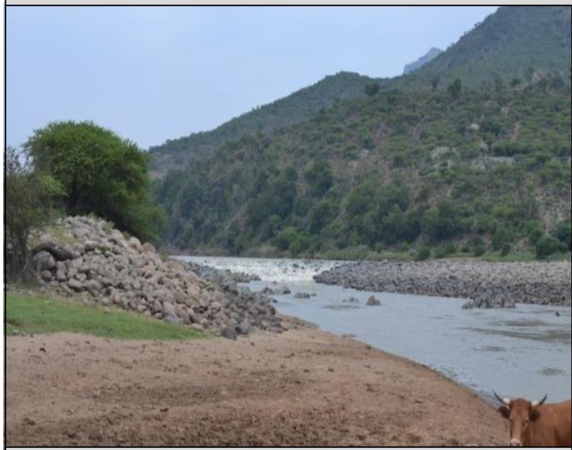
Buffels

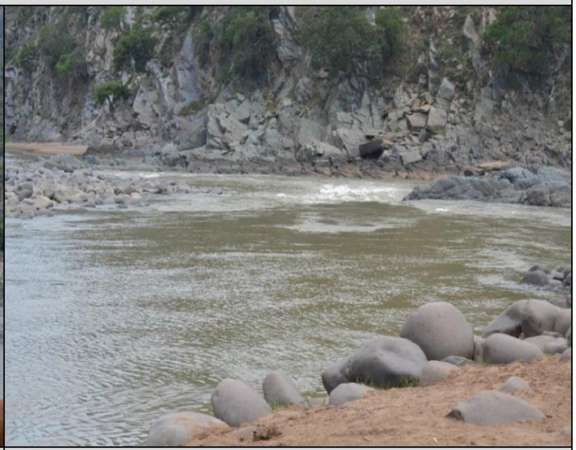




Statistics		**Comments**
Head:	9m	• Visible potential head • Not accessible due to private fenced off land • Existing electricity grid
Flow:	$3.512 m^3/s$	
Potential Power:	266.66kW	
Installation Type:	MRR2	

Bassons drift 2





Statistics		Comments
Head:	7m	• Potential head visible • No electric grid visible on most households • ±300m penstock • Nearby homesteads
Flow:	3.512m³/s	
Potential Power:	207.41kW	
Installation Type:	MRR2	

***Flow – Flow rate present 95% of the time**

****Potential Power – Potential energy generation utilising the total available head and the flow rate present 95% of the time**

Table 4-15 gives a summary of the sites visited, including the revised available and potential power generated at the different potential sites within the uMzinyathi DM

Table 4-15 - uMzinyathi Sites Visited - Summary

No.	Local Municipality	River	Site	Potential Head (m)	Potential Flow (m^3/s) (95% of time)	Potential Power Generation (kW)
1	Endumeni - 174	Buffels	Tayside	2	0.465	7.85
2	Endumeni - 174	Buffels	De Jagersdrift	1	0.465	3.92
3	Nquthu - 171	Buffels	Rorke's Drift	2	0.465	7.85
4	Nquthu - 171	Buffels	Dunudunu	10	0.465	39.23
5	Nquthu - 171	Buffels	Goba	4	0.465	15.69
6	Msinga - 173	Mooi	Dungamanzi	23	0.380	80.60
7	Nquthu - 171	Mangeni	Ntanyeni	39	No Record	-
8	Nquthu - 171	Mangeni	Ntanyeni Weir	7	No Record	-
9	Nquthu - 171	Buffels	Camp Buffalo	14	0.465	54.92
10	Nquthu - 171	Buffels	Woza	16	0.465	62.77
11	Msinga - 173	Thukela	Jolwayo	12	1.368	138.50
12	Msinga - 173	Thukela	Buffels	9	3.512	266.66
13	Msinga - 173	Thukela	Bassonsdrift 2	7	3.512	207.41

4.6.2 Pictorial overview of sites visited in OR Tambo DM

Table 4-16 gives an overview of the potential sites visited within the OR Tambo DM.

Table 4-16 - Potential Sites Visited – OR Tambo

Dikeni

Statistics		**Comments**
Head:	7m	• Low potential head, large flow visibly present in the river. • Installation of Kinetic turbines possible. • Site is accessible. • No visible existing Eskom grid.
Flow:	$0.512m^3/s$	
Potential Power:	30.24kW	
Installation Type:	K1	

eSixohotyeni

Statistics		**Comments**
Head:	n/a	• Existing electrical grid at nearest homestead. • 6m measured potential head available. • Evidence of flooding and debris visible on the downstream bridge. • No visible sediment build up or damage.
Flow:	$0.646m^3/s$	
Potential Power:	n/a	
Installation Type:	RR2	

KuNjemane Weir

Statistics		**Comments**
Head:	5m	• Minimal civil works required, due to existing weir structure and outlet pipe. • Existing Eskom grid. • ±4m drop across weir structure. • The site is accessible by vehicle.
Flow:	2.337m³/s	
Potential Power:	78.87kW	
Installation Type:	RR2	

KwaMiya

Statistics		**Comments**
Head:	14m	• ±14m measured potential head over mountain. • Existing Eskom grid, however residents at homestead have no connections to the grid. • Difficult to access site, no roads leading to site.
Flow:	2.337m³/s	
Potential Power:	276.03kW	
Installation Type:	MRR1	

Matyeni

Statistics		**Comments**
Head:	18m	• 18m estimated potential head. • The upstream site is located at a bridge structure. • Civil construction work and placement of the turbine difficult. • Low visible flow in the river.
Flow:	n/a	
Potential Power:	n/a	
Installation Type:	MRR1	

Siqikini

Statistics		**Comments**
Head:	32m	• Estimated 32m drop. • Not accessible, due to road being washed away.
Flow:	$0.512m^3/s$	
Potential Power:	138.23kW	
Installation Type:	MRR1	

Siroshweni

Statistics		**Comments**
Head:	16m	• Existing Eskom grid at site. • Good accessibility upstream. Downstream side is not easily accessible.
Flow:	0.335m^3/s	
Potential Power:	45.22kW	
Installation Type:	MRR1	

Thina Falls

Statistics		**Comments**
Head:	42m	• Estimated 42m available potential head. • Very high flow rate. • Easily accessible upstream side. • The area downstream not easily accessible. • No existing Eskom grid in the area.
Flow:	0.639m^3/s	
Potential Power:	226.42kW	
Installation Type:	MRR1	

Tsitsa Falls

Statistics		Comments
Head:	45m	• ±45m potential head available. • Development of a hydropower system at the site might be a problem due to environmental impact. • Large hydropower plant planned on Tsitsa River upstream
Flow:	0.747m^3/s	
Potential Power:	283.60kW	
Installation Type:	RR2	

Eskweleni

Statistics		Comments
Head:	34m	• ±34m measured potential head available. • High flow in the River. • Not easily accessible • Existing electrical grid running close to the site.
Flow:	0.512m^3/s	
Potential Power:	160.53kW	
Installation Type:	MRR1	

***Flow – Flow rate present 95% of the time**

****Potential Power – Potential energy generation utilising the total available head and the flow rate present 95% of the time**

Table 4-17 gives a summary of the sites visited, including the revised available and potential power generated at the different potential sites within the uMzinyathi DM

Table 4-17 - OR Tambo Sites Visited - Summary

No.	Local Municipality	River	Site	Potential Head (m)	Potential Flow (m^3/s) (95% of time)	Potential Power Generation (kW)
1	*KSD - 229	Mthatha	Dikeni	7	0.512	30.24
2	KSD - 229	Mbhashe	eSixhotyeni	6	0.646	32.70
3	KSD - 229	Mthatha	Eskweleni	34	0.512	146.86
4	KSD - 229	Mbhashe	KuNjemane	4	2.337	78.87
5	KSD - 229	Mbhashe	KwaMiya	14	2.337	276.03
6	KSD - 229	Ngqungqu	Matyeni	18	No Record	-
7	KSD - 229	Mthatha	Siqikini	Inaccessible		
8	KSD - 229	Mbhashe	Siroshweni	16	0.335	45.22
9	Mhlontlo - 223	Thina	Thina Falls	42	0.639	226.42
10	Mhlontlo - 223	Tsitsa	Tsitsa Falls	45	0.747	283.60

*KSD – King Sabata Dalindyebo

4.7 PRELIMINARY REFINED SITE SHORTLIST

From the potential sites visited within the uMzinyathi and OR Tambo District Municipalities, the sites listed in Table 4-18 were identified as the most feasible sites to develop. These sites were shortlisted as the selected sites to develop. Actual sites to develop will finalised after a detailed design and financial calculations in sections to follow. Within the previous section the potential energy generation was determined as per the available head and the available flow at 95% of the time within the data flow record. For environmental reasons not all flow within the river is diverted through the hydro turbine. Only a percentage of flow from the 95% percent of flow available is used and the values displayed for flow in Table 4-18 were calculated as such.

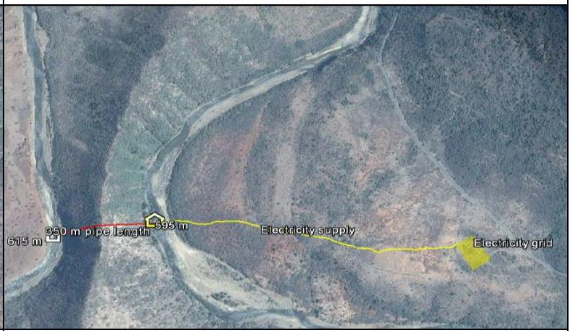
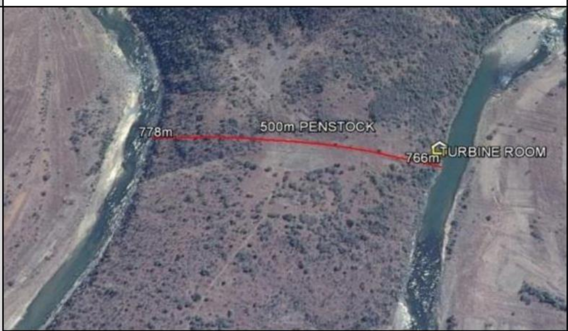
Table 4-18 - Shortlisted Selected Sites and Potential

No.	DM	LM	River	Site	Potential Head (m)	Potential Flow Used (m³/s)	% Potential Flow Utilized	Potential Power Generation (kW)	Accessible	Rural Settlement	Distance	Population	Landowners
1	uMzinyathi	Nquthu - 171	Buffels	Dumdumu	10	0.20	43	15.70	✓	✓	✓	✓	✓
2	uMzinyathi	Msinga - 173	Mooi	Dungamanzi	23	0.20	53	36.10	✓	✓	✓	✓	✓
3	uMzinyathi	Nquthu - 171	Buffels	Woza	16	0.20	43	25.11	✓	✓	✓	✓	✓
4	uMzinyathi	Msinga - 173	Thukela	Jolwayo	12	0.20	15	18.84	✗	✓	✓	✓	✓
5	OR Tambo	*KSD - 229	Mbhashe	KuNjemane	4	0.20	9	6.28	✓	✗	✗	✗	✓
6	OR Tambo	Mhlontlo - 223	Thina	Thina Falls	42	0.15	23	49.44	✓	✓	✓	✓	✓
7	OR Tambo	KSD - 229	Mthatha	Dikeni	Kinetic Turbine		-	5.00**	✓	✓	✓	✓	✓
8	OR Tambo	KSD - 229	Mthatha	Eskweleni	34	0.15	29	40.02	✗	✓	✓	✓	✓

*KSD – King Sabata Dalindyebo
** 5kW per turbine installed

Table 4-19 shows the preliminary planning on transmission of electricity to potential end users or communities, and the preliminary proposed location of the turbine rooms.

Table 4-19 - Preliminary Layouts - Reviewed Sites

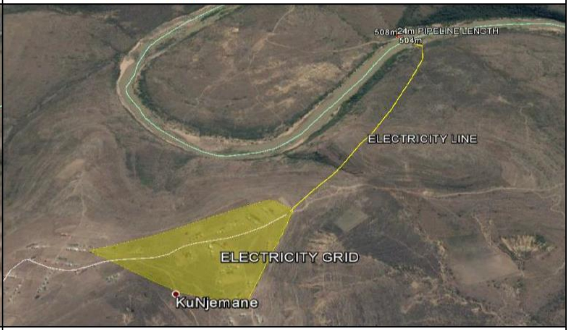
<table>
<tr><th>Site</th><th>Hydropower scheme option</th><th>Settlement grid connection</th></tr>
<tr><td rowspan="2">Dunudunu</td><td>
</td><td>
</td></tr>
<tr><td>±11m drop.
Strong rock foundation for housing structure.
350m pipeline required</td><td>±580m from turbine room to settlement.
Accesible turbine room.</td></tr>
<tr><td rowspan="2">Dungamanzi</td><td>
</td><td>
</td></tr>
<tr><td>±20m Potential head.
350m pipeline drilled through mountain.</td><td>±1061 m to nearest settlement.
No visible existing electrical grid nearby.
Accessible site, nearby existing road infrastructure</td></tr>
<tr><td rowspan="2">Woza</td><td>
</td><td>
</td></tr>
<tr><td>±12m Potential head
500m pipeline drilled through mountain.
High flow available.</td><td>No existing electrical grid.
Accesible.
±1100km to settlement.</td></tr>
</table>

<table>
<tr><td rowspan="2">Jolwayo</td><td>
</td><td>
</td></tr>
<tr><td>

- Existing weir provides 8m Potential head.
- 730m pipeline running adjacent to river bed.

</td><td>

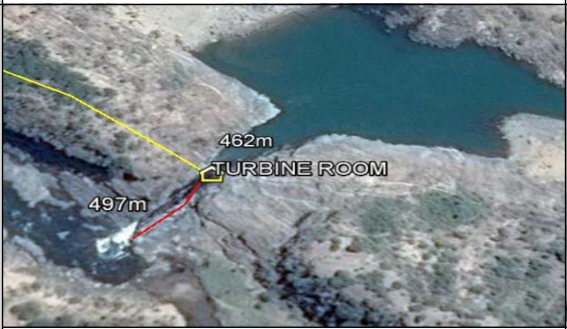
- ±1000m to nearest settlement.
- No visible existing electrical grid connection.
- Not accessible.

</td></tr>
<tr><td rowspan="2">KuNjemane</td><td>
</td><td>
</td></tr>
<tr><td>

- ±4m drop over weir.
- Strong rock foundation for housing structure.
- 24m pipeline conveyance required, or existing pipeline build into weir structure with outlet on the downstream side could be used as a penstock.

</td><td>

- ±1620m from turbine room to settlement.
- Accesible turbine room.
- Minimal civil works required due to existing weir structure and outlet pipe.

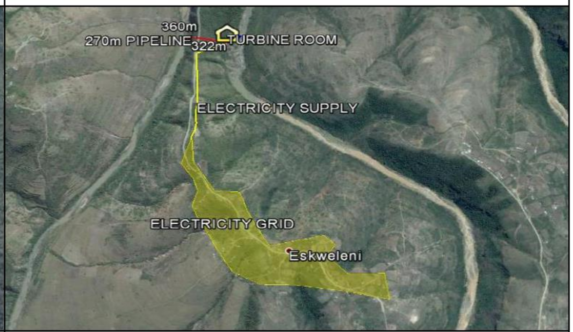
</td></tr>
<tr><td rowspan="2">Thina Falls</td><td>
</td><td>
</td></tr>
<tr><td>

- ±35m drop over waterfall.
- Strong rock foundation for housing structure.
- ±60m penstock required, depending on the chosen position of the turbine room.
- Very high flow and potential head at the site.

</td><td>

- ±760 from turbine room to settlement.
- There is no existing road or access to the downstream side of the falls where the turbine housing will be placed.

</td></tr>
</table>

<table>
<tr>
<td rowspan="2">Dikeni</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>• 3 options for the installation of Kinetic turbines directly into the river are shown.
• The river has a significant amount of flow 95% of the time.
• Due to narrowing of the river at the shown areas high velocities occur. This allows for the installation of kinetic turbines.</td>
<td>• The settlement is in close proximity of the river, the furthest turbine placement being a distance of 600m.
• Minimal civil works required if kinetic turbines are used.</td>
</tr>
<tr>
<td rowspan="2">Eskweleni</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>• ±38m potential head available.
• Flat wide riverbanks occur on the downstream side of the river. This prevents the turbine room from being exposed to frequent flooding.
• 290m pipeline required as penstock. Directional drilling will be necessary for the pipeline to run through the mountain.</td>
<td>• ±840m from turbine room to settlement.
• The steep mountain slope on the downstream side of the river will cause difficulty in accessing the turbine room, but this will be a good factor in preventing vandalism of the hydropower setup.</td>
</tr>
</table>

4.8 PREFERED SITES FOR DEVELOPMENT

After the consideration of the site selection criteria as well as the current and proposed development of electrical infrastructure within the rural communities of the Eastern Cape and Kwa-Zulu Natal Province, the following six (6) sites are the preferred sites for development of small-scale hydropower plants for rural electrification:

1. Dunudunu
2. Jolwayo
3. Woza
4. Thina Falls
5. Eskweleni
6. Dikeni

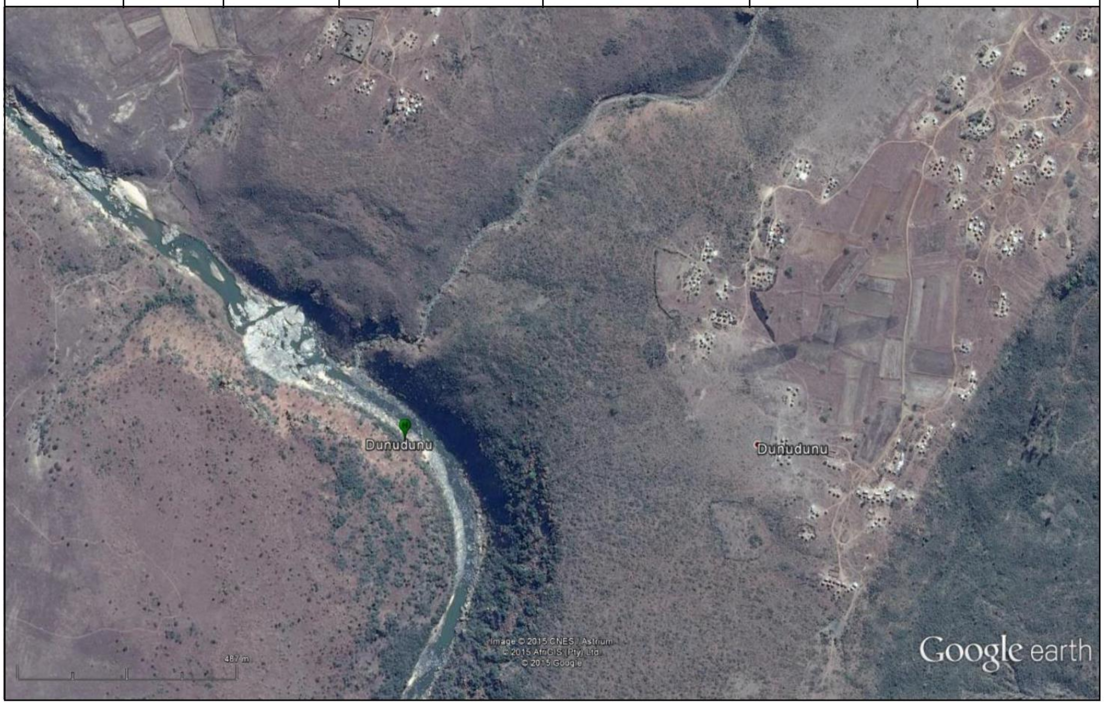
Table 4-20 summarises the selected sites, reflecting the total potential energy, total potential power generated, proposed community as end users of energy as well as operating characteristics of the plant (head and flow). The contents of Table 4-20 is a preliminary estimate and was refined during the final design.

The detailed designs of these six (6) sites are discussed in the following chapter and followed by costing of the designs and construction of the SSHP plants.

Table 4-20 - Selected Sites

1. DUNUDUNU	
DM:	uMzinyathi
LM:	Nquthu
River:	Buffels

Scheme	Head	Flow	Total Potential Energy	Potential Power Generation	Community	Population (Households)
RR1	10m	0.47m³/s	39.23kW	15.70kW	Ncepheni B	54



2. JOLWAYO	
DM:	uMzinyathi
LM:	Msinga
River:	Thukela

Scheme	Head	Flow	Total Potential Energy	Potential Power Generation	Community	Population (Households)
RR1	12m	1.37m³/s	138.50kW	18.84kW	N/A	N/A

3. WOZA

DM:	uMzinyathi
LM:	Msinga
River:	Buffels

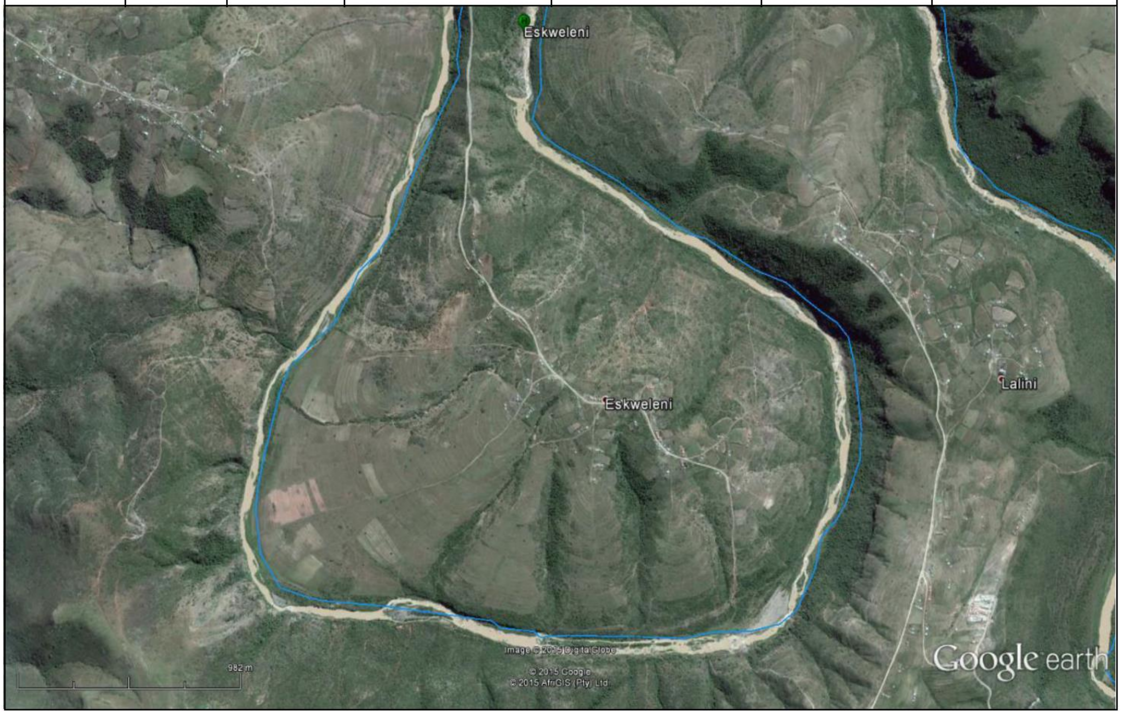
Scheme	Head	Flow	Total Potential Energy	Potential Power Generation	Community	Population (Households)
RR1	16m	0.46m^3/s	62.77kW	25.11kW	Mahlaba	320

4 THINA FALLS	
DM:	OR Tambo
LM:	Mhlontlo
River:	Thina

Scheme	Head	Flow	Total Potential Energy	Potential Power Generation	Community	Population (Households)
MRR1	42m	0.64 m^3/s	226.42kW	49.44kW	Kwa Madiba	117

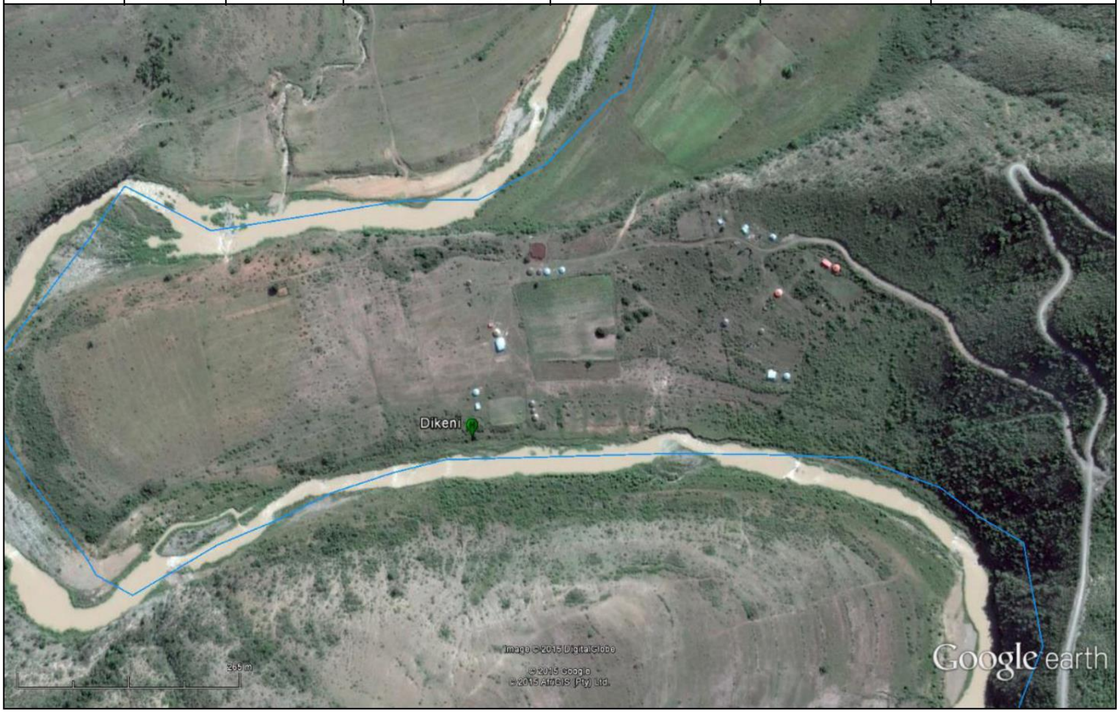
5. ESKWELENI	
DM:	OR Tambo
LM:	Nyandeni
River:	Mbhashe

Scheme	Head	Flow	Total Potential Energy	Potential Power Generation	Community	Population (Households)
MRR1	34m	0.51m^3/s	146.86kW	40.20kW	Eskweleni	52



6. DIKENI	
DM:	OR Tambo
LM:	King Sabata Dalindyebo
River:	Mthatha

Scheme	Head	Flow Velocity	Total Potential Energy	Potential Power Generation	Community	Population (Households)
K1	N/A	1 - 3 m/s	N/A	5.00kW per turbine installed	N/A	22



5 DESIGN

5.1 LEGISLATIVE AND REGULATORY PROSEDURES

In a study by Scharfetter (2015), an in depth review of the institutional complexities of implementing small-scale hydropower projects for rural electrification in South Africa as pertaining to legislative and regulatory procedures, three focus areas has been identified, namely electricity generation, environmental authorisation and water use authorisation.

The following three sections highlight the considerations, permit and license applications considered into the design and the costing of the proposed small-scale hydropower projects. The procedures are taken from the study by Scharfetter (2015).

5.1.1 Electricity generation

The current legislative and regulatory requirements to implement non-grid electrification schemes in South Africa are summarised in Table 5-1

Electricity generated for "islanded use" is completely independent of municipal- or Eskom distribution networks and can be applied for commercial- or non-commercial purposes.

Electricity generated for islanded use, and used for non-commercial purposes does not require a NERSA electricity generation licence. Electricity generated for commercial purposes, requires a NERSA electricity generation licence (Department of Minerals and Energy, 2006).

Table 5-1 - Electricity generated for Islanded Use

	Commercial use	Non-commercial use
NERSA Generation Licence	Yes	No
Local electricity utility involvement	Applications to the DoE for non grid electrification through the INEP to be done by the local municipality	Good practice to inform
Proof of land ownership/ permission to use land	Needed for NERSA licensing requirements	Good practice to have
Environmental ROD	Needed for NERSA licensing requirements (show proof of appointment of EIA consultant, indicate Public Participation Process that is being followed, DEA approval of scoping report) Amendment to existing EIA or BA required for Brownfield's development (pers.comms. legal opinion) Yes, if required by NEMA Record of Decision (ROD) required based on a Basic Assessment (GN544) or full EIA (GN545) Opinion of Environmental professional needed if none required	Yes, if required by NEMA
Water Use licence	Needed for NERSA licensing requirements Yes, if required by National Water Act Legal opinion if none is required	Yes, if required by Water Act
Water allocation confirmation.	If conduit hydropower, WSP must confirm that water is available and hydropower generation will not affect security of supply	If conduit hydropower, WSP must confirm that water is available and hydropower generation will not affect security of supply

5.1.2 Environmental authorisation

When initiating and constructing a small hydropower scheme, An environmental authorisation based on either a full Environmental Impact Assessment (EIA) or a Basic Assessment (BA) could be a requirement.

Schedule GN983 requires a BA to be undertaken if any one of the following 2 activities related to electricity generation and distribution are applicable (Department of Environmental Affairs 2014b):

- *Listing Notice 1, activity 1: "the development of facilities or infrastructure for the generation of electricity from a renewable resource where-*
  the electricity output is more than 10 MW but less than 20 MW; or
  the output is less than 10 MW but the total extent of the facility covers an area in excess of 1 hectare.
  Excluding where such development of facilities or infrastructure is for photovoltaic installations and occurs within an urban area."

- *Listing Notice 1, activity 2: "The development and related operation of facilities or infrastructure for the generation of electricity from a non-renewable resource where-*
  the electricity output is more than 10 MW but less than 20 MW; or
  the output is less than 10 MW but the total extent of the facility covers an area in excess of 1 hectare.

- *Listing Notice 1, activity 11: "The development of facilities or infrastructure for the transmission and distribution of electricity-*
  outside urban areas or industrial complexes with a capacity greater than 33 kV but less than 275 kV; or
  inside urban areas or industrial complexes with a capacity of 275 kV or more."

When either one of the following two electricity generation and distribution activities are applicable, Schedule GN984 states that an EIA will need to be undertaken (Department of Environmental Affairs 2014c):

- *Listing Notice 2, activity 1: "the development of facilities or infrastructure for the generation of electricity from a renewable resource where the electricity output is 20 MW or more, excluding where such facilities of infrastructure is for photovoltaic installations and occurs within an urban area."*

- *Listing Notice 2, activity 2: "The development and related operation of facilities or infrastructure for the generation of electricity from a non-renewable resource where the electricity output is than 20 MW or more."*

- *Listing Notice 2, activity 9: "The development of facilities or infrastructure for the transmission and distribution of electricity with a capacity of 275 kV or more, outside an urban area or industrial complex."*

An EIA and a BA environmental authorisation will not be required for the initiation and construction of the electricity components of small-scale hydropower schemes, Based on the electricity generation and distribution activity listings of GN983 and GN984 and due to the fact that:

- *by the definition of "small-scale hydropower", such projects will have installed capacity of less than 10 MW,*
- *would be constructed over an area most likely covering less than 1ha, and*
- *rural electrification will most likely require electricity distribution at 22 kV.*

Listed activities pertaining to the construction or alteration of water infrastructure must also be considered.

Schedule GN983 states that a BA will need to be undertaken when any one of the following bulk water transportation and construction activities are applicable: (Department of Environmental Affairs 2014b):

- *Listing Notice 1, activity 9 "The development of infrastructure exceeding 1000 m in length for the bulk transportation of water or storm water-*
  with an internal diameter of 0.36 M or more; or
  with a peak throughput of 120ℓ/s or more.
  Excluding where such infrastructure is for bulk transportation of water or storm water or storm water drainage inside a road reserve; or
  where such development will occur within an urban area."
  Listing Notice 1, activity 12: "The development of-
  Canals exceeding 100 m^2 in size;
  Channels exceeding 100 m^2 in size;
  Bridges exceeding 100 m^2 in size;
  Dams, where the dam, including infrastructure and water surface area, exceeds 100 m^2 in size;
  Weirs, where the weir, including infrastructure and water surface area, exceeds 100 m^2 in size;
  Bulk storm water outlet structures exceeding 100 m^2 in size;

Marinas exceeding 100 m^2 in size;
Jetties exceeding 100 m^2 in size;
Slipways exceeding 100 m^2 in size,
Buildings exceeding 100 m^2 in size
Boardwalks exceeding 100 m^2 in size; or
infrastructure or structures with a physical footprint of 100 m^2 or more;

where such development occurs-
within a watercourse;
in front of a development setback or
if no development setback exists, within 32 m of a watercourse measured from the edge of a watercourse,

Excluding
….where such development occurs within an urban area or within existing roads or road reserves."

- *Listing Notice 1, activity 19: "The infilling or depositing of any material of more than 5 cubic metres into, or the dredging, excavation, removal or moving of soil, sand, shells, shell grit, pebbles or rock of more than 5 cubic metres from (i) a watercourse…"*

When the following water development activities are applicable Schedule GN984 states that an EIA will need to be undertaken: (Department of Environmental Affairs 2014c)

- *Listing Notice 2, activity 11 "The development of facilities or infrastructure for the transfer of 50 000 m3 or more of water per day, from and to or between any combination of the following; water catchments, water treatment works or impoundments excluding treatment works where water is to be treated for drinking purposes"*

Based on the water activity listings of GN983 and GN984, there is a possibility that a BA would be required for a particular scope of work for certain SSHP rural electrification projects.

5.1.3 Water use authorisation

A set of 11 consumptive and non-consumptive water uses are defined in Section 21 of the National Water Act, any one of which would necessitate the attainment of a water use authorisation:

- *21(a) taking water from a water resource;*

- *21(b) storing water;*
- *21(c) impeding or diverting the flow of water in a watercourse;*
- *21(d) engaging in a stream flow reduction activity contemplated in section 36;*
- *21(e) engaging in a controlled activity identified as such…;*
- *21(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;*
- *21(g) disposing of waste in a manner which may detrimentally impact on a water resource;*
- *21(h) disposing in any manner of water which contains waste from or which has been heated in any industrial or power generation process;*
- *21(i) altering the bed, banks course or characteristics of a watercourse;*
- *21(j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and*
- *21(k) using water for recreational purposes.*

21(c) and 21(i) are of particular relevance to small-scale hydropower projects.

The DWS is allowed to authorise large numbers of people to take up water without the need for a licence by means of General Authorisations. Such general authorisation can be limited to a specific group of people, and/or specific water resources. There are several advantages to General Authorisations and includes the following (DWS 2015):

- *"Smaller scale emerging users would not need to be ready to apply for a licence;*
- *General authorisations can be adapted for specific regional and social needs;*
- *General authorisations can promote the uptake of smaller amounts of water by many people - and hence can have a greater impact on poverty;*
- *They can reduce the administrative burden;*
- *They can allow for the gradual uptake of water by the poor, paralleled with the gradual reduction of use by existing lawful water users."*

The current applicable General Authorisation, GA1199 published in December 2009 for Section 21(c) and 21(i) water uses, is currently under review. There has been a reqeust made to the DWS to include the construction of small-scale hydropower projects towards non-grid electrification in the rural areas of South Africa into the new General Authorisation (GA). This review process is currently in progress.

If this request is successful, SSHP projects for rural electrification purposes would not need to follow a full water use license application process, but would need only to follow a registration process to attain the required water use authorisation.

The procedures and legislation highlighted in these abstracts from the study by Scharfetter (2015), were used in the design and the costing of the proposed SSHP within the scope of this study.

5.2 UMZINYATHI DM – SSHP DESIGNS

5.2.1 Dunudunu SSHP

5.2.1.1 Site Selection Process

5.2.1.1.1 Hydropower Potential – Buffels River at Dunudunu

For the initial identification of potential sites for small scale hydropower generation within the uMzinyathi District Municipality, a desktop study was utilised. The focus of the desktop study was to preliminarily identify sites based solely on potential head available at different individually selected sites.

The different rivers and river sections within the uMzinyathi Tambo DM were investigated utilizing the Google Earth program. The elevation tool within Google Earth was used to identify height differences within the different rivers which would create head differences suitable for small scale hydropower generation. Height differences were verified by site investigations and physical measurements. Sites with a higher potential head difference initially gained preference over sites with higher flows due to the increase in cost of larger equipment to convey the larger flows.

Focus was placed on the perennial rivers with historical flow data records from DWS. The desktop study showed a potential head difference in the Buffels River at Dunudunu, within the Nquthu Local Municipality, of 8 m. From a physical site visit and measurements, the potential head in the Buffels River at Dunudunu (Figure 5-1) was calculated as between 12 and 14 m.

Figure 5-1 - Buffels River at Dunudunu (Flow rate = 4.191 m^3/s)

The total theoretical hydropower generation at Dunudunu, utilizing all the flow present in the river at 95% of the time and incorporating the total height difference of 14 M, amounts to 44 kW. The potential power increases as the flow within the Buffels River at Dunudunu increases.

5.2.1.1.2 Rural Electrification – Dunudunu

Several site selection parameters, other than potential head and flow, was used to evaluate identified potential small-scale hydropower sites. Parameters included Nearest Rural Settlement, Distance to nearest Rural Settlement, Population of Rural Settlement, Accessibility by vehicle, Electrical Grid Connected and Future Electrical Grid Connectivity, Environmental Impact and Social Impact.

From satellite imagery and a site visit, the physical distance from the proposed turbine room/powerhouse on the Buffels River at Dunudunu to the closest end users at the Ndodekhling-Shayiwe settlement was measured as **830 m**. The physical site visit also showed no existing electrical infrastructure within Ndodekhling-Shayiwe (Figure 5-2). The 2011 Census showed **54** households within the Ndodekhling-Shayiwe rural settlement, although from the site visit the amount of households seems to be less, approximately **32** households.

Figure 5-2 - Ndodekhling-Shayiwe

Environmentally the Dunudunu potential hydropower site will have a minimal to no impact on the environment due to the fact that only small amounts of flow will be rerouted through the turbine and return to the natural watercourse within a distance of less than 700 m downstream of the intake. The social impact on the community is positive, as the 32 households without electricity previous will be provided with power from the hydro turbine installed on the Buffels River at Ndodekhling-Shayiwe.

5.2.1.2 Hydrological Analysis

Hydrological data was obtained from the Department of Water and Sanitation (DWS). The data from the flow gauging station, V3H010 – Tayside (Figure 5-3), in the Buffels River upstream of Dunudunu was used. Flow at Dunudunu was taken as similar to that at V3H010.

Figure 5-3 - V3H010 - Tayside

Figure 5-4, Figure 5-5 and Table 5-2 shows a summary and analysis of the historic flow data record for V3H010.

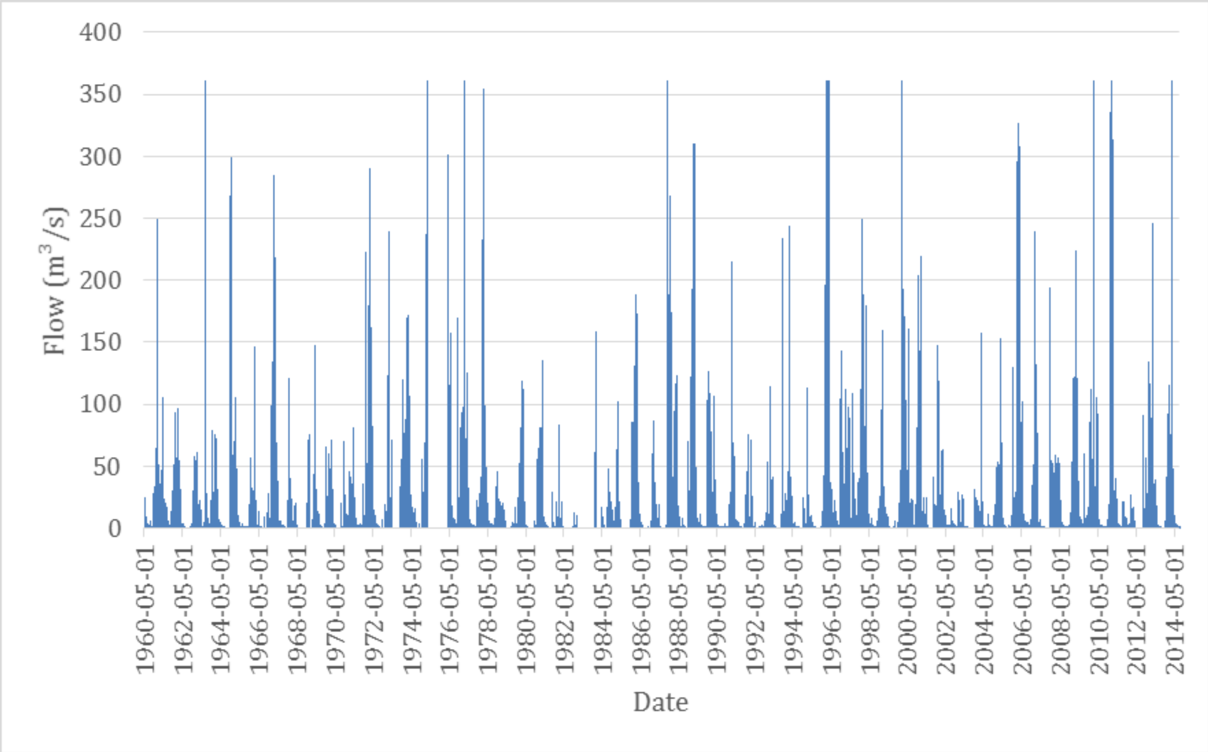


Figure 5-4 - V3H010 - Flow Data Record

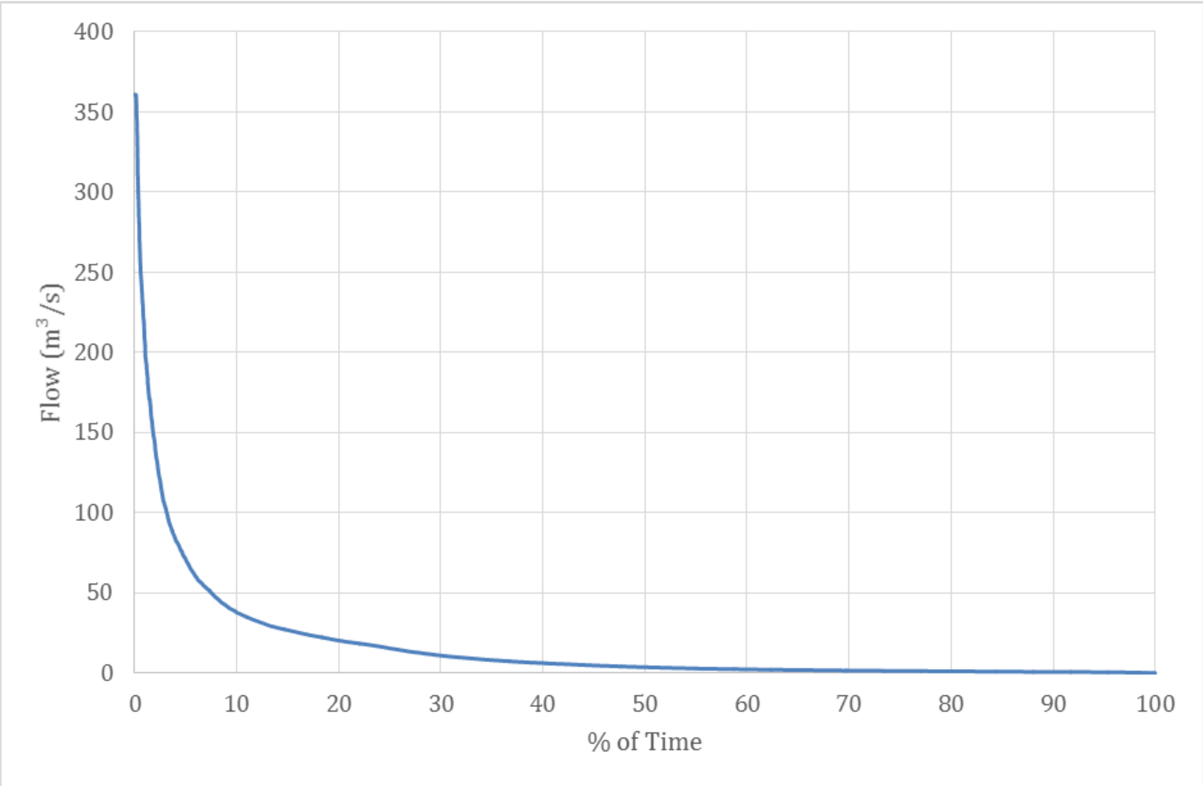


Figure 5-5 - V3H010 - Flow Duration Curve

Table 5-2 - Hydrological Analysis Statistics – V3H010

V3H010	
Mean (m^3/s)	16.25
Standard Deviation (m^3/s)	37.15
Minimum (m^3/s)	-
Maximum (m^3/s)	360.73
Flow 95.0% of Time (m^3/s)	0.466

From the statistical analysis of the flow data record obtained from the V3H010 (Tayside) gauging station from the DWS, it can be concluded that a flow rate of 466 l/s is present within the Buffels River at Dunudunu 95% of the time.

The Utility Programs for Drainage (UPD) software package was used to do flood calculations by means of the Statistical Methods up to the 1:100 flood. The statistical plots for the different statistical methods were analysed and the Log Pearson Type 3 (LP3) distribution was seen to fit the most accurate curve to the historical data plot. LP3 was therefor used as the calculated floods for the Buffels River at Dunudunu. Figure 5-6 shows the LP3 statistical plot.

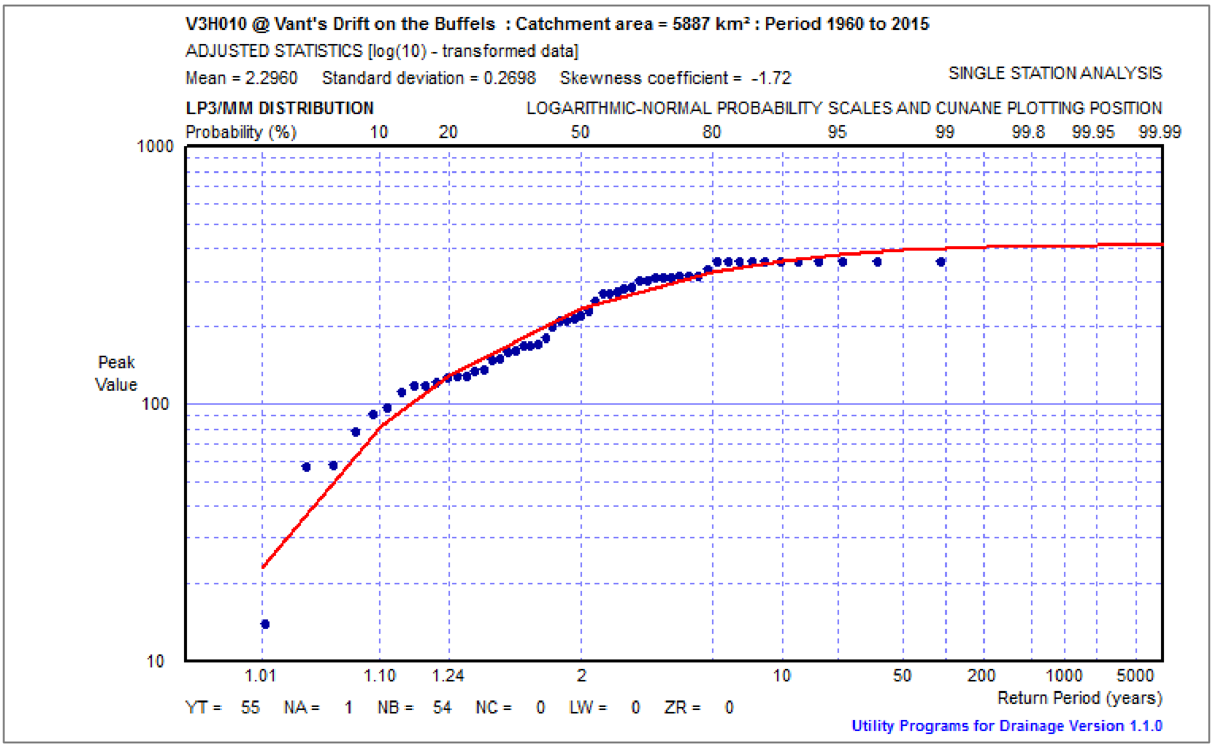


Figure 5-6 - Log-Pearson Type 3 - Statistical Plot

The LP3 1:100 flood of 401 m^3/s was used in the calculation of the safe founding level for the containerised turbine room/powerhouse on the Buffels River at Dunudunu. Normal flow depth was assumed downstream of the intake at the turbine room, and calculated by using the slope of the Buffels River for a 1 km section, 1.27%, and measuring the average river width within this section of 68 m.

River banks were conservatively assumed as vertical. The normal flow depth of the Buffels River downstream of intake for the 1:100 year flood was calculated by using Manning's Equation with an n-value of 0.06 s/m$^{1/3}$ (Chow, 1959). The normal flow depth was calculated as 2.03 m. The position of the containerised turbine room/powerhouse was designed to be placed above this level. The placement and location of the infrastructure will be as such to prevent damage from frequent flooding.

5.2.1.3 Hydraulic Analysis

The preliminary design of the Dunudunu SSHP was done as a run-off-river scheme (RR1) using a low head turbine. The relatively low head compared to the penstock length needed to obtain the potential head difference necessitated the need for the low head turbine installation as an alternative to conventional run-off-river schemes. The low head turbine room can be constructed higher upstream from the tailrace than i.e. a crossflow turbine, as the pressure head over the low head is calculated as the difference in water level from the intake upstream to the submerged outlet (tailrace) downstream.

Frictional and secondary losses were calculated on the intake structure and penstock. Figure 5-7 indicates the preliminary positions of the intake (A), start of penstock (B), the powerhouse (C) and the outlet/tailrace (D).

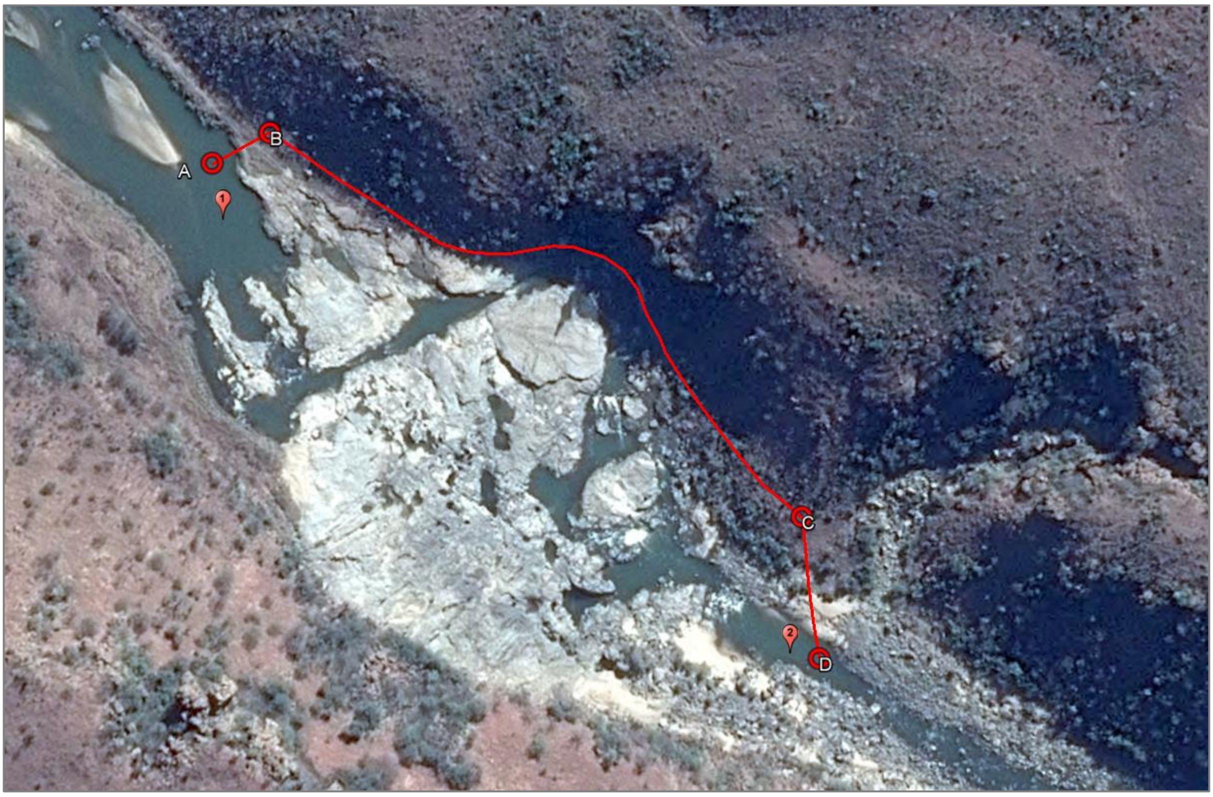


Figure 5-7 - Preliminary Site Layout – Dunudunu

The intake structure at A consists of a screen with cleaning rack and pipework conveying water from the intake at A to the start of the penstock at B, with the option of control gate valve at B. Pipework from A to C is laid at as shallow a gradient as possible just to ensure the head available from B to C is more than the headloss in the penstock. The headloss/friction loss from B to C with a 355 mm diameter penstock and 200 l/s flow is 3.7 m. From point C water is released form the turbine room through the tailrace/outlet which is submerged at point D.

Water levels at point 1 and point 2 (Figure 5-7) were measured on site as 1007 m and 993 m respectively. The turbine room/powerhouse at point C is placed 2.5 m meters above the measured water level at point 2. (Water level was measured during flow rate of 4.191 m^3/s). The available pressure head at point C is **10.3 m.** From the horizontally measured distances from satellite imagery and the gradients the total length of pipeline from point A to point D is **396 m.**

Hydraulic analysis was done and frictional and secondary losses determined using the calculated geometrics and by varying the flow between 100 l/s and 300 l/s and the pipe diameter between 160 mm OD and 400 mm OD. From the analysis it was found that for the Dunudunu SSHP the frictional losses become more than the available head for diameters of less than 315 mm. Figure 5-8 displays the calculated energy losses (frictional and secondary) for the different flow and pipe diameter configurations (>315 Mm diameters).

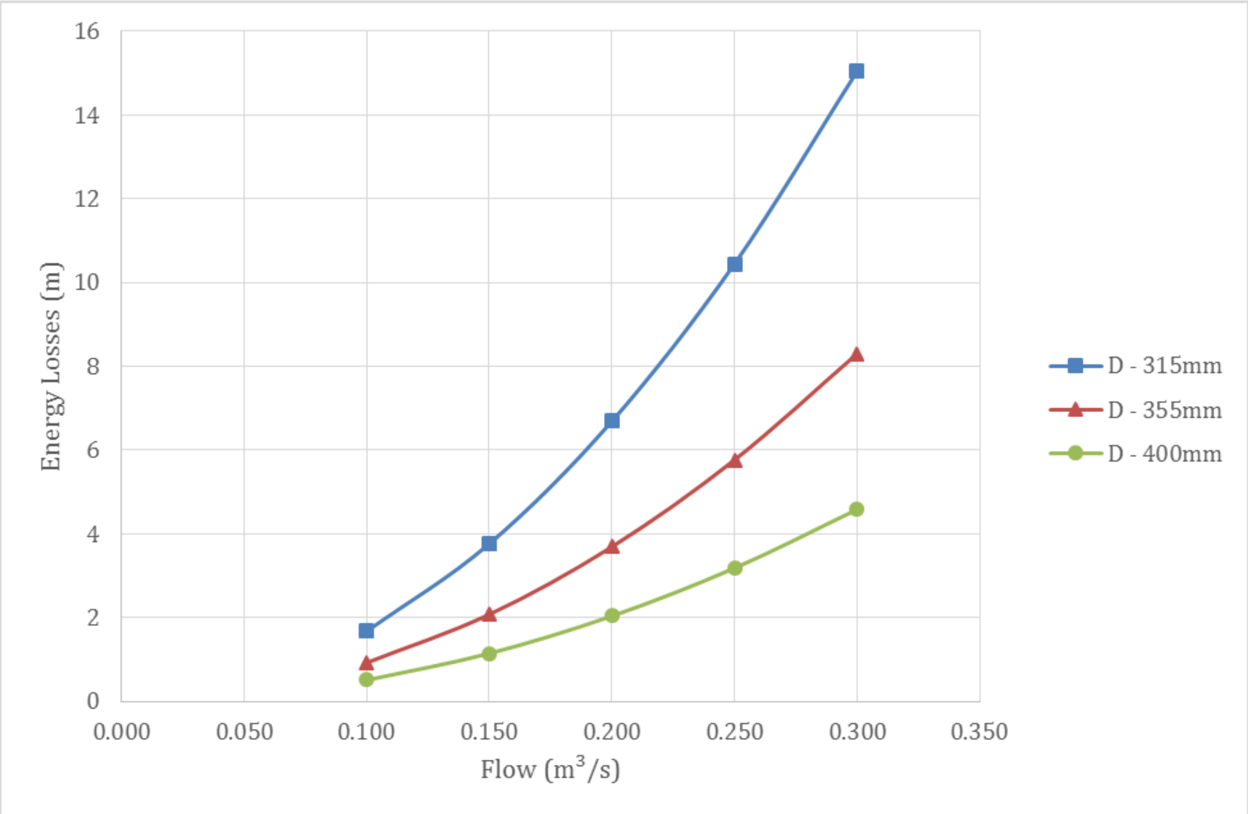


Figure 5-8 - Enegry Losses - Dunudunu

From the analysis of energy losses the power generation potential for the Dunudunu SSHP for different configurations of flow rate and pipe diameter sizes were calculated and are given in Figure 5-9.

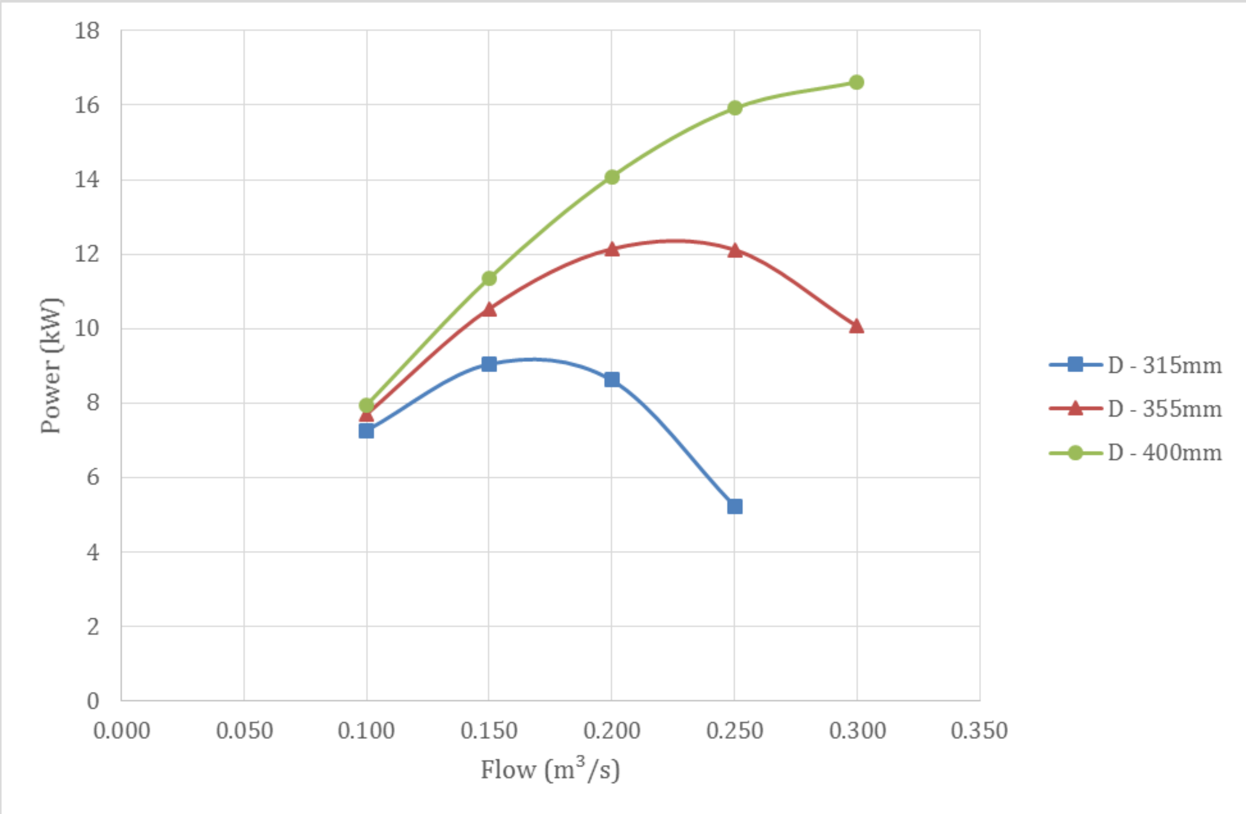


Figure 5-9 - Potential Power Generation - Dunudunu

The hydraulic analysis was used in the design of the Dunudunu SSHP.

5.2.1.4 Hydropower System Design

Figure 5-10 gives an overall schematic representation of the Dunudunu SSHP, with all the civil components. The design of the individual components, as noted in Figure 3-2, are discussed in detail in the sections following. The design of the individual components of the subsequent SSHP plants are also discussed as per description in Figure 3-2.

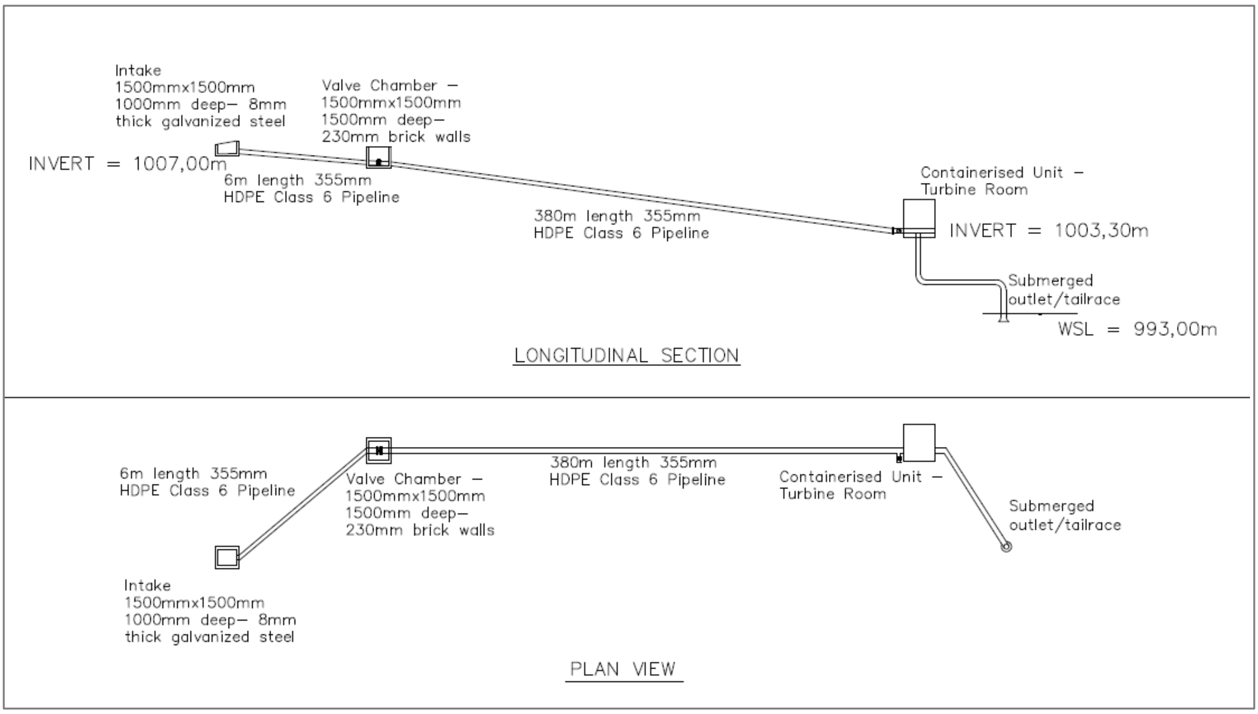


Figure 5-10 - Dunudunu SSHP schematic

Technical data of the Dunudunu SSHP plant is summarized in Table 5-3.

Table 5-3 - Dunudunu technical data

Design Flow Rate	200 l/s
Design Head	10.3
Design Power Output	10.0 kW – 12 kW
Intake invert level	1007.00 m
Turbine room invert level	1003.30 m
Tailrace submerged level	992.00 m
Penstock Length (tailrace incl.)	397 m
Penstock diameter	355 mm
Energy Losses	3.0 m

Intake and Penstock

The designed intake and penstock positions are shown in Figure 5-11. Figure 5-12 shows the hydraulic design for the penstock pipeline and include the intake structure and valve chamber. The connection to the containerised turbine room is discussed in the following section. Detail of the intake and valve chamber is given in Figure 5-13 and Figure 5-14.

Figure 5-11 - Intake and penstock location and layout

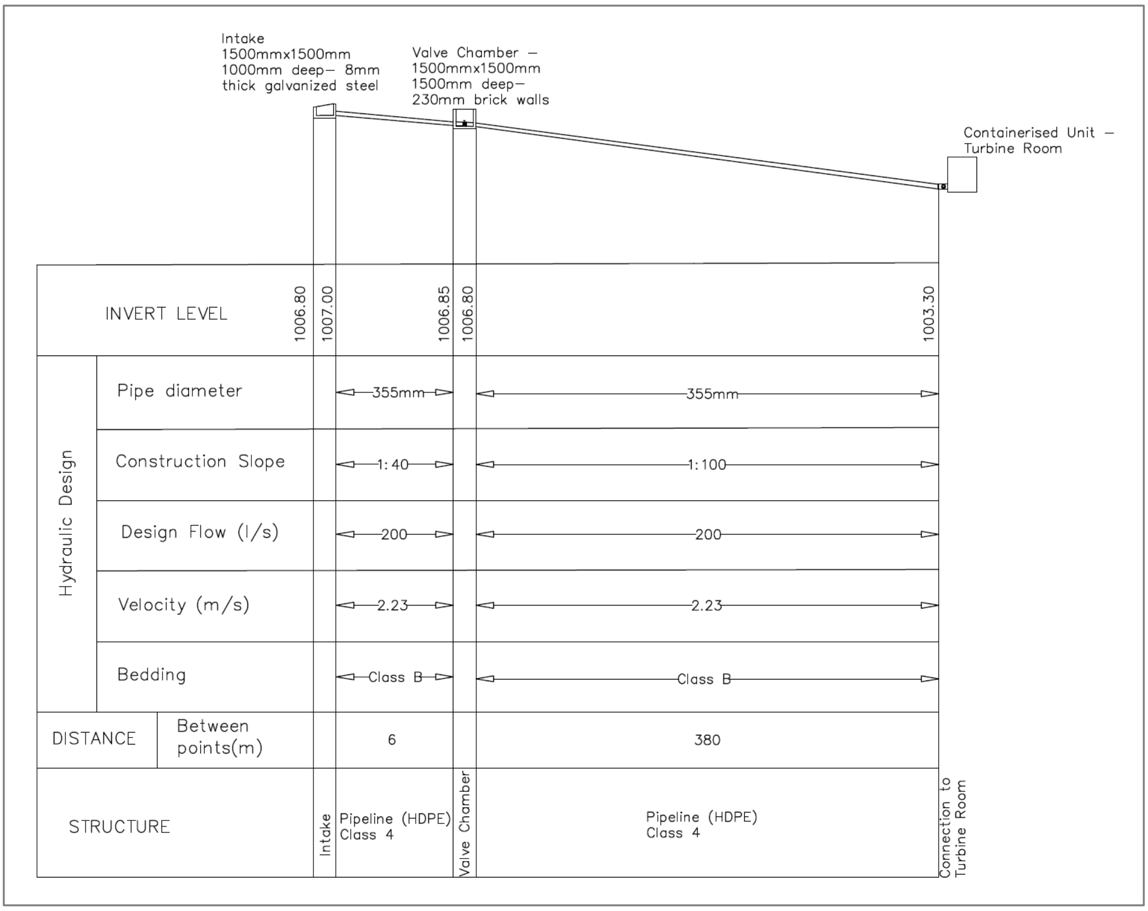


Figure 5-12 - Intake and penstock design

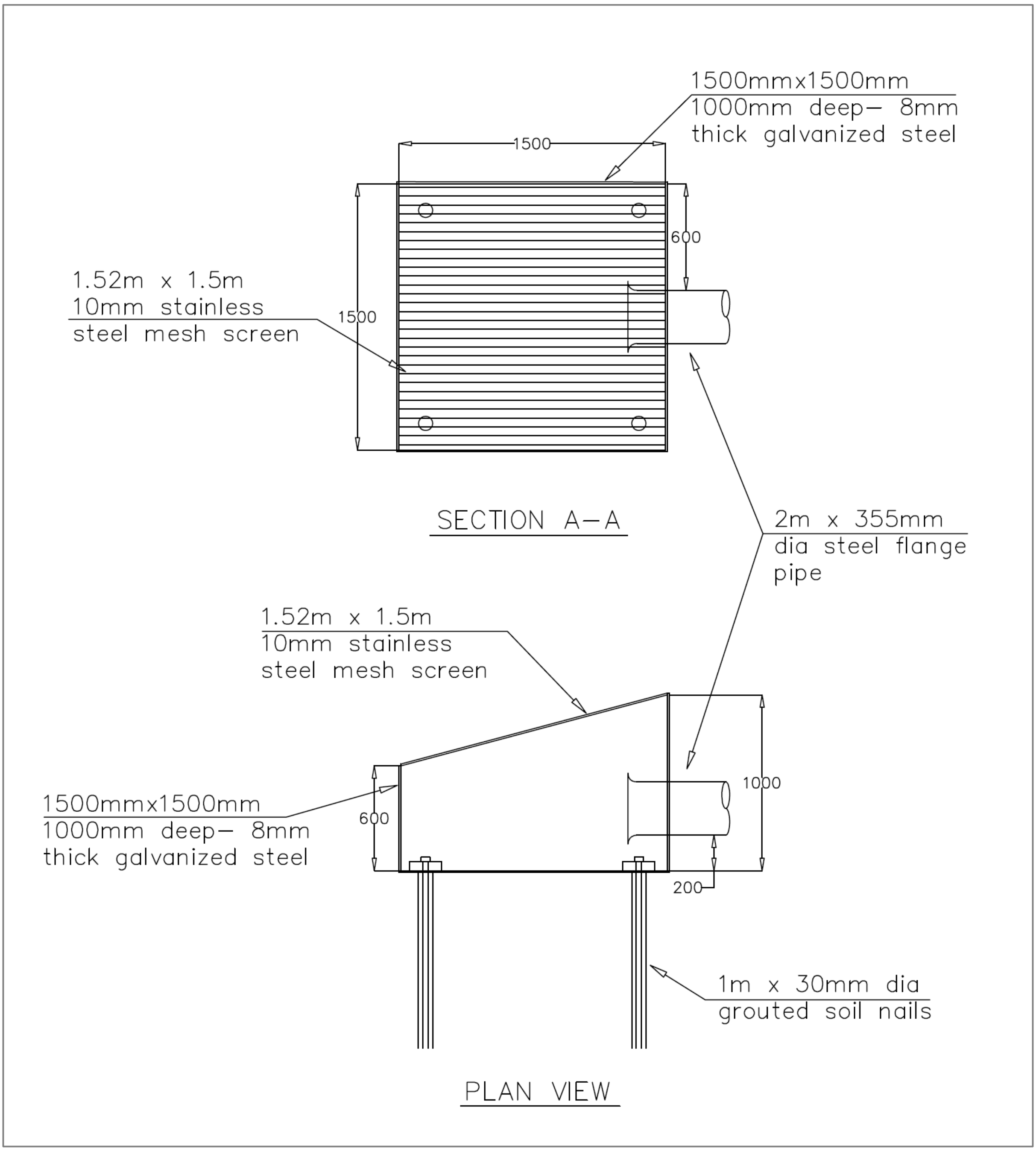


Figure 5-13 - Intake Detail

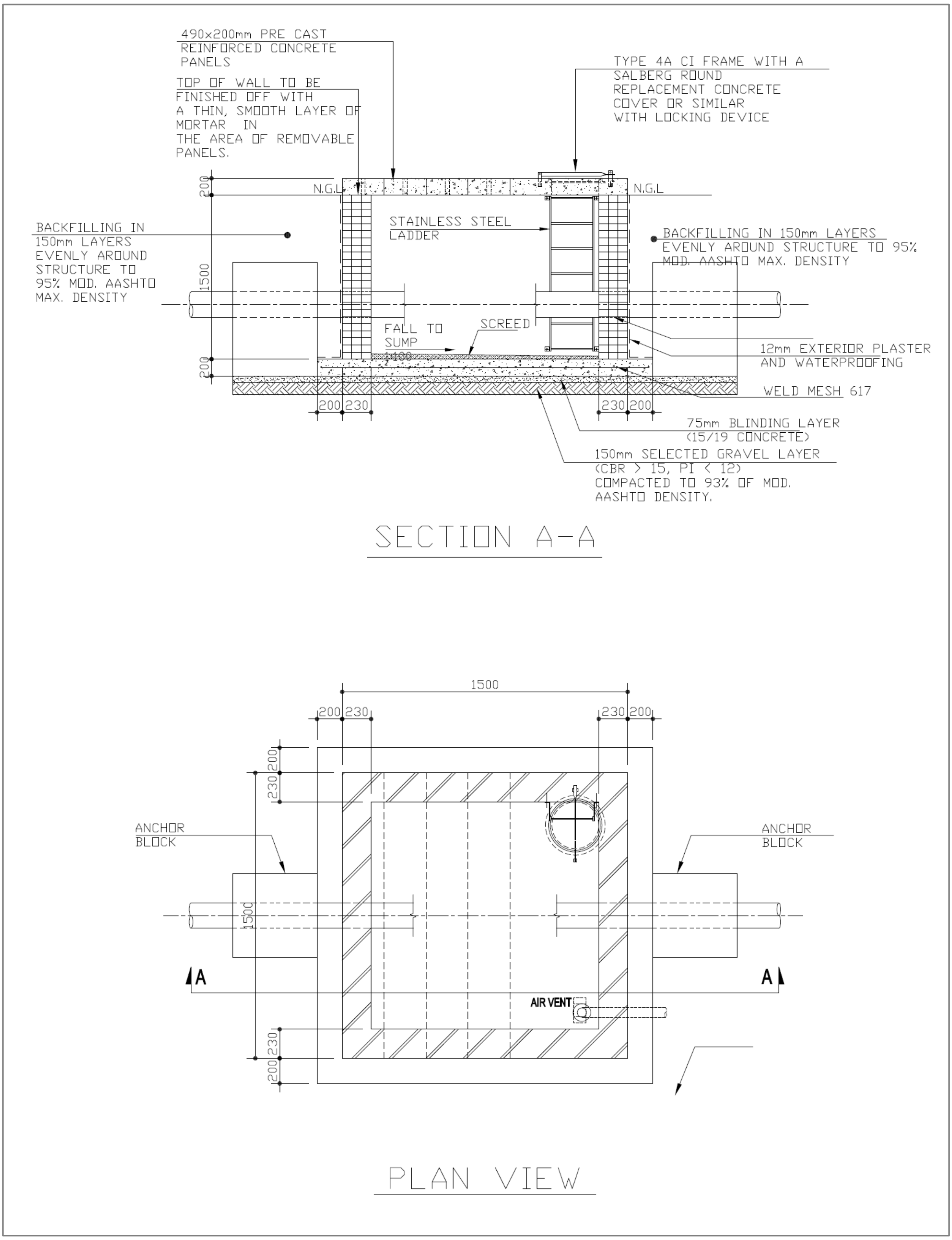


Figure 5-14 - Valve Chamber Detail

The intake structure will abstract and reroute **200 l/s** through the penstock and the turbine room and back to the natural watercourse 400 m downstream of the intake, as per the design of the SSHP at Dunudunu (Figure 5-15). The energy losses in the intake structure and penstock was calculated as **3.0 m**.

The invert level of the intake is **1007.00 m.** The HDPE pipe is laid at a **1.0%-1.5%** gradient and has an invert level at the connection to the containerised turbine room of **1003.3 m**.

Figure 5-15 - Dunudunu SSHP - Intake and Penstock

Turbine

The turbine design for the Dunudunu SSHP is a LH1500-Pro (Figure 5-16) low head turbine supplied by PowerSpout, complete with Maximum Power Point Tracking (MPPT) charge controller and inverter, diversion load and with the option of a battery bank. Figure 5-17 shows the typical components of a low head turbine off-grid system setup as is designed for the Dunudunu SSHP.

Figure 5-16 - LH1500 Pro Low head turbine (PowerSpout, 2012)

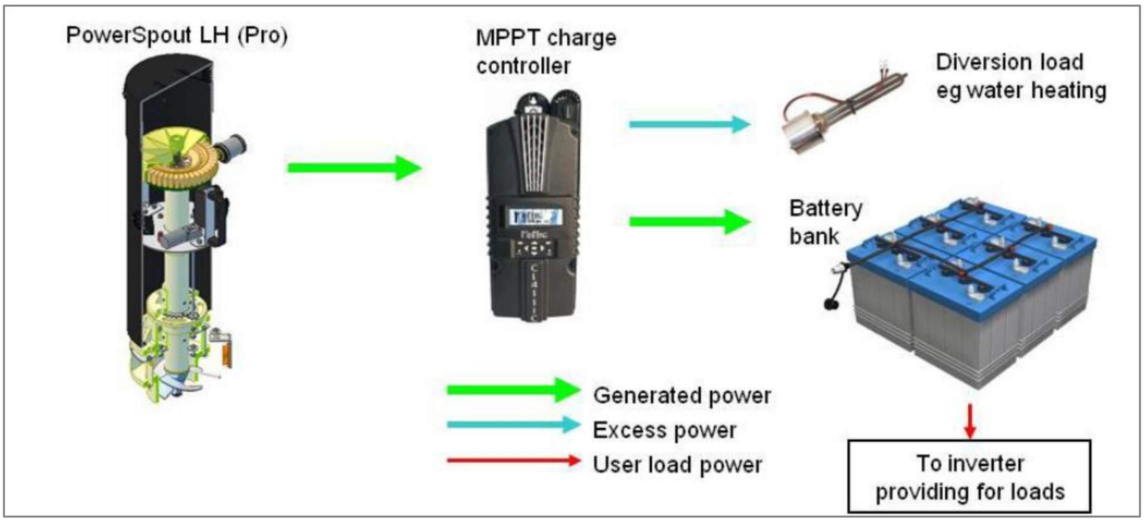


Figure 5-17 - PowerSpout LH Pro off-grid system setup (PowerSpout, 2012)

For a higher power supply to be generated, several low head turbines can be used at a single site as long as sufficient flow can be diverted to each turbine for power generation. For the Dunudunu SSHP ten low head turbines were used in the design, with a total generating potential of 14 kW. However with the flow available 95% of the time only a potential power generation of 10 kW was designed for. If higher flow is present in the Buffels River at Dunudunu it will be able to generate up to a maximum of 14 kW.

Turbine Room

The turbine room for the Dunudunu SSHP is identical to that of the Jolwayo SSHP. The turbine room/powerhouse of the Dunudunu SSHP plant is designed as a containerised unit (Figure 5-18 and

Figure 5-19). The unit is assembled off-site and transported to site and connected once the penstock and turbine room foundation is completed. The containerised unit reduces overall construction time and eliminates construction restraints in confined and remote locations. The turbine room/powerhouse houses the turbine, generator, controls and regulators of the Dunudunu SSHP plant.

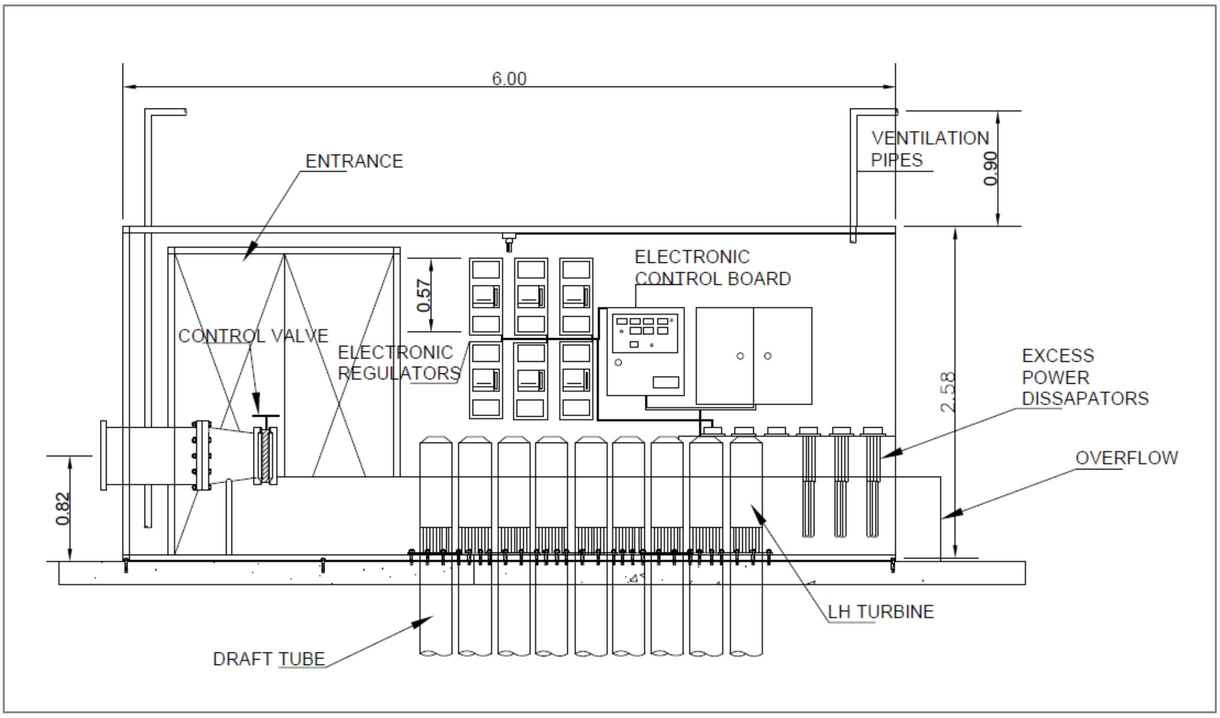


Figure 5-18 - Containerised Turbine Room - Dunudunu SSHP - Side view

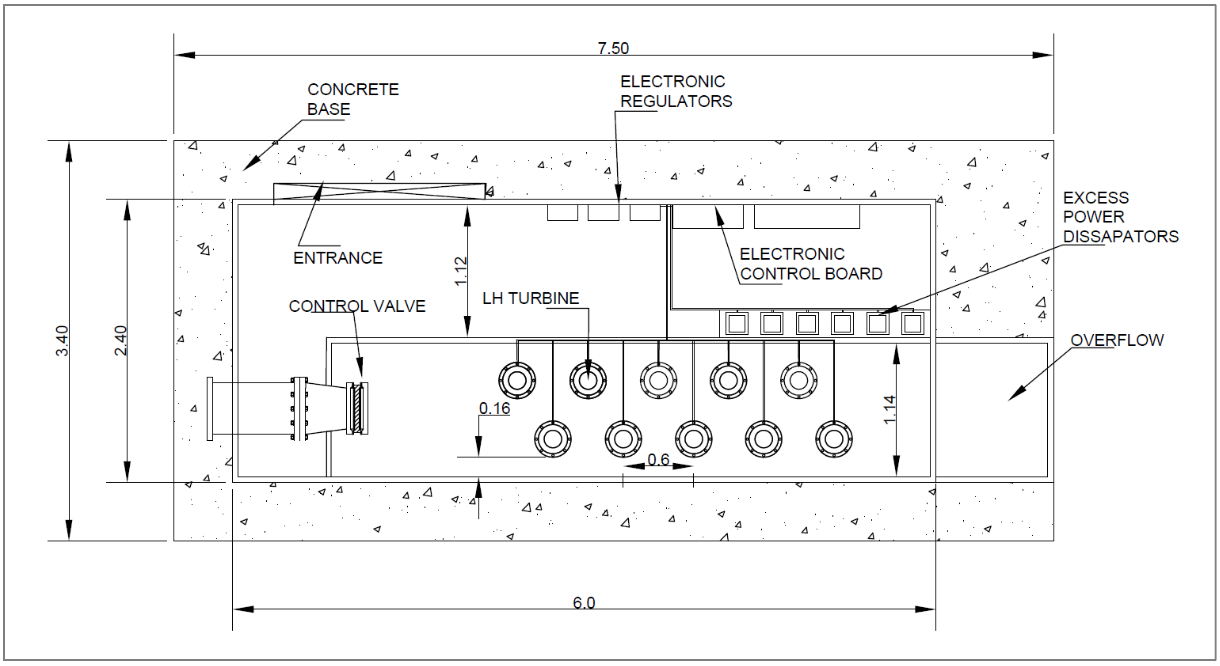


Figure 5-19 - Containerised Turbine Room - Dunudunu SSHP - Top View

Tailrace

The outlet/tailrace length is included in the calculation of the energy losses through the penstock for a low head turbine installation, due to the fact that the tailrace is submerged and the elevation difference between the turbine and the water surface level provides the potential head for power generation. The SSHP plant is a non-consumptive use of water and therefor the outfall/release from turbine room is equal to the flow at the intake structure, **200 l/s**. Figure 5-20 shows the design of the tailrace of the Dunudunu SSHP.

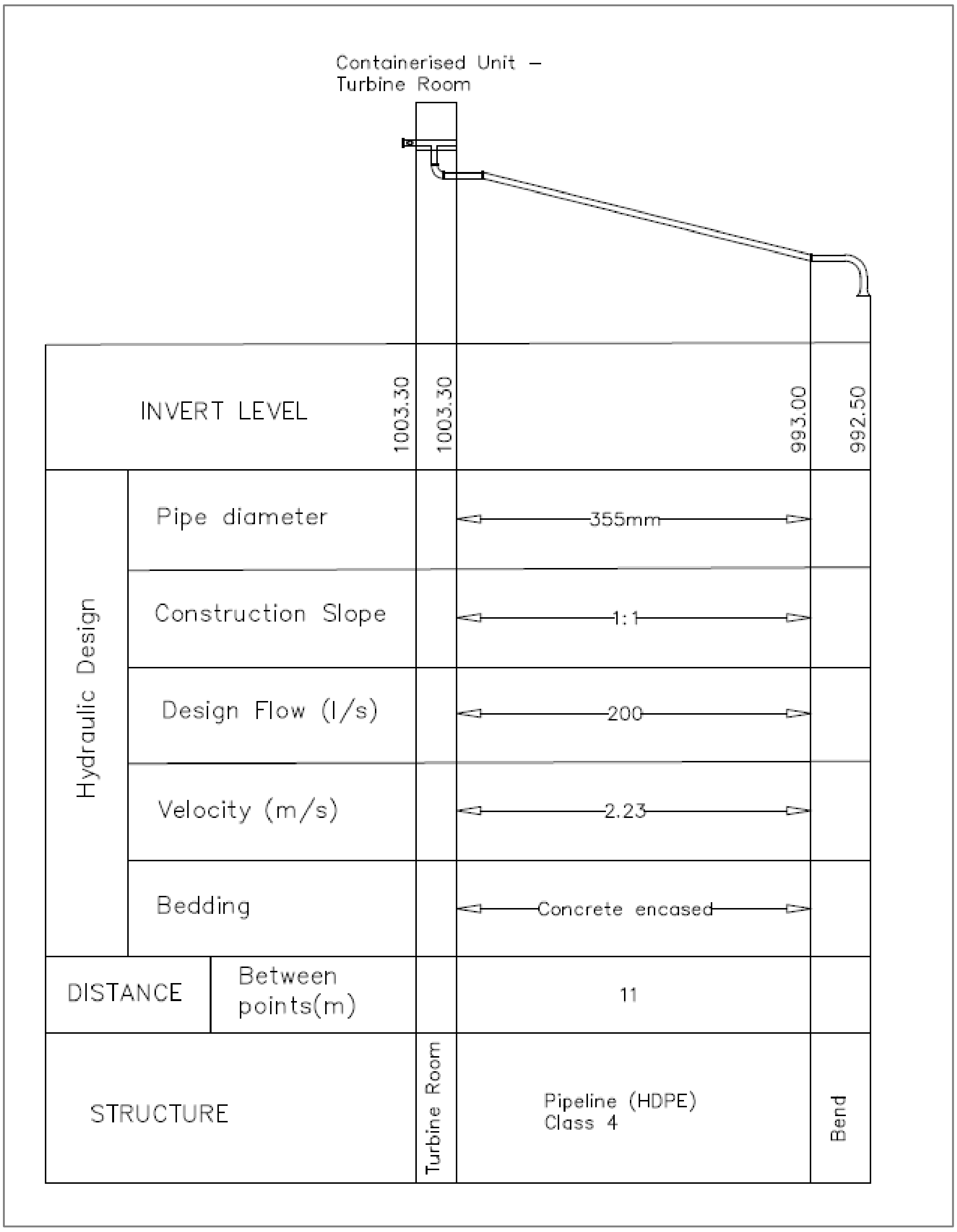


Figure 5-20 - Tailrace Design - Dunudunu SSHP

5.2.2 Jolwayo SSHP

5.2.2.1 Site Selection Process

5.2.2.1.1 Hydropower Potential – Buffels River at Jolwayo

Similarly as with the Ndodekhling-Shayiwe SSHP, the initial desktop study showed a potential head difference in the Thukela River at Jolwayo, within the Msinga Local Municipality, of 12 m. From physical site visits and future measurements and inspection, the potential head in the Thukela River at Jolwayo (Figure 5-21), was calculated as between 12 and 15 m.

Figure 5-21 – Thukela River at Jolwayo

The total theoretical hydropower generation at Jolwayo, utilizing all the flow present in the river at 95% of the time and incorporating the total height difference of 15 m, amounts to 140 kW. The potential power increases as the flow within the Thukela River at Jolwayo increases.

5.2.2.1.2 Rural Electrification – Jolwayo

Several site selection parameters, other than potential head and flow, was used to evaluate identified potential small-scale hydropower sites. Parameters included Nearest Rural Settlement, Distance to nearest Rural Settlement, Population of Rural Settlement, Accessibility by vehicle, Electrical Grid Connected and Future Electrical Grid Connectivity, Environmental Impact and Social Impact.

From satellite imagery and a site visit, the physical distance from the proposed turbine room/powerhouse on the Thukela River to the end users at the Jolwayo settlement was measured as 631

m. However from the physical site visit it was also observed that there are farmers directly adjacent to the proposed turbine room location who are not connected to any local or national electrical grid. The 2011 Census showed 216 households within the Jolwayo rural settlement, although as seen from the site visit the amount of households on farms adjacent to the Thukela rivers seems to be much less, and is approximated at not more than 12 households.

Environmentally the Jolwayo potential hydropower site will have a minimal to no impact on the environment due to the fact that only small amounts of flow will be rerouted through the turbine and return to the natural watercourse within a distance of less than 500 m downstream of the intake. There exist existing infrastructure in the form of a gauging weir which is positive, yet the infrastructure belongs to DWS and therefor development issues can cause delays in implementation. Vehicular access to the proposed site is also limited and might render the project unfeasible on such grounds alone.

5.2.2.2 Hydrological Analysis

Hydrological data was obtained from the DWS. The data from the flow gauging station, V6H007 – Impafana Loc. in the Thukela River downstream of Jolwayo was used. Flow at Jolwayo was taken as similar to that at V6H007. This is a conservative approach as there are several other tributaries to the Thukela River between V6H007 and Jolwayo.

Figure 5-22, Figure 5-23 and Table 5-4 shows a summary and analysis of the historic flow data record for V3H010.

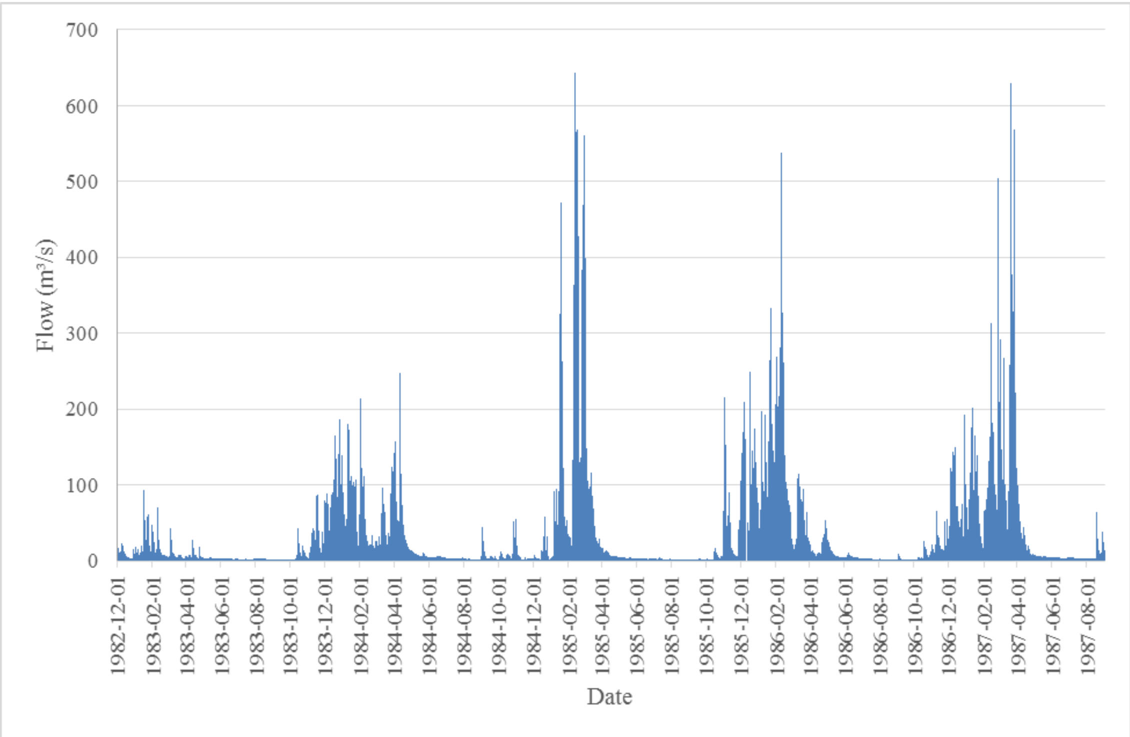


Figure 5-22 - V6H007 - Flow Data Record

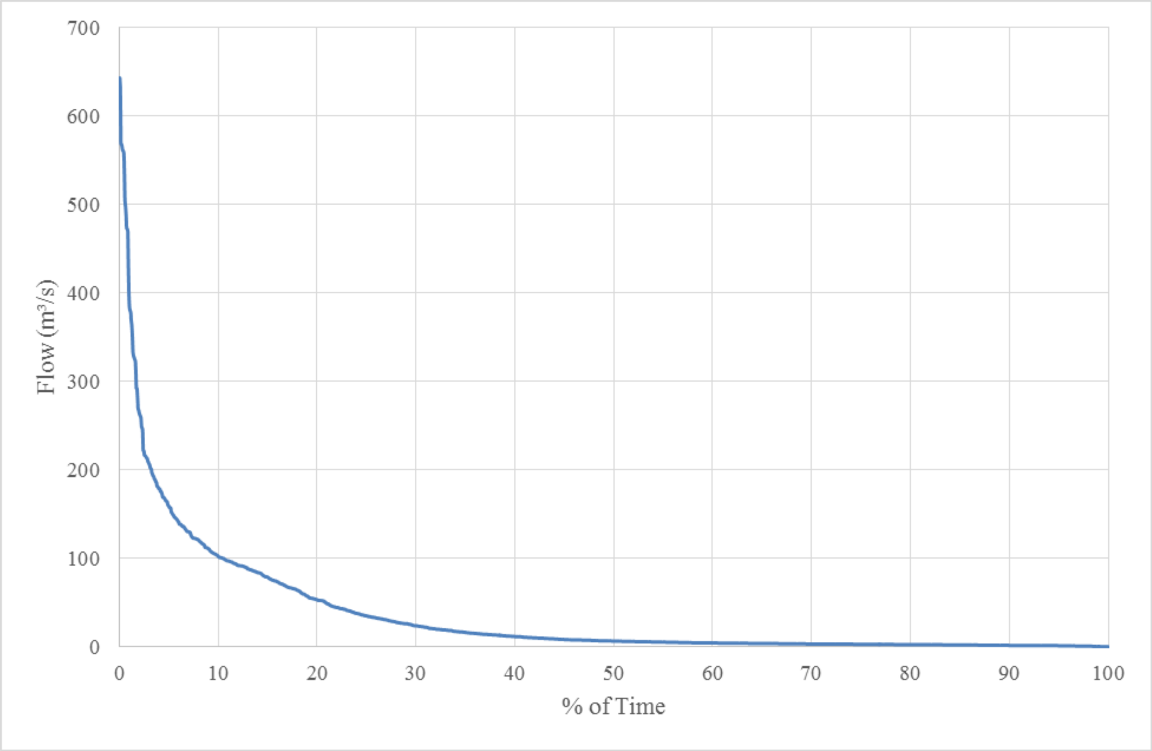


Figure 5-23 - V6H007 - Flow Duration Curve

Table 5-4 - Hydrological Analysis Statistics - V6H007

Statistics	
Mean (m^3/s)	36.24
Standard Deviation (m^3/s)	73.06
Minimum (m^3/s)	0.17
Maximum (m^3/s)	643.46
Flow 95.0% of Time	1.368

From the statistical analysis of the flow data record obtained from the V6H007 (Impafana Loc.) gauging station from the DWS, it can be concluded that a flow rate of 1368 l/s is present within the Thukela River at Jolwayo 95% of the time. V6H007 does not have a long flow record and additional studies with other hydrological data should be done to verify potential flow within the Thukela River at Jolwayo, should this potential site be chosen to be developed.

Due to the short flow record at V6H007, data from V6H002 – Tugela Ferry, which is downstream of V6H007 in the Thukela River, were used for the statistical analysis and flood level calculation. The Utility Programs for Drainage (UPD) software package was used to do flood calculations by means of the Statistical Methods up to the 1:100 flood. The statistical plots for the different statistical methods were analysed and the Extreme Value Type 1 (EV1) distribution was seen to fit the most accurate curve to the historical data plot (Figure 5-24) .EV1 was therefor used as the calculated floods for the Thukela River at Jolwayo.

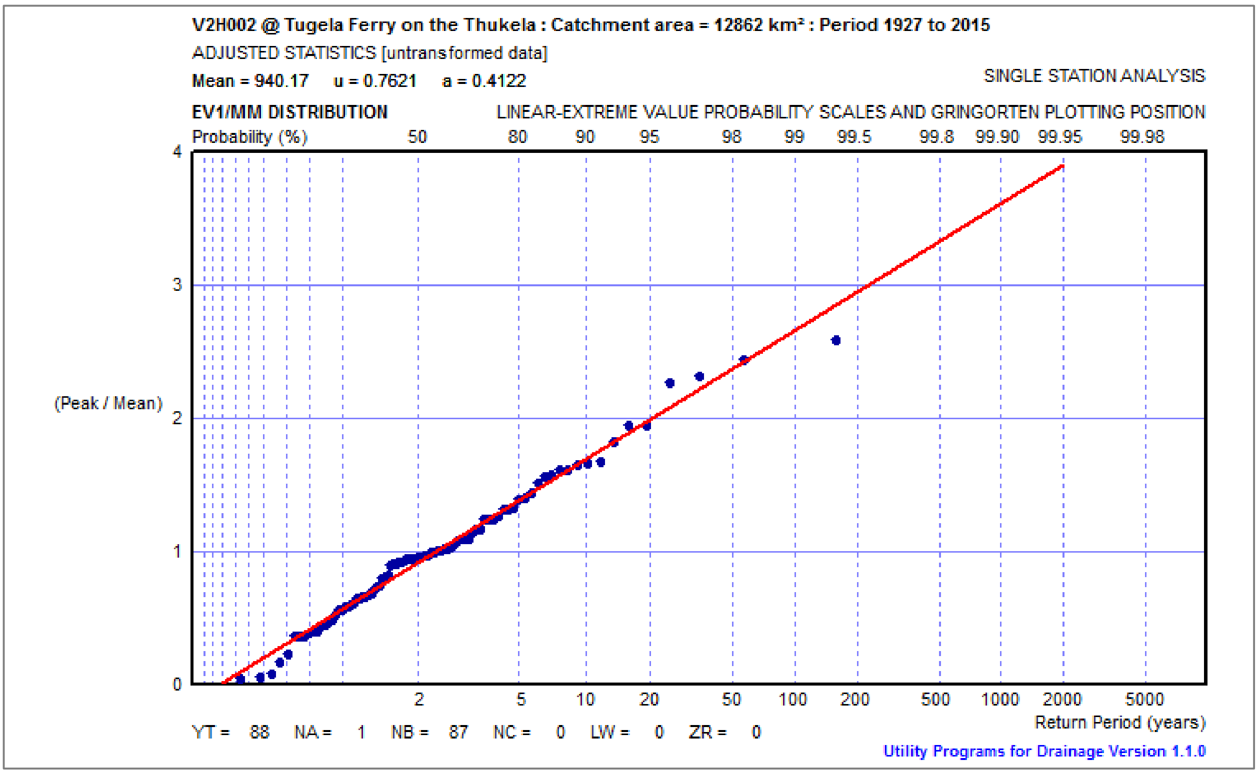


Figure 5-24 – Extreme Value Type 1 - Statistical Plot

The EV1 1:100 flood of 2499 m3/s was used in the calculation of the safe founding level for the containerised turbine room/powerhouse on the Thukela River at Jolwayo. Normal flow depth was assumeddownstream of the intake at the turbine room, and calculated by using the slope of the Thukela River for a 1 km section, 4.4%, and measuring the average river width within this section of 110 m. River banks were conservatively assumed as vertical. The normal flow depth of the Thukela River downstream of intake for the 1:100 year flood was calculated by using Manning's Equation with an n-value of 0.06 s/m1/3 (Chow, 1959). The normal flow depth was calculated as 3.13 m. The position of the containerised turbine room/powerhouse was designed to be placed above this level. The placement and location of the infrastructure will be as such to prevent damage from frequent flooding.

5.2.2.3 Hydraulic Analysis

Similarly to the Ndodekhling-Shayiwe SSHP, the preliminary design of the Jolwayo SSHP was done as a run-off-river scheme (RR1) using a low head turbine. The relatively low head compared to the penstock length needed to obtain the potential head difference necessitated the need for the low head turbine installation as an alternative to conventional run-off-river schemes.

Frictional and secondary losses were calculated on the intake structure and penstock using the Karman Prandlt friction equation for turbulent flow. Figure 5-25 indicates the preliminary positions of the intake (A), start of penstock (B), the powerhouse (C) and the outlet/tailrace (D).

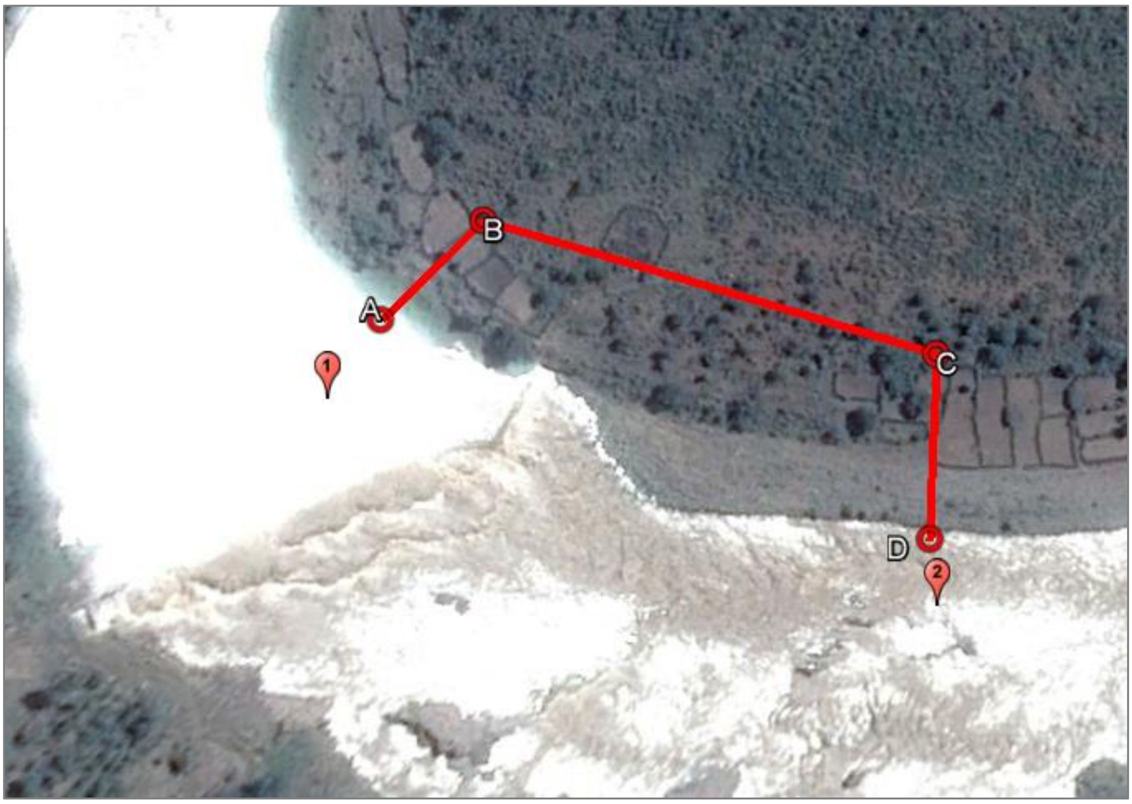


Figure 5-25 - Preliminary Site Layout - Jolwayo

The preliminary layout is similar to that of the Ndodekhling-Shayiwe SSHP. The intake structure at A consists of a screen with cleaning rack and pipework conveying water from the intake at A to the start of the penstock at B, with the option of control gate valve at B. Pipework from A to C is laid at as shallow a gradient as possible just to ensure the head available from B to C is more than the headloss in the penstock. The headloss/friction loss from B to C with a 355 mm diameter penstock and 300 l/s flow is 5.7 m. From point C water is released form the turbine room through the tailrace/outlet which is submerged at point D.

Water levels at point 1 and point 2 (Figure 5-25) were measured as 583 m and 571 m respectively. The turbine room/powerhouse at point C is placed 5.3 m meters above the measured water level at point 2. (Water level was measured during flow rate of 0.719 m^3/s). The available pressure head is 5.3 m. From the horizontally measured distances from satellite imagery and the gradients the total length of pipeline from point A to point D is 250 m.

Hydraulic analysis was done and frictional and secondary losses determined using the calculated geometrics and by varying the flow between 100 l/s and 300 l/s and the pipe diameter between 160 mm OD and 400 mm OD. From the analysis it was found that for the Jolwayo SSHP the frictional losses become more than the available head for diameters of less than 250 mm. Figure 5-26 displays the calculated energy losses (frictional and secondary) for the different flow and pipe diameter configurations (>250 mm diameters).

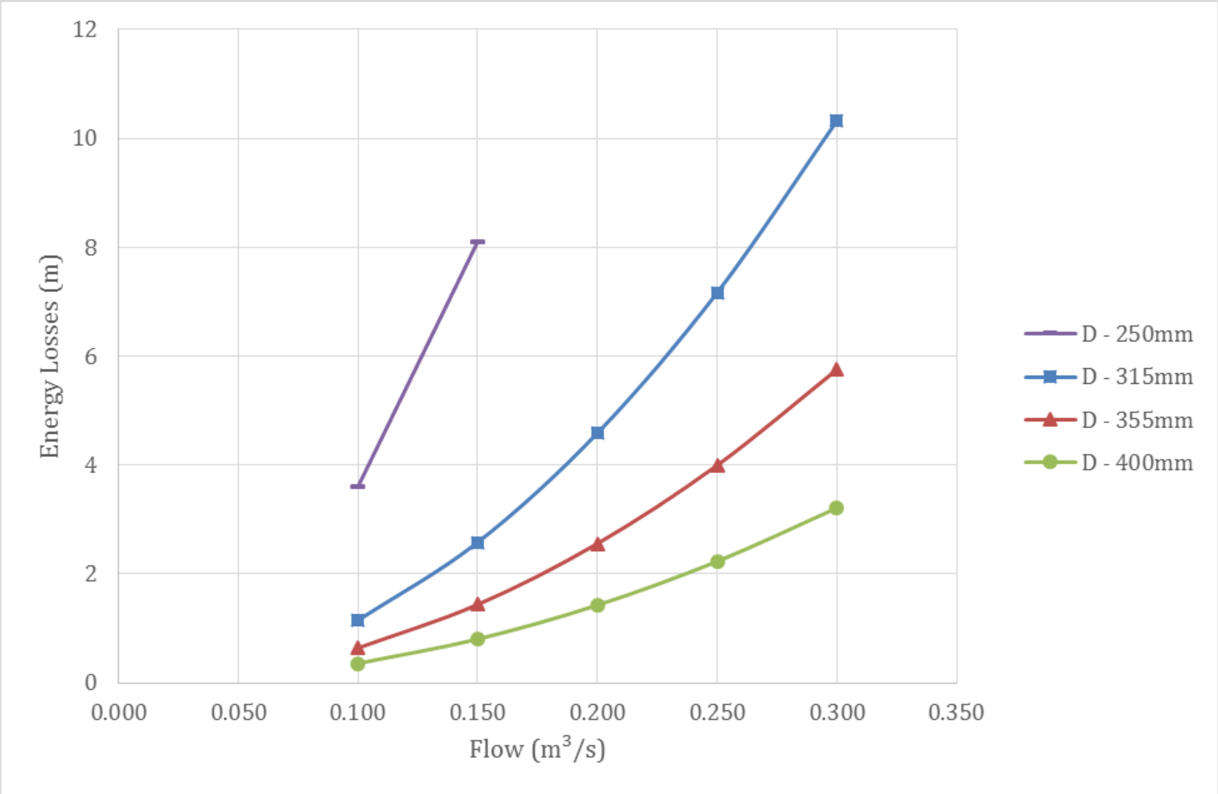


Figure 5-26 - Energy Losses - Jolwayo

From the analysis of energy losses the power generation potential for the Jolwayo SSHP for different configurations of flow rate and pipe diameter sizes were calculated and are given in Figure 5-27 below.

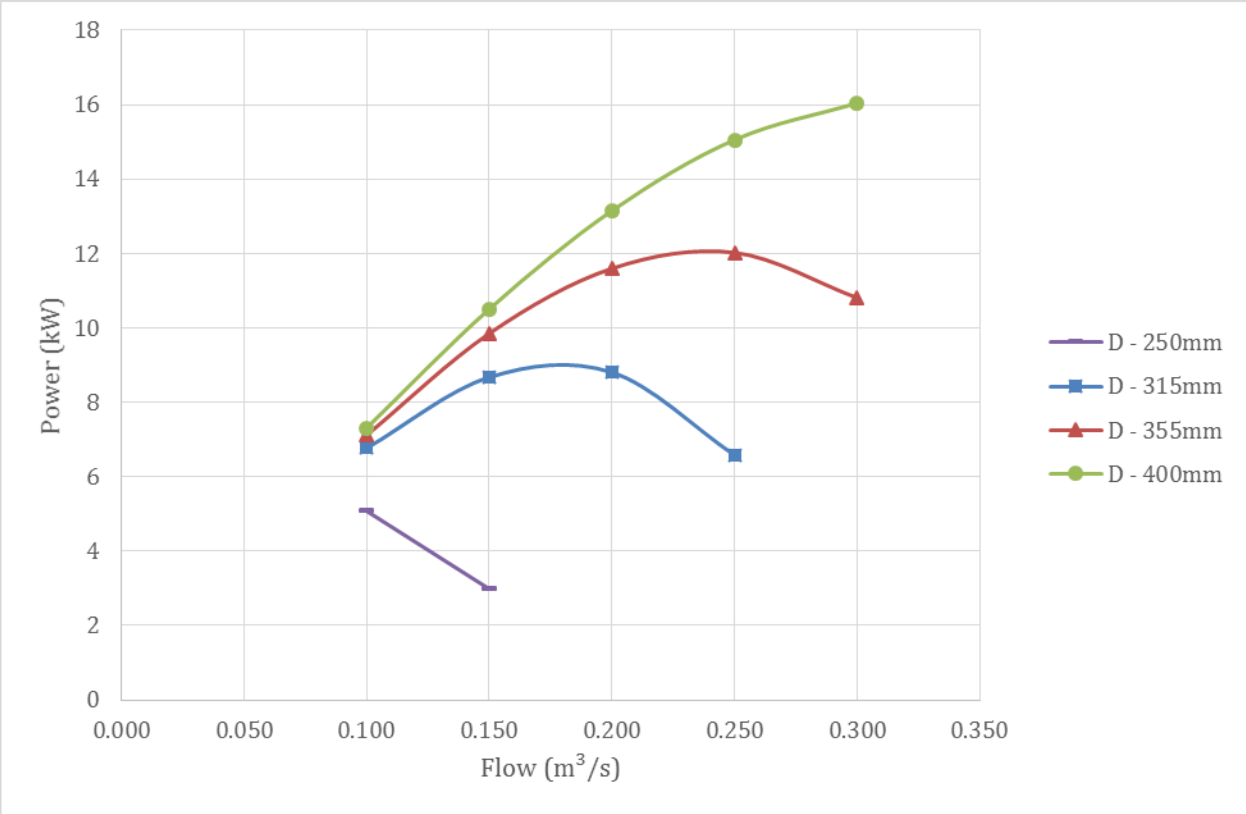


Figure 5-27 - Potential Power Generation - Jolwayo

The hydraulic analysis was used in the design of the Jolwayo SSHP.

5.2.2.4 Hydropower System Design

The system design of the Jolwayo SSHP is similar to that of the Ndodekhling-Shayiwe SSHP. Figure 5-28 gives an overall schematic representation of the Jolwayo SSHP, with all the civil components. The design of the individual components are discussed in the sections following.

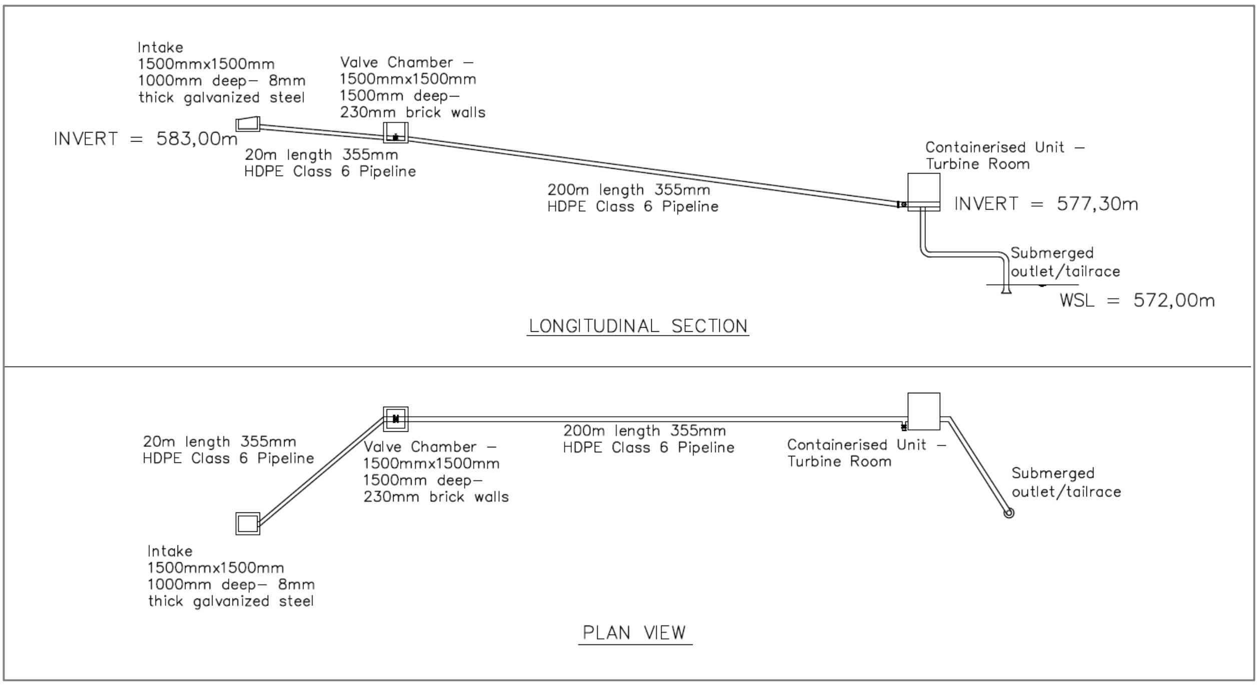


Figure 5-28 - Jolwayo SSHP schematic

Technical data of the Jolwayo SSHP plant is summarized in Table 5-5.

Table 5-5 - Jolwayo technical data

Design Flow Rate	300 l/s
Design Head	5.3 m
Design Power Output	10.0 kW
Intake invert level	582.00 m
Turbine room invert level	577.30 m
Tailrace submerged level	571.00 m
Penstock Length (tailrace incl.)	250 m
Penstock diameter	355 mm
Energy Losses	5.7 m

Intake and Penstock

The designed intake and penstock positions are shown in Figure 5-29. Figure 5-30 shows the hydraulic design for the penstock pipeline and include the intake structure and valve chamber. The connection to the containerised turbine room is discussed in the following section. Detail on the intake and valve chamber is similar to that of the Ndodekhling-Shayiwe SSHP and is given in Figure 5-13 and Figure 5-14.

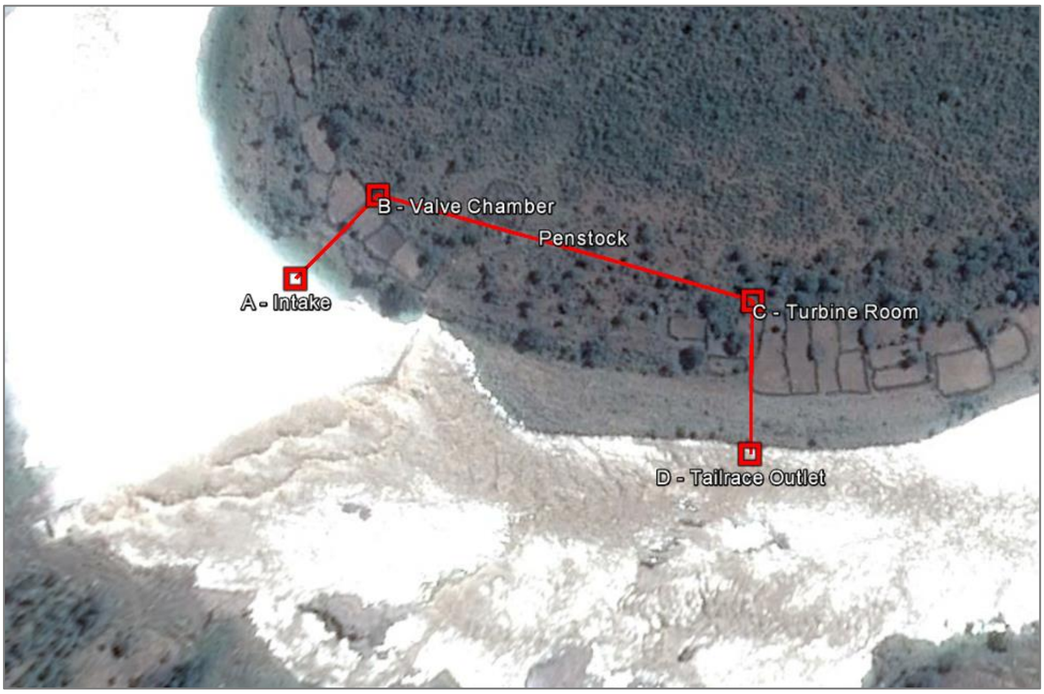


Figure 5-29 - Intake and penstock location and layout - Jolwayo SSHP

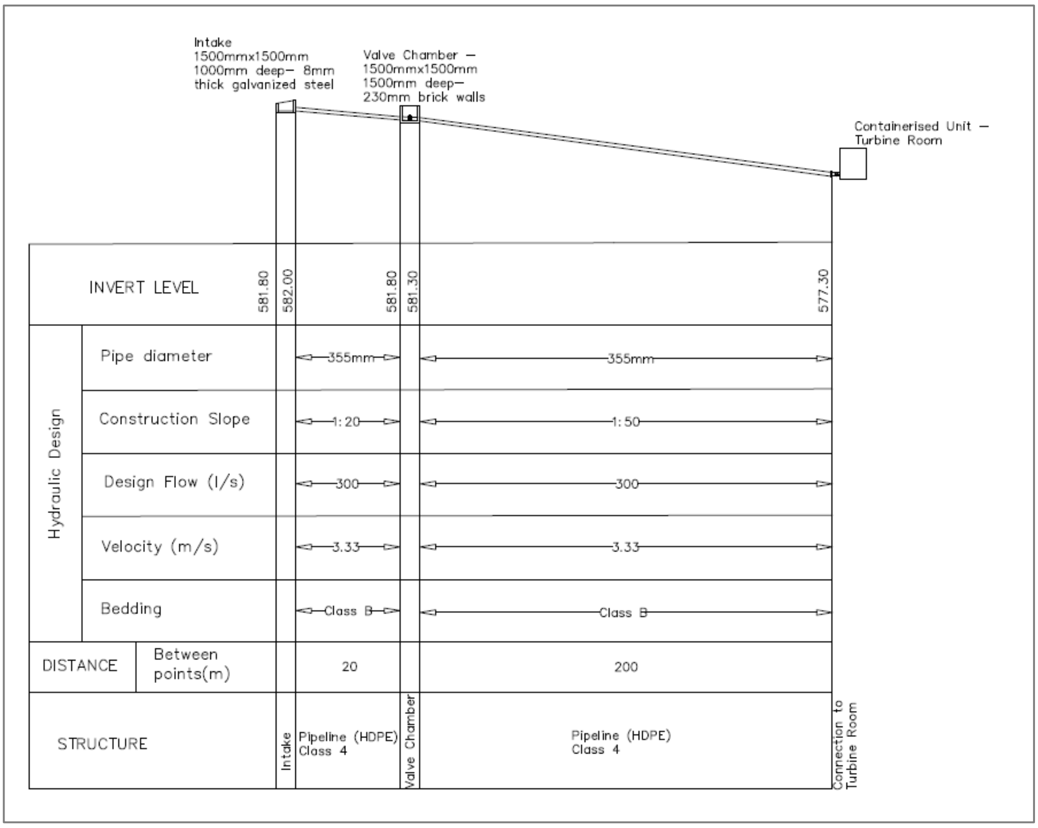


Figure 5-30 - Intake and penstock design - Jolwayo SSHP

The intake structure will abstract and reroute 300 l/s through the penstock and the turbine room and back to the natural watercourse 300 m downstream of the intake, as per the design of the SSHP at Jolwayo. The energy losses in the intake structure and penstock was calculated as 5.7 m. The invert level of the intake is 582.00 m. The HDPE pipe is laid at a 1.0%-2.0% gradient and has an invert level at the connection to the containerised turbine room of 577.30 m.

Turbine

The turbine design for the Jolwayo SSHP is similar to that of the Ndodekhling-Shayiwe SSHP and is ten (10) LH1500-Pro (Figure 5-16) low head turbine supplied by PowerSpout, complete with Maximum Power Point Tracking (MPPT) charge controller and inverter, diversion load and with the option of a battery bank.

The Jolwayo SSHP was designed for flow of 300 l/s and a total power generations of 10 kW. If higher flow is present in the Thukela River at Jolwayo it will be able to generate up to a maximum of 14 kW.

Turbine Room

The design for the turbine room of the Jolwayo SSHP is identical to that of the Ndodekhling-Shayiwe SSHP and only differs in the location of the turbine room. The design of the turbine room can be seen in Figure 5-18 and Figure 5-19. The unit is assembled off-site and transported to site and connected once the penstock and turbine room foundation is completed. The containerised unit reduces overall construction time and eliminates construction restraints in confined and remote locations

Tailrace

The outlet/tailrace length is included in the calculation of the energy losses through the penstock for a low head turbine installation, due to the fact that the tailrace is submerged and the elevation difference between the turbine and the water surface level provides the potential head for power generation. The SSHP plant is a non-consumptive use of water and therefor the outfall/release from turbine room is equal to the flow at the intake structure, **300 l/s**. Figure 5-31 shows the design of the tailrace of the Jolwayo SSHP.

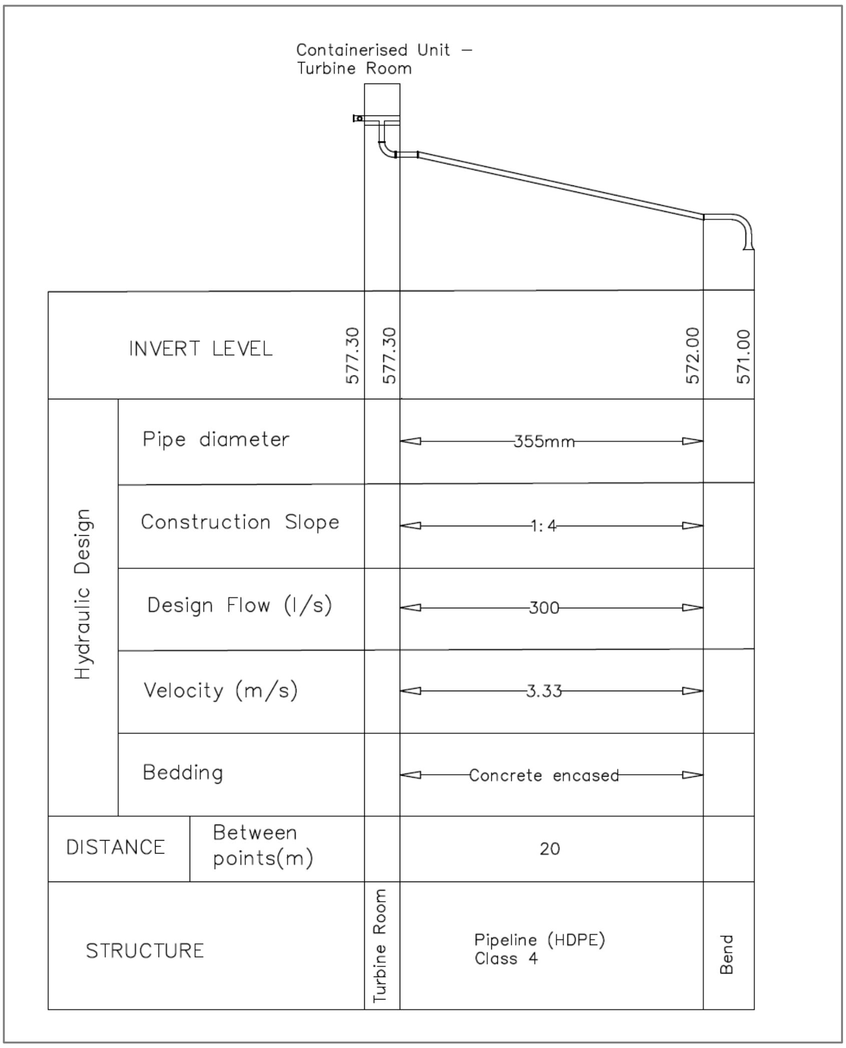


Figure 5-31 - Tailrace Design - Jolwayo SSHP

5.2.3 Mahlaba SSHP (Woza)

From site visits and investigations, the proposed end users of proposed SSHP project at Woza was found to be located in the Mahlaba community. Therefor the name of the proposed SSHP was change from Woza to the Mahlaba SSHP.

5.2.3.1 Site Selection Process

5.2.3.1.1 Hydropower Potential – Buffels River at Mahlaba (Woza)

Similarly as with the Ndodekhling-Shayiwe SSHP, the initial desktop study showed a potential head difference in the Buffels River at Mahlaba, within the Msinga Local Municipality, of 16 m. From physical site visits, measurements and inspection, the potential head in the Buffels River at Mahlaba (Figure 5-32), was confirmed as 16 m.

Figure 5-32 - Buffels River at Mahlaba

The total theoretical hydropower generation at Mahlaba, utilizing all the flow present in the Buffels River at 95% of the time and incorporating the total height difference of 16 m, amounts to 52 kW. The potential power increases as the flow within the Buffels River at Mahlaba increases.

5.2.3.1.2 Rural Electrification – Mahlaba

Similar to the Ndodekhling-Shayiwe SSHP and Jolwayo SSHP, several parameters were used to evaluate the identified potential small-scale hydropower site at Mahlaba. From satellite imagery and a site visit, the physical distance from the proposed turbine room/powerhouse on the Buffels River to the end users at the Mahlaba settlement (Figure 5-33) was measured as **960 m**. The physical site visit also showed no existing electrical infrastructure within Mahlaba. The 2011 Census showed 320 households within the Mahlaba rural settlement. The entire Mahlaba settlement however is spread much wider than the proposed end users of the small-scale hydropower. From a site visit and from the satellite imagery the amount of households to be served by the SSHP seems to be in the range of 70 to 90 households.

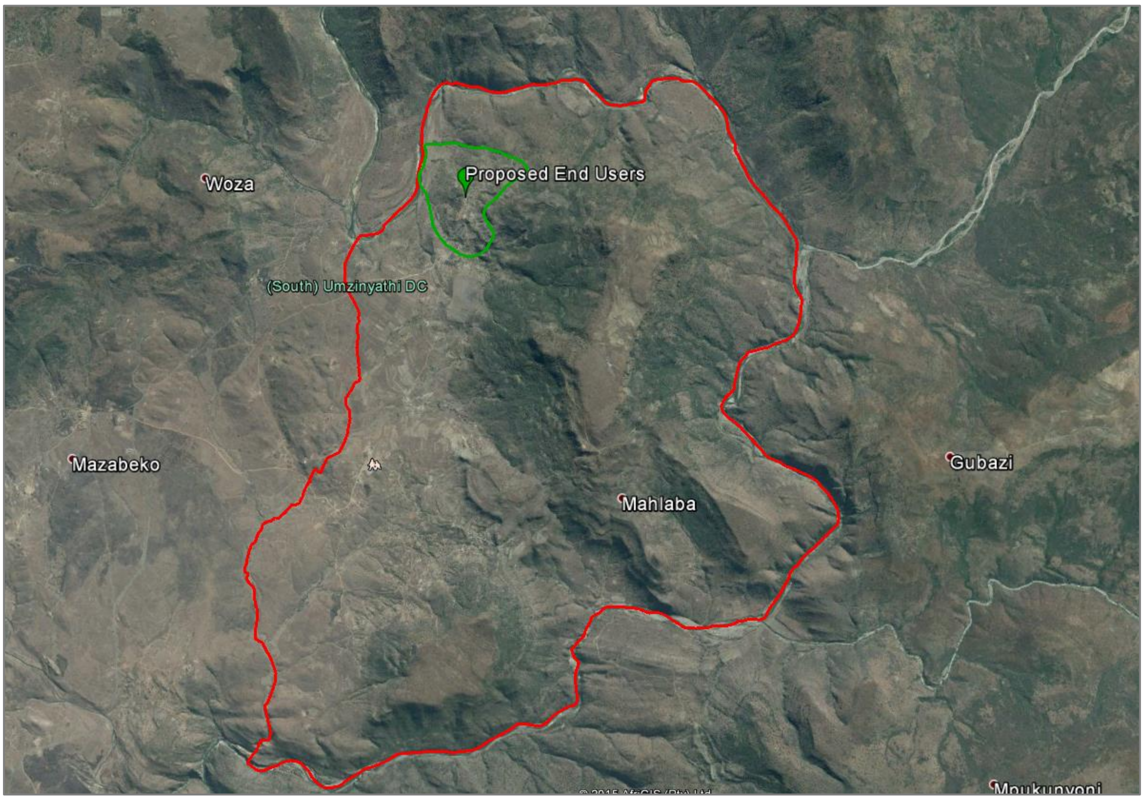


Figure 5-33 - Mahlaba Rural Settlement

Similar to the designed Ndodekhling-Shayiwe SSHP and Jolwayo SSHP the Mahlaba SSHP will have a minimal to no impact on the environment due to the fact that only a percentage of flow will be rerouted through the turbine and return to the natural watercourse within a distance of less than 700 m downstream of the intake. The social impact on the community is positive, as households without previous electricity will be provided with power from the hydro turbine installed on the Buffels River at Mahlaba, herby uplifting their standard of life and service delivery.

Both sides of the proposed Mahlaba SSHP, the intake side and the turbine room side of the proposed penstock through the hill, is easily accessible to both inspection and construction vehicles.

5.2.3.2 Hydrological Analysis

The potential SSHP site for Mahlaba in the Buffels River sits downstream of the Ndodekhlin-Shayiwe potential SSHP site. Data for the hydrological analysis for the Mahlaba site was obtained from DWS for the gauging station V3H010 – Tayside. This is the same station from which data was used for the hydrological analysis of Ndodekhling-Shayiwe. Therefor the hydrological analysis for Mahlaba is the same as that for Ndodekhling-Shayiwe.

From the statistical analysis of the flow data record obtained from the V3H010 (Tayside) gauging station from the DWS, it can be concluded that a flow rate of 466l/s is present within the Buffels River at Mahlaba 95% of the time.

The Utility Programs for Drainage (UPD) software package was used to do flood calculations by means of the Statistical Methods up to the 1:100 flood. The statistical plots for the different statistical methods were analysed and the Log Pearson Type 3 (LP3) distribution was seen to fit the most accurate curve to the historical data plot. LP3 was therefor used as the calculated floods for the Buffels River at Mahlaba.

The LP3 1:100 flood of 401 m^3/s was used in the calculation of the safe founding level for the containerised turbine room/powerhouse on the Buffels River at Mahlaba. Normal flow depth was assumed downstream of the intake at the turbine room, and calculated by using the slope of the Buffels River for a 1 km section, 1.00%, and measuring the average river width within this section of 40 m. River banks were conservatively assumed as vertical. The normal flow depth of the Buffels River downstream of intake for the 1:100 year flood was calculated by using Manning's Equation with an n-value of 0.06 $s/m^{1/3}$ (Chow, 1959). The normal flow depth was calculated as 2.3 m. The position of the containerised turbine room/powerhouse was designed to be placed above this level.

5.2.3.3 Hydraulic Analysis

Measurements from satellite imagery (Google Earth) and physical measurements on site was used in the hydraulic analysis of the design of the Mahlaba SSHP.

Frictional and secondary losses were calculated on the intake structure. Figure 5-34 indicates the preliminary positions of the intake and start of penstock (A) and the powerhouse (B).

Figure 5-34 - Preliminary Site Layout - Mahlaba

The intake structure at A consists of a screen with cleaning rack and pipework conveying water from the intake through the start of the penstock to the turbine room at B. From the intake at point A water is supplied through the penstock, which is tunnelled, to the powerhouse at position B. Tunnel is constructed by means of directional or rock drilling.

Water levels at point 1 and point 2 (Figure 5-34) were measured on site as 780 m and 762 m respectively. The turbine room/powerhouse at point B is placed 2.2 m above the river bed. From the calculated flow depth at 1:100 it is calculated as 2 above the measured water level at point 2. (Water level was measured during flow rate of 1.165 m^3/s). The available pressure head at point B is 16 m (780 – 762 – 2 = 16). Horizontal distances measured from satellite imagery from A to B is 450 m.

Hydraulic analysis was done and frictional and secondary losses determined using the calculated geometrics and by varying the flow between 100 l/s and 300 l/s and the pipe diameter between 200 mm OD and 355 Mm OD. Based on the proposed construction method of using directional drilling or rock drilling, the diameter range was limited to the above mentioned 200 mm OD to 355 mm OD. Figure 5-35 displays the calculated energy losses (frictional and secondary) for the different flow and pipe diameter configurations.

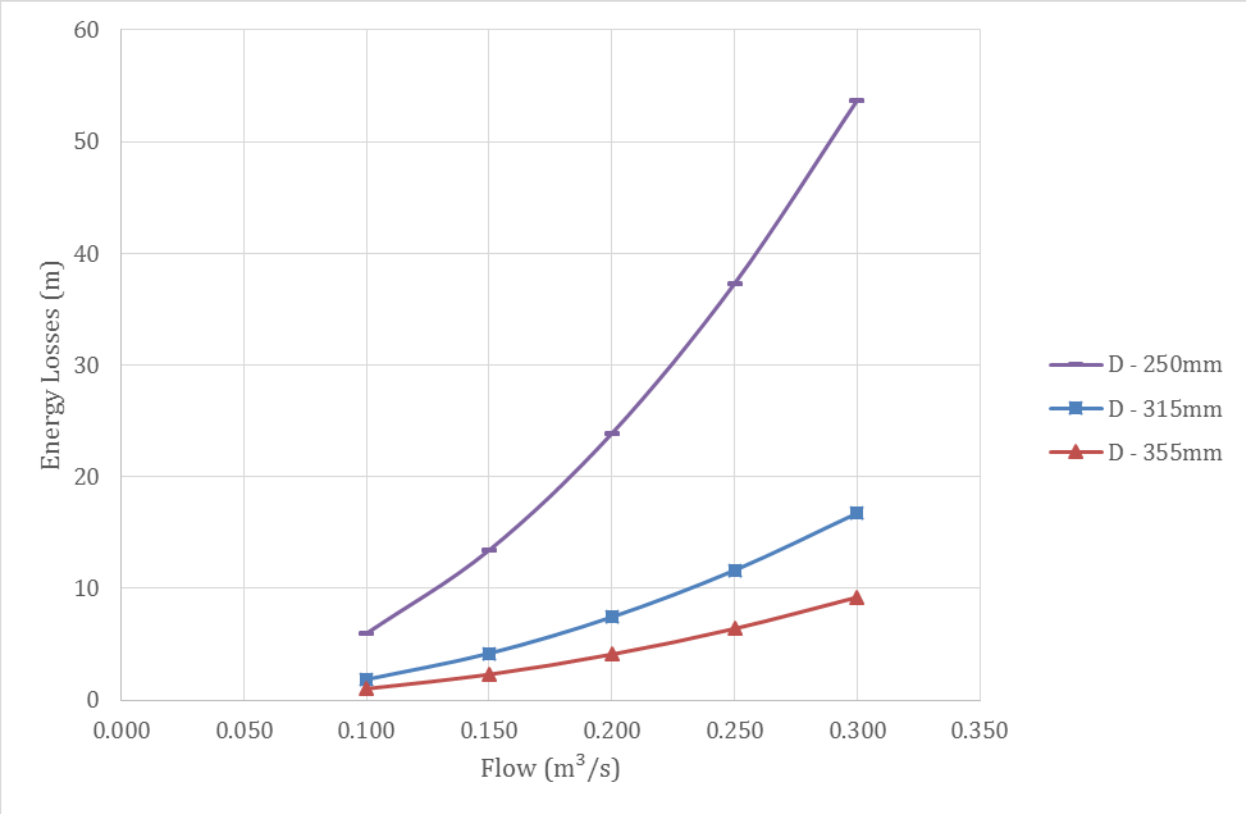


Figure 5-35 - Energy Losses – Mahlaba

From the analysis of energy losses the power generation potential for the Mahlaba SSHP for different configurations of flow rate and pipe diameter sizes were calculated and are given in Figure 5-36 below. The friction losses for a pipe diameter less than 200 mm become more than the available head at Mahlaba and is therefor not included in the further power generation calculations and graphs.

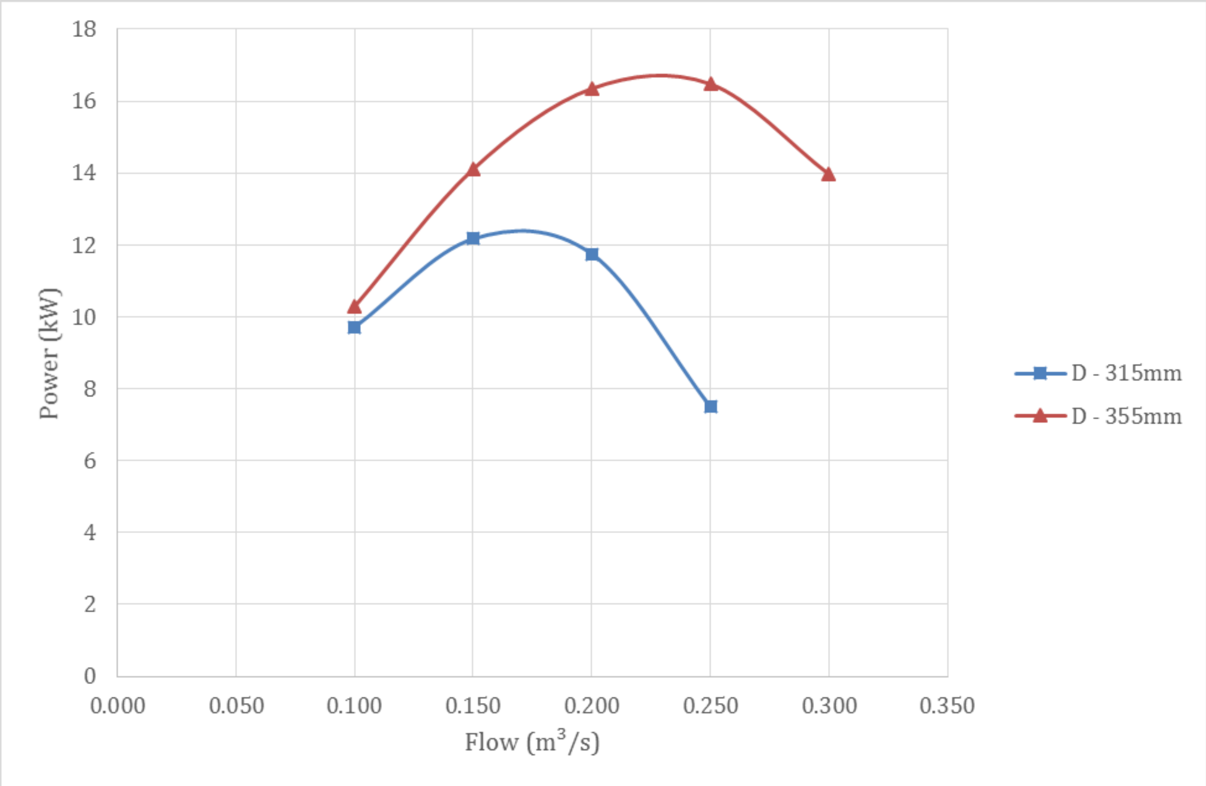


Figure 5-36 - Potential power generation - Mahlaba

The hydraulic analysis was used in the design of the Mahlaba SSHP.

5.2.3.4 Hydropower System Design

Figure 5-37 gives an overall schematic representation of the Mahlaba SSHP, with all the civil components. The design of the individual components are discussed in detail in the sections following.

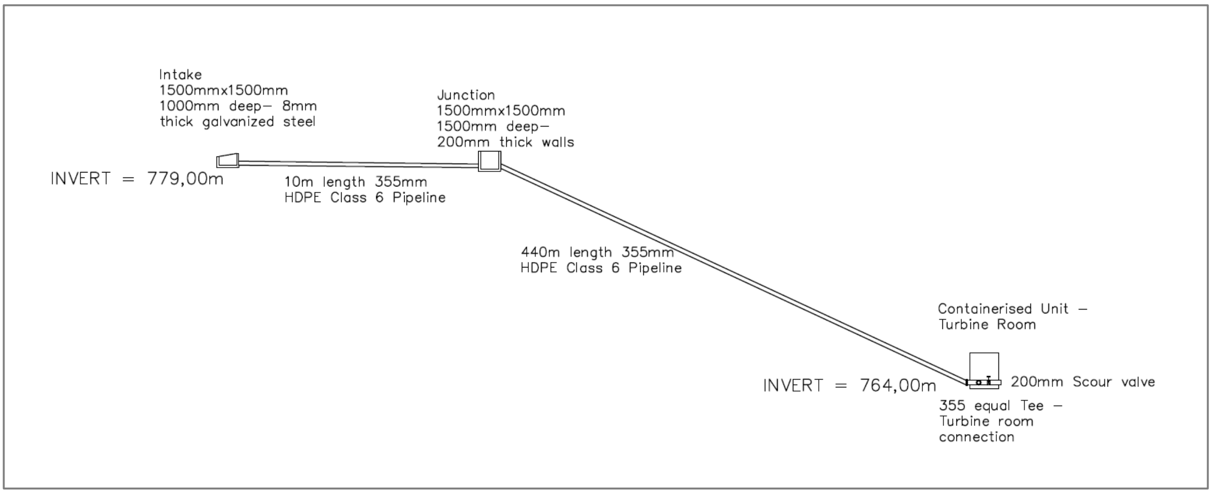


Figure 5-37 - Mahlaba SSHP schematic

Technical data of the Mahlaba SSHP plant is summarized in Table 5-6.

Table 5-6 - Mahlaba SSHP technical data

Design Flow Rate	200 l/s
Design Head	11.9 м
Design Power Output	16.3 kW
Intake invert level	779.00 m
Penstock invert level	778.80 m
Turbine room invert level	764.00 m
Intake pipeline length	10 m
Penstock Length	440 m
Penstock diameter	355 mm
Energy Losses	4.0 m

Intake and Penstock

From Figure 5-34, the intake structure and penstock is constructed from point A to point B. The intake structure consists of an intake, primary screen and cleaning rack at point A, a 10 m 355 mm diameter HDPE (class 6) PN 6.3 pipeline from point A to a junction box at point J (Figure 5-38). At the junction box at point J the intake structure is connected to the penstock. Detailed hydraulic design of the intake structure is shown in Figure 5-39.

Figure 5-38 - Junction Box - Mahlaba SSHP

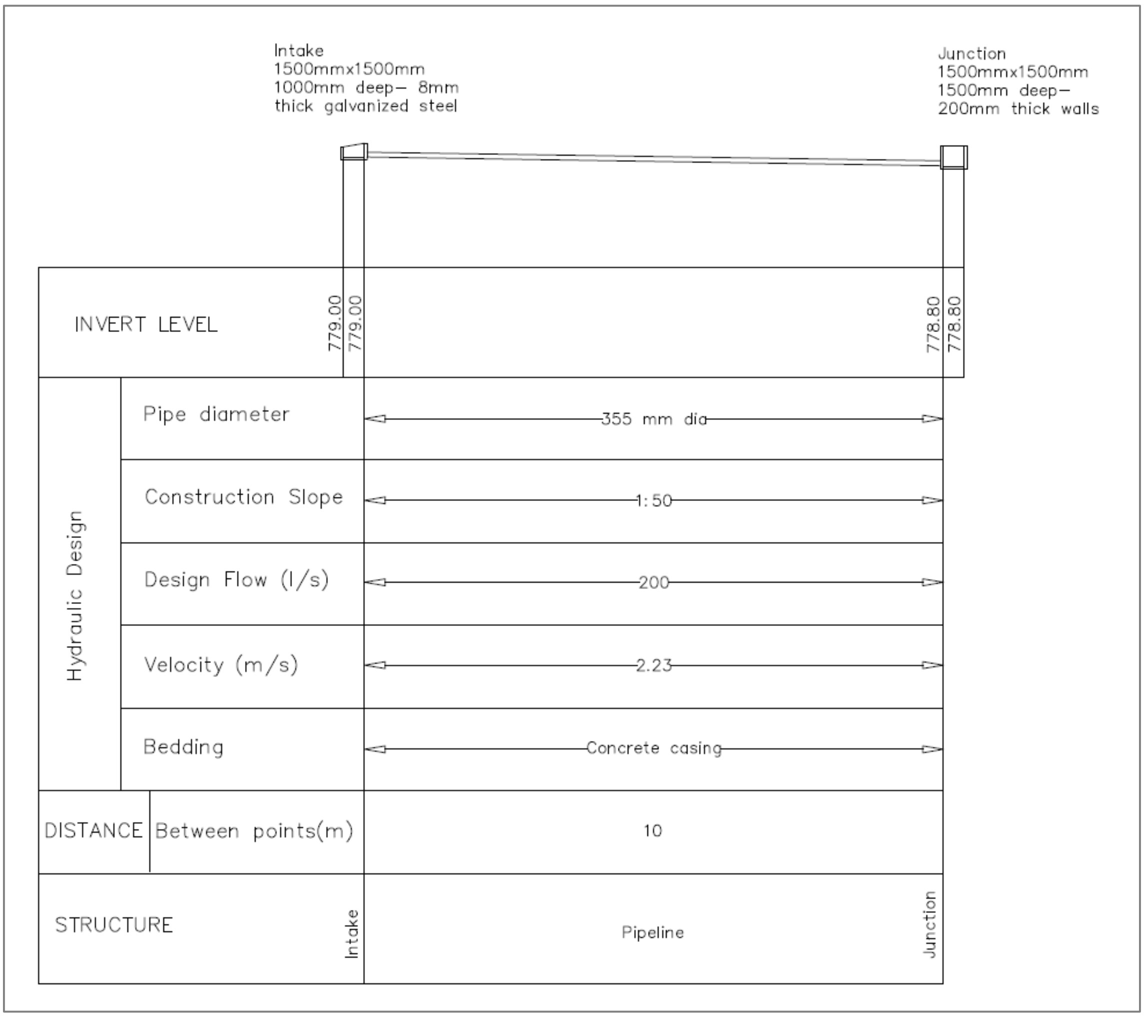


Figure 5-39 - Intake structure design - Mahlaba SSHP

The intake structure will abstract and reroute **200 l/s** as per the design of the SSHP plant at Mahlaba. The energy losses in the intake structure was calculated as **0.08 m**. The invert level of the pipeline from the intake is **779.0 m**. The HDPE pipe is laid at a 2% gradient and has an invert level at the outlet to the junction box of **778.8 m**.

As shown below in Figure 5-40, the penstock is from the junction box at point J to the turbine room inlet at point B. The penstock will convey 200 l/s as per the design of the SSHP plant at Mahlaba. The penstock is design to be constructed by means of directional or rock drilling and consisting of a 440 m length 355 mm diameter HDPE (class 6) PN 6.3 pipe. The invert level of the penstock at the junction box is 778.80 m and the invert at the turbine room connection is 764.0 m. The energy losses in the penstock was calculated as 4.0 m. The detailed hydraulic design of the penstock is shown in Figure 5-41.

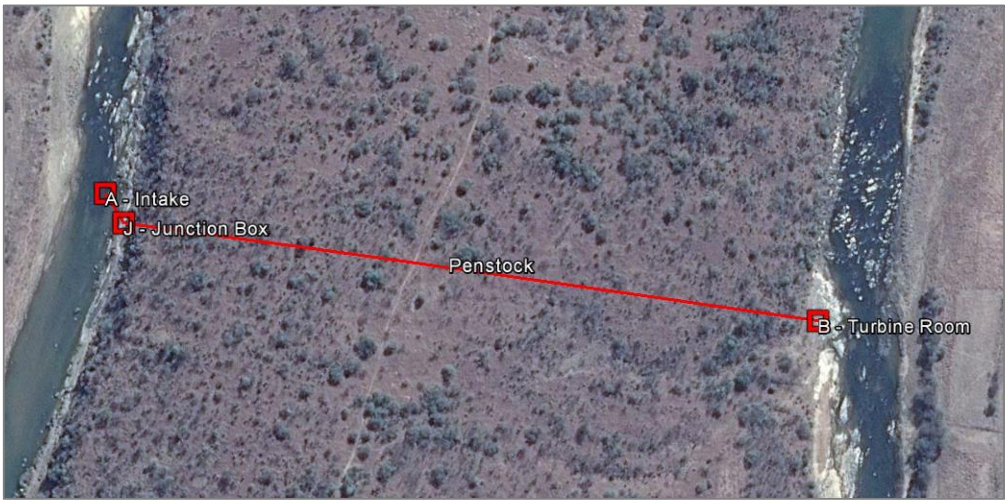


Figure 5-40 - Junction Box and Penstock - Mahlaba SSHP

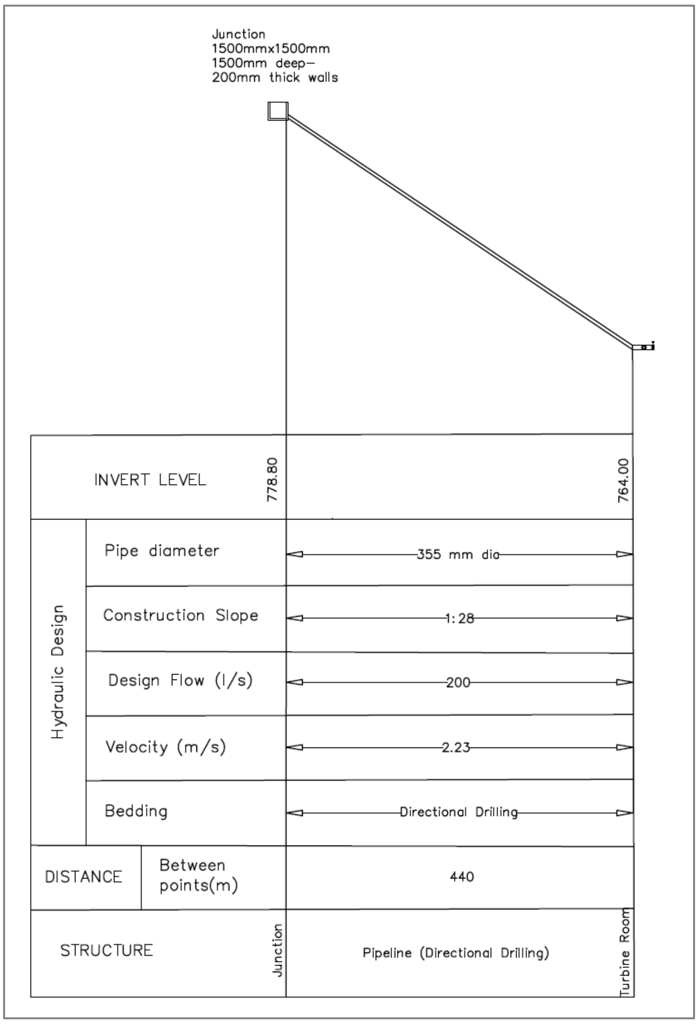


Figure 5-41 - Penstock design - Mahlaba SSHP

<u>Turbine Room</u>

The turbine room for the Mahlaba SSHP is identical to that of the Kwa Madiba SSHP and the Eskweleni SSHP. The turbine room/powerhouse of the Mahlaba SSHP plant is designed as a containerised unit (Figure 5-42). The unit is assembled off-site and transported to site and connected once the penstock and turbine room foundation is completed. The containerised unit reduces overall construction time and eliminates construction restraints in confined and remote locations. The turbine room/powerhouse houses the turbine, generator, controls and regulators of the Mahlaba SSHP plant. At the connection of the penstock to the turbine room the pipeline is fitted with secondary screen to protect the impeller of the turbine against erosion by finer particles which passed the primary screen at the intake structure. The turbine room is designed to be fitted with a scour valve immediately upstream of the containerised unit for maintenance purposes. The scour valve (Figure 5-43) releases directly onto rock which eliminates scouring erosion effects.

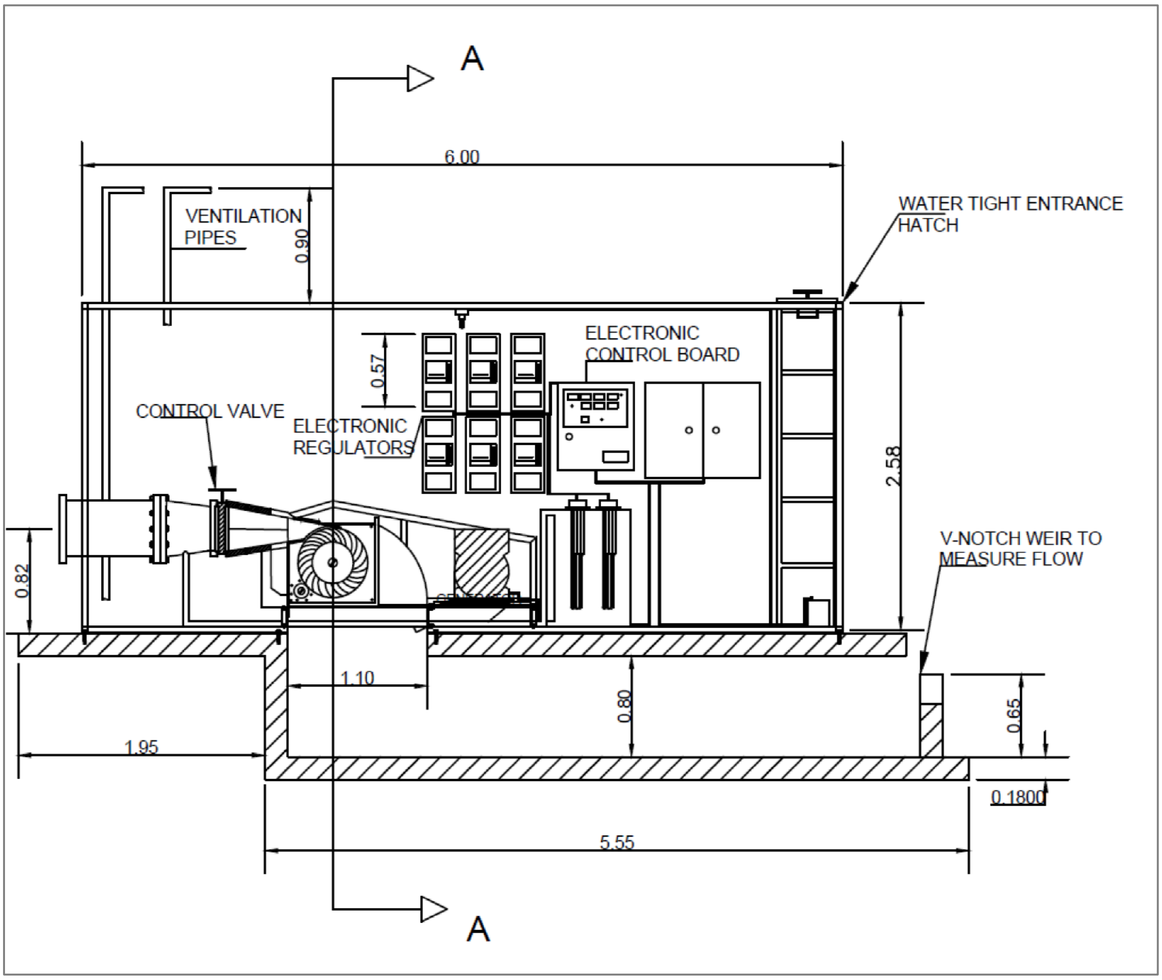


Figure 5-42 - Mahlaba SSHP turbine room/powerhouse - Containerised unit

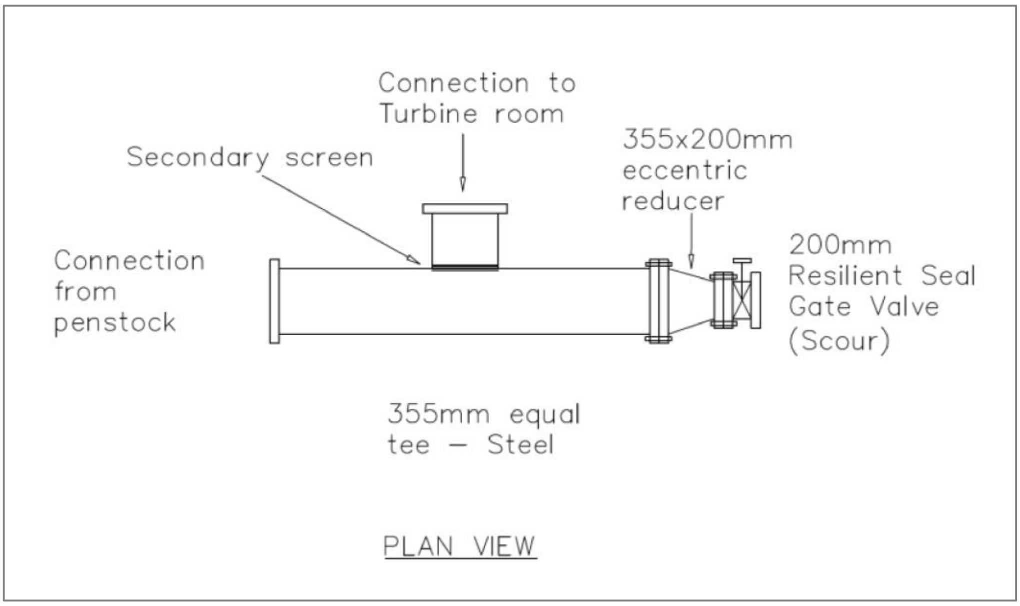


Figure 5-43 - Scour valve - Mahlaba SSHP turbine room

Turbine

The hydroelectric turbine (Figure 5-44), complete with electric distribution board and electronic regulating system supplied by IREM or similar turbine supplier, designed for the Mahlaba SSHP, are as follows:

1) ECOWATT Micro hydroelectric power plant type TBS

Complete with:

- Cross Flow turbine in stainless steel type 4-1
- Synchronous generator type AL15
- Revolution multiplier by cogged driving belt
- Manual flow regulation
- Manual butterfly general valve
- Steel base
- Coupling flange for connection to the penstock

Figure 5-44 - Cross Flow Turbine (Banki) and Synchronous generator (IREM) - Mahlaba SSHP

2) Electronic Regulating System RMP 10.000/B with water dissipation resistances

Complete with:

- Box unit, which include the electronic control board to micro-processor and the power control
- Transient voltage protection (TVP)
- Fuse, which protect the regulator
- LED to indicate the protection failed
- Resistors for dissipation equipped with 10 kW
- Spare parts

3) Technical data:

- Nominal voltage: three/single phase 400/230V 6050Hz
- Generated electric power: P= 16 kW approx.
- Net head axis turbine: H= 15 m
- Flow: Q= 200 l/s

<u>Tailrace</u>

Tailrace construction of the Mahlaba SSHP plant is restricted to the outflow channel within the turbine room. From the turbine room water in the tailrace is released directly onto the rock outcrop on which the containerized turbine room unit is constructed (Figure 5-45). Releasing directly onto the rock surface eliminates any scouring effect from the tailrace and release of the Mahlaba SSHP plant. The SSHP plant is a non-consumptive use of water and therefor the outfall/release from turbine room is equal to the flow at the intake structure, **200 l/s**. The tailrace for both the Kwa Madiba SSHP and Eskweleni SSHP are designed on the same principle as that of the Mahlaba SSHP. Where excessive scouring is found to be present from the operation of the SSHP, a concrete apron or channel or gabion mattresses should be constructed downstream of the turbine room outlet.

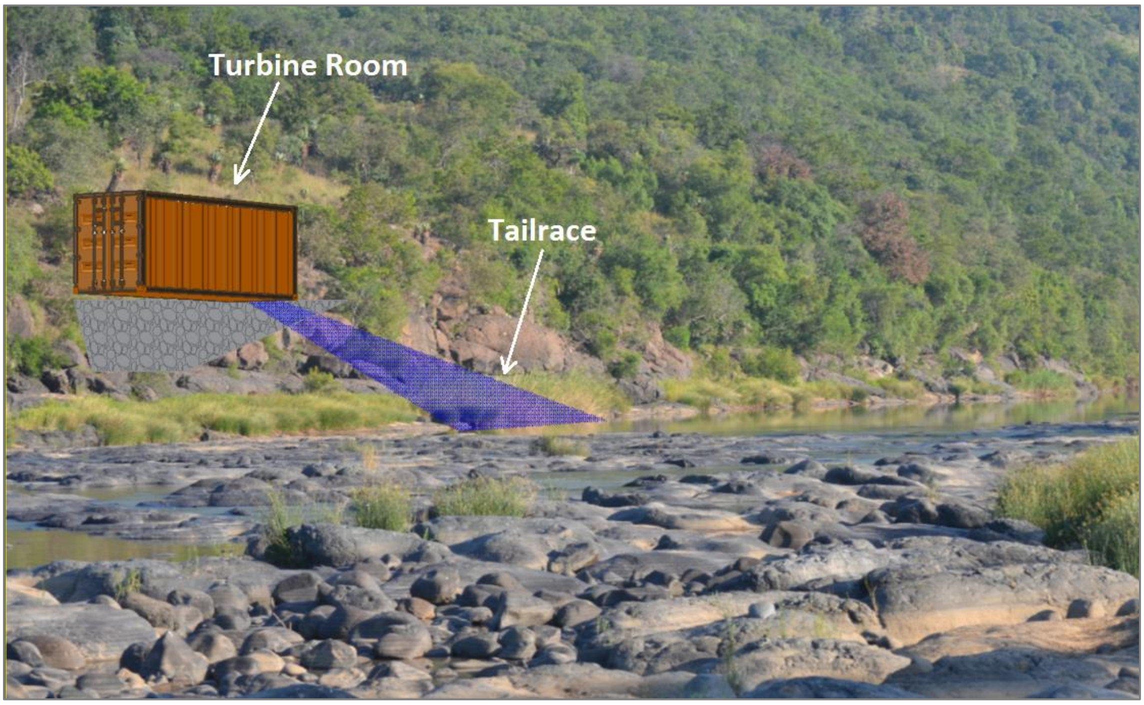


Figure 5-45 - Tailrace location and release - Mahlaba SSHP

5.3 OR TAMBO DM - SSHP DESIGNS

5.3.1 Kwa Madiba SSHP – Thina Falls

5.3.1.1 Site Selection Process

5.3.1.1.1 <u>Hydropower Potential – Thina Falls</u>

For the initial identification of potential sites for small scale hydropower generation within the OR Tambo District Municipality, a desktop study was utilised. The focus of the desktop study was to preliminarily identify sites based solely on potential head available at different individually selected sites.

The different rivers and river sections within the OR Tambo DM were investigated utilizing the Google Earth program. The elevation tool within Google Earth was used to identify height differences within the different rivers which would create head differences suitable for small scale hydropower generation. Height differences were verified by site investigations and physical measurements. Sites with a higher potential head difference initially gained preference over sites with higher flows due to the increase in cost of larger equipment to convey the larger flows.

Figure 5-46 - Thina Falls (1.2 m^3/s) - OR Tambo DM

The geometrical layout of the Thina Falls in the Thina River (Figure 5-46), within the Mhlontlo Local Municipality as well as the relatively high perennial flows within the Thina River offers a feasible opportunity for Small-scale Hydropower development. The total theoretical hydropower generation at Thina Falls, utilizing all the flow present in the river at 95% of the time and incorporating the total height difference between the upstream and downstream levels of the Thina Falls, amounts to 350 kW. This potential reaches megawatts when higher flows are utilized within higher flow periods.

Innovative design using directional drilling (Figure 5-47) to construct the penstock from an upstream intake to a downstream turbine room/powerhouse allows for the rerouting of smaller amounts of flow for hydropower generation while still maintaining the bulk of the flow over the Thina Falls.

Figure 5-47 - Directional Drilling Equipment (Vermeer)

5.3.1.1.2 Rural Electrification – Kwa Madiba

Several site selection parameters, other than potential head and flow, was used to evaluate identified potential small-scale hydropower sites. Parameters included Nearest Rural Settlement, Distance to nearest Rural Settlement, Population of Rural Settlement, Accessibility by vehicle, Electrical Grid Connected and Future Electrical Grid Connectivity, Environmental Impact and Social Impact.

From satellite imagery and a physical site visit, the Kwa Madiba settlement was found to be the nearest rural settlement to the Thina Falls potential hydropower site. The physical distance from the proposed turbine room/powerhouse to the end users was measured as **1 060 m**. The physical site visit also showed no existing electrical infrastructure within Kwa Madiba (Figure 5-48). The 2011 Census showed **117** households within the Kwa Madiba rural settlement, although from the site visit the amount of households seems to be less, approximately **39** households.

Figure 5-48 - Kwa Madiba

Environmentally the Kwa Madiba/Thina Falls potential hydropower site will have a minimal to no impact on the environment due to the fact that only small amounts of flow will be rerouted through the directionally drilled penstock for hydropower generation. Small amounts of flow is sufficient due to the high available head difference at the Thina Falls. The social impact on the community is positive, as the 39 households without electricity previous will be provided with power from the hydro turbine installed downstream of the Thina Falls. The introduction of electricity to the community and the added possibility/opportunity of connecting a pump to the electrical supply for pumping raw water to the community for the irrigation of their crops as subsistence farmers, further uplifts the social standing of Kwa Madiba. Figure 5-49 shows members of the project team on a site visit along with members of the Kwa Madiba community.

Figure 5-49 - Physical site visits – Kwa Madiba

Kwa Madiba passes all the parameters of the proposed site selection criteria, and is an ideal site for the development of Small-scale Hydropower for Rural Electrification.

5.3.1.2 Hydrological Analysis

Hydrological data was obtained from the Department of Water and Sanitation (DWS). The data from the flow gauging station, T3H005 – Mahlungulu (Figure 5-50), in the Thina River upstream of the Thina Falls was used. Flow at Thina Falls was taken as similar to that at T3H005. This is a conservative approach as there are several other tributaries to the Thina River between T3H005 and Thina falls.

Figure 5-50- T3H005 - Mahlungulu

Figure 5-51, Figure 5-52 and Table 5-7 shows a summary and analysis of the historic flow data record for T3H005.

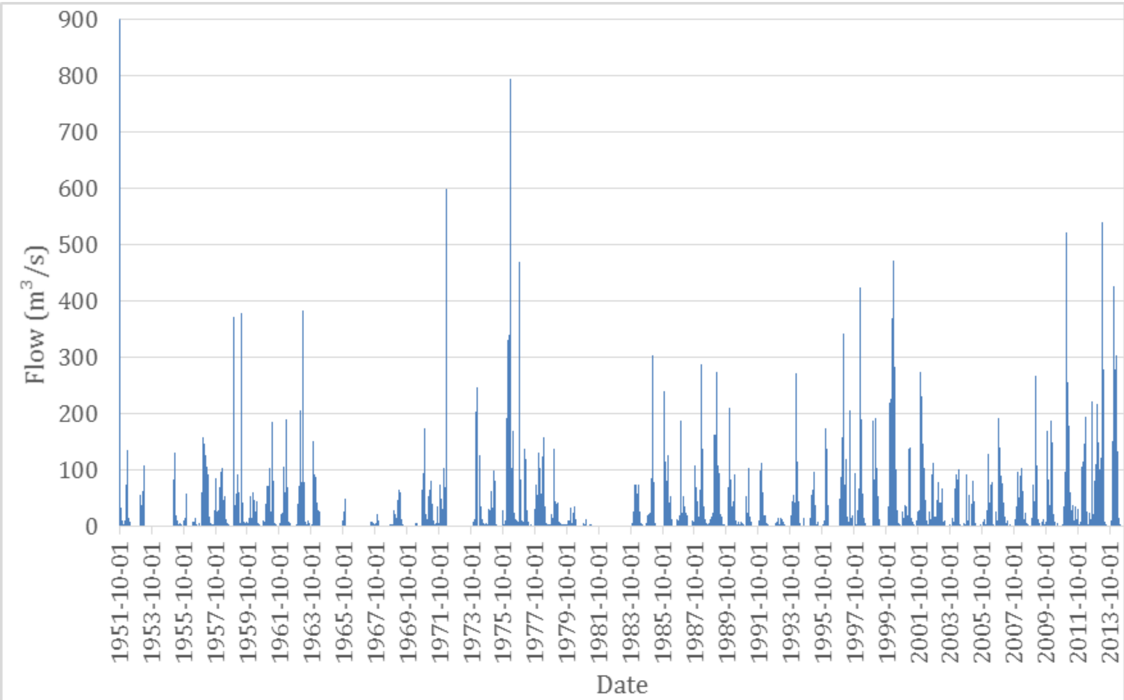


Figure 5-51 – T3H005 – Flow Data Record

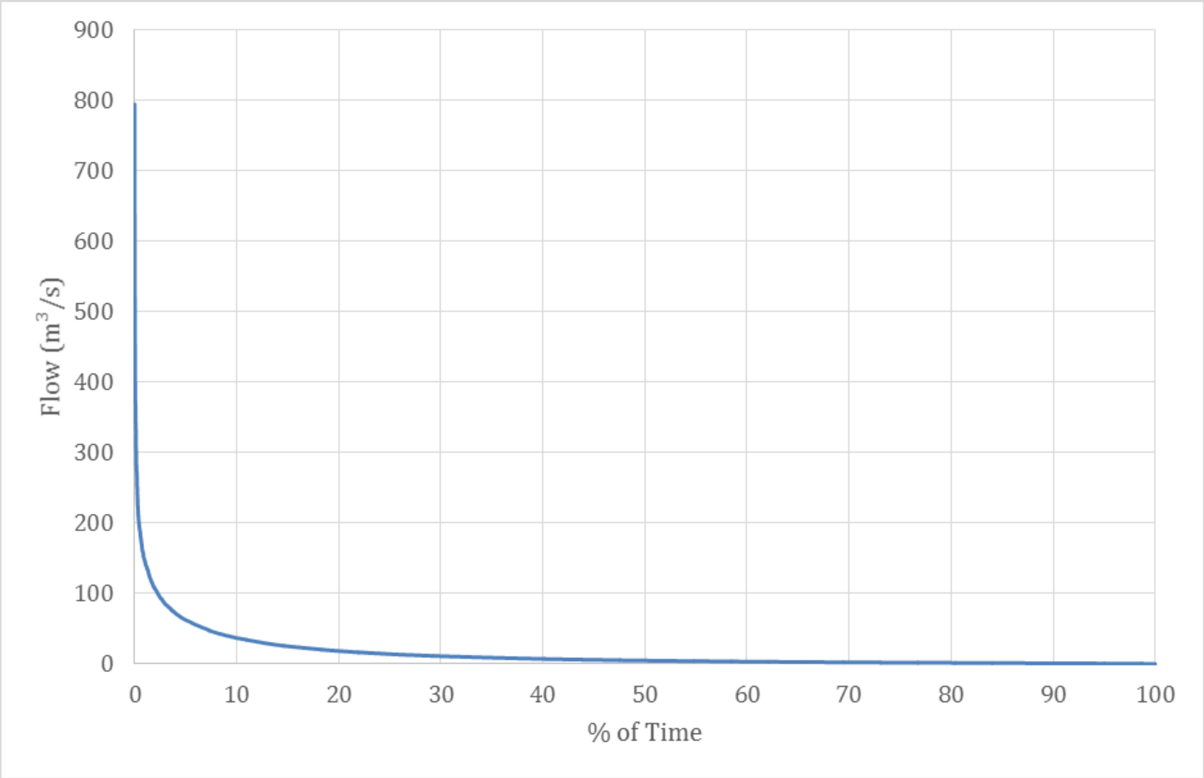


Figure 5-52 – T3H005 - Flow Duration Curve

Table 5-7 - Hydrological Analysis Statistics – T3H005

T3H005	
Mean	14.86
Standard Deviation	30.80
Minimum	-
Maximum	794.73
Flow 95.0% of Time	0.640

From the statistical analysis of the flow data record obtained from the T3H005 (Mahlungulu) gauging station from the DWS, it can be concluded that a flow rate of 640 l/s is present within the Thina River at Thina Falls 95% of the time.

The Utility Programs for Drainage (UPD) software package was used to do flood calculations by means of the Statistical Methods up to the 1:100 flood. The statistical plots for the different statistical methods were analysed and the Log Pearson Type 3 (LP3) distribution was seen to fit the most accurate curve to the historical data plot (Figure 5-53). LP3 was therefor used as the calculated floods for the Thina River at Thina Falls.

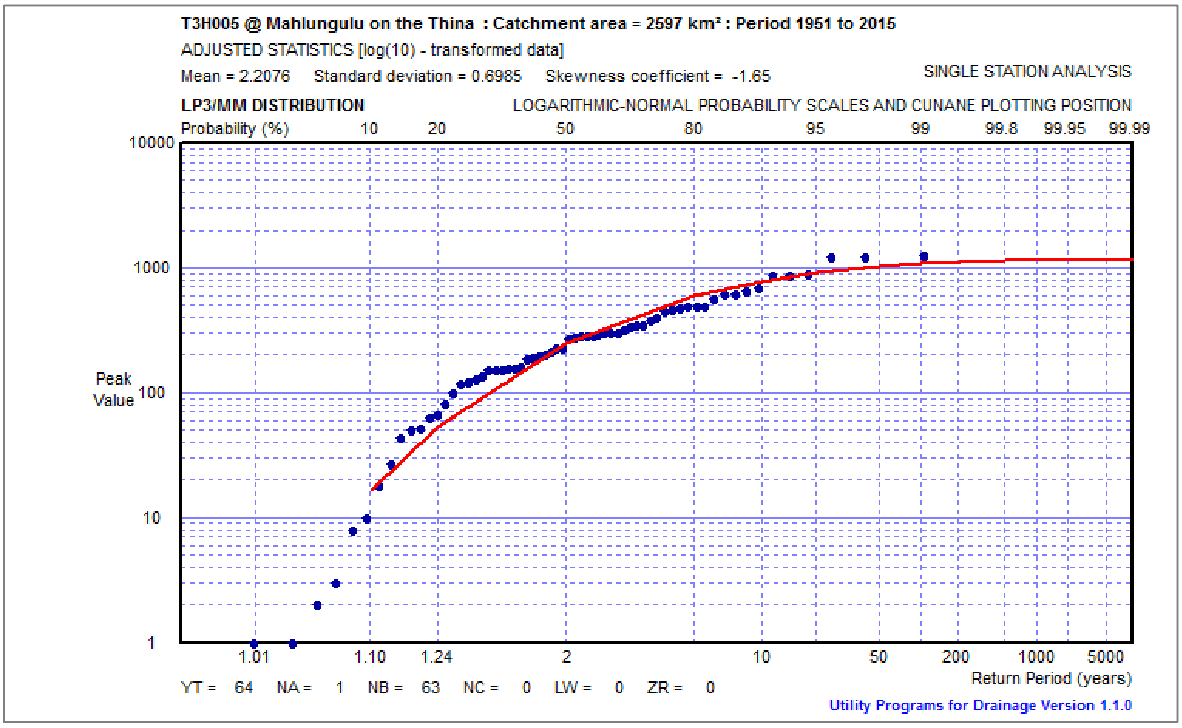


Figure 5-53 - Log Pearson Type 3 - Statistical Plot

The LP3 1:100 flood of 1072 m^3/s was used in the calculation of the safe founding level for the containerised turbine room/powerhouse downstream of Thina Falls. Normal flow depth was assumed downstream of the falls, and calculated by using the slope of the Thina River for a 1 km section, 1.45%, and measuring the average river width within this section of 75 m. River banks were conservatively assumed as vertical. The normal flow depth of the Thina River downstream of Thina Falls for the 1:100 year flood was calculated by using Manning's Equation with an n-value of 0.07 $s/m^{1/3}$ (Chow, 1959). The normal flow depth was calculated as 3.7 m. The position of the containerised turbine room/powerhouse was designed to be placed above this level. The placement and location of the infrastructure will be as such to prevent damage from frequent flooding.

5.3.1.3 Hydraulic Analysis

Measurements from satellite imagery (Google Earth) and physical measurements on site was used in the hydraulic analysis of the preliminary design of the Kwa Madiba SSHP.

Frictional and secondary losses were calculated on the intake structure and penstock using the Karman Prandlt friction equation for turbulent flow. Figure 5-54 indicates the preliminary positions of the intake (A), start of penstock (B) and the powerhouse (C).

Figure 5-54 – Preliminary Site Layout – Kwa Madiba

The intake structure at A consists of a screen with cleaning rack and pipework conveying water from the intake at A to the start of the penstock at B. Pipework from A to B is laid at a 1.5% gradient. From point B water is supplied through the penstock, which is tunnelled, to the powerhouse at position C.

Water levels at point 1 and point 2 (Figure 5-54) were measured on site as 492 m and 440 m respectively. The turbine room/powerhouse at point C is placed 3.7 m above the measured water level at point 2. (Water level was measured during flow rate of 1.2 m^3/s). The available pressure head at point C is **48.3 m** (492 – 440 – 3.7 = 48.3).

Horizontal distances measured from satellite imagery is as follows:

A ⟶ B = 42 m

B ⟶ C = 106 m

From the horizontally measured distances and the gradients the total length of intake and penstock from point A to point C is **158 m**.

Hydraulic analysis was done and frictional and secondary losses determined using the calculated geometrics and by varying the flow between 100 l/s and 200 l/s and the pipe diameter between 200 mm OD and 355 mm OD. Based on the proposed construction method of using directional drilling, the diameter range was limited to the above mentioned 200 mm OD to 355 mm OD. Figure 5-55 displays the calculated energy losses (frictional and secondary) for the different flow and pipe diameter configurations.

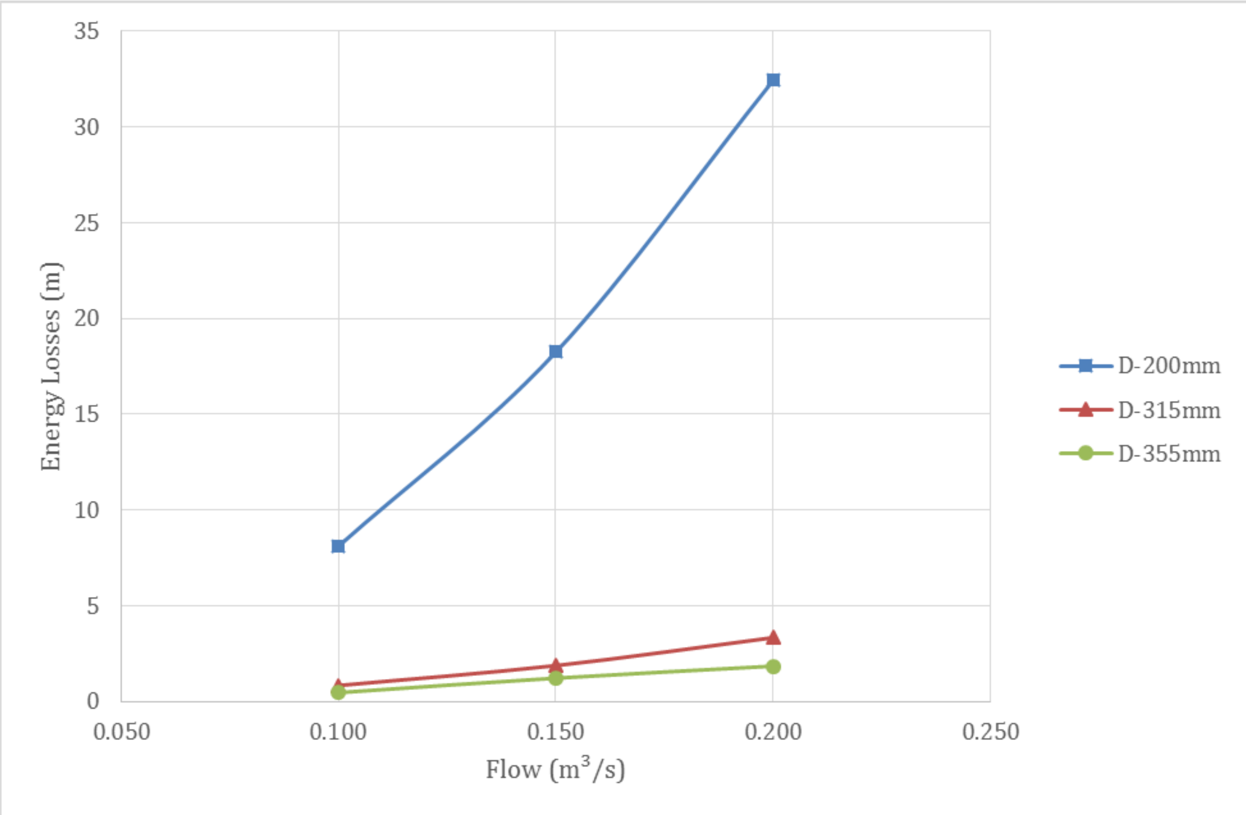


Figure 5-55 - Energy losses – Kwa Madiba

From the analysis of energy losses the power generation potential for the Kwa Madiba SSHP for different configurations of flow rate and pipe diameter sizes were calculated and are given in Figure 5-56.

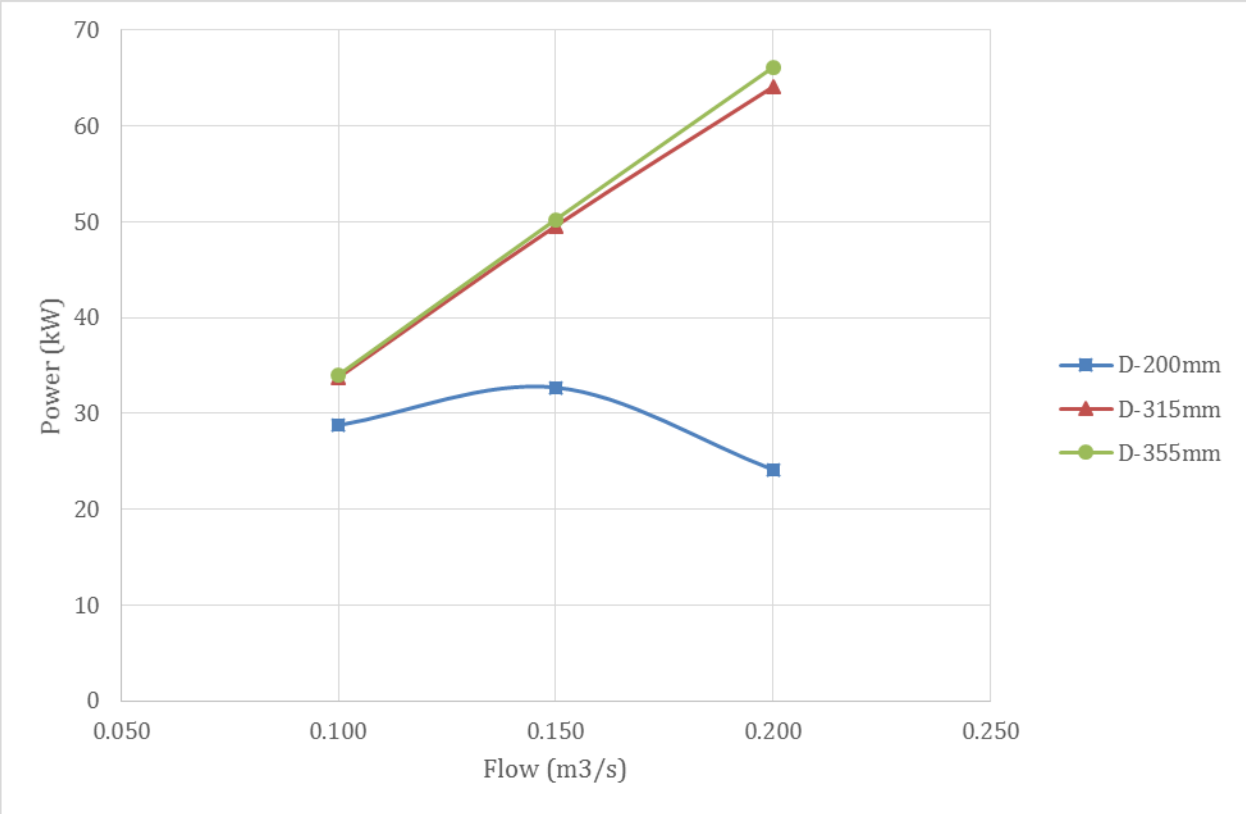


Figure 5-56 - Potential power generation - Kwa Madiba

The 315 mm and 355 mm diameter pipes react similarly, however the 200 mm pipe sees a reduction in power generation form the SSHP from flows higher than 150 l/s.

The hydraulic analysis was used in the preliminary design of the Kwa Madiba SSHP.

5.3.1.4 Hydropower System Design

Figure 5-57 gives an overall schematic representation of the Kwa Madiba SSHP, with all the civil components. The design of the individual components are discussed in detail in the sections following.

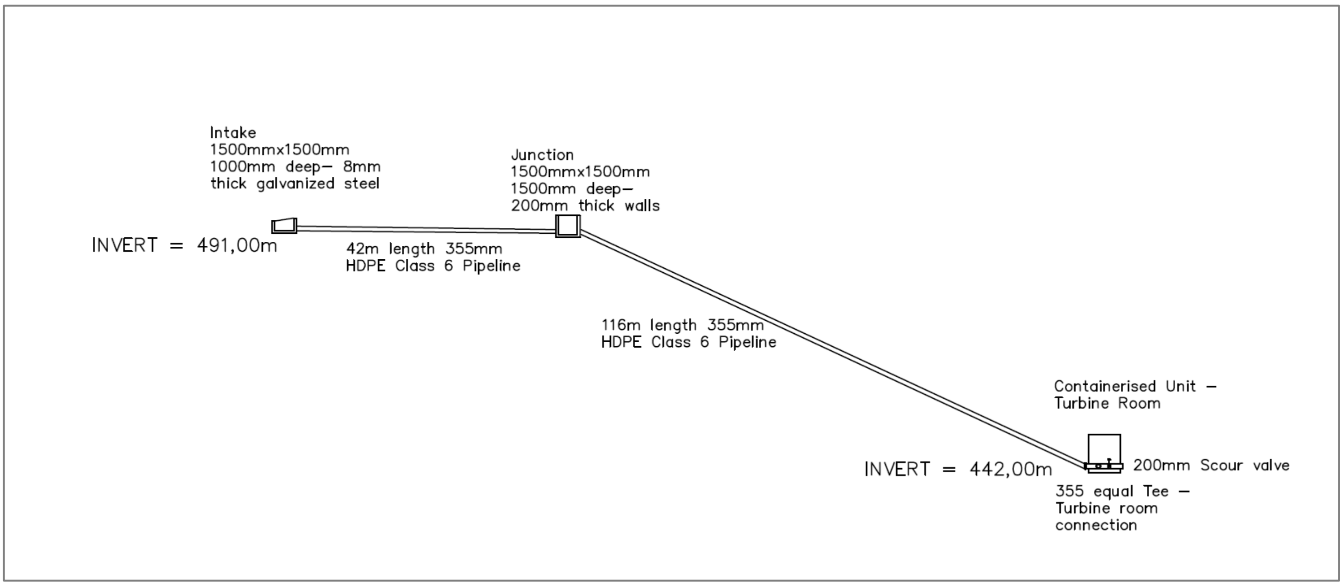


Figure 5-57 - Kwa Madiba SSHP schematic

Technical data of the Kwa Madiba SSHP plant is summarized in Table 5-8.

Table 5-8- Kwa Madiba technical data

Design Flow Rate	150 l/s
Design Head	48.8 м
Design Power Output	50.0 kW
Intake invert level	491.00 m
Penstock invert level	490.32 m
Turbine room invert level	442.00 m
Intake pipeline length	42 m
Penstock Length	116 m
Penstock diameter	355 mm
Energy Losses	1.2 m

Intake

As shown in Figure 5-54 and Figure 5-58, the intake structure is constructed from point A to point B. The intake structure consists of an intake, primary screen and cleaning rack at point A, a **42 m 355 mm** diameter HDPE (class 6) PN 6.3 pipeline from point A to point B, and a junction box at point B. At the junction box at point B the intake structure is connected to the penstock. Detailed hydraulic design of the intake structure is shown in Figure 5-59.

Figure 5-58 - Intake location and layout – Kwa Madiba

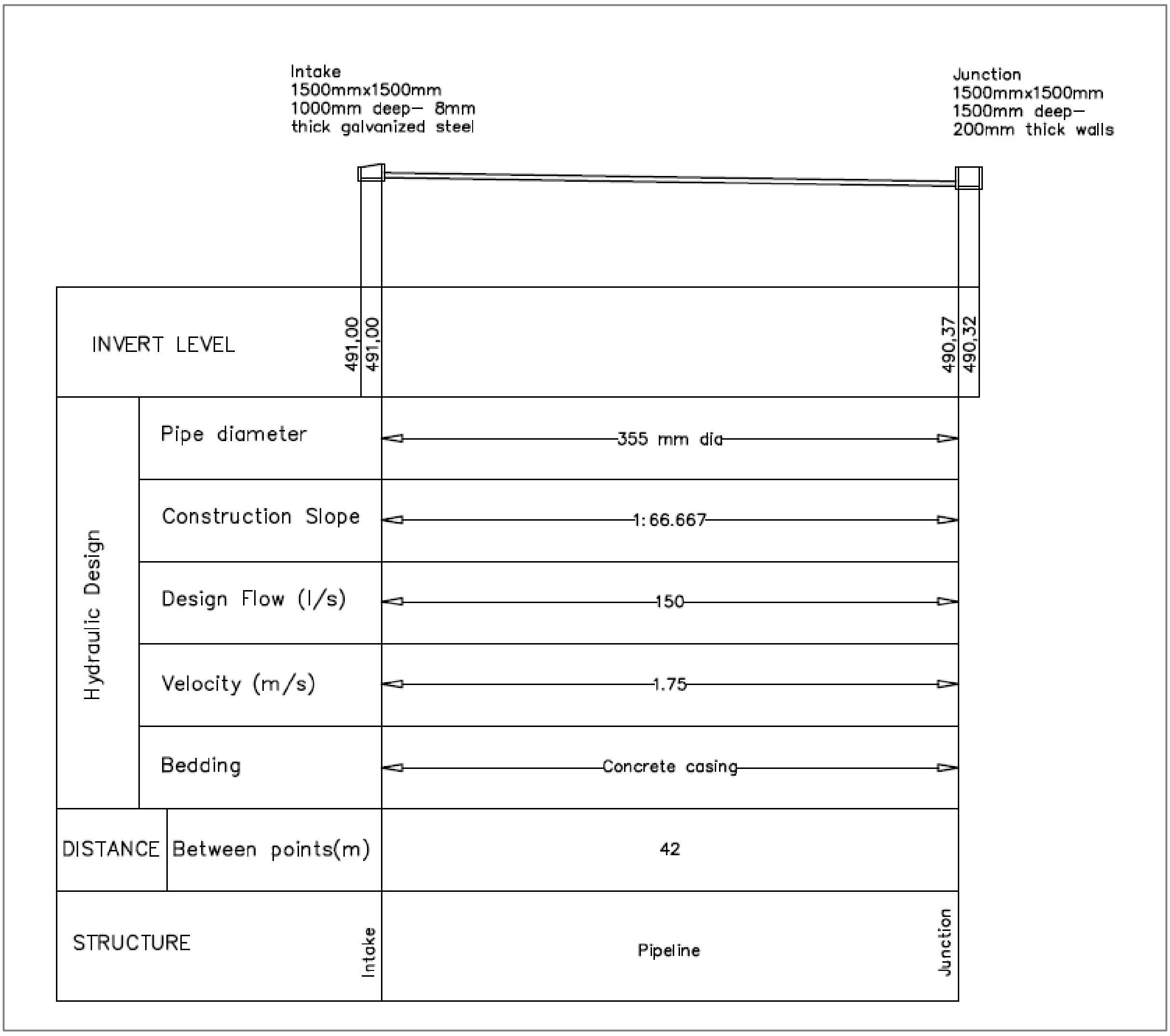


Figure 5-59 – Intake structure design – Kwa Madiba

The intake structure (Figure 5-60) will abstract and reroute **150 l/s** as per the design of the SSHP plant at Kwa Madiba. The energy losses in the intake structure was calculated as **0.38 m**. The invert level of the pipeline from the intake is **491.00 m.** The HDPE pipe is laid at a **1.5%** gradient and has an invert level at the outlet to the junction box of **490.37 m**.

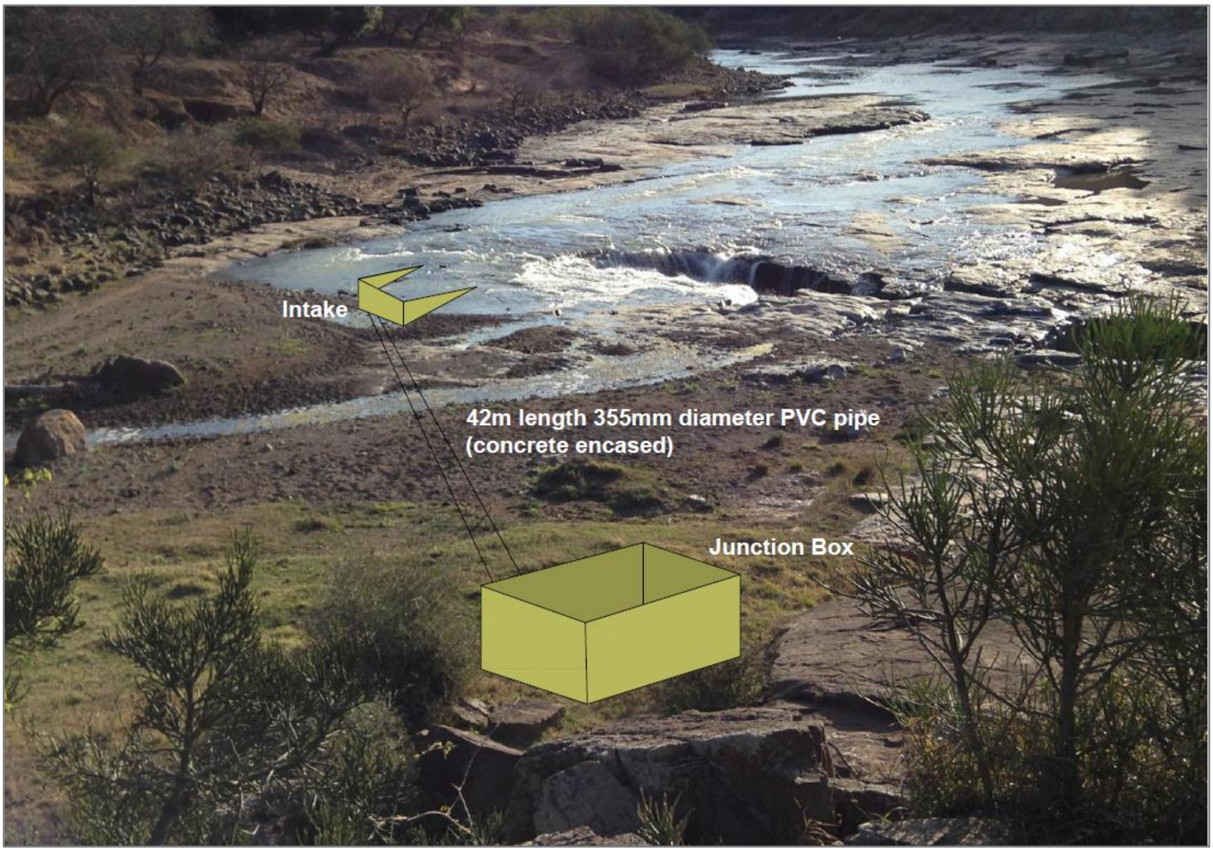


Figure 5-60 - Intake structure schematic – Kwa Madiba

Penstock

As shown in Figure 5-54, the penstock is from the junction box at point B to the turbine room inlet at point C. The penstock will convey **150 l/s** as per the design of the SSHP plant at Kwa Madiba. The penstock is design to be constructed by means of directional drilling, and consisting of a **116 m** length **355 mm** diameter HDPE (class 6) PN 6.3 pipe. The invert level of the penstock at the junction box is **490.32 m** and the invert at the turbine room connection is **442.00 m**. The energy losses in the penstock was calculated as **0.66 m**. The detailed hydraulic design of the penstock is shown in Figure 5-61.

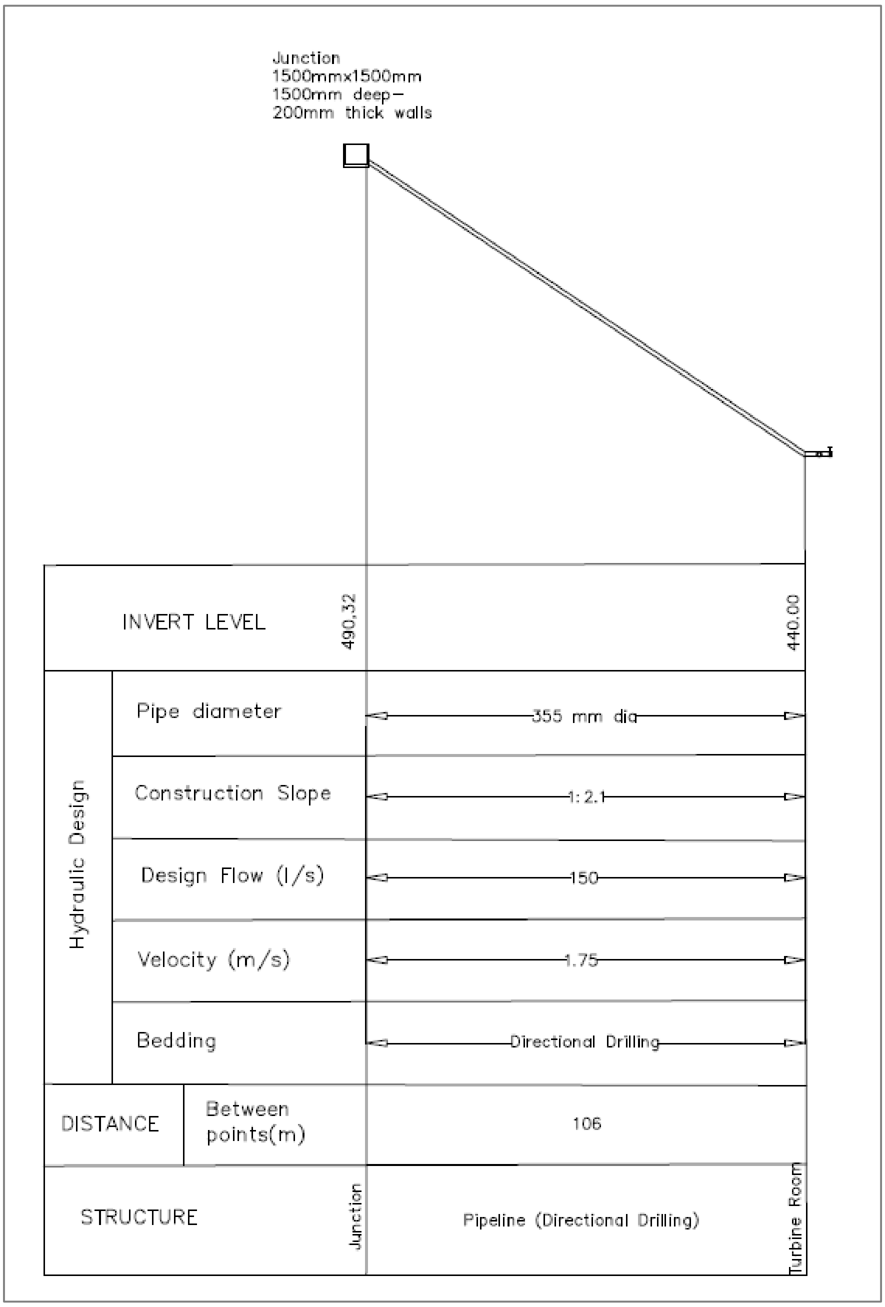


Figure 5-61 - Penstock design – Kwa Madiba

Turbine Room

The turbine room/powerhouse of the Kwa Madiba SSHP plant is designed as a containerised unit (Figure 5-62 and Figure 5-63). The unit is assembled off-site and transported to site and connected once the penstock and turbine room foundation is completed. The containerised unit reduces overall construction time and eliminates construction restraints in confined and remote locations. The turbine room/powerhouse houses the turbine, generator, controls and regulators of the Kwa Madiba SSHP plant. At the connection of the penstock to the turbine room the pipeline is fitted with secondary screen to protect the impeller of the turbine against erosion by finer particles which passed the primary screen at the intake structure.

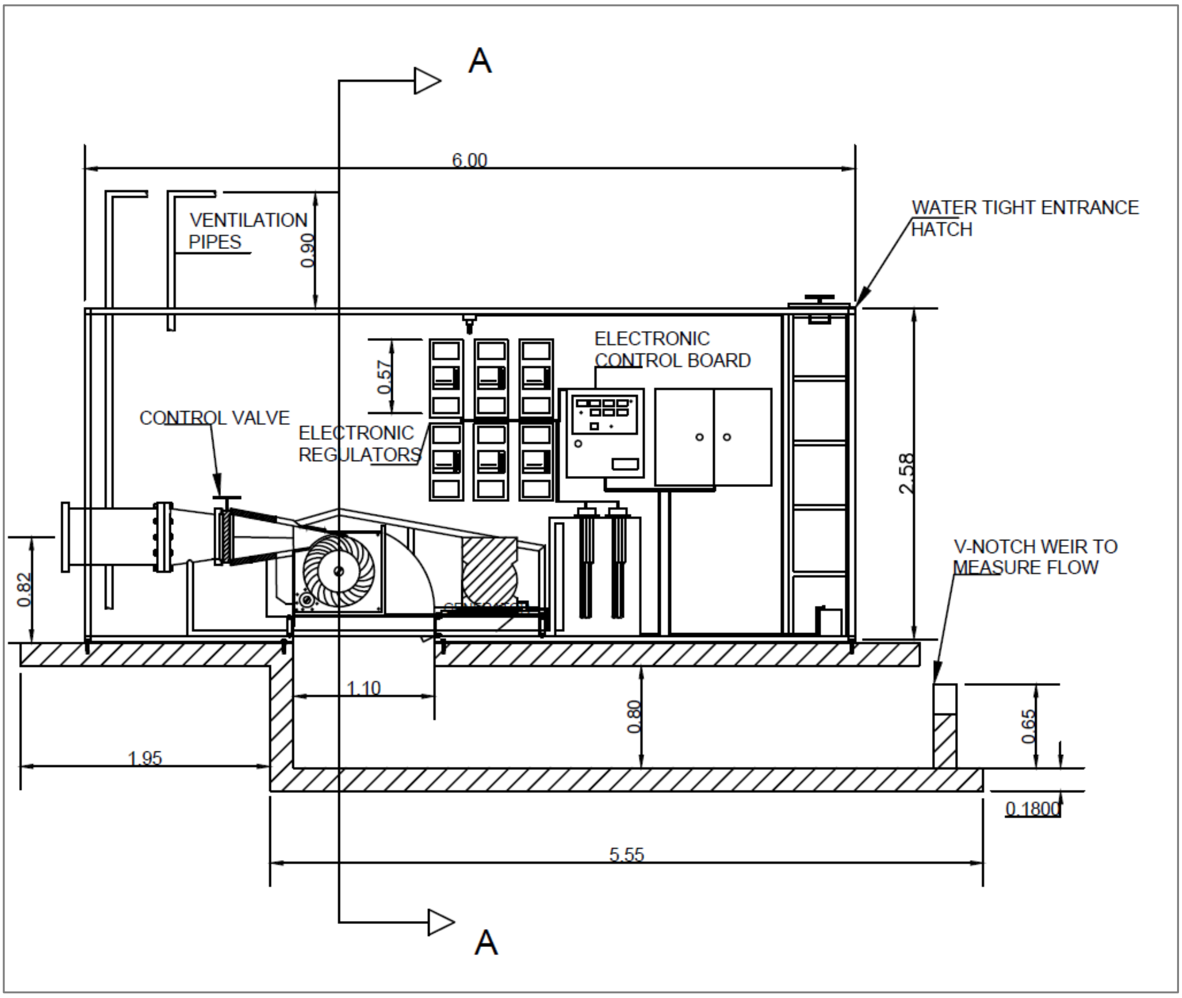


Figure 5-62 - Kwa Madiba turbine room/powerhouse - Containerised unit - Primary View

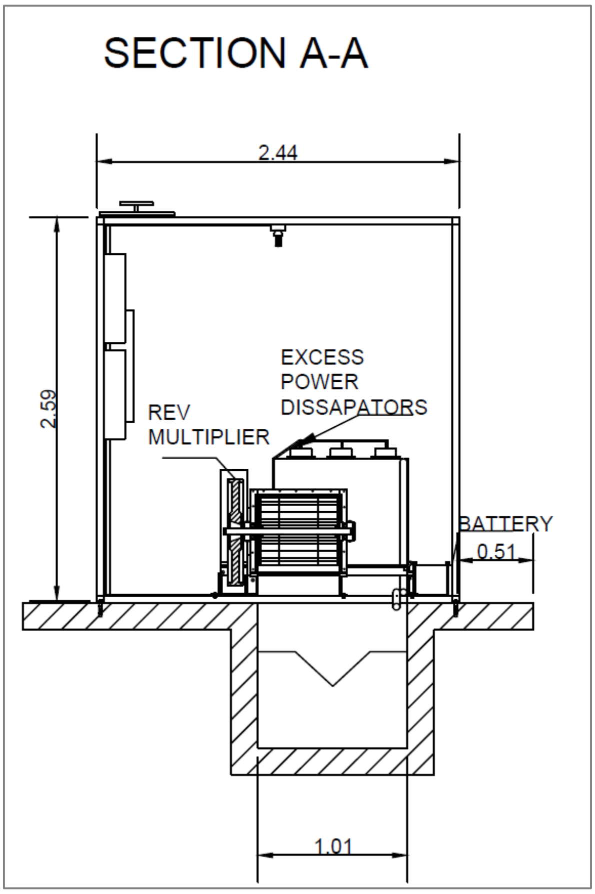


Figure 5-63 - Kwa Madiba - Containerised unit - Section A-A

The turbine room is designed to be fitted with a scour valve immediately upstream of the containerised unit for maintenance purposes. The scour valve (Figure 5-64) releases directly onto rock which eliminates scouring erosion effects.

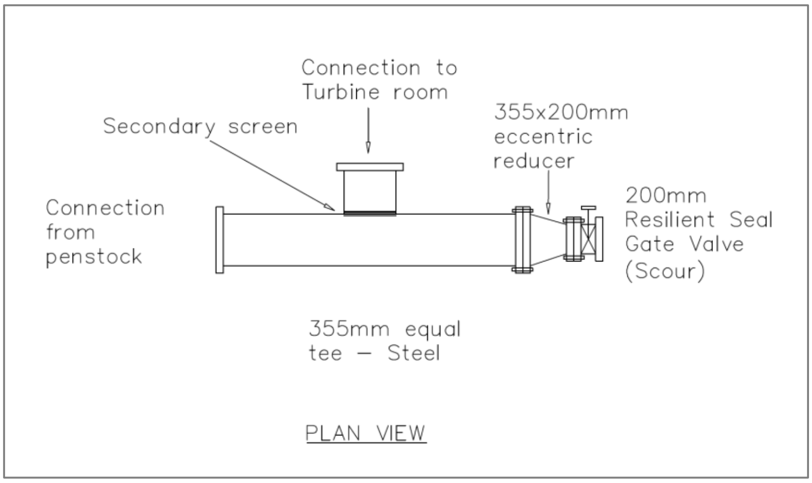


Figure 5-64 – Scour valve – Kwa Madiba turbine room

Turbine

The hydroelectric turbine (Figure 5-65), complete with electric distribution board and electronic regulating system supplied by IREM or similar turbine supplier, designed for the Kwa Madiba SSHP, are as follows:

1) ECOWATT Micro hydroelectric power plant type TBS 2

Complete with:

- Cross Flow turbine in stainless steel type 4-0.5
- Synchronous generator type AS60
- Revolution multiplier by cogged driving belt
- Manual flow regulation
- Manual butterfly general valve
- Steel base
- Coupling flange for connection to the penstock

Figure 5-65 – Cross Flow Turbine (Banki) and Synchronous generator (IREM) – Kwa Madiba

2) Electronic Regulating System RMP 10.000/B with water dissipation resistances similar to that of the Mahlaba SSHP plant.

3) Technical data:

- Nominal voltage: three/single phase 400/230V 6050Hz
- Generated electric power: P= 50 kW approx.
- Net head axis turbine: H= 49 m
- Flow: Q= 150 l/s

Tailrace

Tailrace construction of the Kwa Madiba SSHP plant is restricted to the outflow channel within the turbine room. From the turbine room water in the tailrace is released directly onto the rock outcrop on which the containerized turbine room unit is constructed (Figure 5-66). Releasing directly onto the rock surface eliminates any scouring effect from the tailrace and release of the Kwa Madiba SSHP plant. The SSHP plant is a non-consumptive use of water and therefor the outfall/release from turbine room is equal to the flow at the intake structure, **150 l/s**.

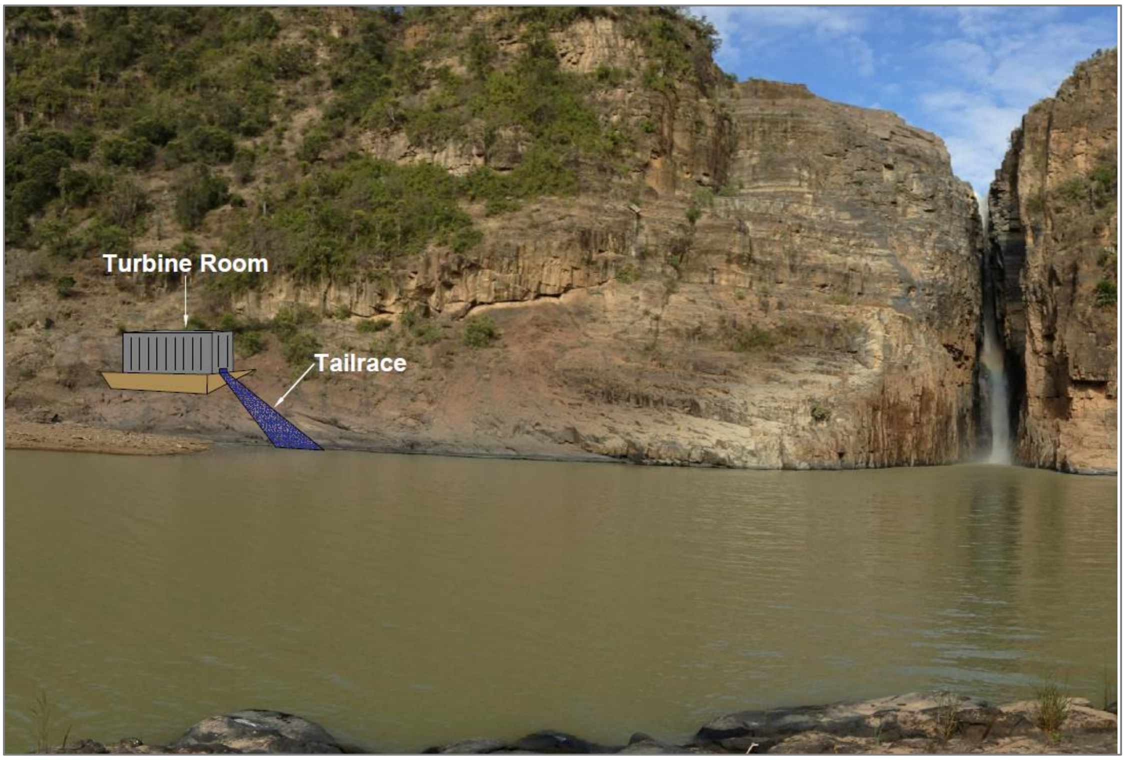


Figure 5-66 - Tailrace location and release

Electrical Mini-Grid

The electrical transmission and distribution lines for the stand-alone mini-grid for the Kwa Madiba Settlement as has been designed, complete with overhead lines, poles and pole mounted transformers, is shown in Figure 5-67.

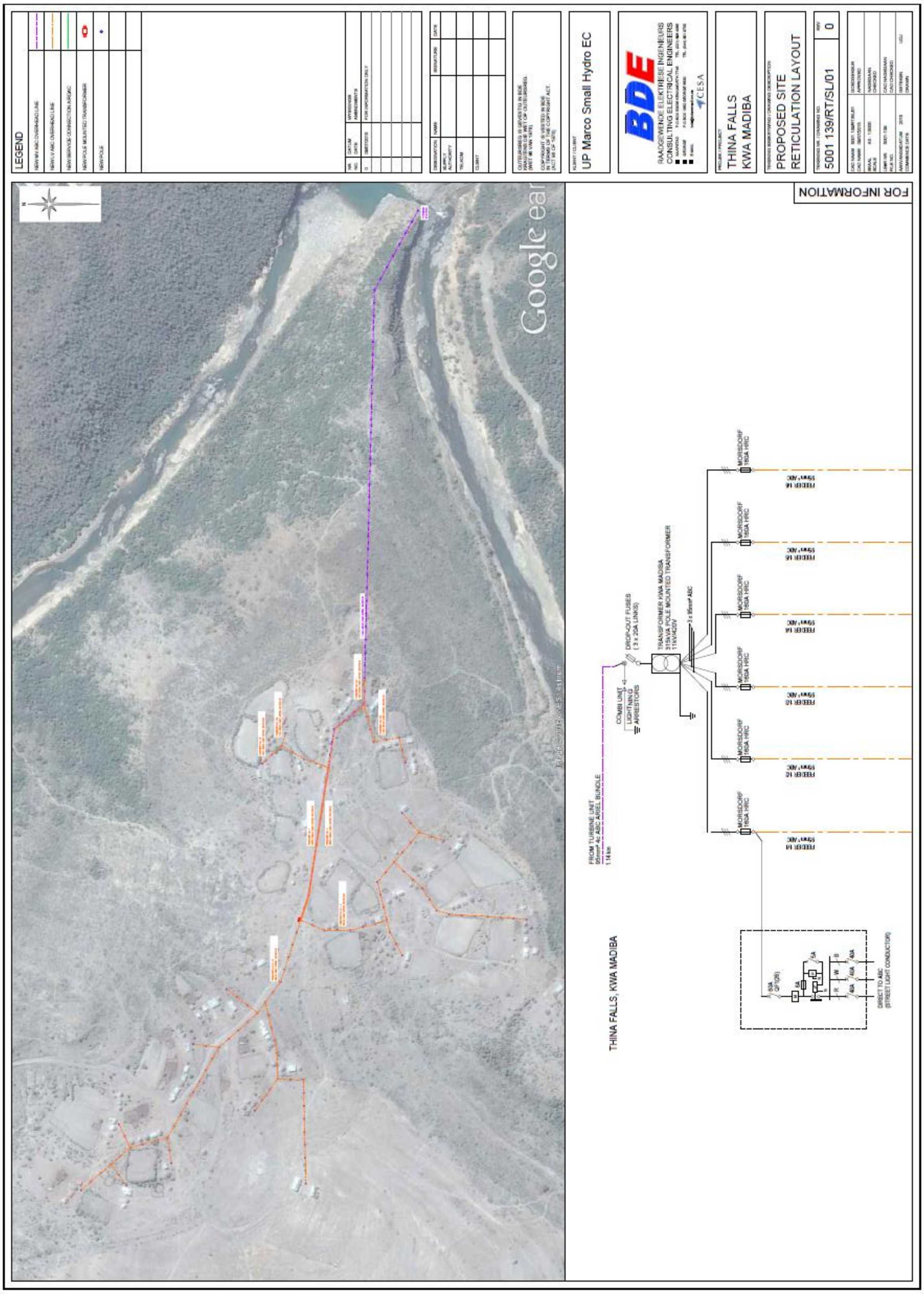


Figure 5-67 - Electrical Transmission and Distribution – Kwa Madiba SSHP

5.3.2 Eskweleni SSHP

5.3.2.1 Site Selection Process

5.3.2.1.1 Hydropower Potential – Mthatha River at Eskweleni

Similar to the Kwa Madiba SSHP, for the initial identification of potential sites for small scale hydropower generation, a desktop study was utilised. The focus of the desktop study was to preliminarily identify sites based solely on potential head available at different individually selected sites. Focus was placed on the perennial rivers with historical flow data records from DWS. Several potential sites within the Mthatha River were investigated. The desktop study showed a potential head difference in the Mthatha River at Eskweleni, within the Nyandeni Local Municipality, of 42 m. This potential head is achieved by the same innovative design as present within the Kwa Madiba SSHP design. From the use of directional or rock drilling, small quantities of flow can be rerouted to "take a shortcut" through a hill within a meandering river (Figure 5-68). From a physical site visit and measurements, the potential head in the Mthatha River at Eskweleni (Figure 5-69) was confirmed as between 35 and 40 m.

Figure 5-68 - Flow rerouting - Meandering Mthatha River

Figure 5-69 - Mthatha River at Eskweleni

The total theoretical hydropower generation at Eskweleni, utilizing all the flow present in the river at 95% of the time and incorporating the total height difference of 40 m, amounts to 140 kW. The potential power increases as the flow within the Mthatha River at Eskweleni increases.

5.3.2.1.2 Rural Electrification – Eskweleni

Several site selection parameters, other than potential head and flow, was used to evaluate identified potential small-scale hydropower sites the same as in the case of the previous and following SSHP sites. Parameters included Nearest Rural Settlement, Distance to nearest Rural Settlement, Population of Rural Settlement, Accessibility by vehicle, Electrical Grid Connected and Future Electrical Grid Connectivity, Environmental Impact and Social Impact.

From satellite imagery and a site visit the physical distance from the proposed turbine room/powerhouse to the end users was measured as **1 764 m**. The physical site visit showed some existing electrical infrastructure close to the Eskweleni settlement (Figure 5-70), although not all households in the region are connected to the local or national electricity grid. The 2011 Census showed **52** households within the Eskweleni rural settlement, from the satellite imagery and site visit the amount of households seems to correlate with the census data and was counted as in the range of 50 to 60 households.

Figure 5-70 - Eskweleni

Accessibility to the settlement of Eskweleni was found to be relatively good with regards to inspection and construction vehicles. Access to the river sections for intake and turbine room construction is only by footpaths and construction of the proposed SSHP could become troublesome for this reason. The proposed intake and turbine room sites however are not far from the existing access to the Eskweleni settlement and proper temporary access could be constructed to the intake as well as the turbine room location.

5.3.2.2 Hydrological Analysis

Hydrological data was obtained from the Department of Water and Sanitation (DWS). The data from the flow gauging station, T2H002 – Norwood in the Mthatha River upstream of Eskweleni was used. Flow at Eskweleni was taken as similar to that at T2H002.

Figure 5-71, Figure 5-72 and Table 5-9 shows a summary and analysis of the historic flow data record for V3H010.

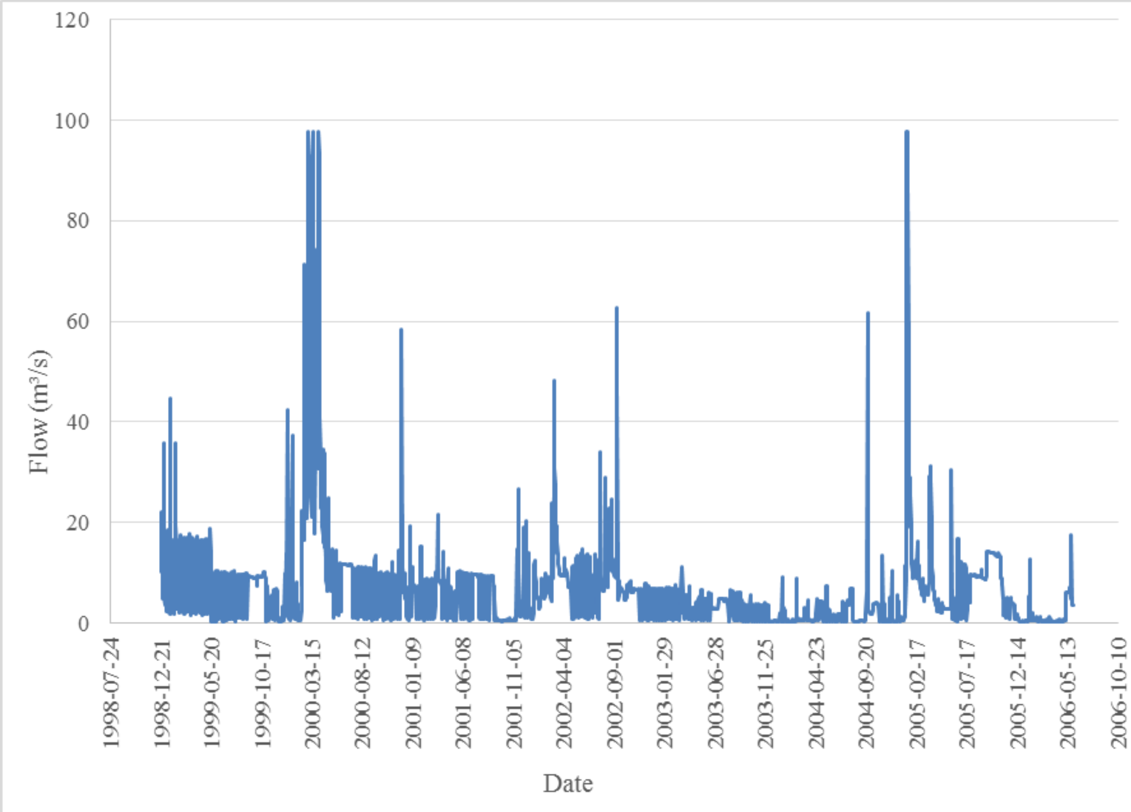


Figure 5-71 - T2H002 - Flow Data Record

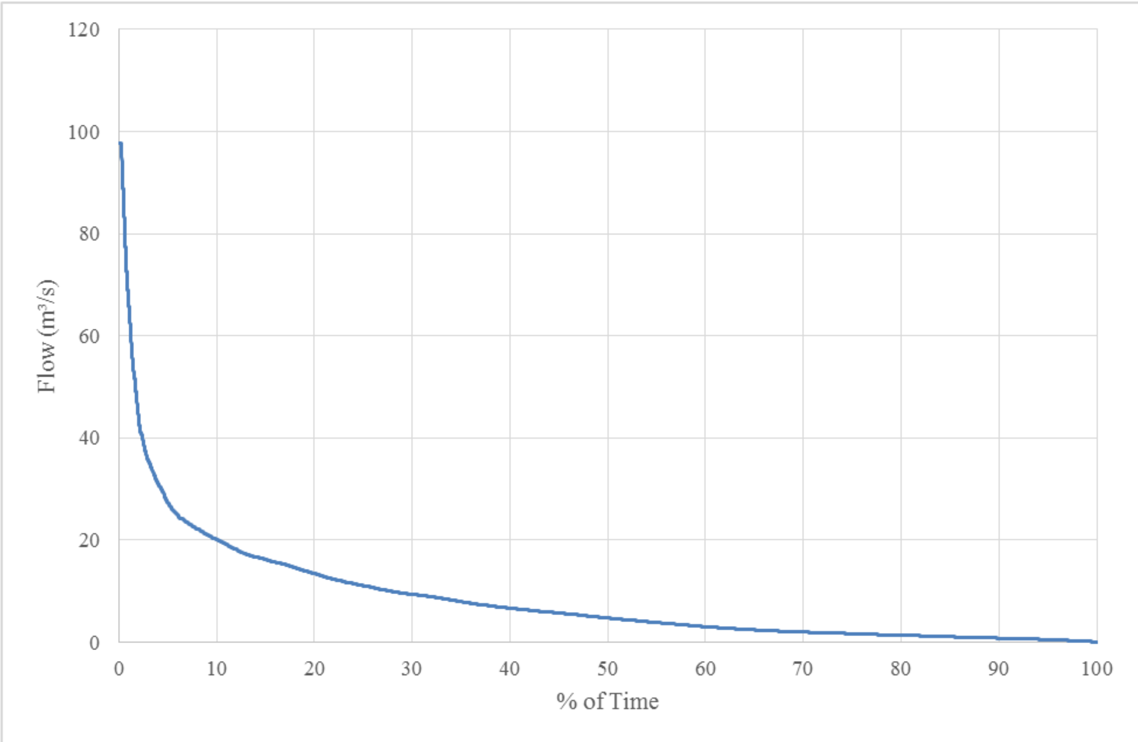


Figure 5-72 – T2H002 - Flow Duration Curve

Table 5-9 - Hydrological Analysis Statistics – T2H002

Statistics	
Mean (m^3/s)	8.64
Standard Deviation (m^3/s)	11.94
Minimum (m^3/s)	0.00
Maximum (m^3/s)	97.71
Count	16 693
Flow 95.0% of Time	0.512

From the statistical analysis of the flow data record obtained from the T2H002 (Norwood) gauging station from the DWS, it can be concluded that a flow rate of 512 l/s is present within the Mthatha River at Eskweleni 95% of the time.

The Utility Programs for Drainage (UPD) software package was used to do flood calculations by means of the Statistical Methods up to the 1:100 flood. The statistical plots for the different statistical methods were analysed and the Log Pearson Type 3 (LP3) distribution was seen to fit the most accurate curve to the historical data plot (Figure 5-73). LP3 was therefor used as the calculated floods for the Mthatha River at Eskweleni.

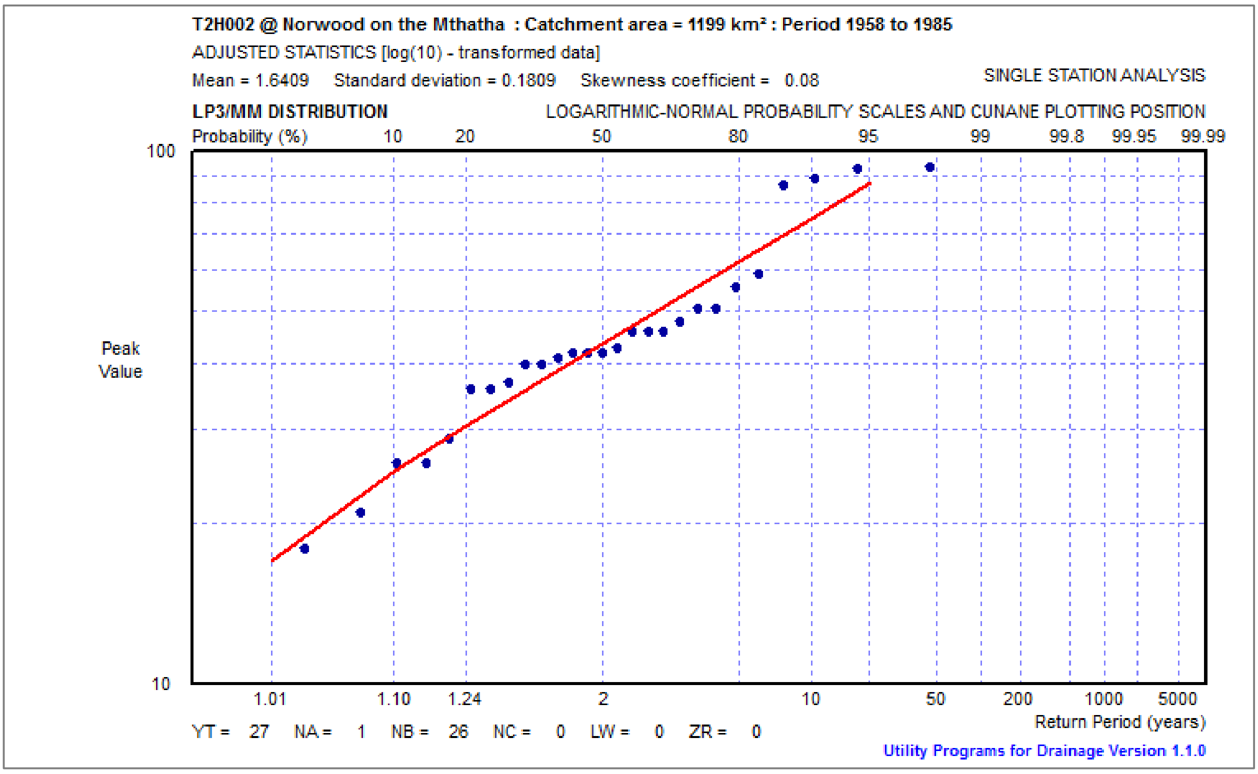


Figure 5-73 - Log Pearson Type 3 - Statistical Plot

The LP3 1:100 flood of 118 m^3/s was used in the calculation of the safe founding level for the containerised turbine room/powerhouse on the Mthatha River at Eskweleni. Normal flow depth was assumed downstream of the intake at the turbine room, and calculated by using the slope of the Mthatha

River for a 1 km section, 1.5%, and measuring the average river width within this section of 65 m. River banks were conservatively assumed as vertical. The normal flow depth of the Mthatha River downstream of intake for the 1:100 year flood was calculated by using Manning's Equation with an n-value of 0.06 $s/m^{1/3}$ (Chow, 1959). The normal flow depth was calculated as 0.7 m. The position of the containerised turbine room/powerhouse was designed to be placed above this level. The placement and location of the infrastructure will be as such to prevent damage from frequent flooding.

5.3.2.3 Hydraulic Analysis

Measurements from satellite imagery (Google Earth) and physical measurements on site was used in the hydraulic analysis of the design of the Eskweleni SSHP.

Frictional and secondary losses were calculated on the intake structure and penstock using the Karman Prandlt friction equation for turbulent flow. Figure 5-74 indicates the preliminary positions of the intake and start of penstock (A) and the powerhouse (B).

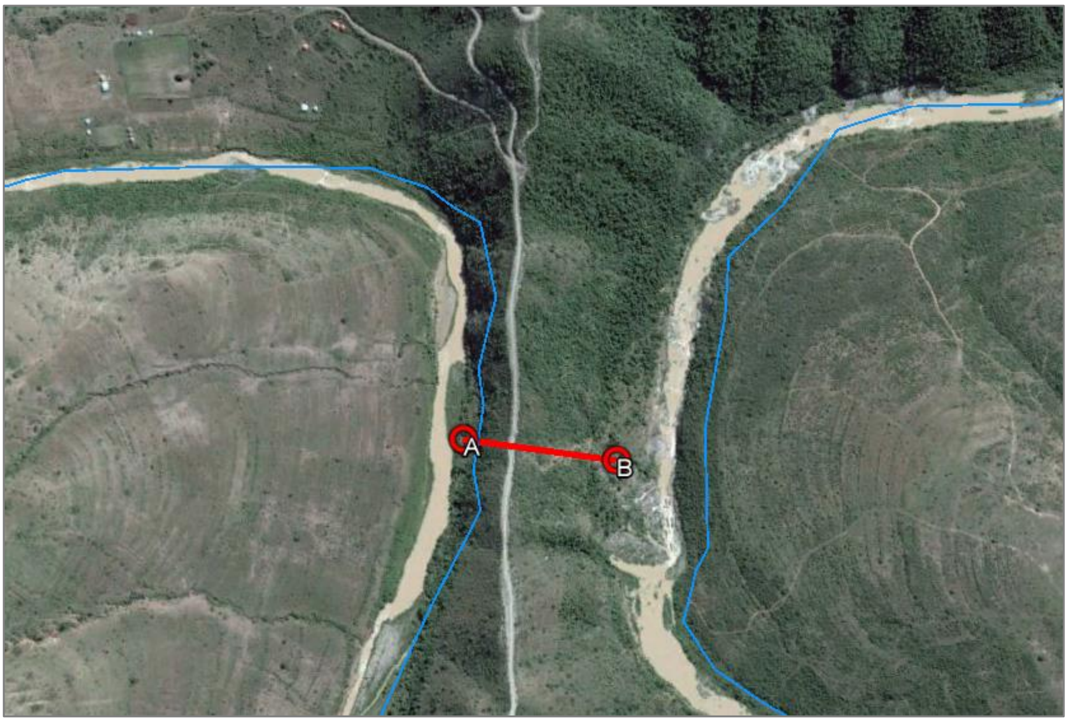


Figure 5-74 - Preliminary Site Layout - Eskweleni

The intake structure at A consists of a screen with cleaning rack and pipework conveying water from the intake through the start of the penstock to the turbine room at B. From the intake at point A water is supplied through the penstock, which is tunnelled, to the powerhouse at position B. Tunnel is constructed by means of directional or rock drilling.

Elevation difference between the water surface upstream and downstream of the proposed SSHP was measured from satellite imagery as 42 m. The difference in elevation between the water level at the proposed intake position and the natural ground level at the proposed turbine room location downstream was measured during a site visit as 34 m. the proposed turbine room location takes into account the 1:100 year flood. The theoretically available pressure head at point B is therefor 34 m. Horizontal distances measured from satellite imagery from A to B is 290 m.

Hydraulic analysis was done and frictional and secondary losses determined using the calculated geometrics and by varying the flow between 100 l/s and 300 l/s and the pipe diameter between 200 mm OD and 355 mm OD. Based on the proposed construction method of using directional drilling or rock drilling, the diameter range was limited to the above mentioned 200 mm OD to 355 mm OD. Figure 5-75 displays the calculated energy losses (frictional and secondary) for the different flow and pipe diameter configurations.

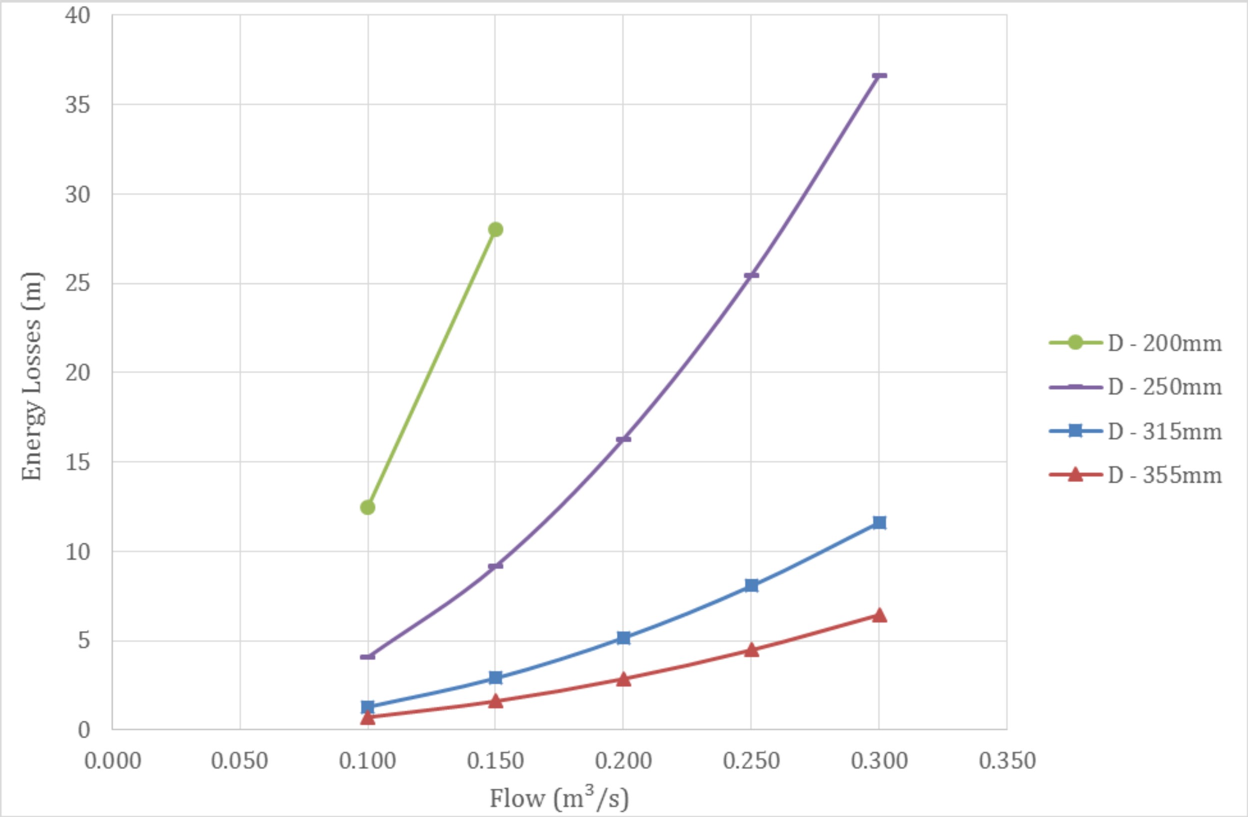


Figure 5-75 - Energy Losses - Eskweleni

From the analysis of energy losses the power generation potential for the Eskweleni SSHP for different configurations of flow rate and pipe diameter sizes were calculated and are given in Figure 5-76. The friction losses for a pipe diameter less than 200 mm become more than the available head at Eskweleni and is therefor not included in the further power generation calculations and graphs. At a pipe diameter of 200 mm and a flow higher than 150 l/s frictional losses also increased higher than the available head.

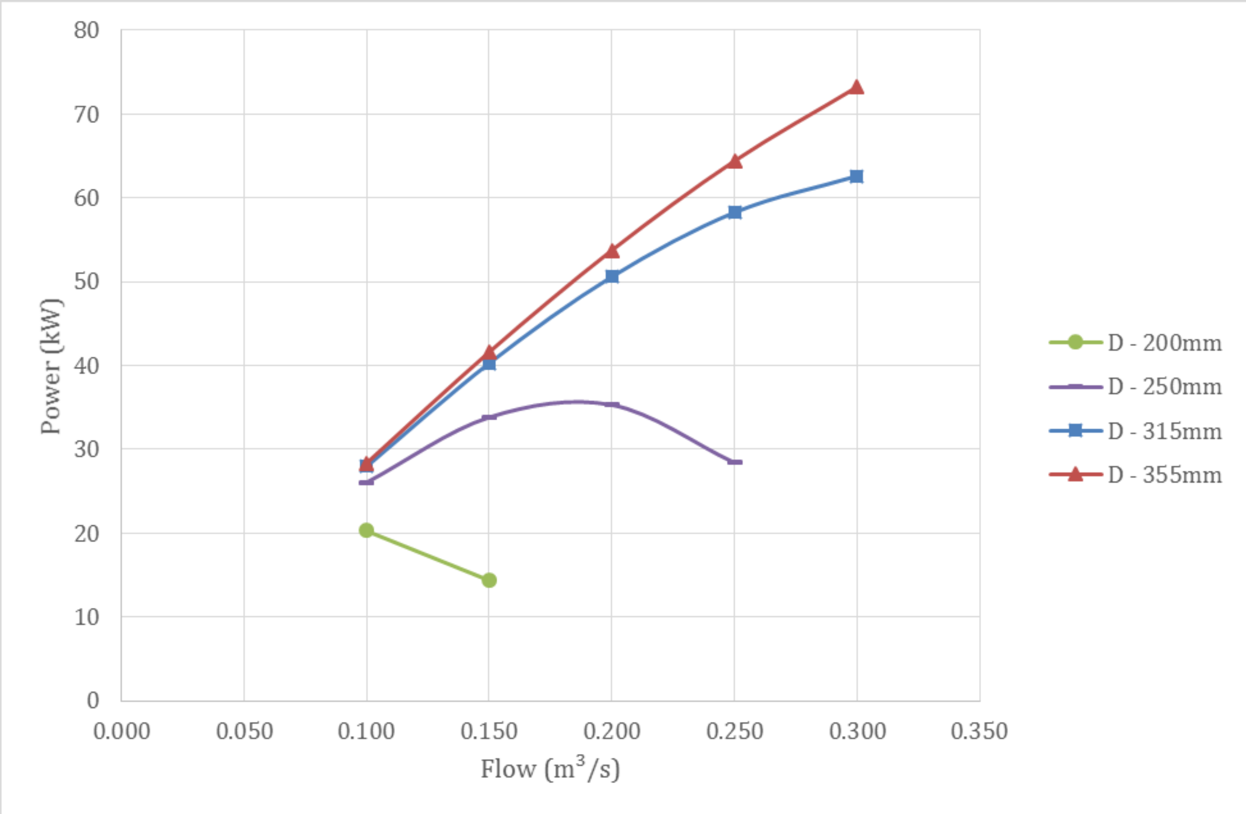


Figure 5-76 - Potential power generation - Eskweleni

From the graph it can be seen that the potential power generation at Eskweleni SSHP for a 355 mm diameter penstock is still rising for flows higher than 300 l/s flow. The analysis however was only done up to 300 l/s since higher flows necessitates larger physical turbine infrastructure. Higher flows abstracted and rerouted from the natural stream might also have adverse effects on the environment.

The hydraulic analysis was used in the design of the Mahlaba SSHP.

5.3.2.4 Hydropower System Design

Figure 5-77 gives an overall schematic representation of the Eskweleni SSHP, with all the civil components. The design of the individual components are discussed in detail in the sections following.

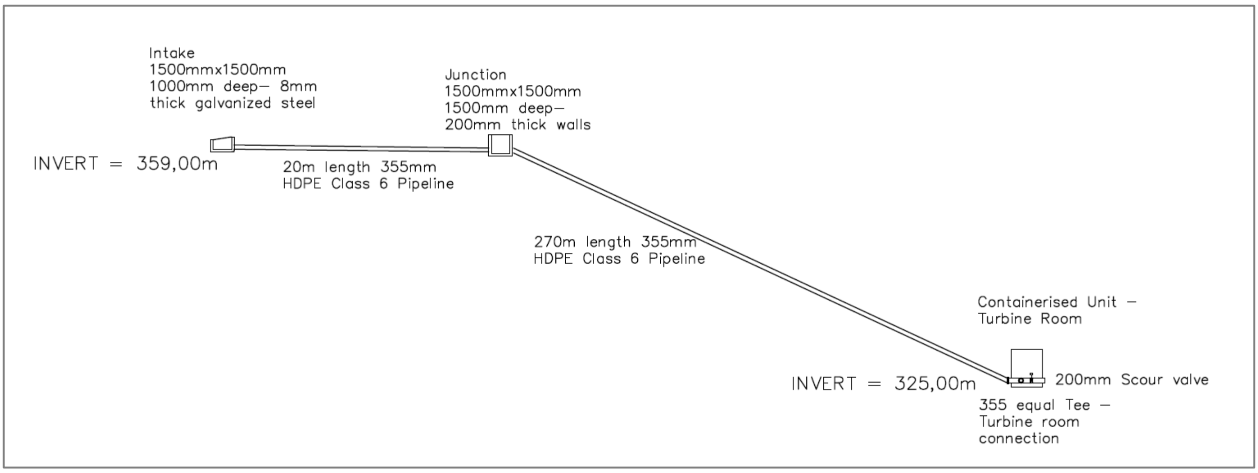


Figure 5-77 - Eskweleni SSHP schematic

Technical data of the Eskweleni SSHP plant is summarized in Table 5-10.

Table 5-10 - Eskweleni SSHP technical data

Design Flow Rate	200 l/s
Design Head	31.1 m
Design Power Output	42.8 kW
Intake invert level	359.00 m
Penstock invert level	358.60 m
Turbine room invert level	325.00 m
Intake pipeline length	20 m
Penstock Length	270 m
Penstock diameter	355 mm
Energy Losses	2.9 m

Intake and Penstock

From Figure 5-74, the intake structure and penstock is constructed from point A to point B. Similarly to the design of the Mahlaba SSHP and Kwa Madiba SSHP, the intake structure consists of an intake, primary screen and cleaning rack at point A, a 20 m 355 mm diameter HDPE (class 6) PN 6.3 pipeline from point A to a junction box at point J (Figure 5-78). At the junction box at point J the intake structure is connected to the penstock. Detailed hydraulic design of the intake structure is shown in Figure 5-79.

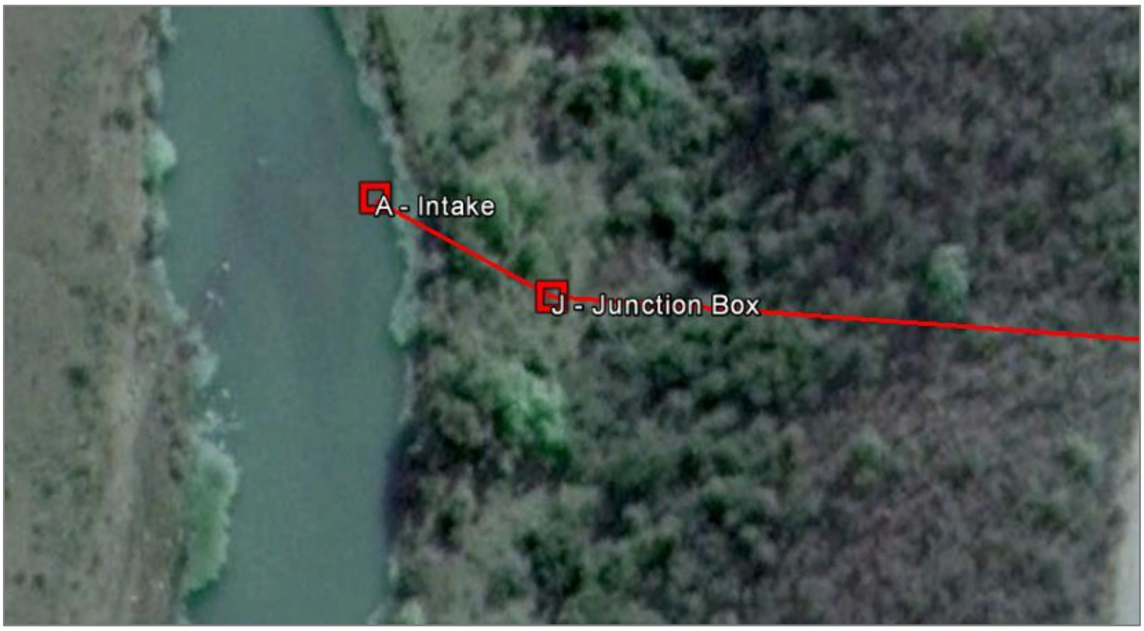


Figure 5-78 - Junction Box - Eskweleni SSHP

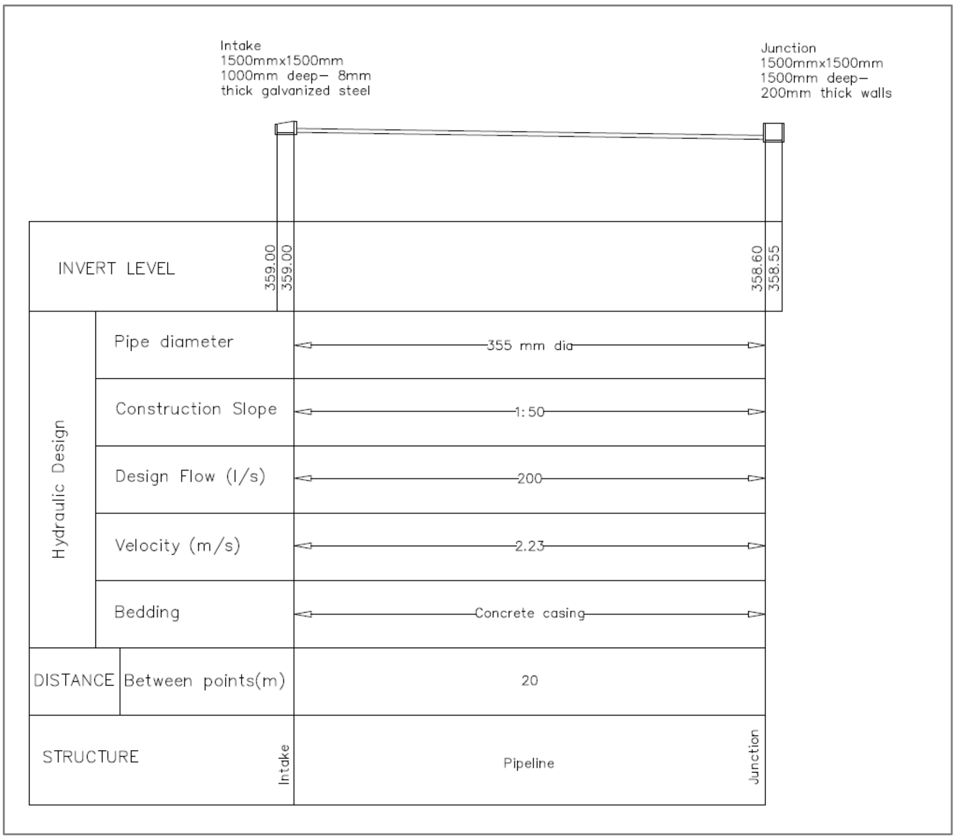


Figure 5-79 - Intake structure design - Eskweleni SSHP

The intake structure will abstract and reroute **200 l**/s as per the design of the SSHP plant at Eskweleni. The energy losses in the intake structure was calculated as **0.15 m**. The invert level of the pipeline from the intake is **359.00 m**. The HDPE pipe is laid at a 2% gradient and has an invert level at the outlet to the junction box of **358.60 m**.

As shown below in Figure 5-80, the penstock is from the junction box at point J to the turbine room inlet at point B. The penstock will convey 200 l/s as per the design of the SSHP plant at Eskweleni. The penstock is design to be constructed by means of directional or rock drilling and consisting of a 270 m length 355 mm diameter HDPE (class 6) PN 6.3 pipe. The invert level of the penstock at the junction box is 358.55 m and the invert at the turbine room connection is 325.00 m. The energy losses in the penstock was calculated using the Karman Prandlt equation, as 2.7 m. The detailed hydraulic design of the penstock is shown in Figure 5-81.

Figure 5-80 - Junction Box and Penstock - Eskweleni SSHP

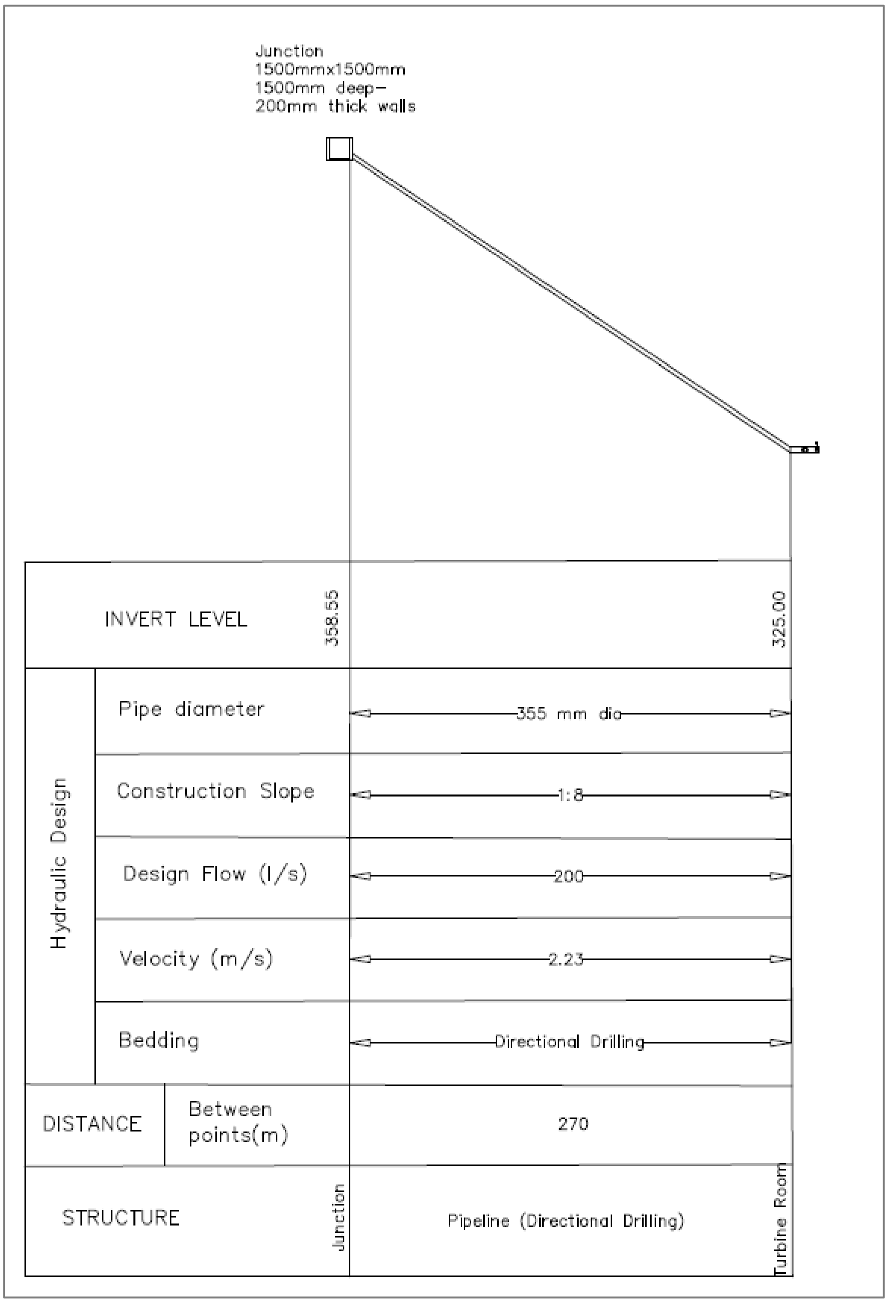


Figure 5-81 - Penstock Design - Eskweleni SSHP

Turbine Room

The turbine room for the Eskweleni SSHP is identical to the turbine room for the design of both the Mahlaba SSHP and Kwa Madiba SSHP. The unit is assembled off-site and transported to site and connected once the penstock and turbine room foundation is completed. The containerised unit reduces overall construction time and eliminates construction restraints in confined and remote locations. The turbine room/powerhouse houses the turbine, generator, controls and regulators. Schematics and drawings of the designed turbine room for the Eskweleni SSHP, as for the Kwa Madiba SSHP, can be seen in Figure 5-62, Figure 5-63 and Figure 5-64.

Turbine

The hydroelectric turbine, complete with electric distribution board and electronic regulating system supplied by IREM or similar turbine supplier (Figure 5-65), designed for the Eskweleni SSHP, are similar as for the Kwa Madiba SSHP and are as follows:

1) ECOWATT Micro hydroelectric power plant type TBS 2

2) Electronic Regulating System RMP 10.000/B with water dissipation resistances

3) Technical data:

- Nominal voltage: three/single phase 400/230V 6050Hz
- Generated electric power: P= 42 kW approx.
- Net head axis turbine: H= 34 m
- Flow: Q= 200 l/s

Tailrace

The tailrace for the Eskweleni SSHP is similar to that of the Kwa Madiba SSHP and the Mahlaba SSHP. Tailrace construction of the Mahlaba SSHP plant is restricted to the outflow channel within the turbine room. From the turbine room water in the tailrace is released directly onto the rock outcrop on which the containerized turbine room unit is constructed. Releasing directly onto the rock surface eliminates any scouring effect from the tailrace and release of the Eskweleni SSHP plant. The SSHP plant is a non-consumptive use of water and therefor the outfall/release from turbine room is equal to the flow at the intake structure, **200 l/s**. Where excessive scouring is found to be present from the operation of the SSHP, a concrete apron or channel or gabion mattresses should be constructed downstream of the turbine room outlet.

5.3.3 Dikeni SSHP

5.3.3.1 Site Selection P rocess

5.3.3.1.1 Hydropower Potential –Mthatha River at Dikeni

Similarly as for the previous SSHP designs, at the initial potential site identification stage the focus was to preliminarily identify sites based solely on potential head available. The higher the potential available head is the lower the flow is for the same power generation, therefor lower higher heads need lower flows and lower flows in turn enables to use of physically smaller components such as the impeller size and overall turbine size.

Focus was later also placed on kinetic hydro turbine installations for SSHP. The kinetic turbine installations require only a minimum submergence and high flow velocity. Sites with narrow streams of sudden contractions in rivers were included in the site identification.

Due to the high stream velocity needed and the relatively low flow in several rivers within the scope of the study, sites with the opportunity to construct a contraction in a river was also included in the identification process.

Kinetic hydro turbines however does not have as high efficiencies as i.e. cross-flow or Pelton turbines. Individual kinetic turbines, in the size that is considered for the study, only generates up to a maximum of 5.0 kW per turbine. For these low power generations it is envisaged that a kinetic turbine SSHP might become unfeasible when transmission lines become very long and transmission and distribution cost become very high.

For reasons above, the Dikeni SSHP site was identified as a potential SSHP site. Dikeni is a small enough community to be adequate provided by electricity from a kinetic turbine SSHP, it is close to the source of power and the Mthatha River at Dikeni (Figure 5-82) is narrow enough to construct an artificial contraction in the river to increase flow velocities to an acceptable range for a kinetic turbine SSHP.

5.3.3.1.2 Rural Electrification – Dikeni

Form the several selected site parameters the proposed Dikeni SSHP was found to favourable in terms of Nearest Rural Settlement, Distance to nearest Rural Settlement, Population of Rural Settlement, and Accessibility by vehicle, Electrical Grid Connected and Future Electrical Grid Connectivity, Environmental Impact and Social Impact. The following is information of the site selection parameters for the Dikeni SSHP:

- Nearest Rural Settlement – Dikeni
- Distance to nearest Rural Settlement – less than 120 m
- Population of Rural Settlement – 10 households
- Accessibility by vehicle – Properly maintained gravel road
- Electrical Grid Connected – No electrical grid

The proposed Dikeni SSHP (Figure 5-82) could not be found as part of any of the 2011 Census data. The closet rural settlement for which data exists is Dikeni, with 19 households according to the 2011 Census data. The proposed end users for the Dikeni SSHP does however not form part of the 2011 Census data for Dikeni. The proposed end users of the SSHP however is a small islanded community as seen in Figure 5-83. The amount of households within the proposed end users section is 10 households as stated in the site selection parameters above.

Figure 5-82 - Dikeni SSHP

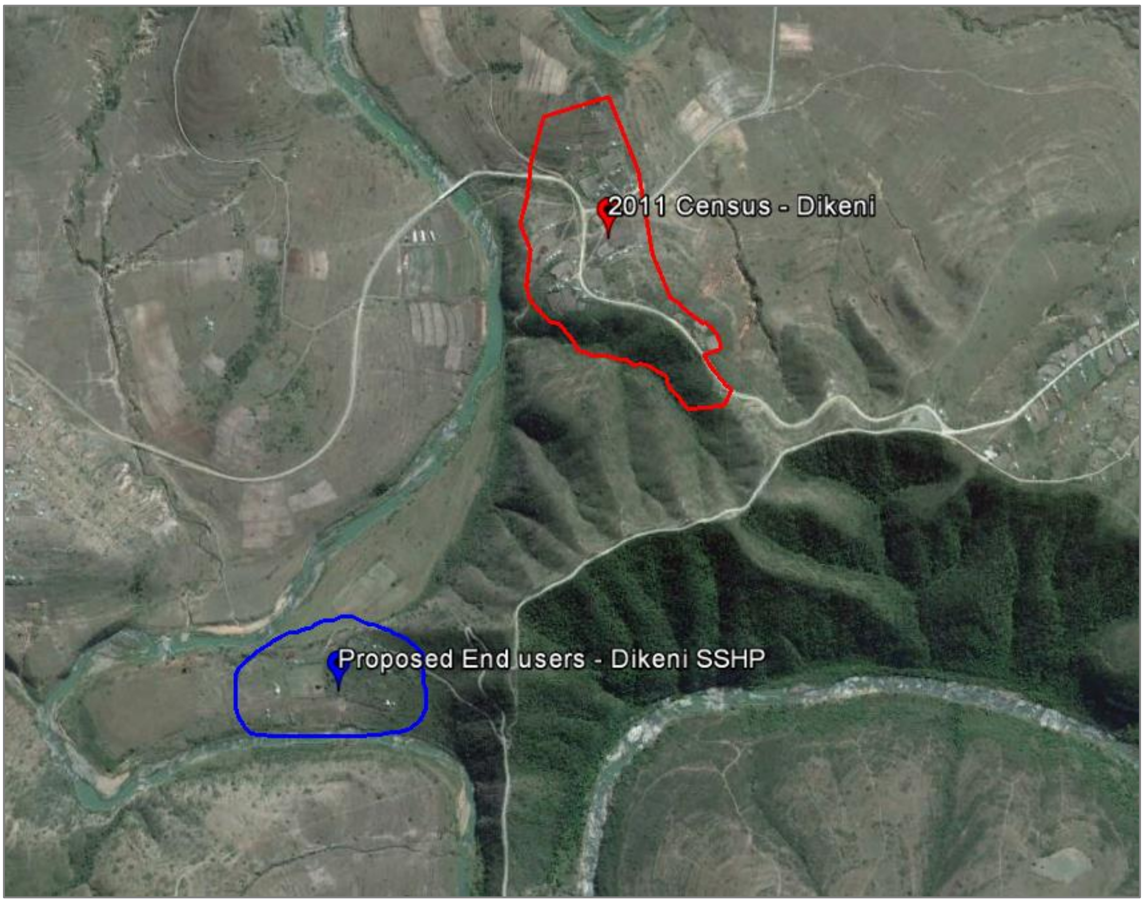


Figure 5-83 – Proposed End Users – Dikeni SSHP

5.3.3.2 Hydrological Analysis

The potential SSHP site for Dikeni in the Mthatha River is located upstream of the Eskweleni SSHP site. Data for the hydrological analysis for the Dikeni site was obtained from DWS for the gauging station T2H002 – Norwood. This is the same station from which data was used for the hydrological analysis of Eskweleni. Therefor the hydrological analysis for Dikeni is the same as that for Eskweleni.

From the statistical analysis of the flow data record obtained from the T2H002 (Norwood) gauging station from the DWS, it can be concluded that a flow rate of 512 l/s is present within the Mthatha River at Dikeni 95% of the time.

The Utility Programs for Drainage (UPD) software package was used to do flood calculations by means of the Statistical Methods up to the 1:100 flood. The statistical plots for the different statistical methods were analysed and the Log Pearson Type 3 (LP3) distribution was seen to fit the most accurate curve to the historical data plot. LP3 was therefor used as the calculated floods for the Mthatha River at Eskweleni.

The LP3 1:100 flood of 118 m^3/s was used in the calculation of the safe founding level for the containerised turbine room/powerhouse on the Mthatha River at Dikeni. Normal flow depth was assumed downstream of the intake at the turbine room, and calculated by using the slope of the Mthatha River for a 1 km section, 0.7%, and measuring the average river width within this section of 30 m. River banks were conservatively assumed as vertical. The normal flow depth of the Mthatha River downstream of intake for the 1:100 year flood was calculated by using Manning's Equation with an n-value of 0.06 $s/m^{1/3}$ (Chow, 1959). The normal flow depth was calculated as 1.1 m. The position of the containerised turbine room/powerhouse was designed to be placed above this level.

5.3.3.3 Hydraulic Analysis

The Dikeni SSHP was proposed as a kinetic turbine small-scale hydropower installation, therefor no pipework and valves are involved in the design of the SSHP eliminating the need for calculations with regards to frictional and secondary losses.

Kinetic turbine small-scale hydropower installations are also not concerned about head differences but rather about flow velocities as seen from Equation 2-2. The proposed kinetic turbines have a rotor dimension of 1000 mm, and overall submerged dimension of 1600 mm width and 2010 mm depth. It has an optimum operating velocity of 2.8 m/s. This implicates that for a streamflow of 512 l/s, which is available 95% of the time within the Mthatha River at Dikeni, a flow area of 0.18 m^2 will be necessary to achieve the optimum operating velocity of 2.8 m/s. Another restriction is the minimum depth of flow of the height dimension of the turbine of 2.01 m. Therefor a stream width of 0.09 m will be required with a streamflow of 512 l/s. This is both unrealistic and impossible.

Therefor the kinetic turbine small-scale hydropower installation is sized for a minimum area of just greater than the minimum submerged area of the turbine and the required flow to maintain optimum flow velocity is determined.

The minimum area is therefor 3.216 m^2 (1600 x 2010 mm). For practical and construction purposes the area is limited to 4 m^2 (2 x 2 m). To maintain the optimum flow velocity at this area the turbine requires a flow of 11 m^3/s. From the hydrological analysis and historical flow data records from DWS, this flow is present in the Mthatha River 25% of the time. The kinetic turbine only becomes not functional at flow velocities of less than 1 m/s, therefor at flows of less than 4 m^3/s at Dikeni. From the hydrological analysis and historical flow data records from DWS, this flow is present in the Mthatha River 54% of the time. Therefor the kinetic turbine small-scale hydropower installation can statistically be operating at full capacity for 25% of time, reduced capacity for 29% of the time, and it will be standing 46 % of the time.

The Mthatha River at Dikeni does not have such narrow sections and additional infrastructure will be needed to narrow the river section to obtain the required flow velocity.

5.3.3.4 Hydropower System Design

River contraction

The kinetic turbine SSHP is an “inline” installation. The turbine is installed in the stream flow and anchored to the river bed by means of a cable connected to a constructed anchor block on the river bed. The kinetic turbine SSHP therefor does not have an intake and a penstock.

From section 5.3.3.3 it is observed that the kinetic turbine in the scope of the study requires an area of flow of 4 m^2. To obtain this area of flow for the required flow rate, a contraction will have to be constructed in the river section to allow the stream flow to be concentrated at a specific point. Construction within the river of flood plain might pose legislative and regulatory issues which in turn will increase cost and might render such a SSHP unfeasible or not viable. In canal sections where the canals are privately owned, a kinetic SSHP installation becomes feasible more easily.

Turbine

For the Dikeni SSHP, a single kinetic hydro turbine supplied by Smart Hydro Power (Figure 5-84) was designed as the turbine, with the option of expanding in to several more hydro turbines in future.

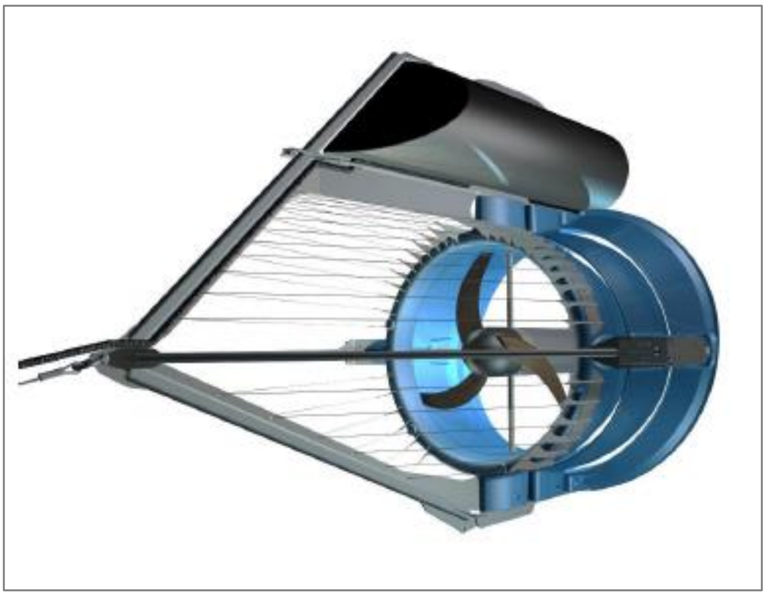


Figure 5-84 - Kinetic Turbine (Smart Hydro Power)

The Smart Hydro Power kinetic turbine used in the design for the Dikeni SSHP system has the following dimensions, specifications and characteristics:

- Output – 250 – 5000 W
- Dimensions – Length: 3130 mm
  Width: 1600 mm
  Height: 2010 mm
- Rotational Speed – 90 – 230 rpm
- Weight – 380 kg
- Rotor Diameter – 1000 mm
- Max power output at 2.8 m/s flow velocity

The Dikeni SSHP is designed as a hybrid system and is complete with the following components:

- 5 kW Hydro turbine
- PV-panels (Photovoltaic)
- Regulators/Ballast load (dump load)
- AC inverter
- Off-grid inverter
- Battery bank

Figure 5-85 below shows a schematic of a hybrid system as is designed for the Dikeni SSHP.

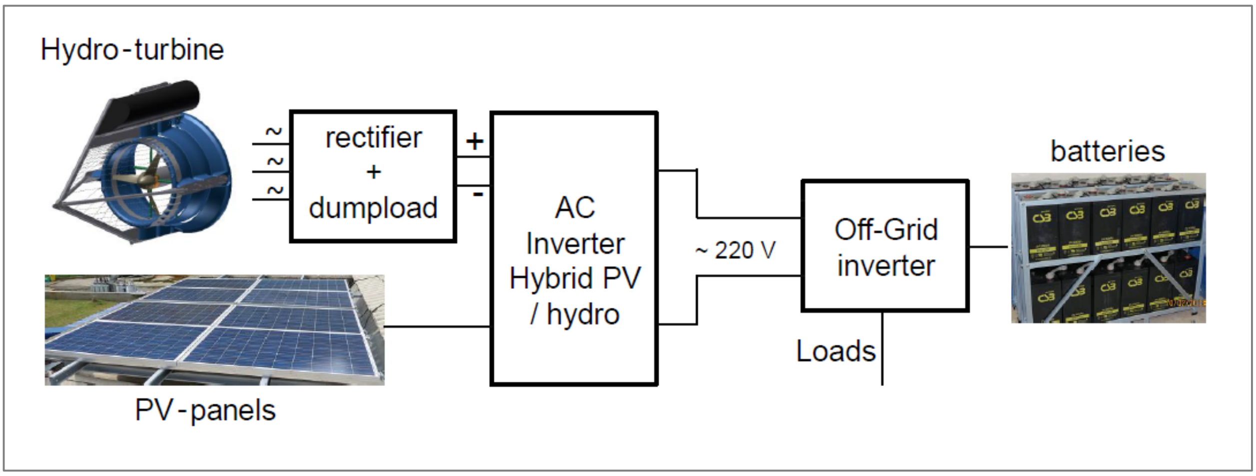


Figure 5-85 - Hybrid System (Smart Hydro Power)

Turbine Room/Control Room

For the kinetic turbine SSHP the conventional turbine room is replaced by only a control room. The controls for the kinetic turbine SSHP is compact and there is no need for a containerised unit. A control room can be constructed as a control box/electrical distribution box (Figure 5-86) placed adjacent to the nearest electricity user or as a stand-alone shed/room which contains the distribution box, additional batteries and photo-voltaic cells on the roof, in the case of hybrid systems.

Figure 5-86 - Kinetic Turbine Controls (Smart Hydro Power)

For the Dikeni SSHP project, the control room is designed as a stand-alone room which contains the distribution box, additional batteries and photo-voltaic cells on the roof. The Dikeni SSHP is designed as a hybrid system due to the inability to provide the required flow for the high flow velocity needed 95% of the time. An example of such a control room as constructed in Peru is shown in Figure 5-87.

Figure 5-87 - Control Room (Smart Hydro Power)

Tailrace

The kinetic turbine SSHP does not require the design of a tailrace. The turbine is installed in the river section and flow is not rerouted but only concentrated through a certain section of the already existing flow path. Where flow velocities become excessive, construction of an apron downstream of the contraction will be necessary to mitigate scouring of the riverbed.

Electrical Mini-Grid

The electrical transmission and distribution lines for the stand-alone mini-grid for the Dikeni SSHP Settlement as has been designed, complete with overhead lines, poles and pole mounted transformers, is shown in Figure 5-88.

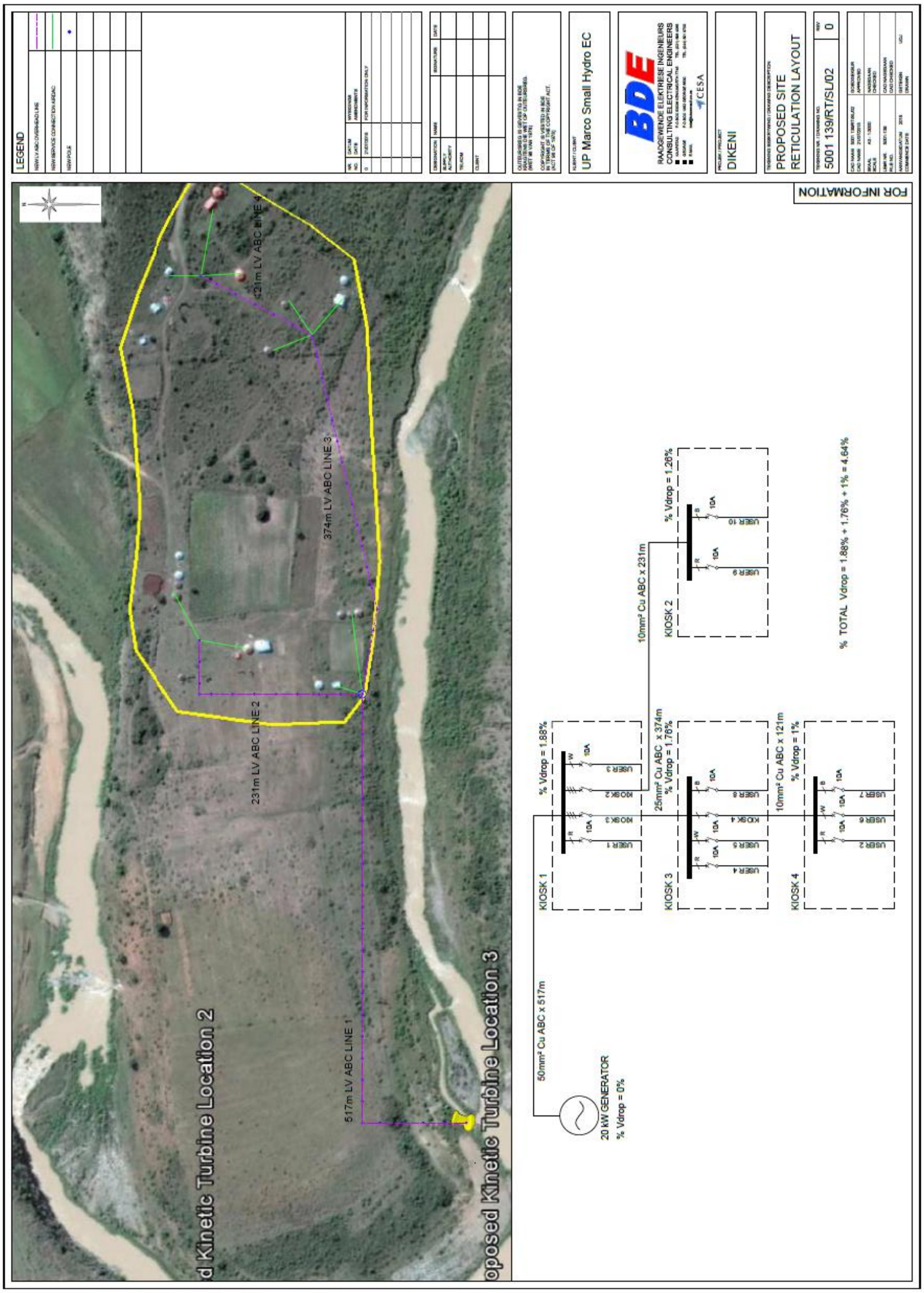


Figure 5-88 - Electrical Transmission and Distribution - Dikeni SSHP

5.4 CONCLUSION

Small-scale Hydropower Plants (SSHP) were designed for the different selected sites from the potential sites identified within Chapter 3. From the designed SSHP systems, a bill of quantities (BOQ) were compiled and the designs for the different SSHP systems priced and financially analysed.

The designs follow the same format and trends. This was done in order to attempt to standardise several different scenarios of head and flow availability to specific designs for such scenarios. It was also envisaged to design a standard containerised unit as turbine room which can be modified to suite different head and flow configurations and turbine sizes. The containerised unit also houses the controls of the system.

Electrical mini-grids were completely designed for the Kwa Madiba and Dikeni SSHP's. The electrical designs for these systems were used in estimating cost for the electrical designs and construction of the other designed SSHP's. Designs for the electrical mini-grids, other than for the Kwa Madiba and Dikeni SSHP's are therefor not included in this report.

Chapter 5 discusses the financial analysis done on the priced BOQ's developed by different pricing models. The pricing models incorporate contingencies for site specific variations in quantities. The financial analyses were done in order to evaluate the different sites on Net Present Value, Internal Rate of Return, Levelised Cost of Energy, Financial Payback Period and Capital Cost Comparison Ratios.

The Dikeni SSHP was not evaluated financial. From the design of the kinetic turbine SSHP at Dikeni it was concluded that kinetic turbine SSHP's are most suitable for canal based installations as wider river sections require additional infrastructure which in turn reduces the feasibility of such a project significantly.

6 FINANCIAL ANALYSIS

The designs for the several selected sites done in chapter 4, were priced and analysed financially. The financial analysis is linked to the description in the implementation model in Figure 3-3. The designs for the different selected sites were priced using pricing models obtained from the civil construction industry from both contracting and consulting engineers. The pricing models refer to financial tools used by contracting engineers or civil contractors for tender pricing purposes and financial tools used by consulting engineers for estimating purposes. The pricing models were populated with current material prices received from several local and international pipe and pipe fitting manufacturers and distributors.

A scheduled bill of quantities were developed and compiled for each design. The complete bill of quantities for the Ndodekhling-Shayiwe SSHP is attached in Appendix C. The bill of quantities for the different designs follows a template of the Ndodekhling-Shayiwe SSHP bill of quantity. Table 6-1 shows an example of the capital cost summary for a SSHP project, with typical percentages of the total capital cost for different components of the SSHP project.

A financial analyses were done on the several different sites to calculate and evaluate the following factors:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Levelised Cost of Energy
- Financial Payback Period
- Capital Cost Comparison Ratio (CCCR)

Table 6-1 - Capital cost summary example

ITEM	DESCRIPTION	% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**10 - 15%**
A.1	Prefeasibility Study	
A.2	Design	
A.3	Legal and regulatory	
A.4	Environmental and social assessment	
B	**CIVIL WORKS**	**30 - 45%**
B.1	Preliminary & General Cost	
B.2	Preparation of site	
B.3	Turbine Room	
B.4	Inlet works	
B.5	Tailrace works	
B.6	Pipework and valves (supply and install)	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**35 - 50%**
C.1	Turbines	
C.2	Generators	
C.3	Controls units (HPU, cooling and lubricating etc.)	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure)	
C.5	Import costs	
D	**IMPLEMENTATION COST**	**10 - 15%**
D.1	Commissioning, erecting and project management provided by the Supplier	
D.2	Construction supervision (Consultant)	
D.3	Training	
D.4	Spare components to be stored on site	
D.5	Integration of system components (telemetry etc.)	
D.6	Contingencies	
	TOTAL:	**100%**

For the calculation of the NPV for each selected site or potential plant the cost from the scheduled bill of quantities were used as the capital costs under the following items:

- Planning and Design Costs
- Civil Works
- Electro-Mechanical Equipment
- Implementation Costs

It is envisaged that electricity from the SSHP will not be sold to end users on a per c/kW basis, but that a certain amount of electricity will be provided to each household for a nominal operation cost fee which will be discussed later in the document. Due to this fact the annual income from the plant is not used as electricity sales but rather than a saving in electricity cost by the renewable technology.

Annual operation and maintenance (O&M) cost of the SSHP were calculated as a percentage of the capital cost, as per industry standards, and assumed escalation factors were used to calculate the NPV of each component of the annual O&M cost. The O&M cost components were calculated as follows:

- Civil works = 0.25% of Civil Works Capital Costs
- Transmission = 0.8% of Transmission and Distribution Capital Costs
- Operation = 0.4% of Total Capital Costs excluding Planning and Design Costs
- Insurance = 0.3% of Total Capital Costs excluding Planning and Design Costs
- Electrical and mechanical works = 2.0% of Electro-Mechanical Equipment (Turbines, Generators and Controls) Capital Costs

Due to the volatility of interest and inflation rates certain current assumptions were made for the NPV calculations. These assumptions are only accurate at any specific point in time. In Chapter 6 formulas are developed for the calculation of the feasibility of the SSHP installations. Within these formulas the different assumptions made can be changed and a sensitivity analysis can be done on i.e. different inflation rates or different discount rates. The following assumptions, based on current market trends and energy costs, were made and applied to the NPV calculations:

- Escalation of Operational costs = 8%
- Escalation of Maintenance cost = 10%
- Escalation of other costs = 10%
- Escalation of Energy costs = 10%
- Discount rate (Value of Capital) = 5%
- Construction time = 1 year
- Expected operational life = 40 years
- Average value of generated electricity = 0.59 R/kWh

The average value of generated electricity was calculated using the ESKOM 2013 MegaFlex tariff structure, applying the relevant transmission zone and voltage and defining the high demand season from June to August and the low demand season from September to May. The average value of electricity was then calculated using the peak, standard and off-peak rates according to the different peak durations within the ESKOM 2013 MegaFlex tariff structure.

A Capital Cost Comparison Ratio (CCCR) for each installation was calculated by comparing the capital cost of the installation to the capital cost of providing electrical infrastructure (transmission and distribution lines) to connect the rural settlement or community to the existing local or national electricity grid. The CCCR does not take into account the cost of the electricity sales from the grid or the discounted cost of electricity from the small scale hydropower plant. The CCCR does also not take into account electricity sales from the small scale hydropower plant but assumes that the electricity from the SSHP is supplied at a nominal cost which only covers annual operation and maintenance of the plant. The CCCR is therefor calculated as the ratio of the capital cost of the SSHP and the cost of providing electrical infrastructure (transmission and distribution lines) to connect the rural settlement or community to the existing local or national electricity grid.

The component of the NPV for the operation cost estimate is used to calculate monthly instalments or operation cost fees to be paid by energy or electricity end users in the SSHP network. These monthly operation fees could be entered back into the financial analysis to calculate a new NPV and IRR.

Neither the NPV nor the Financial Payback Period has taken into account sales of SSHP generated electricity or operational cost fees recovered from the end users. Taking these figures into account increases the NPV and IRR and reduces the Financial Payback Period

The following sections summarises the financial analyses for the following proposed SSHP:

- Dunudunu
- Jolwayo
- Mahlaba (Woza)
- Kwa Madiba (Thina Falls)
- Eskweleni

The complete financial analysis for the Ndodekhling-Shayiwe SSHP is attached in Appendix D.

6.1 DUNUDUNU

Table 6-2 shows the total capital cost for the development of a SSHP at the Dunudunu proposed site. The characteristics of the site are as follows:

- Design Head = 10.0 m
- Design Flow Rate = 200 l/s
- Penstock Length = 396 m
- Transmission Line Length = 700 m
- Total Energy Generation = 10 Kw

With the calculated capital cost and the methodology discussed for the financial analysis, the site was analysed and the following results obtained:

- Net Present Value (NPV) = R 1 464 749
- Internal Rate of Return (IRR) = 6.65 %
- Levelised Cost of Energy = 244.41 c/kWh
- Financial Payback Period = 34 – 35 years
- CCCR = 0.39

Table 6-2 - Dunudunu Capital Cost

ITEM	DESCRIPTION	AMOUNT	% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**R 300 830**	**12%**
A.1	Prefeasibility Study	R 50 000	
A.2	Design	R 185 800	
A.3	Legal and regulatory	R 37 160	
A.4	Environmental and social assessment	R 27 870	
B	**CIVIL WORKS**	**R 845 071**	**34%**
B.1	Preliminary & General Cost	R 38 074	
B.2	Preparation of site	R 34 612	
B.3	Turbine Room	R 180 015	
B.4	Inlet works	R 35 895	
B.5	Tailrace works	R 55 962	
B.6	Pipework and valves (supply and install)	R 500 510	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**R 998 753**	**40%**
C.1	Turbines	R 270 000	
C.2	Generators	Incl. in Turbines	
C.3	Controls units (HPU, cooling and lubricating etc.)	Incl. in Turbines	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure)	R 674 753	
C.5	Import costs	R 54 000	
D	**IMPLEMENTATION COST**	**R 323 847**	**13%**
D.1	Commissioning, erecting and project management provided by the Supplier	R 49 937	
D.2	Construction supervision (Consultant)	R 138 286	
D.3	Training	R 8 100	
D.4	Spare components to be stored on site	R 8 100	
D.5	Integration of system components (telemetry etc.)	R 16 200	
D.6	Contingencies	R 103 222	
	TOTAL:	**R 2 468 502.35**	**100%**

6.2 JOLWAYO

Table 6-3 shows the total capital cost for the development of a SSHP at the Jolwayo proposed site. The characteristics of the site are as follows:

- Design Head = 5.2 m
- Design Flow Rate = 300 l/s
- Penstock Length = 250 m
- Transmission Line Length = 235 m
- Total Energy Generation = 9.3 kW

With the calculated capital cost and the methodology discussed for the financial analysis, the site was analysed and the following results obtained:

- Net Present Value (NPV) = R 1 642 759
- Internal Rate of Return (IRR) = 7.05 %
- Levelised Cost of Energy = 230.05 c/kWh
- Financial Payback Period = 33 – 34 years
- CCCR = 0.64

Table 6-3 - Jolwayo Capital Cost

ITEM	DESCRIPTION	AMOUNT		% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**R**	**261 205**	**13%**
A.1	Prefeasibility Study	R	50 000	
A.2	Design	R	156 448	
A.3	Legal and regulatory	R	31 289	
A.4	Environmental and social assessment	R	23 467	
B	**CIVIL WORKS**	**R**	**699 819**	**34%**
B.1	Preliminary & General Cost	R	34 950	
B.2	Preparation of site	R	30 829	
B.3	Turbine Room	R	180 015	
B.4	Inlet works	R	35 895	
B.5	Tailrace works	R	55 962	
B.6	Pipework and valves (supply and install)	R	362 167	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**R**	**847 651**	**41%**
C.1	Turbines	R	270 000	
C.2	Generators		Incl. in Turbines	
C.3	Controls units (HPU, cooling and lubricating etc.)		Incl. in Turbines	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure)	R	523 651	
C.5	Import costs	R	54 000	
D	**IMPLEMENTATION COST**	**R**	**277 758**	**13%**
D.1	Commissioning, erecting and project management provided by the Supplier	R	42 382	
D.2	Construction supervision (Consultant)	R	116 060	
D.3	Training	R	8 100	
D.4	Spare components to be stored on site	R	8 100	
D.5	Integration of system components (telemetry etc.)	R	16 200	
D.6	Contingencies	R	86 915	
	TOTAL:	**R**	**2 086 435.06**	**100%**

6.3 MAHLABA (WOZA)

Table 6-4 shows the total capital cost for the development of a SSHP at the Mahlaba (Woza) proposed site. The characteristics of the site are as follows:

- Design Head = 11.9 m
- Design Flow Rate = 200 l/s
- Penstock Length = 450 m
- Transmission Line Length = 960 m
- Total Energy Generation = 16.3 kW

With the calculated capital cost and the methodology discussed for the financial analysis, the site was analysed and the following results obtained:

- Net Present Value (NPV) = -R 6 488 556 (negative NPV)
- Internal Rate of Return (IRR) = N/A
- Levelised Cost of Energy = 363.11 c/kWh
- Financial Payback Period = N/A
- CCCR = 0.81

Table 6-4 - Mahlaba (Woza) Capital Cost

ITEM	DESCRIPTION	AMOUNT	% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**R 672 715**	**11%**
A.1	Prefeasibility Study	R 50 000	
A.2	Design	R 461 271	
A.3	Legal and regulatory	R 92 254	
A.4	Environmental and social assessment	R 69 190	
B	**CIVIL WORKS**	**R 2 921 705**	**48%**
B.1	PrelimInary & General Cost	R 61 669	
B.2	Preparation of site	R 36 011	
B.3	Turbine Room	R 180 015	
B.4	Inlet works	R 35 895	
B.5	Tailrace works	R 55 962	
B.6	Pipework and valves (supply and install)	R 2 552 151	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**R 1 690 183**	**28%**
C.1	Turbines	R 691 200	
C.2	Generators	Incl. in Turbines	
C.3	Controls units (HPU, cooling and lubricating etc.)	Incl. in Turbines	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure) (As per Electrical Consultants)	R 860 743	
C.5	Import costs	R 138 240	
D	**IMPLEMENTATION COST**	**R 769 606**	**13%**
D.1	Commissioning, erecting and project management provided by the Supplier	R 84 509	
D.2	Construction supervision (Consultant)	R 345 891	
D.3	Training	R 20 736	
D.4	Spare components to be stored on site	R 20 736	
D.5	Integration of system components (telemetry etc.)	R 41 472	
D.6	Contingencies	R 256 261	
	TOTAL:	**R 6 054 211**	**100%**

6.4 KWA MADIBA (THINA FALLS)

Table 6-5 shows the total capital cost for the development of a SSHP at the Kwa Madiba (Thina Falls) proposed site. The characteristics of the site are as follows:

- Design Head = 48.8 m
- Design Flow Rate = 150 l/s
- Penstock Length = 116 m
- Transmission Line Length = 1140 m
- Total Energy Generation = 50 Kw

With the calculated capital cost and the methodology discussed for the financial analysis, the site was analysed and the following results obtained:

- Net Present Value (NPV) = R 9 481 367
- Internal Rate of Return (IRR) = 9.68%
- Levelised Cost of Energy = 102.58 c/kWh
- Financial Payback Period = 22 – 23 years
- CCCR = 0.38

Table 6-5 – Kwa Madiba (Thina Falls) Capital Cost

ITEM	DESCRIPTION	AMOUNT	% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**R 555 194**	**11%**
A.1	Prefeasibility Study	R 50 000	
A.2	Design	R 374 218	
A.3	Legal and regulatory	R 74 843	
A.4	Environmental and social assessment	R 56 132	
B	**CIVIL WORKS**	**R 1 337 910**	**27%**
B.1	Preliminary & General Cost	R 190 971	
B.2	Preparation of site	R 27 356	
B.3	Turbine Room	R 180 015	
B.4	Inlet works	R 35 895	
B.5	Tailrace works	R 55 962	
B.6	Pipework and valves (supply and install)	R 847 709	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**R 2 343 804**	**48%**
C.1	Turbines	R 691 200	
C.2	Generators	Incl. in Turbines	
C.3	Controls units (HPU, cooling and lubricating etc.)	Incl. in Turbines	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure) (As per Electrical Consultants)	R 1 514 364	
C.5	Import costs	R 138 240	
D	**IMPLEMENTATION COST**	**R 684 161**	**14%**
D.1	Commissioning, erecting and project management provided by the Supplier	R 117 190	
D.2	Construction supervision (Consultant)	R 276 128	
D.3	Training	R 20 736	
D.4	Spare components to be stored on site	R 20 736	
D.5	Integration of system components (telemetry etc.)	R 41 472	
D.6	Contingencies	R 207 898	
	TOTAL:	**R 4 921 071.01**	**100%**

6.5 ESKWELENI

Table 6-6 shows the total capital cost for the development of a SSHP at the Eskweleni proposed site. The characteristics of the site are as follows:

- Design Head = 31.1 m
- Design Flow Rate = 200 l/s
- Penstock Length = 290 m
- Transmission Line Length = 1 764 m
- Total Energy Generation = 42.8 kW

With the calculated capital cost and the methodology discussed for the financial analysis, the site was analysed and the following results obtained:

- Net Present Value (NPV) = R 4 036 405
- Internal Rate of Return (IRR) = 7.05 %
- Levelised Cost of Energy = 144.01 c/kWh
- Financial Payback Period = 31 – 32 years
- CCCR = 0.82

Table 6-6 - Eskweleni Capital Cost

ITEM	DESCRIPTION	AMOUNT	% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**R 674 042**	**11%**
A.1	Prefeasibility Study	R 50 000	
A.2	Design	R 462 254	
A.3	Legal and regulatory	R 92 450	
A.4	Environmental and social assessment	R 69 338	
B	**CIVIL WORKS**	**R 2 200 190**	**36%**
B.1	PrelimInary & General Cost	R 161 322	
B.2	Preparation of site	R 31 865	
B.3	Turbine Room	R 180 015	
B.4	Inlet works	R 35 895	
B.5	Tailrace works	R 55 962	
B.6	Pipework and valves (supply and install)	R 1 735 128	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**R 2 389 339**	**39%**
C.1	Turbines	R 691 200	
C.2	Generators	Incl. in Turbines	
C.3	Controls units (HPU, cooling and lubricating etc.)	Incl. in Turbines	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure) (As per Electrical Consultants)	R 1 559 899	
C.5	Import costs	R 138 240	
D	**IMPLEMENTATION COST**	**R 803 433**	**13%**
D.1	Commissioning, erecting and project management provided by the Supplier	R 119 466	
D.2	Construction supervision (Consultant)	R 344 214	
D.3	Training	R 20 736	
D.4	Spare components to be stored on site	R 20 736	
D.5	Integration of system components (telemetry etc.)	R 41 472	
D.6	Contingencies	R 256 807	
	TOTAL:	**R 6 067 006**	**100%**

6.6 RESULTS AND COMPARISON

Figure 6-1 and Figure 6-2 shows comparisons of the levelised cost and the cost/benefit ratios of the several financially analysed proposed SSHP projects above. A feasibility study form the financial analysis results is discussed in Chapter 7. Figure 6-3 shows the cost per kilowatt of the several different SSHP sites.

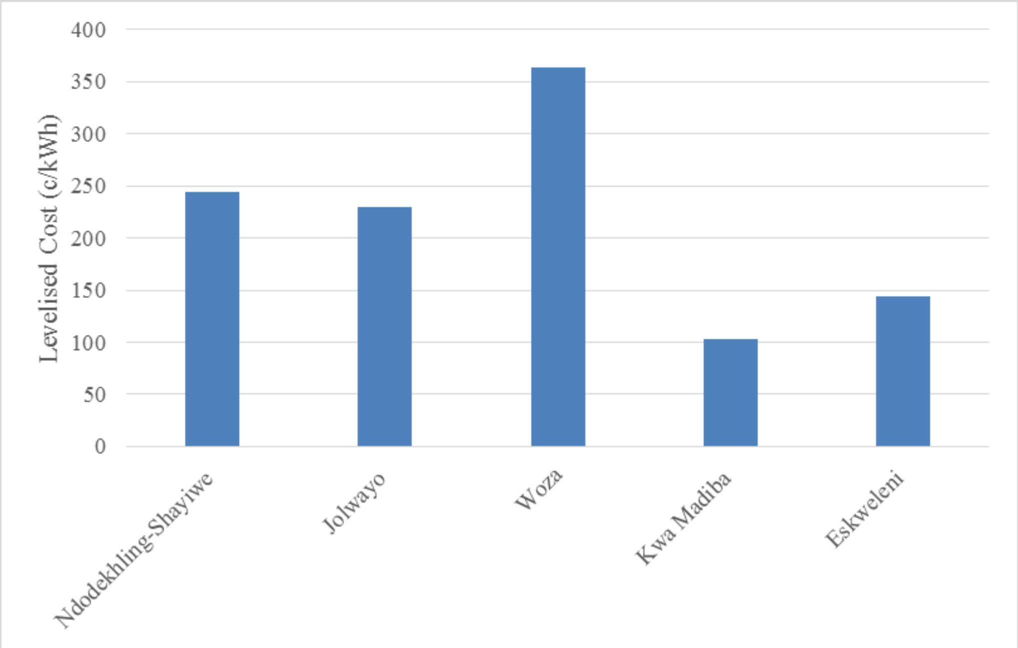


Figure 6-1 - Levelised cost comparison

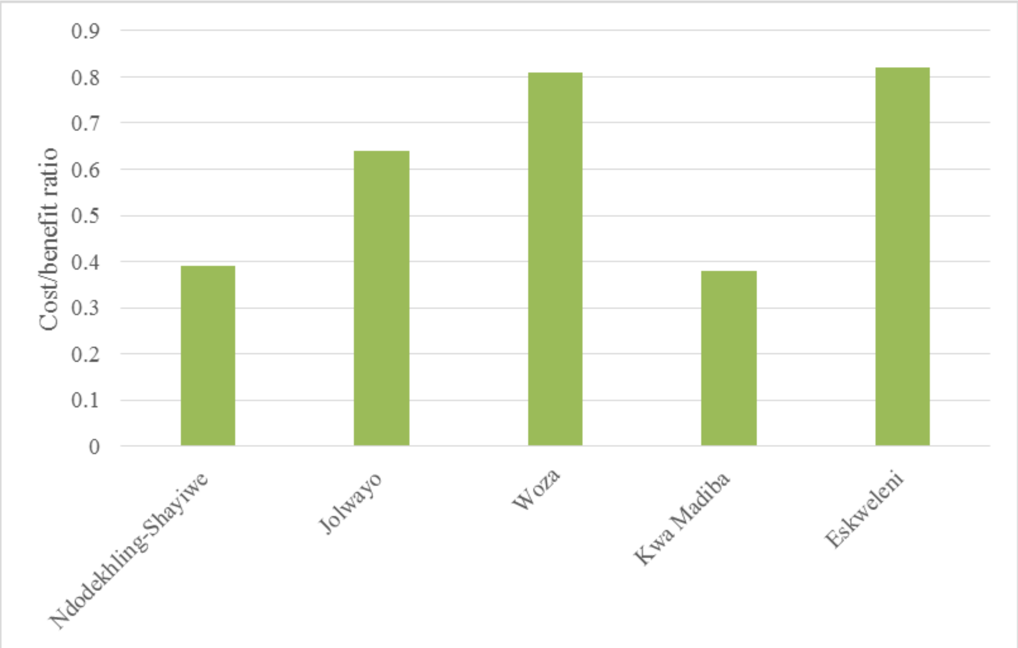


Figure 6-2 - CCCR comparison

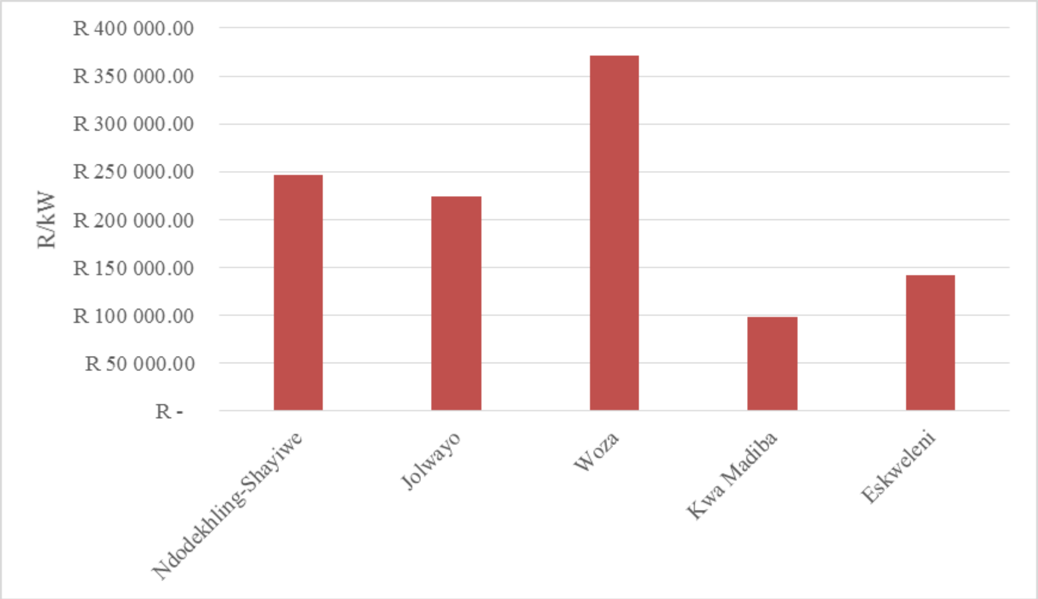


Figure 6-3 - Rand per kilowatt comparison

From the financial analysis results above it is observed that a low levelised cost is not always associated with a low CCCR and vice versa. The levelised cost of SSHP is lowered by developing sites with shorter penstock lengths for higher elevation differences, to obtain a higher head while minimizing penstock lengths and capital costs. Due to high cost of transmission and distribution lines the cost/benefit of SSHP is increasingly lower over larger distances of existing grid extensions. Sites with a lower levelised cost is preferred over sites with higher levelised costs. Similarly a site with a lower cost/benefit ratio is preferred over sites with higher cost/benefit ratios. A feasibility analysis on different scenarios of SSHP installations has been done and is discussed in Chapter 7.

7 FEASIBILITY AND DESIGN CHART DEVELOPMENT

The feasibility study of the SSHP can be approached in several different ways depending on the type of development out of which the development of the SSHP originates.

Firstly, if the development of the SSHP is a commercial development and profit based, the feasibility of the project will be determined solely of the Internal Rate of Return (IRR) on the investment.

Secondly, if the development of the SSHP is by a Non-Profit Organization or a government grant and revenue is only obtained to cover the initial capital cost and operation and maintenance costs, the feasibility of the project will be determined by the NPV.

Thirdly, if the development of the SSHP is for rural electrification for remote communities not connected to the local or national electricity grid, a CCCR of less than one will determine the feasibility of the project.

For the purposes of the study the focus will be on the latter two examples as well as the levelised cost of the SSHP as per the implementation model in Figure 3-1 to Figure 3-3. Therefor the feasibility of the proposed SSHP installations were evaluated on NPV and cost/benefit ratios. The NPV and cost/benefit ratios were determined within the financial analysis of the proposed SSHP projects and Table 7-1 shows the outcome of the feasibility study of the proposed SSHP projects.

Table 7-1 - Feasibility - Proposed SSHP Projects

SSHP	NPV	Cost/Benefit Ratio	Feasibility on NPV	Feasibility on Cost/Benefit ratio
1. Ndodekhling-Shayiwe	R 1 464 749	0.39	✔	✔
2. Jolwayo	R 1 642 759	0.64	✔	✔
3. Woza	- R 6 488 556	0.81	✖	✔
4. Kwa Madiba	R 9 481 367	0.38	✔	✔
5. Eskweleni	R 4 036 405	0.82	✔	✔

Following the feasibility study of the five (5) individually designed proposed small scale hydropower plants, a feasibility analysis was done and a design chart developed for future potential small scale hydropower plant projects.

The methodology followed in conducting the feasibility analysis for other potential sites consisted out of the following steps:

- STEP 1: Developing cost formulae from the priced Bill of Quantities (BOQ's), literature and past projects for the different components of the SSHP
    - Planning and design costs

- Civil Works Capital Costs
- Electro-Mechanical Equipment Capital Costs
- Electrical Transmission and Distribution Capital Costs
- Implementation Costs
- Annual Operation and Maintenance Costs

- STEP 2: Developing income/saving formulae from SSHP literature, current and predicted energy costs and past projects.
- STEP 3: Developing a NPV formula, CCCR formula and levelised cost formula for SSHP projects for the different types of plant installations focused on within the scope of the study.
- STEP 4: Setting up a model for the development of a design chart for a SSHP.
- STEP 5: Calculating the NPV, cost/benefit ratio and levelised cost for the different scenarios within the model by varying different parameters within the developed formulae.
- STEP 6: Setting up the design chart for the different scenarios within the model.
- STEP 7: Analysing and interpreting results

The following sections discusses the development of the different formulae and design chart, the design chart model, results and interpretation thereof.

For the financial analysis and calculation of the different formulae within this chapter and within the scope of the study, the base year for construction was used as 2015 and the current Rand/Euro exchange rate at the time of the analysis was used as R 13.50/€ 1.00 (06-05-2015).

7.1 DEVELOPMENT OF COST RELATIONSHIPS

In this section of the report formulae were developed for calculating the NPV for the three different configurations or schemes of SSHP under consideration within the scope of the study. The three different schemes are as follows:

1. Conventional Run-off-river Scheme (Run-off-river)
2. Run-off-river Schemes incorporating directional drilling penstock (Modified Run-off-river)
3. Kinetic turbine Hydropower plants (Kinetic)

As discussed, the cost and potential saving/income from the implementation of the three different schemes of SSHP within different scenarios were analysed and priced. From the priced BOQ's for different scenarios as well as literature and previous projects formulae was developed to calculate the NPV.

To develop the formulae for the calculation of the NPV for the different scenarios of the three different schemes the following cost and income/saving formulae were developed:

1. Capital Cost
   a. Planning and Design Costs
      i. Prefeasibility Study
      ii. Design
      iii. Legal and regulatory
      iv. Environmental and social assessment
   b. Civil Works Costs
      i. Preliminary & General Cost
      ii. Preparation of site
      iii. Turbine Room
      iv. Inlet works
      v. Tailrace works
      vi. Pipework and valves (supply and install)
   c. Electro-Mechanical Costs
      i. Turbines
      ii. Generators
      iii. Controls units (HPU, cooling and lubricating etc.)
      iv. Transformer cost and integration into electrical grid (Transmission infrastructure)
      v. Import costs
   d. Implementation Costs
      i. Commissioning, erecting and project management provided by the Supplier
      ii. Construction supervision (Consultant)
      iii. Training
      iv. Spare components to be stored on site
      v. Integration of system components (telemetry etc.)
      vi. Contingencies
2. Operation and Maintenance (OM) Cost
3. Energy Savings Cost

The above mentioned three (3) formulas were developed for the three (3) different SSHP schemes and combined to develop a formula for the calculation of the NPV for each of the three (3) different SSHP schemes. The development of the formulae is detailed in the following sections.

7.1.1 Capital Cost

The calculation and therefor the formulae for the capital cost differs for the three different SSHP schemes. The formulae for the capital costs were developed from the priced BOQ's by varying different parameters such as penstock diameters, penstock lengths, number of turbines, transmission line lengths etc.

7.1.1.1 Run-off-river and Modified Run-off-River SSHP

Planning and Design Cost

The Planning and Design Cost for the three different SSHP Schemes within the scope of this study are similar in the sense that the base formulas stays the same with only the variables changing from scheme to scheme.

The base formula for the Planning and Design Cost was developed as follows:

1. Prefeasibility Study – PFS_{Cost}
2. Design Cost– Calculated as $\%_1$ of the Civil Works Cost, the Electro-Mechanical Equipment Cost and the Implementation Cost (excluding contingencies)
3. Legal and regulatory – Calculated as $\%_2$ of the Prefeasibility Study and Design costs
4. Environmental and social assessment – Calculated as $\%_3$ of the Prefeasibility Study and Design costs

The total Planning and Design Cost for the Run-off-River SSHP is calculated as follows:

$$P\&D_{Cost} = (1 + \%_2 + \%_3) \times \%_1(CW_{Cost} + EM_{Cost} + IMP_{Cost} - Con_{Cost}) + \mathrm{PFS}_{Cost}$$

Equation 7-1

Where:

$P\&D_{Cost}$ = Planning and Design Cost (R)

CW_{Cost} = Civil Works Cost (R)

EM_{Cost} = Electro-Mechanical Cost (R)

IMP_{Cost} = Implementation Cost (R)

Con_{Cost} = Contingencies (R)

PFS_{Cost} = Prefeasibility Study Cost (R)

$\%_1$ = Design Cost variable

$\%_2$ = Legal and Regulatory Cost variable

$\%_3$ = Environmental and social assessment variable

Civil Works Cost

For the civil work cost component of the Run-of-River schemes there are different cost components for the conventional Run-of-River scheme and the Modified Run-off-River scheme.

From the priced BOQ's the variable for the calculation of the Civil Works cost for the Run-off-River SSHP schemes is inlet works, the tailrace length, penstock length and penstock diameter. By standardising the inlet works and limiting the tailrace length to 20 m, the variables for the calculation of the Civil Works Costs becomes the penstock length and penstock diameter. From the priced BOQ's the variables for the calculation of the Civil Works cost for the Modified Run-off-River SSHP schemes is inlet works, the tailrace length, directionally drilled penstock length and penstock diameter. By standardising the inlet works and limiting the tailrace length to 20 m, the variables for the calculation of the Civil Works Costs becomes the directionally drilled penstock length and penstock diameter.

The priced BOQ is based on the design within Chapter 4 and therefor incorporates the prices of designed turbine units. Formula may vary for different turbine suppliers. From the priced BOQ's the following formula was developed for the Civil Works Cost (CWC) for the Run-off-River SSHP schemes within Microsoft Excel with regression analysis by using the method of least squares for six (6) selected penstock diameters:

- 250 mm diameter:

$$CW_{Cost} = 533.04L_{PEN(250)} + 439266$$

Equation 7-2

Where:

CW_{Cost} = Civil Works Cost

$L_{PEN(250)}$ = Length representative of a 250 mm diameter Penstock

- 315 Mm diameter:

$$CW_{Cost} = 850.38L_{PEN(315)} + 462182$$

Equation 7-3

- 355 Mm diameter:

$$CW_{Cost} = 1032.3L_{PEN(355)} + 481429$$

Equation 7-4

- 400 mm diameter:

$$CW_{Cost} = 1267.9L_{PEN(400)} + 517156$$

Equation 7-5

- 450 mm diameter:

$$CW_{Cost} = 1569.5L_{PEN(450)} + 542544$$

Equation 7-6

- 500 mm diameter:

$$CW_{Cost} = 1898.9L_{PEN(500)} + 560547$$

Equation 7-7

From the priced BOQ's the following formula was developed for the Civil Works Cost (CWC) for the Modified Run-off-River SSHP schemes within Microsoft Excel with regression analysis by using the method of least squares for three (3) selected penstock diameters. The directional drilling cost increases exponentially for diameters 400 mm and larger. The directional drilling penstock length is also limited by the capacity of the drill to 800 m. The formulae developed for the Civil Works Cost for the Modified Run-off-River SSHP schemes is as follows:

- 200 mm diameter:

$$CW_{Cost} = 4325L_{PEN(DD200)} + 671271$$

Equation 7-8

- 315 Mm diameter:

$$CW_{Cost} = 4918.3L_{PEN(DD315)} + 690976$$

Equation 7-9

- 355 Mm diameter:

$$CW_{Cost} = 5127.4L_{PEN(DD355)} + 743351$$

Equation 7-10

<u>Electro-Mechanical Cost</u>

From the priced BOQ's for the Electro-Mechanical components of the SSHP, it was observed that the cost of the medium voltage (MV) line is related to change in the transmission line length and the cost of the low voltage (LV) line is related to a change in the distribution line length which correlates directly to the amount of households connected to the mini-grid. If our aim is to provide every household with a minimum of 1 kW or 720 kWh per month the amount of households which can be served is equal to the potential power generation of the SSHP in kW.

The formulae developed for the Electro-Mechanical Cost for the Run-off-River SSHP schemes is as follows:

$$MV_{Cost} = 293.73 \times TL + 168274$$

Equation 7-11

Where:

MV_{Cost} = Medium Voltage line cost (R)

TL = Transmission line length (m)

And,

$$LV_{COST} = 17528 \times HH_{no.} + 4920$$

Equation 7-12

Where:

LV_{COST} = Low Voltage line cost (R)

$HH_{no.}$ = Number of households

Total Electro-Mechanical Cost (EM_{Cost}):

$$EM_{Cost} = 293.73 \times TL + 168274 + 17528 \times HH_{no.} + 4920 + TUR_{Cost}$$

$$\therefore EM_{Cost} = 293.73TL + 17528HH_{no.} + TUR_{Cost} + 292244$$

Equation 7-13

Where:

EM_{Cost} = Electro-Mechanical Cost (R)

TL = Transmission line length (m)

$HH_{no.}$ = Number of households

TUR_{Cost} = Turbine, Generator and Control System Cost + Import cost (Estimated at 20%) (R)

<u>The Implementation Cost</u>

The implementation cost component of the Capital Cost of the SSHP was split as follows and calculated:

1. Commissioning, erecting and project management provided by the Supplier – calculated as % of the Electro-Mechanical Cost:

$$Com_{Cost} = \% * EM_{Cost}$$

Equation 7-14

Where:

Com_{Cost} = Commissioning Cost (R)

EM_{Cost} = Electro-Mechanical Cost (R)

2. Construction supervision (Consultant) – Calculated % of the Electro-Mechanical Cost and Civil Works Cost:

$$Supv = \%(EM_{Cost} + CW_{Cost})$$

Equation 7-15

Where:

$Supv$ = Supervision Cost (R)

EM_{Cost} = Electro-Mechanical Cost (R)

CW_{Cost} = Civil Works Cost (R)

3. Training – Calculated as % of the Turbine, Generator and Control System Cost

$$TRAIN_{Cost} = \% * TUR_{Cost}$$

Equation 7-16

Where:

$TRAIN_{Cost}$ = Training Cost (R)

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

4. Spare components to be stored on site – Calculated as % of the Turbine, Generator and Control System Cost

$$SPARES_{Cost} = \% * TUR_{Cost}$$

Equation 7-17

Where:

$SPARES_{Cost}$ = Spare components to be stored on site (R)

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

5. Integration of system components (telemetry etc.) - Calculated as % of the Turbine, Generator and Control System Cost

$$TELE_{Cost} = \% * TUR_{Cost}$$

Equation 7-18

Where:

$TELE_{Cost}$ = Telemetry Cost (R)

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

At this stage the following assumptions regarding percentage factors were assumed for the calculation of the Implementation Cost:

- Commissioning, erecting and project management provided by the Supplier – 5% of the Electro-Mechanical Cost:
- Construction supervision (Consultant) – 7.5% of the Electro-Mechanical Cost and Civil Works Cost:
- Training – 3% of the Turbine, Generator and Control System Cost
- Spare components to be stored on site – 3% of the Turbine, Generator and Control System Cost
- Integration of system components (telemetry etc.) – 6% of the Turbine, Generator and Control System Cost

6. Contingencies – Calculated as % of the Civil Works Cost, Electro-Mechanical Cost and Implementation cost before contingencies:

$$Con = \%(CW_{Cost} + EM_{Cost} + Com_{Cost} + SPARES_{Cost} + Supv + 0.09TUR_{Cost})$$

Equation 7-19

In the calculation of the total Implementation Cost the contingencies were assumed as 5% of the Civil Works Cost, Electro-Mechanical Cost and Implementation cost before contingencies

The formula for the total Implementation Cost is therefor calculated as the following:

$$IMP_{Cost} = 0.129CW_{Cost} + 0.181EM_{Cost} + 0.126TUR_{Cost}$$

Equation 7-20

Where:

IMP_{Cost} = Implementation Cost

CW_{Cost} = Civil Works Cost

EM_{Cost} = Electro-Mechanical Cost

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

Total Capital Cost

The following percentage factors and constants were assumed for the calculation of the total Capital Costs:

1. Prefeasibility Study – Estimated as R 50 000.00
2. Legal and regulatory – Calculated as 20% of the Prefeasibility Study and Design costs
3. Environmental and social assessment – Calculated as 15% of the Prefeasibility Study and Design costs

The total Capital Cost for the Run-off-River SSHP Scheme was then calculated as,

$$Total\ Cap_{Cost} = P\&D_{Cost} + CW_{Cost} + EM_{Cost} + IMP_{Cost} + Con$$

Equation 7-21

Where:

$Total\ Cap_{Cost}$ =Total Capital Cost

$P\&D_{Cost}$ = Planning and Design Cost

CW_{Cost} = Civil Works Cost

EM_{Cost} = Electro-Mechanical Cost

IMP_{Cost} = Implementation Cost

Con = Contingencies

As the CWC formulae changes for a change in penstock diameters the total Capital Cost for the SSHP changes. As an example the formula for the total Capital Cost for the Run-off-River SSHP with a 355 Mm diameter pipeline penstock and varying transmission line length, households served, turbine cost and currency exchange rate is as follows:

$$Total\ CapCost_{PEN(355)} = 1356.042L_{PEN(355)} + 403.49TL + 24077.99HH_{no.} + 1.52TUR_{Cost} + 1154517.58$$

Equation 7-22

Where:

$Total\ CapCost_{PEN(355)}$ =Total Capital Cost for Run-off-River SSHP with 355 Mm diameter penstock

$L_{PEN(355)}$ = Length of 355 Mm diameter Penstock

TL = Transmission line length (m)

$HH_{no.}$ = Number of households

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

As an example the formula for the total Capital Cost for the Modified Run-off-River SSHP with a 355 Mm diameter pipeline penstock and varying transmission line length, households served, turbine cost and currency exchange rate is as follows:

$$Total\ CapCost_{PEN(355)} = 6735.42L_{PEN(355)} + 403.49TL + 24077.99HH_{no.} + 1.52TUR_{Cost} + 1429781.14$$

Equation 7-23

Where:

$Total\ CapCost_{PEN(355)}$ =Total Capital Cost for Run-off-River SSHP with 355 Mm diameter penstock

$L_{PEN(355)}$ = Length of 355 Mm diameter Penstock

TL = Transmission line length (m)

$HH_{no.}$ = Number of households

TUR_C = Turbine Cost

7.1.1.2 Kinetic

<u>Planning and Design Cost</u>

Similarly as for the Run-off-River SSHP and the Modified Run-off-River SSHP, the total Planning and Design Cost for the Modified Run-off-River SSHP is calculated as follows:

$$P\&D_{Cost} = (1 + \%_2 + \%_3) \times \%_1(CW_{Cost} + EM_{Cost} + IMP_{Cost} - Con_{Cost}) + \text{PFS}_{Cost}$$

Equation 7-24

Where:

$P\&D_{Cost}$ = Planning and Design Cost (R)

CW_{Cost} = Civil Works Cost (R)

EM_{Cost} = Electro-Mechanical Cost (R)

IMP_{Cost} = Implementation Cost (R)

Con_{Cost} = Contingencies (R)

PFS_{Cost} = Prefeasibility Study Cost (R)

$\%_1$ = Design Cost variable

$\%_2$ = Legal and Regulatory Cost variable

$\%_3$ = Environmental and social assessment variable

Civil Works Cost

From the priced BOQ's the variable for the calculation of the Civil Works cost for the Kinetic SSHP schemes is the number of kinetic turbines used in the scheme. The priced BOQ is based on the design within Chapter 4 and therefor incorporates the price of designed turbine units. Formula may vary for different turbine suppliers. From the priced BOQ's the following formula was developed for the Civil Works Cost (CW_{Cost}) for the Kinetic SSHP schemes:

$$CW_{Cost} = 14270TUR_i + 43670$$

Equation 7-25

Where:

CW_{Cost} = Civil Works Cost

TUR_i = Number of Kinetic Turbine Installed

Cognisance should be taken of the fact that there is a difference between the number of kinetic turbines installed,TUR_i, and the cost of turbines installed, TUR_{Cost}.

Electro-Mechanical Cost

The Electro-Mechanical Cost for the Kinetic Turbine SSHP Schemes is calculated similarly to the Implementation Cost of the first two SSHP schemes within the scope of the study as the following:

$$EM_{Cost} = 293.73TL + 17528HH_{no.} + TUR_{Cost} + 292244$$

Equation 7-26

The Implementation Cost

The Implementation Cost for the Kinetic Turbine SSHP Schemes is calculated similarly to the Implementation Cost of the first two SSHP schemes within the scope of the study as the following:

$$IMP_{Cost} = 0.129CW_{Cost} + 0.181EM_{Cost} + 0.126TUR_{Cost}$$

Equation 7-27

Total Capital Cost

The following percentage factors and constants were assumed for the calculation of the total Capital Costs:

1. Prefeasibility Study – Estimated as R 50 000.00
2. Legal and regulatory – Calculated as 20% of the Prefeasibility Study and Design costs
3. Environmental and social assessment – Calculated as 15% of the Prefeasibility Study and Design costs

The total Capital Cost for the Kinetic Turbine SSHP Scheme was then calculated as,

$$Total\ CapCost_{Kinetic} = 19336.38TUR_i + 1.685TUR_{Cost} + +403.49TL + 24077.99HH_{no.} + 582107.39$$

Equation 7-28

Where:

$Total\ CapCost_{Kinetic}$ = Total Capital Cost for Kinetic Turbine SSHP

TUR_i = Number of Kinetic Turbine Installed

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

TL = Transmission line length (m)

$HH_{no.}$ = Number of households

7.1.2 Operation and Maintenance (OM) Cost

The Annual Operation and Maintenance Cost of the three SSHP schemes discussed were calculated for the different components of the SSHP as follows:

- Civil works = 0.25% of Civil Works Cost
- Electrical and mechanical works = 2.00% of Turbine, Generator and Control System
- Transmission = 0.80% of Transmission and Distribution Cost

- Operation = 0.40% of Total Capital Cost
- Insurance = 0.30% of Total Capital Cost

Therefor the total Annual Operation and Maintenance Cost (OM) of the individual SSHP schemes was calculated as the following:

$$OM_{Cost} = 0.0025CW_{Cost} + 0.02TUR_{Cost} + 0.008T\&D_{Cost} + 0.007Cap_{Cost}$$

Equation 7-29

Where:

OM_{Cost} = Annual Operation and Maintenance Cost (R)

CW_{Cost} = Civil Works Cost (R)

EM_{Cost} = Electro-Mechanical Equipment Cost (R)

$T\&D_{Cost}$ = Transmission and Distribution Cost (R)

Cap_{Cost} = Total Capital Cost (R)

7.1.3 Energy Cost

The total annual energy cost for the base year (year 1) was calculated and is applicable to all three of the SSHP schemes. The total annual energy cost for the base year ($AECS_1$) is used in the NPV calculation. For this calculation a total operational life as well as different inflation, escalation and discount rates need to be calculated or assumed. The NPV calculation is discussed in the following section.

The development of a comprehensive formulae for the AEC_1 is detailed below:

$$AEC_1 = 8760P \times EC_1$$

Equation 7-30

Where:

AEC_1 = Annual Energy Cost in year 1 (base year)

P = Average Annual Generating Capacity (kW)

EC_1 = Energy unit cost in year 1 (base year) (R/kWh)

7.2 FEASIBILITY MODEL AND DESIGN CHART

The feasibility model was developed for the three different types of potential SSHP configurations or plants within the scope of the study:

1. Conventional Run-off-river Scheme (Run-off-river)
2. Run-off-river Schemes incorporating directional drilling penstock (Modified Run-off-river)
3. Kinetic turbine Hydropower plants (Kinetic)

For the Run-off-river schemes flow was kept as a constant within the model at 200 l/s (litres per second). This figure was calculated as the amount of flow most commonly present for 95% of the time within the river sections under consideration, as well as the highest value of flow that can be rerouted without adversely effecting the environment at most of the investigated potential sites (sites with a more accurate flow record and a higher statistically estimated minimum flow may reroute larger amounts of flow). For the Modified Run-off-river schemes the value was decreased to 150 l/s, to lower frictional losses and increase power potential and therefor savings. This was due to the relatively high cost of the drilling civil works component.

With flow kept constant, the available head and penstock diameter was varied to obtain different scenarios within the feasibility model. By varying the head at a constant flow, the energy generated, P, also varies and by assuming a basic supply of 1 kW per household (24 kWh per day) the amount of households served is also calculated. For the Kinetic turbine Hydropower plants the velocity of flow as well as the number of turbines were varied.

Table 7-2 and Table 7-3 show the model developed for the feasibility analysis and matrix development. As indicated on the model, 42 different scenarios were analysed. As discussed in the previous sections, the financial assessment for the different scenarios was done and analysed by varying different parameters within the developed formulae. As discussed in Chapter 6, a positive NPV is defined as a feasible SSHP project. The parameters which were varied is as follows:

1. Transmission line lengths
2. Penstock lengths (not applicable to Kinetic turbine Hydropower plants)

The interpretation of the analyses results is discussed within the sections to follow.

Table 7-2 - Feasibility Model (Run-off-River and Modified Run-off-River SSHP)

	Run-off-River*			Mod. Run-off-River		
Flow (Q)	0.2 m³/s			0.15 m³/s		
Available Head (H)	5 m	10 m	20 m	10 m	20 m	50 m
Penstock Diameter (D)	250 mm	250 mm	250 mm	200 mm	200 mm	200 mm
	315 mm	315 mm	315 mm	315 mm	315 mm	315 mm
	355 mm	355 mm	355 mm	355 mm	355 mm	355 mm
	400 mm	400 mm	400 mm	400 mm	400 mm	400 mm
	450 mm	450 mm	450 mm			
	500 mm	500 mm	500 mm			
*for the Run-off-River SSHP the same turbine is used for the 10 m and 20 m head model than in the Mod. Run-off-River SSHP model. For the 5 m head model, Low Head turbine technology is used.						

Table 7-3 - Feasibility Model (Kinetic Type Turbine)

	Kinetic		
Flow Velocity (m/s)	1	2	3
No. of Kinetic Turbines	1	1	1
	2	2	2
	4	4	4
	6	6	6

The calculated NPV formula for the SSHP schemes are given below. The civil works cost, and total capital costs within the NPV formulae differs as per the initial CW_{Cost} and Total Cap_{Cost} formulae developed for the different configurations of penstock diameters. The NPV formula is as follows:

$$NPV = T \times AEC_1 \sum_{i=1}^{T} \left(\frac{1 + ESC_{ENERGY}}{1 + DiscR}\right)^{t+i} - (0.0025CW_{Cost} + 0.02TUR_C)$$
$$+ \sum_{i=1}^{T} \left(\frac{1 + ESC_{MAINT}}{1 + DiscR}\right)^{t+i}$$
$$- 0.004(CW_{Cost} + EM_{Cost} + IMP_{Cost}) \sum_{i=1}^{T} \left(\frac{1 + ESC_{OPER}}{1 + DiscR}\right)^{t+i}$$
$$- [0.008(0.833EM_{Cost} - TUR_{Cost})$$
$$- 0.003(CW_{Cost} + EM_{Cost} + IMP_{Cost})] \sum_{i=1}^{T} \left(\frac{1 + ESC_{OTHER}}{1 + DiscR}\right)^{t+i} - Total\ Cap_{Cost}$$

Equation 7-31

Where:

NPV = Nett Present Value (R)

T = Useful design life (years)

AEC_1 = Annual Energy Cost in year 1 (base year) (R)

ESC_{ENERGY} = Escalation of Energy Cost (%)

$DiscR$ = Discount Rate (Value of Capital) (%)

CW_{Cost} = Civil Works Cost (R)

TUR_{Cost} = Turbine, Generator and Control System Cost (R)

ESC_{MAINT} = Escalation of Maintenance Cost (%)

EM_{Cost} = Electro-Mechanical Equipment Cost (R)

IMP_{Cost} = Implementation Cost (R)

ESC_{OPER} = Escalation of Operational Cost (%)

ESC_{OTHER} = Escalation of Other Cost (%)

$Total\ Cap_{Cost}$ = Total Capital Cost for the SSHP (R)

Parameters which were kept constant, assumed or estimated were as follows:

- Flow – As per model
- Head – As per model
- Penstock Diameter – As per model

- Turbine Cost – As per design
- System lifespan – 40 years
- Construction period – 1 year
- Escalation of Operational costs – 8 %/annum
- Escalation of Maintenance cost – 10 %/annum
- Escalation of Energy costs – 10 %/annum
- Discount rate (Value of Capital) – 5 %/annum
- Escalation of Other costs – 10 %/annum

7.3 RESULTS

The results from different scenarios from the model for the feasibility analysis were plotted to graphically obtain charts for the design of SSHP projects for different head and flow availabilities and varying penstock diameters and transmission line lengths. The diagonal lines for the different penstock diameters represent a zero NPV. The area underneath the diagonal lines represent a positive NPV and therefor a feasible installation, opposed to the area above the diagonal lines represent a negative NPV and therefor an unfeasible installation or project.

Figure 7-1 to Figure 7-3 below shows the design charts for selected head and flow scenarios for Run-of-River, Modified Run-of-River and Kinetic Turbine SSHP projects. An example and explanation on the interpretation of the charts is given in section 7.4.

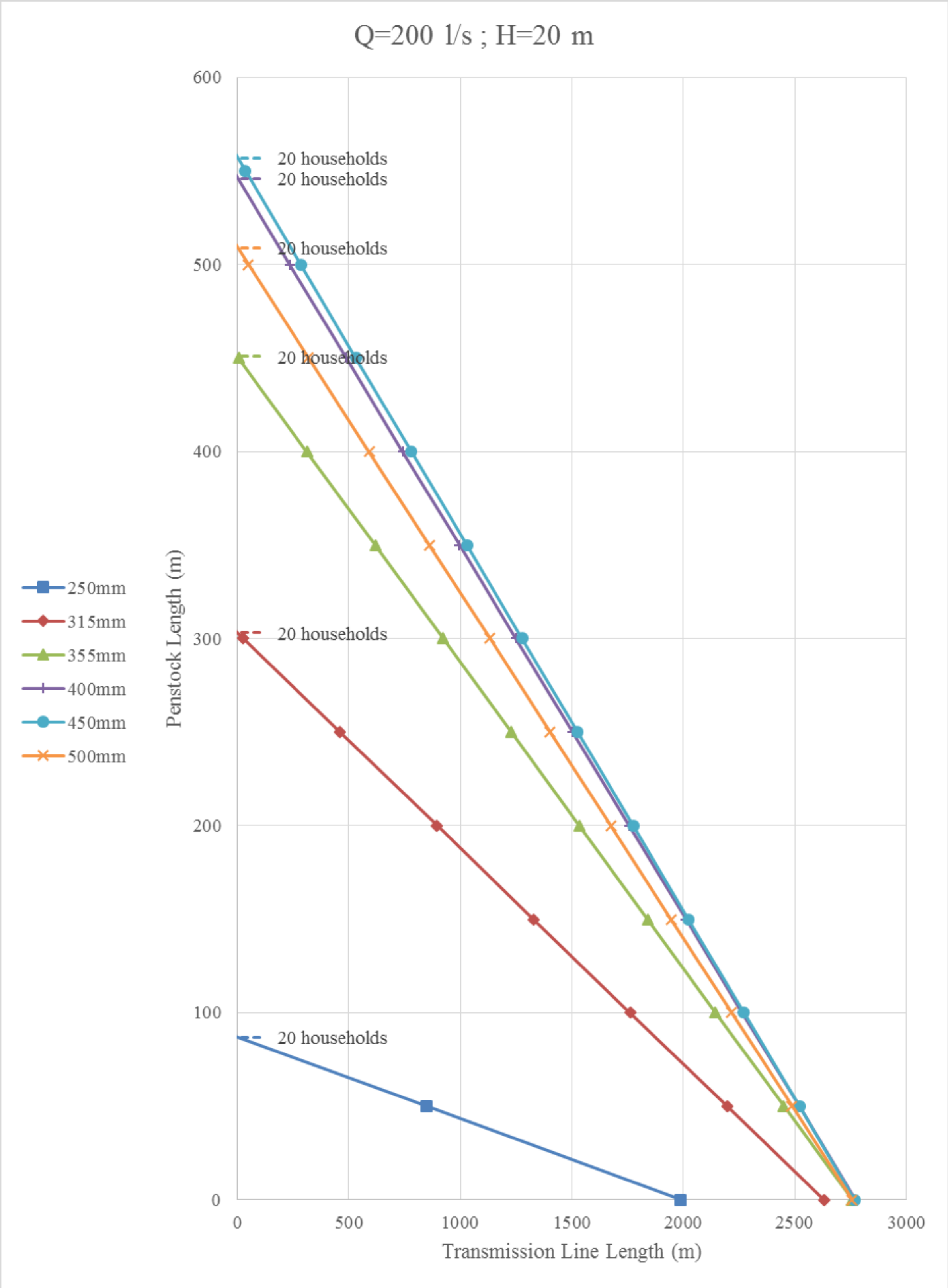


Figure 7-1 - Feasibility Analysis - Design Chart - Run-of-River SSHP NPV

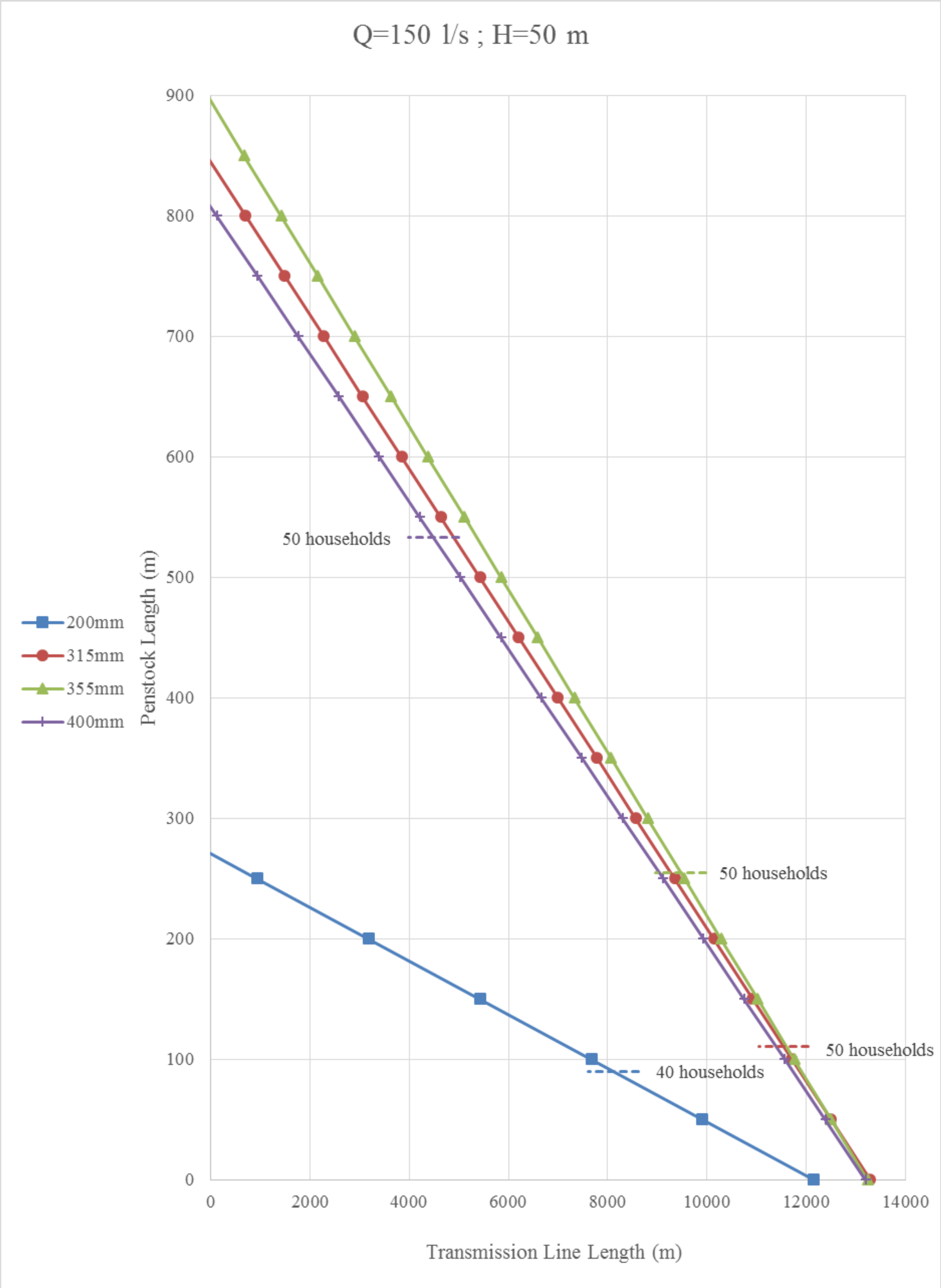


Figure 7-2 - Feasibility Analysis - Design Chart - Modified Run-of-River SSHP NPV

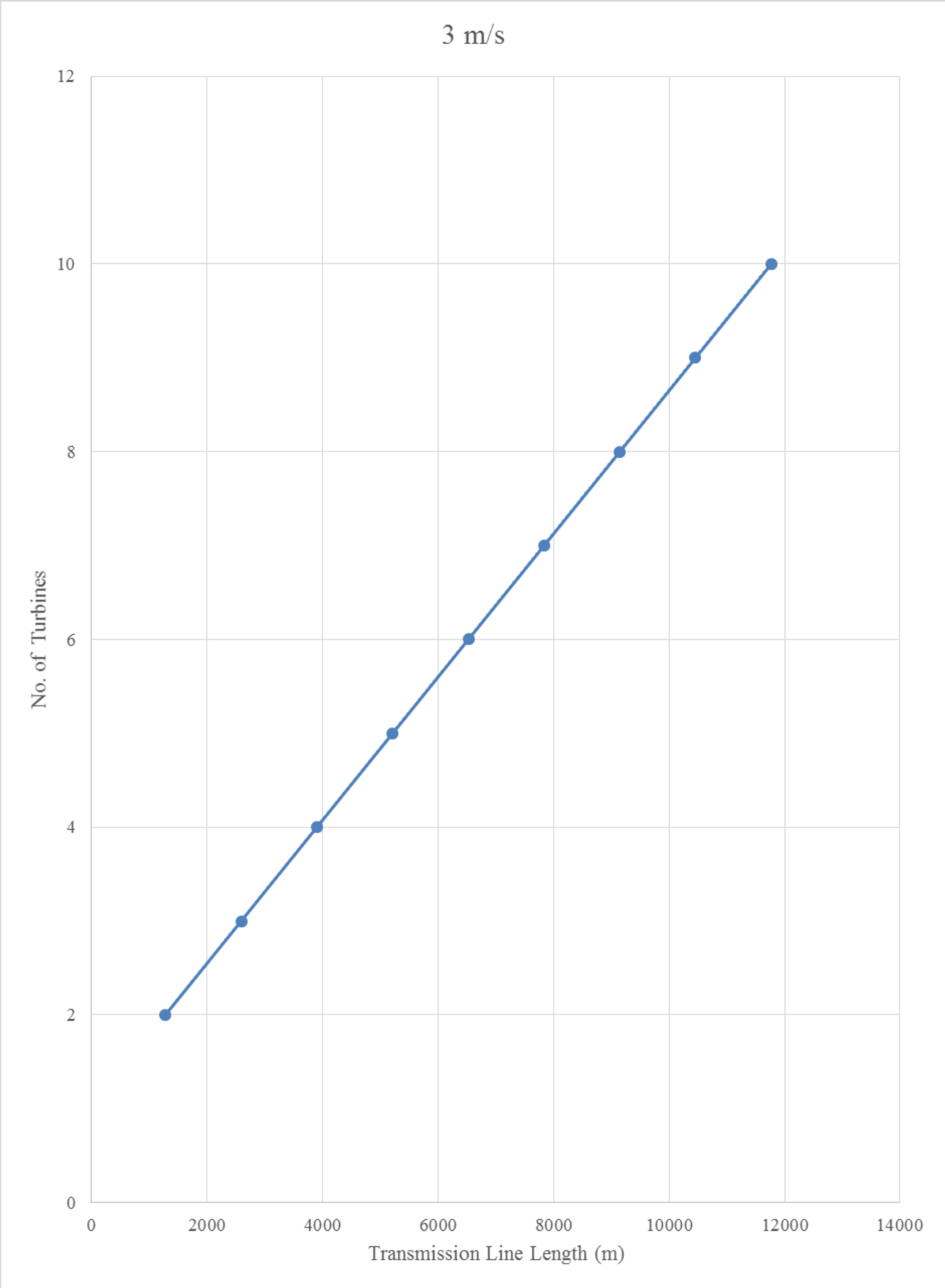


Figure 7-3 - Feasibility Analysis - Design Chart - Kinetic Turbine SSHP NPV

The escalation of energy costs is a major factor in the NPV of a SSHP project. The calculations within the scope of the study was done on an estimation of escalation of energy costs of 10%. Figure 7-4 shows a comparison of the NPV for different escalation of energy costs. The other parameters of the SSHP is kept as follows:

- Scheme – Run-of-River SSHP
- Head available – 20 m
- Flow available – 200 l/s
- Penstock diameter – 315 Mm
- Penstock length – 150 m
- Transmission line length – 800 m
- System lifespan – 40 years
- Construction period – 1 year
- Escalation of Operational costs – 8 %/annum
- Escalation of Maintenance cost – 10 %/annum
- Discount rate (Value of Capital) – 5 %/annum
- Escalation of Other costs – 10 %/annum

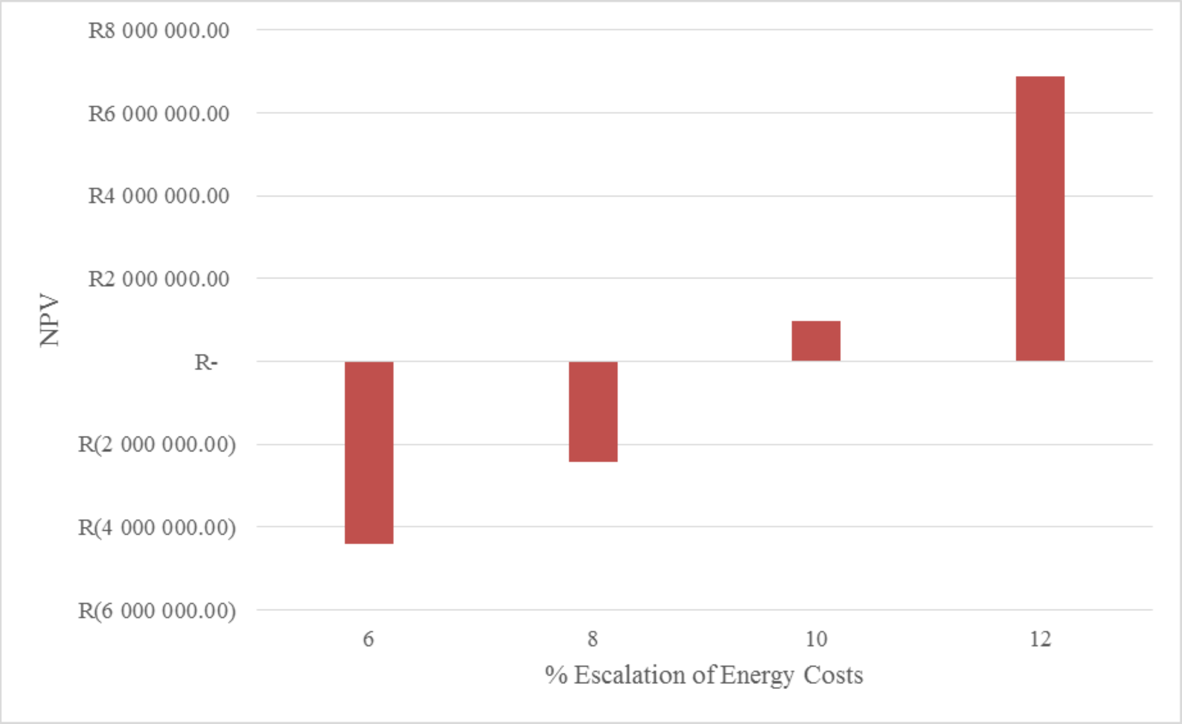


Figure 7-4 - Escalation of Energy Costs - NPV comparison

7.4 INTERPRETATION OF RESULTS AND FEASIBILITY ANALYSIS

The design charts developed in 7.3 graphically depicts a NPV of 0 by the diagonal lines for different designs of penstock diameters for varying penstock lengths and transmission line lengths. When calculating the feasibility of a SSHP project based on a positive NPV, all points below the line for both the Run-of-River and Modified Run-of-River SSHP depicts a SSHP with configuration of penstock length and transmission line length which is feasible for the specific penstock diameter.

The horizontal dotted lines on the graphs represent the total amount of households which can be served with 1 kW electricity for every specific SSHP scheme configuration. All penstock lengths below the household line can serve the amount of households indicated by the dotted line.

For example by using the developed charts the following potential SSHP can be evaluated:

- Scheme – Run-of-River SSHP
- Head available – 20 m
- Flow available – 200 l/s
- Penstock diameter – 315 Mm
- Penstock length – 150 m
- Transmission line length – 1000 m

Using the above data and the developed chart (Figure 7-5) it can be evaluated that the potential SSHP will be feasible on the grounds that it has a positive NPV. It can also be seen that 20 households can be supplied with 1 kW per household.

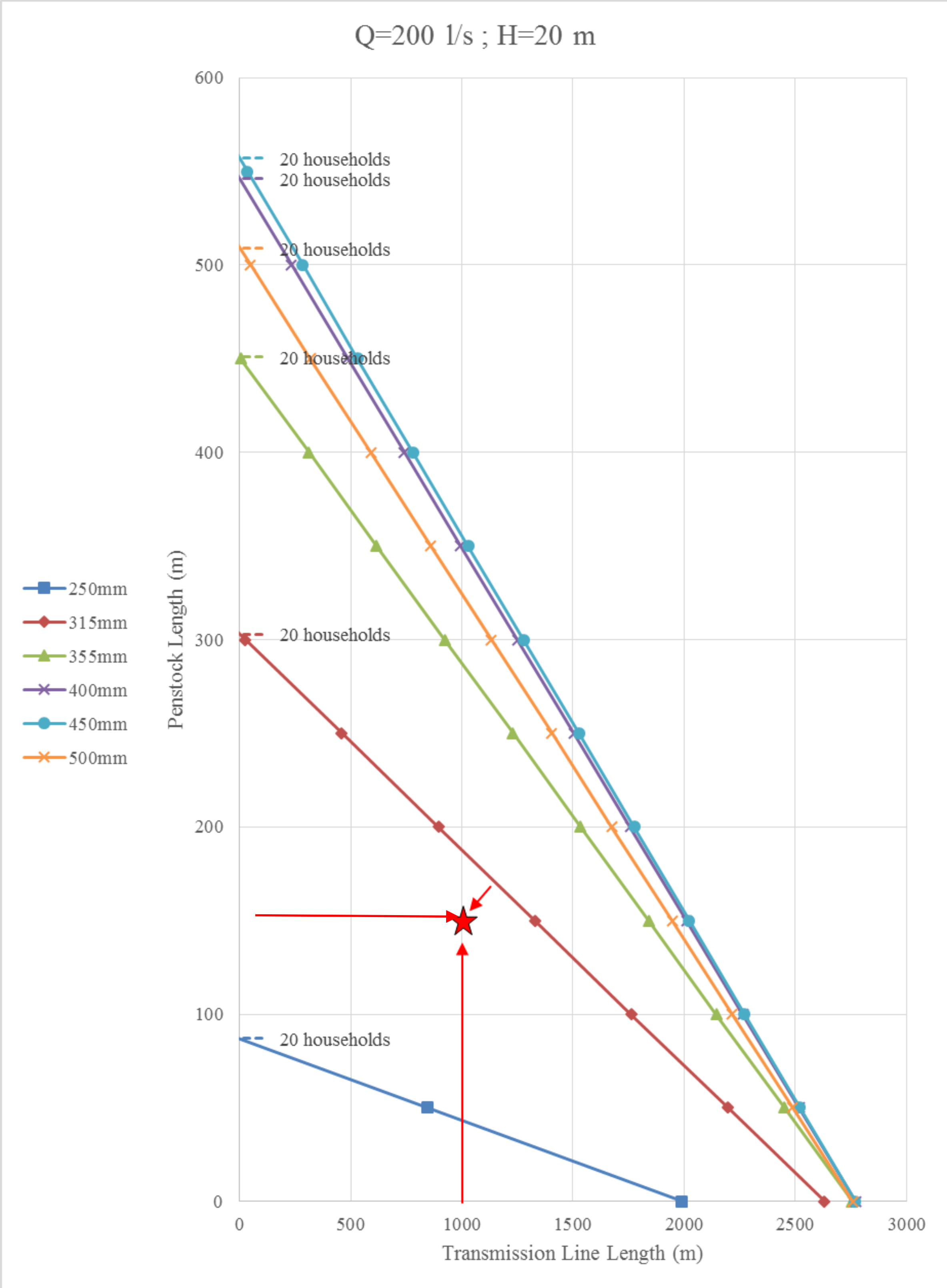


Figure 7-5 - Feasibility Analysis - Design Chart - Run-of-River SSHP NPV – Example

For the kinetic turbine SSHP chart, the diagonal line also represents a NPV of 0. The diagonal line represents a NPV of 0 for different stream velocities at the installation. The difference between the charts for the kinetic turbine SSHP and the Run-of-River and Modified Run-of-River SSHP is that the kinetic turbine does not have a penstock but the NPV is rather calculated with a varying amount of turbines installed. Also all points above the 0 NPV line represents a positive NPV and all the points below the 0 NPV line represents a negative NPV. For the kinetic turbine SSHP, the cost of the turbine in comparison to the energy generated at low stream velocities does not justify the cost of transmission lines when evaluating feasibility on the NPV of the SSHP. For this reason only the installations with an available stream velocity of 3 m/s were considered in the charts.

From the developed Design Charts it can be found that several technically possible configurations of penstock length and transmission line length have negative NPV values. Therefor the NPV can not be used in isolation for determining the feasibility of these configurations. The NPV could be used in isolation in a commercial environment. For this reason the potential SSHP should also be evaluated on both cost/benefit ratio and levelised cost.

7.5 CAPITAL COST COMPARISON RATIO (CCCR)

The CCCR is calculated as described in chapter 5 as the ratio of the capital cost of the SSHP and the cost of providing electrical infrastructure (transmission and distribution lines) to connect the rural settlement or community to the existing local or national electricity grid. Therefor the SSHP benefit of a project can be calculated by the developed formulae.

$$CCCR = \frac{Grid\ Extension\ Capital\ Cost}{SSHP\ Capital\ Cost}$$

Equation 7-32

When calculating the SSHP benefit of a project the following variables are applicable:

- Flow
- Head
- Penstock diameter
- Penstock length
- Transmission line length
- Distance to closest existing electrical grid.

The cost of connecting the rural communities to the local or national electricity grid in Sub-Sahara Africa estimated as between R 1 200 and R1 300 per meter by the World Bank (Deichmann, Meisner, Muaary and Wheeler, 2010). This estimation compares well with similar research done by local consulting companies. Similar as the developed design charts for SSHP, charts for CCCR of less than 1 for different penstock diameters were developed. Figure 7-6 shows an example of such a chart for a 355 mm diameter penstock for a Run-off-River SSHP (Q=200 l/s; H=20 m), with the diagonal lines representing a cost/benefit ratio of 1.00. Everything below the line is a cost/benefit ratio of less than 1.00 and therefor feasible and everything above the line is a cost/benefit ratio of more than 1.00 and therefor unfeasible. The different diagonal lines were constructed using different lengths to the existing electricity grid as can be seen in the legend. Following a similar approach can be used to develop charts for cost ratio benefits of different configurations and SSHP projects.

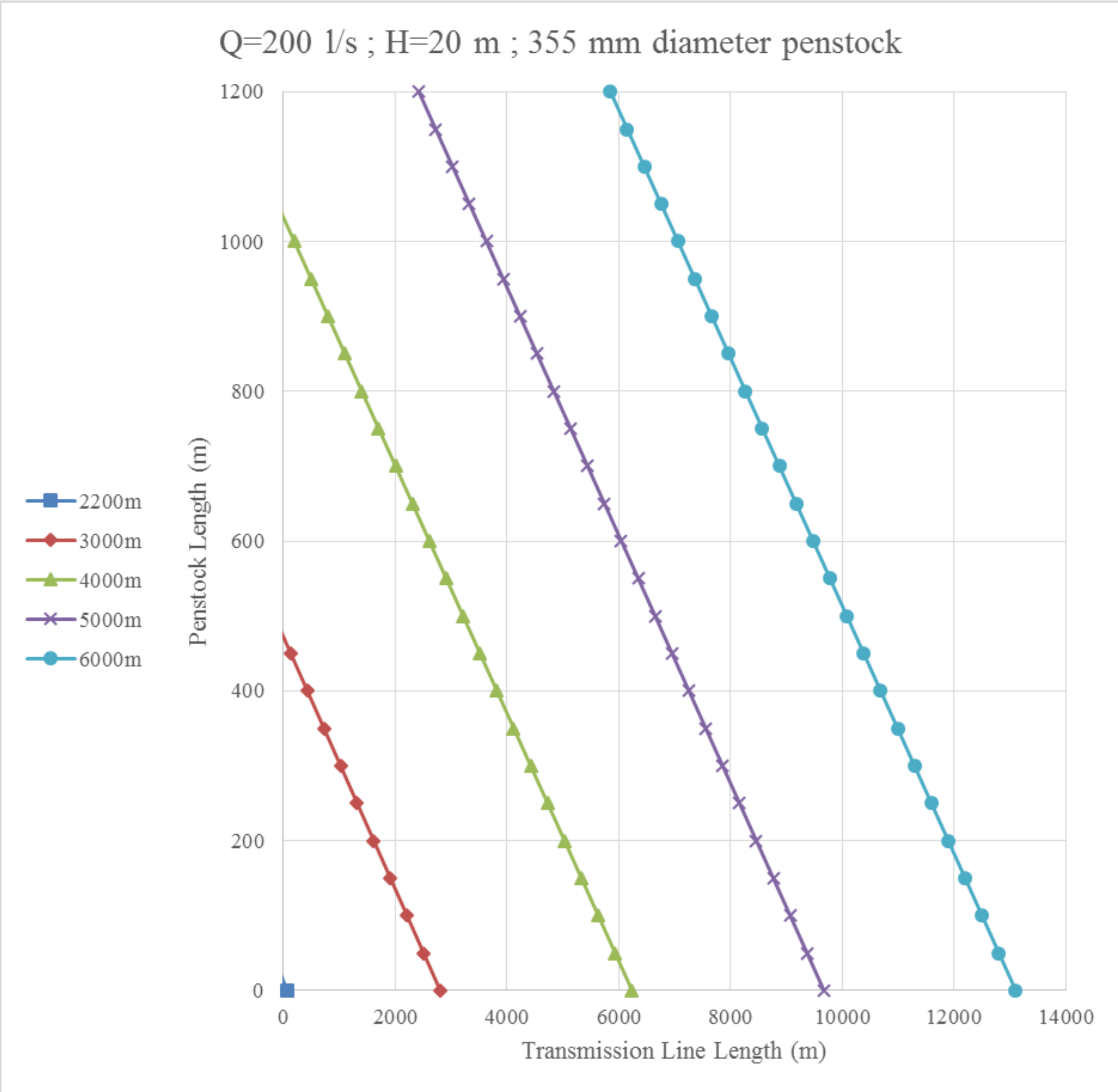


Figure 7-6 - CCCR chart - Run-of-River SSHP

7.6 LEVELISED COST

The SSHP were also evaluated on the levelised cost of the project. The levelised cost of the SSHP is defined as the total cost of the SSHP project over the full operational lifespan of the system divided by the total energy generated over the lifespan of the system. The formula for the levelised cost (c/kWh) of a SSHP is as follows:

$$Levelised\ Cost = \frac{NPV\ of\ costs}{Total\ Energy\ Generated}$$

Equation 7-33

Similar as the analysis for the NPV and the cost/benefit ratio of several SSHP systems, the levelised cost for different SSHP systems were calculated and compared to the levelised cost of fossil fuel generated grid connected electricity. The levelised cost of electricity as generated by ESKOM is between 70 and 80 c/kWh (EPRI, 2012). The levelised cost of different SSHP system were compared to this value. This comparison is seen in Figure 7-7.

Table 7-4 shows the SSHP scenarios were analysed based on levelised cost and compared to a levelised cost for ESKOM to extend the existing grid and supply the remote rural community with electricity. This comprises of the 80 c/kWh levelised cost for ESKOM generation as well as a levelised cost for the grid extension for different distances of the existing grid from the remote rural community:

Table 7-4 - SSHP scenarios for levelised cost comparison

Scenario		Power	Penstock Diameter	Penstock Length	Transmission Line Length
Modified Run-of-River SSHP	Scenario 1	50 kW	355 mm	100 m	1000 m
	Scenario 2	50 kW	355 mm	100 m	2000 m
	Scenario 3	50 kW	355 mm	200 m	1000 m
	Scenario 4	50 kW	355 mm	200 m	2000 m
Eskom		Variable grid extension lengths			

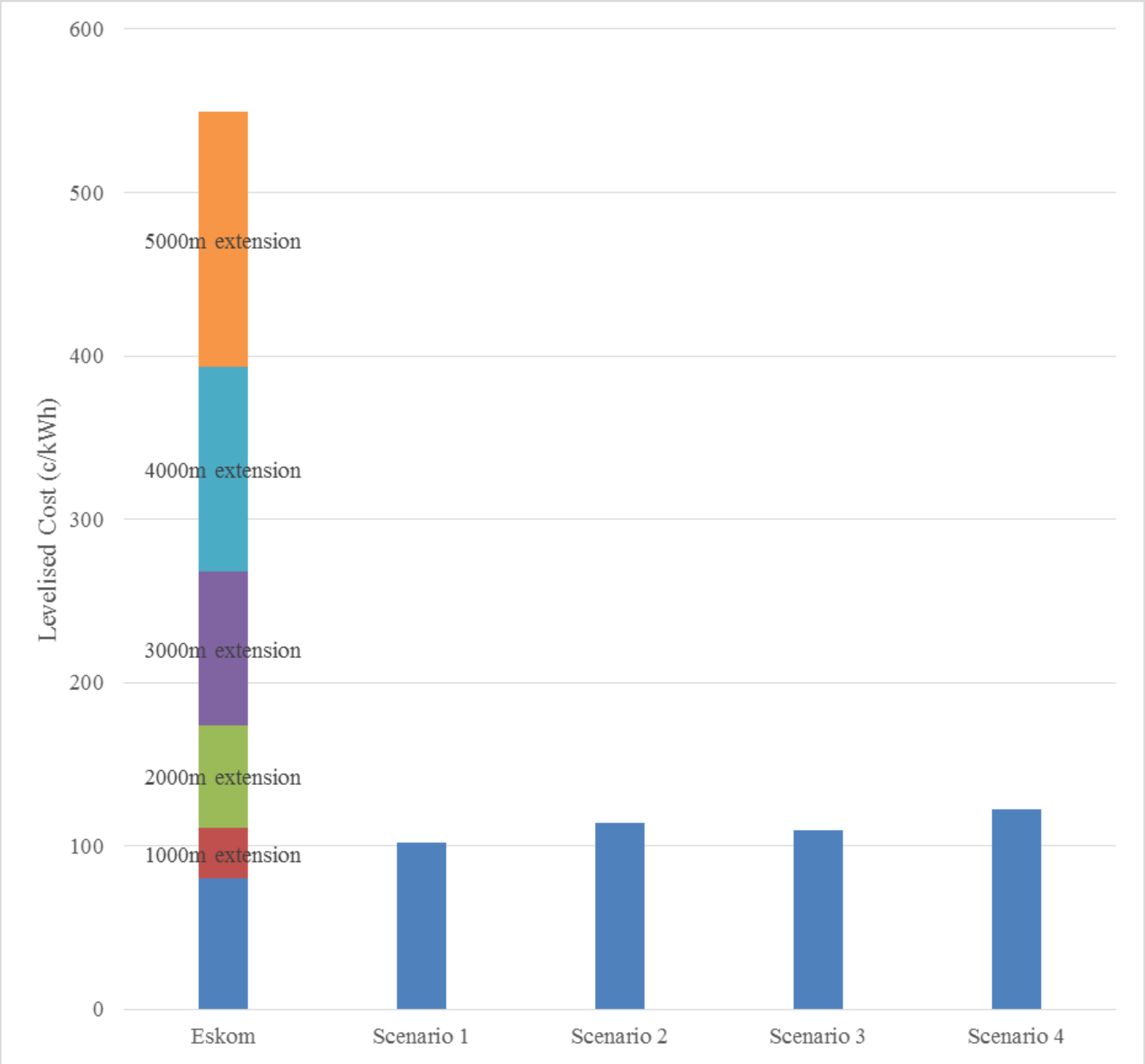


Figure 7-7 - Levelised cost comparison

7.7 RESULTS COMPARISON

As described, there are three different ways or approaches in calculating the feasibility of a SSHP project depending on the type of development out of which the SSHP originates, namely the IRR, NPV and cost/benefit ratio. The feasibility analysis on the SSHP project was only done on the NPV and cost/benefit ratio of proposed projects, with a third variable, the levelised cost, also analysed.

The following example shows the feasibility as determined by the different means and charts developed and discusses the different results obtain for the same SSHP project. The SSHP project for the example has the following parameters:

- Scheme – Run-off-River
- Flow – 200 l/s
- Head – 20 m
- Penstock diameter – 355 mm
- Penstock length – 200 m
- Transmission line length – 2000 m
- System lifespan – 40 years
- Construction period – 1 year
- Escalation of Operational costs – 8 %/annum
- Escalation of Maintenance cost – 10 %/annum
- Escalation of Energy costs – 10 %/annum
- Discount rate (Value of Capital) – 5 %/annum
- Escalation of Other costs – 10 %/annum
- Distance from nearest electricity grid – 4 km

Figure 7-8 shows the feasibility of the SSHP on the NPV design chart and Figure 7-9 shows the feasibility of the SSHP on the cost/benefit ratio chart.

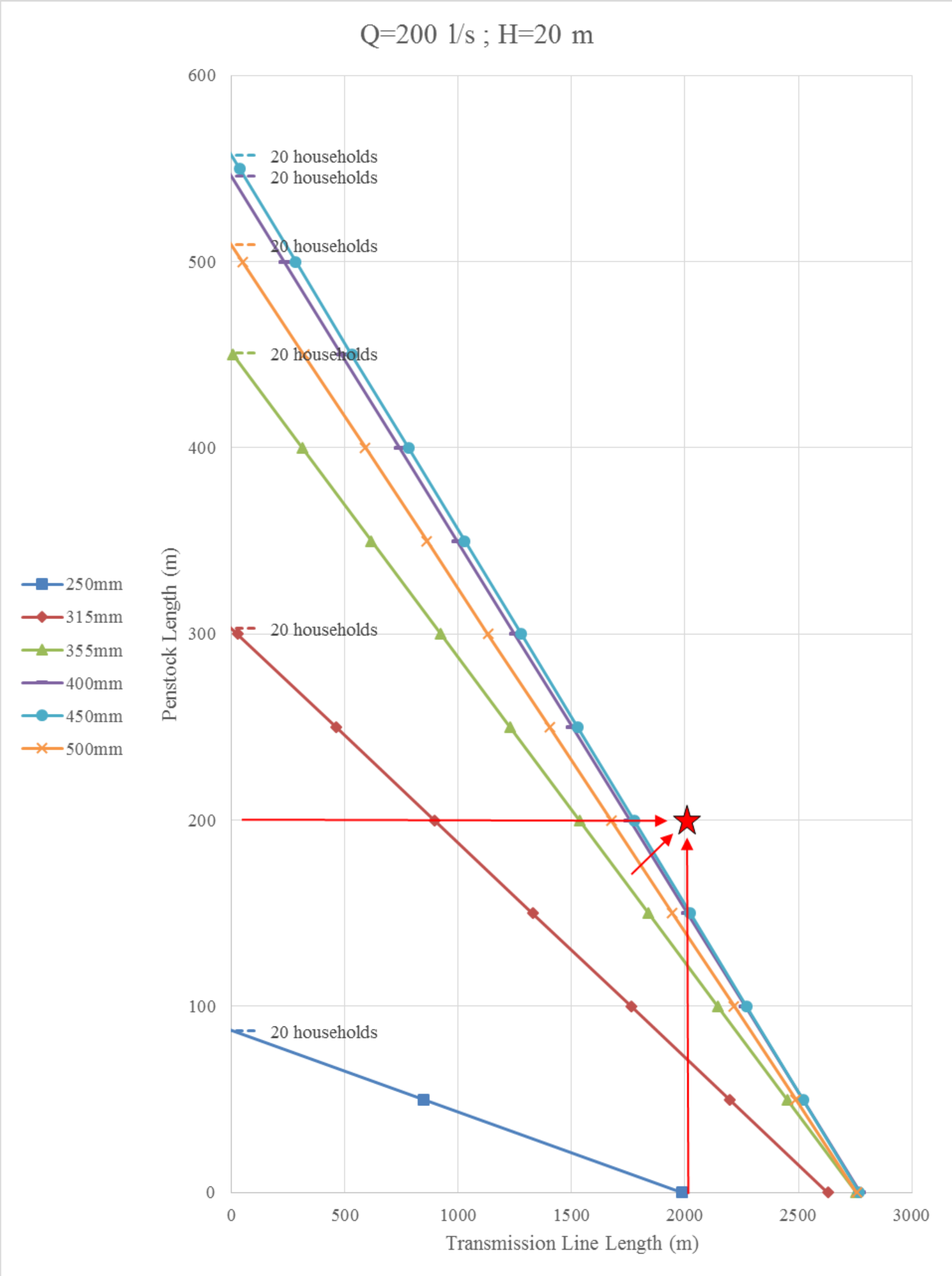


Figure 7-8 - Feasibility example - NPV design chart

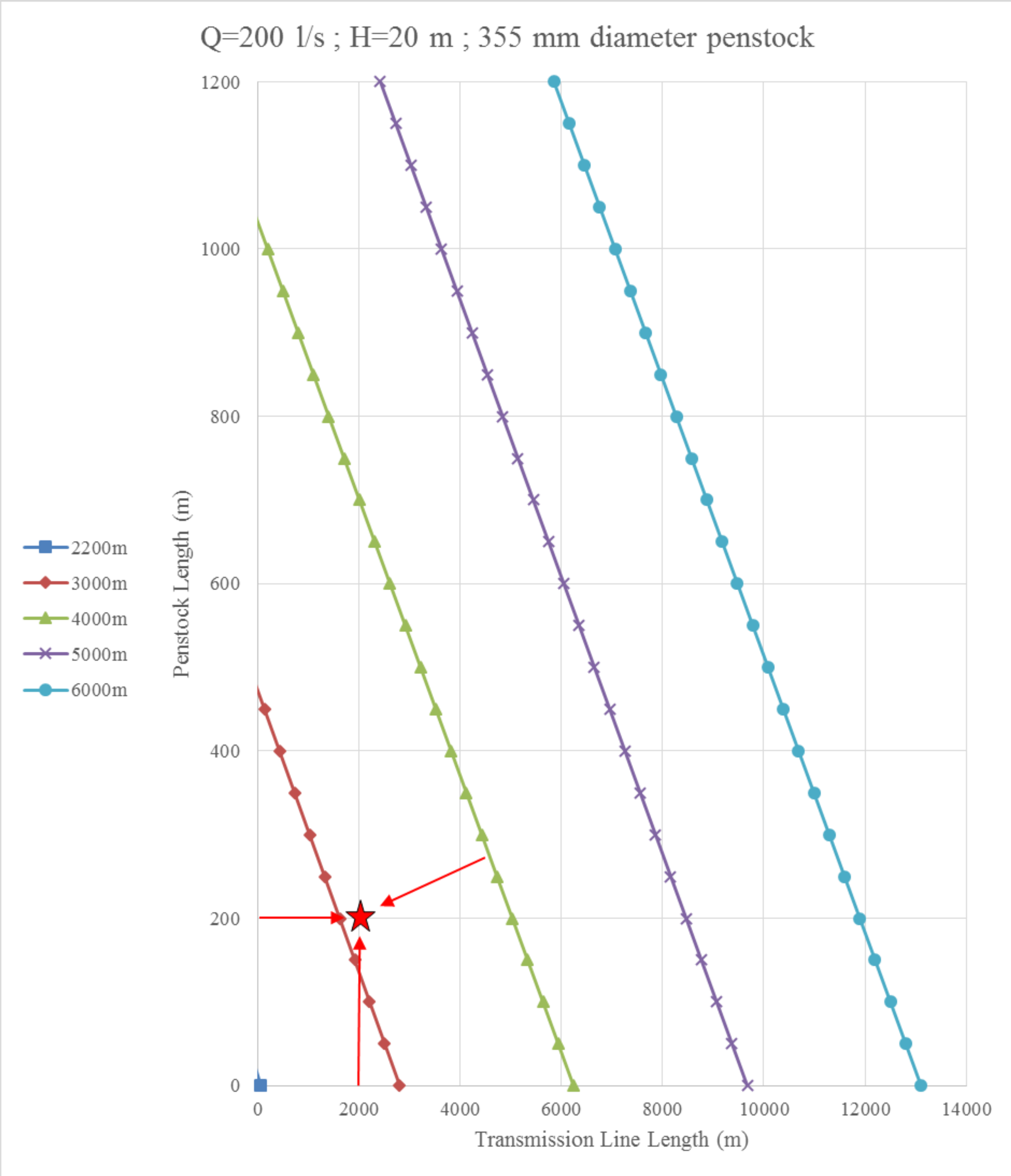


Figure 7-9 - Feasibility example - Cost/Benefit ratio

From Figure 7-8 it can be observed that the SSHP project plots above the diagonal line for a 355 mm penstock and therefor on the basis of NPV the project is not feasible. In Figure 7-9 it can be observed that the SSHP project plots below the line for a 4000 m distance to the nearest electricity grid and therefor the project is feasible based on the CCCR of the project. It can therefor be concluded that the same project can be both feasible and unfeasible for development depending on the nature of the development and the purpose of the infrastructure. The feasibility of SSHP for rural electrification is best calculated by the cost/benefit of the proposed project.

An alternative to both the grid extension and the SSHP project, is the use of diesel generators as electricity supply. As the following example shows, the initial capital cost of a diesel generator is low compared to the initial capital of a SSHP project, yet the operating cost and cost of diesel over the operating lifetime of the generator becomes excessively high compared to the operating cost of the SSHP.

A diesel generator alternative to the 50 kW SSHP plant at Kwa Madiba is as follows:

- 64 kVA (50kW)
- Cost = R 390,997 (Generator + Distribution) (Market related quotation form industry – 28 October 2015)
- Fuel Consumption = 17liters/h @full load
- Diesel price (28/10/2015) = R 10.93
- Diesel cost (Year 1) = R 542,565 (8 hrs/day)

Figure 7-10 shows a comparison of the cost of SSHP, grid extension and the diesel generator alternative for the Kwa Madiba SSHP project.

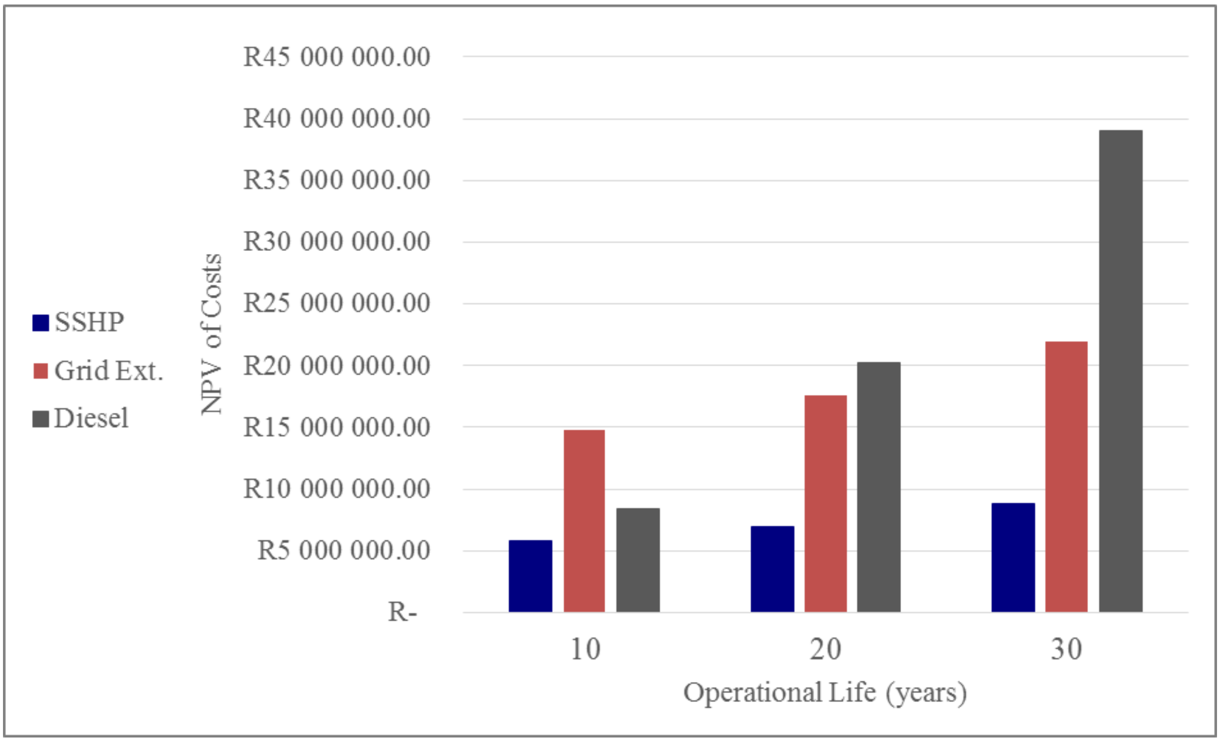


Figure 7-10 - Kwa Madiba alternatives - Cost comparison

7.8 SUMMARY

From the feasibility analysis of the SSHP projects based on the NPV and cost/benefit ratio of the project as well as the levelised cost of energy generated by the SSHP, the following conclusions were made.

- For shorter lengths of transmission lines the SSHP is feasible based on NPV.
- Long lengths of transmission line makes SSHP unfeasible based on NPV.
- Some technical possible SSHP projects have negative NPV based on long transmission line lengths or low income from power generated, but are still possible for rural electrification.
- The CCCR is a more accurate calculation for feasibility of SSHP for rural electrification.
- Turbine cost and distribution line cost are the major influences on the cost and feasibility of SSHP.
- High head, short transmission line and islanded mini-grid SSHP installations are the most feasible.
- Kinetic Turbine installations are feasible at medium to high flow velocities or medium flow velocities with short transmission lines and islanded mini-grids.
- Levelised cost of SSHP is high for low power generation.
- Levelised cost for extending the existing grid is much high than SSHP at low power generation than at higher power generations, which makes SSHP feasible for low power generation.
- Cost/benefit ratios for SSHP with high levelised cost still indicate feasibility of SSHP for rural electrification.

The main conclusion made from the feasibility analysis is summarised as follows:

The levelised cost of SSHP projects indicate that the cost of SSHP for low energy generation is high compared to the levelised cost of grid connected electricity supply, however, the remoteness of SSHP for rural electrification and the cost of infrastructure to connect remote rural communities to the local or national electricity grid provides a low CCCR and renders SSHP for rural electrification feasible on this basis.

8 CONCLUSIONS AND RECOMMENDATIONS

With 80% of the urban areas and 45% rural areas electrified the emphasis of the South African Electrification Programme is shifting from the urban to the rural areas of South Africa. Feasible grid electricity is being extended as far as is possible into the rural areas. However, large numbers of households and communities will not be connected to the national electricity grid for the foreseeable future due to high cost of transmission and distribution systems to remote communities, the relatively low electricity demand within rural communities and the current expenditure on upgrading and constructing of new coal fired power stations.

Small scale hydropower used to play a very important role in the provision of energy to urban and rural areas of South Africa. In South Africa, the concept of generating electricity using water turbines was first suggested in 1879 for lighting purposes in Cape Town (Barta, 2002) and Pretoria by using small scale hydropower schemes. Then the national electricity grid expanded and offered cheap, coal generated electricity and a large number of hydropower systems were decommissioned. Today, small hydropower projects are the most commonly used option to supply electricity to isolated or rural communities throughout the world including countries such as Nepal, India, Peru and China.

Water-scarcity in South Africa has threatened the viability of hydropower as a renewable source of energy. Only a fraction of the potential available for hydropower has been exploited and the lack of explicit models on the sustainable generation and supply of energy using small-scale hydropower for South Africa challenges the criteria for selection. There is also a general lack of awareness of the prospects small-scale hydropower offers amongst local stakeholders.

It was therefor hypothesized that it is technically possible to provide small-scale hydropower installations for rural electrification in South Africa. It was further hypothesized that for specific configurations of small-scale hydropower (SSHP) penstock diameter, penstock length and transmission line lengths SSHP installations are more feasible for rural electrification than local or national electricity grid extension.

Literature on hydropower generation in general and specifically on small-scale hydropower both locally and internationally were reviewed. The options and configurations of hydropower and small-scale hydropower systems are endless. For the South African river systems and for the purposes of rural electrification it was concluded that run-off-river systems are most feasible and easiest to implement. For the mountainous regions of the Eastern Cape within the OR Tambo District municipality the meandering river profiles leant an opportunity for the development of a modified run-off-river small-scale hydropower scheme as best described by the design of the Kwa Madiba SSHP.

Sites within the uMzinyathi DM and OR Tambo DM were identified as potential small-scale hydropower installation opportunities for rural electrification. Several of the identified sites were selected and designs for SSHP at these sites were developed from literature, available technology and construction experience. Based on the designs and incorporating current costing models from several consulting and construction companies within the South African framework and using market related material costs, costing of the designs for the several selected SSHP sites were done and financially analysed. From the financial analyses the different sites were evaluated on Net Present Value (NPV), Internal Rate of Return (IRR), Levelised Cost of Energy, Financial Payback Period and CCCR.

Following the financial analyses and a feasibility study of the individually designed proposed small scale hydropower plants, a feasibility analysis was done and a design chart developed for future potential small scale hydropower plant projects. Design charts for feasible SSHP were developed based on Net Present Value (NPV), Levelised Cost of Energy and CCCR.

From the developed Design Charts it was found that several technically possible configurations of penstock length and transmission line length have negative NPV values. Therefor the NPV can not be used in isolation for determining the feasibility of these configurations. The NPV could be used in isolation in a commercial environment. For this reason the potential SSHP should rather be evaluated on both cost/benefit ratio and levelised cost.

As a resultant of the methodology followed in conducting the study, and from the processes and research outlined within the report distinct conclusions were made. The first conclusion made, and that of which proves the hypothesis of the study is as follows:

1) *Small-scale hydropower is a feasible alternative for rural electrification and at specific distances away from the local and national electricity grid a cheaper alternative than grid extension. Furthermore, small-scale hydropower is a technically possible solution within the South African context and legal framework.*

Second to the main conclusion of the study the following conclusion emanated from the feasibility analysis and developed design charts:

2) *The levelised cost of SSHP projects indicate that the cost of SSHP for low energy generation is high compared to the levelised cost of grid connected electricity supply, however, the remoteness of SSHP for rural electrification and the cost of infrastructure to connect remote rural communities to the local or national electricity grid provides a low CCCR and renders SSHP for rural electrification feasible on this basis.*

These are the main two conclusions form the study. Several additional conclusions supplementary to the main conclusion were made. These supplementary conclusions should be read and understood within the context of the study and is used to further staff and authenticate the initial two conclusions. The following conclusion were made supplementary to the main two conclusions:

- Head becomes a governing factor for potential sites, as higher flows necessitate larger turbines and increases development costs
- A run-off-river scheme or modified run-off-river scheme is more suitable for rural electrification in the South African context than a kinetic turbine installation.
- The additional electricity generation capacity outweighs the costs of increased diameter penstocks due to the high escalation rate of electricity costs in South Africa.
- For shorter lengths of transmission lines the SSHP is feasible based on NPV.
- Long lengths of transmission line makes SSHP unfeasible based on NPV.
- Some technical possible SSHP projects have negative NPV based on long transmission line lengths or low income from power generated, but are still possible for rural electrification.
- The cost/benefit ratio is a more accurate calculation for feasibility of SSHP for rural electrification.
- Turbine cost and distribution line cost are the major influences on the cost and feasibility of SSHP.
- High head, short transmission line and islanded mini-grid SSHP installations are the most feasible.
- Kinetic Turbine installations are feasible at medium to high flow velocities or medium flow velocities with short transmission lines and islanded mini-grids.
- Levelised cost of SSHP is high for low power generation.
- Levelised cost for extending the existing grid is much high than SSHP at low power generation than at higher power generations, which makes SSHP feasible for low power generation.
- Cost/benefit ratios for SSHP with high levelised cost still indicate feasibility of SSHP for rural electrification.

In light of the conclusions made from the study, recommendations are made for the implementation of small-scale hydropower for rural electrification in South Africa.

Firstly, it is recommended that a standard containerised turbine room be developed for certain configurations of SSHP and rolled out for rural electrification in South Africa.

Secondly, Department of Water and Sanitation must review and amend the current applicable General Authorisation, GA1199 published in December 2009 for Section 21(c) and 21(i) water uses, to include the construction of small-scale hydropower projects towards non-grid electrification in the rural areas of South Africa.

Thirdly, feasible SSHP projects should be implemented at local municipality level, and a structure developed for the sustainable operation of the plants, including maintenance plans and payment tariff structures.

To conclude, it is believed that the study succeeded in proving the hypothesis that it is technically possible to provide small-scale hydropower installations for rural electrification in South Africa. It is further hypothesized that for specific configurations of small-scale hydropower (SSHP) penstock diameter, penstock length and transmission line lengths SSHP installations are more feasible for rural electrification than local or national electricity grid extension. Recommendations for further research that emanated from the study is as follows:

- The development of a containerised SSHP for rural electrification.
- Development of more efficient low head turbine technologies for electricity generation for rural electrification within the South African river setting.
- Development of more efficient kinetic turbine technologies for electricity generation for rural electrification within the South African river setting
- Further feasibility studies and design chart developments incorporating more turbine technologies and configurations.
- Potential SSHP developments within other DM's in South Africa
- SSHP development from existing water distribution system for rural settlements within urban areas.
- Development of a payment structure model for rural electrification.

9 REFERENCES

Aggidis, G.A, Luchinskaya, E., Rothchild, R. and Howard, D.C. 2010. The costs of small-scale hydropower production: Impact on the development of existing potential. *International Journal of Renewable Energy*, 35: 2632-2638.

Alliance for Rural Electrification (ARE). 2014. *The potential of small hydro for rural electrification*. Focus: Latin America. Brussels, Belgium.

Armstrong, G. S., Aprahamian, M. W., Fewings, G. A., Gough, P. J., Reader, N. A., & Varallo, P. V. .2004. Environment agency fish pass manual: guidance notes on the legislation, selection and approval of fish passes in England and Wales. *Available on CD from Environment Agency, Llys Afon, Hawthorn Rise, Haverfordwest, Pembrokeshire, SA61 2BQ, Wales, UK.* E-mail: greg. armstrong@ environment-agency. gov. uk.

Bagdadee, A.H. 2014. Rural Electrification with Renewable Energy Based Village Grids in Bangladesh. *International Journal of Scientific & Engineering Research*, Volume 5, Issue 10: 1080-1084

Barta B, Van Dijk M, Van Vuuren SJ. 2011. *Renewable energy: hydropower*. Civil Engineering= Siviele Ingenieurswese 19(5): 37-41.

Barta, B. 2002. Baseline study - hydropower in South Africa. Department of Minerals and Energy. Capacity Building in Energy Efficiency and Renewable Energy. *DME Report No. COWI P54126/EE/RE/70*. Department of Minerals and Energy, Pretoria, South Africa.

Bouk, T. 2011. The Archimedes Screw – environmental impacts, opportunities, and challenges as an Emergent Hydro Technology in CANADA. Proceedings of the Emergent Hydro Workshop, 5 May 2011, Peterborough, Canada.

Brennen, CE. 1994. Hydrodynamics of Pumps, Chapter 6: Bubble Dynamics, Damage and Noise, e-book, Concepts NREC. Available online: http://authors.library.caltech.edu/25019/1/chap6.htm [Accessed 14 May 2015].

Brunner, G. W. 2010. HEC-RAS, river analysis system reference manual version 4.1. *US Army Corps of Engineers-Hydrologic Engineering Center, Davis, CA.*

Bueno, C., & Carta, J. A. 2006. Wind powered pumped hydro storage systems, a means of increasing the penetration of renewable energy in the Canary Islands. *Renewable and Sustainable Energy Reviews*, 10(4), 312-340.

Byns N., Leunis K., Peeters K., Tonnet L. 2011. *The Use of Hydropower in Water Supply*. Report: K.U. Leuven.

Carrasco, F. 2011. *Introduction to hydropower*. World Technologies.

Cecelski, E. and Glatt, S. 1982. The Role of Rural Electrification in Development. *Discussion Paper D 73E, Energy in Developing Countries Series*. Center for Energy Policy Research, Washington DC.

Chang, K. T. 2008. *Introduction to Geographical Information Systems*. New York: McGraw Hill

Choulot, A, Denis, V and Punys, P .2012. Integration of small hydro turbines into existing water infrastructures. *Hydropower, Practice and Application*.

Chow, V.T. 1959. *Open-channel hydraulics*. McGraw-Hill, New York.

Clemen, DM. 1999. *Hydro Plant Electrical Systems*. PennWell

Colorado Energy Office. 2007. *Small Hydropower Handbook*, e-book. The Colorado Energy Office. Available online: http://www.colorado.gov/cs/Satellite?c=Document_C&childpagename=GovEnergyOffice%2FDocument_C%2FCBONAddLinkView&cid=1251643418897&pagename=CBONWrapper. [Accessed 14 May 2015].

De Siervo, F and De Leva, F. 1976. Modern trends in selecting and designing Francis turbines. *Water Power & Dam Construction*, August 1976, pages 28-35.

De Siervo, F and De Leva, F. 1977. Modern trends in selecting and designing Kaplan turbines: Part 1. *Water Power & Dam Construction*, December 1977, pages 51-56.

De Siervo, F and De Leva, F. 1978. Modern trends in selecting and designing Kaplan turbines: Part 2. *Water Power & Dam Construction*, January 1978, pages 52-58.

Deichman U, Meisner C, Muaary S and Wheeler D. 2010. *The Economics of Renewable Energy*

Department of Energy (DoE). 2012. *Non-Grid Electrification Policy Guidelines*, DoE. Available online:http://www.energy.gov.za/files/policies/electrification/NON%20GRID%20ELECTRIFICATION%20POLICY%202012.13.pdf [Accessed 18 May 2015]

Department of Energy (DoE). 2013. *New Households Electrification Strategy*, DoE. Available online: http://www.energy.gov.za/files/IEP/CapeTownWorkshop/Overview-of-Universal-Energy-Access-Strategy-25Oct2013.pdf [Accessed 18 May 2015]

Department of Energy Energy Utilization Management Bureau (DoE EUMB). 2009. *Manuals and Guidelines for Micro-hydropower Development in Rural Electrification Volume I: Manual for Design, Implementation and Management for Micro-hydropower Development*, MHP-1. Department of Energy. Energy Complex Merritt Road, Fort Bonifacio, Taguig City, Metro Manila

Department of Environmental Affairs, 2014b. National Environmental Management Act No 107 of 1998-Listing Notice 1: List of activities and competent authorities identified in terms of sections 24(2) and 24D
GNR983. Regulation edn. Pretoria: South Africa.

Department of Environmental Affairs, 2014c. National Environmental Management Act No 107 of 1998-Listing Notice 2: List of activities and competent authorities identified in terms of sections 24(2) and 24D
GNR984. Regulation edn. Pretoria: South Africa.

Department of Minerals and Energy, 2006. *Electricity Regulation Act.* Pretoria: South Africa.

Electrical Engineering Tutorials. 2015. Available online: http://electricalengineeringtutorials.com/different-turbines-used-in-hydroelectric-power-plant/

Energy Sector Management Assistance Programme (ESMAP). 2000. *Mini-Grid Design Manual*. Energy, Mining and Telecommunications Department. The World Bank. ESMAP Technical Paper. USA.

EPRI, 2012. *Power Generation Technology Data for Integrated Resource Plan of South Africa.* EPRI, Palo Alto, CA: 2012.

ESKOM. 2009. *Generation Divisions Plant Mix*. Available online: www.eskom.co.za/live/content.php?Item_ID=28. [Accessed: 15 October 2011].

ESRI .2012. *The 50th Anniversary* of GIS. ESRI. ArcNews, Fall 2012. Available online: http://www.esri.com/news/arcnews/fall12articles/the-fiftieth-anniversary-of-gis.html. [Accessed on 15 May 2015].

European Commission, 1997. *Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan*, COM(97)599 final, 26/11/1997. Available online: http://europa.eu/documents/comm/white_papers/pdf/com97_599_en.pdf [Accessed 14 March 2015].

European Small Hydropower Association (ESHA), 2004. *Guide on How to Develop a Small Hydropower Plant*, e-book. European Small Hydropower Association. Available online:

http://www.ieelibrary.eu/index.php?option=com_jombib&task=showbib&id =624. [Accessed 14 March 2012].

European Small Hydropower Association (ESHA). 2009. *Energy Recovery in Existing Infrastructures with Small Hydropower Plants: Multipurpose Schemes – Overview and Examples*, e-book. European Small Hydropower Association. Available online: http://www.esha.be/index.php?id=97. [Accessed 14 March 2012].

Expansion in Rural Sub-Saharan Africa. Washington D.C.: World Bank.

Frey, G.W. and Linke, D.M. 2002. Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. *Energy Policy*. *Volume 30 (14),* pages 1261 1265.

Future Energy Yorkshire (FEY). 2012. *Archimedes' screw: Copley Hydropower Generator*. Yorkshire Forward. York, United Kingdom.

Giugni, M., Fontana, N., & Portolano, D. 2009. Energy saving policy in water distribution networks. *Renewable Energy Power Qual*. J, 7, 1-6.

Gulliver, J.S. and Arndt, R.E.A. 1991. *Hydropower Engineering Handbook*. McGraw-Hill. New York, USA.

Hall, D. G. 2006. *Feasibility assessment of water energy resources of the United States for new low power and small hydro classes of hydroelectric plants* (No. DOE/ID-11263). Department of Energy (DOE).

Harvey, A., Brown, A., Hettiarachi, P. and Inversin, A. 1993. *Micro-Hydro Design Manual: A Guide to Small-scale Hydropower Schemes*. Practical Action Publishing Ltd, United Kingdom.

Husain, Z, Abdullah, Z and Alimuddin, Z. 2009. *Basic fluid mechanics and hydraulic machines.* Hyderabad, India: BS Publications; Boca Raton, Fla.: CRC Press, 2009

Hydrovolts. 2011. *Cross-Axis Hydrokinetic Turbines for Power Generation in Water Currents*. Hydrovolts. Seattle, USA.

Idelchik, I. E., & Fried, E. 1986. *Handbook of hydraulic resistance*.

International Energy Agency (IEA). 2008. *Implementing Agreement for Hydropower Technologies and Programmes Annex-2: Small Scale Hydropower Sub-Task B5 "Computerized tools for preliminary design, assessment and equipment selection"*: Summary Report. International Energy Agency. Available online: http://www.smallhydro.com/Doc-Sharing-Home/Documents-Home/Public-Documents/Site-Documents.aspx. [Accessed 18 May 2015].

International Energy Agency (IEA). 2009. *World Energy Outlook 2009.* Paris, France: International Energy Agency. Available online: http://www.iea.org/search/?q=2009%20outlook#gsc.tab =0&gsc.q=2009%20outlook&gsc.page=1 . [Accessed: 5 September 2013].

International Energy Agency (IEA). 2010. *Implementing Agreement for Hydropower Technologies and Programmes Annex-2: Small Scale Hydropower Sub-Task B2 "Innovative Technologies for Small-Scale Hydro":* Summary Report. International Energy Agency. Available online: http://www.smallhydro. com/Programs/innovative-technologies.aspx [Accessed 11 February 2013].

International Finance Corporation (IFC). 2013. *Toward Universal Energy Access: Designing a New Household Electrification Strategy for South Africa*. EE Publishers.

IREM. 2014. *Ecowatt Hydro Turbines*. Available online: www.irem.it [accessed: 18 February 2015]

Islam S, Das Gupta S, Shah Masum M, Ashraful Karim S, Golam Rahman M. 2013. *A Case Study of the Notion and Model of Micro Hydropower Plant Using the Kinetic Energy of Flowing Water of Burinadi and Meghna Rivers of Bangladesh*. Engineering Journal, Volume 17 Issue 4, pg 47 – 60.

Jonker Klunne, WE. 2009. Small hydropower for rural electrification in South Africa - using experiences from other African countries. *Proceedings of the ISES Solar World Congress 2009: Renewable Energy Shaping Our Future*, October 2009, pp 975-980

Jonker Klunne, WE. 2012. Current status and future developments of small and micro hydro in Southern Africa. *Proceedings of the Hidroenergia 2012 Conference*, 23-26 May 2012, Wroclaw, Poland.

Jorde, K. and Hartmann, E. 2009. *Good & Bad of Mini Hydropower*. Asean Centre for Energy (ACE). Volume 1.

Kanagy, J. 2011. *Northwest PowerPipeTM, an Innovative In-Conduit Power Generating Technology*. Lucid Energy Technologies, LLP. Available online: http://s36.a2zinc.net/clients/pennwell/hydrovisioninternational2011/Custom/Handout/Speaker9394_Session728_1.pdf. [Accessed on 28 October 2011].Kaunda, Kimambo and Nielson, 2012:

Kaunda, C. S., Kimambo, C. Z., & Nielsen, T. K. 2012. Potential of small-scale hydropower for electricity generation in Sub-Saharan Africa. *International Scholarly Research Notices* (2012).

Kaundinya, D.P., Balachandra, P and Ravindranath N.H. 2009. Grid-connected versus stand-alone energy systems for decentralized power—A review of literature. *Renewable and Sustainable Energy Reviews*. Elsevier, 13 (2009) 2041–2050.

Khan, M.A. and Badshah, S. 2014. Design and Analysis of Cross Flow Turbine for Micro Hydro Power Application using Sewerage Water. *Research Journal of Applied Sciences, Engineering and Technology*. 8(7): 821-828, 2014

Kirubi, C, Jacobson, A, Kammen, DM and A Mills. 2009. *Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya*. World Development 37 (7): 1208-1221.

Kougias, I., Patsialis, T., Zafirakou, A., and Theodossiou, N. 2014. Exploring the Potential of Energy reocvery using Micro Hydropower Systems in Water Supply Systems. *Water Utility Journal 7* (2014), pages 25-33.

Kumar, A., T. Schei, A. Ahenkorah, R. Caceres Rodriguez, J.-M.Devernay, M. Freitas, D. Hall, A. Killingtveit, Z. Liu. 2011. *Hydropower. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Lauterjung, H. and G. Schmidt .1989. *Planning of Water intake structures for irrigation or hydropower,* Eschborn: Deutsche Gesellschaft fur Technische Zusammenarbeit.

Lewis, A., S. Estefen, J. Huckerby, W. Musial, T. Pontes, J. Torres-Martinez. 2011. *Ocean Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Leyland, B. 2014. *Small Hydroelectric Engineering Practice*. CRC Press.

Loots, I., Van Dijk M, Van Vuuren SJ, Bhagwan J, Kurtz A. (2014). *Conduit-hydropower potential in the City of Tshwane water distribution system: A discussion of potential applications, financial and other benefits*. Journal of the South African Institution of Civil Engineering 56(3): 02-13.

Loots, I., Van Dijk, M., Barta, B., Van Vuuren, S. J., & Bhagwan, J. N. (2015). *A review of low head hydropower technologies and applications in a South African context*. Renewable and Sustainable Energy Reviews, 50, 1254-1268.

Mavel. 2013. *Mavel's Micro Turbines*. Mavel, a.s. Available online: www.mavel.cz [Accessed: 5 September 2013].

Mellacher, B. and Fiedler, T. 2013. ANDRITZ micro hydropower. *Proceeding of the Clean Power Africa Conference*, 14-15 May 2013, Cape Town, South Africa.Mtalo 2005

Muhammad, A. and K. Karimov. 2010. *Micro-Hydropower Systems. Utilization of Hydropower*, VDM Verlag, Dr. Muller, Aktiengesellschaft & Co. KG and lisensors.

Muller, G. 2004. *Water wheels as a Power Source*. Available online: http://hmf.enseeiht.fr/travaux/CD0708/beiere/3/html/bi/3/fichiers/Muller_histo.pdf. [Accessed 5 May 2013].

Muller, J. 1999. *South African renewable energy resource database: Chapter 2 Modelling hydropower potential*, CSIR, Pretoria.

Natel Energy. 2013. *The HydroEngine: SLH10 and SLH100, Version 4*. Natel Energy. Available online: www.natelenergy.com [Accessed: 17 December 2013].

Natural Resources Canada. 2004. *Micro-Hydropower Systems: A Buyer's Guide*, e-book. Natural Resources Canada. Available online: http://www.oregon.gov/energy/RENEW/Hydro/docs/MicroHydroGuide.pdf. Accessed 3 March 2015].Natural Resources Canada, 2004b

New Energy Corporation. 2015. *5 kW Power Generation System*. Available online: http://www.newenergycorp.ca/Products/PowerGeneration/5 kWPowerGenerationSystem/tabid/69/Default.aspx

Ogayar, B. and Vidal, P.G. 2009. Cost determination of the electro-mechanical equipment of a small hydro-power plant. *International Journal of Renewable Energy*, 34: 6-13.

Ortega-Achury Sandra L., McAnally William H., Davis Trey E. and Martin James L. 2010. *Hydrokinetic Power Review*. Civil and Environmental Engineering, James Worth Bagley College of Engineering, Mississippi State University.

Oud, E. 2002. The evolving context for hydropower development. *Energy Policy. Volume 30 (14)*, pages 1215–1223.

Paish, O. 2002. Small hydropower: technology and current status. *Renewable and Sustainable Energy Reviews.* Volume 6 (6), pages 537–556.

Papantonis, D. 2001. *Small Hydropower Stations*. Simeon, Athens, Greece.

Penche, C. 1998. *Layman's handbook on how to develop a small hydro site*. ESHA, European Commission.

Powerspout, 2012. *PowerSpout Low Head Turbine Installation Manual: Variants LH and LH Pro*. EcoInnovation Ltd, New Plymouth, New Zealand.

Punys, P., Dumbrauskas, A., Kvaraciejus, A. and Vyciene, G. 2011. Tools for small hydropower plant resource planning and development: A review of technology and applications. *Energies*, 4(9), 1258-1277.

Reuters. 2011. *China acknowledges downside to Three Gorges Dam*. Reuters.com, Wednesday May 18, 2011. Available online: http://www.reuters.com/article/2011/05/18/us-china-dam-idUSTRE74H30720110518 [Accessed on 18 May 2015].

Rodriguez, L and Sanchez, T. 2011. *Designing and building mini and micro hydropower schemes: a practical guide*. Practical Action Publishing, Rugby, England.

Scharfetter, BG. 2015. *Unravelling the Institutional Complexities of Implementing Small-Scale Hydropower Projects for Rural Electrification in South Africa* (Unpublished master's dissertation). University of Pretoria, Pretoria, South Africa.

Smart Hydro Power, 2015. *SMART Monofloat Kinetic Micro Hydro System: Technical Spesifications.* Available online: http:// http://www.smart-hydro.de/en/product/turbine.html311872 [Accessed 18 May 2015].

South Africa. 2006. No. 4 of 2006: Electricity Regulation Act, 2006. *Government Gazette Vol. 493,* Cape Town, 5 July 2006, No. 28992.

South African National Roads Agency Limited (SANRAL). 2013. *Drainage Manual (6th revised edition).* South African National Road Agency Limited, Pretoria South Africa.

Stephenson, D. 1997. *Preliminary report on potential hydro-electric sites in Transkei*

Stephenson, D. 2002. Simple Guide for Design of Air Vessels for Water Hammer Protection of Pumping Lines. *Journal of Hydraulic Engineering*, (August 2002) pages 792-797.

Swiftriverhydrocom. 2015. *Sebec Electric LP*. Swift River Hydro Operations Company. Available online: http://www.swiftriverhydro.com/sebec%20hydro.htm [Accessed 5 February 2015].

Szewczuk, S., Fellows, A., and van der Linden, N. (2000). Renewable energy for rural electrification in South Africa. *European Commission, FP5 Joule-Thermie Programme*.

US EPA. 2013. U.S. Environmental Protection Agency. *EIA Technical Review Guidelines: Energy Generation and Transmission, Vol. 1*

USAID/ARE. 2011. *Hybrid mini-grids for rural electrification: Lessons learned*. Washington D.C. and Brussels: USAID and the Alliance for Rural Electrification.

Van Dijk, M, Kgwale M, Bhagwan J, Loots I. (2015). *Bloemwater conduit hydropower plant launched.* South African Institution of Civil Engineering

Van Dijk, M, Van Vuuren F, Bhagwan J, Loots I. (2014). *Small-scale hydropower development for rural electrification in South Africa: water engineering.* Civil Engineering= Siviele Ingenieurswese 22(5): 42-46.

Van Vuuren, S.J., Van Dijk, M., Loots, I., Barta, B. and Scharfetter, B.G. 2014. *Conduit Hydropower Development Guide. WRC Report No TT597/14*. Water Research Commission. Pretoria, South Africa.

Wade S, Wade, D and G Milton. 2015. *Wyoming Small Hydropower Handbook*. Wenck Associates, Inc. 1904 East 15th Street, Cheyenne, WY 82001.

Wagner, H. J., and Mathur, J. 2011. *Introduction to hydro energy systems: basics, technology and operation*. Springer Science & Business Media.

Wahl, T. L. 2003. *Design guidance for Coanda-effect screens*. US Department of the Interior, Bureau of Reclamation.

Wang, R. W. 2008. *Aspects of design and monitoring of nature-like fish passes and bottom ramps.* Techn. Univ., Lehrstuhl für Wasserbau und Wasserwirtschaft.

Warnick, C. C. 1984. *Hydropower engineering*.

Wemvalvescom. 2015. Sluice Gate (Penstock) SERIES 1500. Available online: http://www.wemvalves.com/index.php?lay=show&ac=article&Id=311872 [Accessed 18 May 2015].

Williams, A. 2003. *Pumps as Turbines: A User's Guide (2nd edition).* Practical Action Publishing Ltd, Warwickshire, UK.

Williams, A.A., Smith, N.P.A., Bird, C., and Howard, M. (1998). *Pumps as Turbines and Induction Motors as Generators for Energy Recovery in Water Supply Systems*. Journal CIWEM. UK. June. 175 - 178.

Williamson, S.J., Stark, B.H. and Booker, J.D. 2012. Low head pico hydro turbine selection using a multi-criteria analysis. *Proceedings of World Renewable Energy Congress* 2011, 8-11 May 2011, Linköping, Sweden

World Bank. 2008. Issues *Note of the REToolkit. REToolkit: A Resource for Renewable Energy Development.* Washington D.C.: World Bank.

Zhang, Qin Fen, Smith, Brennan T, and Zhang, Wei. 2012. *Small Hydro Reference Model Project*. United States. doi:10.2172/1055120

Zotlöterer, F. 2013. *Zotlöterer Gravitational Vortex Power Plant*. Available online: http://www.zotloeterer.com/ [Accessed 12 December 2014]

APPENDIX A – IDENTIFIED POTENTIAL SSHP SITES

*NO DATA – Sites on rivers with no gauging weirs and historical flow measurements available.

**n/a –Potential power generation and suitable turbines not available due to lack of flow data.

***Kinetic Turbine sites not included in identified potential SSHP site list.

****UNKNOWN – community or settlement name unknown

No.	Province	District Municipality	Local Municipality	River	Site	Co-ordinates		Current Structure	Potential Head (m)	Potential Flow (m^3/s) (95% of time)	Potential Power Generation (kW)	Suitable Turbines
						Lat	Long					
1	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Cicira	Roode Heuvel	31°33'24.01"S	28°44'13.99"E	T2H010	Gauging Station	NO DATA	n/a	n/a
2	Eastern Cape	OR Tambo	Nyandeni - 228	Corana	Corana Dam	31°26'14.81"S	28°52'27.15"E	T2R003	Gauging Station	NO DATA	n/a	n/a
3	Eastern Cape	OR Tambo	Mhlontlo - 222	Inxu	St Augustine Mission	31°13'09.98"S	28°37'50.98"E	T3H014	Gauging Station	NO DATA	n/a	n/a
4	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Dudlaka	31°17'21.54"S	29°11'59.56"E	None	25	0.747	157.55	Francis/Turgo/Crossflow
5	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Zixhotyeni	31°18'18.71"S	29° 6'14.13"E	None	18	0.747	113.44	Francis/Turgo/Crossflow
6	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Laleni	31°14'29.53"S	28°55'25.83"E	None	14	0.747	88.23	Francis/Turgo/Crossflow
7	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	KuGomeni	31°13'56.56"S	28°47'48.61"E	None	13	0.747	81.93	Francis/Turgo/Crossflow
8	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	KuGomeni 2	31°13'6.75"S	28°49'19.61"E	None	13	0.747	81.93	Francis/Turgo/Crossflow
9	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Mdeni	31°11'58.04"S	28°45'56.55"E	None	12	0.747	75.63	Francis/Turgo/Crossflow
10	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Mhlabati	31°15'17.08"S	28°51'16.71"E	None	10	0.747	63.02	Francis/Turgo/Crossflow
11	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Tsitsa	31° 3'55.07"S	28°30'50.72"E	None	9	0.747	56.72	Turgo/Crossflow/Kaplan
12	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Mahoyana	31°16'45.22"S	28°58'31.16"E	None	8	0.747	50.42	Turgo/Crossflow/Kaplan
13	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Tsitsa Bridge	31°14'14.49"S	28°50'37.79"E	None	7	0.747	44.11	Turgo/Crossflow/Kaplan
14	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Mfabantu	31° 2'51.22"S	28°29'35.79"E	None	6	0.747	37.81	Crossflow/Kaplan
15	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Famini	31°13'47.68"S	28°45'42.44"E	None	6	0.747	37.81	Crossflow/Kaplan
16	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Malepelepe	31°12'40.49"S	28°46'6.50"E	None	5	0.747	31.51	Crossflow/Kaplan
17	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Ngqongweni	31° 6'58.30"S	28°40'26.19"E	None	4	0.747	25.21	Crossflow/Kaplan
18	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Xonkonxa	31°14'17.01"S	28°51'07.99"E	T3H006	Weir	0.747	n/a	n/a
19	Eastern Cape	OR Tambo	Mhlontlo - 222	iTsitsa	Xonkonxa	31°14'16.00"S	28°50'45.99"E	T3H016	Gauging Station	0.747	n/a	n/a
20	Eastern Cape	OR Tambo	Ingquza Hill - 224	KwaDlambu	Lupondo	31°17'3.71"S	29°52'48.75"E	None	26	NO DATA	n/a	n/a
21	Eastern Cape	OR Tambo	Ingquza Hill - 224	KwaDlambu	Mkambati	31°17'43.34"S	29°55'17.29"E	None	11	NO DATA	n/a	n/a
22	Eastern Cape	OR Tambo	Ingquza Hill - 224	KwaDlambu	Nentsentse	31°12'38.40"S	29°49'33.11"E	None	8	NO DATA	n/a	n/a
23	Eastern Cape	OR Tambo	Ingquza Hill - 224	KwaDlambu	Kwa-Dlambu	31°13'20.96"S	29°49'26.55"E	None	4	NO DATA	n/a	n/a
24	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Qombe	31°59'29.31"S	28°32'54.36"E	None	29	0.335	81.96	Francis/Turgo/Crossflow
25	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	KwaMiya	31°52'13.81"S	28°25'11.36"E	None	18	2.337	354.89	Francis/Turgo/Kaplan
26	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Zangcete	32° 0'5.56"S	28°36'27.53"E	None	17	0.335	48.05	Francis/Turgo/Crossflow
27	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Siroshweni	31°55'27.84"S	28°28'2.32"E	None	16	0.335	45.22	Francis/Turgo/Crossflow
28	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Ndyebo	31°53'46.02"S	28°26'30.67"E	None	15	2.337	295.75	Francis/Turgo/Kaplan
29	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Njakazi	31°58'48.89"S	28°31'16.15"E	None	15	0.335	42.39	Francis/Turgo/Crossflow
30	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Sidikidi	31°57'55.04"S	28°32'12.46"E	None	14	0.335	39.57	Francis/Turgo/Crossflow
31	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Caba	31°41'32.74"S	28°19'26.63"E	None	10	0.646	54.50	Francis/Turgo/Crossflow
32	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Kunqwati	31°44'52.92"S	28°21'21.78"E	None	5	0.646	27.25	Crossflow/Kaplan
33	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Ntseleni	31°48'49.93"S	28°20'37.31"E	None	4	0.646	21.80	Crossflow/Kaplan
34	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Msila	31°56'24.55"S	28°30'50.07"E	None	4	0.335	11.31	Crossflow/Kaplan
35	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	KuMvezo	31°57'38.17"S	28°28'16.82"E	None	3	0.335	8.48	Crossflow/Kaplan
36	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Rara 34	32°00'02.01"S	28°34'54.01"E	T1H015	Gauging Station	NO DATA	n/a	n/a
37	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Bashee Bridge	31°55'13.00"S	28°26'52.00"E	T1H004	Gauging Station	0.335	n/a	n/a
38	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Rune	31°51'03.59"S	28°23'33.68"E	T1H014	Weir	2.337	n/a	n/a
39	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	Gxwali Bomvu	31°47'58.81"S	28°19'58.90"E	T1H013	Weir	0.646	n/a	n/a
40	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	eSixhotyeni	31°47'59.32"S	28°19'57.75"E	Weir	Weir	0.646	n/a	n/a
41	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mbhashe	KuNjemane	31°51'4.64"S	28°23'34.55"E	Weir	Weir	2.337	n/a	n/a
42	Eastern Cape	OR Tambo	Mhlontlo - 222	Mhlahlane	Mabeleni Dam	31°26'48.33"S	28°33'44.81"E	T2R002	Gauging Station	NO DATA	n/a	n/a
43	Eastern Cape	OR Tambo	Port St Johns - 227	Mngazana	Mafusini	31°38'23.95"S	29°21'39.06"E	None	22	NO DATA	n/a	n/a
44	Eastern Cape	OR Tambo	Port St Johns - 227	Mngazana	Lundine	31°37'34.38"S	29°17'33.21"E	None	18	NO DATA	n/a	n/a
45	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazana	Mdumazulu	31°37'8.35"S	29° 8'40.57"E	None	17	NO DATA	n/a	n/a
46	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazana	Ngqonuweni	31°37'51.79"S	29°13'18.31"E	None	12	NO DATA	n/a	n/a
47	Eastern Cape	OR Tambo	Port St Johns - 227	Mngazana	Nkwilini	31°40'38.25"S	29°22'59.89"E	None	12	NO DATA	n/a	n/a
48	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazana	Mabeleni	31°36'50.70"S	29°10'8.60"E	None	9	NO DATA	n/a	n/a
49	Eastern Cape	OR Tambo	Port St Johns - 227	Mngazana	Glengazi	31°38'13.29"S	29°20'45.88"E	None	7	NO DATA	n/a	n/a
50	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Marubeni	31°28'34.52"S	29° 3'57.57"E	None	22	0.112	20.79	Francis/Turgo/Crossflow
51	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Volibi	31°33'27.70"S	29°15'51.77"E	None	13	0.112	12.28	Francis/Turgo/Crossflow
52	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Ntabantsimbi	31°28'48.59"S	29° 7'33.27"E	None	10	0.112	9.45	Francis/Turgo/Crossflow
53	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Ngconcgo	31°31'13.39"S	29°10'32.52"E	None	10	0.112	9.45	Francis/Turgo/Crossflow
54	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Makhuzeni	31°32'39.53"S	29°11'29.62"E	None	8	0.112	7.56	Crossflow
55	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Makotyana	31°28'12.25"S	29° 1'40.78"E	None	5	0.112	4.72	Crossflow
56	Eastern Cape	OR Tambo	Nyandeni - 228	Mngazi	Mgwenyana Loc. 22	31°33'04.32"S	29°14'37.68"E	T7H001	Weir	0.112	n/a	n/a
57	Eastern Cape	OR Tambo	Port St Johns - 227	Mntafufu	Ntafufu Loc. 35	31°29'45.99"S	29°31'43.71"E	T6H001	Weir	0.055	n/a	n/a

No.	Province	District Municipality	Local Municipality	River	Site	Co-ordinates		Current Structure	Potential Head (m)	Potential Flow (m^3/s) (95% of time)	Potential Power Generation (kW)	Suitable Turbines
						Lat	Long					
58	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Babane	31°15'50.93"S	29°42'36.46"E	None	30	0.030	7.59	Crossflow/Pelton
59	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Ndindindi	31°18'44.59"S	29°51'54.46"E	None	30	0.030	7.59	Crossflow/Pelton
60	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Mawotsheni	31°14'58.55"S	29°44'29.99"E	None	24	0.030	6.07	Crossflow/Pelton
61	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Ntongwana	31°16'9.78"S	29°40'35.43"E	None	23	NO DATA	n/a	n/a
62	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Ndanya	31°17'21.35"S	29°46'56.82"E	None	20	0.030	5.06	Crossflow/Pelton
63	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Ndzaka	31°11'1.42"S	29°35'42.32"E	None	16	NO DATA	n/a	n/a
64	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Nkcele	31°18'5.40"S	29°49'39.81"E	None	10	0.030	2.53	Crossflow
65	Eastern Cape	OR Tambo	Ingquza Hill - 224	Msikaba	Nqxambane	31°14'19.04"S	29°39'41.05"E	None	7	NO DATA	n/a	n/a
66	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	Lutsheko 2	31°37'52.01"S	29° 4'18.68"E	None	14	NO DATA	n/a	n/a
67	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	Mtyu	31°34'56.90"S	29° 1'38.07"E	None	13	NO DATA	n/a	n/a
68	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	KuBhodi	31°39'20.45"S	29° 4'10.70"E	None	13	NO DATA	n/a	n/a
69	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	Jovu	31°35'35.16"S	29° 1'43.17"E	None	10	NO DATA	n/a	n/a
70	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	Mazizini	31°39'31.87"S	29° 5'5.20"E	None	10	NO DATA	n/a	n/a
71	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	Mazizini 2	31°40'14.80"S	29° 5'55.91"E	None	7	NO DATA	n/a	n/a
72	Eastern Cape	OR Tambo	Nyandeni - 228	Mtakatye	Lutsheko	31°36'42.67"S	29° 3'23.04"E	None	2	NO DATA	n/a	n/a
73	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Ndyebo	31°53'15.84"S	28°27'35.92"E	None	21	NO DATA	n/a	n/a
74	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mtuvi	31°51'52.01"S	28°28'37.61"E	None	16	NO DATA	n/a	n/a
75	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	KwaPingilili 2	31°48'22.07"S	28°28'58.51"E	None	9	NO DATA	n/a	n/a
76	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Malindini	31°49'1.04"S	28°29'2.38"E	None	9	NO DATA	n/a	n/a
77	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mqekezweni 5	31°45'56.35"S	28°29'2.49"E	None	8	NO DATA	n/a	n/a
78	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mabongweni 2	31°51'20.85"S	28°27'55.99"E	None	8	NO DATA	n/a	n/a
79	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	eMangweni	31°52'53.51"S	28°27'47.45"E	None	8	NO DATA	n/a	n/a
80	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mtuvi 2	31°52'12.72"S	28°28'58.43"E	None	7	NO DATA	n/a	n/a
81	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mqekezweni	31°44'35.83"S	28°29'23.30"E	None	6	NO DATA	n/a	n/a
82	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mqekezweni 3	31°45'24.33"S	28°29'5.30"E	None	6	NO DATA	n/a	n/a
83	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Krancola 2	31°46'46.27"S	28°29'23.49"E	None	6	NO DATA	n/a	n/a
84	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mqekezweni 4	31°45'38.07"S	28°28'59.62"E	None	5	NO DATA	n/a	n/a
85	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Krancola 1	31°46'36.96"S	28°29'11.11"E	None	5	NO DATA	n/a	n/a
86	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	KuNcengane	31°50'10.16"S	28°28'45.55"E	None	5	NO DATA	n/a	n/a
87	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mqekezweni 2	31°44'50.51"S	28°29'18.15"E	None	4	NO DATA	n/a	n/a
88	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	KwaPingilili	31°47'32.73"S	28°29'12.45"E	None	4	NO DATA	n/a	n/a
89	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Nqencu	31°50'23.91"S	28°28'0.43"E	None	2	NO DATA	n/a	n/a
90	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mtentu	Mabongweni	31°51'5.82"S	28°27'46.57"E	None	2	NO DATA	n/a	n/a
91	Eastern Cape	OR Tambo	Nyandeni - 228	Mthatha	Eskweleni	31°47'35.94"S	28°53'58.12"E	None	37	0.512	159.82	Crossflow/Francis/Turgo/Pelton
92	Eastern Cape	OR Tambo	Nyandeni - 228	Mthatha	Siqikini	31°45'11.93"S	28°54'40.17"E	None	32	0.512	138.23	Crossflow/Francis/Turgo/Pelton
93	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Mapalo	31°50'42.46"S	28°58'55.06"E	None	12	0.512	51.83	Crossflow/Francis/Turgo
94	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Mlawu	31°54'29.07"S	29° 7'14.02"E	None	10	0.512	43.20	Crossflow/Francis/Turgo
95	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Ntsunguzini	31°28'48.89"S	28°32'43.46"E	None	7	0.128	7.56	Crossflow/Kaplan
96	Eastern Cape	OR Tambo	Nyandeni - 228	Mthatha	Dikeni	31°47'23.07"S	28°53'21.87"E	None	7	0.512	30.24	Crossflow/Kaplan
97	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	KwaNyembezi	31°27'54.68"S	28°38'11.17"E	None	6	0.128	6.48	Crossflow/Kaplan
98	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Mpafana	31°30'21.69"S	28°30'40.99"E	None	4	0.128	4.32	Crossflow/Kaplan
99	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Mpindweni	31°52'0.77"S	29° 1'12.69"E	None	4	0.512	17.28	Crossflow/Kaplan
100	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Norwood	31°35'03.98"S	28°47'03.01"E	T2H002	Gauging Station	0.512	n/a	n/a
101	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Gate To Turbine From	31°35'03.01"S	28°47'06.00"E	T2H007	Gauging Station	0.142	n/a	n/a
102	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Umtata	31°34'08.00"S	28°45'50.00"E	T2H008	Weir	0.128	n/a	n/a
103	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Pipeline to Purificatior	31°33'14.00"S	28°44'42.00"E	T2H009	Gauging Station	0.471	n/a	n/a
104	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Mthatha	Umtata Dam	31°33'03.70"S	28°44'27.59"E	T2R001	Gauging Station	NO DATA	n/a	n/a
105	Eastern Cape	OR Tambo	Mhlontlo - 222	Mthatha	Kambi Forest Res.	31°28'13.87"S	28°37'02.89"E	T2H003	Gauging Station	NO DATA	n/a	n/a
106	Eastern Cape	OR Tambo	Nyandeni - 228	Mthatha	Dumasi Loc 5	31°41'02.83"S	28°53'00.92"E	T2H001	Gauging Station	NO DATA	n/a	n/a
107	Eastern Cape	OR Tambo	Port St Johns - 227	Mzimvubu	Mafusini	31°33'8.67"S	29°29'39.71"E	None	10	5.701	480.97	Francis/Kaplan
108	Eastern Cape	OR Tambo	Nyandeni - 228	Mzimvubu	Tshatsheni	31°22'33.04"S	29°13'10.97"E	None	8	5.701	384.78	Francis/Kaplan
109	Eastern Cape	OR Tambo	Port St Johns - 227	Mzimvubu	Etyeni	31°26'4.48"S	29°19'13.72"E	None	6	5.701	288.58	Francis/Kaplan
110	Eastern Cape	OR Tambo	Port St Johns - 227	Mzimvubu	Ntlanjana	31°28'43.06"S	29°21'58.75"E	None	5	5.701	240.49	Francis/Kaplan
111	Eastern Cape	OR Tambo	Nyandeni - 228	Mzimvubu	Qeza	31°24'25.02"S	29°17'11.61"E	None	4	5.701	192.39	Francis/Kaplan
112	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzimvubu	Nontela	31°23'43.79"S	29°15'54.28"E	T3H020	Weir	5.701	n/a	n/a
113	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Kuxhaka	31°26'26.16"S	29°34'59.03"E	None	22	NO DATA	n/a	n/a
114	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Buchele	31°29'25.33"S	29°38'29.31"E	None	17	NO DATA	n/a	n/a

No.	Province	District Municipality	Local Municipality	River	Site	Co-ordinates		Current Structure	Potential Head (m)	Potential Flow (m^3/s) (95% of time)	Potential Power Generation (kW)	Suitable Turbines
						Lat	Long					
115	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Mtambalala	31°27'42.21"S	29°35'40.21"E	None	16	NO DATA	n/a	n/a
116	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Gxeni	31°29'3.02"S	29°37'33.73"E	None	15	NO DATA	n/a	n/a
117	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Mbudu	31°25'50.13"S	29°33'53.40"E	None	13	NO DATA	n/a	n/a
118	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Njojo	31°30'17.21"S	29°39'25.19"E	None	13	NO DATA	n/a	n/a
119	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Melaba	31°25'34.89"S	29°32'48.14"E	None	10	NO DATA	n/a	n/a
120	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Kuxhaka 2	31°26'16.83"S	29°35'38.83"E	None	8	NO DATA	n/a	n/a
121	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Ludiwana	31°06'15.40"S	29°23'58.99"E	T3H017	Gauging Station	0.291	n/a	n/a
122	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Bulembu	31° 4'35.31"S	29°24'33.43"E	None	20	0.291	49.10	Crossflow/Francis/Turgo
123	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Egqina	30°57'32.38"S	29°29'0.49"E	None	50	0.291	122.75	Crossflow/Francis/Turgo/Pelton
124	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Magqabasini	30°56'8.63"S	29°30'37.21"E	None	8	0.291	19.64	Crossflow
125	Eastern Cape	OR Tambo	Ingquza Hill - 224	Mzintlava	Baleni	31° 5'25.36"S	29°24'29.33"E	None	60	0.291	147.30	Crossflow/Francis/Turgo/Pelton
126	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Mahobo	31°51'33.71"S	28°46'53.91"E	None	34	NO DATA	n/a	n/a
127	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Sankobe	31°50'42.28"S	28°48'18.90"E	None	25	NO DATA	n/a	n/a
128	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Matyeni	31°51'5.01"S	28°49'22.65"E	None	20	NO DATA	n/a	n/a
129	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	KwaGawu 2	31°51'53.28"S	28°54'33.53"E	None	16	NO DATA	n/a	n/a
130	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Singingqini	31°52'21.35"S	28°50'47.76"E	None	8	NO DATA	n/a	n/a
131	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Mabumsheni	31°51'6.18"S	28°43'35.02"E	None	7	NO DATA	n/a	n/a
132	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	KwaPhahla	31°51'38.55"S	28°50'39.19"E	None	6	NO DATA	n/a	n/a
133	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	KwaGawu	31°52'0.19"S	28°53'54.61"E	None	6	NO DATA	n/a	n/a
134	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	KuLozulu 2	31°52'26.27"S	28°47'5.91"E	None	6	NO DATA	n/a	n/a
135	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Lubolena 3	31°50'50.53"S	28°43'6.28"E	None	4	NO DATA	n/a	n/a
136	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Maxesibeni	31°51'46.33"S	28°47'58.31"E	None	4	NO DATA	n/a	n/a
137	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Mshini	31°52'11.16"S	28°53'12.56"E	None	4	NO DATA	n/a	n/a
138	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Lubolena 2	31°50'44.21"S	28°42'32.45"E	None	3	NO DATA	n/a	n/a
139	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Komkhulo	31°52'1.45"S	28°44'17.18"E	None	3	NO DATA	n/a	n/a
140	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	Lubolena	31°50'41.21"S	28°42'27.95"E	None	2	NO DATA	n/a	n/a
141	Eastern Cape	OR Tambo	King Sabata Dalindyebo - 229	Ngqungqu	KuLozulu	31°51'58.29"S	28°44'38.97"E	None	2	NO DATA	n/a	n/a
142	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Ngcolo	31°12'44.75"S	29° 6'43.34"E	None	46	0.639	247.99	Crossflow/Francis/Turgo/Pelton
143	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Lwandlana 2	31° 3'19.89"S	28°52'29.66"E	None	35	0.639	188.68	Crossflow/Francis/Turgo/Pelton
144	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Ngxalana	31° 7'20.69"S	29° 0'49.55"E	None	28	0.639	150.95	Crossflow/Francis/Turgo
145	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Majantshi	30°58'6.34"S	28°51'52.70"E	None	18	0.639	97.04	Crossflow/Francis/Turgo
146	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Sikwayini	30°57'12.14"S	28°49'41.14"E	None	17	0.639	91.65	Crossflow/Francis/Turgo
147	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mmangweni	31°14'28.98"S	29° 8'10.56"E	None	15	0.639	80.86	Crossflow/Francis/Turgo/Kaplan
148	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mpindweni	31° 8'48.44"S	29° 1'52.59"E	None	14	0.639	75.47	Crossflow/Francis/Turgo/Kaplan
149	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	KuNobamba	30°57'20.28"S	28°48'49.01"E	None	12	0.639	64.69	Crossflow/Francis/Turgo/Kaplan
150	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mbombo	31°10'12.04"S	29° 2'41.46"E	None	12	0.639	64.69	Crossflow/Francis/Turgo/Kaplan
151	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Nyushwini	30°56'40.35"S	28°51'0.23"E	None	11	0.639	59.30	Crossflow/Francis/Turgo/Kaplan
152	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	KwaNyokana	31° 6'32.47"S	29° 0'42.76"E	None	10	0.639	53.91	Crossflow/Francis/Turgo/Kaplan
153	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mafusini	31° 0'16.78"S	28°52'25.79"E	None	9	0.639	48.52	Crossflow/Francis/Kaplan
154	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mangwaneni	31° 3'42.58"S	28°57'46.50"E	None	9	0.639	48.52	Crossflow/Francis/Kaplan
155	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mpindweni 2	31° 8'58.06"S	29° 1'17.60"E	None	9	0.639	48.52	Crossflow/Francis/Kaplan
156	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mbizeni	30°55'37.12"S	28°49'10.90"E	None	7	0.639	37.74	Crossflow/Francis/Kaplan
157	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Mahlungulu	31°01'54.51"S	28°53'04.19"E	T3H005	Weir	0.639	n/a	n/a
158	Eastern Cape	OR Tambo	Mhlontlo - 222	Thina	Lwandlana	31° 1'54.35"S	28°53'2.01"E	Weir	Weir	0.639	n/a	n/a
159	Eastern Cape	OR Tambo	Mhlontlo - 223	Thina	Mnqunyana	31° 4'15.50"S	28°57'59.87"E	None	10	0.639	53.91	Crossflow/Francis/Turgo/Kaplan
160	Eastern Cape	OR Tambo	Mhlontlo - 223	Thina	Kwa Madiba	31°11'38.62"S	29° 3'18.18"E	None	42	0.639	226.42	Crossflow/Francis/Turgo/Pelton
161	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Ntongwana 2	31°17'27.45"S	29°40'18.94"E	None	29	0.030	7.34	Crossflow/Pelton
162	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Hombe	31°18'44.75"S	29°38'0.66"E	None	19	0.030	4.81	Crossflow/Pelton
163	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Nqaqhumbe	31°20'5.96"S	29°37'5.56"E	None	12	0.030	3.04	Crossflow
164	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Dick	31°19'32.53"S	29°30'47.11"E	None	8	0.030	2.02	Crossflow
165	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Hombe 2	31°17'58.76"S	29°39'21.87"E	None	7	0.030	1.77	Crossflow
166	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Mayalweni 2	31°19'45.75"S	29°35'55.20"E	None	7	0.030	1.77	Crossflow
167	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Mrhoshozo	31°18'0.04"S	29°27'15.94"E	None	6	0.030	1.52	Crossflow
168	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Dick 2	31°19'25.31"S	29°31'9.19"E	None	6	0.030	1.52	Crossflow
169	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Palmarton Mission	31°19'26.19"S	29°29'10.66"E	None	6	0.030	1.52	Crossflow
170	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Dumasi	31°19'7.01"S	29°34'8.91"E	None	5	0.030	1.27	Crossflow
171	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Dumasi 2	31°18'57.60"S	29°35'5.44"E	None	4	0.030	1.01	Crossflow

No.	Province	District Municipality	Local Municipality	River	Site	Co-ordinates Lat	Co-ordinates Long	Current Structure	Potential Head (m)	Potential Flow (m^3/s) (95% of time)	Potential Power Generation (kW)	Suitable Turbines
172	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Xura	31°19'42.61"S	29°31'44.30"E	None	4	0.030	1.01	Crossflow
173	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Xura 2	31°19'9.38"S	29°32'20.55"E	None	4	0.030	1.01	Crossflow
174	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Ndimbaneni	31°18'46.57"S	29°28'31.06"E	None	3	0.030	0.76	Crossflow
175	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Mayalweni	31°19'13.54"S	29°35'26.02"E	None	3	0.030	0.76	Crossflow
176	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Nyarheni	31°17'40.28"S	29°26'50.95"E	None	1	0.030	0.25	Crossflow
177	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Lusikisiki Purification	31°20'03.98"S	29°31'41.01"E	T6H005	Gauging Station	0.030	n/a	n/a
178	Eastern Cape	OR Tambo	Ingquza Hill - 224	Xura	Xura 27	31°19'40.00"S	29°31'36.01"E	T6H004	Gauging Station	0.030	n/a	n/a
179	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Vant's Drift	28° 14' 45.52"S	30° 30' 33.15"E	V3H001	Gauging Station	NO DATA	n/a	n/a
180	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Tayside	28° 03' 33.55"S	30° 22' 24.13"E	V3H010	Weir	0.466	n/a	n/a
181	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	De Jagersdrift	28° 00' 37.58"S	30° 23' 39.15"E	V3H006	Gauging Station	NO DATA	n/a	n/a
182	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Buffels 1	28° 1'38.30"S	30°23'6.49"E	None	2	0.465	7.85	Crossflow/Kaplan
183	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Buffels 2	28° 3'27.88"S	30°22'36.48"E	None	1	0.465	3.92	Crossflow/Kaplan
184	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Buffels 3	28° 5'24.14"S	30°23'57.28"E	None	3	0.465	11.77	Crossflow/Kaplan
185	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Buffels 4	28°11'5.12"S	30°29'8.53"E	None	26	0.465	102.00	Crossflow/Francis/Turgo
186	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Buffels 5	28°12'59.02"S	30°29'43.85"E	None	3	0.465	11.77	Crossflow/Kaplan
187	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Hlathi-Dlamini	28°14'14.73"S	30°30'46.05"E	None	5	0.465	19.62	Crossflow/Kaplan
188	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Hlathi-Dlamini 2	28°14'50.41"S	30°30'28.07"E	None	5	0.465	19.62	Crossflow/Kaplan
189	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Buffels	Hlathi-Dlamini 3	28°15'43.33"S	30°30'14.72"E	None	4	0.465	15.69	Crossflow/Kaplan
190	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Jabavu	28°16'3.85"S	30°31'30.71"E	None	2	0.465	7.85	Crossflow/Kaplan
191	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Jabavu 2	28°16'43.64"S	30°30'56.89"E	None	3	0.465	11.77	Crossflow/Kaplan
192	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Masotsheni	28°18'55.83"S	30°31'9.39"E	None	3	0.465	11.77	Crossflow/Kaplan
193	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Rorke's Drift 2	28°20'49.18"S	30°34'7.00"E	None	13	0.465	51.00	Crossflow/Francis/Turgo
194	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Rorke's Drift	28°20'56.94"S	30°32'39.90"E	None	2	0.465	7.85	Crossflow/Kaplan
195	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Ndodekhling-Shayiwe	28°21'57.98"S	30°35'9.70"E	None	10	0.465	31.93	Crossflow/Kaplan
196	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Goba	28°22'55.92"S	30°36'11.35"E	None	16	0.465	62.77	Crossflow/Francis/Turgo
197	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Mpandeni	28°23'32.83"S	30°37'38.38"E	None	16	0.465	62.77	Crossflow/Francis/Turgo
198	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Klwayisi	28°24'42.52"S	30°37'32.68"E	None	11	0.465	43.15	Crossflow/Francis/Turgo
199	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Woodleigh	28°27'4.86"S	30°37'2.97"E	None	6	0.465	23.54	Crossflow/Kaplan
200	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Belungwana	28°28'24.61"S	30°37'57.51"E	None	4	0.465	15.69	Crossflow/Kaplan
201	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Woza	28°29'47.30"S	30°37'45.14"E	None	13	0.465	51.00	Crossflow/Francis/Turgo
202	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Gubazi	28°31'54.32"S	30°40'16.00"E	None	6	0.465	23.54	Crossflow/Kaplan
203	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Ngqulu	28°34'28.03"S	30°36'20.30"E	None	3	0.465	11.77	Crossflow/Kaplan
204	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Ngqulu 2	28°35'53.76"S	30°36'51.06"E	None	4	0.465	15.69	Crossflow/Kaplan
205	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Buffels	Mngeni	28°37'40.40"S	30°36'56.67"E	None	16	0.465	62.77	Crossflow/Francis/Turgo
207	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Mangeni	Maphungu 2	28°27'36.96"S	30°46'8.40"E	None	5	NO DATA	n/a	n/a
208	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Mangeni	Maphungu	28°27'37.55"S	30°46'14.32"E	Weir	Weir	NO DATA	n/a	n/a
209	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Mangeni	aMagogo 2	28°27'39.49"S	30°47'45.86"E	None	3	NO DATA	n/a	n/a
210	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Mangeni	Ntanyeni	28°27'47.32"S	30°45'55.31"E	None	38	NO DATA	n/a	n/a
211	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Mangeni	aMagogo	28°27'56.81"S	30°47'58.98"E	None	4	NO DATA	n/a	n/a
212	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Mangeni	Belungwana 2	28°29'8.17"S	30°43'1.85"E	None	6	NO DATA	n/a	n/a
213	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Keate's Drift	28°51'35.38"S	30°29'59.13"E	V2H008	Gauging Station	NO DATA	n/a	n/a
214	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Dungamanzi	28°49'5.33"S	30°31'54.19"E	None	23	0.380	73.74	Crossflow/Francis/Turgo
215	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Keate's Drift 3	28°51'34.99"S	30°29'5.60"E	None	5	0.380	16.03	Crossflow/Kaplan
216	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Keate's Drift 2	28°52'17.79"S	30°28'25.70"E	None	3	0.380	9.62	Crossflow/Kaplan
217	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Mandulane	28°52'55.38"S	30°27'8.39"E	None	2	0.380	6.41	Crossflow/Kaplan
218	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Ntabakayishi 2	28°54'26.80"S	30°24'59.08"E	None	4	0.380	12.82	Crossflow/Kaplan
219	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Emachunweni	28°54'42.87"S	30°23'35.45"E	None	5	0.380	16.03	Crossflow/Kaplan
220	KwaZulu-Natal	uMzinyathi	Msinga - 173	Mooi	Ntabakayishi	28°55'5.24"S	30°24'37.28"E	None	2	0.380	6.41	Crossflow/Kaplan
221	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Scheepersdaal	29°01'59.37"S	30°21'36.14"E	V2H001	Weir	0.380	n/a	n/a
222	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Muden 3	28°58'28.83"S	30°22'51.60"E	None	3	0.380	9.62	Crossflow/Kaplan
223	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Muden	28°59'14.16"S	30°22'3.54"E	None	4	0.380	12.82	Crossflow/Kaplan
224	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Muden 2	28°59'5.98"S	30°23'26.23"E	None	3	0.380	9.62	Crossflow/Kaplan
225	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Lembethe	29° 0'55.10"S	30°22'37.03"E	None	2	0.380	6.41	Crossflow/Kaplan
226	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Lembethe	29° 1'22.04"S	30°22'31.00"E	None	3	0.380	9.62	Crossflow/Kaplan
227	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Mooi 4	29° 1'28.74"S	30°22'7.40"E	None	4	0.380	12.82	Crossflow/Kaplan
228	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Mooi 3	29° 1'48.95"S	30°21'34.33"E	None	7	0.380	22.44	Crossflow/Kaplan
229	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Mooi 2	29° 1'59.16"S	30°21'44.63"E	None	3	0.380	9.62	Crossflow/Kaplan

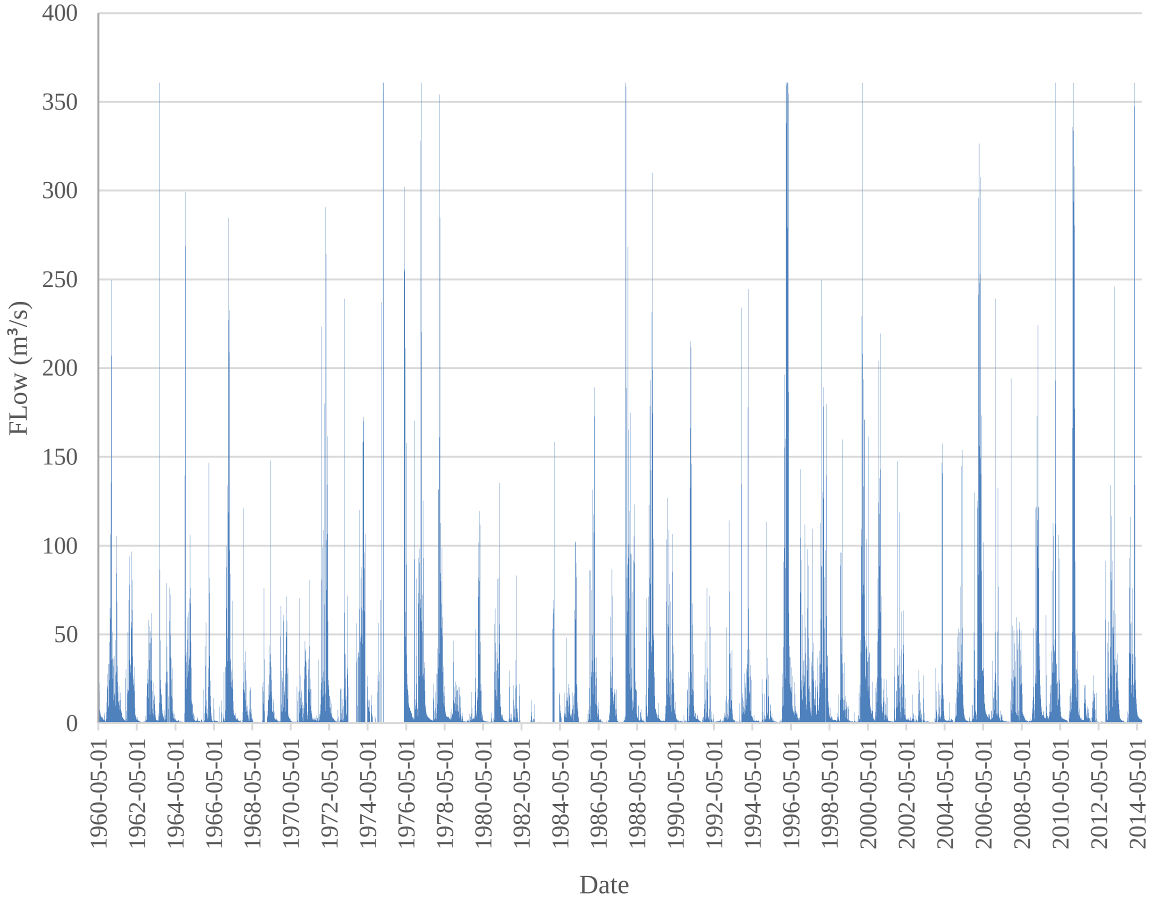
No.	Province	District Municipality	Local Municipality	River	Site	Co-ordinates		Current Structure	Potential Head (m)	Potential Flow (m³/s) (95% of time)	Potential Power Generation (kW)	Suitable Turbines
						Lat	Long					
230	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mooi	Mooi 1	29° 2'20.75"S	30°21'58.84"E	None	3	0.380	9.62	Crossflow/Kaplan
231	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mistley	29°09'42.91"S	30°37'47.99"E	U4H002	Weir	0.047	n/a	n/a
232	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 7	29° 7'53.08"S	30°39'6.25"E	None	2	0.047	0.79	Crossflow
233	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 10	29° 8'11.68"S	30°40'29.09"E	None	3	0.047	1.19	Crossflow
234	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 9	29° 8'16.78"S	30°40'17.99"E	None	6	0.047	2.38	Crossflow
235	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 8	29° 8'33.91"S	30°39'55.18"E	None	4	0.047	1.59	Crossflow
236	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 5	29° 8'36.69"S	30°38'35.44"E	None	2	0.047	0.79	Crossflow
237	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 6	29° 8'7.19"S	30°38'36.25"E	None	3	0.047	1.19	Crossflow
238	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 11	29° 8'7.41"S	30°41'49.11"E	None	3	0.047	1.19	Crossflow
239	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Umvoti Vlei	29° 9'12.23"S	30°35'17.13"E	None	1	0.047	0.40	Crossflow
240	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 4	29° 9'15.08"S	30°38'34.61"E	None	5	0.047	1.98	Crossflow
241	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Umvoti River Station	29° 9'27.76"S	30°37'27.67"E	None	1	0.047	0.40	Crossflow
242	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 12	29° 9'47.94"S	30°41'41.08"E	None	50	0.047	19.83	Crossflow/Pelton
243	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Fairfield Mill	29° 9'55.20"S	30°38'11.62"E	None	3	0.047	1.19	Crossflow
244	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 3	29°10'44.51"S	30°30'50.87"E	None	6	0.047	2.38	Crossflow
245	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 1	29°11'16.59"S	30°30'1.35"E	None	1	0.047	0.40	Crossflow
246	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Njengabanthu	29°11'33.15"S	30°48'38.39"E	None	3	0.047	1.19	Crossflow
247	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Kwambuzi 2	29°11'51.84"S	30°46'55.21"E	None	4	0.047	1.59	Crossflow
248	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 2	29°11'9.14"S	30°30'29.62"E	None	2	0.047	0.79	Crossflow
249	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mvoti 13	29°12'23.28"S	30°43'48.38"E	None	4	0.047	1.59	Crossflow
250	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Kwambuzi	29°12'27.76"S	30°44'50.06"E	None	4	0.047	1.59	Crossflow
251	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Mkhize	29°13'31.25"S	30°51'18.74"E	None	3	0.047	1.19	Crossflow
252	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Umvoti Location 2	29°14'30.96"S	30°54'53.53"E	None	4	0.047	1.59	Crossflow
253	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Ngwempisi	29°14'40.35"S	30°56'14.51"E	None	23	0.047	9.12	Crossflow
254	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Umvoti Location	29°14'41.99"S	30°54'34.01"E	None	2	0.047	0.79	Crossflow
255	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Sindi	29°15'12.39"S	30°58'56.96"E	None	11	0.047	4.36	Crossflow
256	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Dayingubo	29°15'12.54"S	30°53'32.52"E	None	4	0.047	1.59	Crossflow
257	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Dayingubo 3	29°14'22.79"S	30°54'8.51"E	None	3	0.047	1.19	Crossflow
258	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Dayingubo 2	29°14'48.40"S	30°53'44.73"E	None	4	0.047	1.59	Crossflow
259	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Mvoti	Njengabanthu 2	29°12'5.75"S	30°48'20.63"E	None	48	0.047	19.03	Crossflow
260	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Ngwebini	Magala 2	28°16'28.85"S	30°47'0.98"E	None	2	NO DATA	n/a	n/a
261	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Ngwebini	Magala	28°16'36.30"S	30°46'49.78"E	None	7	NO DATA	n/a	n/a
262	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Ngwebini	Kwa-Vuma	28°17'23.01"S	30°46'10.21"E	None	2	NO DATA	n/a	n/a
263	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Ngwebini	Ngwebini	28°18'27.00"S	30°43'31.53"E	None	2	NO DATA	n/a	n/a
264	KwaZulu-Natal	uMzinyathi	Nquthu - 171	Ngwebini	Esiginqa	28°18'34.95"S	30°44'6.30"E	None	5	NO DATA	n/a	n/a
266	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Sampofu 1	28°31'27.02"S	30°27'1.55"E	None	5	NO DATA	n/a	n/a
267	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Sampofu 2	28°31'44.02"S	30°27'20.98"E	None	2	NO DATA	n/a	n/a
268	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Sampofu 3	28°31'52.89"S	30°27'29.66"E	None	5	NO DATA	n/a	n/a
269	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Sampofu 5	28°31'55.08"S	30°28'0.96"E	None	5	NO DATA	n/a	n/a
270	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Sampofu 4	28°31'55.87"S	30°27'39.53"E	None	6	NO DATA	n/a	n/a
271	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Makhasana	28°33'13.26"S	30°27'57.29"E	None	3	NO DATA	n/a	n/a
272	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Makhasana 2	28°33'43.93"S	30°27'46.81"E	None	2	NO DATA	n/a	n/a
273	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Pomeroy	28°34'22.08"S	30°27'8.50"E	None	2	NO DATA	n/a	n/a
274	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Matshematshe	28°36'29.88"S	30°25'55.68"E	None	6	NO DATA	n/a	n/a
275	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Matshematshe 2	28°37'17.11"S	30°25'50.51"E	None	4	NO DATA	n/a	n/a
276	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Matshematshe 3	28°37'37.77"S	30°24'53.90"E	None	8	NO DATA	n/a	n/a
277	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Macanco	28°39'9.57"S	30°25'2.15"E	None	6	NO DATA	n/a	n/a
278	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Mabuzela	28°41'18.76"S	30°24'46.48"E	None	4	NO DATA	n/a	n/a
279	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Ezimbovini	28°42'51.15"S	30°25'25.50"E	None	4	NO DATA	n/a	n/a
280	KwaZulu-Natal	uMzinyathi	Msinga - 173	Sampofu	Esijozini	28°43'30.98"S	30°24'56.29"E	None	15	NO DATA	n/a	n/a
281	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Tugela Ferry	28°45'00.10"S	30°26'31.99"E	V6H002	Gauging Station	3.512	n/a	n/a
282	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Impafana Loc.	28°44'46.42"S	30°22'43.14"E	V6H007	Gauging Station	1.368	n/a	n/a
283	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Phalafini	28°41'49.16"S	30°17'38.73"E	None	4	1.368	46.17	Crossflow/Kaplan
284	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Mashunka	28°43'18.77"S	30°19'1.49"E	None	4	1.368	46.17	Crossflow/Kaplan
285	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Buffels	28°43'2.73"S	30°38'15.38"E	None	9	3.512	266.66	Crossflow/Kaplan/Francis
286	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Bassonsdrift 2	28°43'33.29"S	30°37'58.01"E	None	7	3.512	207.41	Crossflow/Kaplan/Francis
287	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Jolwayo	28°44'14.43"S	30°19'27.05"E	None	12	1.368	138.50	Crossflow/Kaplan/Francis

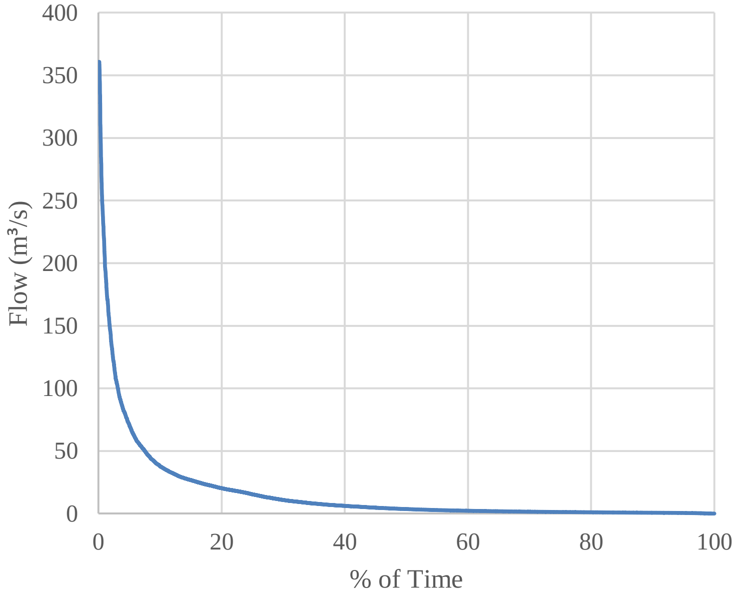
No.	Province	District Municipality	Local Municipality	River	Site	Co-ordinates		Current Structure	Potential Head (m)	Potential Flow (m³/s) (95% of time)	Potential Power Generation (kW)	Suitable Turbines
						Lat	Long					
288	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Bassonsdrift	28°44'23.17"S	30°37'9.74"E	None	4	3.512	118.52	Crossflow/Kaplan
289	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Mbabane	28°44'44.93"S	30°22'46.03"E	None	6	1.368	69.25	Crossflow/Kaplan
290	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Mbhono	28°45'31.23"S	30°32'39.93"E	None	2	3.512	59.26	Crossflow/Kaplan
291	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Ndaya	28°45'48.71"S	30°34'27.49"E	None	4	3.512	118.52	Crossflow/Kaplan
292	KwaZulu-Natal	uMzinyathi	Msinga - 173	Thukela	Ezingulubeni	28°45'53.78"S	30°29'44.52"E	None	7	3.512	207.41	Crossflow/Kaplan
293	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Sihosheni	28°43'20.99"S	30°45'56.04"E	None	7	3.512	207.41	Crossflow/Kaplan
294	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Jameson's Drift	28°45'49.35"S	30°53'24.16"E	None	5	3.512	148.15	Crossflow/Kaplan
295	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Ndimakude	28°45'52.69"S	30°48'30.53"E	None	4	3.512	118.52	Crossflow/Kaplan
296	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Khothongwe	28°46'24.12"S	30°50'28.48"E	None	6	3.512	177.78	Crossflow/Kaplan
297	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Pholela 1	28°46'45.14"S	30°51'55.40"E	None	5	3.512	148.15	Crossflow/Kaplan
298	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Tulwana	28°47'36.48"S	30°56'34.89"E	None	4	3.512	118.52	Crossflow/Kaplan
299	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Sokheni	28°47'55.89"S	30°44'49.92"E	None	9	3.512	266.66	Crossflow/Kaplan
300	KwaZulu-Natal	uMzinyathi	Umvoti - 187	Thukela	Ezilozini	28°48'51.38"S	30°55'32.80"E	None	29	3.512	859.25	Crossflow/Kaplan/Francis
301	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Kuikvlei	28°18'35.49"S	30°08'52.11"E	V6H003	Weir	0.120	n/a	n/a
302	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank 1	28°10'20.66"S	30° 3'42.46"E	Weir	Weir	0.120	n/a	n/a
303	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank 2	28°11'14.21"S	30° 5'47.17"E	None	3	0.120	3.04	Crossflow
304	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank 3	28°11'39.05"S	30° 6'0.83"E	None	1	0.120	1.01	Crossflow
305	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Siyanda	28°12'17.08"S	30° 6'33.36"E	None	3	0.120	3.04	Crossflow
306	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Siyanda 2	28°12'22.37"S	30° 6'47.27"E	None	2	0.120	2.02	Crossflow
307	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank 4	28°12'49.99"S	30° 7'26.18"E	None	3	0.120	3.04	Crossflow
308	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wallsend	28°13'23.38"S	30° 7'41.31"E	None	2	0.120	2.02	Crossflow
309	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wallsend 2	28°14'18.47"S	30° 7'42.58"E	None	2	0.120	2.02	Crossflow
310	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Uithoek	28°14'55.89"S	30° 7'24.43"E	None	5	0.120	5.06	Crossflow
311	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Uithoek 2	28°15'4.71"S	30° 7'22.87"E	None	2	0.120	2.02	Crossflow
312	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Uithoek 3	28°15'42.68"S	30° 7'10.86"E	None	5	0.120	5.06	Crossflow
313	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank 5	28°16'14.28"S	30° 6'50.92"E	None	2	0.120	2.02	Crossflow
314	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank 6	28°16'21.61"S	30° 6'54.08"E	None	1	0.120	1.01	Crossflow
315	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank Town 1	28°17'36.03"S	30° 7'23.71"E	None	3	0.120	3.04	Crossflow
316	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank Town 2	28°18'5.34"S	30° 8'18.25"E	None	3	0.120	3.04	Crossflow
317	KwaZulu-Natal	uMzinyathi	Endumeni - 174	Wasbank	Wasbank Town 3	28°19'12.74"S	30° 9'28.36"E	None	2	0.120	2.02	Crossflow

APPENDIX B – FLOW DATA

<u>uMzinyathi DM Gauging Station Data</u>

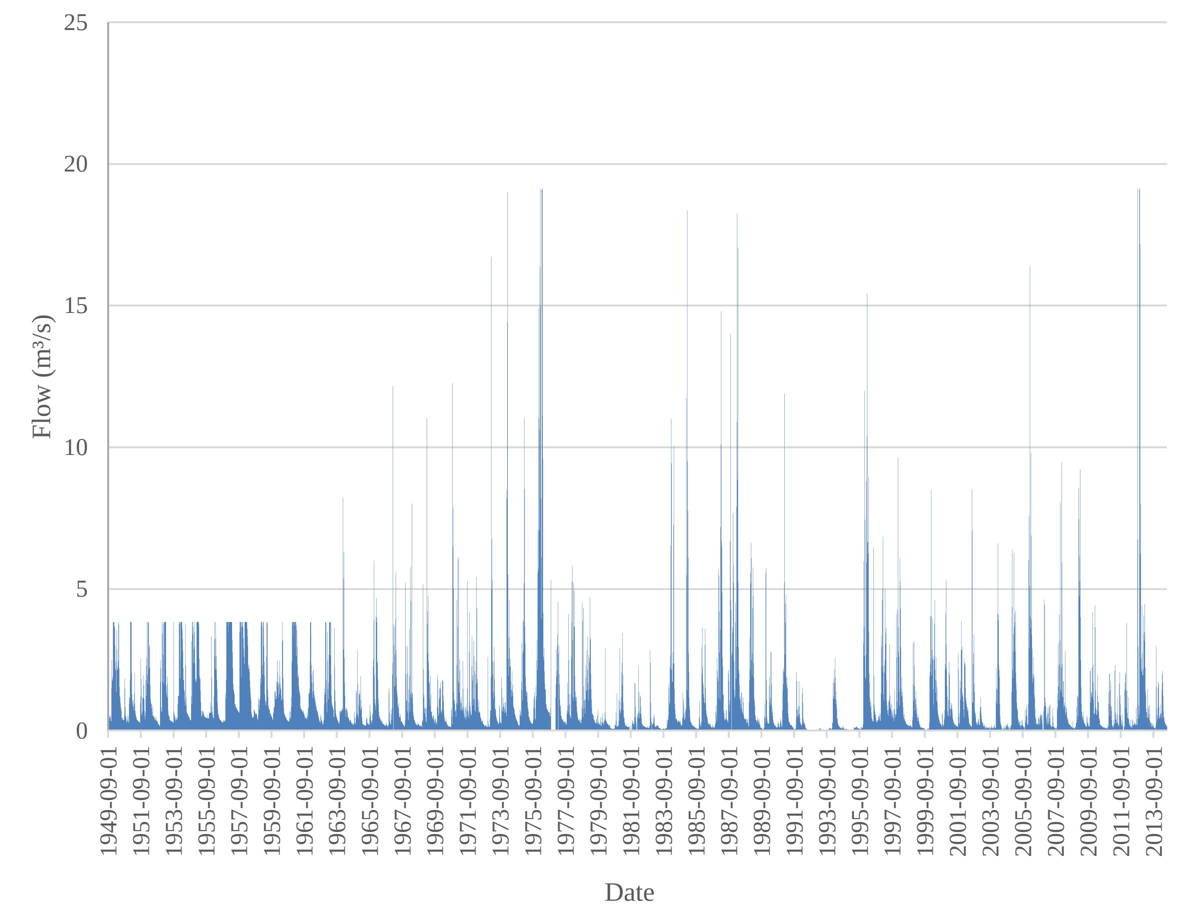
V3H010 – Tayside

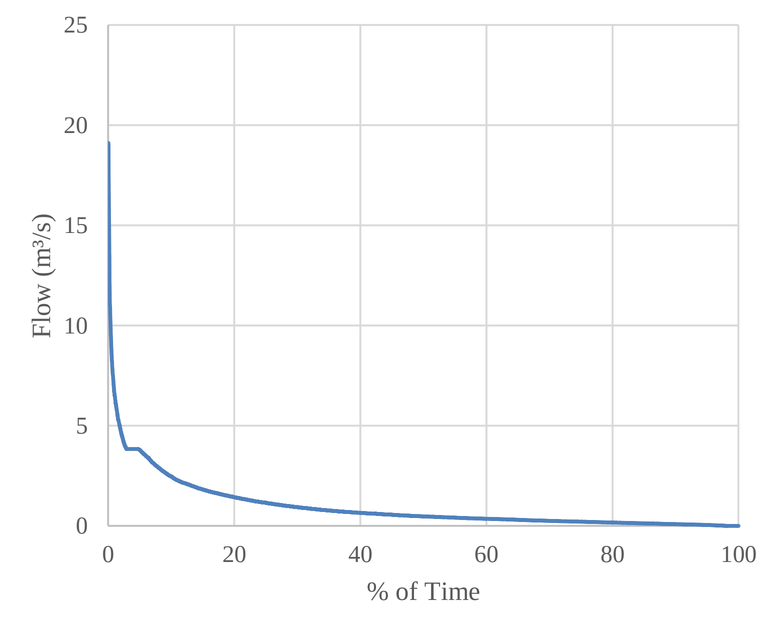




Statistics	
Mean (m^3/s)	16.25
Standard Deviation	37.15
Minimum (m^3/s)	-
Maximum (m^3/s)	360.73
Count	18 097
Confidence Level (95.0%)	0.541

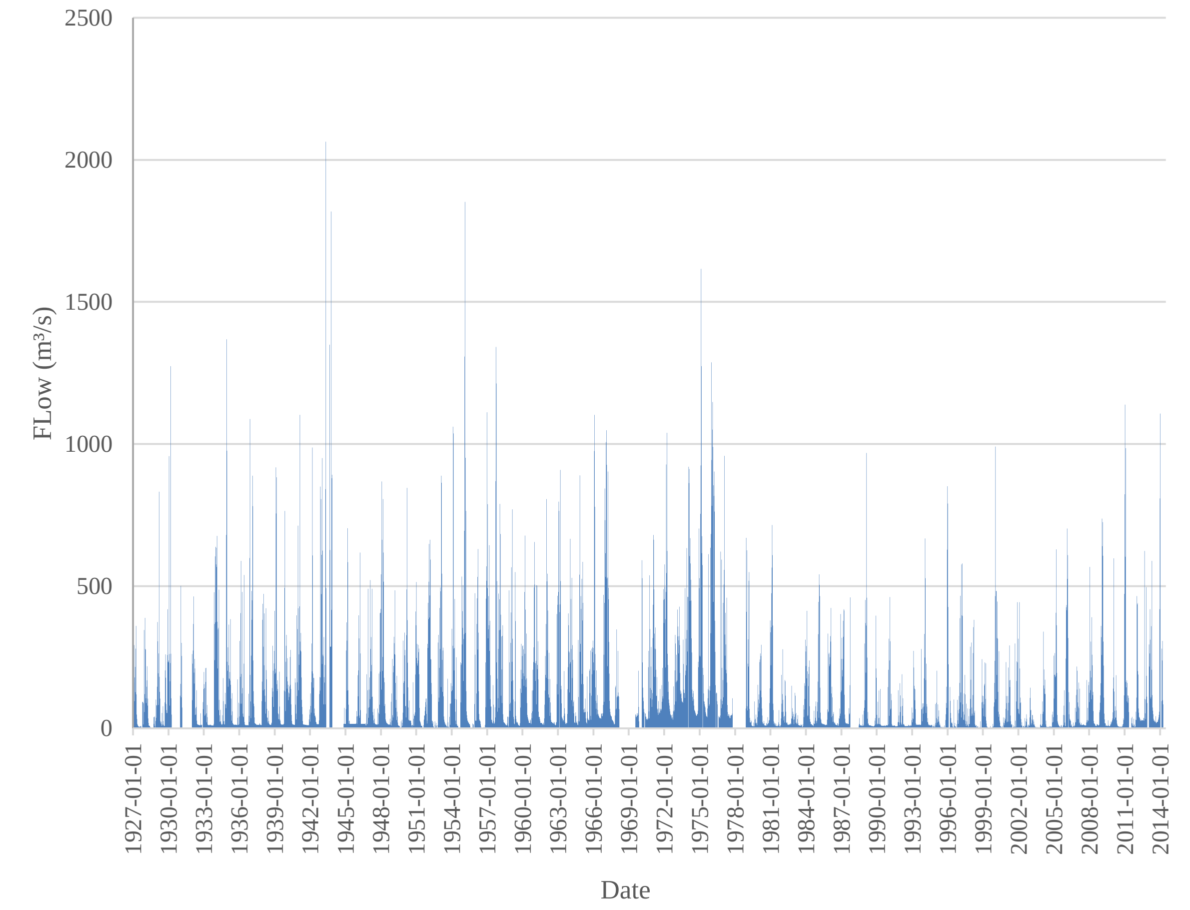
U4H002 – Mistley

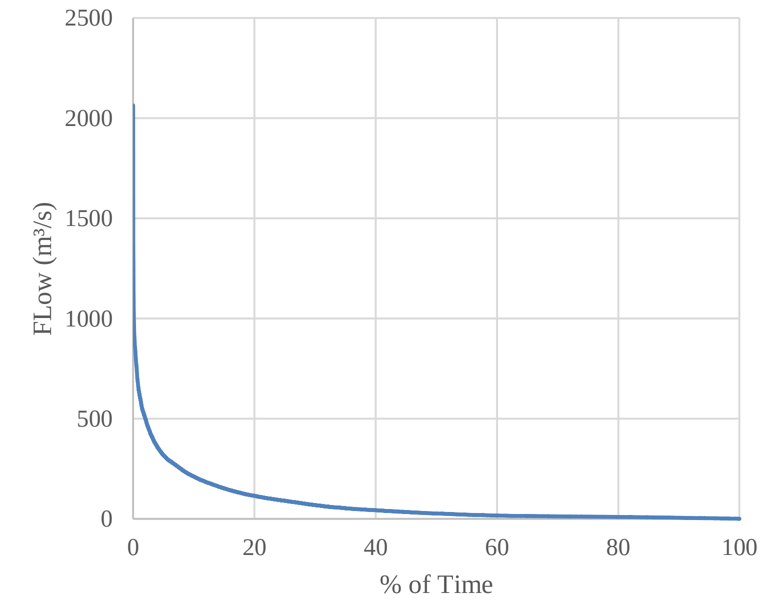




Statistics	
Mean (m^3/s)	0.97
Standard Deviation	1.44
Minimum (m^3/s)	-
Maximum (m^3/s)	19.12
Count	23 303
Confidence Level (95.0%)	0.019

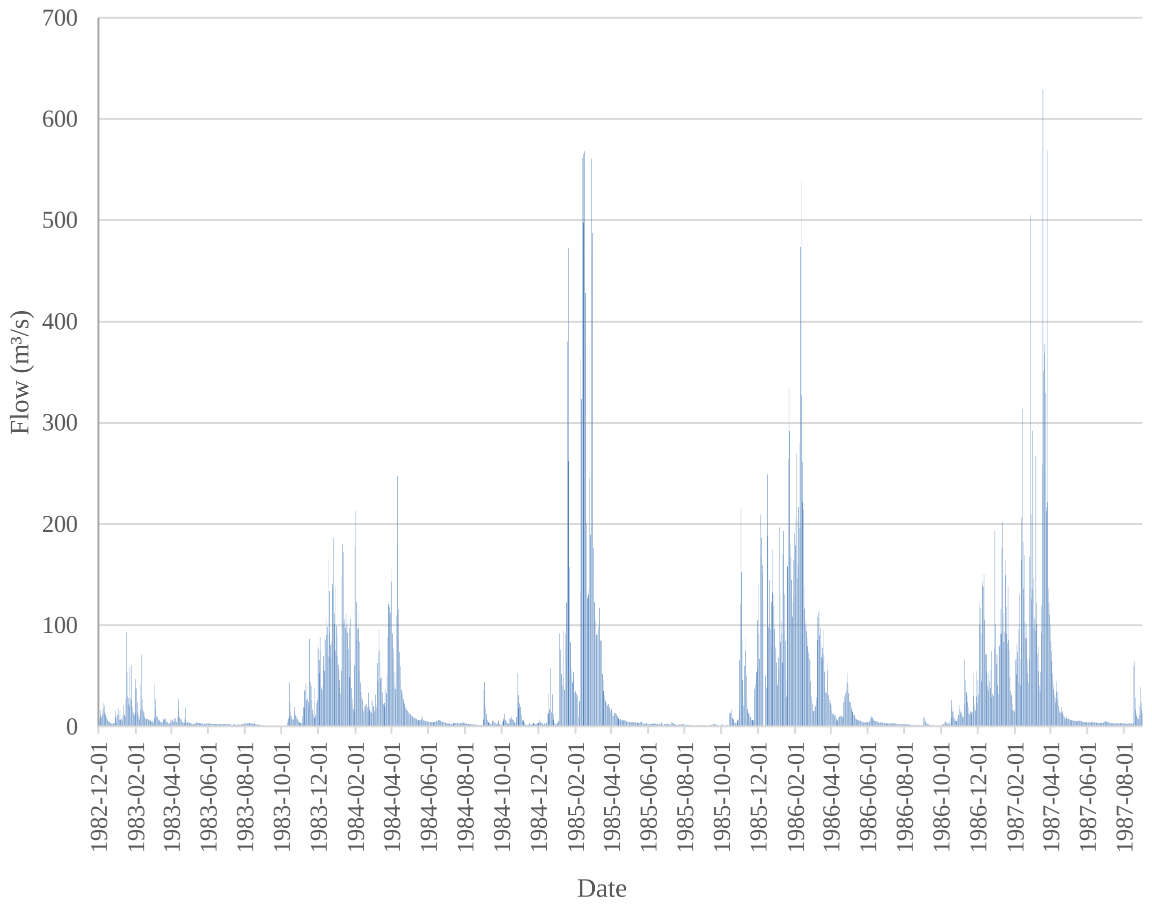
V6H002 - Tugela Ferry

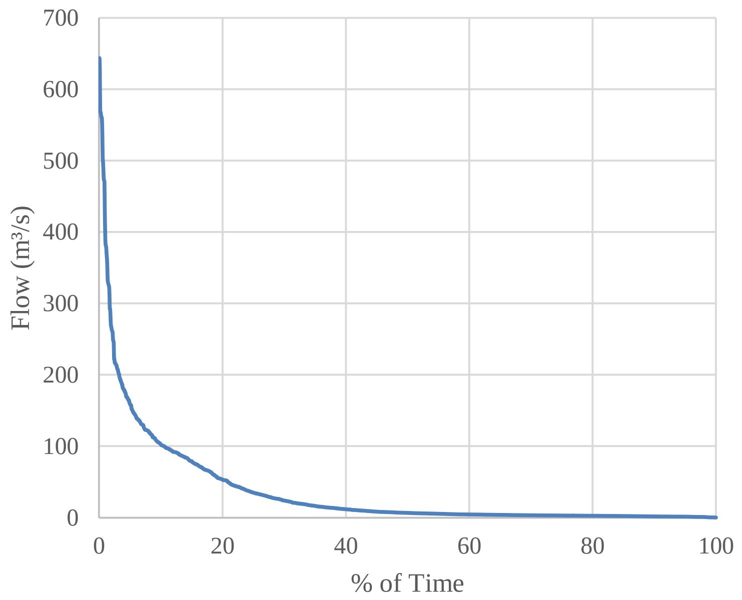




Statistics	
Mean (m^3/s)	78.05
Standard Deviation	127.78
Minimum (m^3/s)	-
Maximum (m^3/s)	2 064.45
Count	29 075
Confidence Level (95.0%)	1.469

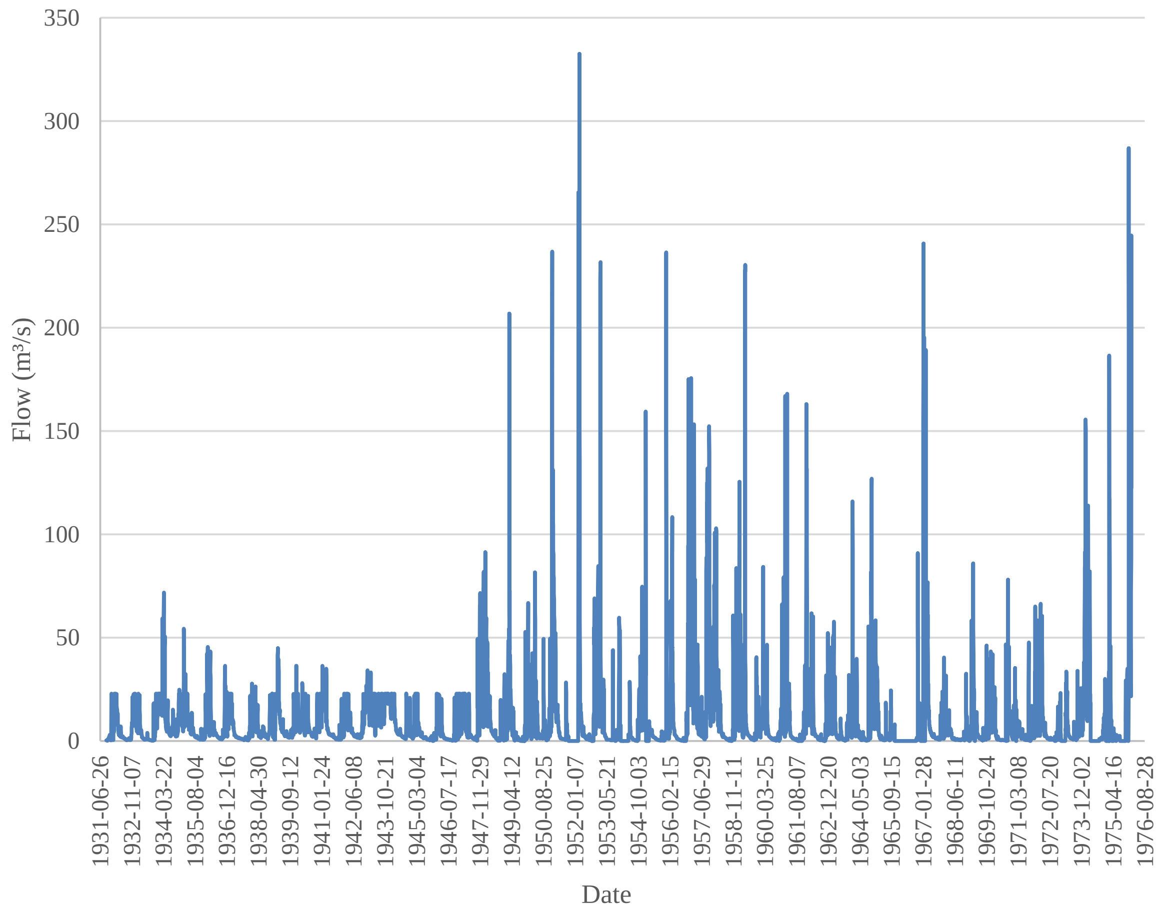
V6H007 - Impafana Loc.

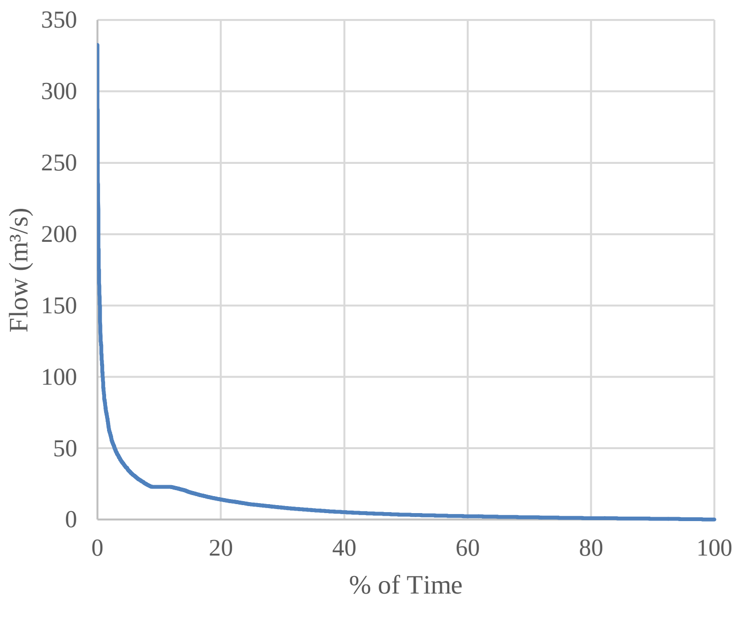




Statistics	
Mean (m^3/s)	36.24
Standard Deviation	73.06
Minimum (m^3/s)	0.17
Maximum (m^3/s)	643.46
Count	1 730
Confidence Level (95.0%)	3.445

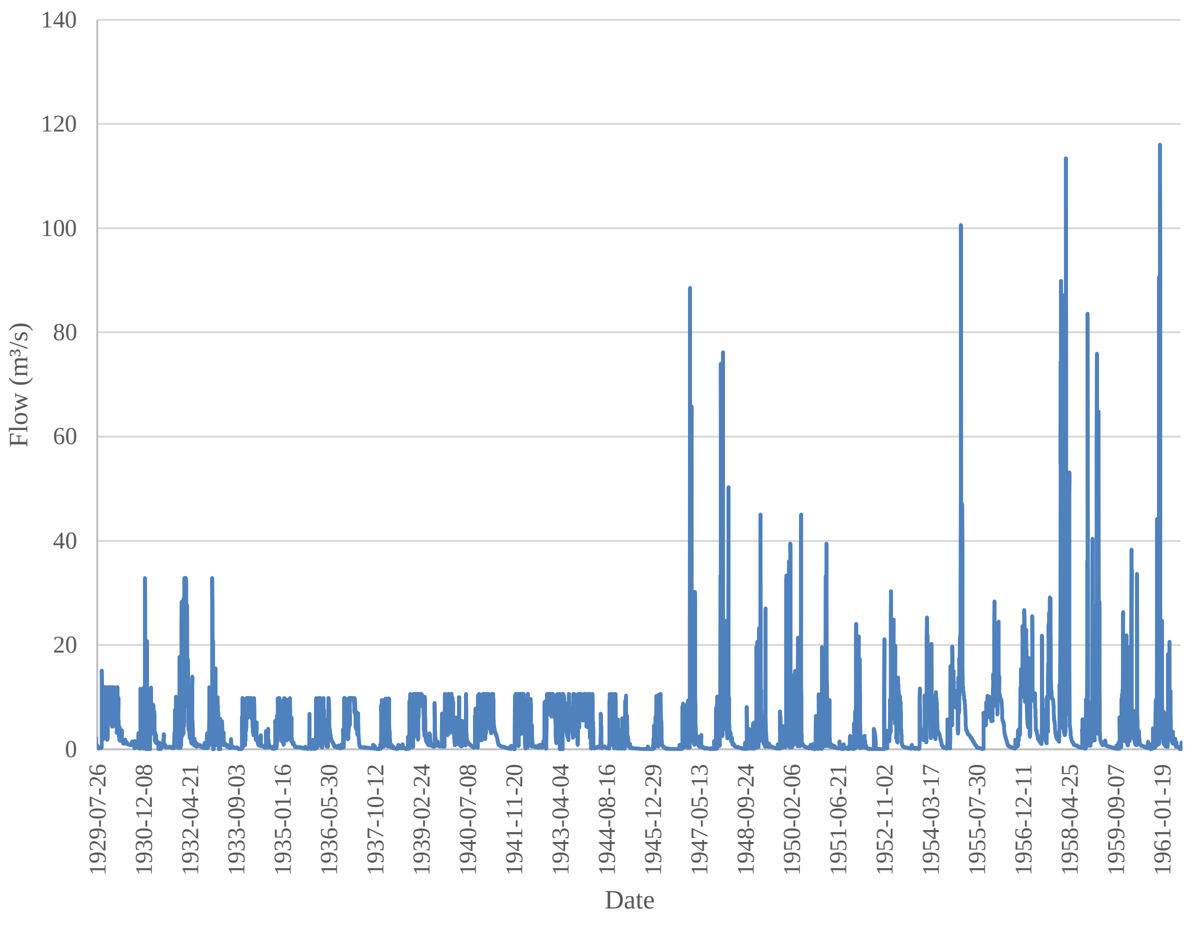
V2H001 - Scheepersdal

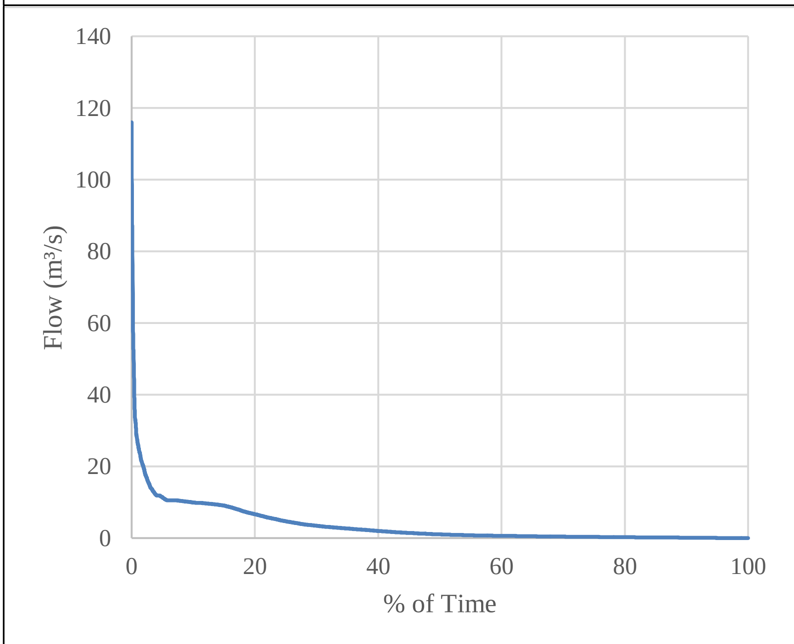




Statistics	
Mean (m^3/s)	9.67
Standard Deviation	18.69
Minimum (m^3/s)	0.01
Maximum (m^3/s)	332.63
Count	15 038
Confidence Level (95.0%)	0.30

V3H003 - Kuikvlei.

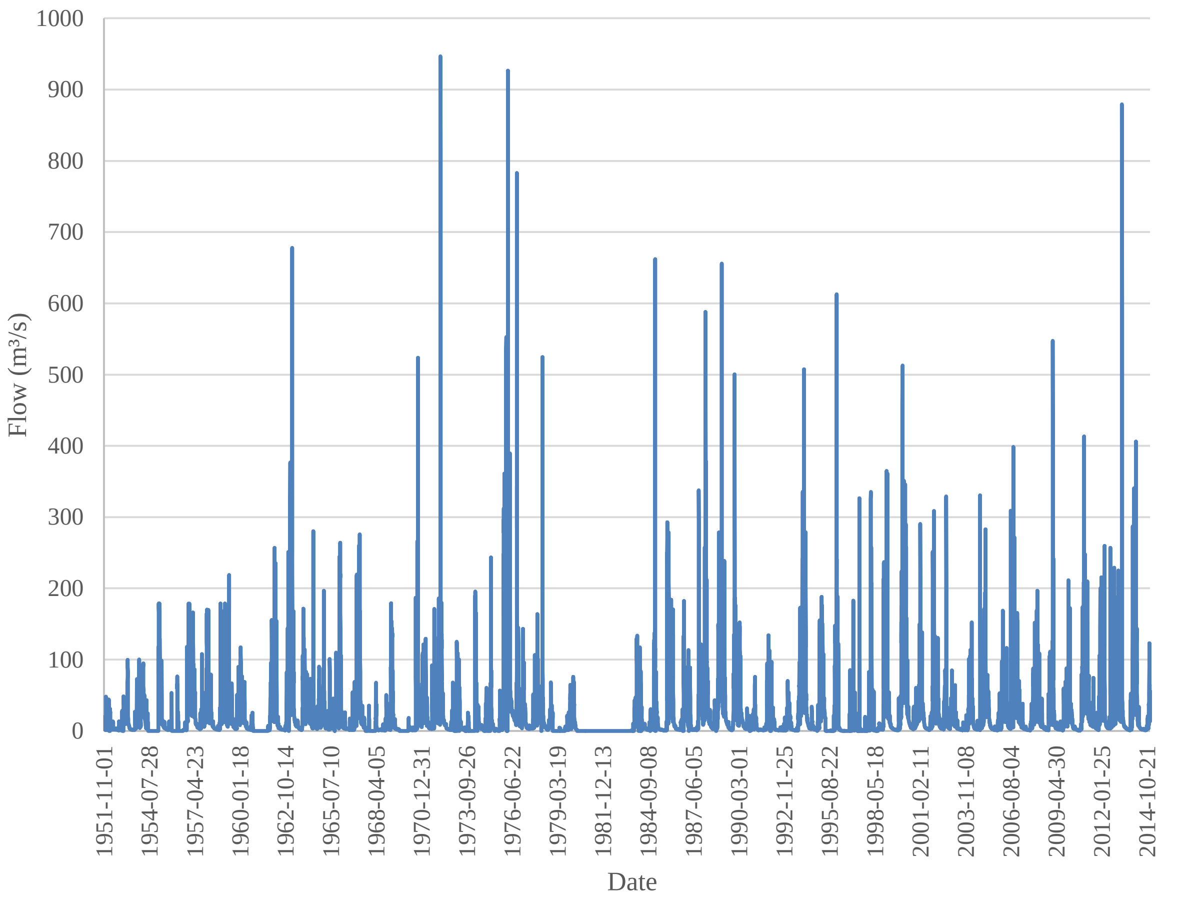


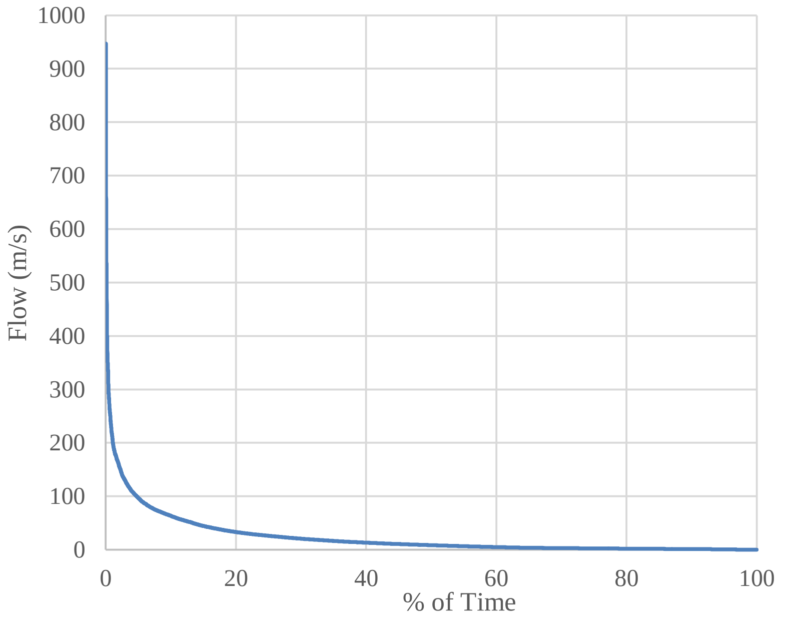


Statistics	
Mean (m^3/s)	3.61
Standard Deviation	6.48
Minimum (m^3/s)	-
Maximum (m^3/s)	116.02
Count	11 690
Confidence Level (95.0%)	0.12

OR Tambo DM Gauging Station Data

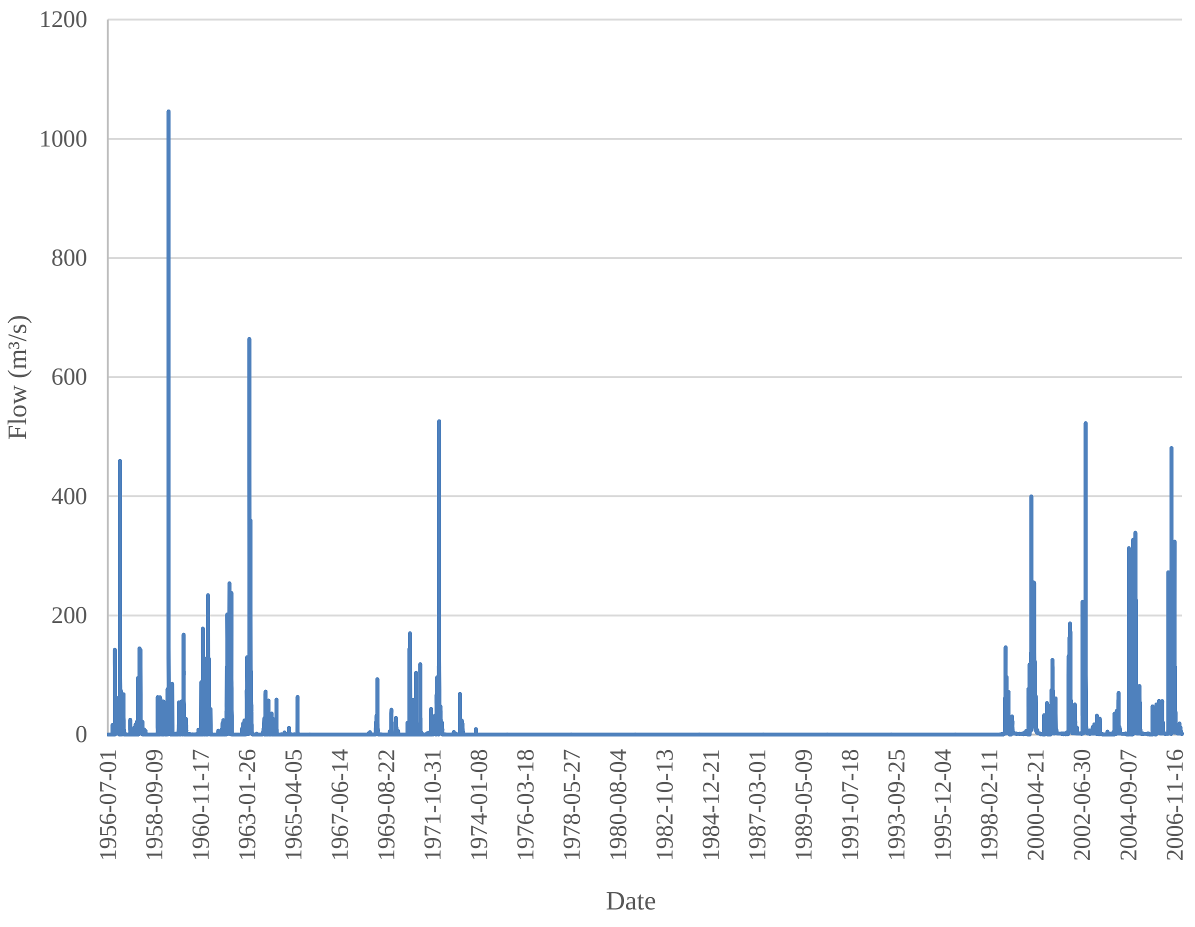
T3H006 - Xonkonxa

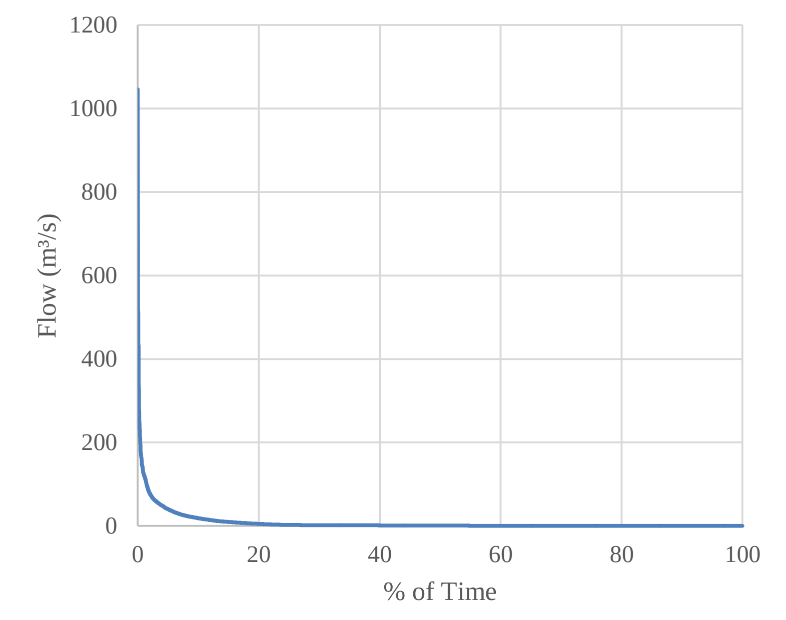




Statistics	
Mean (m^3/s)	24.13
Standard Deviation	46.51
Minimum (m^3/s)	-
Maximum (m^3/s)	946.77
Count	19 934
Confidence Level (95.0%)	0.646

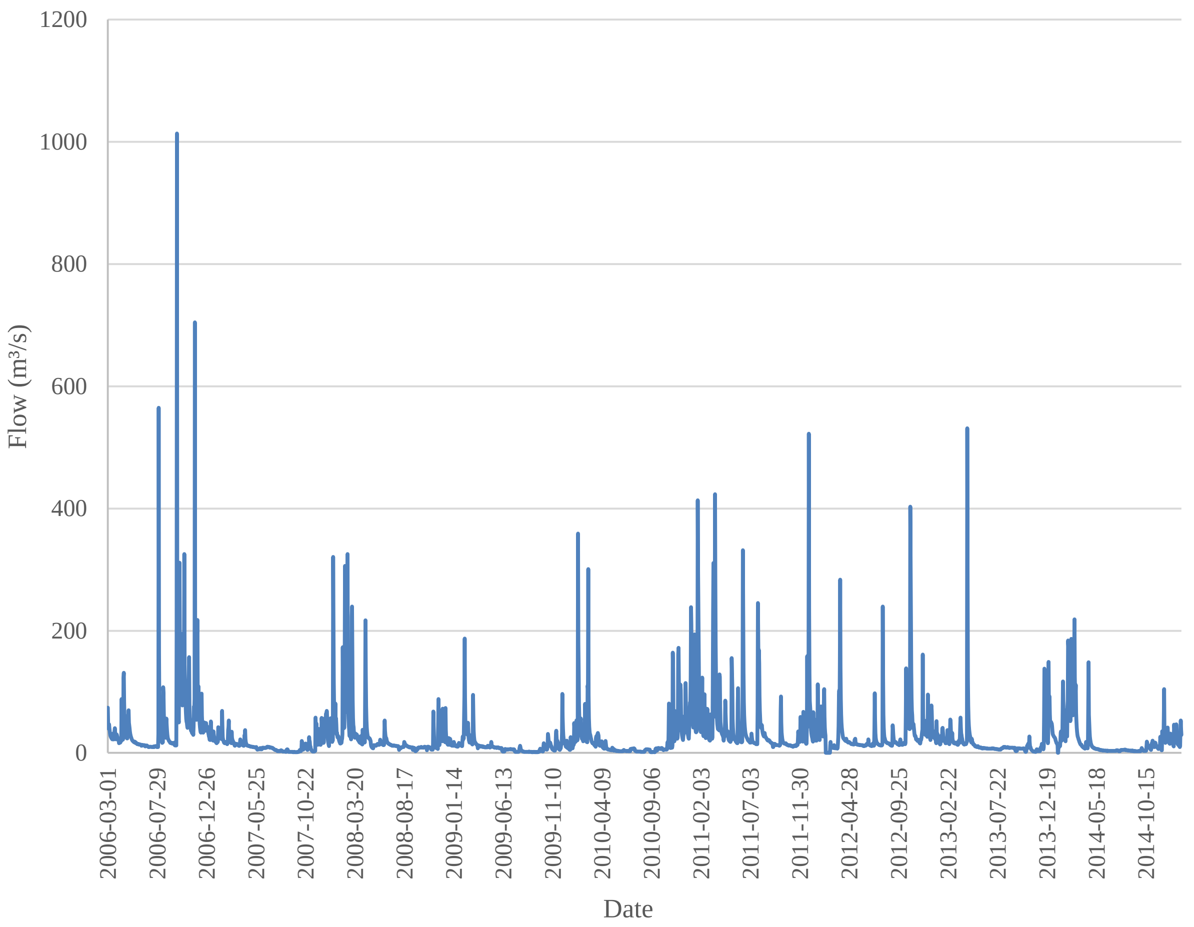
T1H004 - Bashee Bridge

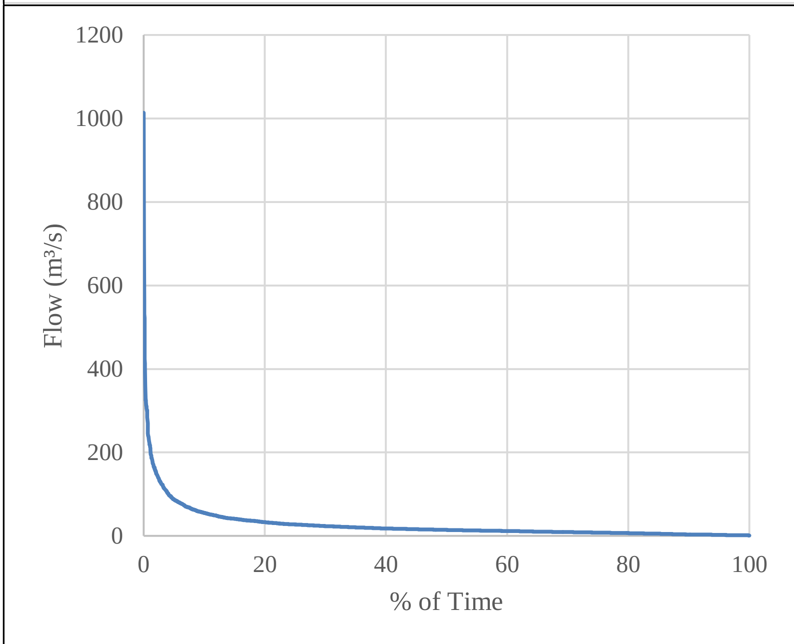




Statistics	
Mean (m^3/s)	7.98
Standard Deviation	31.22
Minimum (m^3/s)	-
Maximum (m^3/s)	1 045.88
Count	8 141
Confidence Level (95.0%)	0.678

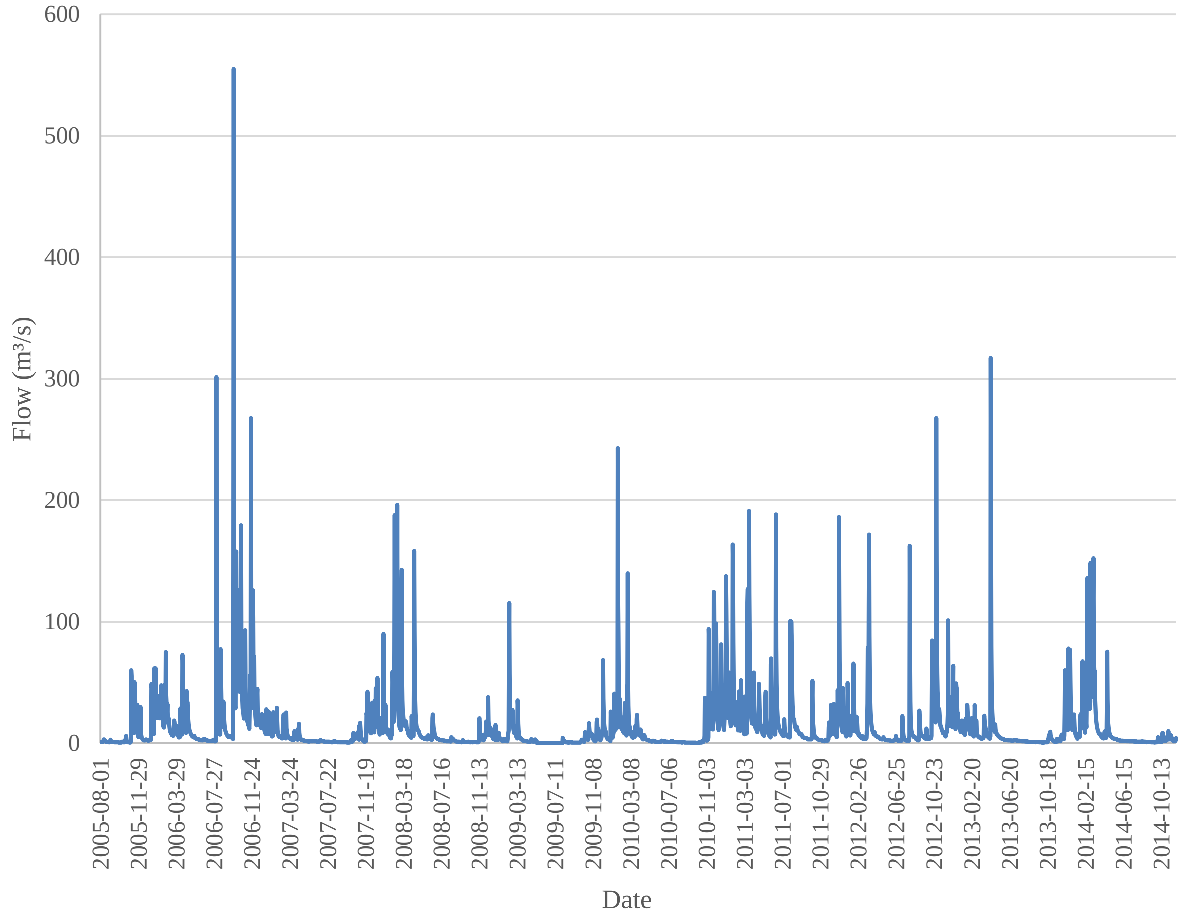
T1H014 - Rune

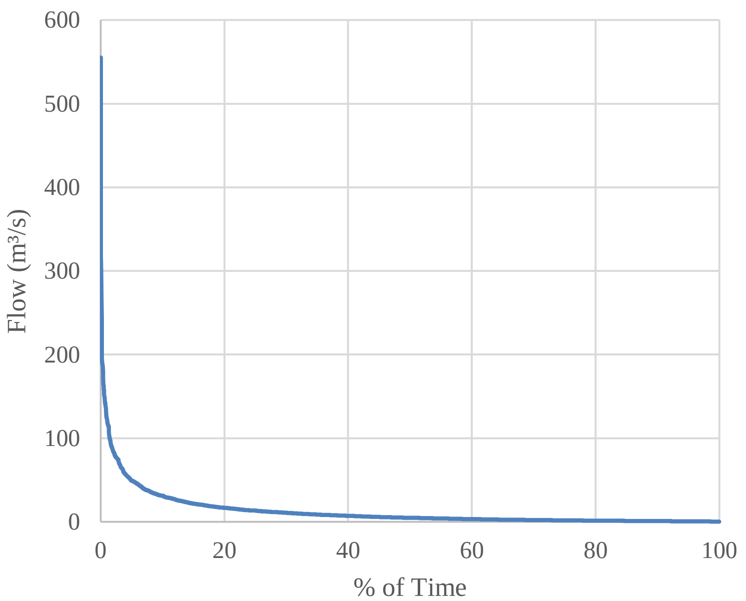




Statistics	
Mean (m^3/s)	26.64
Standard Deviation	45.86
Minimum (m^3/s)	1.19
Maximum (m^3/s)	1 013.74
Count	3 243
Confidence Level (95.0%)	1.579

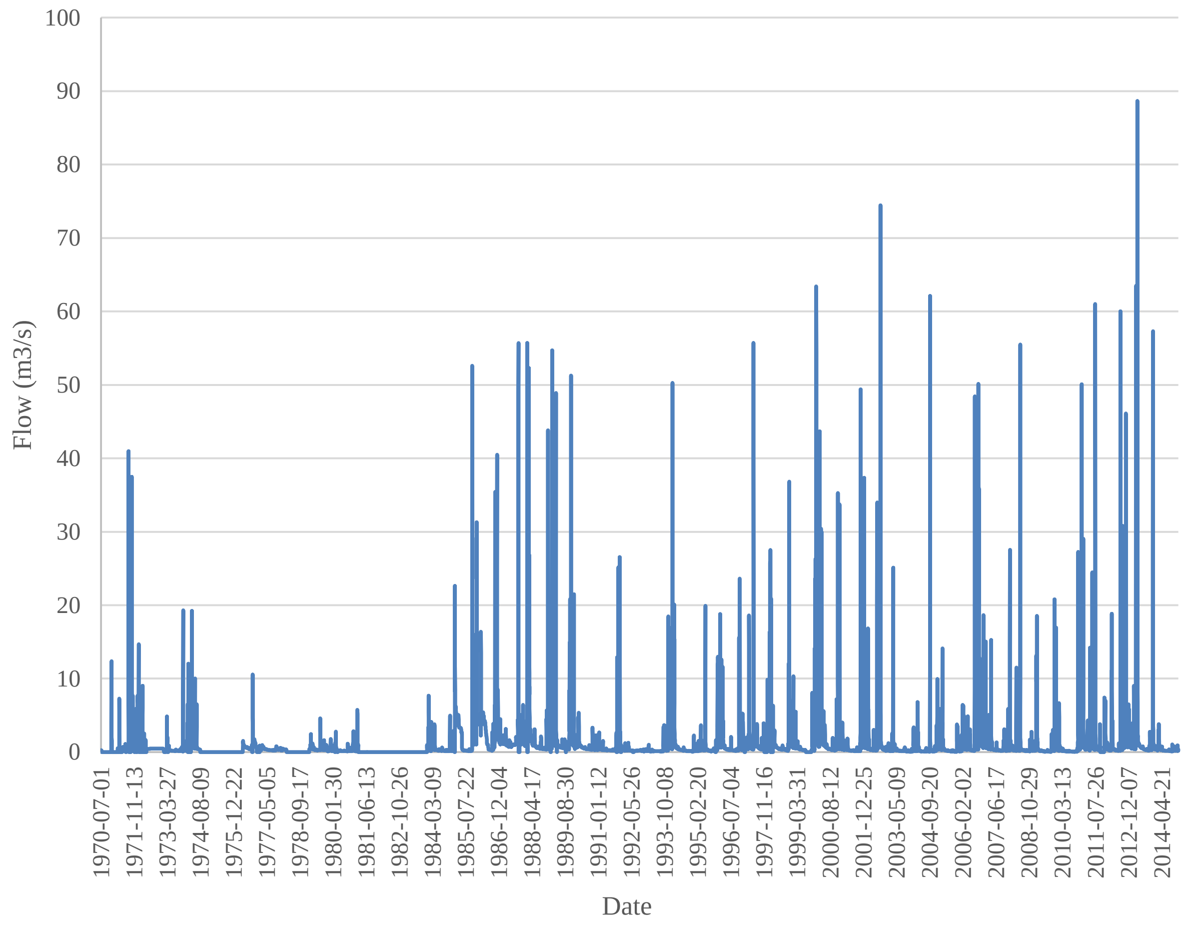
T1H013 - Gxwali Bomvu

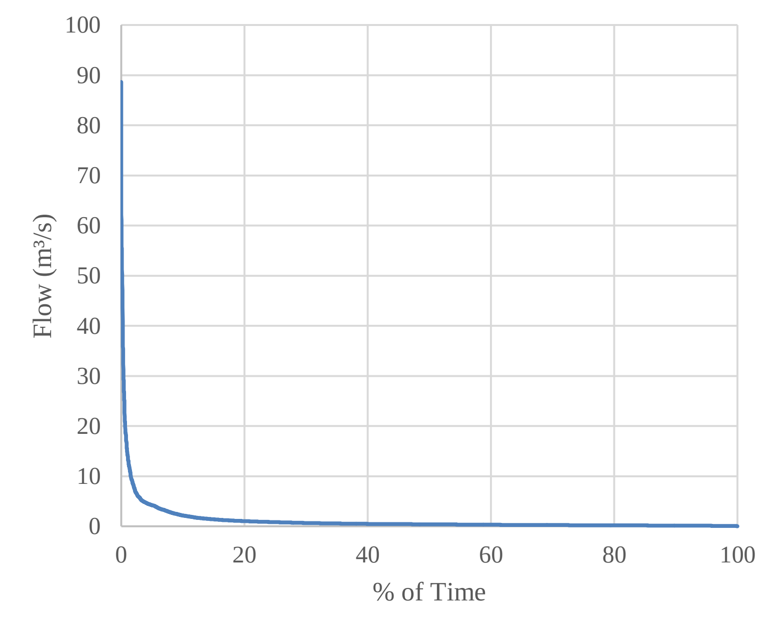




Statistics	
Mean (m^3/s)	12.85
Standard Deviation	25.33
Minimum (m^3/s)	0.21
Maximum (m^3/s)	555.13
Count	3 328
Confidence Level (95.0%)	0.861

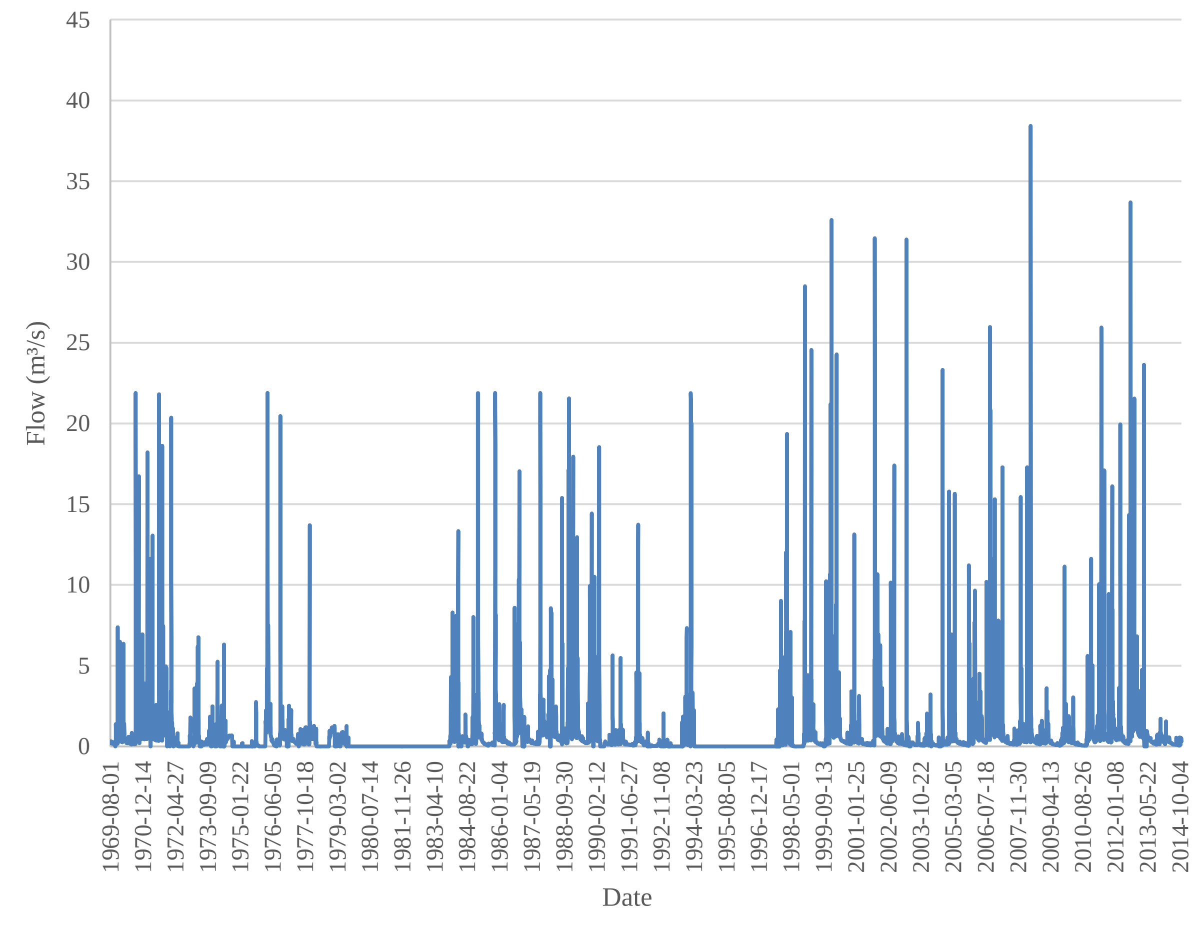
T7H001 - Mgwenyana Loc. 22

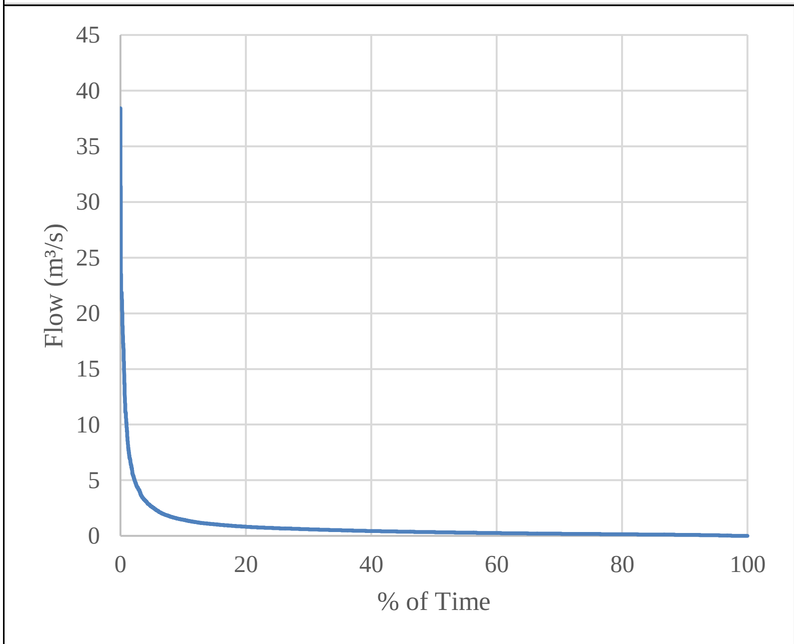




Statistics	
Mean (m^3/s)	1.18
Standard Deviation	3.66
Minimum (m^3/s)	0.03
Maximum (m^3/s)	88.62
Count	13 440
Confidence Level (95.0%)	0.062

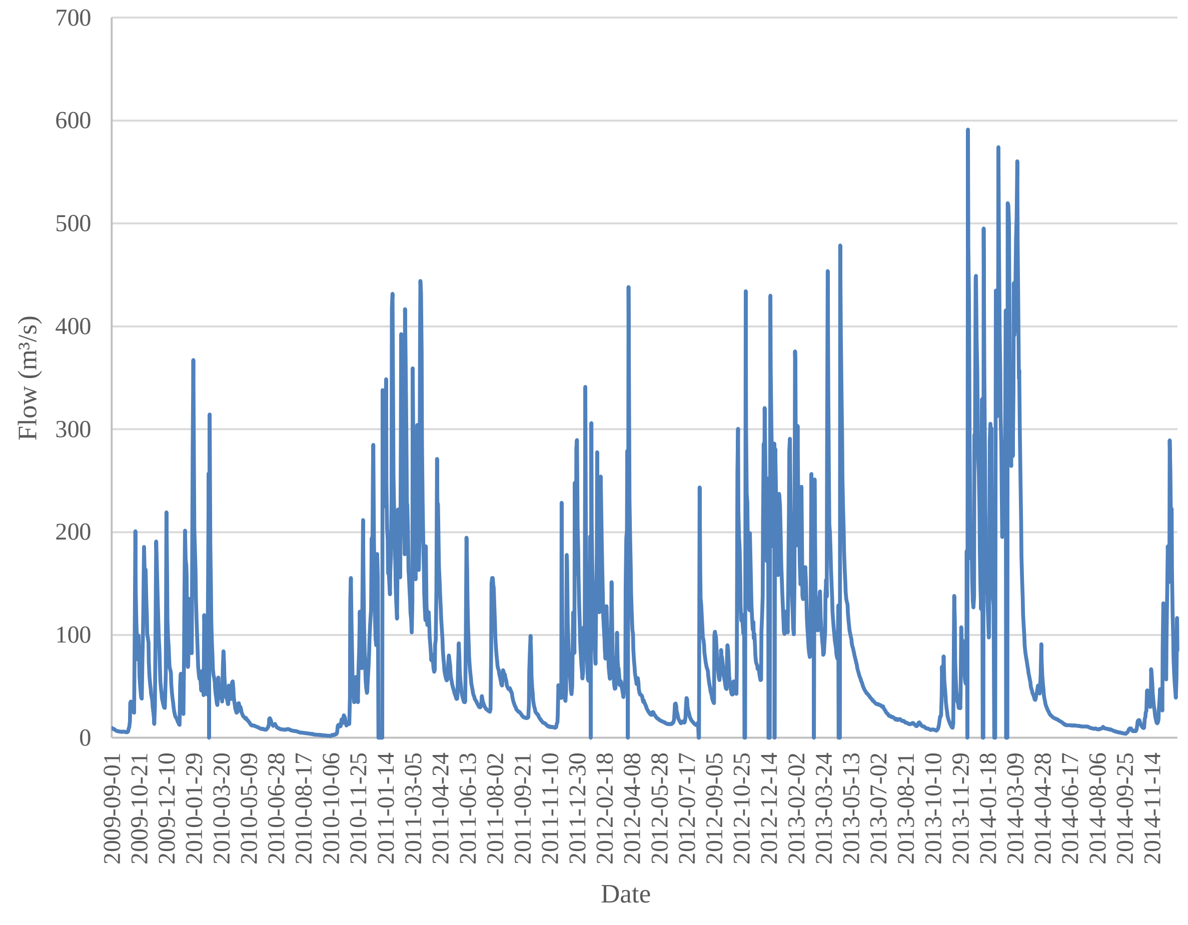
T6H001 - Ntafufu Loc. 35

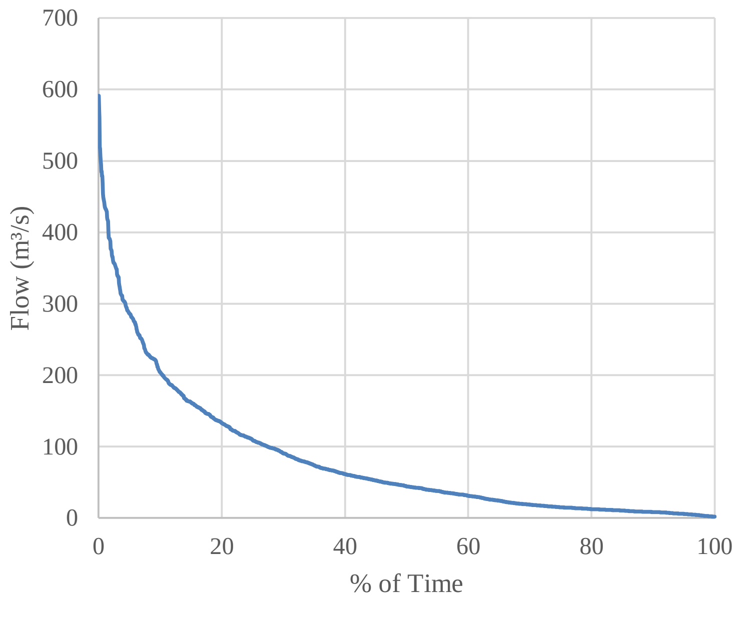




Statistics	
Mean (m^3/s)	0.80
Standard Deviation	1.99
Minimum (m^3/s)	-
Maximum (m^3/s)	38.42
Count	12 312
Confidence Level (95.0%)	0.035

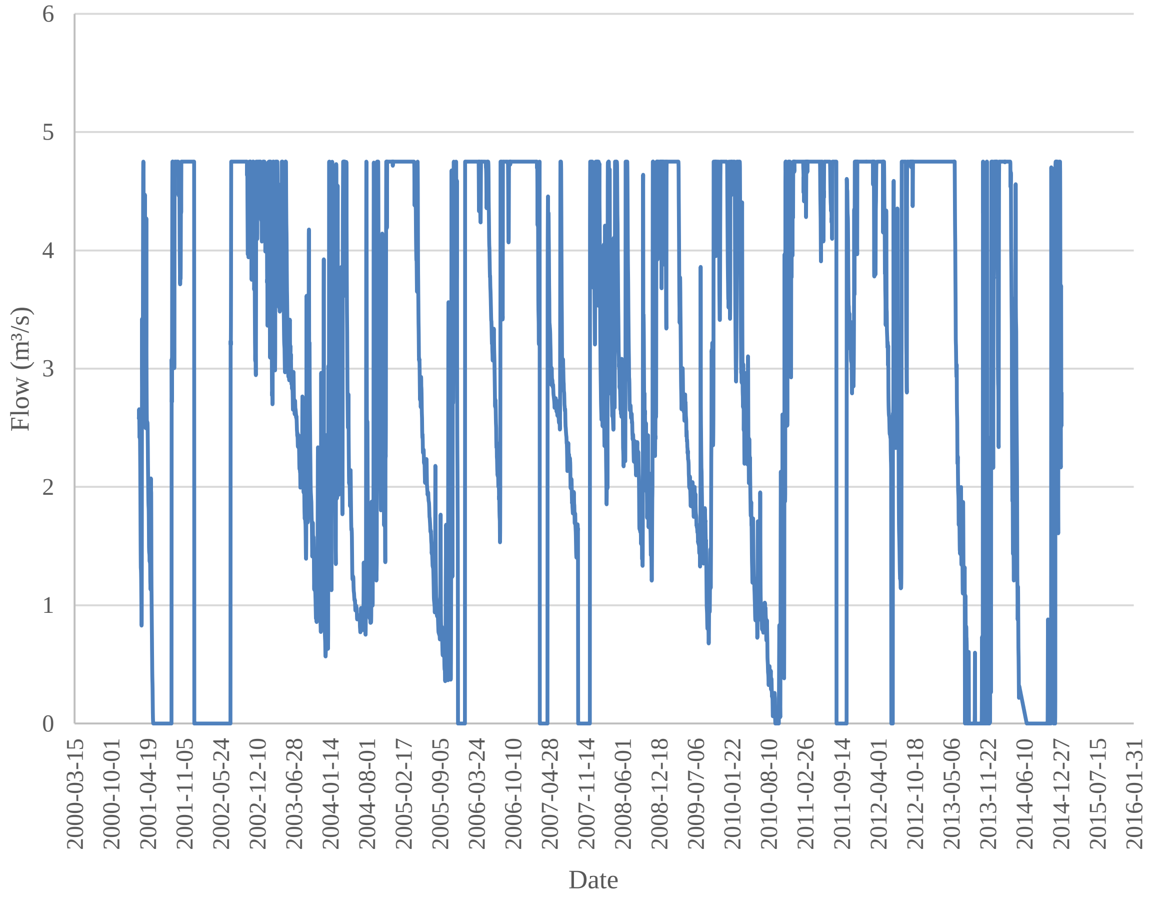
T3H020 - Nontela

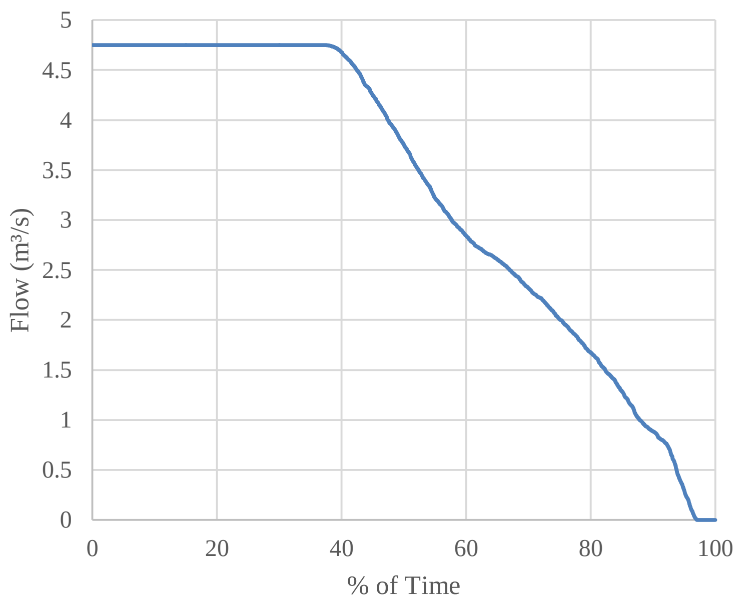




Statistics	
Mean (m^3/s)	80.28
Standard Deviation	94.11
Minimum (m^3/s)	1.80
Maximum (m^3/s)	591.27
Count	1 916
Confidence Level (95.0%)	4.217

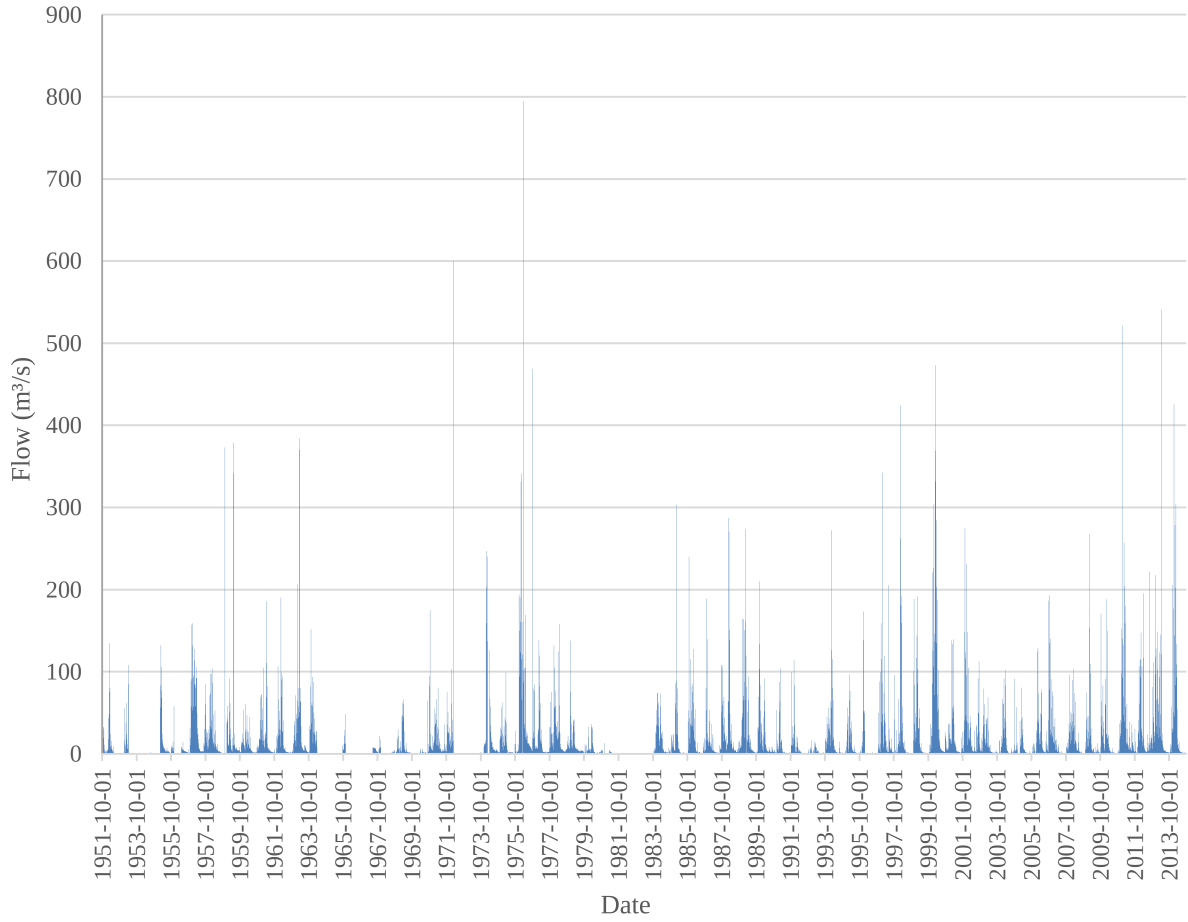
T3H017 - Ludiwana

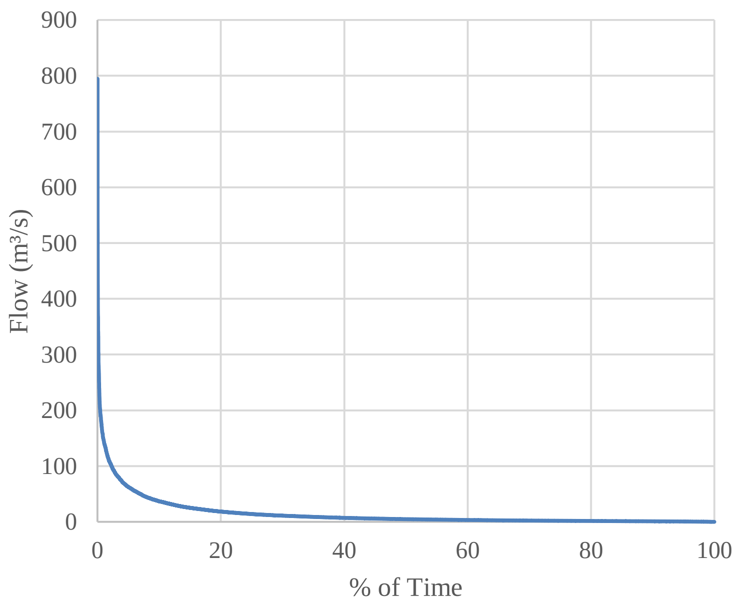




Statistics	
Mean (m^3/s)	3.27
Standard Deviation	1.57
Minimum (m^3/s)	-
Maximum (m^3/s)	4.75
Count	4 428
Confidence Level (95.0%)	0.046

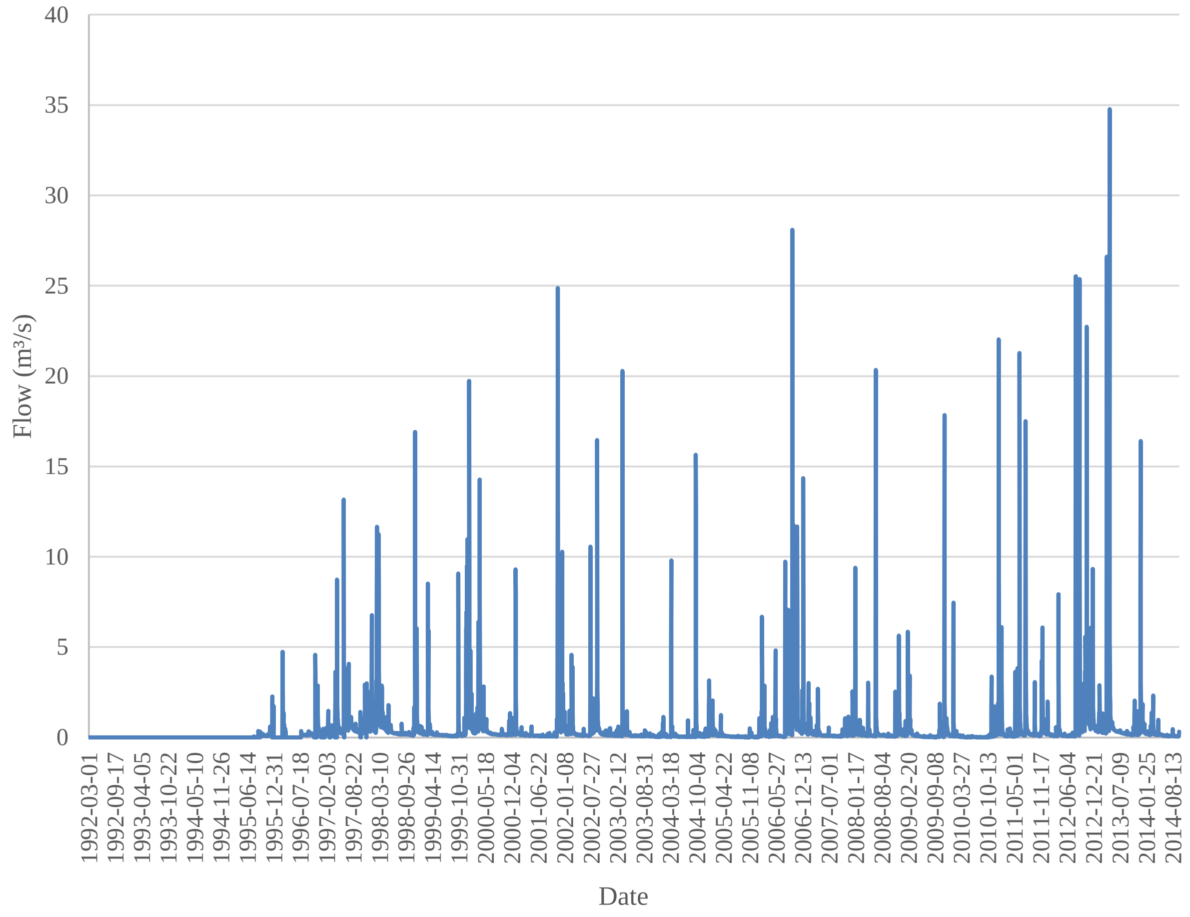
T3H005 - Mahlungulu

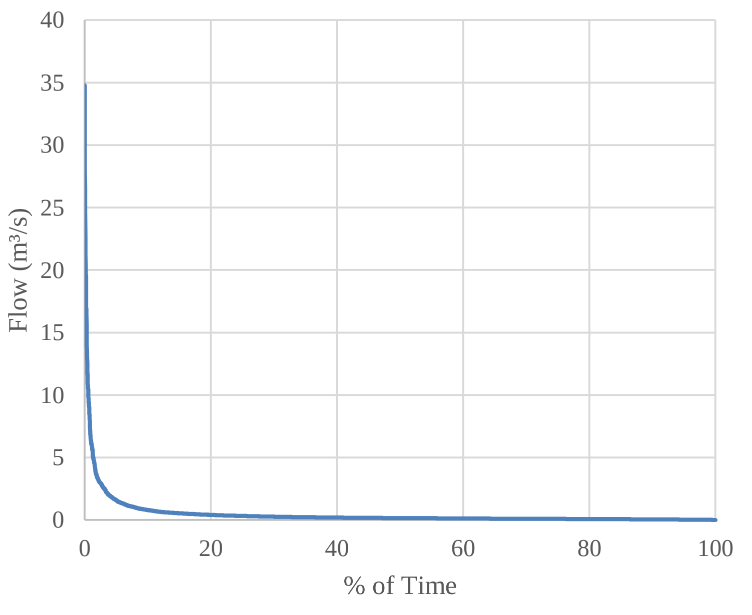




Statistics	
Mean (m^3/s)	14.86
Standard Deviation	30.80
Minimum (m^3/s)	-
Maximum (m^3/s)	794.73
Count	18 174
Confidence Level (95.0%)	0.448

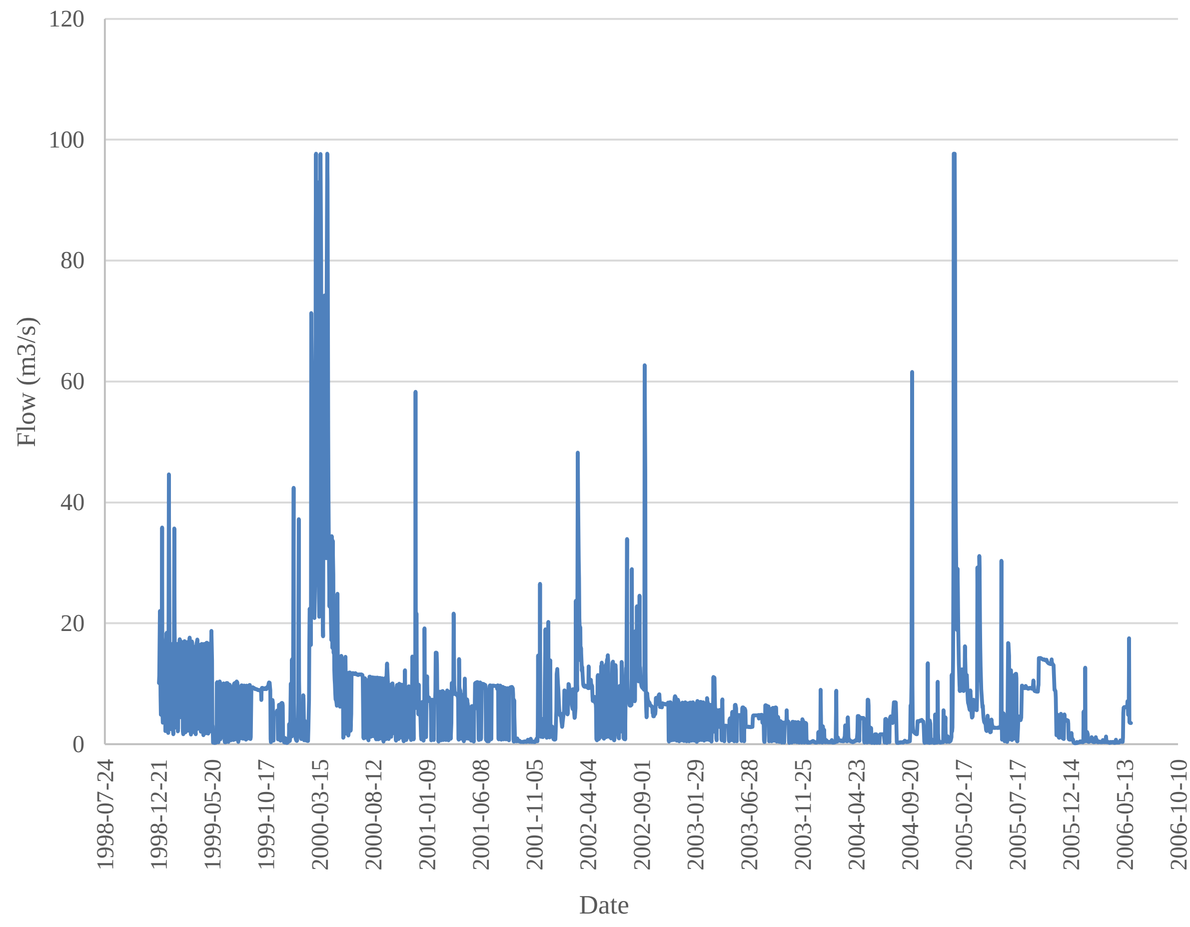
T6H004 - Xura 27

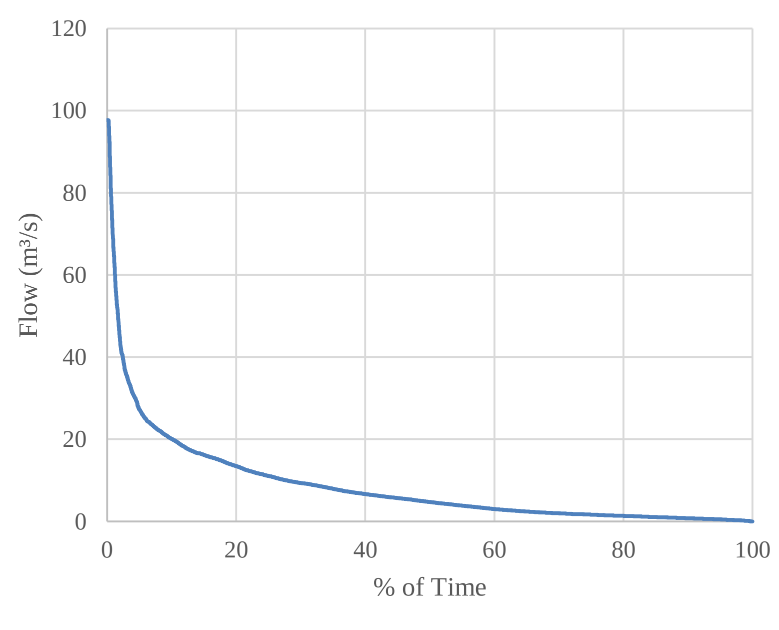




Statistics	
Mean (m^3/s)	0.47
Standard Deviation	1.55
Minimum (m^3/s)	0.00
Maximum (m^3/s)	34.77
Count	6 739
Confidence Level (95.0%)	0.037

T2H002 - Norwood





Statistics	
Mean (m^3/s)	8.64
Standard Deviation	11.94
Minimum (m^3/s)	0.00
Maximum (m^3/s)	97.71
Count	16 693
Confidence Level (95.0%)	0.181

APPENDIX C – BILL OF QUANTITY – DUNUDUNU

ITEM	DESCRIPTION		AMOUNT	% OF CAPITAL COST
A	**PLANNING AND DESIGN COSTS**	**R**	**300 830.59**	**12%**
A.1	Prefeasibility Study	R	50 000.00	
A.2	Design	R	185 800.44	
A.3	Legal and regulatory	R	37 160.09	
A.4	Environmental and social assessment	R	27 870.07	
B	**CIVIL WORKS**	**R**	**845 071.26**	**34%**
B.1	Preliminary & General Cost	R	38 074.96	
B.2	Preparation of site	R	34 612.37	
B.3	Turbine Room	R	180 015.09	
B.4	Inlet works	R	35 895.13	
B.5	Tailrace works	R	55 962.73	
B.6	Pipework and valves (supply and install)	R	500 510.98	
C	**ELECTRO-MECHANICAL EQUIPMENT**	**R**	**998 753.50**	**40%**
C.1	Turbines	R	270 000.00	
C.2	Generators		Incl. in Turbines	
C.3	Controls units (HPU, cooling and lubricating etc.)		Incl. in Turbines	
C.4	Transformer cost and integration into electrical grid (Transmission infrastructure)	R	674 753.50	
C.5	Import costs	R	54 000.00	
D	**IMPLEMENTATION COST**	**R**	**323 847.00**	**13%**
D.1	Commissioning, erecting and project management provided by the Supplier	R	49 937.67	
D.2	Construction supervision (Consultant)	R	138 286.86	
D.3	Training	R	8 100.00	
D.4	Spare components to be stored on site	R	8 100.00	
D.5	Integration of system components (telemetry etc.)	R	16 200.00	
D.6	Contingencies	R	103 222.46	
	TOTAL:	**R**	**2 468 502.35**	**100%**

PRELIMINARY & GENERAL COST

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE	AMOUNT
1200 A	8.3	**FIXED-CHARGE AND VALUE-RELATED ITEMS**				
1200 A	8.3.2	Establishment of facilities on the site	Sum	1	R 9 174.69	R 9 174.69
1200 A	8.3.4	Removal of site establishment	Sum	1	R 3 058.23	R 3 058.23
1200 A	8.4	**TIME-RELATED ITEMS**				
1200 A	8.4.2	Operation and maintenance of facilites on site, for duration of construction, except where otherwise stated	Sum	1	R 15 291.15	R 15 291.15
1200 A	8.5	**PRIME COST SUMS**				
		(a) For work to be executed by the Contractor and valued in terms of the valuation" of variations clause in" the conditions of contract	Prov Sum	1	R 2 446.58	R 2 446.58
		(b) (1) For work to be executed by the Employer or a nominated subcontractor				
		(i) Additional tests ordered by Engineer	Prov Sum	1	R 1 529.12	R 1 529.12
		(2) Overheads, charges and profit on (1) above				
		(i) Additional tests ordered by Engineer	%	30%		R 458.73
1200 A	8.8	**TEMPORARY WORKS**				
1200 A	8.8.1	Main access road to works (construction and maintenance)	Sum	1	R 3 058.23	R 3 058.23
1200 A	8.8.7 B	Compliance with OHS Act and Construction regulations	Sum	1	R 3 058.23	R 3 058.23
					TOTAL:	R 38 074.96

PREPARATION OF SITE

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE	AMOUNT
		PREPARATION OF SITE				
		INTAKE AND PENSTOCK				
1200 C		SITE CLEARANCE				
1200 C	8.2.1 B	Clear and grub:				
		(a) Areas	m²	421.74	R 5.20	R 2 193.73
		(b) Strips, 3,0 m wide	m	-	R 18.70	R 0.00
1200 C	8.2.10	Topsoiling	m²	421.74	R 19.13	R 8 067.89
		TURBINE ROOM AREA AND TAILRACE				
1200 C	8.2.1 B	Clear and grub:				
		(a) Areas	m²	65	R 5.20	R 338.10
		(b) Strips, 3,0 m wide	m	0	R 18.70	R -
1200 D	8.3.2	Excavation				
		(b) Excavate in all materials and use for embankment or backfill or dispose, as ordered				
		(1) Container foundation: up to 1.5m	m³	54	R 76.00	R 4 104.00
		(c) Extra-over for				
		(1) Intermediate excavation	m³	10.8	R 200.00	R 2 160.00
		(2) hard rock excavation	m³	5.4	R 270.00	R 1 458.00
		(3) boulder excavation, Class A	m³	5.4	R 43.72	R 236.06
		(4) boulder excavation, Class B	m³	5.4	R 43.72	R 236.06
1200 D	8.3.2 B	Extra over item 8.3.2 above for:				
		(a) Hand excavation and backfill where ordered by the Engineer	m³	10	R 44.10	R 441.02
		(b) Backfill stabilized with 5% cement where directed by the Engineer	m³	10	R 525.55	R 5 255.51
		(c) G6 Backfill compacted to 95% of MOD AASHTO	m³	28.92	R 350.00	R 10 122.00
					TOTAL:	R 34 612.37

TURBINE ROOM

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE		AMOUNT	
		TURBINE ROOM						
1200 G	8.2	Formwork:						
1200 G	8.2.2	Smooth						
		(a) Vertical						
		(1) Turbine base and tailrace channel	m²	39	R	520.00	R	20 280.00
		(b) Horizontal						
		(1) Turbine base and tailrace channel	m²	36	R	520.00	R	18 720.00
1200 G	8.3.1	Steel bars						
		(b) High-tensile reinforcement	t	0.22	R	9 500.00	R	2 090.00
1200 G	8.3.2	High-tensile welded mesh						
		(a) Ref 617 mesh	kg	10.000	R	8.66	R	86.60
1200 G	8.4.2	Blinding Layer						
		(b) Class 15 MPa concrete	m³	1.8	R	1 450.00	R	2 610.00
1200 G	8.4.3	Strength Concrete						
		(a) Class 35 MPa/19 mm	m³	12.96	R	2 105.00	R	27 280.80
1200 G	8.4.4	Unformed surface finishes						
		(a) Wood-floated finish	m²	28	R	28.50	R	798.00
		(b) Steel-floated finish	m²	8	R	28.50	R	228.00
1200 G	8.4.7 B	Screed	m³	3.6	R	1 450.00	R	5 220.00
1200 G	8.5	Joints						
		(a) Expansion joints complete	m	25	R	160.00	R	4 000.00
1200 HA	8.3.3	Galvanised steel ladder with handrailings, as per detail	number	1	R	4 000.00	R	4 000.00
1200 HA	8.3.4 B	Flooring, complete and installed as per detail						
		(a) 40mm thick galvanised Rectagrid	m²	3.5	R	2 000.00	R	7 000.00
		(b) 50 x 50 x 8 SS angle iron with 40 x 5 MS fishtailed lugs, 200 long @ 400mm c/c for open steel flooring (2500 x 1400mm frame)	m	7.8	R	200.00	R	1 560.00
1200 LE	8.2.9	(a) Brickwork						
		(1) 115 mm thick	m²	29	R	350.00	R	10 150.00
		(2) 230 mm thick	m²	0	R	752.46		
1200 HA	8.3.7 B	20' Container	number	1	R	28 215.00	R	28 215.00
1200 HA	8.3.8 B	50mm thick polystyrene	m²	0.42	R	100.00	R	42.00
1200 HA	8.3.9 B	Waterstops 20mm thick with joint filler and sealer including a 200mm wide rearguard waterstop	m	20	R	500.00	R	10 000.00
1200 HA	8.3.10 B	Drilling and dowelling for turbine installation complete using Epidermix 396	number	8	R	150.00	R	1 200.00
1203 HA	8.3.13 B	Type DV steel transformer door	number	1	R	7 400.00	R	7 400.00
1205 HA	8.3.14 B	Ventilation Shafts (supplied and installed as per detail)	number	2	R	4 000.00	R	8 000.00
1207 HA	8.3.15 B	Steel louvre	number	2	R	2 000.00	R	4 000.00
1200 DK	8.2	Gabions and Stone Picthing						
1200 DK	8.2.1	Surface preparation for bedding of gabions						
		(a) Cavities filled with approved excavated material or rock	m²	4.8	R	48.00	R	230.40
		(b) Cavities filled with Grade 15 concrete (provisional)	m²	4.8	R	145.00	R	696.00

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE		AMOUNT	
1200 DK	8.2.2	Gabions						
		(a) Construct mattresses of size 3,0m long by 1,0m wide by 0,3m deep using galvanised wire with mesh size 80mm and diaphragm spacing 0,6m	m³	7.2	R	1 371.68	R	9 876.10
1200 DK	8.2.3	Extra-over 8.2.2 for packing selected stone for exposed face (degree of accuracy to be stated)	m²	24	R	225.30	R	5 407.20
1200 DK	8.2.4	Geotextile (or geomembrane)						
		(a) Bidim U14 or similar approved	m²	28.8	R	32.12	R	924.98
						TOTAL:	R 180 015.09	

INLET WORKS

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE	AMOUNT
		INLET WORKS				
1200 D	8.3.2	Excavation				
		(b) Excavate in all materials and use for embankment or backfill or dispose, as ordered				
		(1) Intake Structure Strip Foundation	m³	2.56	R 79.48	R 203.47
		(c) Extra-over for				
		(1) Intermediate excavation	m³	0.512	R 15.90	R 8.14
		(2) hard rock excavation	m³	0.256	R 63.59	R 16.28
		(3) boulder excavation, class A	m³	0.128	R 79.48	R 10.17
		(4) boulder excavation, class B	m³	0.128	R 119.22	R 15.26
1200 GA	8.2	SCHEDULED FORMWORK ITEMS				
1200 GA	8.2.2	Smooth				
		(a) Vertical				
		(1) Intake Structure walls	m²	27.2	R 572.00	R 15 558.40
1200 GA	8.3	SCHEDULED REINFORCEMENT ITEMS				
1200 GA	8.3.2	High-tensile welded mesh				
		(a) Ref. 395	m²	20	R 97.85	R 1 957.07
		(b) Ref. 617	m²	20	R 152.88	R 3 057.62
1200 GA	8.4	SCHEDULED CONCRETE ITEMS				
1200 GA	8.4.2	Blinding layer				
		(a) 100 mm minimum thickness, grade 15 MPa concrete (Intake Structure Foundation)	m²	6.4	R 174.00	R 1 113.60
1200 GA	8.4.3	Strength concrete				
		(a) Class 35 MPa/19 mm	m³	4	R 2 526.00	R 10 104.00
1200 GA	8.5	JOINTS				
		(a) Sealed joints in concrete walls and base				
		(1) Provide and place expansion board filler 200mm wide x 25mm thick	m	2	R 30.10	R 60.20
		(2) 25mm x 12mm "Expandite high duty sealer"	m	2.4	R 96.08	R 230.60
1200 GA	8.8	HD BOLTS AND MISCELLANEOUS METAL WORK				
	8.8.1 B	(a) Supply and install intake gate as per detail	t	1	R 3 200.00	R 3 200.00
	8.8.2 B	Supply and place pipes,valves, and specials (short pipe runs) as detailed on the drawings and pipe reference sketch				
		(a) 1000 mm x 250 mm dia flanged steel pipe	Number	1	R 360.32	R 360.32
		(b) 1000 mm x 315 mm dia flanged steel pipe	Number	0	R 544.66	R -
		(c) 1000 mm x 355 mm dia flanged steel pipe	Number	0	R 689.29	R -
		(d) 1000 mm x 400 mm dia flanged steel pipe	Number	0	R 889.81	R -
		(e) 1000 mm x 450 mm dia flanged steel pipe	Number	0	R 1 176.01	R -
		(f) 1000 mm x 500 mm dia flanged steel pipe	Number	0	R 1 434.33	R -
					TOTAL:	R 35 895.13

TAILRACE WORKS

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE		AMOUNT	
		TAILRACE WORKS						
1200 D	8.3.2	Excavation						
		(b) Excavate in all materials and use for embankment or backfill or dispose, as ordered						
		(1) Tailrace Channel	m³	12.47	R	79.48	R	991.31
		(c) Extra-over for						
		(1) Intermediate excavation	m³	2.49	R	15.90	R	39.65
		(2) hard rock excavation	m³	1.25	R	63.59	R	79.30
		(3) boulder excavation, class A	m³	0.62	R	79.48	R	49.57
		(4) boulder excavation, class B	m³	0.62	R	119.22	R	74.35
1200 GA	8.2	SCHEDULED FORMWORK ITEMS						
1200 GA	8.2.2	Smooth						
		(a) Vertical						
		(1) Intake Structure walls	m²	4	R	520.00	R	2 080.00
1200 GA	8.3	SCHEDULED REINFORCEMENT ITEMS						
1200 GA	8.3.2	High-tensile welded mesh						
		(a) Ref. 395	m²	62.36	R	97.85	R	6 102.21
1200 GA	8.4	SCHEDULED CONCRETE ITEMS						
1200 GA	8.4.2	Blinding layer						
		(a) 100 mm minimum thickness, grade 15 MPa concrete (Intake Structure Foundation)	m²	62.36	R	174.00	R	10 850.76
1200 GA	8.4.3	Strength concrete						
		(a) Class 35 MPa/19 mm	m³	6.24	R	2 526.00	R	15 752.31
1200 GA	8.5	JOINTS						
		(a) Sealed joints in concrete channel						
		(1) Provide and place expansion board filler 200mm wide x 25mm thick	m	20.79	R	30.10	R	625.65
		(2) 25mm x 12mm "Expandite high duty sealer"	m	20.79	R	96.08	R	1 997.26
1200 DK		STONE PITCHING						
1200 DK	8.2.5	Pitching						
		(a) 100mm Stone pitching, tailrace channel.	m²	62.36	R	277.74	R	17 320.36
						TOTAL:	R	55 962.73

PIPEWORK AND VALVES

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE		AMOUNT	
		PIPEWORK AND VALVES						
1200 DB		**EARTHWORKS (PIPE TRENCHES)**						
1200 DB	8.3.2	(a) Excavate in all materials for trenches, backfill, compact and dispose of surplus material:						
		(2) Over 125 mm and up to 700 mm dia pipes for depths:						
		Up to 1.0 m	m	-	R	43.72	R	-
		1.0 m to 2.0 m	m	396.00	R	63.39	R	25 101.19
142.01	142.02	Extra over item 142.51 above for:						
		.03 Hand excavation and backfill where ordered by the Engineer	m³	24.57	R	44.10	R	1 083.43
		.04 Backfill stabilized with 5% cement where directed by the Engineer	m³	24.57	R	525.55	R	12 910.87
142.02	142.03	Excavate and dispose of unsuitable material from trench bottom	m³	14.74	R	29.03	R	427.95
142.03	142.04	Excavation ancillaries:						
		.01 Make up deficiency in backfill material: 0.01 From other necessary excavations on Site	m³	14.74	R	11.03	R	162.51
		MEDIUM-PRESSURE PIPELINES (DRILLING)						
		P's and G's						
		Transport and Establishment	PC	-	R	75 000.00	R	-
		Daily Rate for Accommodation etc	Day	-	R	2 500.00	R	-
		Horizontal Directional Drilling						
		HDD and installation of a 200mm OD HDPE CL10 pipe including the supply of the pipe in Hard Rock material	m	-	R	9 000.00	R	-
		HDD and installation of a 315mm OD HDPE CL10 pipe including the supply of the pipe in Hard Rock material	m	-	R	15 000.00	R	-
		HDD and installation of a 355mm OD HDPE CL10 pipe including the supply of the pipe in Hard Rock material	m	-	R	15 000.00	R	-
		Butt Welding of HDPE Pipe						
		Welding of HDPE Pipe (Based on 5 welds per day)	Day	-	R	7 000.00	R	-
		Establishment for Welding Team (Based on a 200m drill)	Each	-	R	25 000.00	R	-
1200 L		**MEDIUM-PRESSURE PIPELINES**						
1200 L	8.2.1	Supply, lay and bed pipes complete with couplings						
		(a) PVC-U pressure pipe with integral rubber ring joints (SANS 966 Part 1), Class 4 (400kPa) pipes:						
		(1) 250 mm diameter	m	-	R	294.75	R	-
		(2) 315 mm diameter	m	-	R	449.18	R	-
		(3) 355 mm diameter	m	-	R	563.33	R	-
		(4) 400 mm diameter	m	-	R	711.57	R	-
		(5) 450 mm diameter	m	-	R	1 002.87	R	-
		(6) 500 mm diameter	m	-	R	1 197.13	R	-
		(b) HDPE pressure pipe (SANS 966 Part 1), Class 6 (600kPa) pipes:						
		(1) 250 mm diameter	m	-	R	358.72	R	-
		(2) 315 mm diameter	m	-	R	569.32	R	-
		(3) 355 mm diameter	m	396.00	R	723.00	R	286 306.02
		(4) 400 mm diameter	m	-	R	918.29	R	-
		(5) 450 mm diameter	m	-	R	1 159.34	R	-
		(6) 500 mm diameter (PVC-U)	m	-	R	1 434.33	R	-
		(c) PVC-U pressure pipe with integral rubber ring joints (SANS 966 Part 1), Class 9 (900kPa) pipes:						
		(1) 250 mm diameter	m	-	R	517.49	R	-
		(2) 315 mm diameter	m	-	R	776.46	R	-
		(3) 355 mm diameter	m	-	R	991.00	R	-
		(4) 400 mm diameter	m	-	R	1 280.64	R	-
		(5) 450 mm diameter	m	-	R	1 659.06	R	-
		(6) 500 mm diameter	m	-	R	2 038.15	R	-

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE	AMOUNT
1200 L	8.2.2	Extra-over 8.2.1 for the supplying, laying, and bedding of specials complete with couplings				
		(a) 45° bends:				
		(1) 250 mm diameter PVC	Number	-	R 1 450.00	R -
		(2) 315 mm diameter PVC	Number	-	R 4 004.00	R -
		(3) 355 mm diameter Steel Flanged	Number	4.00	R 3 266.40	R 13 065.60
		(4) 400 mm diameter Steel Flanged	Number	-	R 3 915.60	R -
		(5) 450 mm diameter Steel Flanged	Number	-	R 4 644.00	R -
		(6) 500 mm diameter Steel Flanged	Number	-	R 5 005.20	R -
		(b) 90° bends:				
		(1) 250 mm diameter PVC	Number	-	R 1 450.00	R -
		(2) 315 mm diameter PVC	Number	-	R 4 140.00	R -
		(3) 355 mm diameter Steel Flanged	Number	4.00	R 3 686.40	R 14 745.60
		(4) 400 mm diameter Steel Flanged	Number	-	R 3 836.40	R -
		(5) 450 mm diameter Steel Flanged	Number	-	R 5 187.60	R -
		(6) 500 mm diameter Steel Flanged	Number	-	R 5 756.40	R -
		(c) Tees:				
		(1) 250 mm diameter PVC	Number	-	R 1 570.54	R -
		(2) 315 mm diameter PVC	Number	-	R 2 729.43	R -
		(3) 355 mm diameter PVC	Number	4.00	R 4 644.00	R 18 576.00
		(4) 400 mm diameter Steel Flanged	Number	-	R 5 776.00	R -
		(5) 450 mm diameter Steel Flanged	Number	-	R 7 274.00	R -
		(6) 500 mm diameter Steel Flanged	Number	-	R 8 936.00	R -
		(d) Reducers				
		(1) 300mm dia x 250mm dia Steel Flanged	Number		R 1 930.80	
		2) 355mm dia x 300mm dia Steel Flanged	Number		R 2 566.80	
		(3) 400mm dia x 250mm dia Steel Flanged	Number		R 2 743.20	
		(4) 400mm dia x 300mm dia Steel Flanged	Number		R 2 924.40	
		(5) 400mm dia x 315mm dia Steel Flanged	Number		R 2 924.40	
		(6) 400mm dia x 355mm dia Steel Flanged	Number		R 3 184.80	
		(7) 450mm dia x 300mm dia Steel Flanged	Number		R 3 418.80	
		(8) 450mm dia x 400mm dia Steel Flanged	Number		R 3 913.20	
		(9) 500mm dia x 250mm dia Steel Flanged	Number		R 3 842.40	
		(10) 500mm dia x 300mm dia Steel Flanged	Number		R 4 023.60	
		(11) 500mm dia x 315mm dia Steel Flanged	Number		R 4 023.60	
		(12) 500mm dia x 355mm dia Steel Flanged	Number		R 4 284.00	
		(13) 500mm dia x 400mm dia Steel Flanged	Number		R 4 465.20	
		(14) 500mm dia x 450mm dia Steel Flanged	Number		R 4 827.60	
		(e) Adaptor Flanged				
		(1) 250 mm diameter	Number	-	R 1 579.52	R -
		(2) 315 mm diameter	Number	-	R 2 758.10	R -
		(3) 355 mm diameter	Number	5.00	R 2 992.80	R 14 964.00
		(4) 400 mm diameter	Number	-	R 3 774.00	R -
		(5) 450 mm diameter	Number	-	R 4 492.80	R -
		(6) 500 mm diameter	Number	-	R 4 908.00	R -
1200 L	8.2.3	Extra-over 8.2.1 for the supplying, fixing, and bedding of valves				
		(a) 250 mm diam. Flanged RSV Valve	Number	-	R 8 408.23	R -
		(b) 315 mm diam. Flanged RSV Valve	Number	-	R 15 292.62	R -
		(c) 355 mm diam. Flanged RSV Valve	Number	2.00	R 23 857.51	R 47 715.01
		(d) 400 mm diam. Flanged RSV Valve	Number	-	R 39 216.11	R -
		(e) 450 mm diam. Flanged RSV Valve	Number	-	R 49 171.56	R -
		(f) 500 mm diam. Flanged RSV Valve	Number	-	R 56 506.04	R -
1200 L	8.2.4	Extra-over 8.2.1 for the cutting of the pipe and the supply and fixing of the extra coupling				
		(a) PVC-U pressure pipe with integral rubber ring joints (SANS 966 Part 1), Class 4 (400kPa) pipes:				
		(1) 250 mm diameter	Number	-	R 1 143.16	R -
		(2) 315 mm diameter	Number	-	R 1 234.30	R -
		(3) 355 mm diameter	Number	-	R 2 244.65	R -
		(4) 400 mm diameter	Number	-	R 2 485.51	R -
		(5) 450 mm diameter	Number	-	R 2 649.58	R -
		(6) 500 mm diameter	Number	-	R 2 958.14	R -
		(b) PVC-U pressure pipe with integral rubber ring joints (SANS 966 Part 1), Class 6 (600kPa) pipes:				
		(1) 250 mm diameter	Number	-	R 1 143.16	R -
		(2) 315 mm diameter	Number	-	R 1 234.30	R -
		(3) 355 mm diameter	Number	2.00	R 2 244.65	R 4 489.30
		(4) 400 mm diameter	Number	-	R 2 485.51	R -
		(5) 450 mm diameter	Number	-	R 2 649.58	R -
		(6) 500 mm diameter	Number	-	R 2 958.14	R -

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE	AMOUNT
		(c) PVC-U pressure pipe with integral rubber ring joints (SANS 966 Part 1), Class 9 (900kPa) pipes:				
		(1) 250 mm diameter	Number	-	R 1 143.16	R -
		(2) 315 mm diameter	Number	-	R 1 234.30	R -
		(3) 355 mm diameter	Number	-	R 2 244.65	R -
		(4) 400 mm diameter	Number	-	R 2 485.51	R -
		(5) 450 mm diameter	Number	-	R 2 649.58	R -
		(6) 500 mm diameter	Number	-	R 2 958.14	R -
1200 L	8.2.7	Extra-over 8.2.1 for encasing joints	Number	2.00	R 1 263.00	R 2 526.00
1200 L	8.2.10	Temporary valves, etc.	Prov Sum	1.00	R 15 000.00	R 15 000.00
1200 L	8.2.11	Anchor/thrust blocks and pedestals pedestals				
		(b) (1) Concrete: Class 35 MPa/19 mm	m³	2.00	R 2 105.00	R 4 210.00
		(2) Formwork: Smooth	m²	9.09	R 520.00	R 4 726.80
		(3) Reinforcement: Mesh Ref. 395	t	0.10	R 9 500.00	R 950.00
		(4) Concrete finish: Smooth	m²	3.00	R 28.50	R 85.50
		(5) Blinding	m³	2.00	R 1 450.00	R 2 900.00
1200 L	8.2.12	Concrete casing (specify grade concrete)	m³	4.91	R 2 105.00	R 10 342.44
1200 L	8.2.14	(a) Manholes				
		(1) .... (describe manhole, ref to drg)	No.	4.00	R 2 157.57	R 8 630.27
		(b) (1) Extra-over (a) for manholes of depth exceeding 1,5 m as shown on the drawings (unit may also be increments of 0,25 m)				
		(2) .... (etc for others)	Prov Sum	1.00	R 10 000.00	R 10 000.00
1200 LB		**BEDDING (PIPES)** BEDDING FOR WATER PIPES				
1200 LB	8.2.1	Provision of bedding from trench excavations				
		(a) Selected granular material	m³	42.17	R 18.88	R 796.25
		(b) Selected fill material	m³	42.17	R 18.88	R 796.25
1200 LB	8.2.2	Supply only of bedding by importation				
1200 LB	8.2.2.3	From commercial sources (provisional)				
		(a) Selected granular material	m³	6.33		R -
		(b) Selected fill material	m³	6.33		R -
					TOTAL:	R 500 510.98

TURBINES

SANS SPEC	ITEM	DESCRIPTION	UNIT	BILLED QUANTITY	SELLING RATE	AMOUNT
		TURBINES				
		Cross-Flow (a) ECOWATT Micro hydroelectric power plant type TBS Complete with: - Cross Flow turbine in stainless steel type 4-1.75 - Synchronous generator type AS30 - Revolution multiplier by cogged driving belt - Manual flow regulation - Manual butterfly general valve - Steel base - Coupling flange for connection to the penstock	Number	1	R -	R -
		(b) Electric Distribution Board Mod. CT 30.000 Complete with: - a voltmeter, a digital frequency-meter, ammeters indicating the total current distributed by the generator, ammeters indicating the current drawn by the consumers - magneto thermal, which protects the generator from possible short circuits on the consumer line - electronic voltage relay, operating a warning buzzer and a visual signal in the event the voltage variation exceeds the limits - terminal boards for connection	Number	1	INCL.	R -
		(c.) Electronic Regulating System RMP 10.000/B with water dissipation resistances Complete with: - box unit, which include the electronic control board to micro processor and the power control - transient voltage protection (TVP) - fuse, which protect the regulator - LED to indicate the protection failed - resistors for dissipation equipped with 10 kW - heat elements in inox case - Spare parts	Number	1	INCL.	R -
		Low-Head (a) Powerspout LH400 or LH400Pro	Number	1	R 270 000.00	R 270 000.00
TOTAL:	**TOTAL:**					R 270 000.00

ELETRICAL PG's

Item	Description	Unit	Qty	Unit Price				Total	
				Material		Labour			
A1	**CONTRACTORS FIXED CHARGES**								
A1.1	Contractual Requirements	Item	1	R	12 900.00	R	550.00	R	13 450.00
A1.2	Establishment of construction site facilities such as plant, sheds, water, electricity, lighting, etc.	Item	1	R	2 500.00			R	2 500.00
A1.3	Erection and removal of project notice board	Item	1	R	6 000.00	R	2 500.00	R	8 500.00
A1.4	Compliance with the Ocupational Health and Safety Act Regulations	Item	1	R	6 500.00	R	2 500.00	R	9 000.00
A1.5	Compliance with the Environmental Management Plan	Item	1	R	1 500.00	R	500.00	R	2 000.00
A1.6	Preparation of construction drawings	Item	1	R	750.00	R	750.00	R	1 500.00
A1.7	Testing and commisioning	Item	1	R	1 500.00	R	1 500.00	R	3 000.00
A1.6	Preparation of as built manuals	Item	1	R	500.00	R	500.00	R	1 000.00
A1.7	Operation and maintenance training of Employer staff	Item	1	R	350.00	R	150.00	R	500.00
A1.8	Sum for collection and handling of the material issued by the Municipality as per the list attached to the BOQ	Sum	1	R	1 000.00			R	1 000.00
A2	**CONTRACTORS TIME RELATED ITEMS**								
A2.1	Contractual Requirements	Item	1	R	1 500.00	R	350.00	R	1 850.00
A2.2	Operation/maintenance of facilities/site	Item	1	R	750.00			R	750.00
A2.3	Works Supervision	Item	1	R	12 500.00			R	12 500.00
A2.4	Company and Head Office overhead costs	Item	1	R	15 000.00			R	15 000.00
A3	All other items deemed necessary to complete the works. ***(Specify):***								
A3.1	Accommodation	Item	1	R	12 500.00			R	12 500.00
A3.2	Crane Truck	Item	1	R	34 000.00			R	34 000.00
A3.3	Transport	Item	1					R	-
A3.4									
A3.5									
A3.6									
	Total carried forward to Summary							R	119 050.00

MEDIUM VOLTAGE NETWORK

ITEM	DESCRIPTION, note all items to be supplied, installed tested and commissioned to Engineer's satisfaction	UNIT	QTY	UNIT PRICE MATERIAL		UNIT PRICE LABOUR		TOTAL COST	
B1	**Transformers Installation**								
B1.1	100 kVA 0.4/3.3kV Pole mounted transformer	each	1	R	40 000.00	R	650.00	R	40 650.00
B1.2	100 kVA 3.3/0.4kV Pole mounted transformer	each	1	R	40 000.00	R	650.00	R	40 650.00
B2	**11kV Overhead Line**								
	Assembly, erection and planting of towers. All poles are 11m, 160mm pole top minimum unless otherwise stated. Towers, complete with 11 kV insulators and with all hard ware for attachment, stays and all other hardware, earthing and bonding, required as per Municipal drawings and specifications to secure a Fox conductor. Pole and stay excavations excluded								
B2.1	Intermediate Structure	sum	0	R	1 493.94	R	450.00	R	-
B2.2	Strain structure 0-60deg	sum	3.68421	R	2 526.66	R	450.00	R	10 966.64
B2.3	Strain termination	each	3.07018	R	1 876.04	R	450.00	R	7 141.35
B3.4	Stays complete	sum	12.2807	R	857.55	R	115.00	R	11 943.60
B3.5	11m Wooden Pole X160 top	each	36.8421	R	1 900.00	R	450.00	R	86 578.95
B3.6	11m Wooden Pole X180 top		4.91228	R	2 170.00	R	450.00	R	12 870.18
B3.7	Transformator structure	each	2	R	6 130.24	R	528.00	R	13 316.48
B3	**Line Support**								
B3.1	Strut poles including bracket	each	2.45614	R	220.00	R	450.00	R	1 645.61
B3.2	Full tension joints	each	7.36842	R	120.75	R	10.00	R	963.42
B4	**Supply and stringing of conductors**								
B4.1	Supply of Fox conductor	m	2100	R	7.36	R	2.00	R	19 656.00
B4.2	Stringing of 1 span of 3 Fox conductors	each	36.8421			R	680.00	R	25 052.63
B4.3.	Supply and install vibration dampers								
B4.3.1	Fox conductor	each	22.1053	R	65.25	R	15.00	R	1 773.95
B4.4	Supply and install in line connectors								
B4.4.1	Fox conductor	each	rate only	R	150.00	R	50.00		
B4.5	Earthing								
B4.5.1	Medium voltage side of transformer	each	2	R	1 600.00	R	1 000.00	R	5 200.00
B4.5.2	Low voltage side of transformer	each	2	R	1 200.00	R	900.00	R	4 200.00
B4.5.3	Earthing for surge arrestors	each	2	R	950.00	R	450.00	R	2 800.00
B5	**Excavations**								
B5.1	11m wooden pole holes	each	41.7544			R	250.00	R	10 438.60
B5.2	Stay holes	each	12.2807			R	1 350.00	R	16 578.95
B5.3	Bush clearing of power line route	m	0						
B5.4	900mm x 300mm cable trench	m	12			R	120.00	R	1 440.00
B5.5	6.3.1 Concrete mix to concrete stay	each	rate only	R	400.00	R	400.00		

ITEM	DESCRIPTION, note all items to be supplied, installed tested and commissioned to Engineer's satisfaction	UNIT	QTY	UNIT PRICE				TOTAL COST	
				MATERIAL		LABOUR			
B6	**Transformer Distribution Boards as per drawings**								
B6.1	Typical Transformer Distribution Board 300A L20B Main Breaker 4 x 150A J25S Feeder breakers	each	1	R	36 108.00	R	450.00	R	36 558.00
B6.2	2 pole galvanised mounting bracket for Distribution board	each	1	R	850.00	R	150.00	R	1 000.00
B7	**Protection**								
B7.1	Set of 12kV surge arrestors assembly, complete with cross arm	set	2	R	1 250.00	R	280.00	R	3 060.00
B7.2	12kV Load Break switch	each	1	R	18 750.00	R	650.00	R	19 400.00
TOTAL CARRIED FORWARD TO SUMMARY:								R	373 884.35

LOW VOLTAGE NETWORK

ITEM	REF	DESCRIPTION, note all items to be supplied, install tested and commissioned to Engineer's satisfaction	UNIT	QTY	UNIT PRICE				TOTAL COST
					MATERIAL		LABOUR		
C1		**Distribution poles**							
C1.2		9m wooden poles in distribution line	each	31.790301	R	1 000.00	R	200.00	R 38 148.36
C2		**Pole Boxes**							
C2.1		Pole top box	each	6.3075994	R	350.00	R	100.00	R 2 838.42
C2.2		30A single phase circuit breakers wired into Pole box with all accessories required	each	10.092159	R	115.00	R	50.00	R 1 665.21
C3		**LV ABC Overhead Line**							
C3.1		150mm² LV Arial Bundle Conductor including streetlight Core	m	597.96042	R	79.00	R	6.00	R 50 826.64
C3.2		35mm² LV Arial Bundle Conductor to Pole top box	m	18.922798	R	41.00	R	4.00	R 851.53
C3.3		Arial Bundle Conductor strain clamp complete Sicame or similar approved	each	15.138239	R	85.00	R	50.00	R 2 043.66
C3.4		Arial Bundle Conductor suspension clamp complete Sicame or similar approved	each	29.267261	R	40.00	R	50.00	R 2 634.05
C3.5		Arial Bundle Conductor terminations Rachem or similar approved	each	12.362895	R	480.00	R	450.00	R 11 497.49
C4		**Line Support**							
C4.1		Stays Complete	each	17.408974	R	650.00	R	250.00	R 15 668.08
C4.2		Strut complete	each	1	R	350.00	R	350.00	R 700.00
C5		**Street Lighting**							
C5.1		1.5mm² x 2 tails from ABC to street light ftting	m	20.184318	R	13.50	R	2.00	R 0.00
C5.2		Luminaire	each	10.092159	R	1 150.00	R	80.00	R 0.00
C5.3		Fly fuse	each	10.092159	R	70.00	R	30.00	R 0.00
C5.4		600mm outreach arm and bracket	each	10.092159	R	280.00	R	75.00	R 0.00
C5.5		Wiring of Streetlight	each	10.092159	R	65.00	R	30.00	R 0.00
C5.6		Connection of ABC to streetlight cores including all accessories required	each	10.092159	R	40.00	R	35.00	R 0.00
C6		**Earthing**							
C6.1		35mm Cu Pole coil earth as per project specification	each	4.5414716	R	355.00	R	75.00	R 1 952.83
C6.2		16mm Cu Pole coil earth as per project specification	each	6.5599034	R	170.00	R	75.00	R 1 607.18
C7		**ABC Connection Clamps**							
C7.1		Connection of ABC to ABC including all accessories required	each	3.2799517	R	140.00	R	110.00	R 819.99
C7.2		Connection of ABC to 35 x 2 core to Pole box including all accessories required	each	6.3075994	R	110.00	R	80.00	R 1 198.44
TOTAL CARRIED FORWARD TO NEXT PAGE:									R 132 451.87

LOW VOLTAGE NETWORK

ITEM	REF	DESCRIPTION, note all items to be supplied, install tested and commissioned to Engineer's satisfaction	UNIT	QTY	UNIT PRICE MATERIAL	UNIT PRICE LABOUR	TOTAL COST
		TOTAL BROUGHT FORWARD					R 132 451.87
C8		**Service Connections**					
C8.1		10 mm² Airdac service connection cables	m	302.76477	R 35.00	R 2.50	R 11 353.68
C8.2		Connection of 10 mm² 2 core Cu to pole top box	each	10.092159	R 40.00	R 35.00	R 756.91
C8.3		Connection of 10 mm² 2 core Cu to ready board	each	10.092159	R 40.00	R 35.00	R 756.91
C8.4		Airdac Conductor strain clamp complete Sicame or similar approved	each	20.184318	R 18.00	R 20.00	R 767.00
C9		**Residential unit installation**					
C9.1		Readyboards incl. Mounting board	each	10.092159	R 540.00	R 60.00	R 6 055.30
C9.2		single phase split pre-payment metering unit	each	10.092159	R 900.00	R 200.00	R 11 101.37
C9.3		Earthing of Residential unit to SANS 10142	each	10.092159 0	R 175.00	R 50.00	R 2 270.74
C10		**Excavation**					
C10.1		9m wooden pole	each	31.790301		R 220.00	R 6 993.87
C10.2		Stay hole	each	17.408974		R 220.00	R 3 829.97
C10.3		Strut pole hole	each	1		R 220.00	R 220.00
C11		**General**					
C11.1		Testing and commissioning of complete installation	sum	1	R 2 500.00	R 1 500.00	R 4 000.00
C11.2		Earthing of residential units according to SANS 0142	sum	10.092159			R 0.00
C11.3		COC as per SANS 10142	each	10.092159	R 90.00	R 35.00	R 1 261.52
TOTAL CARRIED FORWARD TO SUMMARY:							R 181 819.15

ELECTRICAL SUMMARY

Item	Description	Material	Labour	Total
A	PRELIMINARY AND GENERAL			R 119 050.00
	RETICULATION WORK			
B	MEDIUM VOLTAGE NETWORK			R 373 884.35
C	LOW VOLTAGE NETWORK			R 181 819.15
D	SUBTOTAL			R 674 753.50
F	PROVISIONAL COST SUMS			R 115 135.19
F1	Health and Safety Monitoring		R 20 000.00	
F2	Sum for Prepayment meters		R 11 101.37	
F3	Sum for street lighting		R 19 033.81	
F4	Civil		R 25 000.00	
F5	Earthing		R 25 000.00	
F6	5m Poles		R 15 000.00	
G	SUBTOTAL			R 789 888.69
H	10 % CONTINGENCY OMITTED			R 0.00
I	NETT TENDER AMOUNT, EXCLUDING VAT			R 789 888.69
J	14% VAT			R 110 584.42
K	GROSS TENDER AMOUNT CARRIED FORWARD TO OFFER		- "Offer"	R 900 473.10

APPENDIX D – FINANCIAL ANALYSIS – DUNUDUNU

Ndodekhling-Shayiwe SSHP - Low-Head Turbine			Variable	Cost	Units
Power Rating (Expected electrical output)				10.1	kW
Design flow			(Q)	0.300	m^3/s
Design flow corresponding head			(H)	5.7	m
Turbine type				**Cross-flow**	
Cost Estimate for the implementation	**Cost ID**	**Comments**			
Professional fees:					
Planning and design costs:					
Prefeasibility Study	P1			R 50 000.00	**R**
Design	P2	% of Implementation	**9%**	R 185 800.44	
Legal and regulatory	P3			R 37 160.09	
Environmental and social assessment	P4			R 27 870.07	
Subtotal A	**A**			**R 300 830.59**	
Estimated Capital Cost:					
Civil works:					
PrelimInary & General Cost	C1			R 38 074.96	**R**
Preparation of site	C2			R 34 612.37	
Turbine Room	C3			R 180 015.09	
Inlet works	C4			R 35 895.13	
Tailrace works	C5			R 55 962.73	
Pipework and valves (supply and install)	C6			R 500 510.98	
Electro-mechanical Equipment:					
Turbines	E1			R 270 000.00	**R**
Generators	E2	Included in E1		R 0.00	
Controls units (HPU, cooling and lubricating etc.)	E3	Included in E1		R 0.00	
Transformer cost and integration into electrical grid (Transmission infrastructure)	E4			R 674 753.50	
Import costs	E5	Import item at rate X2		R 54 000.00	
Implementation cost:					
Commissioning, erecting and project management provided by the Supplier	I1	1 week		R 49 937.67	**R**
Construction supervision (Consultant)	I2	6 Man months		R 138 286.86	
Training	I3			R 8 100.00	
Spare components to be stored on site	I4	Sum of E1 to E3	**3.0%**	R 8 100.00	
Integration of system components (telemetry etc.)	I5			R 16 200.00	
Contingencies	I6	Sum of C, E and I items	**5.0%**	R 103 222.46	
Subtotal B	**B**			**R 2 167 671.76**	**R**
Exchange rate - Euro to Rand	X1		**R 13.5**		**R/Euro**
Importing costs (Customs and transportation)	X2		**21%**		**%**
Total cost (Subtotal A + Subtotal B)				**R 2 468 502.35**	**R**
Calculated Implementation Cost per installed kW				**R 244 596.06**	**R/kW**
Notes:					
Information supplied by the Supplier (shaded blocks)					

Cost component	Cost ID	Comment	Variable	Cost	Units
Operational Cost Estimate:					
Expected Operational Life				**40**	Years
Planned year of implementation				**2016**	Year
Time value of money:					
Escalation of Operational costs (O)				8	**%**
Escalation of Maintenance cost (M)				10	**%**
Escalation of other costs (OT)				10	**%**
Escalation of Energy costs				12	**%**
Discount rate (Value of Capital)				5	**%**
Annual operation and maintenance cost:		**Note 1**	**% of Capital Cost**		**Normative**
Civil works	M1		0.25%	R 2 112.68	0.25%
Electrical and mechanical works	M2		2.00%	R 5 400.00	2.00%
Transmission	OT1		0.80%	R 5 398.03	0.80%
Operation	O1		0.40%	R 8 670.69	0.40%
Insurance	OT2		0.30%	R 6 503.02	0.30%
Subtotal (Annual O&M Costs)				**R 28 084.41**	**R**
Annual income for this development:			R/kWh		
Average value of generated electricity	EI1		0.59	**R 33 382.60**	**R**
Investment review					
Net present value of costs				R 5 596 556	**R**
Net present value of income				R 6 996 275	
Total NPV				**R 1 399 719**	
Internal rate of return				**6.56**	**(%)**
Levelised Cost of energy				**247.28**	**c/kWh**
Notes:					
1. These reflect the normative standard cost as % of Capital value					

Cost Benefit Ratio Calculation	
NPV - Energy saved (income)	R -
Grid Extension Capital Costs	R 3 250 000.00
SSHP Capital Costs	R 2 468 502.35
Cost/Benefit	**0.76**