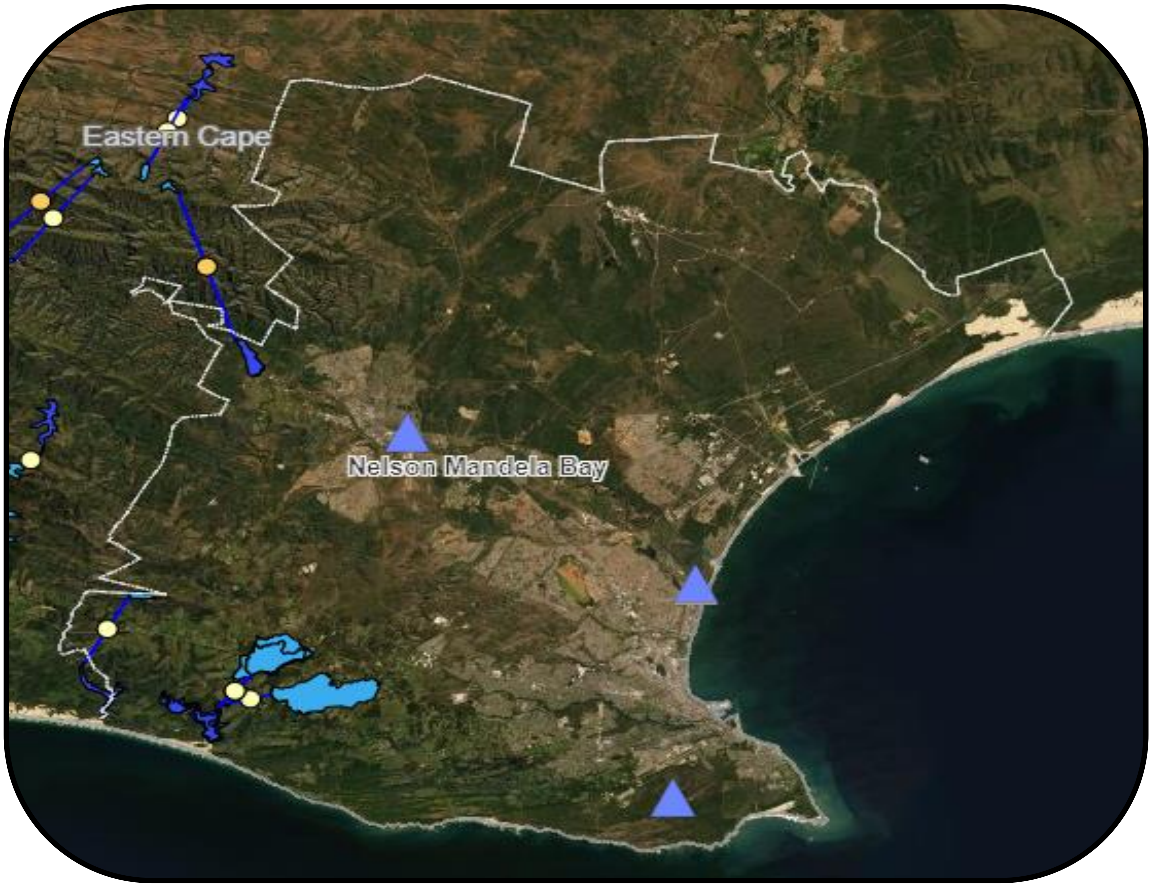
SCOPING STUDY TO EXPLORE HYDRO POTENTIAL IN THE NEARBY VICINITY OF BAAKENS RIVER AND THE LAKE



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by

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EXECUTIVE SUMMARY

The electrification of urban areas in South Africa, including many informal settlements, reached its culmination during recent years. However the electrification of rural areas still has a long way to go before most of the rural communities could be provided with reliable and sustainable electricity supply. The national electricity grid, managed by the parastatal ESKOM, has been experiencing problems caused by various reasons, particularly since 2008. The further development of rural electrification which need to be made available to users already connected to the national grid is currently in the doldrums, mainly due to the shortage in the generation capacity of ESKOM.

The increases in the prices of electricity are starting to be felt by the urban as well as the rural communities. The primary electricity infrastructure (i.e. coal-fired power stations, major supply lines and distribution of electricity within urban areas) is rapidly becoming insufficient and cannot sustain a supply against the demand for electricity from the existing and future users connected to the national grid.

The research project's aim was to enhance the uptake of micro-hydro technology, making local stakeholders (private sector, financial sector, government entities, etc.) aware of the opportunities that this technology brings and the efforts required to get this technology successfully implemented in SA.

A municipal hydropower development tool was developed to assist municipalities with the identification and development of hydropower sites in their area. The tool was developed based on the pre-feasibility phase of the hydropower development process. As a case study, the sites within the Nelson Mandela Bay Municipality were identified based on a pre-feasibility analysis. A site-visit was conducted to enable a feasibility analysis to be conducted on all shortlisted sites.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS/ABBREVIATIONS

Symbol/ abbreviation	Description
AADD	average annual daily demand
BA	basic assessment
B/C	benefit/cost ratio
CHP	conduit hydropower
CO_2	carbon dioxide
D	diameter of penstock or pipe (m)
DME	Department of Minerals and Energy
DoE	Department of Energy
DWS	Department of Water and Sanitation
EIA	environmental impact assessment
ESHA	European Small Hydropower Association
ESKOM	Electricity Supply Commission of South Africa
FSL	full supply level
g	gravitational acceleration (m/s^2) (typically 9.81 m/s^2)
H	effective pressure head (m)
h_f	friction loss (m)
h_l	secondary losses (m)
IHA	International Hydropower Association
IPP	independent power producer
IRP	Integrated Resource Plan
IRR	internal rate of return
K	secondary loss coefficient
L	length of penstock (m)
LCC	life cycle costing
LCOE	levelized cost of electricity
n	number of years
NERSA	National Energy Regulator of South Africa
NPV	net present value
O&M	operation and maintenance
P	mechanical power output (W)
P_{actual}	actual power output of turbine (W)
$P_{theoretical}$	theoretical output at 100% efficiency (W)
PPA	power purchase agreement
PPP	public private partnership
PRS	pressure-reducing station
PRV	pressure-reducing valve
PV	solar photovoltaic

Symbol/ abbreviation	Description
PW	present worth
Q	flow rate through the turbine (m^3/s)
RE	renewable energy
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROD	Record of decision
ROI	return on investment
SA	South Africa
SABS	South African Bureau of Standards
SANEDI	South African National Energy Development Institute
SHP	small hydropower plant
v	velocity of water in penstock or pipe (m/s)
η	Hydraulic efficiency of the turbine (%)
λ	friction coefficient of penstock or pipe (m)
ρ	Hydraulic efficiency of the turbine (%)

GLOSSARY

Alternating current (AC)	:	Electric current that reverses direction many times per second.
Annual maximum demand	:	The greatest energy demand that occurred during a prescribed demand interval of a calendar year.
Availability factor	:	The percentage of time a plant is available for power production.
Base load generation	:	Those generating facilities within a utility system that are operated to the greatest extent possible to maximise system mechanical and thermal efficiency and minimise system operating costs.
Benefit/Cost ration (B/C)	:	The ratio of the present value of the benefit (e.g. revenues from power sales) to the present worth of the project cost.
Capacity	:	The load for which a generating unit, generating plant or other electrical apparatus is rated either by the user or by the manufacturer.
Capacity factor	:	The expected output of the plant over a specific time period as a ratio of the output if the plant is operated at full-rated capacity for the same time period.
Capital cost	:	The total cost of a project from the conceptual to the completion stage including initial studies, management, equipment cost, construction and materials costs, start-up fees, supervision and interest during construction.
Demand	:	The rate at which electric energy is delivered to or by a system, part of a system or a piece of equipment. It is expressed usually in kilowatts at a given instance or averaged over any designated period of time. The primary source of "demand" is the power-consuming equipment of customers.
Demand, Average	:	The demand on, or the power output of, an electric system or any of its parts over any interval of time, as determined by dividing the total number of kilowatt-hours by the number of units of time in the interval.
Demand charge	:	That part of the charge for electric service based upon the electric capacity (kW) consumed and billed on the basis of billing demand under an applicable rate schedule.
Direct current (DC)	:	Electric current which flows in one direction.
Discount rate	:	The factor used in present value calculations that indicates the time value of money, thereby equating current and future costs.
Distributed generation	:	Small-scale technologies to produce electricity close to the end users of power.
Distribution	:	The act or process of delivering electric energy from convenient points on the transmission system (usually a substation) to

		consumers. The network of wires and equipment that distributes, transports or delivers electricity to customers. Electric energy is carried at high voltages along the transmission lines. For consumers needing lower voltages, it is reduced in voltage at a substation and delivered over primary distribution lines extending throughout the area where the electricity is distributed. For users needing even lower voltages, the voltage is reduced once more by a distribution transformer or line transformer. At this point, it changes from primary to secondary distribution.
Distribution line	:	One or more circuits of a distribution system either direct-buried, in-conduit, or on the same line of poles or supporting structures, operating at relatively low voltage as compared with transmission lines.
Draft tube	:	A water conduit, which can be straight or curved depending upon the turbine installation, which maintains a column of water from the turbine outlet and the downstream water level. It takes the water from a turbine, which is discharged at a high velocity, and reduces its velocity by enlarging the cross-section of the tube, to provide a gain in net head.
Efficiency	:	A percentage obtained by dividing the actual power or energy by the theoretical power or energy. It represents how well the hydropower plant converts the energy of the water into electrical energy, i.e. a more energy-efficient technology is one that produces the same service or output with less energy input.
Energy charge	:	That part of the charge for electric service based upon the electric energy (kWh) consumed or billed.
Feasibility study	:	An investigation to develop a project and definitively assess its desirability for implementation.
Generator	:	A rotating machine that converts mechanical energy into electrical energy.
Governor	:	An electronic or mechanical device which regulates the speed of the turbine/generator by sensing frequency and either adjusting the water flow or adjusting a balancing load dump to keep a constant load on the turbine.
Head	:	Vertical change in elevation, expressed either in feet or metres, between the head water level and the tail water level.
Hertz	:	One electrical cycle per second. Usually 50 Hz is maintained.
Impulse turbine	:	A machine which converts the energy of a jet of water at atmospheric pressure into mechanical energy, usually used to turn a generator. Examples are the Pelton, Turgo and Crossflow turbine.

Independent Power Producer (IPP)	:	Any person who owns or operates, in whole or in part, one or more new independent power production facilities.
Inflation	:	A general rise in prices. An increase in a particular price may or may not be inflationary, depending on how it affects other prices and on how promptly it brings to market additional supplies of the product.
Instantaneous peak demand	:	The demand at the instance of greatest load, usually determined from the readings of indicating or graphic metres.
Kilowatt (kW)	:	One kilowatt equals 1 000 watts.
Kilowatt-hour (kWh)	:	This is the basic unit of electric energy equal to one kilowatt of power supplied to or taken from an electric circuit steadily for one hour. One kilowatt-hour equals 1,000 watt-hours.
Levelized cost of energy	:	The discounted total cost of a technology option or project over its economic life, divided by the total discounted output from the technology option or project over that same period, i.e. the levelized cost of energy provides an indication of the discounted average cost relating to a technology option or project.
Load factor	:	The ratio of the average load in kilowatts supplied during a designated period to the peak or maximum load in kilowatts occurring in that period. Load factor, as a percentage, may also be derived by multiplying the kilowatt-hours (kWh) in the period by 100 and dividing it by the product of the maximum demand in kilowatts and the number of hours in the period. Example: Load factor calculation – Load factor = kilowatt-hours/hours in period/kilowatts. Assume a 30-day billing period or 30 times 24 hours for a total of 720 hours. Assume a customer used 10 000 kWh and had a maximum demand of 21 kW. The customer's load factor would be 66 per cent ((10 000 kWh/720 hours/21 kW)*100).
Maximum demand	:	The greatest demand that occurred during a specified period of time such as a billing period.
Megawatt (MW)	:	One megawatt equals one million (1 000 000) watts.
Off-peak energy	:	Energy supplied during periods of relatively low system demand as specified by the supplier.
On-peak energy	:	Energy supplied during periods of relatively high system demand as specified by the supplier.
Operating and maintenance costs	:	This refers to all non-fuel costs such as direct and indirect costs of labour and supervisory personnel, consumable supplies and equipment and outside support services. These costs are made up of two components, i.e. fixed costs and variable costs.
Penstock	:	A closed conduit or pipe for supplying water to the powerhouse.

Present value	:	Present worth of a stream of expenses appropriately discounted by the discount rate.
Reaction turbine	:	A machine which converts the energy of water under pressure to motion. A pressurised case contains the water, which must turn the runner in order to reduce to atmospheric pressure at the tailrace. The action of a reaction turbine is analogous to a pump running in reverse. Types include the propeller, Francis and Kaplan.
Runner	:	The rotating part of the turbine that converts the energy of falling water into mechanical energy. The part of a turbine, consisting of blades or buckets on a wheel or hub, which is turned by the action of pressurised water, either by a jet of water (impulse turbine) or by reducing the pressure of the water (reaction turbine).
Tailrace	:	The channel that carries water away from a dam.
Tailwater	:	The water downstream of the powerhouse.
Tariff	:	A schedule of prices or fees.
Transformer	:	An electromagnetic device for changing the voltage level of alternating-current electricity.
Transmission	:	The act or process of transporting electric energy in bulk from a source or sources of supply to other principal parts of the system or to other utility systems.
Turbine	:	A machine in which the pressure or kinetic energy of flowing water is converted to mechanical energy which, in turn, can be converted to electrical energy by a generator.
Water hammer	:	A change in penstock pressure caused by changing the speed of a column of water in a penstock. The result of a rapid valve closure can produce extremely high pressures capable of rupturing a penstock, while the results of extremely rapid valve opening can reduce pressures, causing potential water column separation and vacuum conditions. Water hammer is controlled by using slow acting valves, pressure relief valves, surge tanks or jet deflectors (on impulse machines).

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SCOPING STUDY TO EXPLORE HYDRO POTENTIAL IN THE IN THE NEARBY VICINITY OF BAAKENS RIVER AND THE LAKE

COMPLETION REPORT

Deliverable 2
Completion report

1. INTRODUCTION

Since 2008 the South African energy suppliers, ESKOM, has been experiencing numerous generation and supply problems. These included the supply not matching the demand as well as the escalation of the electricity costs (Steyn, 2006). Thus, the primary electricity infrastructure (i.e. the coal-fired power stations, the major supply lines and the distribution of the electricity within the urban areas) is rapidly becoming insufficient and cannot sustain a supply against the demand of existing as well as future electricity users connected to the national grid.

ESKOM is currently improving their supply capacity by constructing two new coal-fired power stations, Kusile and Medupi (4800 MW and 4764 MW respectively). The Ingula Pumped Storage Scheme with a capacity of 1332 MW was also built to improve the capacity during peak demand periods. But this is still not sufficient electricity for South Africa. Thus, alternative energy sources need to be considered. The Renewable Energy Independent Power Producers Procurement (REIPPP) program which was opened by the South African Government in 2011, enables private developers to install up to 3725 MW renewable energy generation capacity. These renewable energy resources include biomass, biogas, solar radiation, wind power and small hydropower schemes (Department of Energy, 2017).

A nation's industrial growth as well as the quality of life are dependent on energy supply and demand. The industrial growth contributes to the economic growth which leads to a better quality of life. With the current situation of the supply of energy and a growing demand, small-scale hydropower projects could play an important role, especially in providing electricity to remote areas and utilizing existing water infrastructure in South Africa. These hydropower projects could be stand-alone isolated mini grids or could be linked to the national electricity grids.

Over the last few years several new water supply infrastructures were constructed in the rural areas for the upliftment of the rural communities. These different infrastructures should urgently be re-evaluated for their possible opportunities in power generation as well as their efficiencies if power is being generated already.

On the more constant rivers, small dams and water intakes were built and pipelines were installed to transport the water to water treatment works as well as communities. At all of these different locations, a possible hidden potential of hydropower ranging from a pico (<20 kW), a micro (up to 100 kW), or even mini (up to 1 MW) scheme, to possibly supply a school or clinic, a cultural village centre or even a whole community (Jonker Klunne, 2009). Municipalities, water utilities and government entities (DWS, ESKOM, etc.) also own and operate water infrastructure which could be modified to provide a multipurpose function.

Although not very well documented, small scale hydropower used to play an important role in the provision of energy to urban and rural areas of South Africa.

The first provision of electricity to cities like Cape Town and Pretoria was based on small scale hydro, while smaller towns also started local distribution of electricity through isolated grids powered by small hydro stations (Jonker Klunne, 2009). However, with the expansion of the national electricity grid and the cheap, coal generated power supplied through this grid, large numbers of systems were decommissioned.

Small hydropower is a proven, mature technology with a long track record, including in Africa. The gold mines at Pilgrims' Rest (South Africa), for example, were powered by two 6 kW hydro turbines as early as 1892, complemented by a 45 kW turbine in 1894 to power the first electrical railway (Eskom (2009) in Jonker Klunne, 2012). Many countries in Africa do have a rich history of small scale hydropower, but over time large numbers of these stations have fallen into disrepair. Some because the national grid reached their location, some because a lack of maintenance or even pure neglect. Recently initiatives have seen the light in a number of countries in Africa to revive the small hydro sector, either through international development agencies or through private sector led initiatives. Particular 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, while in South Africa the first new small hydro station in 20 years was opened in 2009, with more under development.

Even though South Africa is classified as a water scares country by the experts, there is still enough water for small scale hydropower schemes, which could help with the sustainable energy supply for the future (Banks & Schäffler, 2006). The first step in developing small-scale hydropower is to identify the potential sites. Thereafter a more detailed evaluation can be done to determine the feasibility and most suitable technology that could be utilised to harness this renewable energy source. The WRC in particular have aimed to showcase hydropower technologies in SA through numerous pilot studies. This pioneering work was driven by the need to utilise water infrastructure in a more sustainable way.

This project describes the scoping study that provides a platform to demonstrate the evaluation process and procedures to identify hydropower potential at a local level and help design roll-out programmes. It outlines the necessary steps that needs to be followed when considering development of a hydropower plant from site identification, technology selection, technical and feasibility evaluation, implementation to identifying the O&M model most suited.

The research project's aim is to enhance the uptake of micro-hydro technology, making local stakeholders (private sector, financial sector, government entities, etc.) aware of the opportunities that this technology brings and the process required to get this technology successful implemented at a local level.

2. PROJECT AIMS

The aims of the project are:

1. Identify all forms of hydropower (conduit, dams, weirs, run-of-river, etc.) in the water infrastructure of the vicinity of Baakens River and the lake.

2. Develop an evaluation framework and development template for small-scale hydropower development at a local municipal level.

3. Develop an outline of the technology types most suitable for small-scale hydropower and identify O&M models for this technology.

3. ADOPTED RESEARCH METHODOLOGY

The primary objective of this research project was to identify the hydropower opportunities in the vicinity of the Baakens River and lake areas.

The global need to move to cleaner and more sustainable energy systems means that there should be a continuous evaluation of the various energy opportunities. A systematic methodology is required for the identification and analysis of all relevant components and considerations. The proposed methodology is however simple and straight forward.

- Firstly, the different aspects of a hydropower development are described in detail which includes:
  - The regulatory and legislative procedures. How small hydropower fits in South African policy environment (i.e. linkage with the national electrification policy / priorities and regional / municipal Integrated Development Plans);
  - The types of hydropower opportunities which exists;
  - Both the technical and civil aspects regarding the turbine type and selection, generators and transformers, and hydraulics and operational aspects;

- Environmental considerations;
- Social concerns and potential impacts; and,
- Financial aspects including the related costs, potential incomes, and methods of determining financial viability.

- This provided the project team with the knowledge to identify all the parameters that influence the site identification and evaluation criteria of the various sites.

- An evaluation criteria for a first order assessment for the various types of hydropower have previously been developed for certain water infrastructure and rivers and was expanded on.

- The analysis of each site allowed for the confirmation of the flow and available head as well as development constrains such as protected areas, isolation (distance to nearest grid connection) and the need for renewable energy at each specific site.

- To identify potential hydropower sites, technical investigations were carried out which included site visits, topographic surveys, socio-economic environment, historical gauging records, municipal asset registers, etc.

- The overview of the methodology for site selection includes:
    - General understanding of the context of small hydro development in South Africa;
    - Comprehensive data and document collection (DWS, municipal asset registers, etc.);
    - Analysis of data and documents;
    - Review of maps and documents;
    - Site selection criteria application and site selection;
    - Site visits;
    - Technical and feasibility study of each site; and
    - Compiling conceptual designs.

- The evaluation template (a tool developed in Microsoft Excel), focusses on the potential outputs as well as the feasibility of a hydropower project, which includes the evaluation of the potential regarding specific locations, when considering both the engineering and hydrological/hydraulic components, as well as electricity distribution. The tool also includes information regarding new technologies suitable for small-scale hydropower, details and case studies of the hydropower projects.

4. LITERATURE REVIEW

4.1 WORLD ENERGY CRISIS

The world is becoming aware of the need to shift towards harvesting energy from renewable sources as the price of electrify generated from fossil fuels and the pressure associated with reducing energy-related carbon emissions is increasing. According to IPCC, (2018), the gap between aspiring mitigating climate change and the reality of making a large impact on climate change is still significant. The increase in CO_2 emissions and the uneven distribution of effort amongst countries to alleviate this problem, is further increasing this gap between aspiration and reality (IRENA, 2019).

Energy related CO_2 emissions increased in 2017 and 2018 largely due to the increased use of fossil fuels. This is supported by the statement that energy-related CO_2 emissions have increased by approximately 4% since the Paris agreement was signed in 2015 (IRENA, 2019), despite the fact that coal consumption has been declining during recent years, as there is an increased trend observed in countries, corporations, traders and investors to move away from coal investments (IEA, 2018a).

The Paris agreement's central aims are to mitigate the treat of climate change by maintaining the increase in the average global temperature below 2°C and to increase the climate change adaptability of countries (UNFCCC, 2015). In order to meet the aims of the Paris agreement, energy-related CO_2 emissions need to be reduced by 3.5% per year, until 2050 with renewable energy having the ability to play a significant role in achieving this goal. This conclusion was derived from the statement by (IRENA, 2019), that the accelerated stationing of renewable energy measures (for electrification and direct use), combined with increased energy efficiency, can be responsible for the reduction of 90% of the energy-related CO_2 emissions by 2050.

The forecasts, therefore, predict that by 2050, 86% of electricity generated should be from renewable energy, and approximately 60% of the renewable energy contribution will be from solar and wind (IRENA, 2019).

4.2 SOUTH AFRICAN ENERGY SITUATION

South Africa's (SA) energy sector contributes approximately 80% toward total green-house gas (GHG) emissions of the country, with an estimated 50% of GHG emissions as a result of electricity and liquid fuel production. As a condition of being a signatory of the Paris agreement, the GHG emissions of SA are expected to peak in 2025 and decline from there onwards (DoE, 2019). Furthermore, the National Development Plan (NDP) of South Africa, envisions an energy sector that provides reliable and efficient energy services at competitive rates (DoE, 2019).

According to (Bonthuys et al., 2016), South Africa has a long road ahead before realising this goal. The lack of universal access to electricity in SA, which can be attributed to the remoteness, scattered population and low average demands, is emphasised in the electrification statistics, which is 80% for urban areas and 45% for rural areas. Rolling blackouts, which were enforced in 2008 as a result of demand for electricity exceeding the supply, compromised the reliable supply of electricity and set the NDP energy sector plans further off track (Loots et al., 2015).

It can be assumed that the introduction of a greater renewable energy capacity in the current energy generation mix, can alleviate some problems that SA is facing regarding its current energy supply situation.

4.2.1 Current sources of energy

According to (DoE, 2018), the South African energy supply is dominated by coal, with a 59% contribution to the total energy supply. The remainder of the energy supply is from renewables (20%), crude oil (16%), natural gas (3%) and nuclear (2%). Furthermore, approximately 90% of electricity used in South Africa is supplied by the national utility, Eskom.

Eskom operates thirty power stations with a nominal capacity of 44 172 MW (ESKOM, 2019). The generation assets of Eskom and the contribution of each type of energy source are illustrated in Figure 4-1, with the locations of various power stations shown in Figure 4-2.

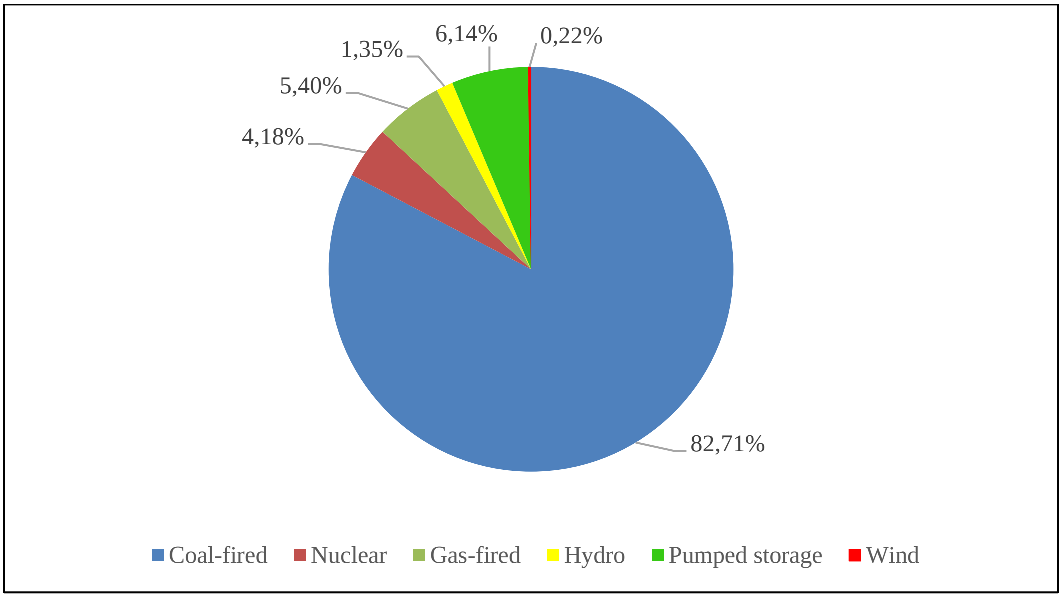


Figure 4-1: ESKOM generation assets (Adapted from (Eskom, 2018))

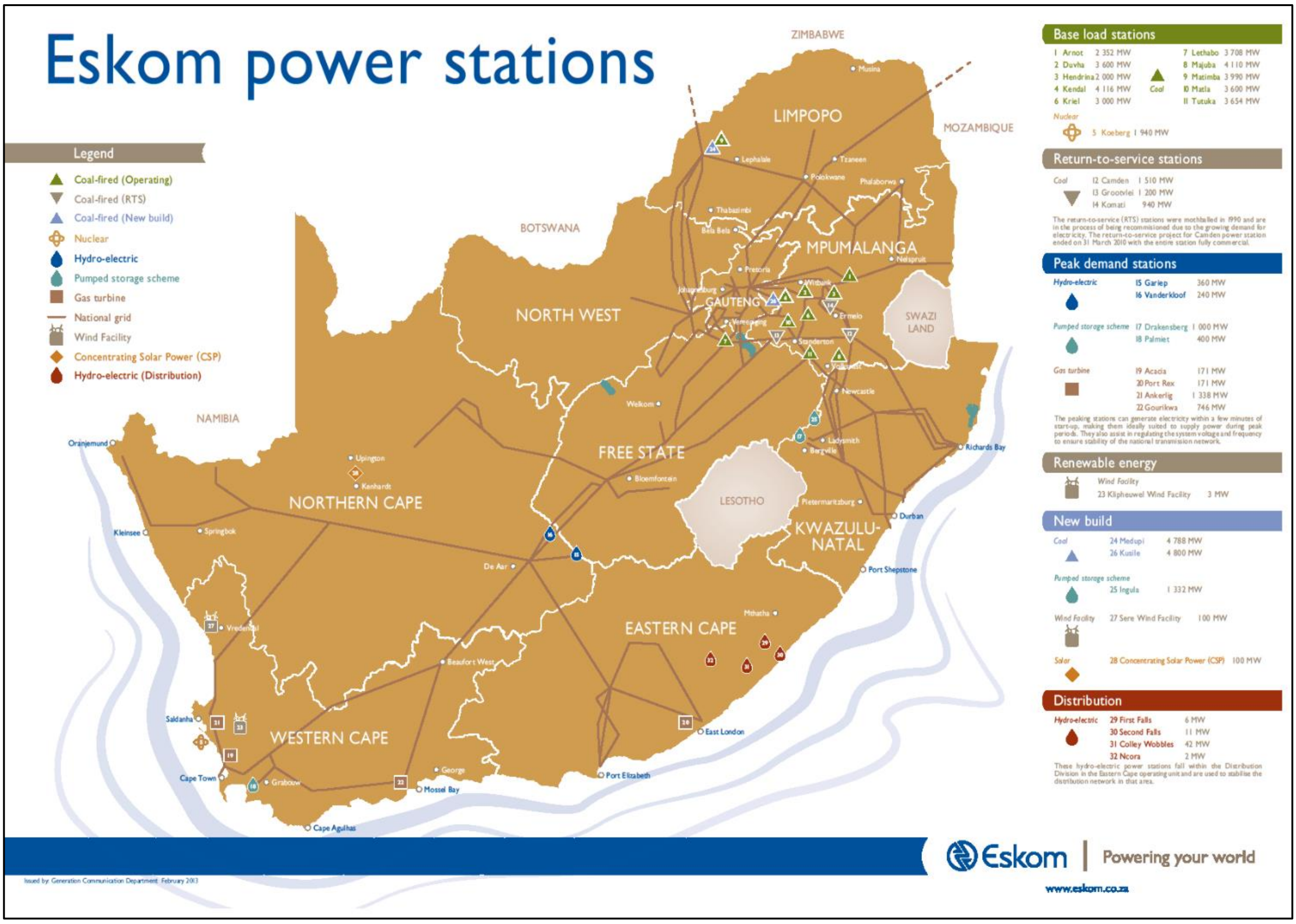


Figure 4-2: Map of ESKOM power stations and electricity grid in South Africa (ESKOM, 2018)

The decline in power generation investment combined with the increased electricity demand have placed additional strain on ESKOM. The electricity shortages that SA has been experiencing over recent years have placed emphasises on the need to set up future electricity development plans, which includes the commitment to invest in renewable energy sources to ensure sustainable electricity supply in the future (Van Vuuren et al., 2014).

4.2.2 Renewable energy in South Africa

Sub-Saharan Africa is regarded as the continent with the greatest vulnerability to climate change due to population growth, subsistence agriculture and the lack of capacity to adapt to change and upcoming water crises. Introducing renewable energy as a form of energy generation for both industrialised and developing countries can result in a reduction in pollution as well as the mitigation of climate change, with the latter being of great importance to developing continents such as Africa.

Renewable energy as an alternative energy option also has the advantage of creating employment, decreasing the dependence on non-renewable and concentrated energy sources as well as reducing Africa's vulnerability to the impending increase in prices of imported fossil fuels (Aliyu *et al.*, 2018). As mentioned previously 40% of the GHG emissions of South Africa can be attributed electricity generation and liquid fuel production (DoE, 2019).

The reduction of carbon emissions by 2020 for South Africa was aimed at 34% as agreed to by being a signatory of the Kyoto Protocol. This motivated the introduction of Integrated Resource Plan (IRP) by the Department of Energy (DoE), with endorsement from the National Energy Regulator of SA (NERSA), which aims at providing sustainable and reliable energy supply as competitive rates whilst reducing carbon emissions in South Africa for 2010-2030. The REIPPP (Renewable Energy Independent Power Producers Programme) has been established as part of the Integrated Resource Plan (IRP) for 2010-2030, which identified the preferred technology (renewable energy) to be responsible for meeting the expected electricity demand in 2030. (DoE, 2019; Loots et al., 2015).

Of the 54 177 MW electricity generation capacity of South Africa, only approximately 16% of the electricity is currently generated from renewable energy sources. A breakdown of the energy generated from renewable energy sources in South Africa is shown in Figure 4-3. Since the implementation of the IRP 2010-2030, 6 422 MW have been produced under the REIPP of which 3 876 MW are operational and available to the grid (DoE, 2019).

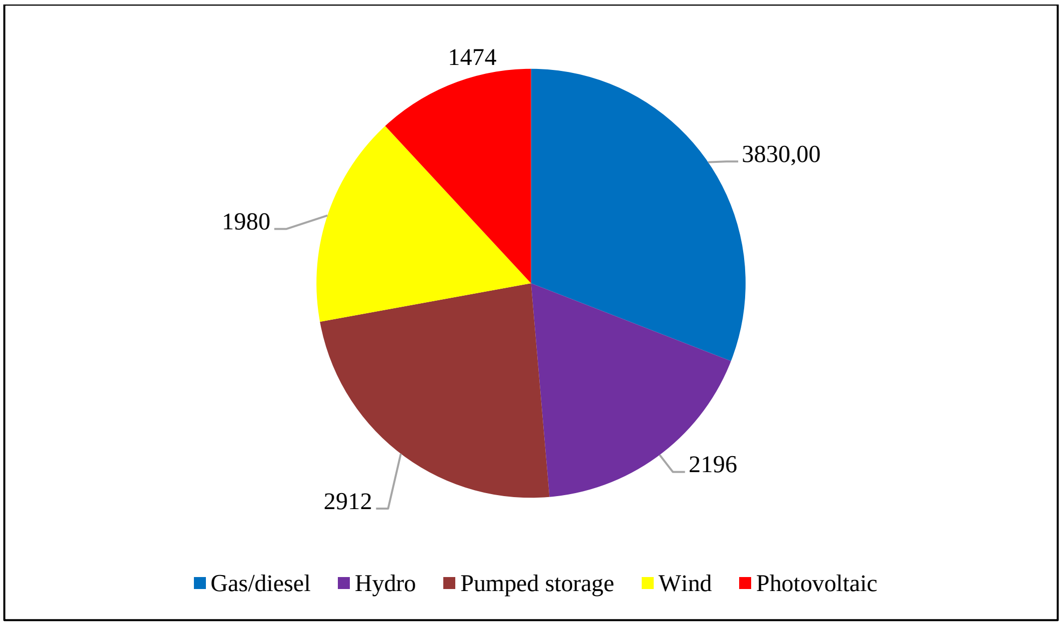


Figure 4-3: Total generation capacity in Megawatt from renewable sources (Adapted from (DoE, 2019))

The annual global growth rates for renewable energy has been 8-9% since 2010 (IEA, 2018b), with wind and solar power being the front-runners with regard to installed capacity for the year of 2018. The same trend can be observed in SA regarding the current and forecasted energy capacity. The 2018 energy statistics of SA shows that approximately 55% of the ESKOM installed renewable energy capacity is generated form wind and solar (Eskom, 2018) and of the 18 GW of renewable energy capacity that has been committed to by 2030, approximately 86% will be generated by wind and solar (DoE, 2019). The global energy forecasts indicates that by 2050, 86% of electricity generation should be from renewable energy, and approximately 60% of the renewable energy contribution will be from wind and solar (IRENA, 2019).

In the compilation of the SA's latest Integrated Resource Plan (IRP) for 2010-2030, the various renewable sources were evaluated and quantified. All the renewable sources, except hydropower, have developed atlases which allowed for a better understanding of the resources available.

The wind atlas of South Africa (WASA) (Figure 4-4) consists of maps indicating the wind resources of SA, thereby enabling the exploitation of wind energy in SA (SANEDI, 2017). The WASA is an example where the total potential for wind energy in SA as indicated in the 2019 IRP, was quantified using the atlas. The realisation that SA has potential for wind energy in locations other than the expected coastal regions is also as a result of the wind atlas that was developed (DoE, 2019).

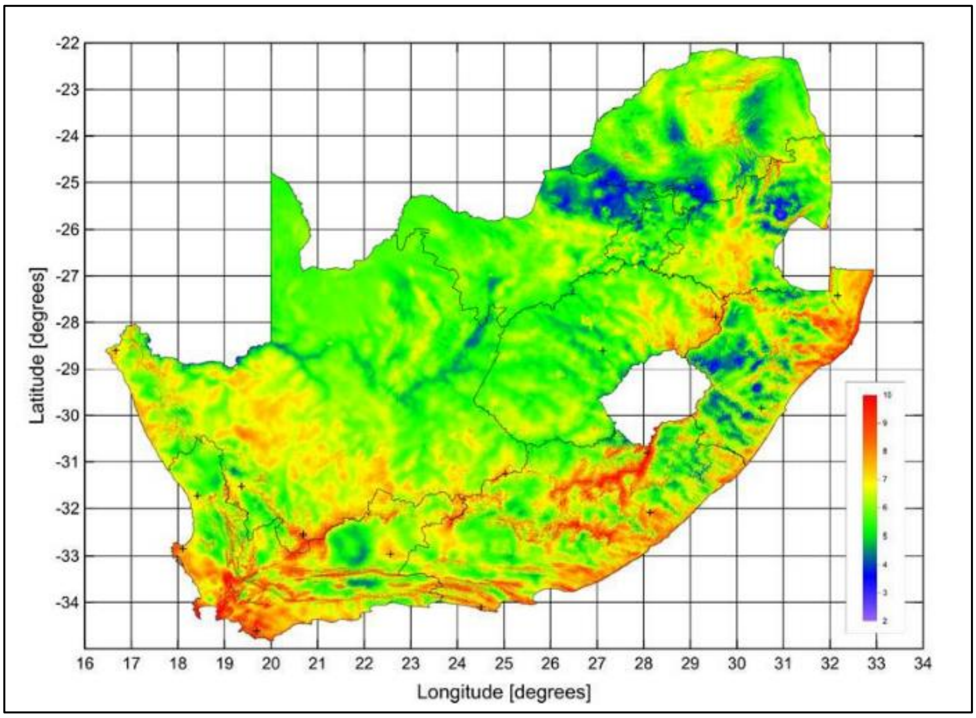


Figure 4-4: Annual wind speed for South Africa, an extract from the WASA database (SANEDI, 2017)

Solar power (photovoltaic and concentrated solar power) is listed in the IRP as a potential significant contributor to the future energy mix of SA. The realisation of the solar power potential in SA can be attributed to the fact that like wind energy, the solar energy potential of SA has been quantified as illustrated from Figure 4-5.

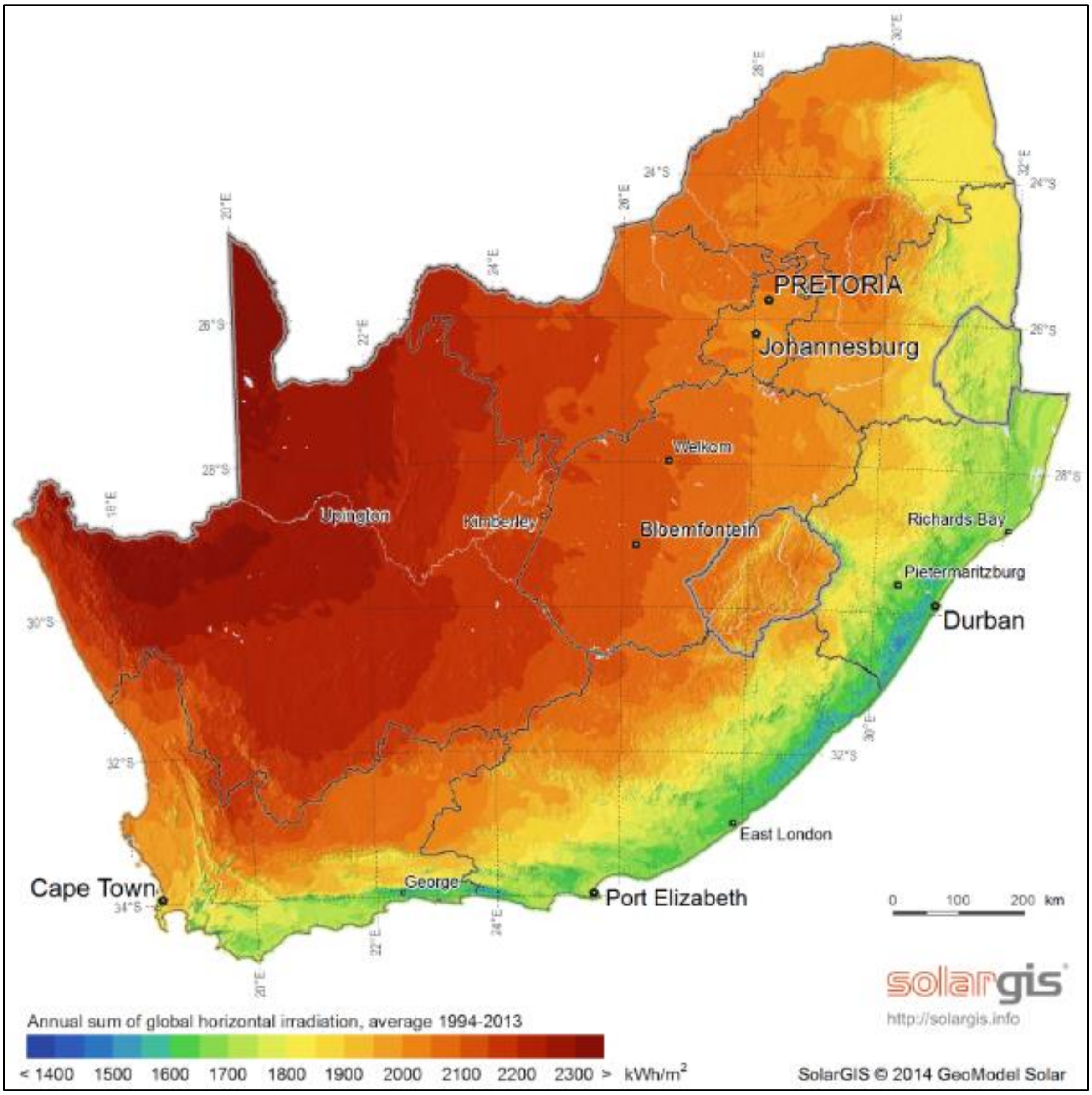


Figure 4-5: Direct Normal Irradiance map of SA (Centre for Renewable and Sustainable Energy Studies, 2014)

The low primary productivity, which is largely constrained by low rainfall, combined with the focus on food security makes bioenergy a relatively unattractive renewable energy source. The unattractiveness of the source, however, does not mean there is no potential for bioenergy in SA. The unattractiveness overshadowing the potential of bioenergy to become a significant contributor to the South African energy mix, was used as an incentive by the Department of Science and Technology to develop the Bioenergy Atlas for South Africa (Figure 4-6).

The bioenergy atlas gives an indication of the bioenergy potential available in SA, especially small scale, and can eventually be used to incorporate bioenergy in the modern energy service (Hugo, 2016).

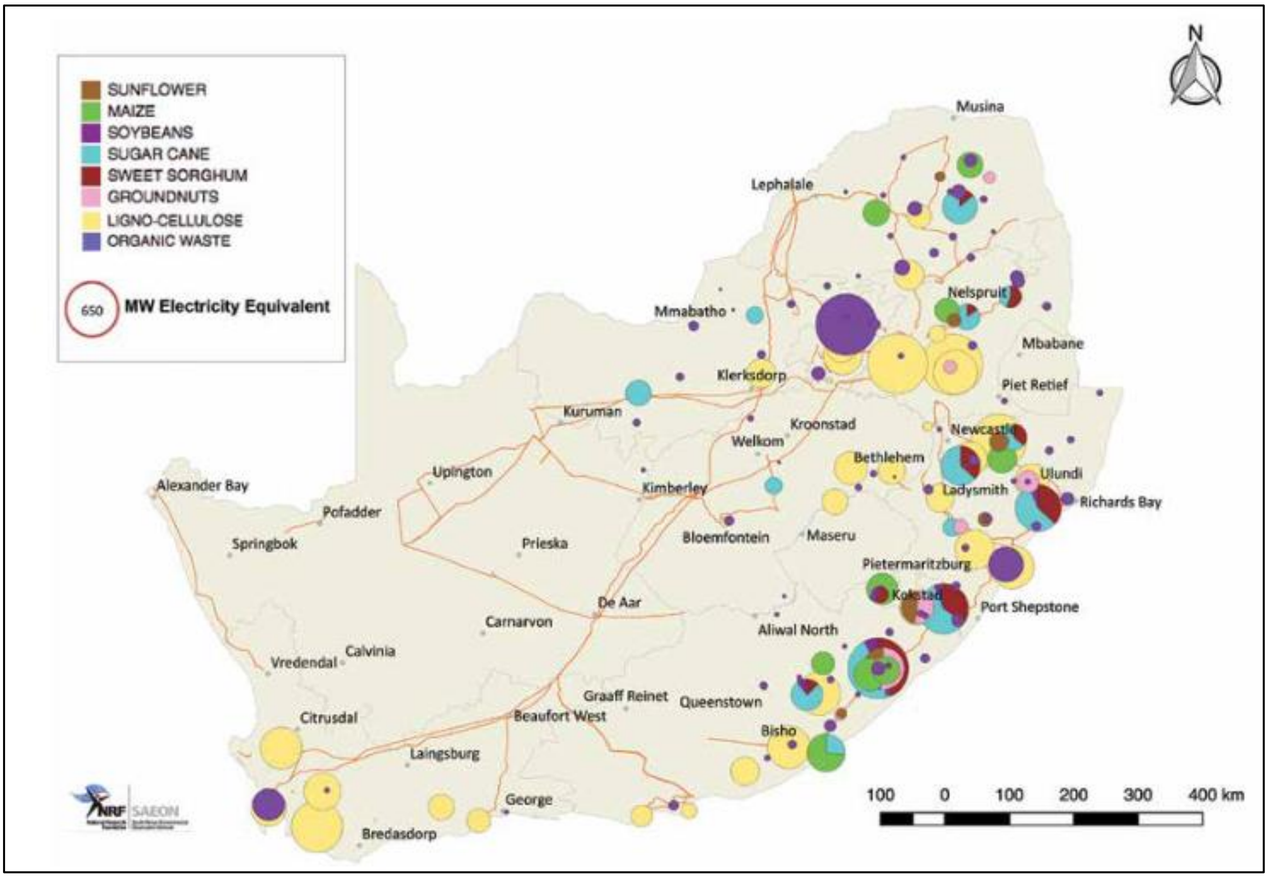


Figure 4-6: Extract from the Bioenergy Atlas for South Africa (Hugo, 2016)

Like biomass, hydropower is not being considered by the government a significant contributor to future energy generation in SA, as the expected contribution to future energy generation is a mere 4% (Hugo, 2016). The problem, however, is that the expected future contribution of hydropower to SA's electricity supply is unclear as the available potential for hydropower development in SA is unknown. This was made clear in the IRP (DoE, 2019), where run-of-river hydropower was listed as the only potential hydropower in SA. Even though SA is a water scarce country, there are multiple locations where hydropower can be generated, including irrigation canals, water distributions systems, wastewater treatment works, transfer schemes, dams, etc. (Loots et al., 2015). Locations where small hydropower potential is available (micro and pico) should also not be neglected as these types of installations can provide electricity to rural and/or isolated communities as previously mentioned.

According to IRENA, (2019), renewable energy technologies, including mini- and off-grid technologies can be used to provide higher electricity access rates to the estimated 1 billion people that do not have access to reliable electricity supply. Small hydropower is an ideal renewable energy alternative for the electrification of isolated communities and assisting in peak supply (Loots, et al., 2014). Furthermore, it is noteworthy that a third of the world has access to water but does not have access to electricity (Behrouzi, et al., 2016).

4.3 HYDROPOWER AS A RENEWABLE ENERGY SOURCE

The water-energy nexus principle describes the directly proportional relationship between water supply and energy demand, which states that the increase in energy use causes an increase in the demand of water and an increased demand in clean, potable water, increases the energy demand. It is, therefore, recommended to explore technologies that can couple water and energy supply, especially in areas with high population densities (Gilron, 2014).

Research conducted by (Spänhoff, 2014), shows that hydropower is the greatest renewable energy contributor to the world's electricity generation, with a 16.5% contribution in 2012. The installed hydropower capacity is forecasted to exceed 1400 GW by 2035, which will be the largest renewable energy source in terms of installed capacity. The top ranked countries with regards to installed hydropower capacity are the United States, Brazil, Canada and China, with the latter having an installed capacity (249 GW in 2012) exceeding the cumulative capacity of the three former countries (Hennig et al., 2013). Furthermore, the global hydropower potential as reported in the World Hydropower Atlas, published by the International Journal of Hydropower and Dams is approximately 14 400 TWh/year (International Journal of Hydropower and Dams, 2000). According to (Paish, 2002), only 18% of the total amount of hydropower potential was exploited in 1999, which is approximately half the installed hydropower capacity of today (IHA, 2019). The literature, therefore, indicates that even though the world's installed hydropower capacity has almost doubled in the last 30 years, there is still a significant amount of hydropower potential to be exploited as shown in Figure 4-7.

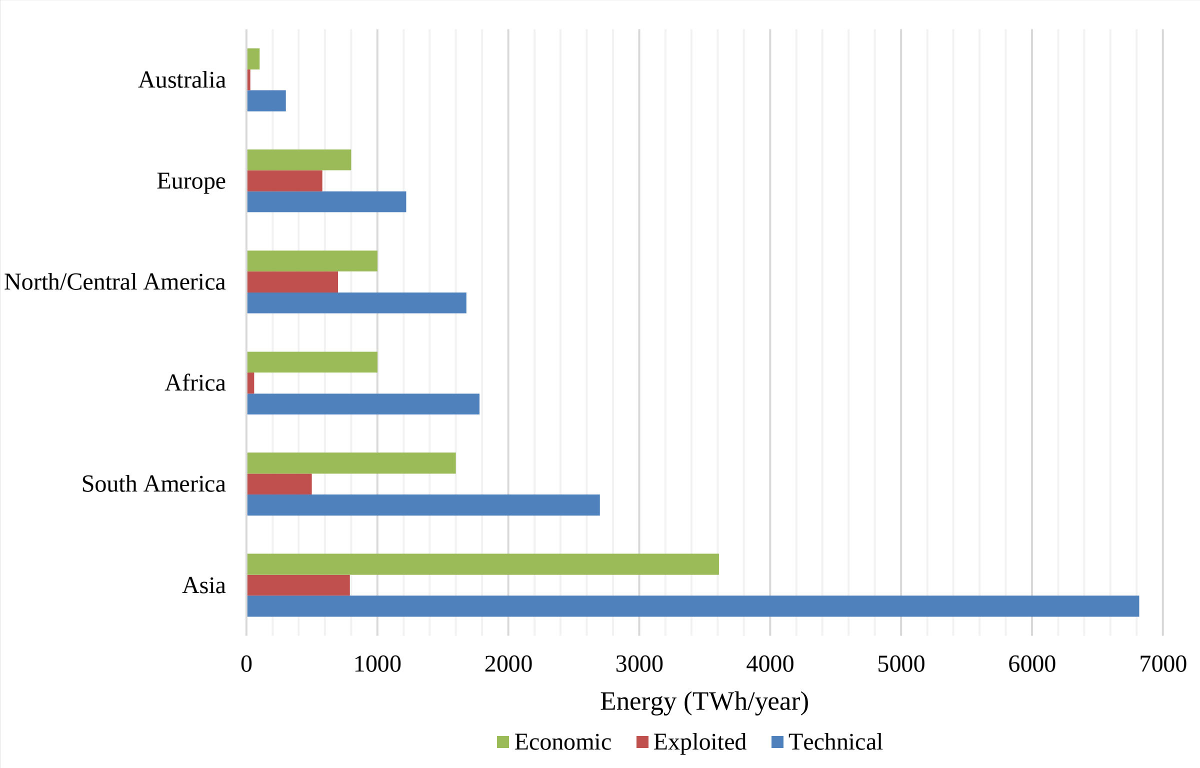


Figure 4-7: World hydropower potential (adapted from Pérez-Sánchez *et al.*, (2017))

4.3.1 Large hydropower

Although there is no internationally agreed definition of different hydropower sizes (Paish, 2002), the distinction between large and small hydropower is whether the installed capacity is larger than 10 MW. Mini hydropower plants refer to installations with an installed capacity between 100 kW and 1 MW. Furthermore, Micro hydropower plants usually have an installed capacity between 20 kW to 100 kW where hydropower plants with an installed capacity below 20 kW is usually referred to as pico hydropower (Loots et al., 2014; Pérez-Sánchez et al., 2017). The international standards defines all dams with a wall height greater than 15 m as large (Nilsson et al., 2005).

4.3.2 Small hydropower

The increase in small hydropower development can largely be attributed to the development of the Francis turbine. This development contributed to the establishment of electrical services in either remote areas or areas located a relative distance from the supply points (Mataix, 2009).

Countries with the largest installed small hydropower capacity are China, Brazil, India, Canada and some European countries (Pérez-Sánchez et al., 2017). A summary of the installed small hydropower capacity of selected countries or continents is provided in Table 4-1.

Table 4-1: Installed small hydropower capacity of selected countries or continents (adapted from (Pérez-Sánchez et al., 2017))

Country/Continent	Small hydropower capacity
China	China has an installed small hydropower capacity equal to 80 GW supplying approximately 650 rural areas (Hennig et al., 2013)
Brazil	There are currently 397 small hydropower plants in operation with an installed capacity of 3.5 GW (in comparison to the 25.9 GW potential available) (Pereira et al., 2013)
United States	Approximately half a million sites were identified with an installed capacity of 100 GW (Kosnik, 2010).
Australia	There are currently 60 existing small hydropower plants with an installed capacity of 0.15 GW (Bahadori et al., 2013).
India	The potential capacity was quantified as 15 GW of which 2.4 GW is currently installed in 674 plants (Nautiyal et al., 2011).
Japan	In 2010 the installed hydropower capacity of Japan was non-existent, but with a hydropower installation rate of 300 MW per year, the installed hydropower capacity is forecast to reach 3.5 GW soon (Liu et al., 2013; Ushiyama, 1999)
Europe	The installed small hydropower capacity in 2005 was 12.4 GW of which Italy, Spain, Germany, Austria, France, Sweden, Switzerland and Norway contributed more than 90% of the capacity (ESHA, 2012).
Africa	Small hydropower, with a capacity lower than 300 kW, is developed in rural areas across the continent (Miller et al., 2015).

Over the last decades the development of mini hydropower plants (100 kW-1 MW) has been considered an effective means of providing electricity to isolated communities and it is predicted that hydropower will expand in developing countries such as India and Pakistan, as the demand for rural electrification is increased (Bhutto et al., 2012). (Spänhoff, 2014) supports the statement by arguing that countries with increased demand for rural electrification will benefit economically from small hydropower and will, therefore, have the highest contribution to the expansion of small hydropower sites. According to (Miller et al., 2015), an increased trend in the development of hydropower plants with an installed capacity less than 300 kW is being observed in Africa as the social benefit associated with these smaller installations are significant. Mini, micro and pico hydropower can, therefore, be utilised as part of the solution to provide electrification to the approximately 2.5 million households without power in SA (Statistics SA, 2017).

4.3.3 Hydropower in South Africa

According to the Hydro4Africa database (Klunne, 2012), South Africa has an installed hydropower capacity of approximately 3 700 MW, which includes the capacity from the hydropower peaking stations.

The existing hydropower mix of SA consists primarily of run-of-river, pumped storage and storage schemes with the top ten contributors of the installed hydropower capacity summarised in Table 4-2.

Table 4-2: Ten largest hydropower sites in South Africa (Adapted from Jonker Klunne, 2007)

Name	Installed Capacity (MW)	Type
Ingula Pumped Storage	1 332	Pumped storage
Drakensberg Pumped Storage	1 000	Pumped storage
Palmiet pumped storage	400	Pumped storage
Gariep	360	Storage
Van der Kloof	240	Storage
Steenbras pumped storage	180	Pumped storage
Collywobbles / Mbashe	42.0	Run-of-river
Neusberg	12.6	Run-of-river
Second Falls	11.0	Run-of-river
First Falls	6.00	Run-of-river

Numerous sites have been identified where small, mini, micro and pico hydropower could theoretically be developed in SA as displayed in Figure 4-8.

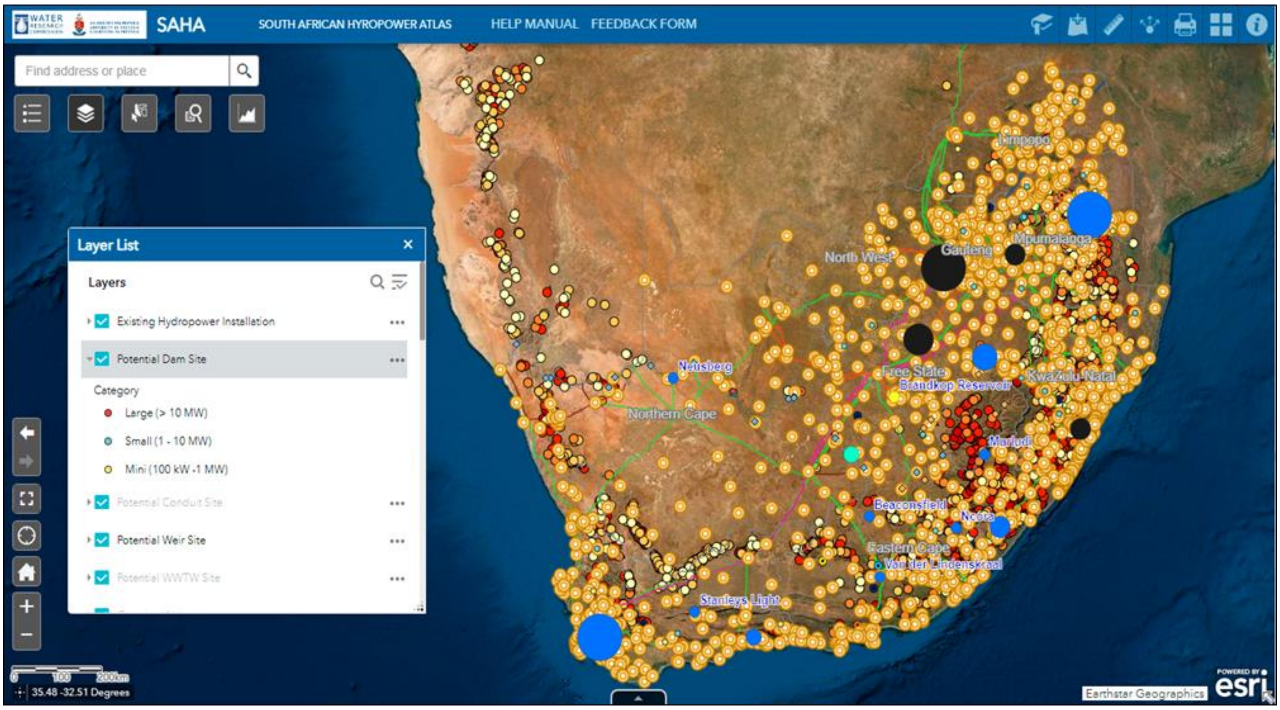


Figure 4-8: Existing and potential hydropower installations in South Africa

The hydropower that can be exploited in South Africa was subdivided into a number of types of hydropower and is estimated to be the following:

- Total conduit hydropower potential of approximately 83 MW from 919 assessed sites:
- Total run-of-river potential between 760 and 882 MW (1.04 MW/km determined in rivers with numerous specific assessed sites);
- Total hydropower of 1102 MW from 654 storage schemes;
- Total hydropower potential of 0.73-3.7 MW from 124 WWTWs;
- Total hydropower potential of 0.67-3.3 MW from 122 WTWs;
- Total hydropower potential of 10.6-50.3 MW from 424 gauging weirs; and
- Total pumped storage potential of approximately 31 000 MW (from overlapping sites).
- Total of more than 22 MW hydropower potential in the primary transfer schemes.

4.4 ASPECTS OF HYDROPOWER

4.4.1 Hydropower types

Hydropower, which utilises the flow of water from existing water infrastructure and rivers to generate electricity, is considered a good renewable energy source and an alternative to fossil fuels. The different locations where hydropower can be considered are illustrated in Figure 4-9.

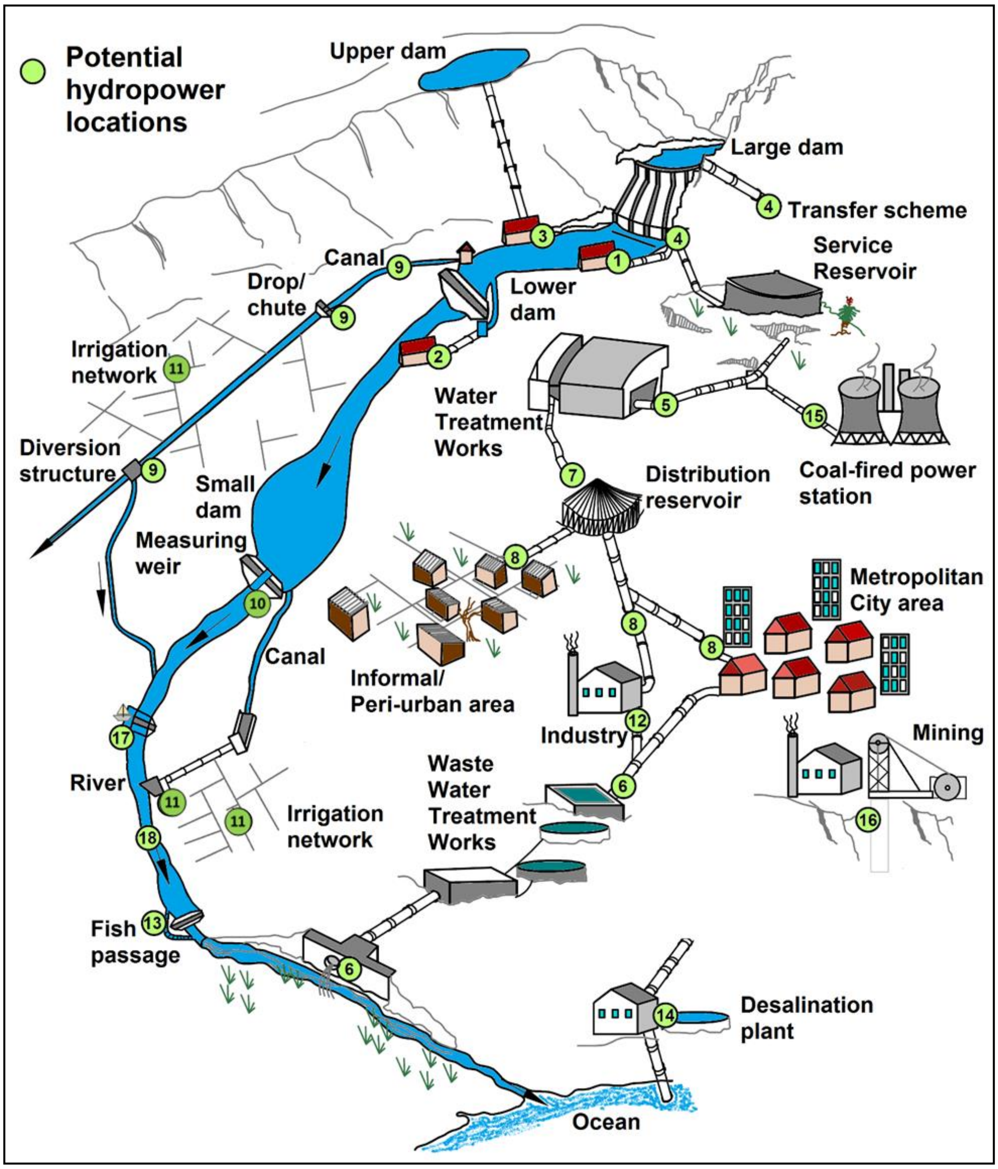


Figure 4-9: Locations of electricity generation potential (Adapted from Loots *et al.*, (2015))

4.4.1.1 Dams and Barrages

Large dams are usually associated with large environmental impacts and therefore only constructed for large-scale projects. There are, however, opportunities at existing dams and weirs where small hydropower schemes may be retrofitted to generate electricity to meet the base or peak electricity demands. Ideal locations to retrofit hydropower schemes are at dams designed for purposes like flood control, irrigation, recreation or water abstraction. It should be noted that there is a fixed number of existing dams and weirs which limits this form of hydropower (Loots et al., 2015). Additionally, regulating the river downstream of the dam allows for the possibility of hydrokinetic installations which in essence will then “re-use” the same water to generate additional energy (Egré and Milewski, 2002).

4.4.1.2 *Irrigation Systems*

Turbines can be installed in irrigation systems where electricity can be generated either through diversion structures or in canal systems as described in Table 4-3. Hydrokinetic energy in canal systems are typically high flow, low head installations (Loots et al., 2015).

Table 4-3: Potential hydropower locations in irrigation systems (Adapted from Loots, et al., (2015))

Structure Type	Description	Example
Diversion structures	Diversion structures are typically used in irrigations systems to canalise water from natural rivers into canals. These structures are ideal locations for low head hydropower to be generated for two main reasons; the infrastructure already exists which will result in a lower implementation cost and most diversions structures span across the entire river which will allow for all the flow to be utilised for energy generation.	
Concrete lined chutes and drop structures	Chutes are generally used to prevent erosion of in-situ material where water is transported down hills. Vertical drop structures, which can be used to house a turbine, are usually constructed where very steep gradients are present.	
Bridges	Pedestrian, vehicle or cattle bridges can in some cases provide opportunity for low head hydropower installations in irrigation channels. Easy installation at this location is ensured as the bridge can provide sufficient anchorage for the hydrokinetic turbine. The power produced at these types of locations are not dependent on the pressure head and flow, but rather on the velocity of the water and the area of the turbine.	
Flow gauging stations	Pico or micro hydropower opportunities can exist in flow measuring structures in irrigation channels if it can be ensured that the flow in the measuring structure is not influenced.	

Structure Type	Description	Example
Open lengths on irrigation channels	Water wheels or hydrokinetic turbines can be installed along open sections of concrete lined channels. It should, however, be noted that this location should only be considered for hydropower if there is a need to provide electricity at a location nearby. The factors that influence the feasibly of hydropower installations at this location include the flow volumes, flow velocity and reliability of flow.	

Large rivers with gentle gradients are often designed for low head installation, where high head usually occurs in small rivers with steep gradients. Furthermore, the power generated in hydrokinetic installations may vary considerably due to the annual and seasonal variation in flow in the rivers. Most hydrokinetic installations are, therefore, designed to provide a constant power output used for the base demand (Egré and Milewski, 2002).

Hydrokinetic turbines can be used to directly capture the kinetic energy from the velocity in flowing water. The physical principles of hydrokinetic turbines are similar to that of wind turbines, with the only difference being that water has 800 times the density of air, making water turbines more efficient even at lower current speeds.

4.4.1.3 Bulk Pipelines and Water Distribution Systems

Water distribution systems often have hidden potential for hydropower generation at Pressure Reducing Stations (PRS) where excess pressures can be utilised for energy generation instead of being dissipated. The utilisation of the excess pressures can be achieved by either replacing the pressure reducing valve (PRV) with a turbine or by installing a turbine in parallel with the existing PRV (Loots et al., 2015).

The advantages of conduit hydropower include the mitigation of vandalism and theft as all the necessary equipment and systems can be housed in the existing PRS. Therefore, conduit hydropower can be utilised on site to power flow and pressure control systems, telemetry or security systems. Servicing off-site energy demand clusters or a municipal grid could be another option of utilising the generated power (Loots et al., 2014). Another advantage of conduit hydropower is the use of the existing water infrastructure to generate power, which implies that if there is a demand hydropower can be generated. The use of the existing water infrastructure also reduces the environmental impact of the hydropower system (Loots et al., 2015).

Other locations for hydropower generation in a water distribution system include locations of high-pressure points or outlets of pipelines into canals or dams which could have potential for low head hydropower (Loots et al., 2015).

4.4.1.4 Water Transfer Schemes (WTS)

Water Transfer Schemes (WTS) play a major role in South African water supply by alleviating supply problems caused by the uneven distribution of rainfall and population. The infrastructure of WTS, which include pipelines, canals, diversion structures and measuring structures provide several opportunities for hydropower generation (Loots et al., 2015).

4.4.1.5 Measuring (Flow Gauging) Weirs

Flow gauging structure or weirs in many South African rivers provide opportunity of hydropower generation. There are, however, some challenges of generating hydropower at these types of location of which some challenges include installing a hydrokinetic turbine without affecting the measurement of the structure or preventing damage of the turbine during flooding of the river (Loots et al., 2015).

4.4.1.6 Wastewater Treatment Works (WWTW) and Industrial Flows

The high and constant flow of water that flows form wastewater treatment facilities makes hydropower installations at these sites feasible. Both the inlet to the works and the outflow provide hydropower generation opportunities. For hydropower generation at the inlet to the works it is recommended that a forebay with a trach rack is installed and that the hydropower plant is situated as close as possible to the treatment facility to ensure a maximum operational head. Usually the outlet of the wastewater treatment works is released into natural streams or channels which transports the water to the river system. The conveyance of the water through gravity allows additional energy to be extracted and harvested for hydropower generation (Loots et al., 2015).

It should, however, be noted that the risk of corrosion is increased for hydropower installations at WWTW as a result of the treated wastewater (Loots et al., 2015).

4.4.1.7 Water Treatment Works (WTW)

There is a potential for hydropower to be generated at WTW by utilising the excess pressure that would otherwise be dissipated before the water enter the treatment works. Furthermore, the potential for hydropower generation at the WTW is dependent on the feeding reservoir level. Incoming pipelines to many treatment works are pressurised which makes this type of hydropower similar to conduit hydropower as discussed before (Loots et al., 2015).

4.4.1.8 Run-of-river Low Head Hydropower

Run-of-river is a conventional type of hydropower where power is generated using a diversion structure, where either all or a portion of the water in the river flow through a turbine. Run-of-river schemes would usually operate with a low weir structure spanning across the river to ensure a constant head of water and the intake structure situated behind the weir. A channel or conduit would normally feed water to a forbay tank which is connected to a pressurised penstock (Loots et al., 2015).

Predicted flows are an important parameter in run-of-river installations and is especially necessary as these types of hydropower installations have no storage capacity. Flow data for a specific site can be obtained from government websites or if no other flow data is available flow information of nearby streams within the same catchment. The energy potential at the site is determined by compiling a flow-duration curve of the flows plotted against the percentage of time that the flow is exceeded (Loots et al., 2015).

4.4.1.9 Pumped Hydro Energy Storage (PHES)

A PHES scheme operates based on the principle of utilising the height difference between two bodies of water to store potential hydraulic energy. The energy stored by pumping water from a lower reservoir to the upper reservoir is recovered by releasing the stored water under gravity conditions through a turbine coupled with a generator (Fitzgerald et al., 2012).

Existing hydropower reservoirs can be transformed to PHES schemes with the addition of a penstock and an upper reservoir, if a suitable location exists.

4.4.2 Hydropower working principles

Conventional hydropower generation at storage schemes utilises the head available as well as the discharge from the dam. The equation used for to calculate the power output of hydropower schemes (Equation 4-1) describes the relationship between power output, flow through the turbine and the available pressure head.

$$\boldsymbol{P = \eta \rho g Q H} \qquad \textbf{(4-1)}$$

Where:
P = mechanical power output (W)
η = hydraulic efficiency of the turbine (%)
ρ = density of water (1000 kg/m^3)
g = gravitational acceleration (9.81 m/s^2)
H = effective pressure head across the turbine (m)
Q = discharge (m^3/s)

The amount of energy that hydrokinetic devices extract from flow flowing water is dependent on the kinetic energy or velocity of the water. According to (Kartezhnikova & Ravens, 2014) the power available from hydrokinetic devices per unit swept area is dependent on the efficiency of the turbine unit as well as the fluid density and flow velocity in the channel or river as shown in Equation 4-2.

$$PD=\xi\frac{\rho}{2}V^3 \tag{4-2}$$

Where:

PD	=	Power density (W/m^2)
ξ	=	Device efficiency (%)
ρ	=	Fluid density (kg/m^3)
V	=	Fluid velocity (m/s)

4.4.3 Advantages of hydropower

Retrofitted hydropower utilises existing infrastructure and harnesses the energy already available for electricity generation. The advantage of retrofitted hydropower is that no new infrastructure is required for energy generation (Van Vuuren et al., 2011). This explains the stamen by Pérez-Sánchez *et al.*, (2017) that hydropower plants are considered the most feasible renewable energy type, when being compared to solar, wind, tidal and photovoltaic energy types.

There are several benefits of using hydropower as a renewable energy source:

- Hydropower is a clean and renewable form of energy as it is generated by using the energy in the water due to the flow and the head without using the water itself (Frey & Linke, 2002);

- Hydropower does not result in any pollution (carbon dioxide, sulphurous oxides, nitrous oxides or ash), release of heat or toxic gasses (Frey & Linke, 2002);

- Hydropower has a low operation (as low as 1% of the initial investment due to high efficiency levels) and maintenance cost and is not subjected to inflation (Oud, 2002) (Loots, et al., 2014);

- Reliable and flexible operation is ensured with hydropower technology;

- Hydropower stations have a long operating lifetime (Frey & Linke, 2002); and

- Hydropower systems can easily respond to a change in load demand (Loots, et al., 2014) This flexibility in energy supply makes hydropower ideal for either base load or peak load generation (or in some cases both) (Egre & Milewski, 2002).

4.5 FEASIBILITY ASPECTS OF HYDROPOWER

4.5.1 Financial considerations

The economics of a small hydro development are crucial in determining overall project feasibility. In some ways, the technical feasibility of a project is more readily established than the financial viability.

The general financial considerations of a hydropower project are shown in Figure 4-10 and summarised in Table 4-4.

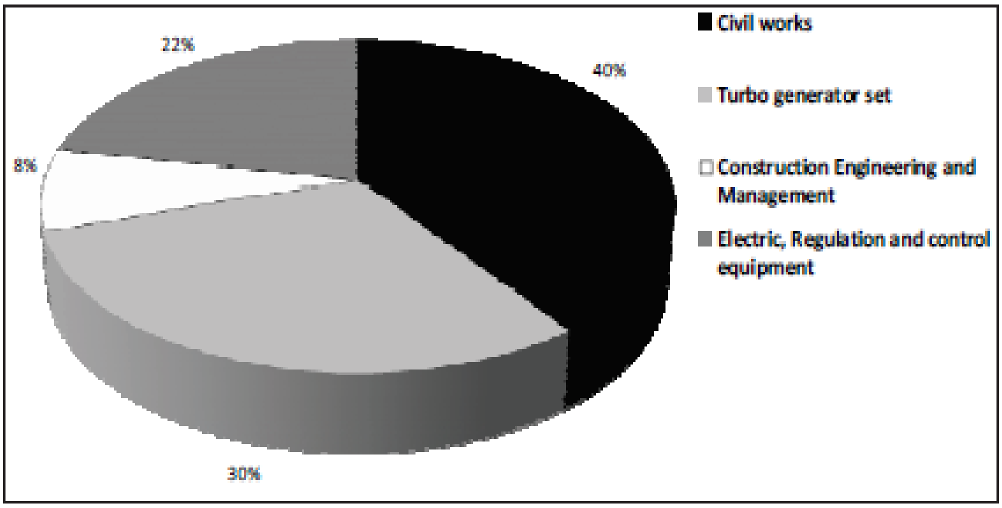


Figure 4-10: Cost contribution of different components in a hydropower project (Ogayar & Vidal, 2009)

Table 4-4: Summary of financial considerations of a hydropower project.

Financial consideration	Description
Legislative costs	Costs can be incurred when obtaining the dam-owner permission, water-use license and the generation license as described previously.
Environmental and social cost	The environmental and social costs is usually incurred as a result of necessary studies conducted to determine the environmental impacts of the project.
Electromechanical equipment costs	The cost contribution of the different components of a hydropower is illustrated in Figure 4-10. As shown in the figure, the turbine cost can contribute approximately 30% to 40% of the project cost whereas the generator contributes only 5% of the total project cost.
Civil works cost	The cost of the civil works is determined as a function of the available head and the installed generation capacity in kW. Furthermore, the civil works contribute approximately 40% of the total cost of a small hydropower plant. And consists of the intake, penstock, powerhouse building and tail-race channel.

Financial consideration	Description
Operation and maintenance costs	The annual operation and maintenance cost are usually calculated as 0.25% of cost of works for the civil works component, 2% of cost of works for the mechanical works component and 4% of the cost of works for the electrical works component.
Design fees	The design fees entail the percentage of costs paid to engineering consultants for the project design. The total value allocated to design services should be a sum of the civil, structural, electrical and mechanical components.
Tariffs	Hydropower development has faced difficulty to be feasible when it needed to be grid connected. Although the average Mega-flex tariff is approximately R1.25 /kWh the typical wheeling costs is are about 30% of this. Furthermore if the small hydropower development is far from the grid then the capital costs required to interconnect results in an unviable scheme.

4.5.2 Environmental and social aspects

Every construction project that takes place in South Africa is subject to environmental regulations under the National Environmental Management Act of 1998. According to the act, plans for the construction of facilities or infrastructure for the generation of electricity which have a capacity of 20 MW or more or cover an area greater than one hectare, require the completion of an Environmental Impact Assessment (EIA) and are subject to regulations under the environmental authority of the province. If, however, the plant does not exceed the aforementioned limitations, only a Basic Assessment Report (BAR) is required.

A thorough review of potential impacts of retrofitted hydropower on the environment identified the following basic areas of consideration:

- The actual use of land and the impact of construction processes;
- The impacts of river diversion, both temporary and permanent on the downstream channel characteristics;
- Type of power that will be generated and hence the type of releases that are required;
- The impact on aquatic fauna and flora;
- Increased noise levels occurring during the construction and operational phases;
- Visual impacts of the final product after construction; and
- The impact on residents in the area by altering the flow of water they receive, destroying land they deem culturally significant, or altering the natural habitat in a way they find unacceptable.

Conduit hydropower has in most cases an insignificant influence on the environment as it is typically installed at already transformed environments.

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

Additionally, the interest of the affected parties plays a major role in the environmental assessment phase of any hydropower project. The increased development of large-scale hydropower projects, especially in developing countries, has led to an increased importance of stakeholder engagement (Klimpt *et al.*, 2002). General areas of consideration of hydropower development are (Van Vuuren et al., 2014):

- The cultural heritage of the site;
- Impacts of hydropower development on downstream agricultural activities;
- Balance between natural resource conservation and satisfying human needs;
- Community and affected parties to become project beneficiaries to ensure public acceptance of and public protection over project; and
- Changes in water quality or downstream flow regimes being a potential public health threat.

4.6 REGULATORY AND LEGISLATIVE ASPECTS OF HYDROPOWER

This section of the report focuses on the regulatory requirements applicable to generators of electricity from predominantly pico-, micro- or mini hydropower installations with a generating capacity between 10 kW and 1 MW, for islanded use, own use or for interconnection with a municipal electricity distribution network.

Where:

- **Generator:** “Means a person who generates electricity by any means” (South Africa, 2006).
- **Pico-, micro and mini hydropower installations**: pico-: up to 20 kW; micro: 20 kW to 100 kW and mini: 100 kW to 1 MW.
- **Water distribution network**: This would include distribution reservoirs and distribution (or connector) pipelines, as well as bulk treated water storage reservoirs and bulk pipelines, providing for excessive gravity or pumping pressure (DBSA, 2011).
- **Islanded use**: Electricity generated for “islanded use” is completely independent of municipal or Eskom distribution networks (South Africa, 2006).

- **Own use:** “in the context of a generation facility means a facility that generates electricity that is used only by the operator or owner of that facility and is not sold to any person and is not transmitted through a transmission power system 1 or distributed through an interconnected distribution power system.2" (South Africa, 2011).
- **Electricity distribution network:** or distribution power system “means a power system that operates at or below 132 kV.” (South Africa, 2006).

Numerous regulatory and legislative requirements govern the implementation of small-scale hydropower schemes in South Africa. Pertinent legislation that needs to be adhered to includes the Constitution of the Republic of South Africa, the Electricity Regulation Act (ERA), the National Water Act (NWA) and the National Environmental Management Act (NEMA). These Acts set out the roles and responsibilities, of National- and Local Government in the electricity sector, as well as distinguishing between the powers and functions of District- and Local Municipalities and services authorities and services providers.

The following sections will summarise the major aspects of considerations being:

1. Electricity generation licencing
2. Water use authorisation
3. Environmental authorization
4. Land use

4.6.1 Electricity generation licencing

The following form the South African electricity sector (Van Vuuren, et al., 2014):

The National Energy Regulator of South Africa (NERSA): NERSA is a regulatory authority established under the National Energy Regulator Act (Act 40 of 2004). NERSA regulates the Electricity, Piped-Gas and Petroleum industries as per the relevant acts. The Electricity Regulation Act as amended, describes, the responsibilities and powers of NERSA, specifically in regard to the processing and issuing of electricity generation-, transmission- and distribution licences.

Department of Energy (DoE): The mandate of the DoE is to ensure secure and sustainable provision of energy for socio-economic development, by formulating energy policies, regulatory frameworks and legislation and overseeing their implementation to ensure energy security, promotion of environmentally-friendly energy carriers and access to affordable and reliable energy for all South Africans. This implies that the DoE is responsible for the development of laws and regulations which govern, direct and guide the sector towards common objectives:

- Policies (e.g. the White Paper on the Energy Policy and the White Paper on Renewable Energy),
- Legislation (e.g. the Electricity Regulation Act),
- Regulations (e.g. the electricity regulations on new generation capacity) and
- Plans (e.g. the Integrated Energy Plan, the Integrated Resource Plan and the Integrated National Electrification Plan)

i. **Eskom Holdings Limited**: ESKOM is a public company and a state-owned enterprise in terms of the Public Finance Management Act that owns and operates the National Electricity Grid. Eskom generates, transmits and distributes electricity to all sectors of South Africa's economy.

ii. **Independent Power Producers (IPPs):** IPP means any person in which the Government or any organ of state does not hold a controlling ownership interest (whether direct or indirect), which undertakes, or intends to undertake the development of New Generation Capacity pursuant to a determination made by the Minister to section 34(1) of the ERA (DoE, 2011).

iii. **Electricity Services Authority and Electricity Services Provider Distribution Supply Authority and Electricity Distribution Utility or Electricity Distributor):** The Municipal Systems Act establishes municipalities as services authorities and introduces an option for the municipality to either provide municipal services themselves, or to appoint appropriate service providers to undertake those municipal services on their behalf, through a service delivery agreement between the municipality and the service provider. This Act therefore, introduces the concepts of services authority and services provider. (South Africa, 2000).

For small-scale hydropower installations, the purpose of electricity generation and the end use of the power governs the process which must be followed. Generated electricity can be used for islanded use (completely independent network), own use (electricity that is used by the operator or owner of the facility and is not sold) or connected to the municipal network (DoE, 2012). For the purpose of the study only electricity used for "own-use" by the municipality is considered. The legislation currently exempts "own use" electricity generators from requiring a NERSA generation licence if the generation capacity is less than 1 MW (Electricity Regulation second amendment Bill).

In cases of interconnection with the Municipal distribution network, which is defined as an "Embedded Generator" (EG) also defined as "*a legal entity that operates a generating plant that is or will be connected to the Distribution Network*" (Eskom, 2011) the following is true:

- For size 10 kW-100 kW: EG systems installed on the host side do not require an electricity generation licence. The EG must be logged and reported to NERSA.
- For side 100 kW-1 MW or more: EG must apply for an electricity generation licence with NERSA.

Additional opportunities are available to certain parties. Water Service Authority's (WSAs), Water Boards (WBs) and Water User Associations (WUAs) have the opportunity to wheel electricity through the Eskom grid to a municipal network to be purchased by the municipalities (provided generators have the appropriate licences to generate and trade from NERSA). The private sector generation also has multiple benefits through the Independent Power Producer (IPP) Procurement Program listed in the Integrated Resource Plan (IRP) (Van Vuuren, et al., 2014).

Considering the municipality itself as an electricity supplier the South African Constitution, Act No. 108 of 1996 states the distribution of electricity to consumers in a specified municipal area of jurisdiction is a municipal function (South Africa, 1996). Except where electricity generation is incidental to the local government function municipalities have no 'original competence' to do so. A municipality can however receive competence to generate electricity through a parliamentary executive delegation or legislative assignment (Scharfetter & Van Dijk, 2017)

4.6.2 Water use authorization

Important considerations must be given to the following water sector entities prior to small HK installation. Permission from the relevant entities must be obtained prior to the use of water infrastructure. These include (Van Vuuren, et al., 2014):

- **Department of Water and Sanitation (DWS):** The DWS is the custodian of all surface and ground water resources. It is primarily responsible for the formulation and implementation of policies governing the water sector. It also has oversight responsibility for water services provided by local government. The DWS owns waterworks infrastructure throughout the country which could be retrofitted appropriately with hydropower technology.

- **Water Services Authorities (WSAs):** In South Africa, electricity distributors may be Eskom, or the municipal electricity service provider (SABS, 2010), either in their capacity as DoE's Implementing Agents on the Integrated National Electrification Programme. Confusion exists the electricity sector as to which municipalities have electricity services authority status; this due to the fact that a process to allocate authority status to either local Municipalities (LMs) or district Municipalities (DMs) was not initiated due to the anticipation that the electricity supply industry would be restructured. WSAs have the constitutional responsibility for ensuring access, planning and regulating provision of water services within their area of jurisdiction.

They may provide water services themselves and/or contract external Water Services Providers (WSPs) to undertake the provision function on their behalf.

- **State owned regional water service providers (WSP's):** WSPs are the organisations that assume operational responsibility for providing water and/or sanitation services (DWAF, 2003).

- **The Water Board (WBs):** WBs are state-owned WSPs providing both bulk services to more than one WSA and retail services on behalf of a WSA. Water Boards typically operate extensive water infrastructure, primarily bulk potable water supply or wastewater systems.

- **Water User Associations (WUA) (former Irrigation Boards):** A WUA is a statutory body established by the Minister of DWS. It is a grouping of water users who wish to work together because of a common interest. The water users 'co-operate' in undertaking water-related activities at the local level for their mutual benefit. The main function of a WUA is to ensure fair and reliable water supply to its members, who are mostly irrigation or livestock farmers.

Other entities of importance may include:

- Regional and local WSP's
- Municipal Water Services Entities (WSE)
- Public Water Utilities (WU)
- Private Water Services Companies

4.6.3 Land use

For all applications (e.g. Electricity generation licence, water use authorization) it must be shown the permission of the landowner has been attained. It is important to know who owns the property (title deeds) and which land use rights the owner is subject to. Where possible construction of civil works may be required, authorization must be obtained.

4.6.4 Environmental authorization

An Environmental Authorization may be required by the NEMA, however based on the electricity and distribution activity listings of GN983 and GN984 it is likely that neither an Environmental Impact Assessment (EIA) nor Basic Assessment (BA) may be required. A general authorization will be required for the construction of the electricity generation and distribution components of a small-scale hydropower plant. Depending on the scope of work a BA may possibly be required (Scharfetter & Van Dijk, 2017).

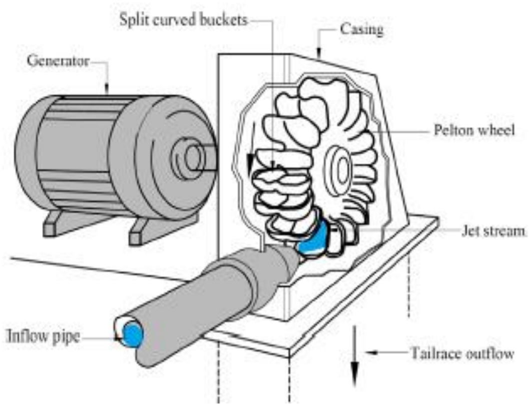
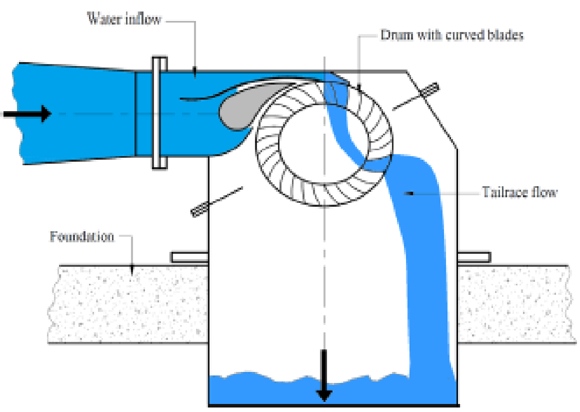
The Department of Environmental Affairs (DEA) is mandated with formulating, coordinating and monitoring the implementation of national environmental policy programmes and legislation. It is also responsible for the protection and conservation of natural resources and for balanced sustainable development through equitable distribution of benefits derived from natural resources.

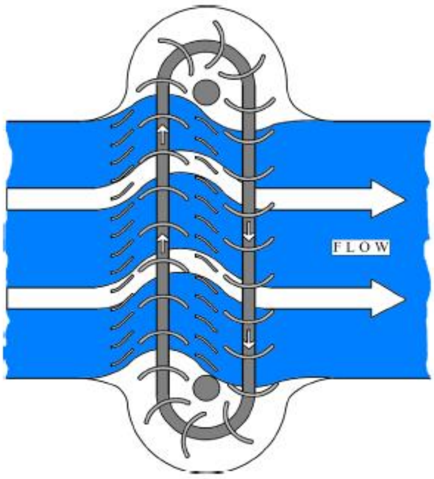
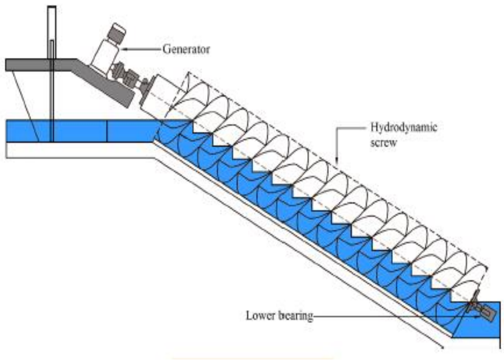
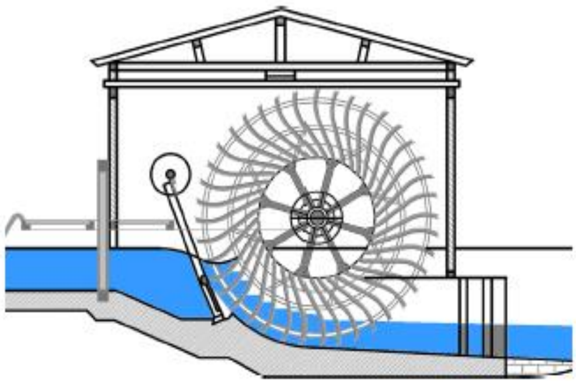
4.7 HYDROPOWER COMPONENTS

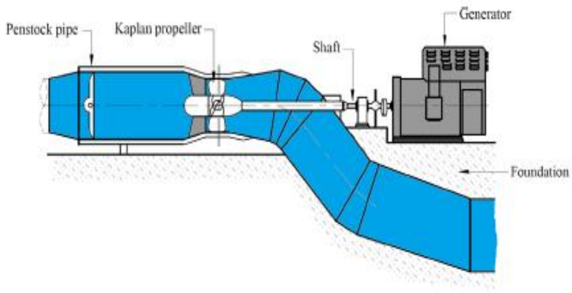
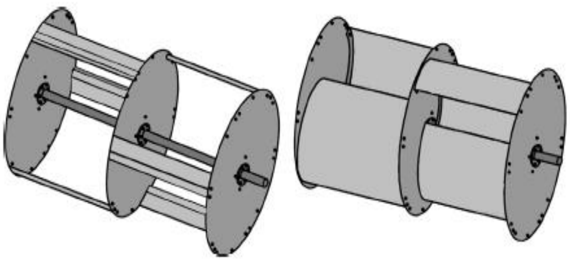
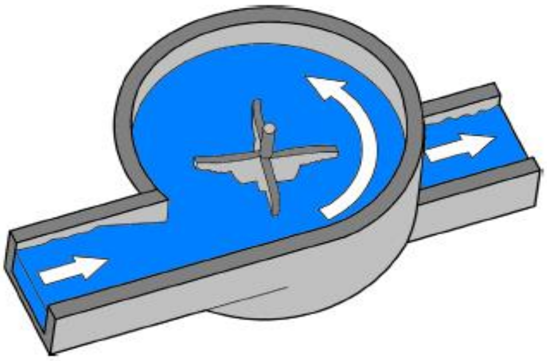
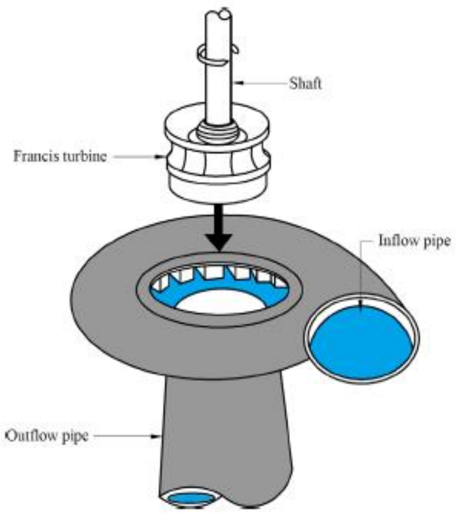
4.7.1 Turbines

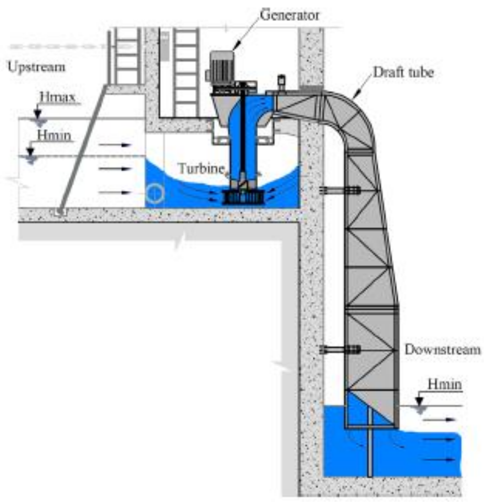
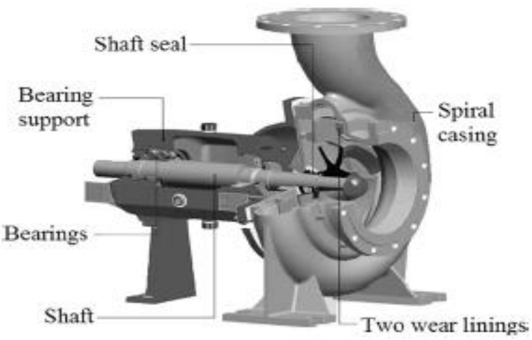
The function the turbine entails converting energy from water into rotational energy. Turbines can be classified as either impulse turbines (runners are used that operated in air by the action of a jet of water at high velocities) or reaction type turbines (upward hydrodynamic forces are generated and used to turn the runner blades by utilising oncoming flow). For high head applications, the appropriate choice would be to use impulse runner type turbines and ration runner type turbines for lower head applications. There are, however, exceptions to this rule. A brief description of each type of turbine is provided in Table 4-5.

Table 4-5: Hydropower turbines (Adapted from Loots *et al.*, (2015))

Turbine Type		Description
Pelton turbine		Pelton type turbines operate on the principle of directing a water jet onto a runner with split buckets, with the water force on the buckets creating a rotation this resulting in torque on its shaft. The water is released into the tailrace with almost no energy remaining in the water. The Pelton turbine is ideally used for high head applications, but there are some exceptions.
Crossflow turbine		Crossflow turbines are generally constructed with two disks joined together with inclined plates. Water enters the turbine, hits the blades twice and is released to atmospheric pressure with very little energy left in the water Crossflow turbines are ideal for installations where flow variation is a problem as the efficiency does not drop significantly with a change in flow.

Turbine Type		Description
HydroEngines		HydroEngine turbines are typically constructed with two shafts connected to blades moving in an elliptical path with power transfer in the linear motion portion of the blade travel. Furthermore, guide vanes are used to direct the water to the first and subsequently the second set of blades. The installation conditions of HydroEngines are similar to that of Kaplan turbines with the exception being that no preventative measures are required to avoid cavitation with the HydroEngine turbine. The turbine can be installed anywhere between the tailwater and headwater elevation, making the civil works required for this type of installation less complicated.
Hydrodynamic screw type turbines		The principle of screw-type turbines is based on an Archimedes screw pump that operate in reverse and utilises the hydrostatic pressure difference across the blades. These types of turbines are typically used for low head and high flow applications. The advantage of using a screw-type turbine is that it is more cost effective than some of the other turbines available (22% cheaper than the equivalent Kaplan turbine). These turbines are also considered to be less harmful to aquatic life.
Water wheels		The traditional method of generating hydropower using water wheels are less efficient than using turbines, but the simplicity regarding the control, construction and maintenance of water wheels can in some cases make it a practical option. Three types of waterwheels exist, with each type having its own application. The three types are the Undershot wheel, Breastshot wheel and the Overshot wheel.

Turbine Type		Description
Kaplan, bulb and propeller turbines		Kaplan, bulb and propeller turbines use the axial flow of water to create hydrodynamic forces that rotate the runner blades. Kaplan turbines are completely submerged (unlike impulse turbines) and make use of guide vanes upstream of the turbine to ensure better efficiency.
Hydrokinetic turbines		Hydrokinetic turbines utilised the kinetic energy of flowing water in low head applications to generate energy instead of the potential energy due to the hydraulic head. The Darrieus and Open Savonius rotors (placed either horizontally or vertically) are the tow rotors most commonly used in hydrokinetic applications.
Vortex turbine		Vortex turbines are used to generate energy using a low hydraulic head. The water passes through a straight inlet into the round basin where a large vortex is formed over the centre bottom drain of the basin. Electrical energy is generated when the turbine extents the rotational energy from the vortex which is then converted to electrical energy by means of a generator.
Francis turbine		A Francis turbine forces the water to flow radially inwards to into the runner and turned to exit the outlet in an axial direction.

Turbine Type		Description
Siphon turbine		The Siphon turbines have blades similar to the Kaplan turbine which are connected to a turbine shaft that turns a generator. The turbine acts as an electromotor pumping the water into the siphon for the first 30 to 60 seconds to prime the siphon, where after it starts functioning as a generator.
Inline turbines		Inline turbines include spherical and ring turbines and are installed directly in a pressurized conduit as there is no need for these types of turbines to be installed in the bypass. Inline-type turbines can be installed for both pico- and micro-hydropower applications.
Pump-as-turbine (PAT)		PATs operate on the principle where centrifugal pumps are placed in reverse to act as a turbine. PATs are an attractive turbine alternative, especially in developing countries, as pumps are mass-produced and therefore more readily available. Even though PATs are generally a more cost-effective turbine alternative, the low efficiencies of a PAT (especially at partial flows) can in some instances make PATs seem less attractive.

Turbine design, which includes the sizing, layout of the turbine, housing and in some cases the electrical components, does not fall within the engineer's scope of work on a hydropower project and the manufacturer will in most cases be consulted regarding this.

4.7.2 Electrical components and control systems

The components that make up the electro-mechanical equipment in a power house includes inlet gate or valve, turbine, speed increaser (if needed), generator, control system, condenser, switchgear, protection systems, DC emergency supply, power and current transformers, etc.

In electricity generation, an electric generator is a device that converts mechanical energy to electrical energy. A generator forces electric current to flow through an external circuit. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, a wind turbine, or any other source of mechanical energy.

Turbines are coupled to generators in a hydropower scheme in order to transform the mechanical energy produced by the turbine into electrical energy. There are two main types of generator, synchronous or asynchronous, that are used depending on what is required in terms of network characteristics. Both types of generators are being constantly improved and the newest ones have efficiencies of almost 100% (Bakis, 2007).

4.7.2.1 Generator

Generators transform mechanical energy into electrical energy. Generators are nowadays usually three-phase alternating current generators used in normal practice. Depending on the characteristics of the network supplied, the generator can either be a synchronous or asynchronous unit (ESHA, 2004):

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

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

Synchronous generators are more expensive (for pico, micro and mini installations) than asynchronous generators and are used in power systems where the output of the generator represents a substantial proportion of the power system load. Asynchronous generators are cheaper and are used in stable grids where their output is an insignificant proportion of the power system load.

Recently, variable-speed constant-frequency systems (VSG), in which turbine speed is permitted to fluctuate widely, while the voltage and frequency are kept constant and undistorted, have become available. The frequency converter, which is used to connect the generator via a DC link to the grid can even "synchronise" to the grid before the generator starts rotating. This approach is often proposed as a means of improving performance and reducing cost especially when the head varies significantly.

4.7.2.2 Principle of Operation

The principle of operation of generators and motors is quite simple: when a wire is moved past a magnet so as to cut through the magnetic field, a voltage is induced in the wire. Three components are necessary: motion, magnetism, and a wire. In generators, alternators and motors, either the wires are moved through the magnetic field, or the magnetic field is moved through the conductors. A.C. generators (sometimes referred to as alternators) produce a varying voltage which alternates above and below to zero voltage points. In effect, the current oscillates back and forth in the electrical circuit in response to the driving voltage. Three phase currents consist of three overlapping single phase voltages displaced 120° from each other.

4.7.2.3 Voltage regulation and synchronisation

An <u>asynchronous generator</u> needs to absorb reactive power from the three-phase mains supply to ensure its magnetisation is even. The mains supply defines the frequency of the stator rotating flux and hence the synchronous speed above which the rotor shaft must be driven.

On start-up, the turbine is accelerated to a speed slightly above the synchronous speed of the generator, when a velocity relay closes the main line switch. From this hyper-synchronised state the generator speed will be reduced to synchronous speed by feeding current into the grid. Speed deviations from synchronous speed will generate a driving or resisting torque that balances in the area of stable operation.

The <u>synchronous generator</u> is started before connecting it to the mains by the turbine rotation. By gradually accelerating the turbine, the generator must be synchronised with the mains, regulating the voltage, frequency, phase angle and rotating sense. When all these values are controlled correctly, the generator can be switched to the grid. In the case of an isolated or off grid operation, the voltage controller maintains a predefined constant voltage, independent of the load. In case of the mains supply, the controller maintains the predefined power factor or reactive power.

A voltage regulator is designed to automatically maintain a constant voltage level. Depending on the design, it may be used to regulate one or more AC or DC voltages.

Electronic voltage regulators are found hydro power station generator plants where they regulate the output of the plant. In an electric power distribution system, voltage regulators may be installed at a substation or along distribution lines so that all customers receive steady voltage independent of how much power is drawn from the line.

Electronic voltage regulators: A simple voltage regulator can be made from a resistor in series with a diode (or series of diodes). Feedback voltage regulators operate by comparing the actual output voltage to some fixed reference voltage. Any difference is amplified and used to control the regulation element in such a way as to reduce the voltage error. This forms a negative feedback control loop; increasing the open-loop gain tends to increase regulation accuracy but reduce stability (stability is avoidance of oscillation during step changes).

Electromechanical regulators: In electromechanical regulators, voltage regulation is easily accomplished by coiling the sensing wire to make an electromagnet. The magnetic field produced by the current attracts a moving ferrous core held back under spring tension or gravitational pull. As voltage increases, so does the current, strengthening the magnetic field produced by the coil and pulling the core towards the field. The magnet is physically connected to a mechanical power switch, which opens as the magnet moves into the field. As voltage decreases, so does the current, releasing spring tension or the weight of the core and causing it to retract. This closes the switch and allows the power to flow once more. The regulators used for DC generators (but not alternators) also disconnect the generator when it was not producing electricity, thereby preventing the battery from discharging back into the generator and attempting to run it as a motor. The rectifier diodes in an alternator automatically perform this function so that a specific relay is not required; this appreciably simplified the regulator design. More modern designs now use solid state technology (transistors) to perform the same function that the relays perform in electromechanical regulators.

Speed: All generators must be driven at constant speed to produce a constant 50 Hz frequency (in South Africa). The speed measured in revolutions per minute (rpm) is determined by the number of poles in the generator. The 2-pole speed of 2900 rpm is too high for practical small hydro use. 1450 rpm is most commonly used, with 760 rpm second. The cost of generators is more or less inversely proportional to speed: the lower the speed, the larger the frame size must be for equivalent output. For this reason, speeds below 760 rpm become costly, but occasionally circumstances will justify their use. Where low speed low head turbines are involved, gear boxes are often used to raise the speed. There is a trade-off between the speed ratio, cost of the gear box, and cost of the generator.

4.7.2.4 Turbine controllers

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.

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.

4.7.2.5 Switchgear equipment

In many countries the electricity supply regulations place a statutory obligation on the electric utilities to maintain the safety and quality of electricity supply within defined limits. The independent producer must operate his plant in such a way that the utility is able to fulfil its obligations. Therefore various associated electrical devices are required inside the powerhouse for the safety and protection of the equipment.

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer. The generator control equipment is used to control the generator voltage, power factor and circuit breakers.

4.7.2.6 Controllers and electrical equipment

Turbine design and selection is based on the premise that operating conditions will be within the turbine's capacity in terms of flow and head. If one of the design parameters changes, it will be necessary to regulate the conditions using devices such as gates, guide vanes, nozzles and valves.

Small hydropower schemes often make use of automated control systems which have three significant advantages in that they can decrease maintenance costs, increase reliability and increase turbine efficiency. The general requirements for the automated control include (ESHA, 2004):

- The system must include the necessary relays and devices to detect malfunctioning of a serious nature and then act to bring the unit or the entire plant to a safe de-energised condition.
- Relevant operational data of the plant should be collected and made readily available for making operating decisions, and stored in a database for later evaluation of plant performance.
- An intelligent control system should be included to allow for full plant operation in an unattended environment.
- It must be possible to access the control system from a remote location and override any automatic decisions.
- The system should be able to communicate with similar units, up and downstream, for the purpose of optimising operating procedures.
- Fault anticipation constitutes an enhancement to the control system. Using an expert system, fed with baseline operational data, it is possible to anticipate faults before they occur and take corrective action so that the fault does not occur.

Various other electrical components are necessary, including a plant service transformer; backup power supply; sensors for the measurement of head and tail water levels; and an outdoor substation (ESHA, 2004).

Transmission lines transfer the generated power from the plant to where the demand for electricity exists. If it is possible to connect to the grid at a location very close to the transmission lines, then this will be a minor consideration. If, however, the site is more remote, the significance of transmission lines can greatly increase. The cost of transmission lines vary with distance, terrain and voltage requirements.

4.7.3 Civil works

The type and layout of the hydropower scheme, local conditions and accessibility to construction material determine the structures required during the hydropower development process. A summary of the civil compounds that are normally found in a hydropower project is provided in Table 4-6.

Table 4-6: Summary of civil works involved in hydropower development (adapted from (Van Vuuren et al., 2011; Van Vuuren et al., 2014))

Component	Description
Dam barrages or weirs	Dams, barrages or weirs are used to store and divert flow into the conveyance system and therefore to the turbine. Dams also ensure additional storage capacity and head. Dams can be constructed from a number of different materials and in a number of different forms. Site topography, environmental considerations, dam safety and budgetary constraints will be the main aspects to consider during dam design. Dams are associated with significant environmental impacts and are normally only constructed for large-scale projects, as dam construction makes small schemes economically unfeasible (ESHA, 2004).
Housing structure	Protection of the electromechanical equipment, generator, turbine, the control and protection system and the transformer are achieved by constructing a turbine-housing structure to house all the aforementioned components. The size and the layout of the components housed by the turbine-housing structure, the available head and the geomorphological conditions on site will determine the size of the housing structure. Factors to be considered in the design of the structure include, cavitation, location, potential flooding, geotechnical conditions, buoyance forces, water forces due to water striking the turbine and the layout of the components as mentioned previously.
Intake structures	The water from the dam or reservoir is conveyed to the powerhouse and turbines via an intake structure. The design of the intake structure should ensure that the head losses, cost, operation and maintenance requirements as well as the negative environmental impacts are minimised as much as possible. This can be achieved by taking into consideration the hydraulic and structural aspects as well as operational aspects such as the design flow rate which will be specific to each project.
Outlet structure	The outlet structure, which in most cases involves the design of a channel, transports the water that has been fed through the turbine back to the river. An outlet structure will not be required if the powerhouse is situated close to the river as direct transfer will be possible. For the case where high exit velocities are expected, it is recommended to minimise erosion by constructing a tailrace or canal structure. The tailrace or canal structure will also ensure that the neither the operation of the turbine runner nor the stability of the powerhouse is affected.

4.8 HYDROPOWER POTENTIAL EVALUATION METHODS

Case studies were conducted in the evaluation methods used around the world to evaluate hydropower potential at different locations. The evaluated case studies are summarised in Table 4-7.

Table 4-7: Hydropower evaluation methods for different hydropower types

Hydropower type	Source	Description of study
Run-of-river	Gergel'ová *et al.*, (2013)	A GIS based approached was followed using the study conducted by (Monk et al., 2009), as a guideline to identify new SHP sites in the Hornád basin, Slovakia.
	Arriagada *et al.*, (2019)	The study assessed the relationships between hydropower potential and large-scale climate change variability and entailed the calculation of historical hydropower potential at every 1 km, using SRTM DEMs and patched daily flow records. The flow record patching consisted of using flow records with a record length of at least 10 years and applying a non-parametric random forest (RF) method to produce a complete data set for the basin. The data patching method was found particularly useful as the study was conducted in a data-scarce region.
	Alterach *et al.*, (2009)	The study describes a methodological approach which involves identifying potential hydropower sites to map the maximum and residual hydropower potential of Italy and applying the methodology to a case study in the Basilicata region, Italy. Furthermore, the approach to calculate flow involved using the usable flow by subtracting the average discharge and 10% of the mean hydrological river discharge (which represents the minimum instream flow) from the natural river flow.
	Ehrbar *et al.*, (2018)	A framework was proposed for the systematic analysis of hydropower potential in the Swiss Alps. The proposed framework contains an evaluation framework with 16 environmental, social and economic criteria that dictates the total points awarded to each site. The point system, with the maximum weight of each criterion, is described in detail and considers factors such as installed capacity, investment cost and land use during the analysis. Apart from run-of-river schemes, the potential for storage schemes and pumped storage schemes are also considered.
	Fujii *et al.*, (2017)	The study conducted entailed the hydropower potential evaluation of six rivers in the Beppu City, Japan. Three different methods (GIS based estimation, H-Q curve-based estimation and discharge estimation from directly measured current velocity) were used to quantify the discharge at a point 500 m from the river mouth for

Hydropower type	Source	Description of study
		each site. The reliability of the three methods to estimate the discharge for hydropower potential quantifications was discussed.
	Hidayah *et al.*, (2017)	The study proposed and implemented a methodology to identify possible run-of-river hydropower sites by utilising GIS to obtain the head available and HEC-HMS to generate long term discharge for the selected rivers based on available rainfall and discharge data.
	Hoes *et al.*, (2017)	A study was conducted to assess the global run-of-river potential, thereby producing a map of the gross hydropower potential distribution of the world. Only rivers with a head of at least 1 m over approximately 220 m and a discharge of at least 100 l/s were selected at suitable hydropower locations.
	Korkovelos *et al.*, (2018)	The study entailed the technical assessment and mapping of small-scale hydropower potential of river networks spanning across 44 countries in sub-Saharan Africa. The methodology of the study entailed using global annual mean runoff data (obtained from Global Streamflow Characteristics Dataset) combined with GIS datasets (DEMs) to quantify the parameters necessary for hydropower evaluation. Exclusion zones were applied to consider possible environmental and social constraints during the identification of potential sites.
	Ballance *et al.*, (2000)	The study entailed the initial assessment of hydropower potential in South African rivers, calculated from digital maps of slope and runoff. Height differences were analysed between 400 m intervals, using GIS techniques, thereby producing a slope map of South Africa. Mean Annual Flow Volumes (MAFV) for each cell within the 400 by 400 m cell map of South Africa were then obtained by multiplying the cell area with the Mean Annual Runoff (MAR). Lastly, hydropower potential was evaluated at every 1 000 m interval.
	Kusre *et al.*, (2010)	The study entails the assessment of a river basin in Assam, India for hydropower potential using GIS combined with a SWAT2000 hydrological model. The following criteria were used to assist with the identification of potential sites: Minimum distance between two consecutive hydropower sites is 500 m; the potential hydropower site should have a head of at least 10 m and the average gradient along the bottom of the stream should be 1:50 or 2% or more for the selected sites.
	Rojanamon *et al.*, (2009)	The study proposed a methodology to alleviate the problems that are consistent with hydropower evaluation of sites located in remote and/or rural areas (e.g. availability of data). The engineering analysis included in the methodology (apart from the economic, environmental and social analysis) recommended using conventional and regional flow duration models were used

Hydropower type	Source	Description of study
		to estimate flow duration curve based on stream gauges within approximately 2000 km^2 of the specific site. Maximum design flow = Q_{30} (flow value at 30% exceedance probability) on flow duration hydrograph was specified and the maximum distance over which head difference can accumulate is 5 000 km. Lastly, only the sites with an installed capacity of 1-10 MW should be considered.
	Moldoveanu *et al.*, (2017)	The study describes the evaluation of hydropower potential in rivers using the Italian designed hydropower assessment software, Vapidro-Aste. The input parameters required for a hydropower assessment are a digital terrain model, hydrological data and technical data as well as economic and financial data. Furthermore, the tool and methodology was implemented to identify 22 kW potential a section of the Topolog River, Romania.
	Monk *et al.*, (2009)	The development of the run-of-river identification tool, rapid hydropower assessment model (RHAM), which was used to identify over 8 000 hydropower sites in British Columbia, Canada, is briefly described in the paper. Discharge was estimated using GIS (to calculate the drainage area) combined with a runoff surface. The head was calculated in 500 m increments from 500 m to 5 000 m using the appropriate GIS functions. Lastly, the tool only considered sites with a mean annul discharge between 0.1 m^3/s and 200 m^3/s, a head between 30 m and 1 000 m and finally a potential power output greater than 500 kW as technically feasible.
	Sammartano *et al.*, (2019)	The study describes the methodology followed to identify potential run-of-river sites in the Taw at Umberleigh basin, South West England using GIS and the Soil Water Assessment Tool for the hydrological analysis. Furthermore, the river flows at 50% and 70% exceedance probability (obtained from the flow duration curve) were used in the hydropower analysis.
	Popescu *et al.*, (2012)	The study entails the evaluation of hydropower potential in the La Plata Basin, South America using the Vapidro-Aste evaluation tool.
	Reichl and Hack, (2017)	The study describes the estimation of flow for ungauged rivers using a modified lumped rainfall-runoff method to calculate the flow duration curve. The method described in the study provided results with moderate accuracy for small catchments were snowmelt is not a factor.
Hydrokinetic	Niebuhr *et al.*, (2019)	The study describes the identification of hydrokinetic potential (using available data) in municipal irrigation infrastructure as well as the design and implementation of South Africa's first hydrokinetic plant.
Pumped storage	Fitzgerald *et al.*, (2012)	The study proposed a model to calculate the theoretical potential for the development of pumped storage schemes from existing

Hydropower type	Source	Description of study
		hydropower reservoirs and non-hydropower reservoirs in Turkey. The methodology followed during the study consisted of taking an existing reservoir and analysing the surrounding area to determine if the site can be converted to a PHES scheme with the addition of a new reservoir. The parameters and constraints included in the methodology are summarised below. • Minimum volume of existing reservoir – 1 000 000 m^3 • Maximum distance between existing reservoir and potential reservoir site – 5 km • Minimum head – 150 m • Maximum slope of second reservoir – 5° • Assumed minimum new, second reservoir surface area – 70 000 m^2 • Minimum distance from new reservoir to inhabited sites – 500 m • Minimum distance from new reservoir to existing transportation structure – 200 m • Minimum distance from new reservoir to an UNESCO site – 5 km
Conduit hydropower	Chacón *et al.*, (2018)	The study describes the methodology followed to identify locations for micro-hydropower in pressurised irrigation networks, specifically locations where excess pressure can be harnessed to generate hydropower. 46 potential locations for energy recovery in 12 irrigation networks in the South of Spain have been identified through implementing the described methodology.
	García *et al.*, (2018)	A study was conducted to evaluate the hydropower potential at existing PRVs and to identify possible locations in the water supply systems where energy recovery can be considered. The methodology, involving the utilisation of EPANET to obtain the head and flow parameters, was applied to seven community owned rural water supply systems in Ireland to identify the total potential available.
	Gómez-Llanos *et al.*, (2018)	A methodology is presented to assist in the identification of hydropower potential is water supply systems. During the study, the flow available wat estimated by using the daily consumption of the population residing in the specific area. The daily consumption was calculated based on the consumption per resident (150 l/day) as quantified by the Spanish Statistics National. Furthermore, the daily consumption was then increased by 12% to account for any uncertainties in the flow estimation. The pressure head available was taken as the gross net head or static head of the system, ignoring the effects of friction and secondary losses. Lastly, the flow range considered was from 0.01 m^3/s to1 m^3/s and the head range from 10 m to 120 m.
	Viccione *et al.*, (2018)	The study investigates the possibility of harvesting excess energy for hydropower generation in water supply systems, specifically at

Hydropower type	Source	Description of study
		the end of the systems. The proposed methodology was implemented on a pipeline in Italy where the parameters necessary for the analysis were obtained from an EPANET model (all input parameters known).
	Soffia *et al.*, (2010)	The study proposed a methodology to evaluate the potential and economic feasibility of energy recovery in potable water systems in the Piemonte Region, Italy using GIS and existing infrastructure data.
	Loots *et al.*, (2014)	In this desktop study the potential annual hydropower generation capacity of the ten largest reservoirs in the City of Tshwane, South Africa were determined. The methodology used to provide an initial estimate of the annual hydropower that can be generated at the ten sites included some conservative assumptions. It was assumed that 50% of the static head would provide a conservative estimate of the pressure head available and the power can be generated for only six hours per day.
Storage schemes	Sule *et al.*, (2018)	A hydrological investigation was conducted on a dam in north central Nigeria to determine the hydropower potential of the dam (using the available flow records). With the available head known, a reservoir-yield analysis was conducted to determine the monthly yield as well as the minimum storage capacity requirements to satisfy the functions of the dam, thereby also estimating the volume available for energy generation.
	Ballance *et al.*, (2000)	The study, as described under the run-of-river section in this table, entailed the initial assessment of hydropower potential in South African rivers. Macro-hydropower potential assessment, however, entails the identification of locations suitable for damming of rivers, thereby creating large storage volumes and a sufficient head. The approach followed, identified areas with large cumulative flows by using the cumulative mean annual flow. This was calculated by accumulating the mean annul flow volumes of all the cells upstream of a specific cell along the simulated river.

5. CONCEPTUAL DESIGN OF MUNICIPAL HYDROPOWER DEVELOPMENT TOOL

5.1 INTRODUCTION

A generic tool was developed to assist municipalities to identify hydropower opportunities within their water infrastructure and rivers. It is a spreadsheet-based tool (Microsoft Excel) which can be used in conjunction with the South African Hydropower Atlas. It will guide the municipality through three phases of hydropower development: Pre-feasibility; Feasibility and Detailed design. A simplified illustration of the tool layout is shown in Figure 5-1.

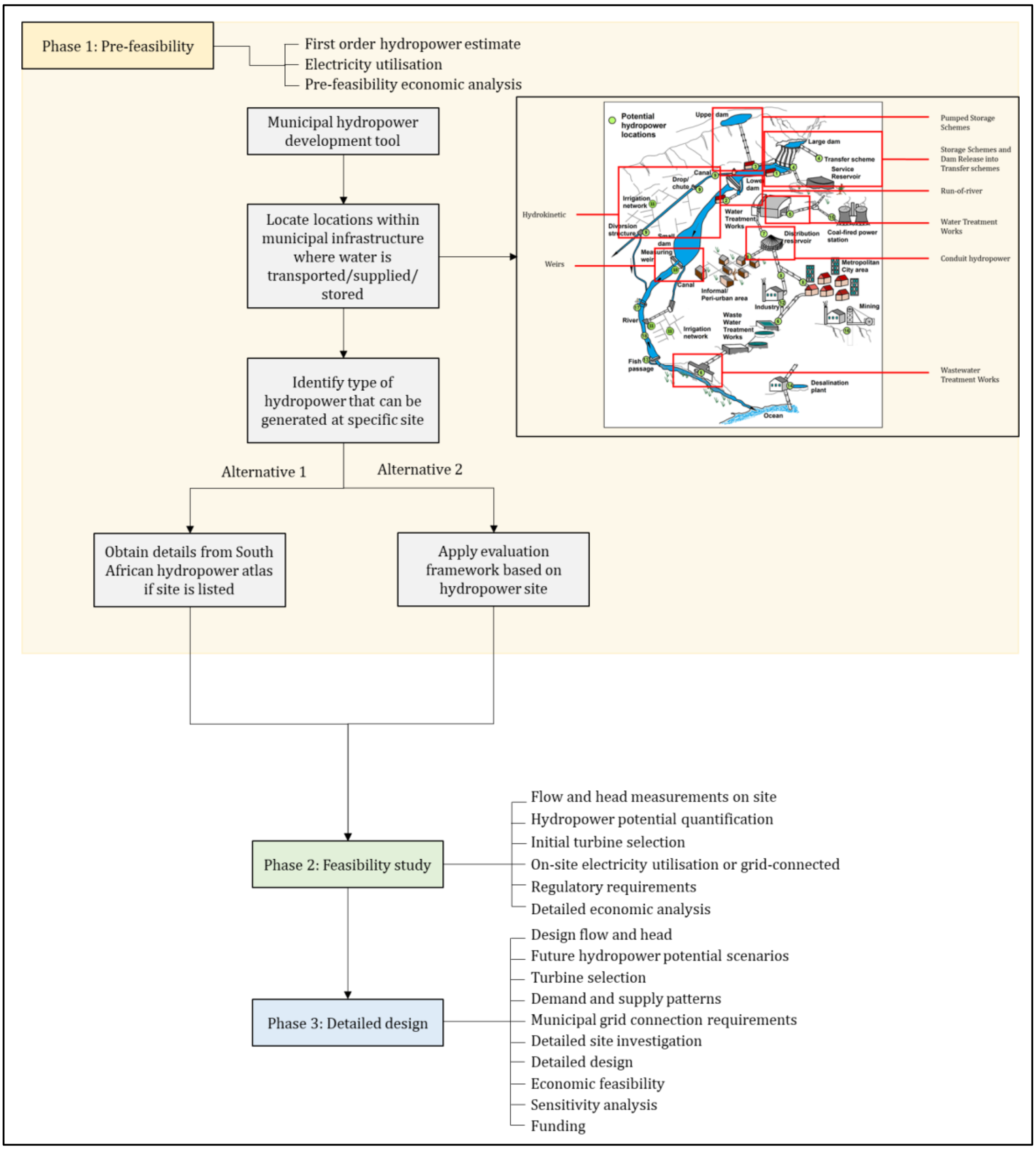


Figure 5-1: Layout of municipal hydropower development tool

5.2 PHASE 1: PRE-FEASIBILITY

The pre-feasibility phase of the project entails the quantification of a first order estimate of the hydropower potential available. This phase of the project only includes using available data to determine whether a specific site could potentially be utilised for hydropower generation. This phase of the hydropower development process entails using two methods to determine the first order hydropower of any site; 1) using the developed hydropower atlas for SA (if applicable for the specific site) and 2) using developed frameworks especially if limited data poses a challenge.

Section 5.2.1 describes the available data sources that any municipality can use for hydropower parameter estimation. Section 5.2.2 describes the developed hydropower frameworks for run-of-river, conduit, hydrokinetic, WWTW, WTW, weirs, storage schemes and pumped storage schemes. Lastly Section 5.2.3 consist of a brief discussion of the developed hydropower atlas for SA.

5.2.1 AVAILABLE DATA SOURCES FOR SITE EVALUATIONS

Various data sources have been identified from which the parameters necessary for the evaluation of hydropower potential could be obtained. Identifying these sources formed a trivial part in the development of the evaluation frameworks for the various hydropower types.

It should be noted that the data sources available to obtain South African water infrastructure and river data are not limited to the sources identified in this study.

5.2.1.1 Department of Water and Sanitation Verified Data

The Department of Water and Sanitation (DWS) website provides information on water infrastructure and rivers in South Africa that are easily accessible and free to the public. The verified data provided on the DWS website that are included in the evaluation criteria are summarised in Table 5-1.

Additionally, the locations of all the stream gauges and dams and a map of the quaternary catchment, primary and secondary rivers are obtainable from the website and is downloadable in a format that is compatible with any GIS program.

Table 5-1: Summary of data provided for DWS water infrastructure and rivers

Type	Data provided
River	Monthly volume (m^3), daily average and primary flow data (m^3/s) with the corresponding water level (m)).
Reservoir and component	Monthly spill volume (m^3), daily average spill (m^3/s) and primary data (flow (m^3/s) and corresponding level above spillway (m)).
Reservoir downstream component	Monthly volume (m^3), daily average flow and primary data (flow (m^3/s) and corresponding water level (m)).
Canals	Monthly volume (m^3), daily average flow and primary data (flow (m^3/s) and corresponding water level (m)).
Closed conduit	Monthly volume (m^3), daily average flow (m^3/s) and primary data (flow (l/s)).

5.2.1.2 WR2005 and WR2012

The Surface Water Resources of South Africa studies (1952-2012) have played a major role in providing access to hydrological data for national water resource planning. The WR2005 study included the reassessment and updating of rainfall, observed streamflow and water data up to September 2006 whereas the WR2012 study focussed on re-evaluating, improving and producing new data and tools. Data is provided at quaternary catchment level for the entire South Africa, Lesotho and Eswatini (WRC, November 2015).

The relevant data provided by WR2005 and WR2012 studies includes:

- GIS River information (location, name, stream order);
- GIS Stream gauge information (location, name);
- GIS Quaternary catchment information;
- Mean annual precipitation and mean annual runoff per quaternary catchment;
- GIS Dams and lakes information
- GIS Water Management Areas (WMA) information; and
- Historical runoff data for every WMA.

5.2.1.3 SANCOLD Registry for Large Dams and DWS List of Registered Dams

South African Notional Committee on Large Dams (SANCOLD) complied a register containing data (dam capacity, spillway capacity, dam wall height, owner, etc.) of all ‘Large’ dams in SA. A dam is classified as ‘Large’ if the following criteria are met:

- Height of the dam must be at least 15 m, measured from the lowest point of the foundation; and
- Dams with at least 3 million m^3 capacity (this includes dams with a height between 5 m and 15 m).

Additionally, a list of all the registered dams in SA is available from the DWS website. The list contains the data of 323 DWS-owned dams and 4907 dams owned by entities other than DWS. Data provided in the registry includes:

- Gauging station name (for DWS-owned dams);
- Quaternary drainage area;
- Spillway type;
- Capacity;
- Catchment area;
- Surface area;
- Purpose of dam; and
- Dam owner.

5.2.1.4 Green Drop Reports

Green drop reports as published by the Department of Water and Sanitation aim to measure and compare the results of the performance of WSA and WSP. The Green Drop also aims to focus on the wastewater treatment function (DWS, 2011). The reports consist of 9 separate reports for each province, with each report containing a list of the WWTWs in each municipality within the specific province, the design capacity (ML/day) and operational capacity of each WWTW expressed as a percentage of the design capacity, as well as a cumulative risk rating for each WWTW.

5.2.1.5 Blue Drop Reports

Blue drop reports as published by the Department of Water and Sanitation aim to measure and compare the results of the performance of WSA and WSP. The Green Drop also aims to encourage progress in the drinking water services management (DWS and WRC, 2015). There are 9 individual reports each province, with each report containing a list of the WTWs in each municipality within the specific province, the design capacity (ML/day) and operational capacity of each WTW expressed as a percentage of the design capacity, as well as the overall Blue Drop score of each WTW.

5.2.1.6 Municipal Asset Registers

Asset Registers (AR) are databases that contain the data on all the significant infrastructure owned by the organization and supports the Asset Management Plan (AMP). According to the Water Services Act, every municipality in SA is required to have an AMP for their water infrastructure and sanitation (Bonthuys et al., 2018).

5.2.1.7 Municipal water services development plans (WSDP)

The WSDP web-based database (hosted by the DWS) contains all the WSDPs for all Water Service Authorities (WSA) (consisting of metropolitan municipalities, some district municipalities and authorised local municipalities) in SA.

The (approved) WSDP, which is available to the public, contains Information pertaining to water and sanitation infrastructure of each municipality.

5.2.1.8 USGS Earth Explorer (DEM)

Digital evaluation models (DEMs) with a 30 m resolution can be freely downloaded for any area in the world from the Unites States Geological Survey (USGS) website. Other sources exist where DEMs can be downloaded and utilized for the same purpose.

5.2.1.9 Other data sources

Table 5-2 provides additional data sources which will be tapped into in the formation of the atlas.

Table 5-2: Other data sources that will be utilized

Variable	Source	Resolution	Comments
Precipitation	TRMM 3B43	0.25 deg raster	Monthly averages, period:1998-2010
	GPCP V2.3	2.5 deg raster	Monthly averages, Period: 1979/01 to 2020/01
	Global Precipitation Measurement (GPM)	0.1° - 30 minute	June 2000 to present
	FAO Water Productivity	5 km	Daily, 1983 to 2013
	CliMond	10' or 30'	Monthly
Evaporation	FAO Water Productivity	200 m	2009-2017
Runoff	Global Runoff Data Centre	Flow gauge records	Varies
Digital Elevation Model (DEM)	SRTM v4.1 CGIAR	90 m	Elevation interpolated DEM with corrections based on new algorithms
	HydroSHEDS	3 arc sec (~90 m)	Hydrologically corrected DEM based on the SRTM data. 15 and 30 arc sec data are also available
	ALOS World 3D - 30 m (AW3D30) Version 3.1	1 arc sec (~30 m)	Uncorrected DEM last updated in 2020
Land cover	Modis		
	CCI	20 m	
	ESA	300 m	2017
	Geoterra Image	30 m	2015
Soil characteristics	quick	quick	

5.2.2 DEVELOPED EVALUATION FRAMEWORKS

The potential hydropower sites to be included in the evaluation process are storage schemes, run-of-river, pumped storage, water treatment works (WTW), waste water treatment works (WWTW), water distribution systems (WDS), irrigation canals and weirs. Evaluation frameworks were developed for all the hydropower types (hydrokinetic, pumped storage conduit, storage schemes, WTW, WWTW and weirs) to assess the hydropower potential and provide a first order estimate of the potential available.

5.2.2.1 Conduit Hydropower

The evaluation of conduit hydropower potential in a water distribution is based on the available flow in the system and the amount of pressure being dissipated by the pressure reducing valves placed at either the inlet to a reservoir or within the water distribution system itself. The parameters that need to be quantified to enable hydropower evaluation are pressure head and flow.

The final conduit hydropower framework is shown in Figure 5-2.

5.2.2.2 Hydrokinetic Energy

The evaluation criteria selected in this sub-section evaluates the hydrokinetic energy in both rivers and channels (natural and manmade). The velocity in the river or channel as well as the turbine swept area are the primary factors influencing the hydrokinetic potential available in a river or channel.

The final hydrokinetic evaluation diagrams are shown in Figure 5-3 to Figure 5-5.

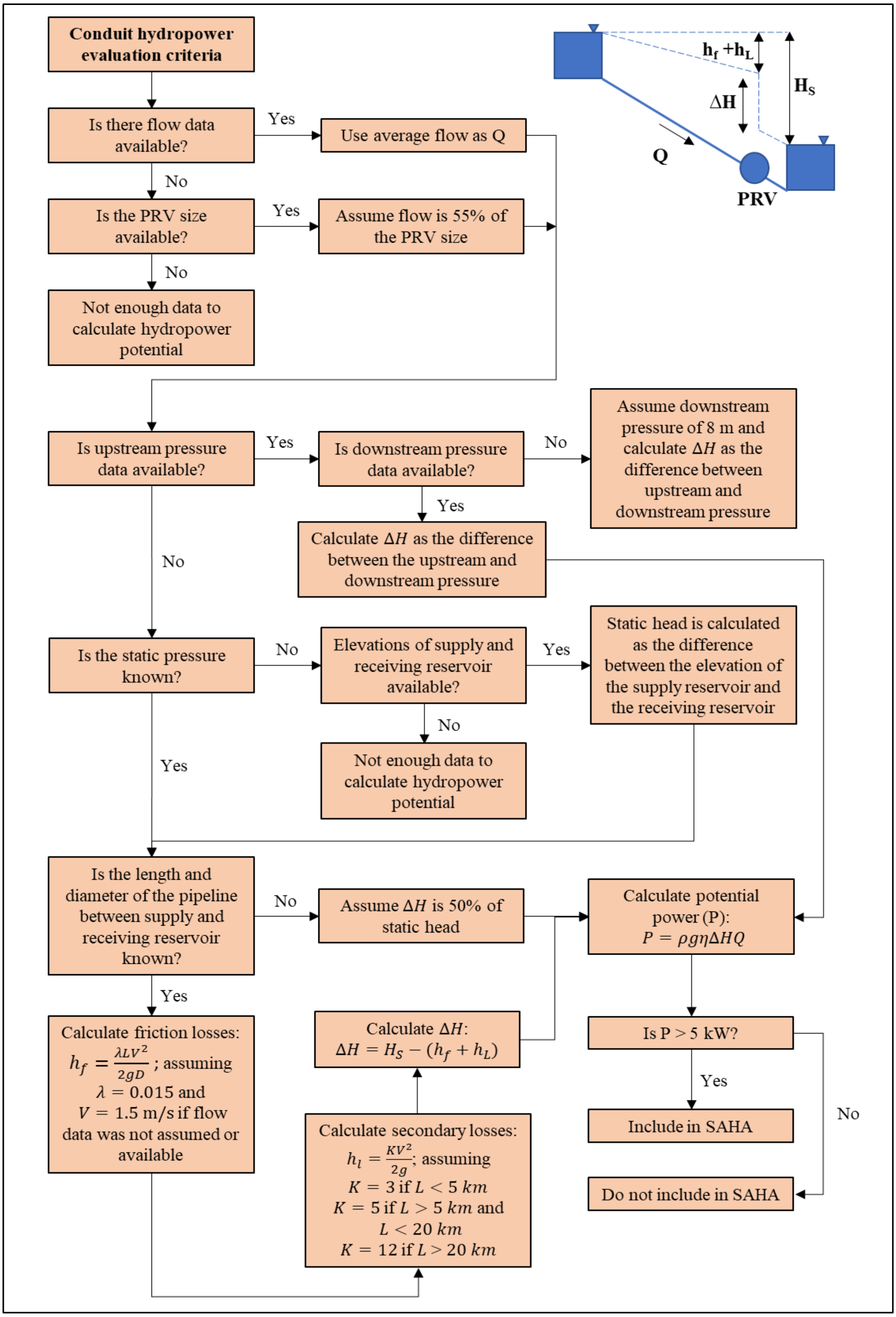


Figure 5-2: Conduit hydropower evaluation framework

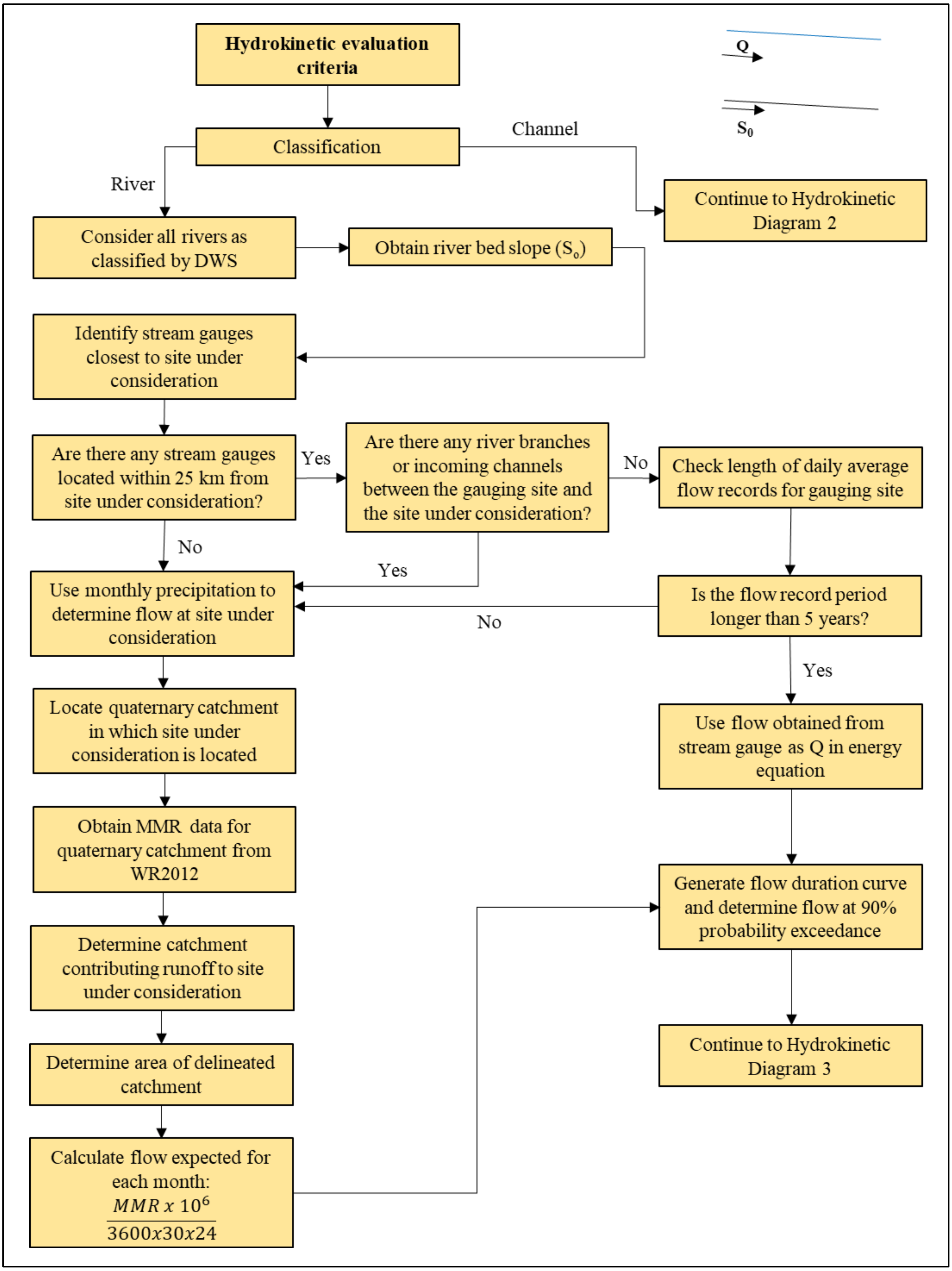


Figure 5-3: Hydrokinetic evaluation diagram 1

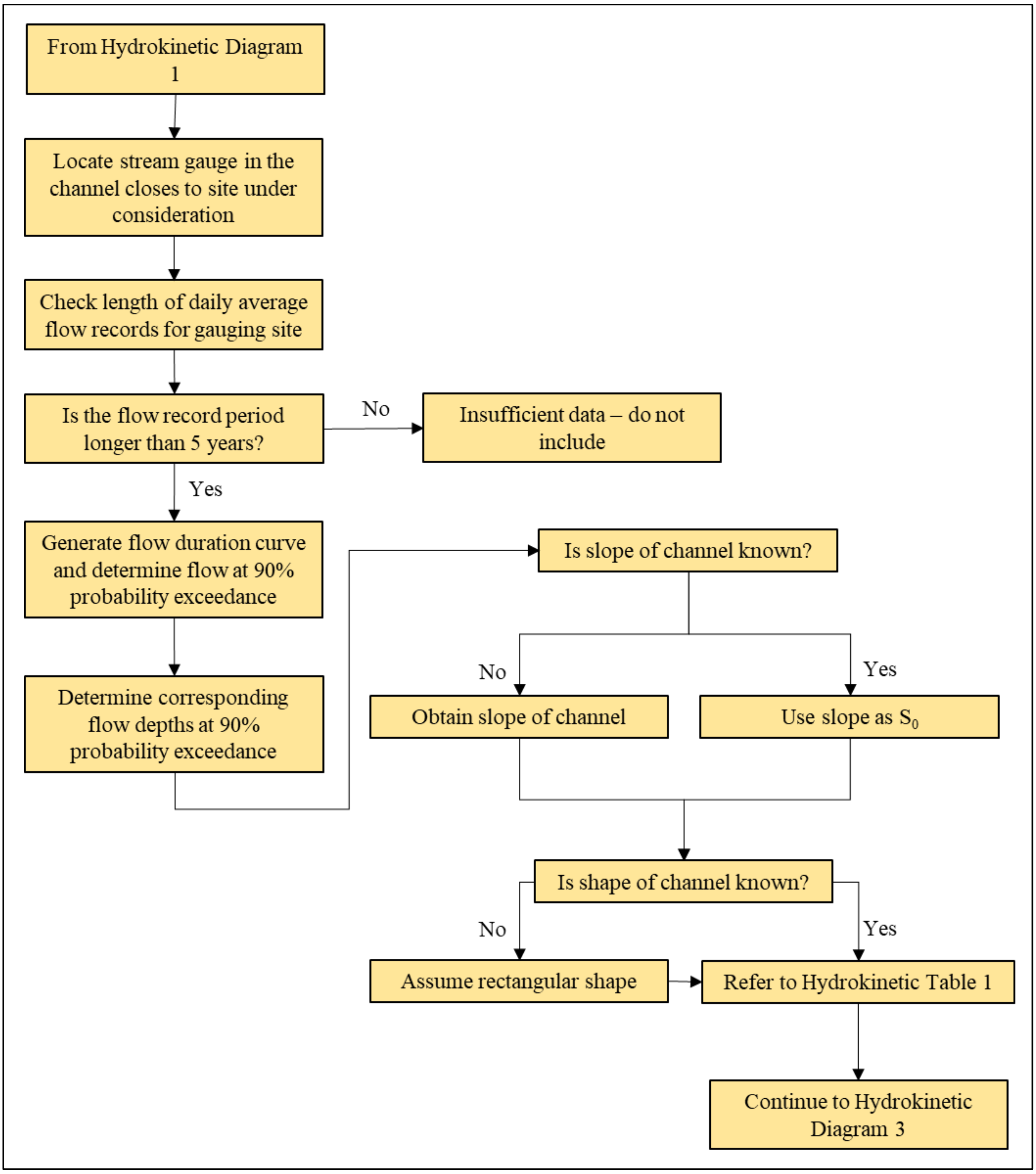


Figure 5-4: Hydrokinetic evaluation diagram 2

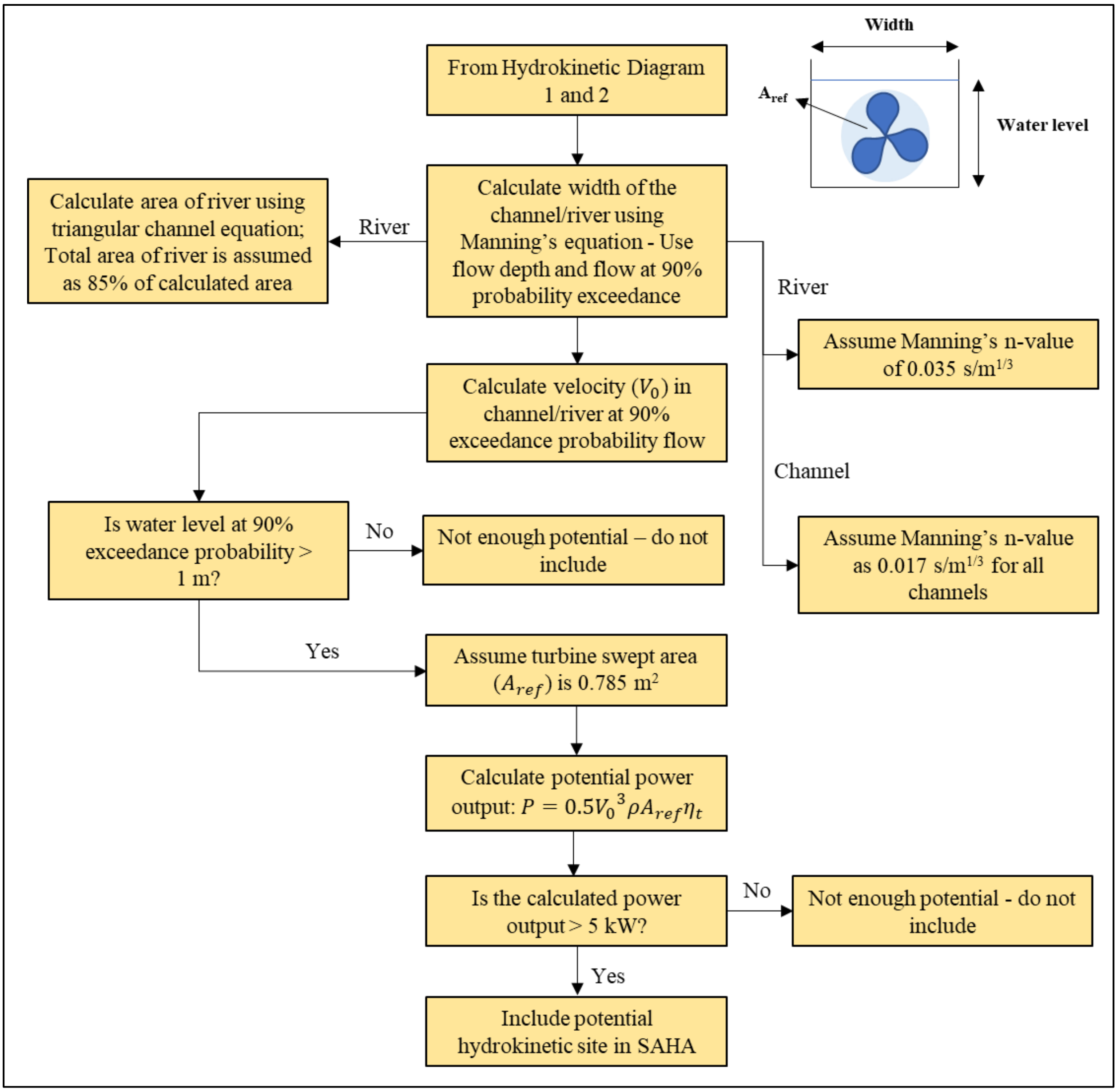


Figure 5-5: Hydrokinetic evaluation diagram 3

5.2.2.3 Run-of-River

The evaluation of the potential for a run-of-river site is based on the available head and the flow in the river. Certain criteria were selected in order to quantify the parameters necessary when using data sets with limited data for hydropower evaluation.

Run-of-river evaluation option 1

The final run-of-river evaluation diagrams are shown in Figure 5-6 and Figure 5-7.

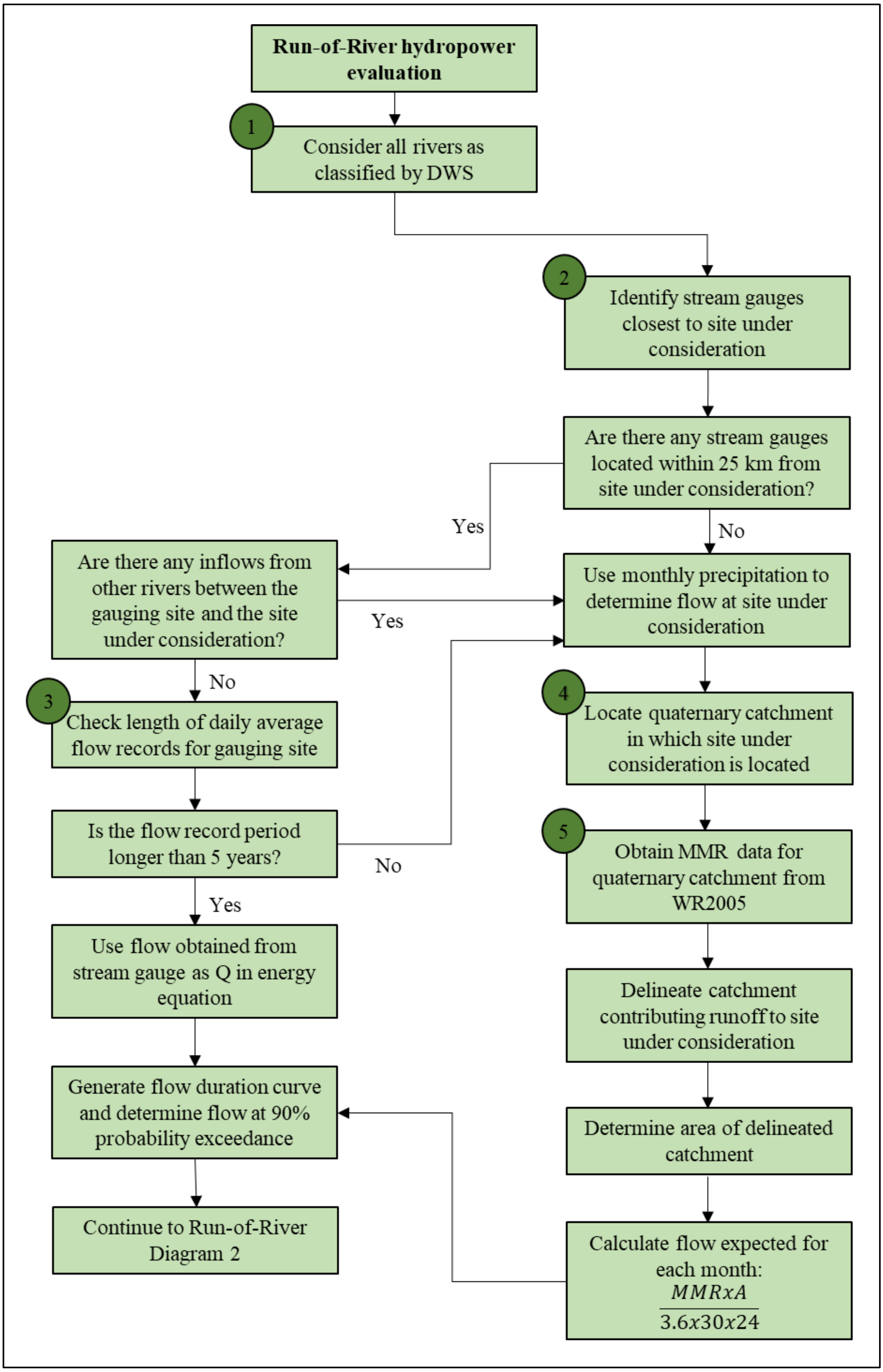


Figure 5-6: Run-of-river evaluation diagram 1

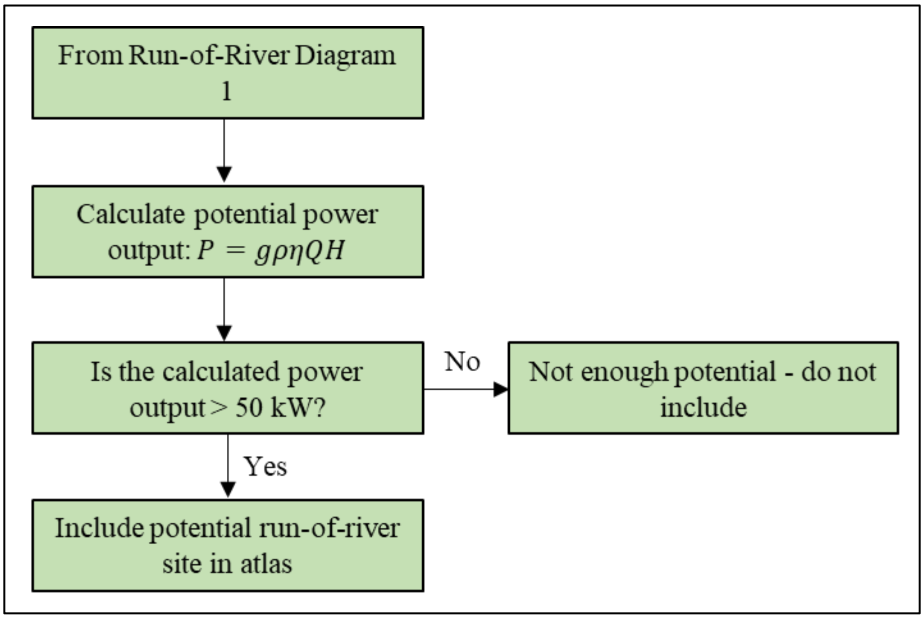


Figure 5-7: Run-of-river evaluation diagram 2

Run-of-river evaluation option 2

Another approach will also be followed where river systems will be analysed which does not have any DWS flow records available.

The considerations for the selection of data to be used in the modelling approach for these potential sites are discussed in the paragraphs below.

Hydrological Study

- Data Collection (climate, topography, channel geometry, land cover and soil characteristics)
- Delineation of catchments, sub-catchments and sub areas
- Derivation of river network
- Runoff and discharge calculation

Hydroelectric potential calculation

The algorithm depicted in Figure 5-8 describes the steps to calculate the hydroelectric potential.

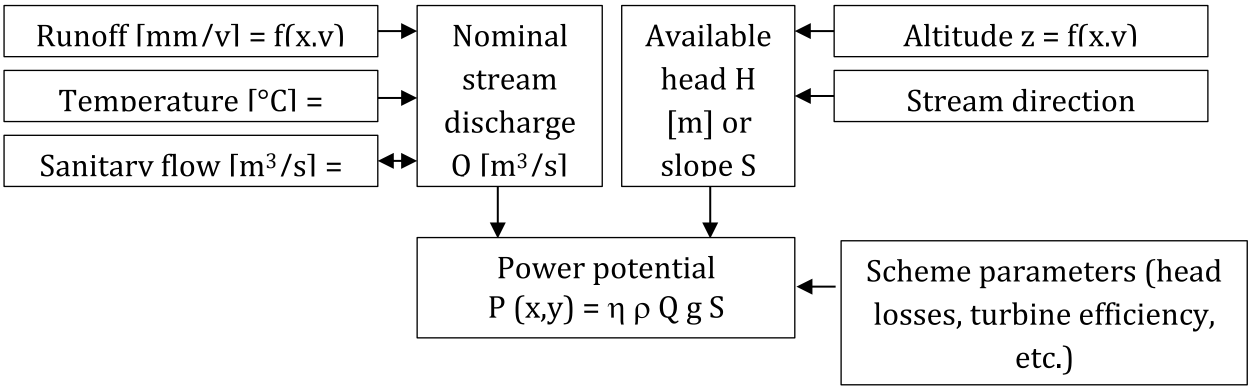


Figure 5-8: Proposed calculation algorithm

The reported output per river reach will be in kW/Km.

5.2.2.4 Storage Schemes

Power can be generated at large reservoirs or dams by utilising the available head combined with the discharge from the reservoir that corresponds with the normal operating conditions of the reservoir. Large hydropower dams have major environmental impacts, but for small hydropower schemes where large dams are retrofitted for hydropower, the environmental impacts are minimised. Existing dams that are utilised for flood control, irrigation, recreation or water abstraction can be retrofitted as hydropower dams in the case where the discharge from the dam is constant.

The final storage scheme evaluation diagram is shown in Figure 5-9.

5.2.2.5 Pumped Storage

Existing reservoirs can be converted into pumped storage schemes with the addition of a second reservoir and ensuring a sufficient elevation difference between the two reservoirs for energy generation. The criteria described in this sub-section entails the analysis of the surrounding area of existing reservoirs to find a suitable site for a new reservoir in order to transform the existing reservoirs or dams to pumped storage schemes. The criteria selected for this hydropower type was primarily based on the criteria selected for the study conducted by Fitzgerald, et al., (2012), where a methodology was developed to identify the potential for transforming existing hydropower and non-hydropower dams into pumped storage schemes.

The hydropower potential of a pumped storage site is based on the available head between the upper and lower reservoir and the available storage capacity (taken as the storage capacity of the reservoir with the lowest storage capacity). The selection of the pumped storage evaluation criteria required certain assumptions to be made with regards to the existing reservoir and potential new reservoir parameters.

The final pumped storage evaluation framework is shown in Figure 5-10.

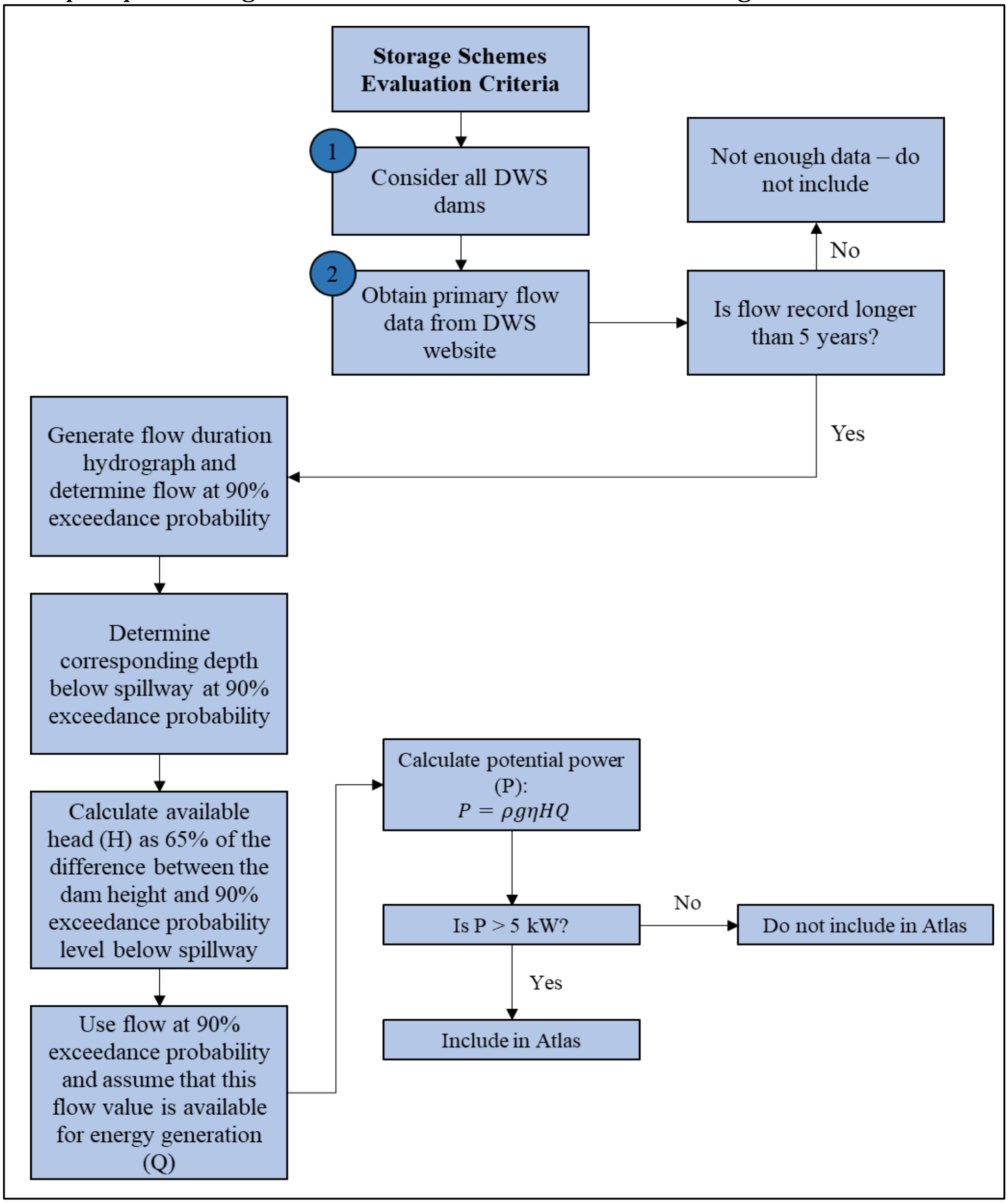


Figure 5-9: Storage scheme evaluation diagram

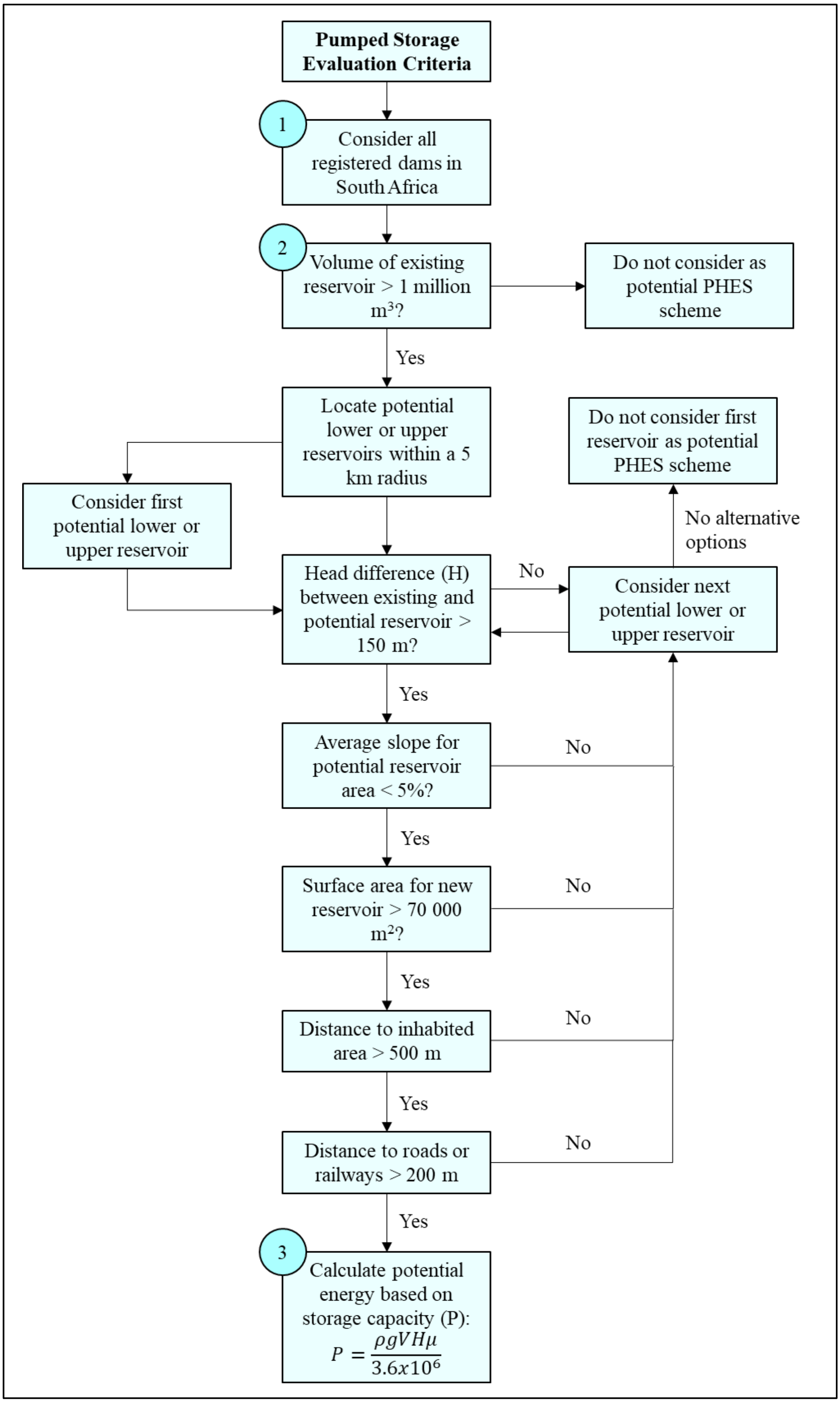


Figure 5-10: Pumped storage evaluation diagram

5.2.2.6 WWTW

The topic of potential estimation methods at the outflows of WWTW, especially when limited data might pose a challenge, is somewhat an unexplored area within the hydropower research field. It was, therefore, necessary to make some assumptions regarding initial criteria included in the framework.

The WWTW evaluation framework in shown in Figure 5-11.

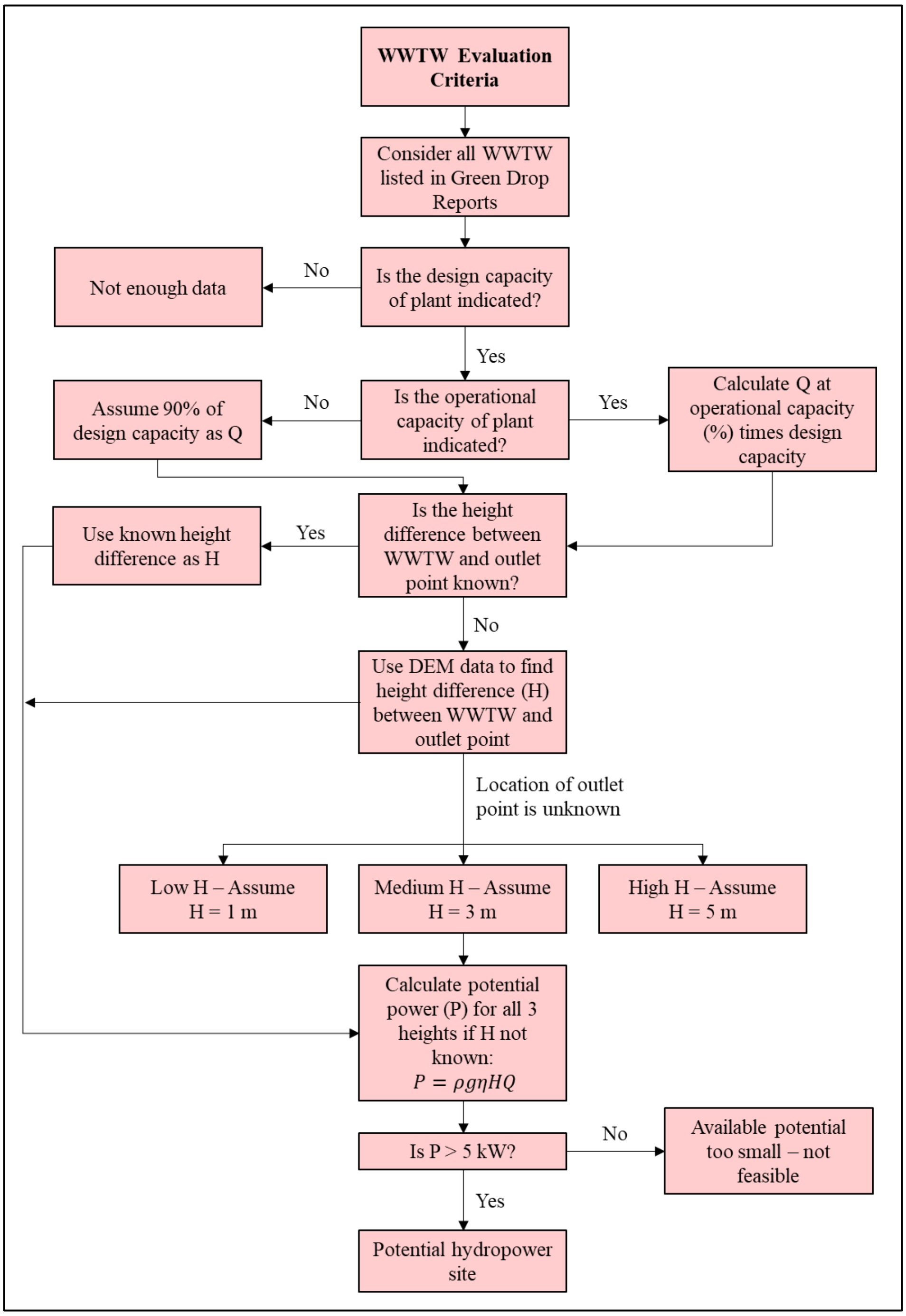


Figure 5-11: Diagrammatic depiction of WWTW evaluation framework

5.2.2.7 WTW

The topic of potential estimation methods at the outflows of WTW, especially when limited data might pose a challenge, is somewhat an unexplored area within the hydropower research field. It was, therefore, necessary to make some assumptions regarding initial criteria included in the framework.

The WTW evaluation framework in shown in Figure 5-12.

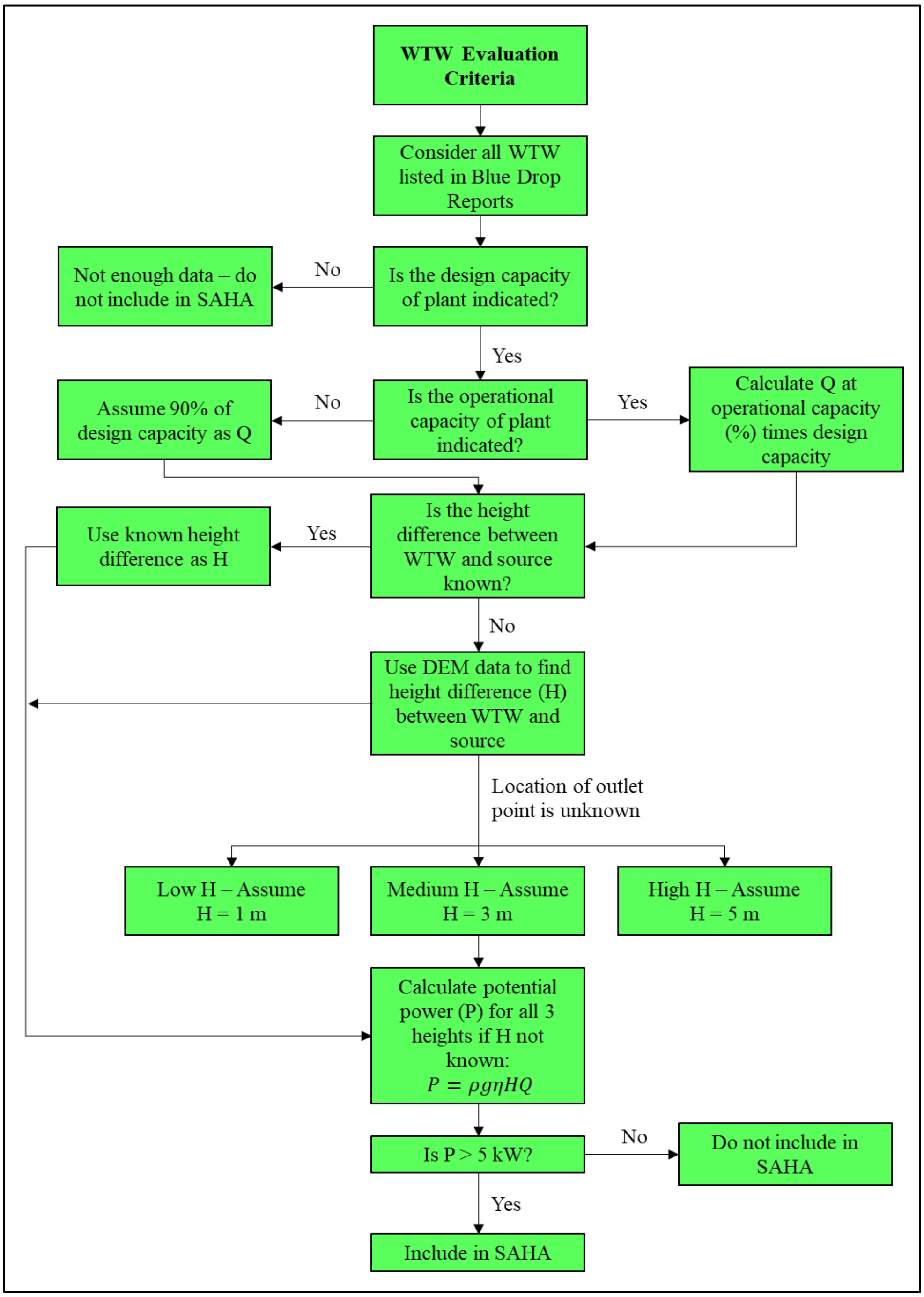


Figure 5-12: WTW evaluation diagram

5.2.2.8 Weirs

The evaluation criteria selected in this sub-section evaluates the potential at weirs. The flow over the weir (in the river) and upstream-downstream head difference over the weir are the primary factors influencing the hydropower potential available at a weir.

The baseline evaluation frameworks for hydropower evaluation at weirs are shown in Figure 5-13 and Figure 5-14.

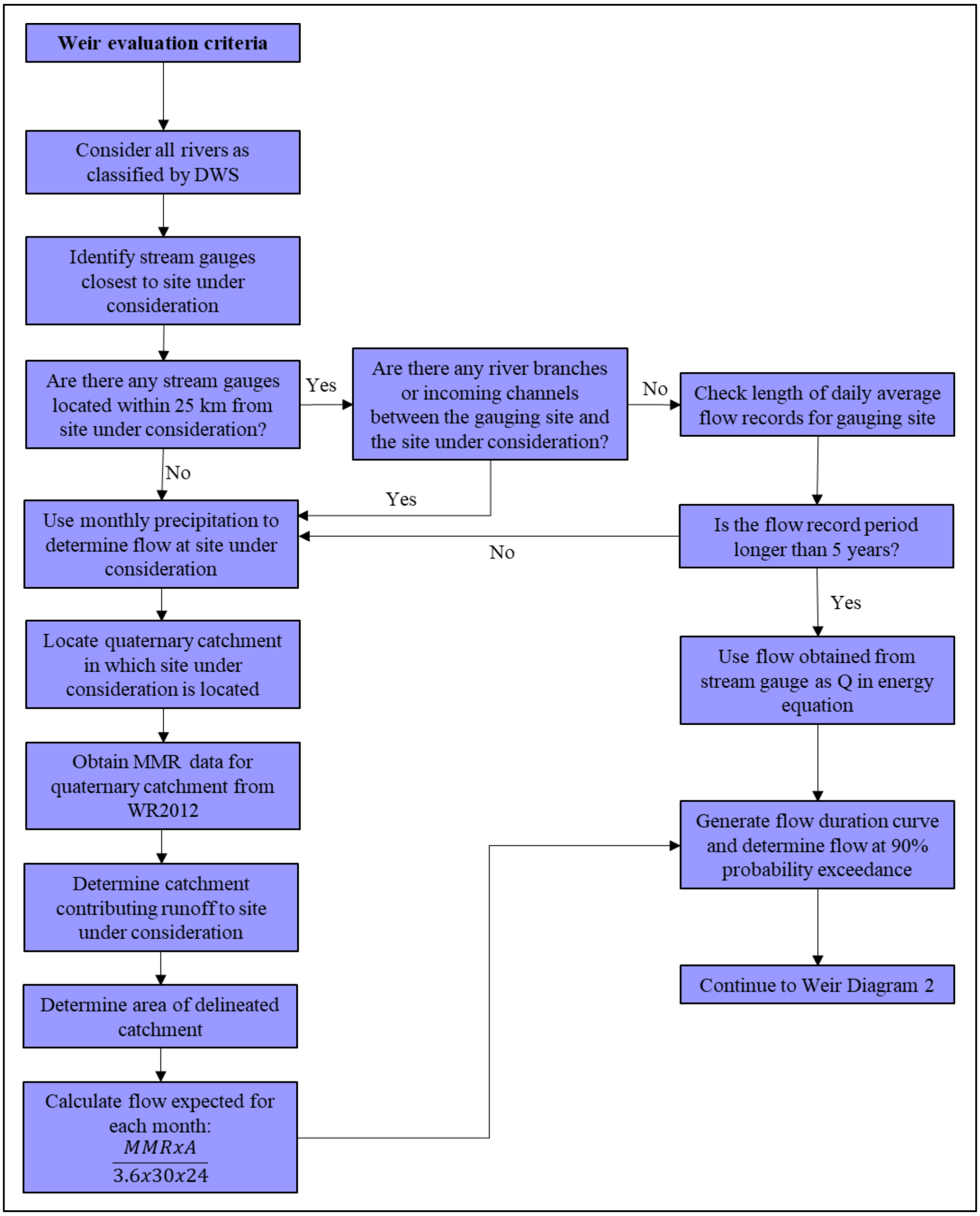


Figure 5-13: Weir evaluation diagram 1

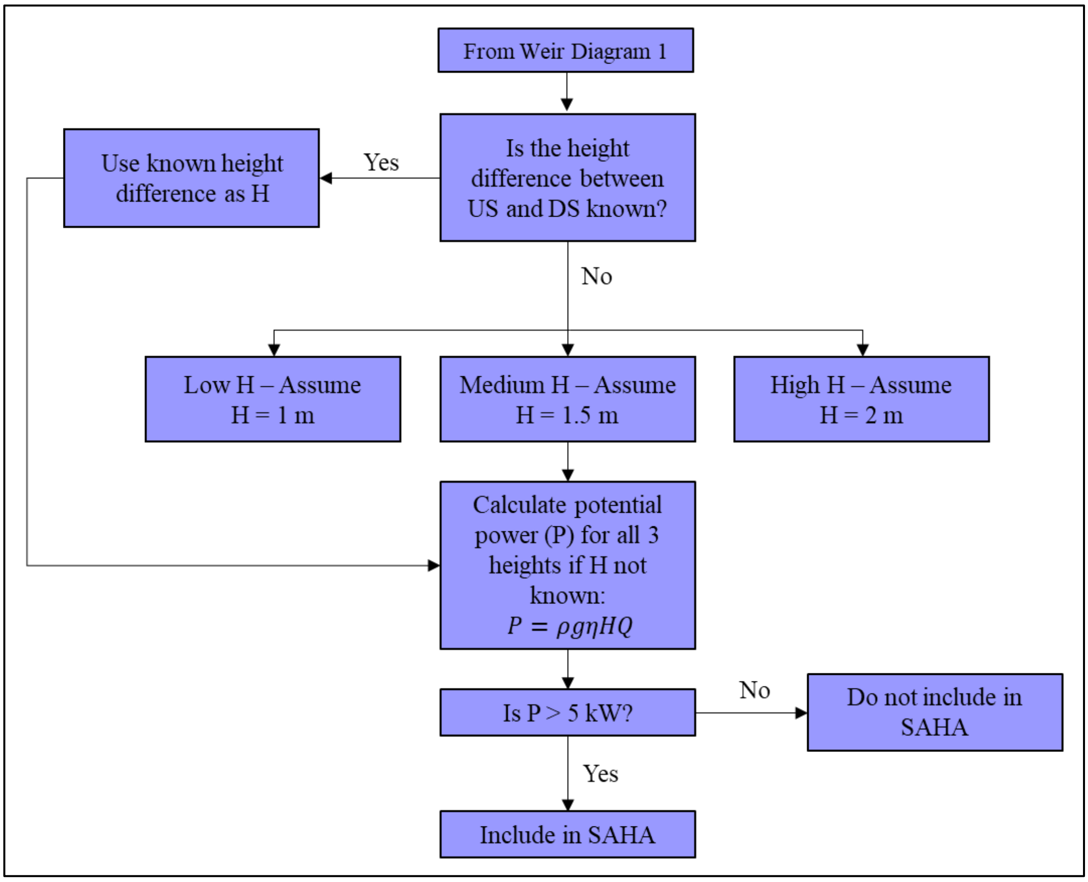


Figure 5-14: Weir evaluation diagram 2

5.2.3 THE SOUTH AFRICAN HYDROPOWER ATLAS

The South African hydropower atlas was developed with the aim of creating a database listing all potential hydropower sites (conduit, WWTW, WTW, weirs, storage schemes, pumped storage schemes, hydrokinetic and run-of-river). The pre-feasibility phase of the projects entails identifying existing locations where water, raw water or sewerage is being transported, treated or stored. The next step is to locate these locations on the South Africa hydropower atlas to determine if the identified locations already have a first order estimate of the hydropower potential specified.

The built in functions and query systems of the atlas will assist with the initial screening process. An overview of the atlas is shown in Figure 5-15.

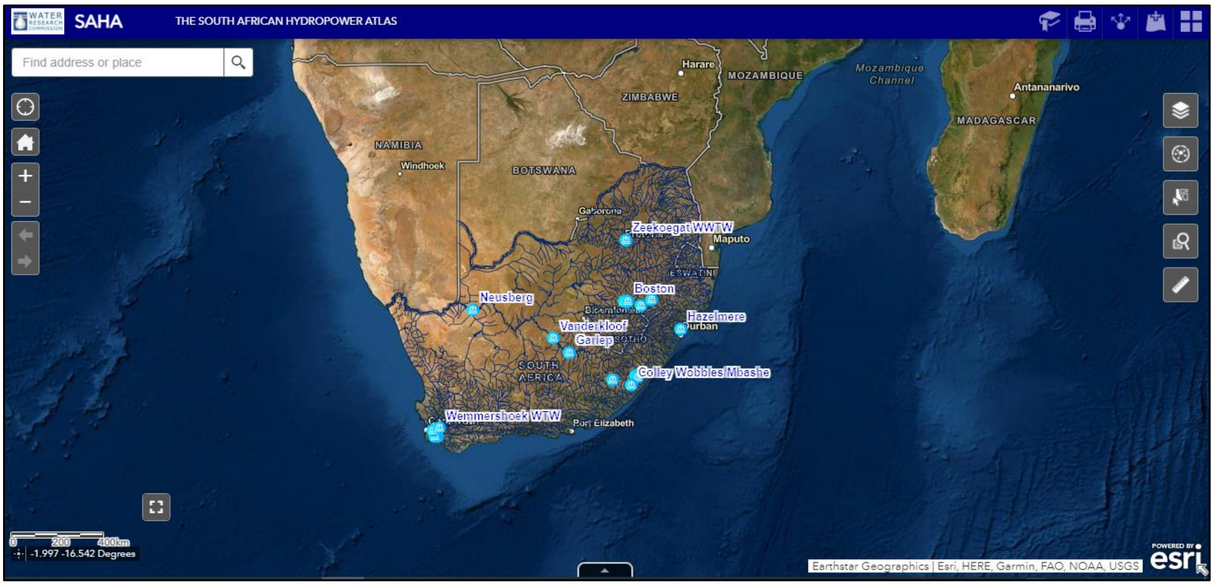


Figure 5-15: Overview of the South African hydropower atlas

Link to South African Hydropower Atlas:
https://uparcgis.maps.arcgis.com/apps/webappviewer/index.html?id=9618bcec00ad4f5398f4cc0cd1a447b8&utm_source=web+map&utm_medium=res&utm_campaign=hydropower

5.3 PHASE 2: FEASIBILITY STUDY

As discussed, Phase 1 of the municipal hydropower development process entails the screening of sites based on a first order evaluations. If a site passes the pre-feasibility phase, it is recommended to move to Phase 2 which entails the feasibility analysis of the site. This would include selecting of a turbine suitable for the flow and head range and installation configuration. A list of possible turbine that could be used are listed in **Appendix A**.

The steps involved in Phase 2 is illustrated in Figure 5-16 and Figure 5-17.

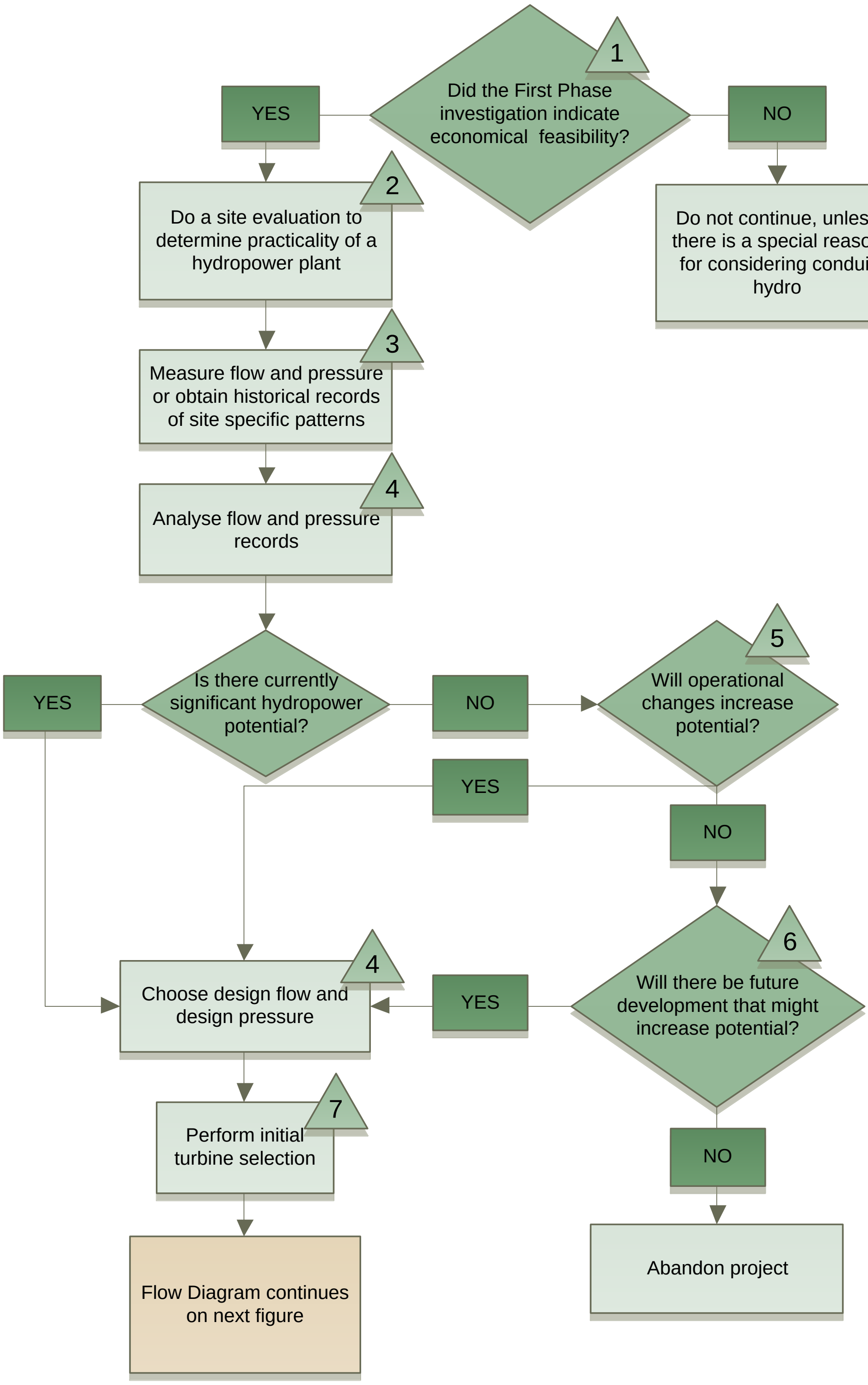


Figure 5-16: Phase 2 flow diagram part A

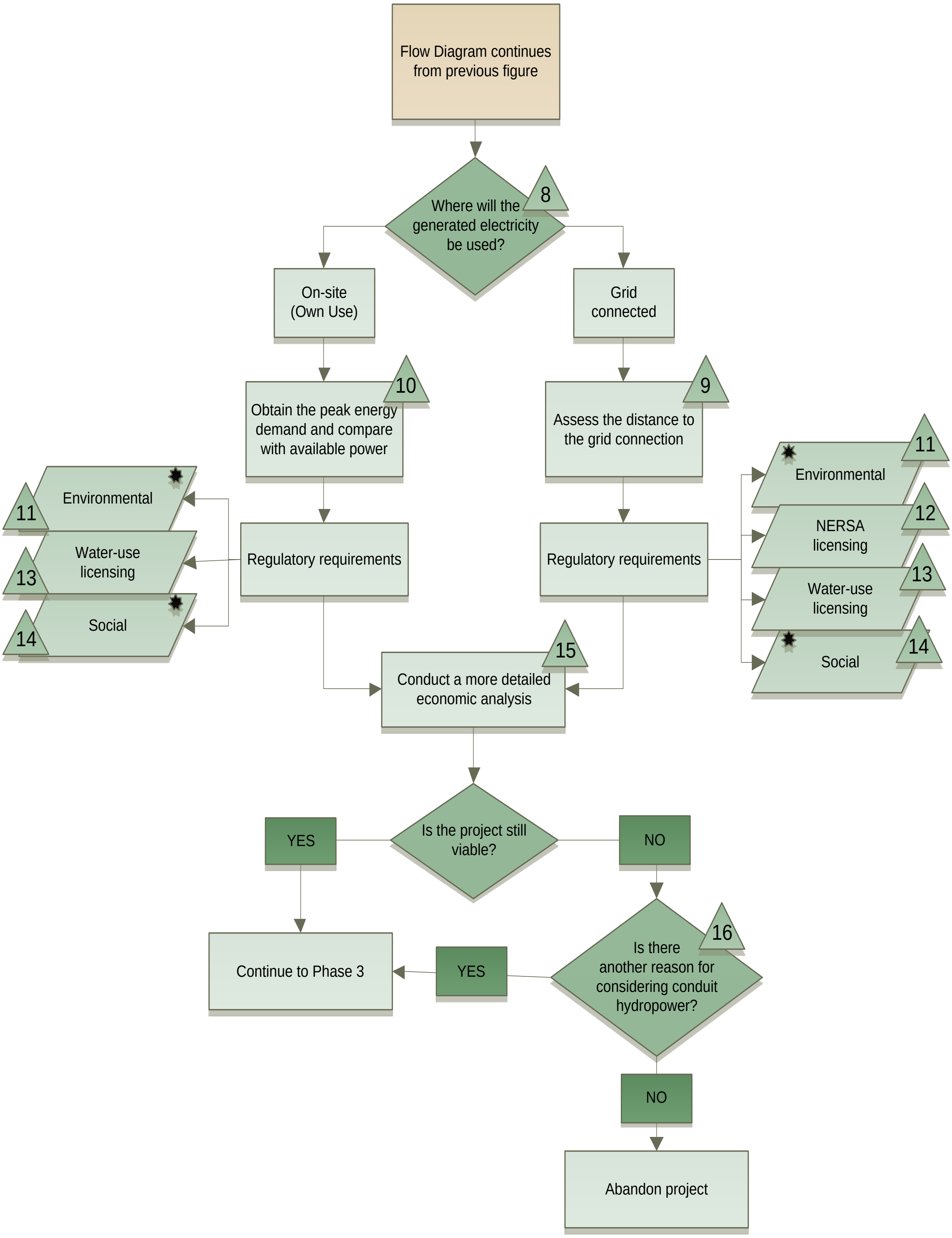


Figure 5-17: Phase 2 flow diagram part B

5.4 PHASE 3: DETAILED DESIGN

If a site passes the feasibility phase (Phase 2), it is recommended to move to Phase 3 which entails the detailed design of the site. The steps involved in Phase 3 is illustrated in Figure 5-18, Figure 5-19 and Figure 5-20.

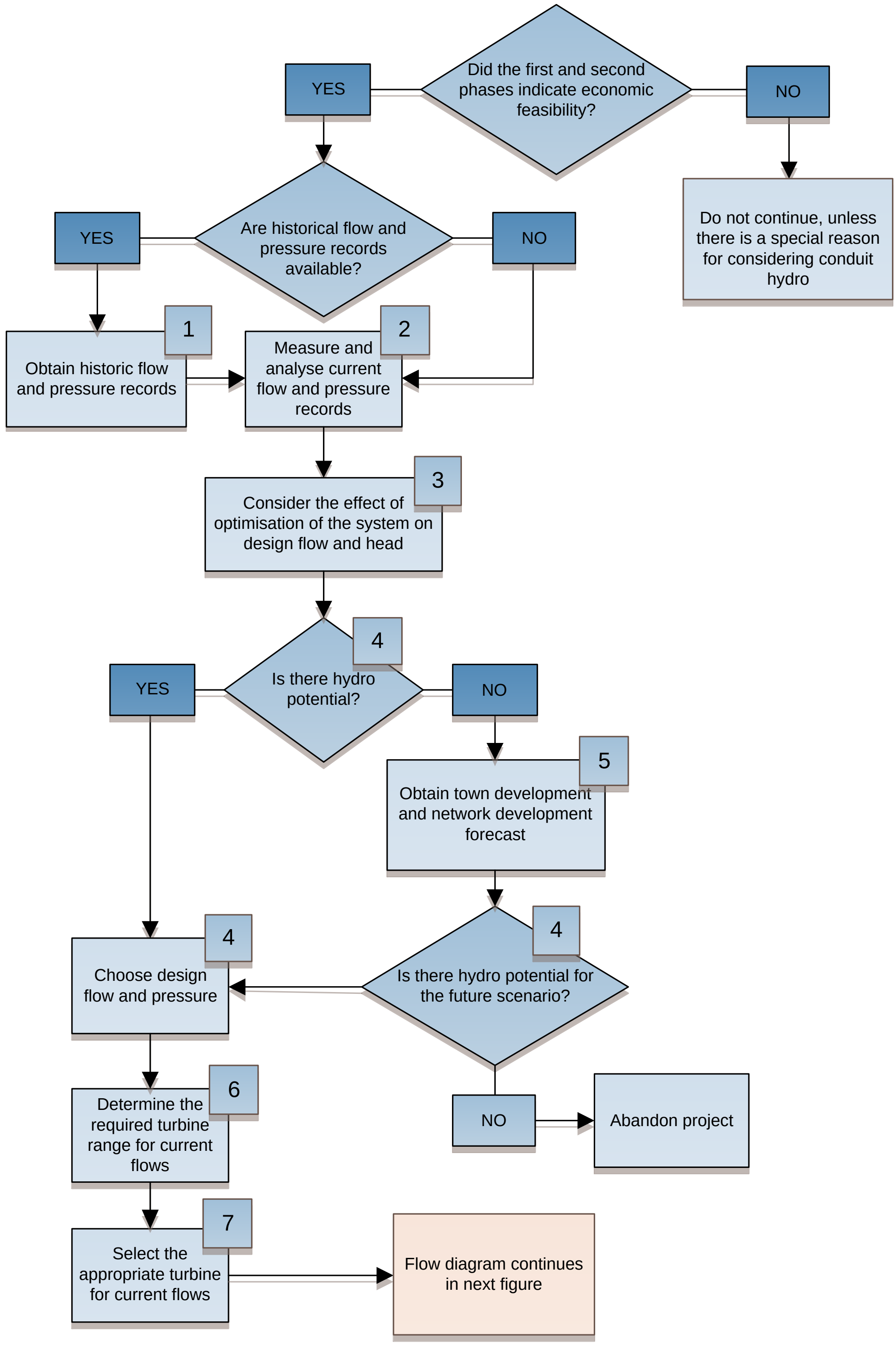


Figure 5-18: Phase 3 flow diagram part A

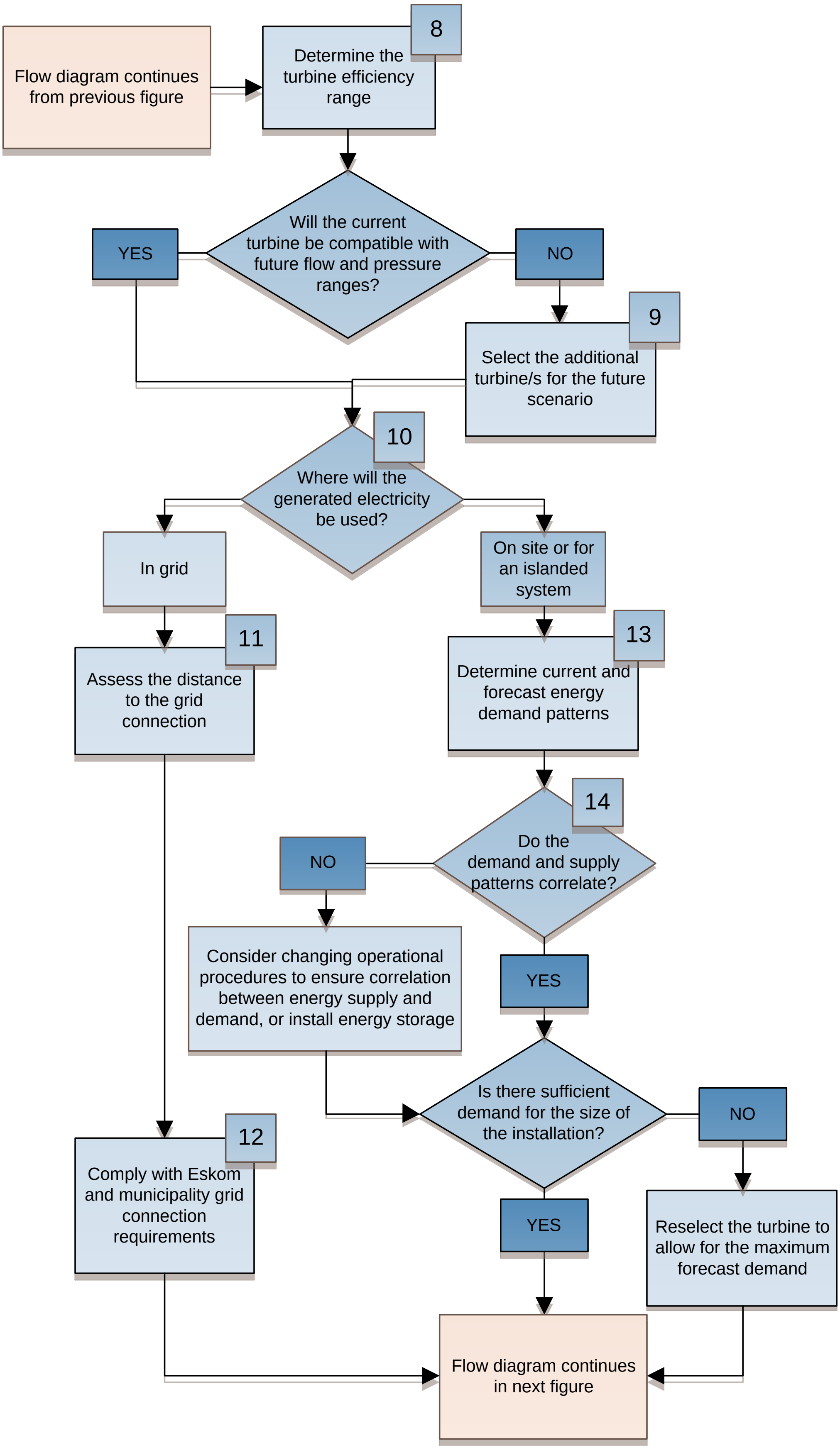


Figure 5-19: Phase 3 flow diagram part B

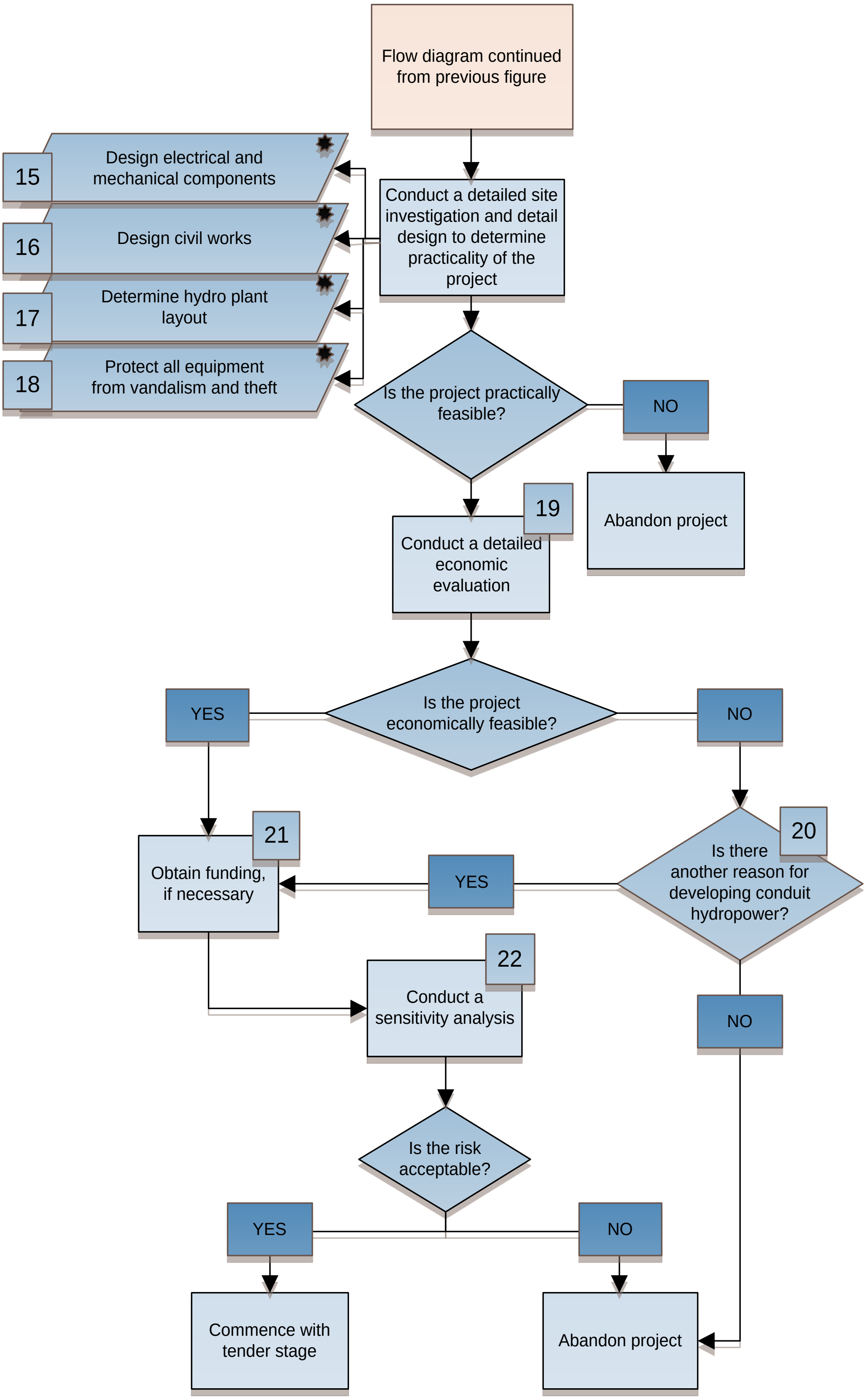


Figure 5-20: Phase 3 flow diagram part C

6. CASE STUDY: SITE EVALUATIONS OF HYDROPOWER WITHIN THE VICINITY OF THE BAAKENS RIVER

The evaluation of the hydropower potential in the vicinity of the Baakens River entailed the identification of potential sites based on a first order and detailed assessment for the entire Nelson Mandela Bay Municipality as shown in Figure 6-1. The assessment of hydropower potential within the Nelson Mandela Bay Municipality assisted with the development of a simplified tool to enable Municipalities to identify hydropower potential within their own infrastructure and rivers.

Figure 6-1: Nelson Mandela Bay Municipal area

The process of analysis followed the three phases as discussed in the previous section.

6.1 PHASE 1: PRE-FEASIBILITY STUDY

The potential sites assessed for hydropower potential during Phase 1 included WWTW, WTW, water supply systems (conduit), run-of-river, hydrokinetic, storage schemes and weirs. There are no storage dams in the NMBM area.

The evaluation frameworks discussed in Section 5.2.2 combined with the South African Hydropower Atlas was used to identify and shortlist all feasible sites within the NMBM, with a brief summary provided. Additionally, a list is provided of all sites that was shortlisted for the site visit.

6.1.1 Conduit hydropower

No potential sites could be identified as access to the Municipality's asset register would be required. The locations that would be of interest are areas where energy is being dissipated with pressure reducing devices.

6.1.2 Hydropower at Weirs

There are multiple gauging weirs within the Nelson Mandela Bay Municipality which could have a potential for hydropower generation. The limitation is however that the majority of the weirs are inactive (as shown in Figure 6-2) implying that no flow data is available. If local knowledge is available that a particular weir has significant constant flow throughout the year and there is a height difference then the weir could also be considered.

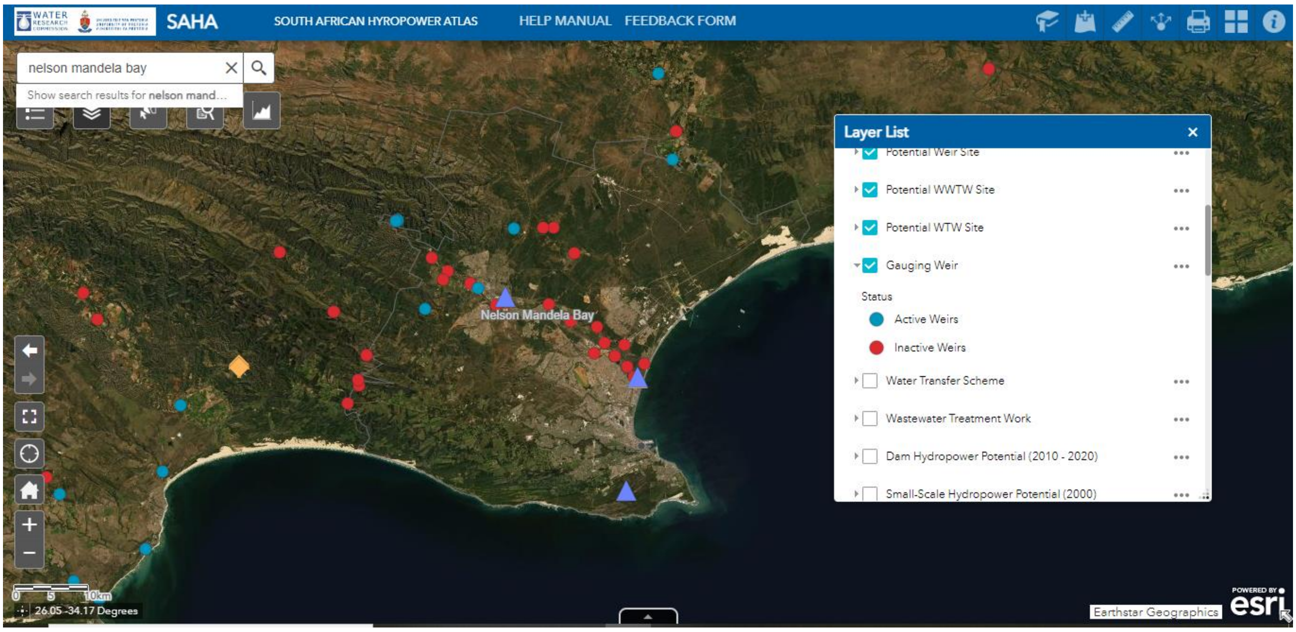


Figure 6-2: Weirs in the Nelson Mandela Bay Municipal area

A list of active weirs within the Municipality is provided in Table 6-1. The Uitenhage weir was selected as a potential hydropower site even though this weir does not meet the minimum requirements as per the SAHA selection criteria to be classified as a potential site.

Based on the available information only approximately 2 kW hydropower potential is available at weirs within the NMBM.

Table 6-1: List of Weirs in the Nelson Mandela Bay Municipal area

Name/Station	Latitude & Longitude	Q_{70} Flow (m^3/s)	Head (m)	Low Potential (kW)	High Potential (kW)	SAHA Classification
Elands River @ Wintcanton M1H004	-33.79728, 25.30900	0	1-5	0	0	Not Enough Potential
*Pipeline to Treatment Works @ Groendal M1H006	-33.69056, 25.26917	0.1	1-5	0.638	3.188	Not Enough Potential
*Compensation Water from Pipeline @ Groendal M1H007	-33.69000, 25.26861	0.065	1-5	0.414	2.072	Not Enough Potential
Swartkops River @ Uitenhage M1H012	-33.77192, 25.38639	0.06	1-5	0.383	1.913	Not Enough Potential

6.1.3 Hydropower at WTW

The SAHA database contained no WTW sites within the Nelson Mandela Bay Municipality. However there are a number of WTW sites outside of the municipal boundaries as listed in Table 6-2 and depicted in Figure 6-3.

Table 6-2: List of WTW supplying Nelson Mandela Bay Municipal area

Name	Latitude & Longitude	Capacity (ML/day) & (Operating capacity)*	Flow (m^3/s)	Static head (m)	Head (m)	Low Potential (kW)	High Potential (kW)
Churchill	-34.0055128, 24.5042931	100 (77.9%)	0.902	12	3-8.4	19.90	55.72
Elandsjagt	-34.0701242, 24.6295711	100 (15.6%)	0.181	-	-	-	-
Groendal (Kabah)	-33.7514536, 25.3815098	20 (49.5%)	0.127	30	3-21	2.81	19.67
Linton	-33.9443155, 25.5118320	20 (27.2%)	0.063	69	3-48.3	1.39	22.37
Loerie	-33.8682492, 25.0383333	100 (34.4%)	0.398	-	-	-	-
Nooitgedacht	-33.5296118, 25.6374961	140 (113.1%)	1.833	52	3-36.4	40.45	490.80
Rocklands	-	0.25 (56%)	0.002	-	-		-
Springs		6.5 (76.9%)	0.058	-	-	-	-

* Information obtained from Green Drop Report (2022)

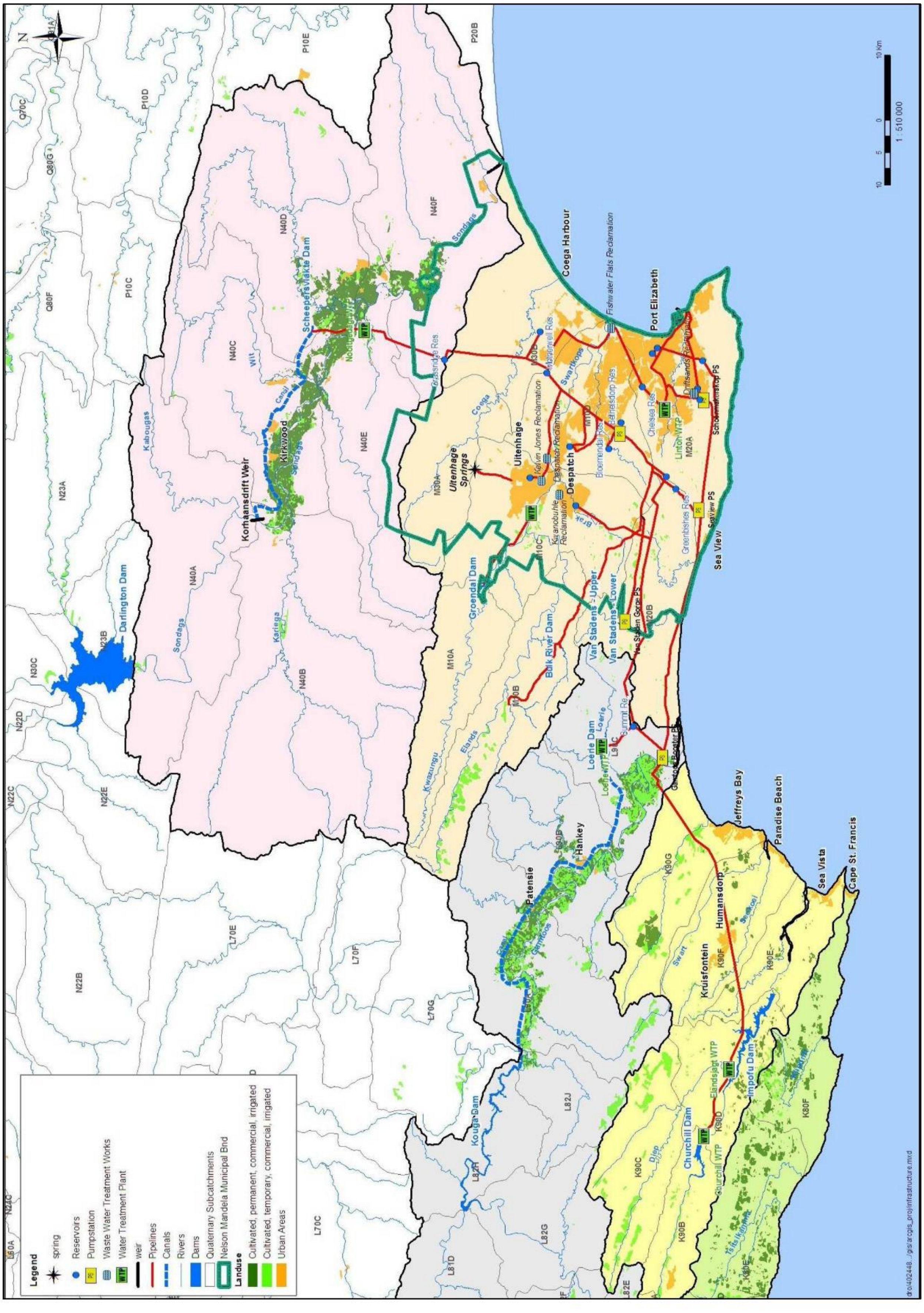


Figure 6-3: The Algoa Water Supply System (AWSS)

Access to the Municipality's asset register would provide additional information to assess the potential at the WTW in greater detail.

6.1.4 Hydropower at WWTW

The potential WWTWs where energy can potentially be generated at the outflows are shown in Figure 6-4. A list of all WWTWs in the Nelson Mandela Bay Municipality are tabulated in Table 6-3, with the shortlisted sites (potential > 5 kW) highlighted.

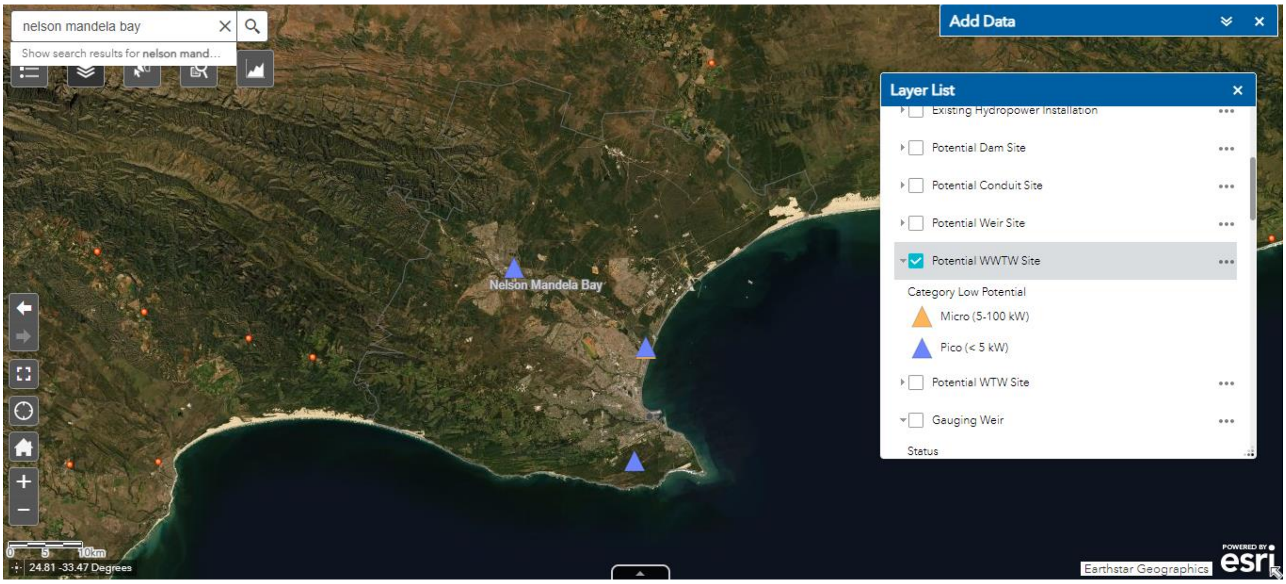


Figure 6-4: WWTW with hydropower potential >5 kW

Table 6-3: All WWTW within Nelson Mandela Bay Municipal area

Site Name	Latitude & Longitude	Flow (m^3/s)	Available Head (m)	Low Potential (kW)	High Potential (kW)	SAHA Classification
Cape Receife WWTW	-34.015, 25.6853	0.0938	1-5	0.598	2.989	Not Enough Potential
Despatch WWTW	-33.7999, 25.4962	0.0938	1-5	0.598	2.989	Not Enough Potential
Rocklands WWTW	-33.8225, 25.312	0	1-5	0	0	Not Enough Potential
Kelvin Jones WWTW	-33.8061, 25.3999	0.0938	1-5	0.598	2.989	Not Enough Potential
Motherwell / Coega WWTW	-33.7737, 25.681	0	1-5	0	0	Not Enough Potential
Rocklands WWTW	-33.8953, 25.3504	0.0019	1-5	0.012	0.060	Not Enough Potential
Driftsands WWTW	-34.0158, 25.6019	0.229	1-5	1.461	7.306	Potential Site

Site Name	Latitude & Longitude	Flow (m^3/s)	Available Head (m)	Low Potential (kW)	High Potential (kW)	SAHA Classification
Fishwater Flats WWTW	-33.8803, 25.6179	0.833	1-5	5.314	26.569	Potential Site
Fishwater Flats WWTW	-33.8787, 25.6178	0.542	1-5	3.454	17.270	Potential Site
Kelvin Jones WWTW	-33.7822, 25.4254	0.25	1-5	1.594	7.97	Potential Site

The pre-feasibility analysis indicates a hydropower potential of approximately 11.8-59.1 kW from WWTWs within the NMBM (estimated from sites with P > 5 kW only).

6.1.5 Run-of-river (ROR) hydropower

The kW/m map (Figure 6-5) shows the river locations with a kW/km potential exceeding 1 kW/km.

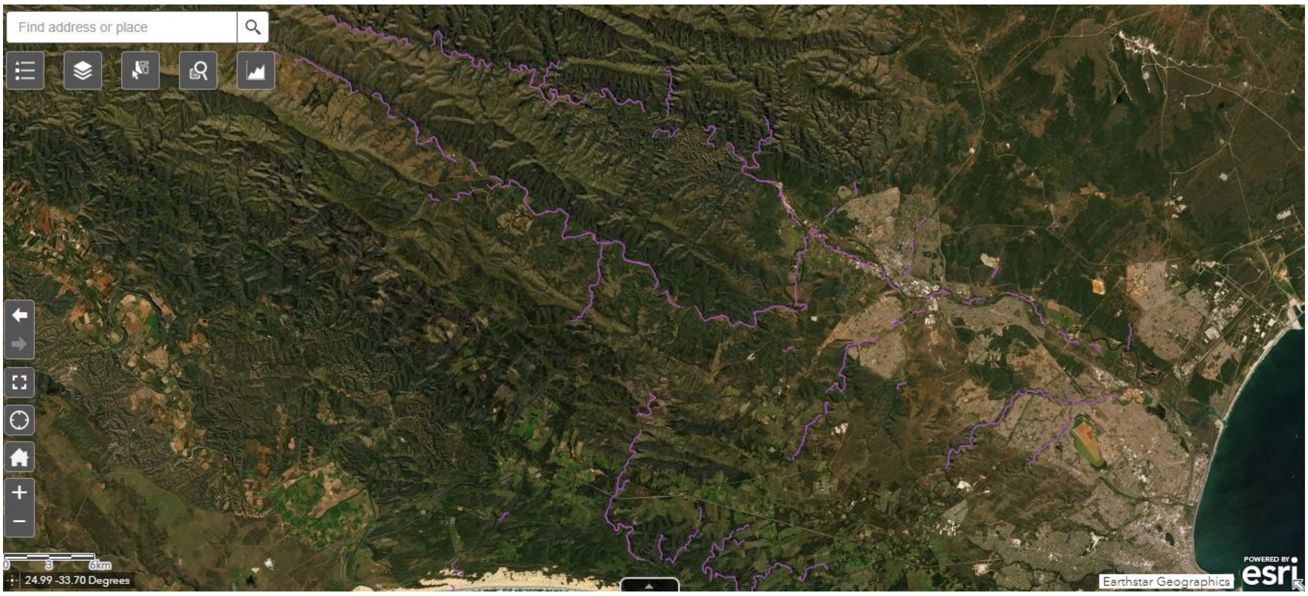


Figure 6-5: ROR potential > 1 kW/km

Locations (Swartkops River) with very high potential (exceeding 5 kW/km) are shown in Figure 6-6. The Swartkops River section between the R334 and R75 was shortlisted for the site visit.

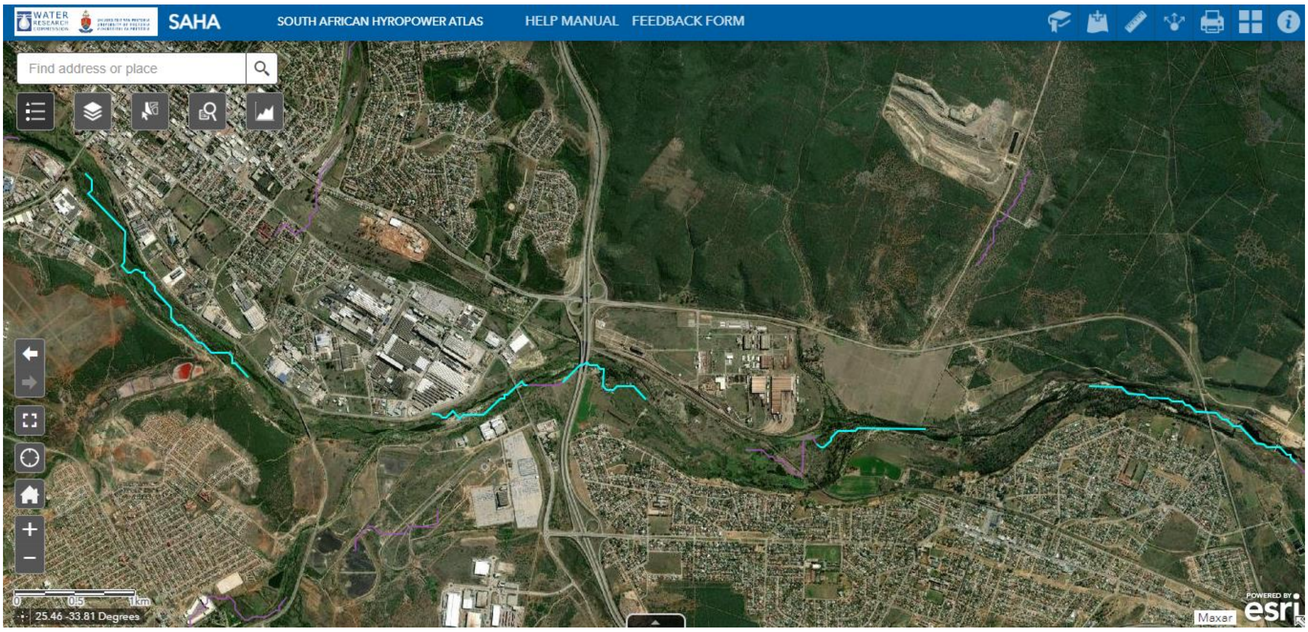


Figure 6-6: River sections with high energy generation potential

6.1.6 Shortlisted hydropower sites

Table 6-4 provides a list with all identified sites with potential exploitable potential. Additional inactive weirs and storage schemes (dams) that were not listed in the SAHA were also added to the list.

Table 6-4: Shortlisted sites for site visit

Type	Site name	Coordinates
WWTW	Driftsands WWTW	-34.01, 25.60
	Fishwater Flats WWTW (1)	-33.88, 25.61
	Fishwater Flats WWTW (2)	-33.87, 25.61
	Kelvin Jones WWTW	-33.78, 25.42
	Cape Receife WWTW	-34.02, 25.68,
	Despatch WWTW	-33.80, 25.49
Weirs	Swartkops River @ Uitenhage (M1H012)	-33.77, 25.39
	Swartkops River @ Uitenhage (M1H011)	-33.78, 25.42
	Swartkops River @ Florida (M1H016)	-33.79, 25.48
WTW	Groenddal WTW	-33.75, 25.38
Rivers	Swartkops River @ Uitenhage	-33.79, 25.41
Dams	Groendal Dam (M1R001)	-33.69, 25.26

As discussed, the municipal hydropower development (spreadsheet-based) tool was applied to the municipality to identify hydropower potential at all sites storing, transporting or treating water. Additionally, the available data sources as discussed were used for parameters estimation and hydropower quantification where applicable.

6.2 PHASE 2: FEASIBILITY STUDY

Phase 2 of the hydropower analysis process, as previously discussed, entails a feasibility analysis based on available information for each site. Comprehensive information was required for each of the 12 sites identified during Phase1 to enable a detailed assessment of the feasibility of each site.

A major challenge during this project was accessing the available information which was difficult to obtain as various parties were involved. This also restricted access to most sites identified during Phase 1, which in turn impacted the evaluations conducted for Phase 2 and Phase 3. This experience, however, proved to be valuable in the development of the municipal assessment tool during this project.

A brief discussion is provided below for some of the shortlisted sites. It was not allowed to take pictures on certain sites.

6.2.1 Fishwater Flats WWTW

The layout of the Fishwater WWTW is shown in Figure 6-7. Fishwater Flats (1) and Fishwater Flats (2), as shortlisted, refer to the 'old' and 'new' sections within the Fishwater Flats WWTW. Based on a brief site visit it was assumed that both sections are still operational and have the same outlet into the ocean as indicated by Figure 6-7. There is an elevation difference between the WWTW and the outlet of approximately 5 m. This corresponds with the upper limit height included in the Phase 1 evaluation framework.

Figure 6-7: Fishwater Flats WWTW layout and identified outlet

No further information regarding treatment capacity or flow records could be obtained. Access to the site could also not be obtained. A summary of the Fishwater Flats WWTW hydropower potential is provided in Table 6-5.

Table 6-5: Summary of Phase 2 analysis for Fishwater Flats

Parameter	Data
Available head	5 m (verified on site)
Available flow	1.37 m^3/s
Hydropower potential	**43.7 kW**
Use for electricity	Yes (On-site)
Space for turbine room	Yes
Feasibility of site	Feasible
Comments	Received cooperation and interest from electrical department. Any information regarding Fishwater Flats WWTW is confidential, and access could not be obtained. Further engagement with the water department is required.

6.2.2 Uitenhage WWTW

The Kelvin Jones WWTW as listed in SAHA was renamed as the Uitenhage WWTW. The layout of the Uitenhage WWTW is shown in Figure 6-8. The layout also indicated two potential locations where hydropower could be generated. As each location there is a vertical drop of approximately 1 m.

Furthermore, the pre-feasibility analysis used a plant design capacity of 24 ML/day (obtained from DWS Green Drop Report), which corresponds to an assumed operational capacity of 21.6 ML/day. However, at the time of the site visit the operational capacity was 15 ML/day. As with Fishwater Flats WWTW no further information could be provided without the appropriate permissions and therefore the WWTW flow record and flow variation throughout the day could not be obtained or established.

Figure 6-8: Uitenhage (Kelvin Jones) WWTW layout and identified outlet

A summary of the Uitenhage WWTW hydropower potential is provided in Table 6-6.

Table 6-6: Summary of Phase 2 analysis for Uitenhage WWTW

Parameter	Data
Available head	1 m (verified on site)
Available flow	0.174 m^3/s
Hydropower potential	**1.1 kW**
Use for electricity	Yes (On-site)
Space for turbine room	Yes
Feasibility of site	Feasible for on-site utilisation only
Comments	Further engagement with the water department is required.

6.2.3 Churchill WTW

No WTW sites were initially listed/identified during the pre-feasibility study, as no sites were within the NMBM municipal boundaries. Identifying the sources of water supply resulted in identifying the various WTWs and their potential. The Churchill Dam supplies the Churchill WTW with water. The WTW as depicted in Figure 6-9 was identified to have a theoretical potential of between 19.9 and 55.7 kW. The available head will be dependent on the water level in the Churchill Dam and the rate of abstraction.

The layout of the Churchill WTW in relation to the Churchill Dam which has an approximate 12 m height difference is depicted in Figure 6-10. The excess pressure (based on 70% of static head) is dissipated at the inlet works and could be potentially used to generate electricity for on-site use.

The current droughts experienced in the Eastern Cape is not a true reflection of the water demands in the Algoa Water Supply System with the normal operating capacity of the WTW at 78%.

Figure 6-9: Churchill WTW layout

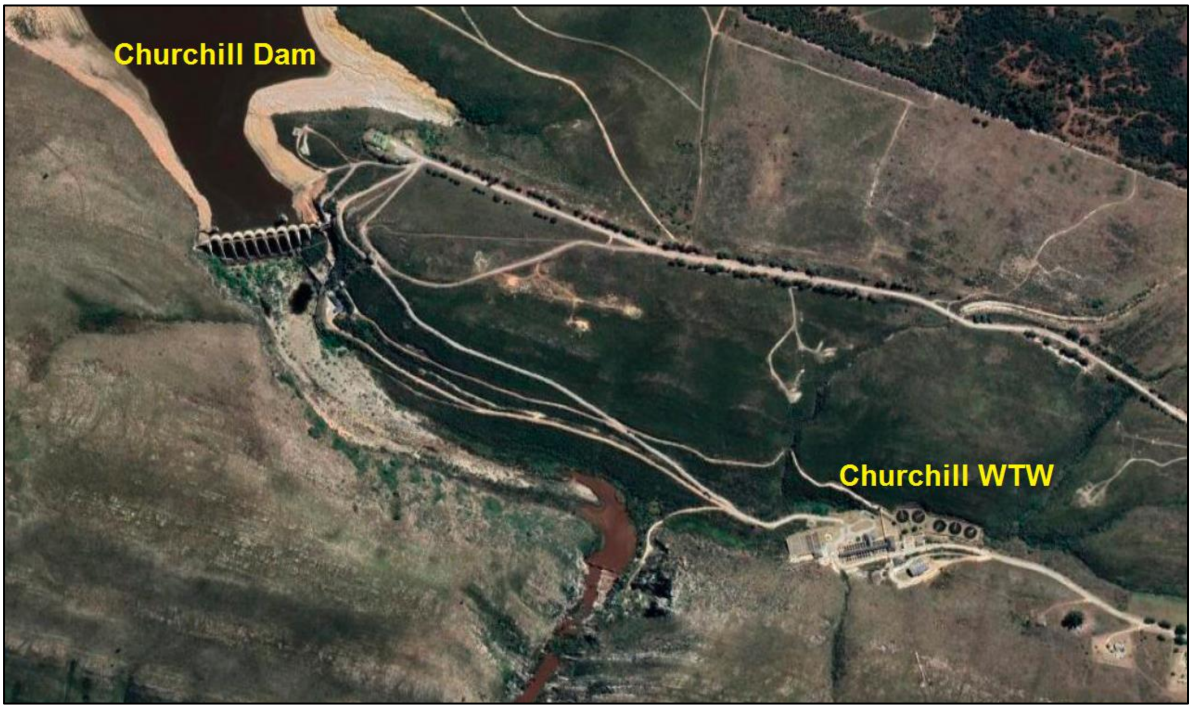


Figure 6-10: Churchill Dam and Churchill WTW

A summary of the Churchill WTW hydropower potential is provided in Table 6-7.

Table 6-7: Summary of Phase 2 analysis for Churchill WTW

Parameter	Data
Available head	8.4 m
Available flow	0.9 m^3/s
Hydropower potential	**55.7 kW**
Use for electricity	Yes (On-site)
Space for turbine room	Yes. If no space in the inlet works then containerised unit could be considered.
Feasibility of site	Feasible for on-site utilisation only
Comments	Further engagement with the water department is required for access to data records. This site seems as if a viable installation could be designed and constructed.

6.2.4 Groendal WTW

No WTW sites were initially listed/identified during the pre-feasibility study, as no sites were within the NMBM municipal boundaries. The WTW as depicted in which could be due to firstly no sites within the NMBM having a first order potential > 5 kW or a lack of available information. The Groendal WTW was initially not listed as a potential site, but later included in Phase 2 assessment.

The layout of the Groendal WTW is shown in Figure 6-11. The water source is the Groendal Dam (Figure 6-12) which is approximately 30 m higher than the Groendal WTW (takings into consideration dam level at 15% of full supply level). The ±21 m excess pressure (based on 70% of static head) is dissipated at the PRS as indicated in figures Figure 6-13and Figure 6-14.

Additionally, the DWS Blue Drop Report indicated a plant design capacity of 20 ML/day with the operation capacity at 55% of the design capacity, i.e. operating at 127 l/s.

Figure 6-11: Groendal WTW layout

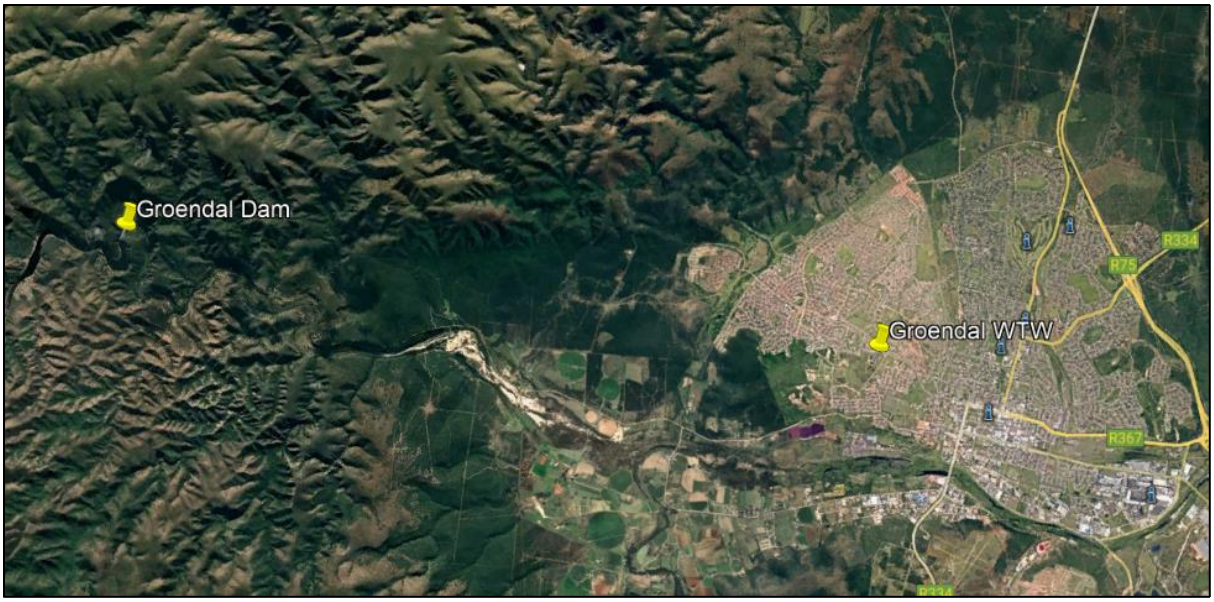


Figure 6-12: Groendal Dam

Figure 6-13: Groendal Dam to Groendal WTW PRS **Figure 6-14: Groendal WTW PRS**

While the accurate identification of the technical potential of a possible hydropower site is crucial, the key to its successful development requires an accurate economic analysis. This is necessary to determine whether the costs incurred for the development of a site can be recovered (ESHA, 2004). The development of any hydropower scheme will include a number of expenses, both initial and throughout the project life, and returns distributed throughout the same period. The expenses include fixed costs (such as capital cost) and variable costs (such as operation and maintenance (O&M) expenses) (ESHA, 2004).

The economics of a small hydro development are crucial in determining overall project feasibility. In some ways, the technical feasibility of a project is more readily established than the financial viability.

The economic and financial considerations necessary for determining project feasibility cannot be viewed as isolated elements or a distinct step in the process. Rather the analyst needs to be constantly mindful of the impacts that a whole range of preliminary decisions arising from the engineering analysis will have on project economics. Depending upon the complexity of the project, it may be necessary to conduct economic assessments at various stages of the project. As more information becomes available from the technical and hydraulic investigations, the quality of the economic analysis will obviously improve and become more detailed.

Still, it would not be appropriate to leave all considerations of economics until after all of the engineering is in hand, since the economic assessments should be used as screening and ranking tools to yield a process of elimination as project alternatives are considered. The economics of the project will be significantly influenced by the technical design, hydraulics and power, and capacity decisions.

However these decisions cannot be made independently from economic considerations. Thus an iterative or staged recognition of economic influences must be built into the feasibility assessment process. Whether the economic assessment is at a conceptual stage or a detailed final feasibility stage, certain data will be required before starting. The basic data requirements are as follows:

- energy and generation capacity estimates for each alternative;
- capital and operating cost estimates for each alternative;
- user demand patterns and growth projections; and
- interest rates and projected future escalation of all rates.

In determining the feasibility of a site conventional economic indicators/parameters are determined:

Static methods of analysis

- Payback period; and
- Return on investment (ROI).

Dynamic economic evaluations

- Present worth of cost (PWOC) technique;
- Net present value (NPV) technique;
- Benefit/cost ratio (B/C) technique;
- Internal rate of return (IRR) technique; and
- Levelised Energy Cost (LEC).

The economic evaluation of this site is described in Table 6-8 and Table 6-9 and indicates that a feasible hydropower plant can be constructed.

The analysis indicates that a viable hydropower plant can be developed with the development cost being approximately R1.57 million. The Internal Rate of Return would be about 19.5% and the scheme would have a payback period of 6.5 years. The benefit/cost ratio for this development would be 2.54. Clean, renewable electricity would be generated at less than 70 c/kWh.

Table 6-8: Economic evaluation of the Groendal WTW hydropower plant

HYDROPOWER ECONOMIC EVALUATION

Groendal Reservoir Hydropower Plant	Cost ID	Comments	Variable	Value	Units
Project Start Date				Jan-23	
Implementation Period				14	months
Project Term				20	years
Total design flow			(Q)	0.127	m^3/s
Design flow corresponding available head			(H)	21.0	m
Efficiency (turbine)				80.0%	
Efficiency (motor)				93.0%	
Overall efficiency				74.4%	
Power Rating (Expected electrical output)				19.5	kW
Nr of turbines				1.0	
Power Rating (Expected electrical output) per unit				19.5	kW
Plant Capacity factor				95.0%	
Suggested turbine type				Francis	
Total annual generating capacity				161.99	MWh/annum
Total annual generating capacity (minus transmission losses)			1%	160.37	MWh/annum
Cost Estimate for the implementation	**Cost ID**	**Comments**			
Professional fees:					
Planning and design costs:					
Prefeasibility Study	P1			R 22 000	**R**
Design	P2	% of Implementation	10.0%	R 115 937	
Legal and regulatory (NERSA, Agreements)	P3		1.0%	R 11 594	
Environmental and social assessment	P4			R 0	
Subtotal A	**A**			**R 149 531**	
Estimated Capital Cost:					
Civil works:					
Preparation of site & contractual P&G	C1			R 47 000	**R**
Construction of turbine room chamber	C2			R 0	
Modifications to outlet works	C3			R 0	
Pipework and valves (supply and install)	C4			R 224 000	
Electro-mechanical Equipment:					
Turbines	E1			R 417 534	**R**
Generators	E2	Included in E1		R 0	
Controls units (HPU, cooling and lubricating etc.)	E3	Included in E1		R 0	
Cost saving if turbine manufactured locally (Assumed 50% of total cost allocated to turbine)			0.0%	R 0	
Transformer cost, power line and integration into electrical grid (Transmission infrastructure)	E4			R 80 000	
Import costs	E5	Import item at rate X2		R 87 682	
Implementation cost:					
Commissioning, erecting and project management provided by the Supplier	I1	Nr of weeks	0.5	R 102 375	**R**
Construction supervision (Consultant)	I2	Nr of Man months	2	R 130 000	
Training	I3			R 28 000	
Spare components to be stored on site	I4	Sum of E1 to E3	3.0%	R 13 779	
Integration of system components (telemetry etc.)	I5			R 29 000	
Subtotal B	**B**			**R 1 159 370**	**R**
Exchange rate - Euro to Rand	X1		R 19.5		**R/Euro**
Importing costs (Customs and transportation)	X2		21.0%		**%**
Total cost (Subtotal A + Subtotal B)				**R 1 308 901**	**R**
Project Management Costs (% of Capex)	M1		9.0%	**R 117 801**	
Contingencies		Sum of C, E, I & M items	10.0%	**R 142 670**	
TOTAL COST				**R 1 569 372**	
Calculated Implementation Cost per installed kW				**R 80 623**	**R/kW**
Notes:					

Table 6-9: Economic indicators of the Groendal WTW hydropower plant

Cost component	Cost ID	Comment	Variable		Units
Operational Cost Estimate:					
Expected Operational Life				20	Years
Project start date				Jan-23	
Start date (generating electricity)				Mar-24	
Time value of money:					
Escalation of Capital costs (C)			5.0%		
Escalation of Operational costs (O)			6.0%		
Escalation of Maintenance cost (M)			7.0%		
Escalation of Other costs (OT)			7.0%		
Escalation of Energy costs			8.0%		
Finance interest rate			7.0%		
Discount rate (Value of Capital)			6.0%		
Annual operation and maintenance cost:		**Note 1**	**% of Capital Cost**	**Cost**	
Civil works	M1		0.50%	R 1 355	
Electrical and mechanical works	M2		2.00%	R 8 351	
Operation	O1		0.40%	R 4 637	
Transmission	OT1		0.80%	R 640	
Insurance	OT2		0.30%	R 3 478	
Subtotal (Annual O&M Costs)				**R 18 461**	**R**
Annual revenue for this development:			R/kWh		
Average value of generated electricity	EI1	**Note 2**	1.44	**R 230 534**	**R**
Investment review					
Net present value of costs				R 2 250 824	**R**
Net present value of income				R 5 718 469	
Total NPV				**R 3 467 645**	
Internal rate of return				**19.45%**	**(%)**
Payback period (from when plant is operational)				**6.50**	**years**
Levelised Cost of energy				**69.47**	**c/kWh**
Notes:					
1. These reflect the normative standard cost as % of Capital value					
2. The average value was calculated using the averaged Megaflex tariffs for 2022/23					

A summary of the Groendal WTW hydropower potential is provided in Table 6-10.

Table 6-10: Summary of Phase 2 analysis for Groendal WTW

Parameter	Data
Available head	21 m
Available flow	0.127 m^3/s
Hydropower potential	**19.6 kW**
Turbine type	Francis
Use for electricity	Yes (On-site)
Space for turbine room	Yes in PRS
Feasibility of site	Feasible for on-site utilisation only
Development cost	R1.57 million
Comments	Further engagement with the water department is required for access to data records. This site seems as if a viable installation could be designed and constructed inside the PRS.

6.2.5 Nooitgedacht WTW

The Nooitgedacht WTW site is being upgraded to utilize more flow from the Gariep Dam. The layout of the Nooitgedacht WTW is shown in Figure 6-15. The water source is the Gariep Dam which transfers water through the Orange Fish Tunnel along the Fishriver system mostly for irrigation purposes.

Some of the water reaches the Scheepersvlakte Dam from where the water is abstracted and conveyed to the Nooitgedacht WTW (Figure 6-16). The height difference between these two locations is approximately 52 m. The ±36 m excess pressure (based on 70% of static head) at an estimated flow rate of 1.83 m^3/s is potentially available to be utilized to generate hydroelectric energy.

Figure 6-15: Nooitgedacht WTW layout

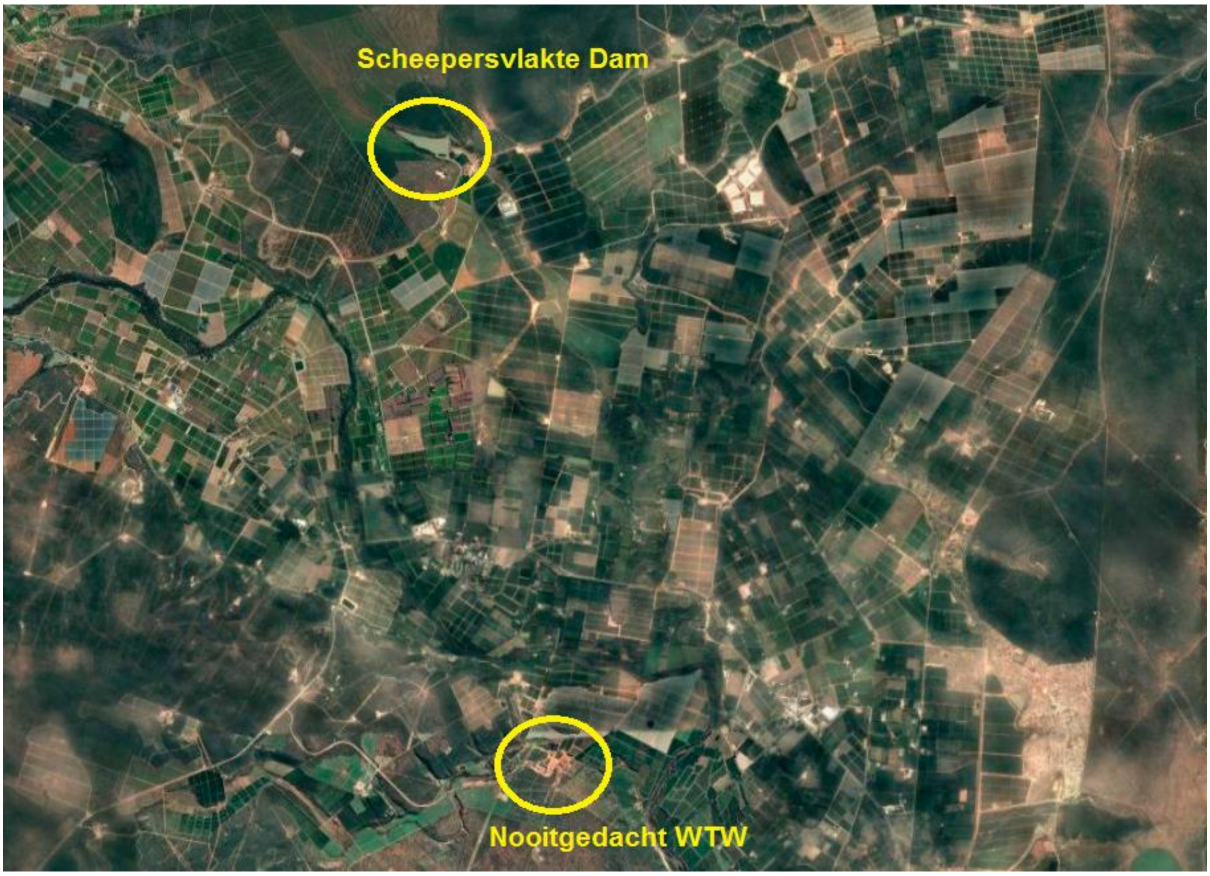


Figure 6-16: Scheepersvlakte Dam to Nooitgedacht WTW

The economic evaluation of this site is described in Table 6-11 and Table 6-12 and indicates that a feasible hydropower plant can be constructed.

The analysis indicates that a viable hydropower plant can be developed with the development cost being approximately R27.8 million. The Internal Rate of Return would be about 26.5% and the scheme would have a payback period of 4.4 years. The benefit/cost ratio for this development would be 3.69. Clean, renewable electricity would be generated at less than 50 c/kWh.

Table 6-11: Economic evaluation of the Nooitgedacht WTW hydropower plant

HYDROPOWER ECONOMIC EVALUATION

Nooitgedacht WTW Hydropower Plant			Variable	Value	Units
Project Start Date				Jan-23	
Implementation Period				20	months
Project Term				20	years
Total design flow			(Q)	1.833	m^3/s
Design flow corresponding available head			(H)	36.4	m
Efficiency (turbine)				80.0%	
Efficiency (motor)				95.0%	
Overall efficiency				76.0%	
Power Rating (Expected electrical output)				497.4	kW
Nr of turbines				1.0	
Power Rating (Expected electrical output) per unit				497.4	kW
Plant Capacity factor				95.0%	
Suggested turbine type				Francis	
Total annual generating capacity				4139.75	MWh/annum
Total annual generating capacity (minus transmission losses)			1%	4098.35	MWh/annum
Cost Estimate for the implementation	**Cost ID**	**Comments**			
Professional fees:					
Planning and design costs:					
Prefeasibility Study	P1			R 125 000	**R**
Design	P2	% of Implementation	11.0%	R 2 258 039	
Legal and regulatory (NERSA, Agreements)	P3		1.0%	R 205 276	
Environmental and social assessment	P4			R 85 000	
Subtotal A	**A**			**R 2 673 315**	
Estimated Capital Cost:					
Civil works:					
Preparation of site & contractual P&G	C1			R 740 000	**R**
Construction of turbine room chamber	C2			R 1 450 000	
Modifications to outlet works	C3			R 885 000	
Pipework and valves (supply and install)	C4			R 2 450 000	
Electro-mechanical Equipment:					
Turbines	E1			R 11 155 240	**R**
Generators	E2	Included in E1		R 0	
Controls units (HPU, cooling and lubricating etc.)	E3	Included in E1		R 0	
Cost saving if turbine manufactured locally (Assumed 50% of total cost allocated to turbine)			15.0%	-R 836 643	
Transformer cost, power line and integration into electrical grid (Transmission infrastructure)	E4			R 650 000	
Import costs	E5	Import item at rate X2		R 2 166 905	
Implementation cost:					
Commissioning, erecting and project management provided by the Supplier	I1	Nr of weeks	3	R 819 000	**R**
Construction supervision (Consultant)	I2	Nr of Man months	6	R 450 000	
Training	I3			R 145 000	
Spare components to be stored on site	I4	Sum of E1 to E3	3.0%	R 368 123	
Integration of system components (telemetry etc.)	I5			R 85 000	
Subtotal B	**B**			**R 20 527 625**	**R**
Exchange rate - Euro to Rand	X1		R 19.5		**R/Euro**
Importing costs (Customs and transportation)	X2		21.0%		**%**
Total cost (Subtotal A + Subtotal B)				**R 23 200 940**	**R**
Project Management Costs (% of Capex)	M1		9.0%	**R 2 088 085**	
Contingencies		Sum of C, E, I & M items	10.0%	**R 2 528 902**	
TOTAL COST				**R 27 817 927**	
Calculated Implementation Cost per installed kW				**R 55 921**	**R/kW**
Notes:					

Table 6-12: Economic indicators of the Nooitgedacht WTW hydropower plant

Cost component	Cost ID	Comment	Variable		Units
Operational Cost Estimate:					
Expected Operational Life				20	Years
Project start date				Jan-23	
Start date (generating electricity)				Aug-24	
Time value of money:					
Escalation of Capital costs (C)			5.0%		
Escalation of Operational costs (O)			6.0%		
Escalation of Maintenance cost (M)			7.0%		
Escalation of Other costs (OT)			7.0%		
Escalation of Energy costs			8.0%		
Finance interest rate			7.0%		
Discount rate (Value of Capital)			6.0%		
Annual operation and maintenance cost:		**Note 1**	**% of Capital Cost**	**Cost**	
Civil works	M1		0.50%	R 27 625	
Electrical and mechanical works	M2		2.00%	R 223 105	
Operation	O1		0.40%	R 82 110	
Transmission	OT1		0.80%	R 5 200	
Insurance	OT2		0.30%	R 61 583	
Subtotal (Annual O&M Costs)				**R 399 623**	**R**
Annual revenue for this development:			R/kWh		
Average value of generated electricity	EI1	**Note 2**	1.44	**R 5 891 382**	**R**
Investment review					
Net present value of costs				R 39 981 165	**R**
Net present value of income				R 147 509 570	
Total NPV				**R 107 528 405**	
Internal rate of return				**26.47%**	**(%)**
Payback period (from when plant is operational)				**4.42**	**years**
Levelised Cost of energy				**48.29**	**c/kWh**
Notes:					
1. These reflect the normative standard cost as % of Capital value					
2. The average value was calculated using the averaged Megaflex tariffs for 2022/23					

A summary of the Nooitgedacht WTW hydropower potential is provided in Table 6-13.

Table 6-13: Summary of Phase 2 analysis for Nooitgedacht WTW

Parameter	Data
Available head	36.4 m
Available flow	1.833 m^3/s
Hydropower potential	**490.8 kW**
Use for electricity	Yes (On-site)
Turbine type	Francis
Space for turbine room	Yes. If no space in the inlet works then containerised unit could be considered.
Feasibility of site	Feasible for on-site utilisation
Development cost	R27.82 million
Comments	Further engagement with the water department is required for access to data records. This site seems as if a viable installation could be designed and constructed.

An example of the layout of a horizontal Francis type turbine installation is depicted in Figure 6-17 and Figure 6-18.

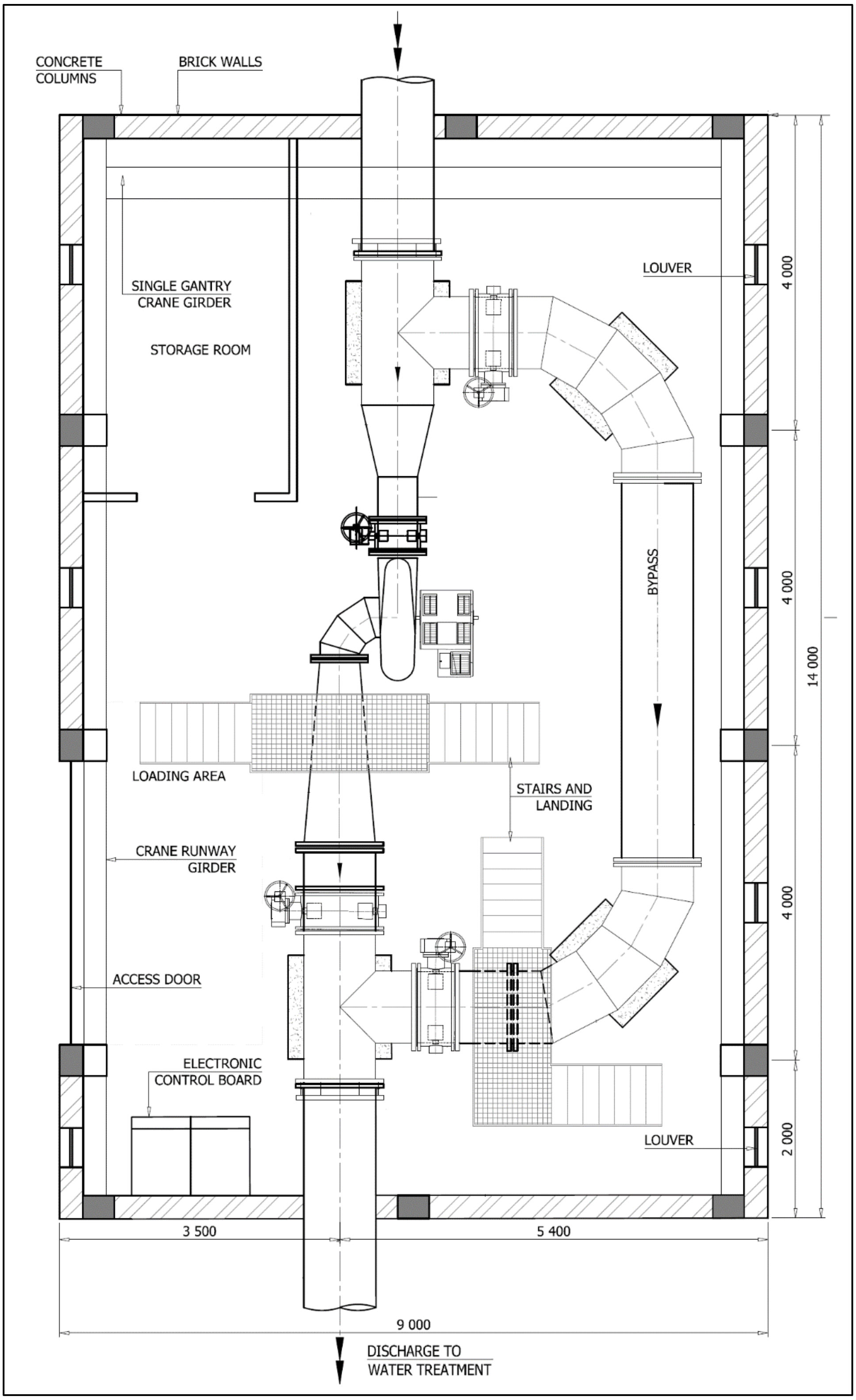


Figure 6-17: Example installation for horizontal Francis installation (Nooitgedacht WTW) – Plan View

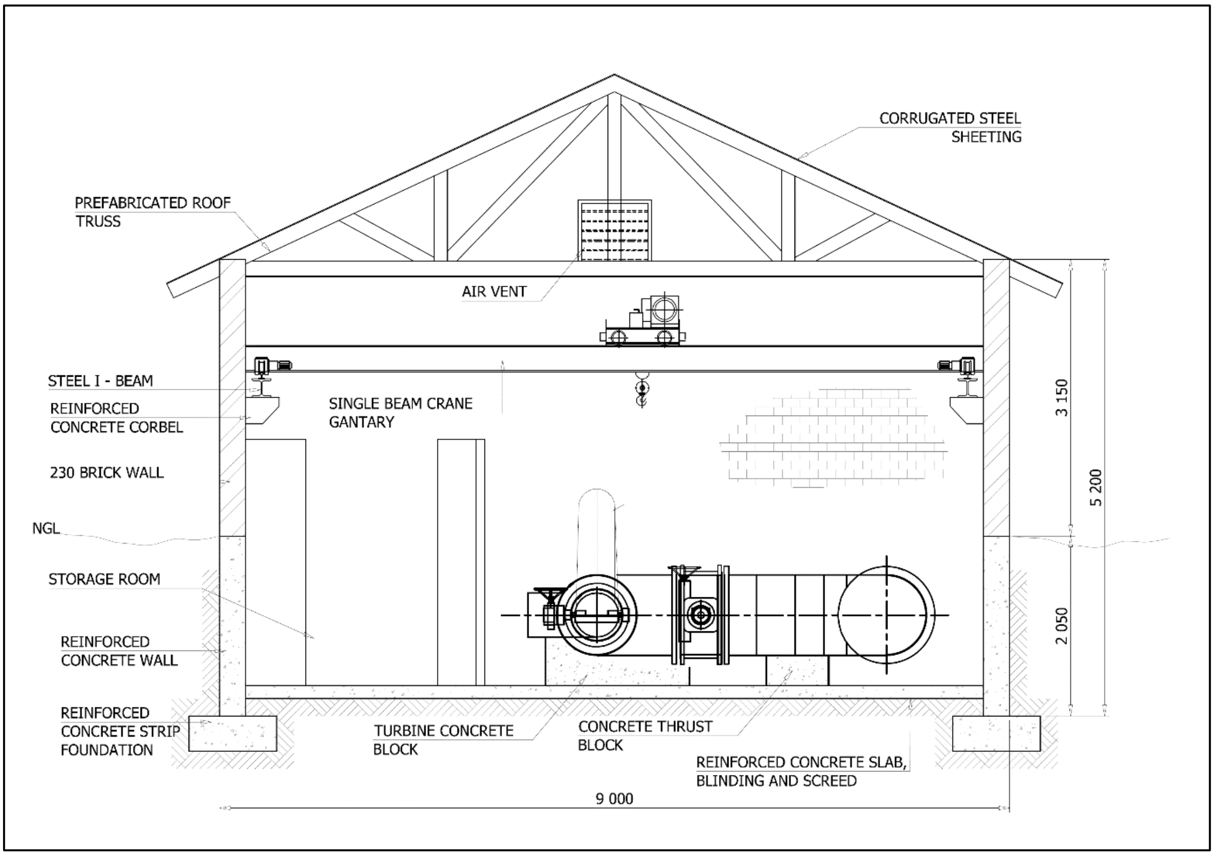


Figure 6-18: Example installation for horizontal Francis installation (Nooitgedacht WTW) – Side View

7. MUNICIPAL EVALUATION TOOL

One of the objectives of the project was the development of an evaluation tool used by Municipalities to identify hydropower potential within their infrastructure and rivers. With the development of the hydropower evaluation tool, more municipalities will be made aware of the potential and the process involved in developing such technologies, thereby enhancing the uptake of this type of renewable energy technology in South Africa's water infrastructure and river.

A simplified spreadsheet-based tool was developed based on the generic evaluation frameworks as discussed in Section 5.2.2. The tool therefore can also be utilised to estimate flow and head parameters when the necessary flow and head data is not available.

The tool is simple to use and does not require the user to have a technical background. Guidelines are provided regarding what data inputs are required, if the potential cannot be calculated due to a missing input, or if a site is simply not feasible, which will be further discussed in this section.

Figure 7-1 shows the initial questionnaire that should be completed before starting with the technical feasibility of a specific site. The initial questionnaire is a short form asking for the details of the necessary contact persons within the Municipality, which typically includes all departments that need to be involved in the development of a municipal hydropower project (e.g. water department, electrical department, etc.). The creation of the initial questionnaire emanated from the Baakens River hydropower analysis where the analysis of most shortlisted sites was restricted due to issues regarding access to site and access to available data. It is therefore recommended to ensure that necessary data and permissions have been obtained before proceeding with the initial hydropower analysis of any site.

Municipal Hydropower Identification Tool: Initial Questionnaire			
Date			
Municipality name			
Necessary contact persons within Municipality	**Name and Surname**	**Title/Rank**	**Contact Details**
Water Department/Division			
Electricity Department/Division			
Pre-feasibility check	**Answer**	**Status/Feedback**	
Can necessary data/permissions be obtained (flow data, head data, access to site etc.)?	Yes	Site should be assessed for hydropower potential	
Is site accessible?	Yes	Site should be assessed for hydropower potential	
Is there a use for the electricity generated?	Yes	Site should be assessed for hydropower potential	
Are there utilisation agreements between relevant parties of the Municipality (Water Department, Electricity Department etc.)	Yes	Site should be assessed for hydropower potential	

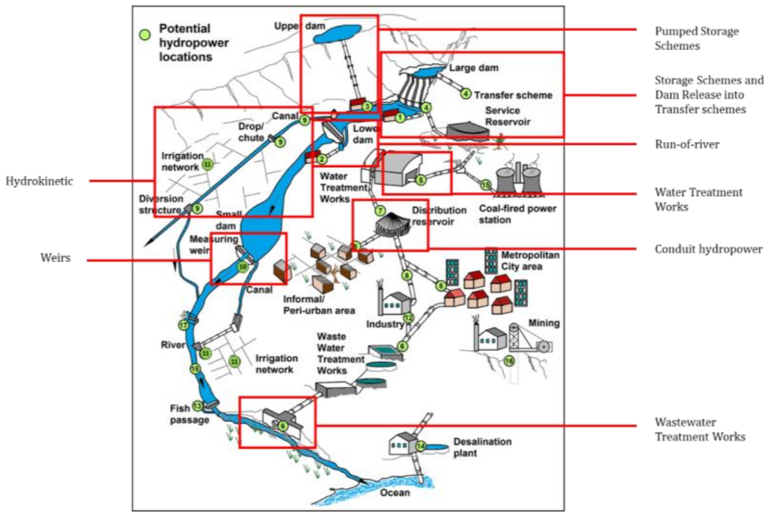
Figure 7-1: Municipal evaluation tool – Initial questionnaire

The hydropower analysis section of the tool first entails the identification of the hydropower type. A simple guideline is provided in the tool (Figure 7-2) to enable the classification of the hydropower type.

Furthermore, the hydropower classification guideline provides a form reference to indicate which form should be used to evaluate the hydropower potential of a specific site. The forms for all hydropower types considered (WWTW, WTW, conduit, hydrokinetic, run-of-river, weirs and storage schemes) are shown in Figure 7-3 to Figure 7-9. The forms were developed to automate the calculation process, guide the user in terms of the data required and automatically apply a criterion if a specific input is unknown. The final feasibility result is provided for each form based on the pre-defined criteria as discussed in Section 5.2.2. The user will also be notified if the potential cannot be calculated due to an input value being required.

Lastly a very simple tool was developed to calculate the average flow from a DWS dataset. The tool requires the user to download flow data from the DWS website and save it as a text format. The tool automatically extracts the data from the specified flow path, sorts and analyse the data to return an average flow available for hydropower potential. The return flow is the flow at 70% exceedance probability. The Flow Calculation Tool (FCT) is shown in Figure 7-5 and has been incorporated in the Municipal evaluation tool.

HYDROPOWER CLASSIFICATION GUIDELINE



Infrastructure Type	Hydropower Type Classification	Form
Storage scheme (Dam)	Storage Scheme	1
River	Hydrokinetic	2
	Run-of-river	3
Gauging Structure or Weir	Weir	4
Canal	Hydrokinetic	2
Wastewater Treatment Works	WWTW	5
Water Treatment Works	WTW	6
Water distribution system (Pressure reducing station)	Conduit	7

Figure 7-2: Municipal evaluation tool – hydropower classification guideline

FORM 1: STORAGE SCHEMES

DWS Gauging Station*		
Wall height*		m
Average Flow from DWS flow data*		m^3/s
Corresponding depth above spillway for Average Flow *		m
Estimated Head	Need to specify both WALL HEIGHT and DEPTH ABOVE SPILLWAY	m
Theoretical Potential	Potential can't be calculted	kW
Pre-feasibility result	**Potential can't be calculated**	

For more information on potential calculation please refer to sheet* ***Storge Schemes*

Figure 7-3: Municipal evaluation tool – Storage scheme

FORM 4: WEIR		
DWS Gauging Station*		
Weir Height* *(-1 if unknown)*		m
Average Flow from DWS flow data* *(Use FCT for analysis to calculate average flow from specified DWS dataset or use flow map)*		m^3/s
(IF WEIR HEIGHT IS UNKNOWN)		
Estimated Head	Weir Height Known	m
Theoretical Potential	Flow needs to be specified	kW
Pre-feasibility result	Potential can't be calculated	

For more information on potential calculation please refer to sheet* ***Weirs*

Figure 7-4: Municipal evaluation tool – Weir

FLOW CALCULATION TOOL

Project Name	
DWS Station Number	
Date	
River Name	

FLOW PARAMETER

DWS File Path	C:\Users\Anja Bekker\Desktop\Weir raw data/A1H001.txt	
	Show example of .txt file format	
Estimated Flow		m^3/s

Calculate First Order Estimate

Reset Tool

Figure 7-5: Flow calculation tool

FORM 5: WWTW		
Design capacity of Plant		ML/day
Operational capacity of Plant *(-1 If unknown)*		%
Available flow	Pant design capacity and or operational capacity need to be specified	m^3/s
Available Head *(-1 if unknown)*		m
(IF AVAILABLE HEAD IS UNKNOWN)		
Estimated Head	Available Head Known	m
Theoretical Potential	Plant design capacity needs to be specified	kW
Pre-feasibility result	Potential can't be calculated	

For more information on potential calculation please refer to sheet* ***WWTW*

Figure 7-6: Municipal evaluation tool – WWTW

FORM 2: HYDROKINETIC		
RIVERS		
DWS Gauging station*		
Average flow* *(Use FCT for analysis to calculate average flow from specified DWS dataset or use flow map)*		m^3/s
Flow depth corresponding with average flow* *(-1 if unknown)*		m
(IF FLOW DEPTH UNKNOWN)		
Assumed flow depth	Please specify flow	m
Flow area based on abovementioned flow depth* *(-1 if unknown)*		m^2
(IF FLOW AREA UNKNOWN)		
River width*		m
Estimated river area	Flow area known or not specified as unknown	m^2
Turbine swept area	Please specify flow depth	m^2
Flow velocity	Please specify average flow	m/s
Theoretical Potential	Not enough information was provided to calculate	kW
Pre-feasibility result	**Not enough information was provided to calculate potential**	
CANALS/CHANNELS		
DWS Gauging station*		
Average flow* *(Use FCT for analysis to calculate average flow from specified DWS dataset or use flow map)*		m^3/s
Flow depth corresponding with average flow* *(-1 if unknown)*		m
(IF FLOW DEPTH UNKNOWN)		
Assumed flow depth	Please specify flow	m
Flow area based on abovementioned flow depth* *(-1 if unknown)*		m^2
(IF FLOW AREA UNKNOWN)		
Channel Slope* *(Obtain from DEM)*		m/m
Manning's N-value	0.017	$s/m^{1/3}$
Channel width* *(Calculate using Manning's Equation)*		m
Estimated channel area	Flow area known or not specified as unknown	m^2
Turbine swept area	Please specify flow depth	m^2
Flow velocity	Please specify average flow	m/s
Theoretical Potential	Not enough information was provided to calculate potential	kW
Pre-feasibility result	**Not enough information was provided to calculate potential**	

For more information on potential calculation please refer to sheet* ***Hydrokinetic*

Figure 7-7: Municipal evaluation tool – Hydrokinetic

FORM 6: WTW		
Design capacity of Plant*		ML/day
Operational capacity of Plant* *(-1 If unknown)*		%
Available flow	Pant design capacity and or operational capacity need to be specified	m^3/s
Available Head* *(-1 if unknown)*		m
(IF AVAILABLE HEAD IS UNKNOWN)		
Estimated Head	Available Head Known	m
Theoretical Potential	Plant design capacity needs to be specified	kW
Pre-feasibility result	Potential can't be calculated	
For more information on potential calculation please refer to sheet **WTW*		

Figure 7-8: Municipal evaluation tool – WTW

FORM 7: CONDUIT HYDROPOWER		
Average Flow*		m^3/s
Average Head*		m
(IF HEAD AND FLOW UNKNOWN)		
Static Head*		m
PRV Size*		mm
Estimated Head	Average Head Known	m
Estimated Flow	Average Flow Known	m^3/s
Theoretical Potential	0	kW
Pre-feasibility result	**Not enough potential - Abort**	
For more information on potential calculation please refer to sheet **Conduit Hydropower*		

Figure 7-9: Municipal evaluation tool – Conduit

8. CONCLUSIONS

Due to the low cost and high availability of coal, electricity generation in South Africa is heavily dependent on this fossil fuel, with the majority of the country's electricity generated in coal fired power stations. With a global shift towards greater concern for the environment, the use of fossil fuels in generating electricity is becoming increasingly unfavourable, because of its production of greenhouse gases and their contribution to global warming. Worldwide, alternative methods involving the use of inexhaustible natural flows of energy to generate electricity are being investigated to determine the feasibility of using renewable energy technologies to generate electricity.

A municipal hydropower development tool was developed to assist municipalities with the identification and development of hydropower sites. The tool was developed based on three phases involved in the hydropower development process: Phase 1: Pre-feasibility, Phase 2: Feasibility and Phase 3: Detailed design. The aim is to provide municipalities with a template of the process required to identify, evaluate and design a hydropower plant in their municipal area.

The NMBM was used as a case study to test the development tool and identify potential sites. It is recommended that the Groendal Reservoir site be developed by NMBM to demonstrate the process and efficacy thereof in reducing the operating costs of the WTW. There are other sites which were also identified that have feasible potential and could be developed as a next phase.

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APPENDIX A

Turbine Supplier Details

INTRODUCTION

Hydropower potential has, until recently, mostly been contributed to high head, high flow applications, for example at dams. With the increased interest in renewable energy, hydropower has been forced to become more diverse in its application. Some of the applications of hydropower that currently enjoy increased attention include hydropower from distribution systems, hydropower at reservoir inlets and low head hydropower.

Low head hydropower refers to electricity generated from large volumes of water at relatively low pressure head. This application of hydropower is found in rivers or irrigational canals and is applicable to sites with less than 5 metres of head (Campbell, 2010).

In this report technology, more specifically turbines, available for the application of low head hydropower will be evaluated and listed. Available pressure head requirements of up to 20 metres will be considered since slightly elevated penstocks will also be incorporated in the study.

Turbines are divided into two broad categories, namely impulse and reaction. Impulse type turbines are more suited to high head applications where reaction type turbines are widely used for low head sites. **Table A1** graphically indicates how the different turbine types are divided into the two categories.

Table A1: Groups of Water Turbines (Adapted from NRC, 2004)

Turbine Runner	**High Head**	**Medium Head**	**Low Head**	**Ultra-Low Head**
	> 100m	**20-100m**	**5-20m**	**< 5m**
Impulse	Pelton Turgo	Cross-flow Turgo Multi-jet Pelton	Cross-flow Multi-jet Turgo	Water wheel Screw Type Hydrokinetic
Reaction	-	Francis Pump-as-Turbine	Propeller Kaplan	Propeller Kaplan

This document discusses several examples of low head turbines. Different types and manufacturers have been included, with contact details. It is important to note that all information was directly sourced from manufacturer – and supplier websites and therefore the source of each table is the included website reference. **Table A2** and **Table A3** summarise the appendix layout, with turbines color-coded according to type, name and manufacturer.

Table A2: Layout of Appendix A: Impulse turbines

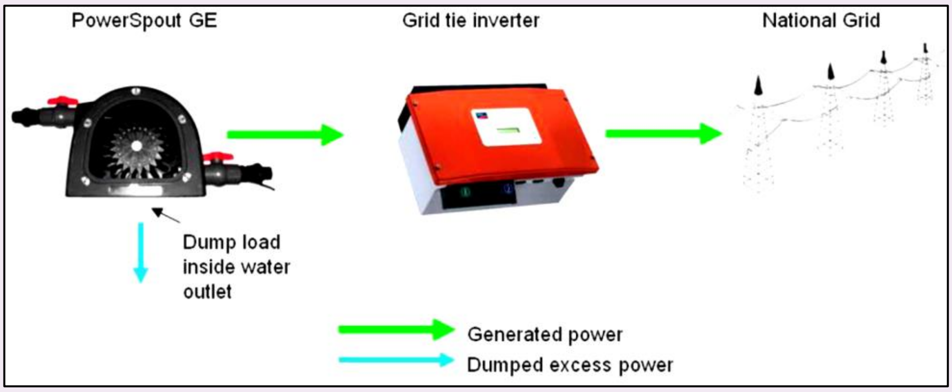
Turbine group	Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power (kW)
Impulse	Pelton	Powerspout	0.008-0.01	3-100	<1.6
		IREM			
	Crossflow	IREM	0.01-1	5-60	<100
		Ossberger	0.04-13	2.5-200	15-3 000
		Wasserkraft Volk	1.5-150	Not given	<2 000
	Hydroengine	Natel energy	1.1-10.1	< 6	50-500
	Hydrodynamic Screw	Andritz	<10	<10	<500
		HydroCoil	<10	4-20	2-8
		3Helix Power	0.2-10	1-10	1.4-700
	Waterwheel	Hydrowatt	0.1-5	1-10	1.5-200
	Hydrokinetic	Alternate hydro	>0.8 m/s	>0.6	1-4
		New energy	2.4-3 m/s	Not given	5-25
		Hydrovolts	1.5-3 m/s	0.15	1.5-12
	Vortex	Zotloeterer	0.05-20	0.7-2	0.5-160
	Steffturbine	Walter Reist	<0.4 (m^3/s)	2.5-5	10

Table A3: Layout of Appendix A: Reaction turbines

Turbine group	Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power (kW)
Reaction	Kaplan	Ossberger	1.5-60	1.5-20	20-35 00
		Mavel	0.3-150	1.5-35	30-20 000
		Voith	Not given	3-95	100-400 000
		Tamanini	0.2-15.0	5-35	10-5 000
		Power Pal	0.04-0.13	1.5	0.2-1
	Turbinator	Clean Power AS	0.5-12	10-60	75-3 300
	Bulb	Alstom	0.3-150	2-30	<130 000
		Voith	2-30	Not given	1 000-80 000
		Voith (MiniHydro)	1-14	2-10	Not given
	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	5-1 000 000
		Tamanini	0.2-10	15-300	10-10 000
	Syphon-turbine	Mavel	0.15-4.5	1.5-6	1-180
	Inline Turbines	Kawasaki Ring	0.14-2.8	3-30	20-500
		Hydro E-Kids	0.1-3.5	2-15	5-200
		Lucidpipe Spherical	1-5.6	0.5-10	14-100
	Moveable Power House	Ossberger Canada	1-25	1-8	350-2 000
	Pump as turbine	Andritz	0.03-6	3-80	3-10 000

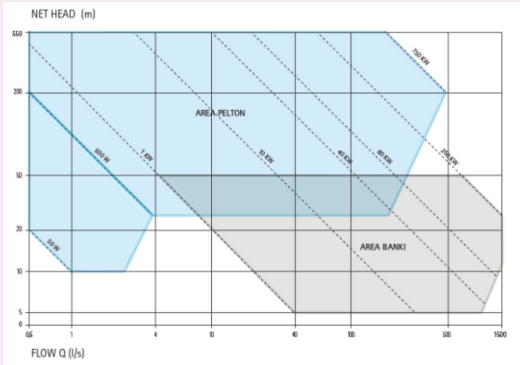
IMPULSE TYPE TURBINES

Turbine Name	**POWERSPOUT PELTON TURBINE**
Company name	**POWERSPOUT** (**Papersmith and Son (PTY) Ltd**. (South African Distribution))
Company Address	PO BOX 72548 Parkview GT 2122 SOUTH AFRICA
Company Tel	+27 011 2406900
Company E-mail	jo@papersmith.co.za
Website	www.powerspout.com
Turbine Description	Powerspout Pelton turbines are made from more than 60% recycled material. This pico turbine can be installed in series to generate up to 16 kW.
Pressure Head Range	3 m to 100 m
Flow Range	0.008 m^3/s to 0.01 m^3/s
Power Range	Up to 1.6 kW per turbine
Illustrations, Photos and Applicable Graphs	 *Pelton runner*  *Powerspout turbine room*

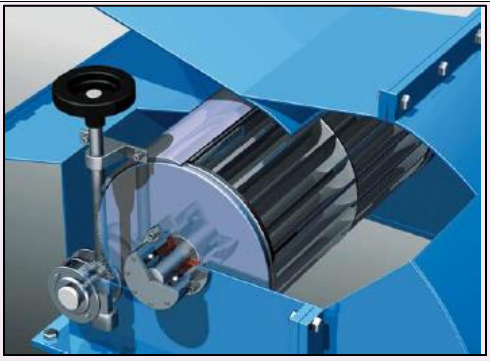
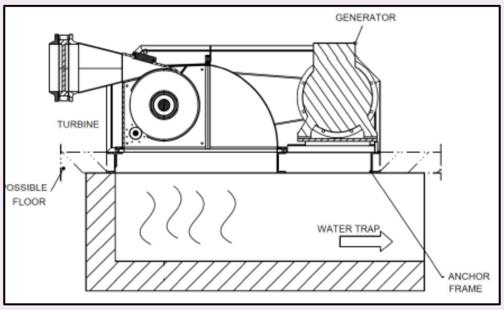
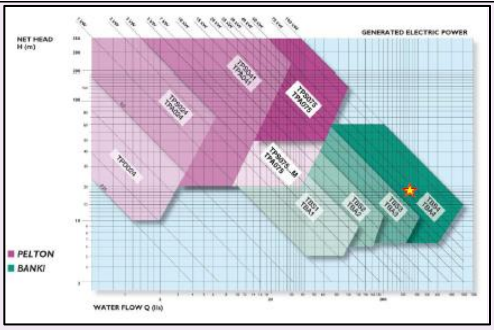


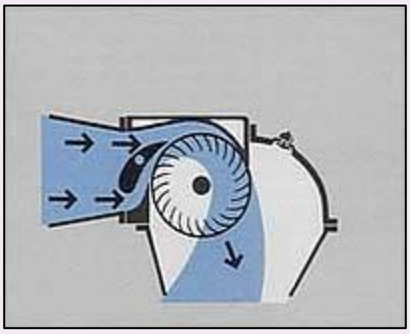
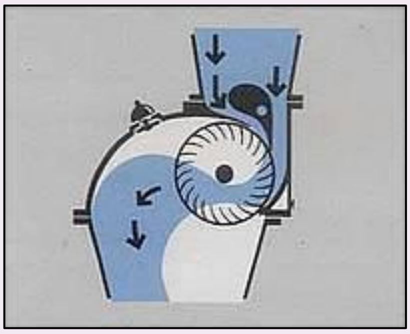
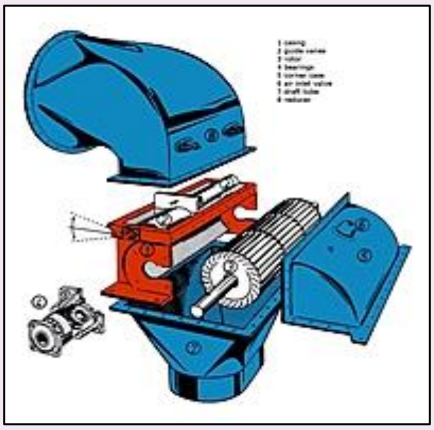
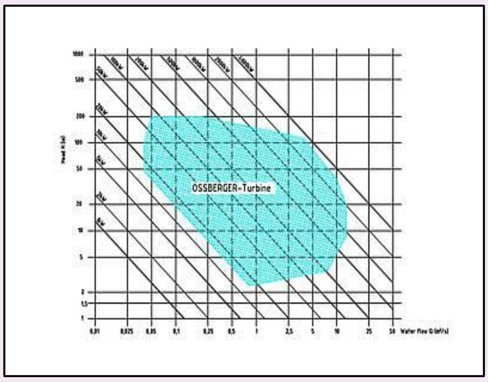
Turbine set-up

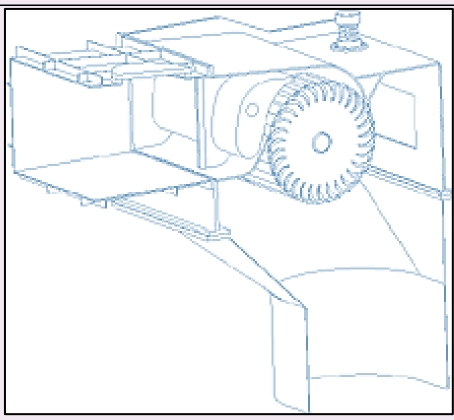
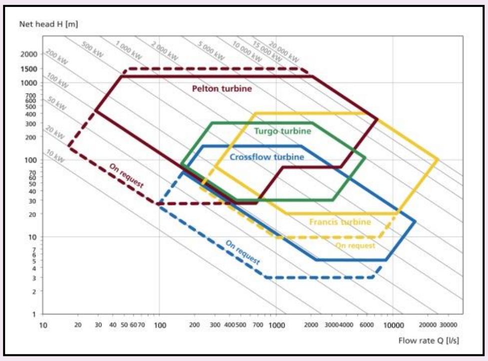
Turbine Name	**PELTON TURBINE**
Company name	**IREM SpA a Socio Unico**
Company Address	Via Abegg 75 Borgone Susa ITALY 10500
Company Tel	+39 011 9648211
Company E-mail	irem@irem.it
Website	www.irem.it
Turbine Description	The IREM Pelton turbine is connected to a belt driven synchronous or asynchronous generator shaft, depending on the electricity use.
Pressure Head Range	10 m to 550 m
Flow Range	0.005 m^3/s to 0.5 m^3/s
Power Range	Up to 750 kW
Illustrations, Photos and Applicable Graphs	 

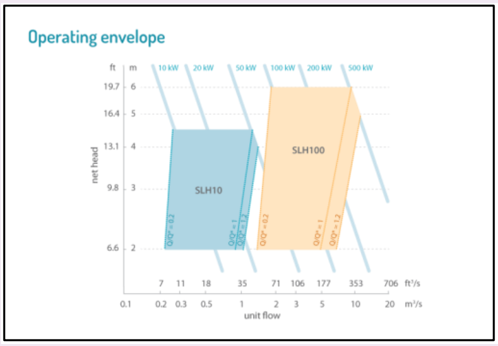
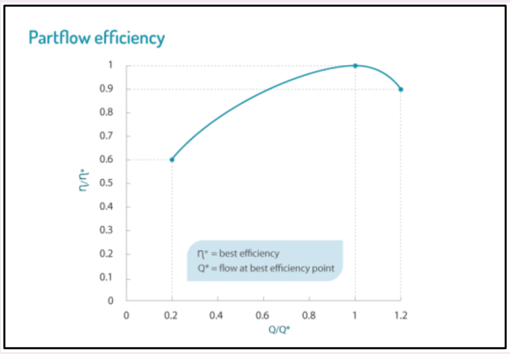
	Pelton runner	*Pelton turbine*
	 *Turbine set-up*	 *IREM turbine range*

Turbine Name	**BANKI (CROSSFLOW) TURBINE**
Company name	**IREM SpA a Socio Unico**
Company Address	Via Abegg 75 Borgone Susa ITALY 10500
Company Tel	+39 011 9648211
Company E-mail	irem@irem.it
Website	www.irem.it
Turbine Description	The IREM Banki turbine is connected to a belt driven synchronous or asynchronous generator shaft, depending on the electricity use.
Pressure Head Range	5 m to 60 m
Flow Range	0.01 m^3/s to 1 m^3/s
Power Range	Up to 100 kW

Illustrations, Photos and Applicable Graphs	 *Banki runner*	 *Banki turbine*
	 *Turbine set-up*	 *IREM turbine range*

Turbine Name	**OSSBERGER-TURBINE**
Company name	**OSSBERGER GmbH + Co**
Company Address	Otto-Rieder-Str. 7 91781 Weissenburg / Bavaria GERMANY
Company Tel	+49 (0)9141/977-0
Company E-mail	info@ossberger.de
Website	www.ossberger.de/cms/pt/hydro/contact/
Turbine Description	Ossberger turbines are designed so that water passes through the runner twice.
Pressure Head Range	2.5 m to 200 m
Flow Range	0.04 m^3/s to 13 m^3/s
Power Range	15 kW to 3 000 kW
Illustrations, Photos and Applicable Graphs	 *Inflow horizontal*  *Inflow vertical*  *Two-cell Ossberger turbine*  *Turbine range*

Turbine Name	**CROSSFLOW TURBINE**
Company name	**Wasserkraft Volk AG**
Company Address	Am Stollen 13 D-79261 Gutach GERMANY
Company Tel	+49 7685-9106-0
Company E-mail	mail@wkv-ag.com
Website	www.wkv-ag.com
Turbine Description	These turbines have high efficiencies down to 17% of design flow. They offer an economic solution, have easily accessible inspection ports and hatches and with bearings rated for more than 100 000 operating hours.
Pressure Head Range	1.5 m to 150 m
Flow Range	Not given
Power Range	Up to 2 000 kW
Illustrations, Photos and Applicable Graphs	 *Crossflow turbine room*  *Crossflow turbine wheel*  *Typical turbine drawing*  *Wasserkraft Volk turbine ranges*

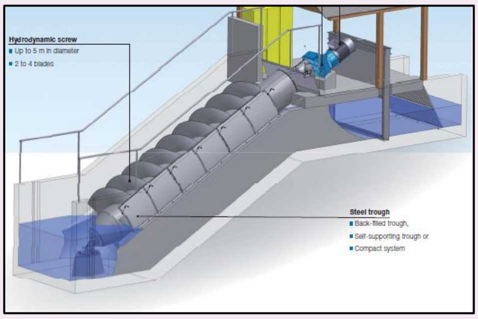
Turbine Name	**HYDROENGINE (SLH10 AND SLH 100)**
Company name	**Natel Energy**
Company Address	2175 Monarch Street Alameda, CA 94501
Company Tel	(506)-984-3639
Company E-mail	gia@natelenergy.com
Website	www.natelenergy.com
Turbine Description	Natel Energy's hydroengine is a unique design using the uplift created as water passes by curved blades.
Pressure Head Range	SLH10 & SLH100 – up to 6 m
Flow Range	SLH10 – up to 1.1 m^3/s SLH100 – up to 10.1 m^3/s
Power Range	SLH10 – up to 50 kW SLH100 – up to 500 kW
Illustrations, Photos and Applicable Graphs	 *Flow ranges*  *Partflow efficiencies*  *Hydroengine cross section*  *Pilot installation*

Turbine Name	**HYDRODYNAMIC SCREW**
Company name	**ANDRITZ Atro**
Company Address	Penzinger Strasse 76 Vienna AUSTRIA 1141
Company Tel	+43 (1)891 00 0
Company E-mail	hydro@andritz.com
Website	www.andritz.com
Turbine Description	This turbine is based on the Archimedean screw and is applicable to very low head open water installations. No control system is necessary. Simple installation and maintenance procedures apply.
Pressure Head Range	Up to 10 m
Flow Range	Up to 10 m^3/s
Power Range	Up to 500 kW

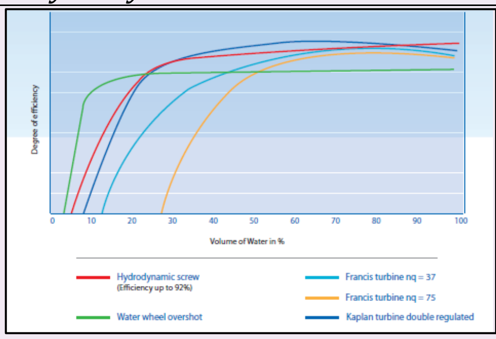
Illustrations, Photos and Applicable Graphs

Hydrodynamic Screw

Hydrodynamic screw installation



Typical layout

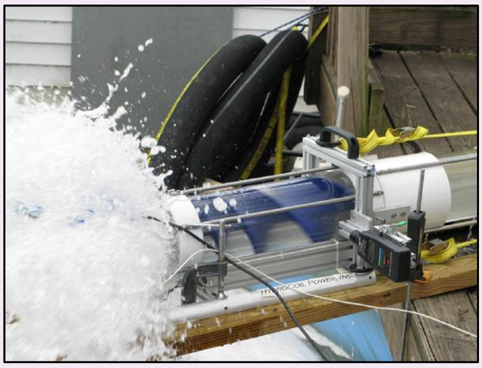


Turbine efficiency

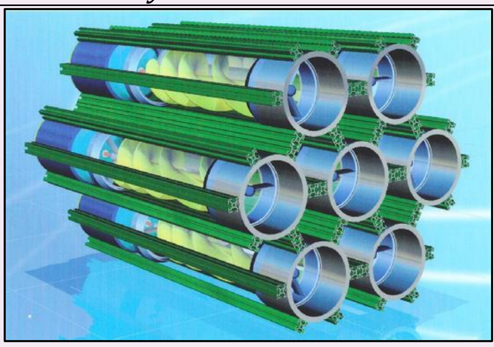
Turbine Name	**HYDROCOIL TURBINE**
Company name	**HydroCoil Power Inc. (HCP)**
Company Address	1164 Saint Andrews Rd. Bryn MawR PA 19010 USA
Company Tel	+1 610-520-4595
Company E-mail	Hydrocoilpower.inc@att.net
Website	www.hydrocoilpower.com
Turbine Description	The turbine is comprised of approximately 28 components, many of which are off-the-shelf. It can be mass-produced and easily assembled in multiple, locations globally. It's essentially a plug-and play requiring no water impoundment or construction.
Pressure Head Range	4 m to 20 m
Flow Range	Up to 10 m^3/s
Power Range	2 kW to 8 kW per turbine

Illustrations, Photos and Applicable Graphs

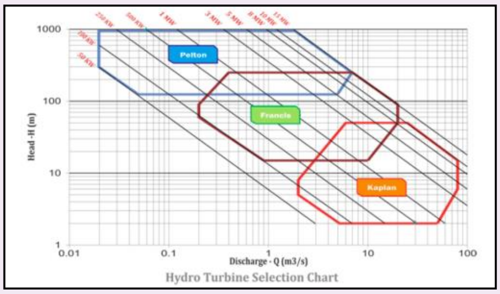
HydroCoil turbine



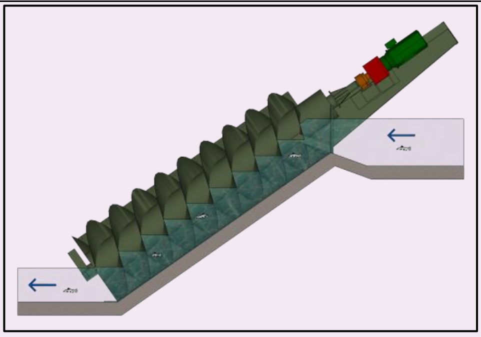
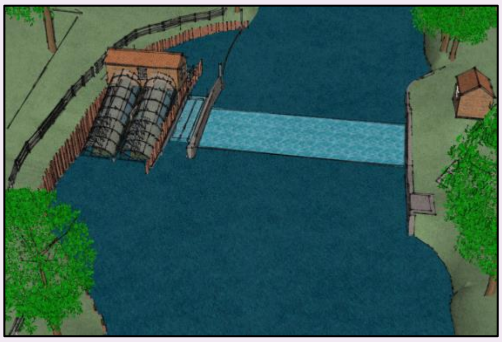
HydroCoil installation

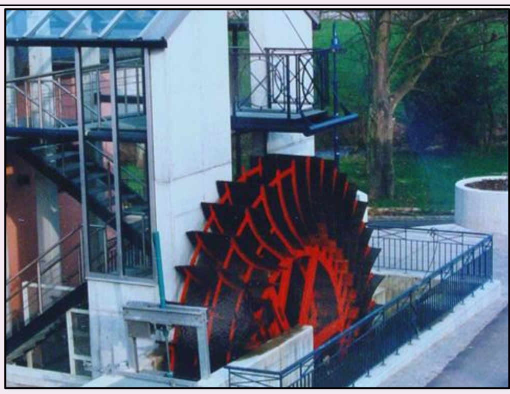


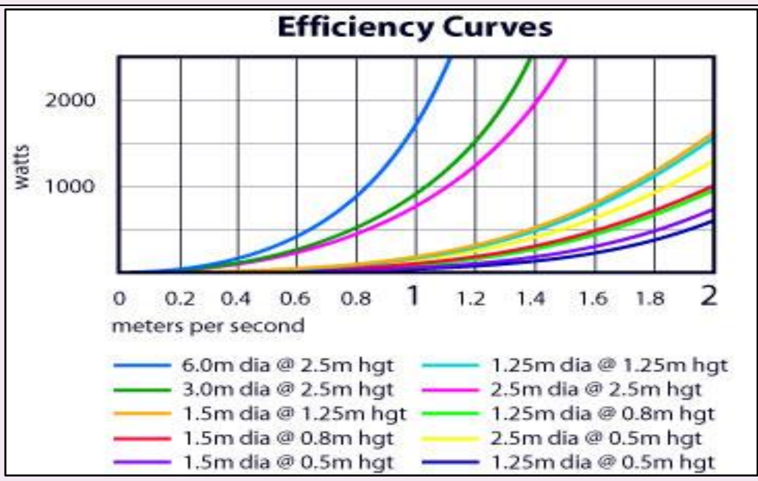
HydroCoil turbines in parallel



Turbine range

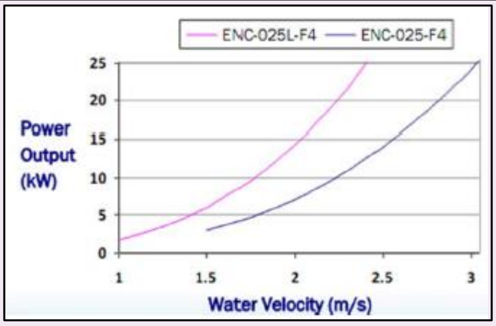
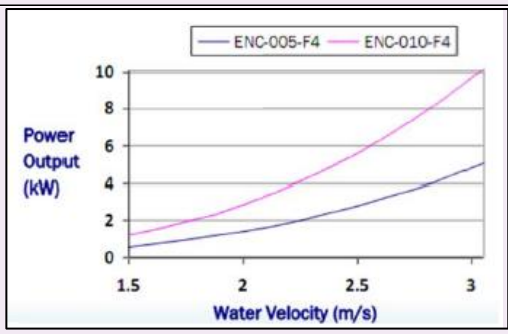
Turbine Name	**ARCHIMEDIAN SCREW**
Company name	**3Helix Power**
Company Address	Not given
Company Tel	US: +1 (0)703.447.2401 UK: +44 (0)203.287.4780
Company E-mail	Gregory@3HelixPower.com
Website	www.3helixpower.com
Turbine Description	3Helix Power is focused on Archimedes screw technology. Archimedes screw hydropower systems are extremely efficient and retain that efficiency even as water levels vary. Additionally, screw systems can operate down to as low as 7% of the design flow, maximizing the time they can generate power. They are also fish-friendly.
Pressure Head Range	1 m to 10 m
Flow Range	0.2 m^3/s to 10 m^3/s
Power Range	1.4 kW to 700 kW per turbine
Illustrations, Photos and Applicable Graphs	 *Archimedes screw*  *Archimedian screw installation*  *Archimedes screws in parallel*  *Turbine and weir design*

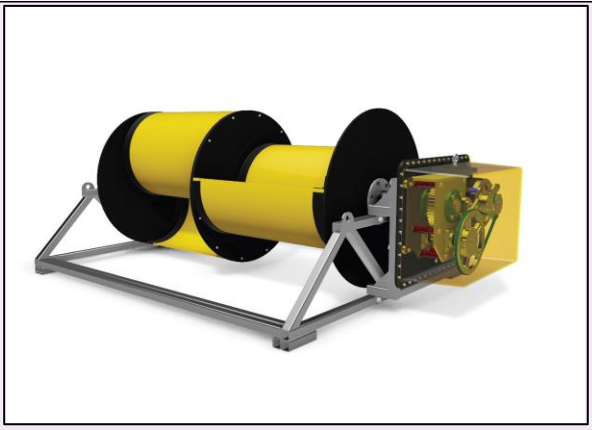
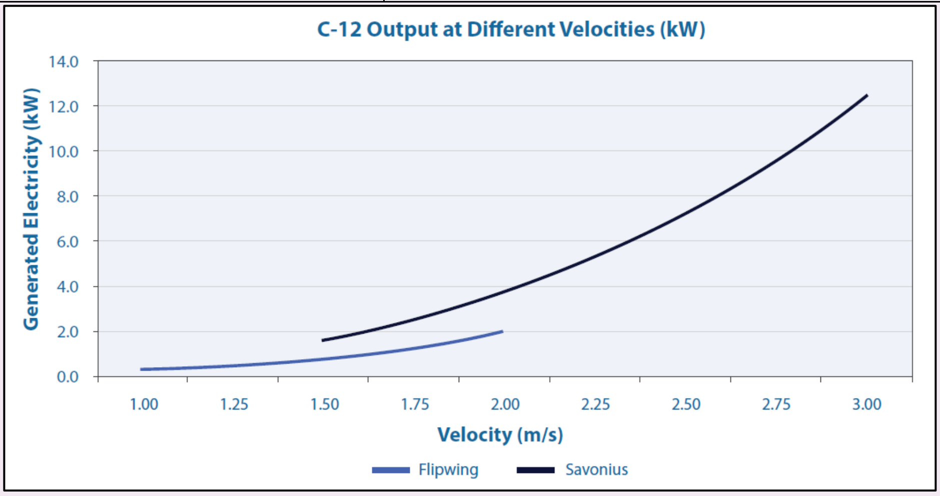
Turbine Name	**WATERWHEEL**
Company name	**HydroWatt**
Company Address	Am Hafen 5 76189 Karlsruhe Germany
Company Tel	+49 (0)721-831 86-0
Company E-mail	info@hydrowatt.de
Website	http://www.hydrowatt.de/sites/english/home.html
Turbine Description	Hydrowatt of Germany, manufacturers both overshot and breastshot waterwheels.
Pressure Head Range	Overshot – 2.5 m to 10m Breastshot – 1 m to 3m
Flow Range	Overshot – 0.1 m^3/s to 2.5 m^3/s Breastshot – 0.5 m^3/s to 5 m^3/s
Power Range	1.5 kW to 200 kW
Illustrations, Photos and Applicable Graphs	 *Overshot wheel*  *Breastshot wheel*  *Large installation*  *Small installation*

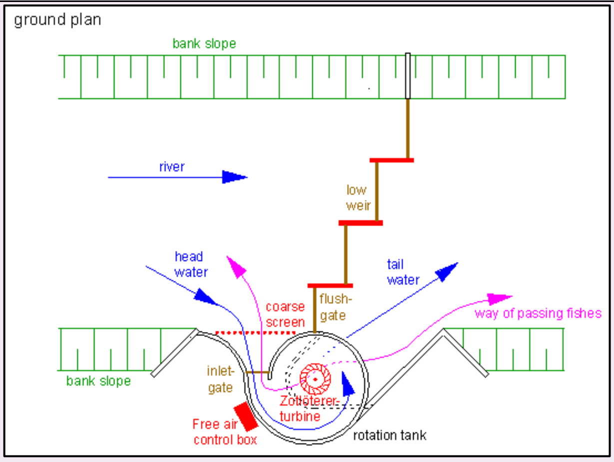
<table>
<tr><td>Turbine Name</td><td>HYDROKINETIC (Darrieus Water Turbine)</td></tr>
<tr><td>Company name</td><td>Alternative Hydro Solutions</td></tr>
<tr><td>Company Address</td><td>Alternative Hydro Solutions Ltd
Suite 421
323 Richmond Street East
Toronto, Ontario
M5A 4S7</td></tr>
<tr><td>Company Tel</td><td>416-368-5813</td></tr>
<tr><td>Company E-mail</td><td>sdgregory@althydrosolutions.com</td></tr>
<tr><td>Website</td><td>www.althydrosolutions.com</td></tr>
<tr><td>Turbine Description</td><td>Generally speaking this turbine can be installed in a canal with a water depth of over 0.6 m and with water velocity of more than 0.7 m/s.</td></tr>
<tr><td>Pressure Head Range</td><td>0.1 m from bed for fast flow (> 1,3 m/s)
0.3 m for slow flow</td></tr>
<tr><td>Flow Range</td><td>Greater than 0.8 m/s</td></tr>
<tr><td>Power Range</td><td>1 kW to 4 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>


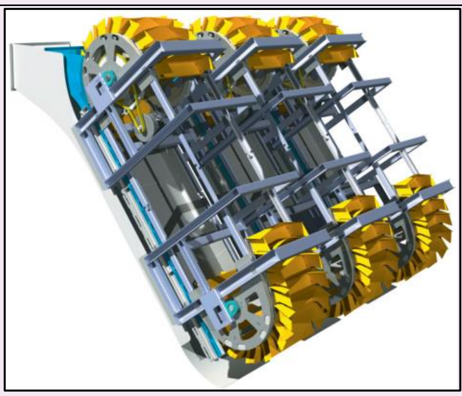
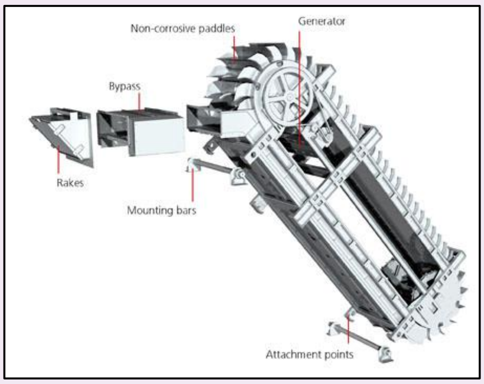
Efficiency curves</td></tr>
<tr><td>

Field installation</td></tr>
</table>

Turbine Name	**HYDROKINETIC (En Current Power Generation System)**
Company name	**New Energy Corporation**
Company Address	3553 – 31 Street NW Suite 473 Calgary, Alberta T2L 2K7
Company Tel	(403) 260-5240
Company E-mail	info@newenergycorp.ca
Website	www.newenergycorp.ca
Turbine Description	New Energy's proprietary EnCurrent Turbine converts the energy inherent in moving water into electricity.
Pressure Head Range	N/A
Flow Range	2.4 m/s to 3 m/s
Power Range	5 kW to 25 kW
Illustrations, Photos and Applicable Graphs	 *Field installation*  *Underwater view*  *25 kW System*  *5 kW System*

Turbine Name	**HYDROKINETIC (C-12 Canal Turbine)**
Company name	**Hydrovolts**
Company Address	210 South Hudson Street #330 Seattle, WA 98134
Company Tel	(260) 658-4380
Company E-mail	info@hydrovolts.com
Website	www.hydrovolts.com
Turbine Description	This run-of-river turbine does not need drops or significant engineering to produce clean, reliable hydropower.
Pressure Head Range	150 mm
Flow Range	1.5 m/s to 3 m/s
Power Range	1.5 kW to 12 kW
Illustrations, Photos and Applicable Graphs	 *Field installation*  *Model*  *Field results*

Turbine Name	**VORTEX POWER PLANT**
Company name	**Zotloeterer**
Company Address	A-3200 Obergrafendorf Wildgansstraße 5 AUSTRIA
Company Tel	0043-(0)2747-3106
Company E-mail	office@zotloeterer
Website	http://www.zotloeterer.com
Turbine Description	This power plant uses the rotational energy at the centre of a vortex to turn a paddle type turbine.
Pressure Head Range	0.7 m to 2 m
Flow Range	0.05 m^3/s to 20 m^3/s
Power Range	0.5 kW to 160 kW
Illustrations, Photos and Applicable Graphs	 *Turbine installation*  *Plant layout*

<table>
<tr><td></td><td colspan="2">
Plant installation</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Turbine Name</td><td colspan="2">STEFFTURBINE</td></tr>
<tr><td>Company name</td><td colspan="2">Walter Reist Holding AG</td></tr>
<tr><td>Company Address</td><td colspan="2">WRH AG
Industriestrasse 1
CH-830 Hinwil</td></tr>
<tr><td>Company Tel</td><td colspan="2">+41 44 938 70 00</td></tr>
<tr><td>Company E-mail</td><td colspan="2">info@steffturbine.com</td></tr>
<tr><td>Website</td><td colspan="2">www.steffturbine.com</td></tr>
<tr><td>Turbine Description</td><td colspan="2">The Steffturbine is the consistent further development of the technical principle of the overshot water wheel. It utilises a conveyor belt system.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">2.5 m to 5 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">Up to 0.4 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">Up to 10 kW per turbine</td></tr>
<tr><td>Illustrations, Photos and Applicable Graphs</td><td>
Model</td><td>

Steffturbine design</td></tr>
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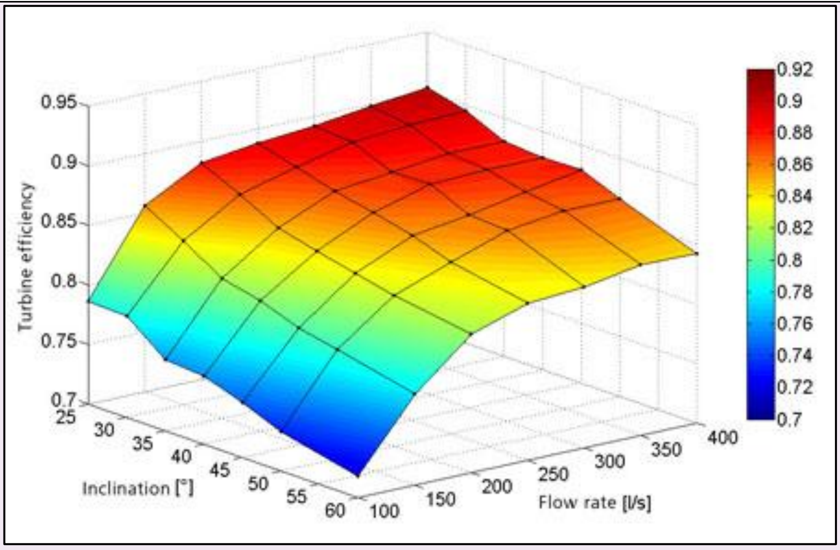
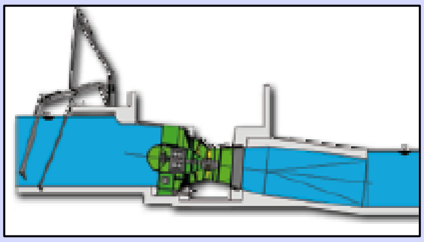
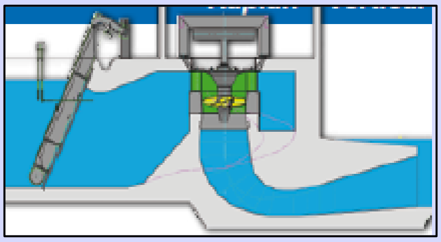
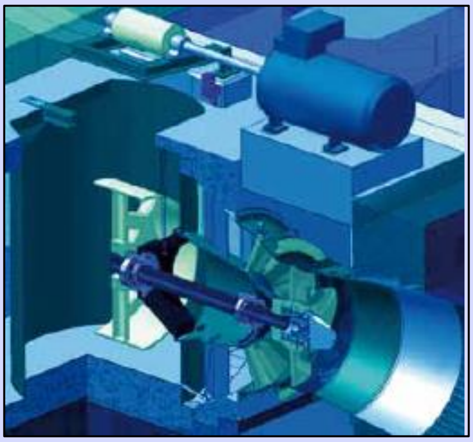
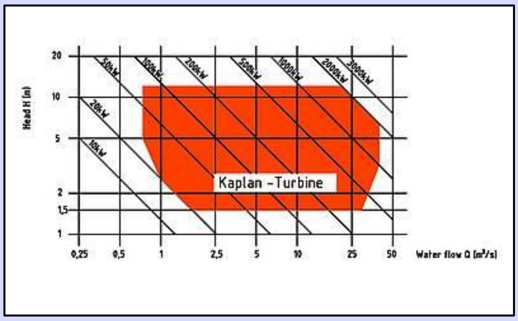


Efficiency

REACTION TYPE TURBINES

Turbine Name	**KAPLAN TURBINE**
Company name	**OSSBERGER GmbH + Co**
Company Address	Otto-Rieder-Str. 7 91781 Weissenburg / Bavaria GERMANY
Company Tel	+49 (0)9141/977-0
Company E-mail	info@ossberger.de
Website	www.ossberger.de/cms/pt/hydro/contact/
Turbine Description	The Ossberger Kaplan turbine has a compact, low-maintenance construction and is easily installed.
Pressure Head Range	1.5 m to 20 m
Flow Range	1.5 m^3/s to 60 m^3/s
Power Range	20 kW to 3 500 kW

Illustrations, Photos and Applicable Graphs	 *Inflow horizontal*	 *Inflow vertical*
	 *Computer generated view of Kaplan*	 *Turbine range*

Turbine Name	**KAPLAN TURBINE**
Company name	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel	+27 21 552 9993
Company E-mail	karenr@sciontechnologies.co.za
Website	www.mavel.cz
Turbine Description	Mavel Kaplan turbines are designed to function with low head and high flow rates.
Pressure Head Range	1.5 m to 35 m
Flow Range	0.3 m^3/s to 150 m^3/s
Power Range	30 kW to 20 MW

<table>
<tr>
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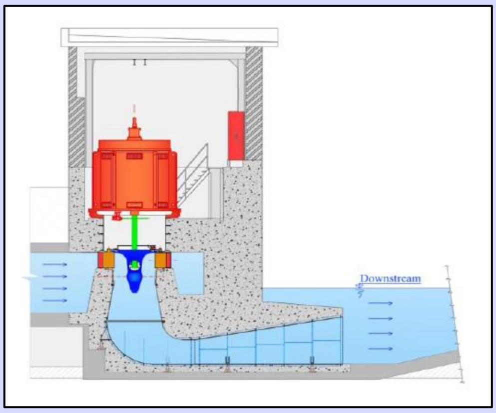
Kaplan turbine runner</td>
<td>

Vertical Turbine layout</td>
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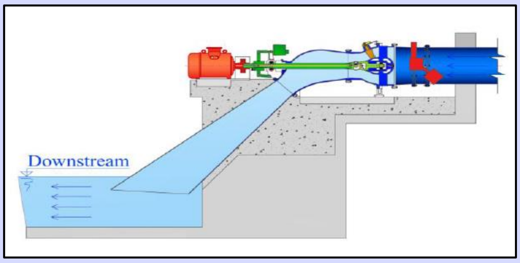
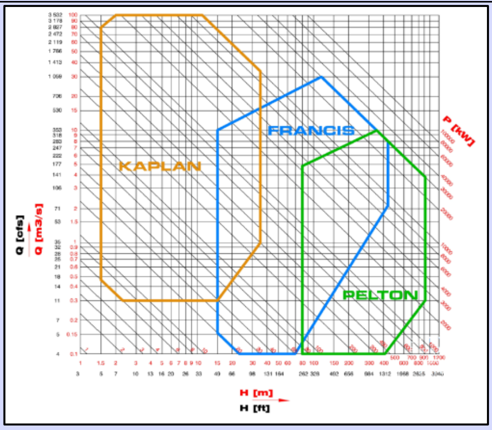
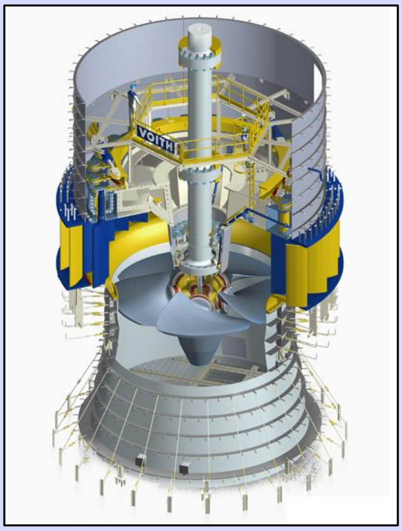
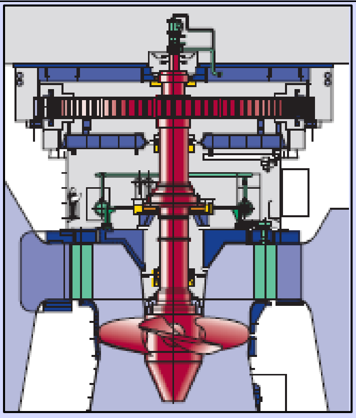
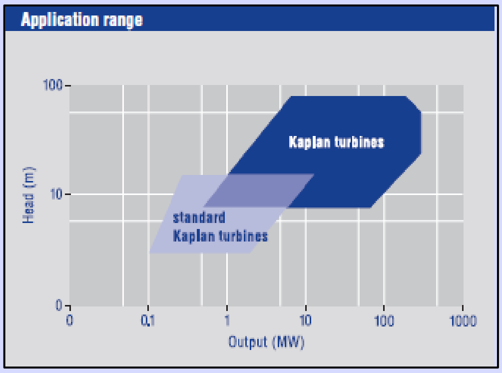
<td>

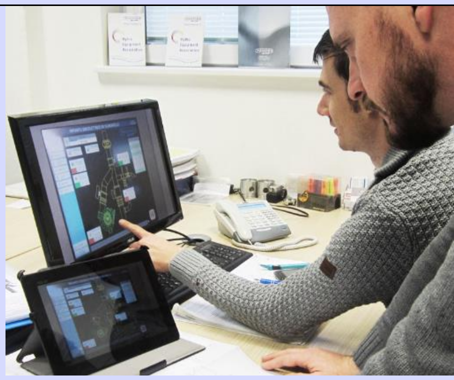
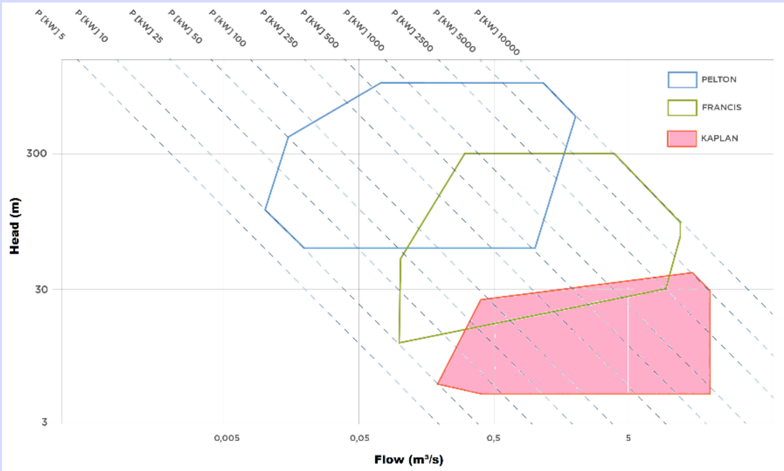
S-type turbine layout</td>
<td>

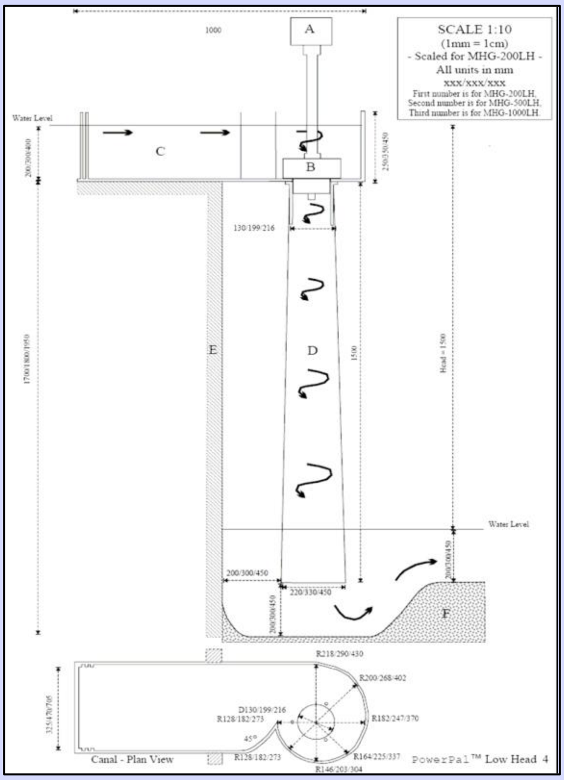
Turbine range</td>
</tr>
</table>

Turbine Name	**KAPLAN TURBINE**
Company name	**Voith Hydro Holding GmbH & Co. KG**
Company Address	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel	+49 7321 37 0
Company E-mail	info.voithhydro@voith.com
Website	www.voithhydro.com
Turbine Description	Voith Kaplan turbines are designed to function with low head and high flow rates.
Pressure Head Range	3 m to 95 m
Flow Range	Not given

<table>
<tr><td>Power Range</td><td colspan="2">100 kW to 400 MW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>
Kaplan turbine runner</td><td>
Turbine layout</td></tr>
<tr><td>
Cross section of a Kaplan runner</td><td>

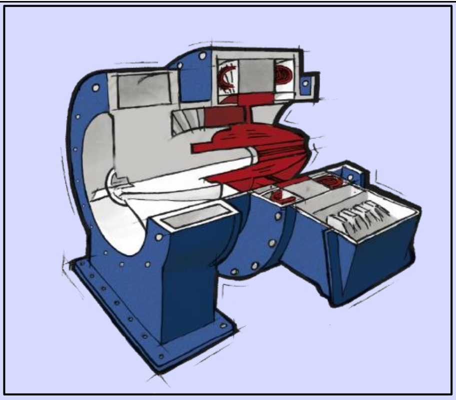
Turbine range</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Turbine Name</td><td colspan="2">KAPLAN TURBINE</td></tr>
<tr><td>Company name</td><td colspan="2">Tamanini Hydro S.r.l</td></tr>
<tr><td>Company Address</td><td colspan="2">Salita ai Dossi,
5 – 38123
Trento (TN)
ITALIA</td></tr>
<tr><td>Company Tel</td><td colspan="2">+39 0461 945307</td></tr>
<tr><td>Company E-mail</td><td colspan="2">stefania@tamanini.it</td></tr>
<tr><td>Website</td><td colspan="2">http://tamanini.it/en/
http://www.tamanini-sa.com/</td></tr>
<tr><td>Turbine Description</td><td colspan="2">The Tamanini Kaplan turbine is specifically designed to provide a high efficiency, a low-maintenance cost and is easily installed.</td></tr>
</table>

Pressure Head Range	5-35 m
Flow Range	0.2-15.0 m^3/s
Power Range	10 kW to 5 000 kW
Illustrations, Photos and Applicable Graphs	 *Manufacturing*  *Design of Kaplan Turbine*  *Turbine range*
Turbine Name	**PROPELLOR TURBINE – (SMALL)**
Company name	**Power Pal**
Company Address	2-416 Dallas Road Victoria, BC V8V 1A9 CANADA
Company Tel	1-250-361-4348
Company E-mail	info@powerpal.com
Website	http://www.powerpal.com
Turbine Description	The Power Pal turbine is a very small, low head propeller type turbine set at the elevation of the incoming water.

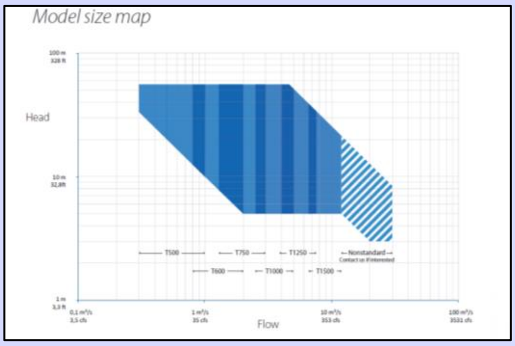
<table>
<tr><td>Pressure Head Range</td><td colspan="2">1.5 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">35 l/s to 130 l/s</td></tr>
<tr><td>Power Range</td><td colspan="2">200 W to 1 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>
Turbine</td><td rowspan="2">

Internal schematic</td></tr>
<tr><td>
Turbine installation</td></tr>
</table>

Turbine Name	**TURBINATOR**
Company name	**CleanPower AS**
Company Address	Omagata 114 N-6517 Kristiansund N Norway
Company Tel	+47 71 56 66 00
Company E-mail	Egil.opsahl@cleanpower.no
Website	http://www.cleanpower.no/Home.aspx
Turbine Description	The Turbinator is an axial flow turbine suitable for low head hydropower applications.
Pressure Head Range	10 m to 60 m
Flow Range	0.5 m³/s to 12 m³/s
Power Range	75 kW to 3.3 MW
Illustrations, Photos and Applicable Graphs	 *Turbinator*  *Turbine layout*



Cross section of a Turbinator



Turbine range

Turbine Name	**BULB TURBINE**
Company name	**Alstom**
Company Address	Country Club Estates 21 Woodlands Drive Woodmead SOUTH AFRICA
Company Tel	+27 11 518 8100
Company E-mail	Not given
Website	www.alstom.com
Turbine Description	Alstom design concepts ensure reliability in all operating circumstances taking account of the Bulb unit's sensitivity to instability and vibrations due to the horizontal position of the generator. They have been developed to handle conditions such as roundness and air gap concentricity, and have been successfully applied in bulb units up to 60 MVA.
Pressure Head Range	2 m to 30 m
Flow Range	0.3 m^3/s to 150 m^3/s
Power Range	Up to 130 MW

<table>
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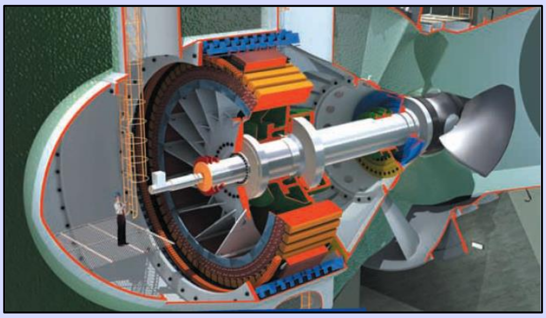
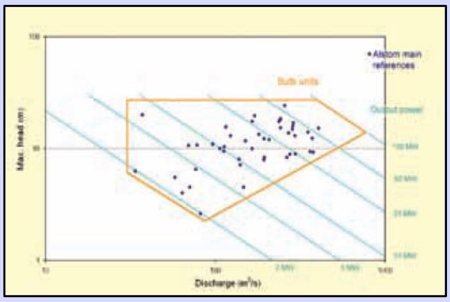
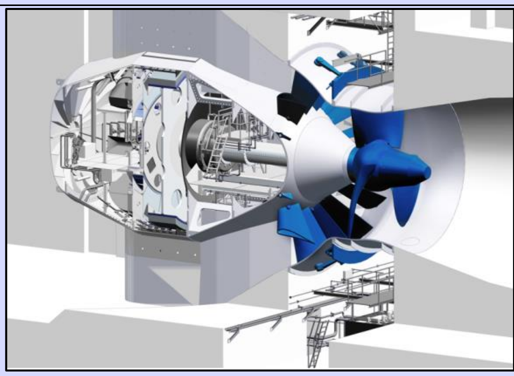
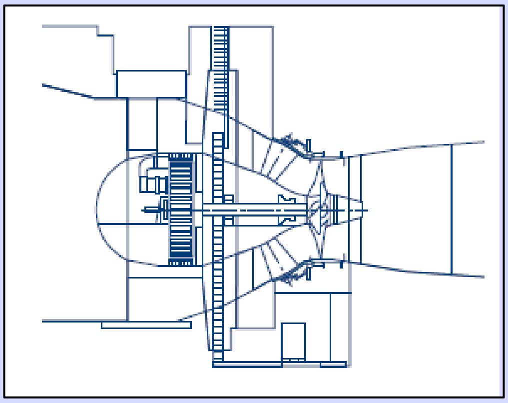
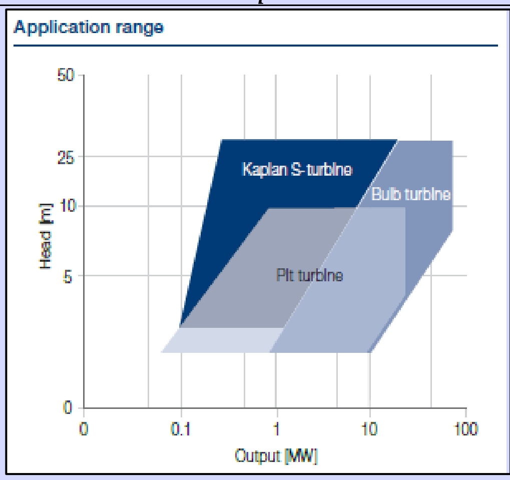
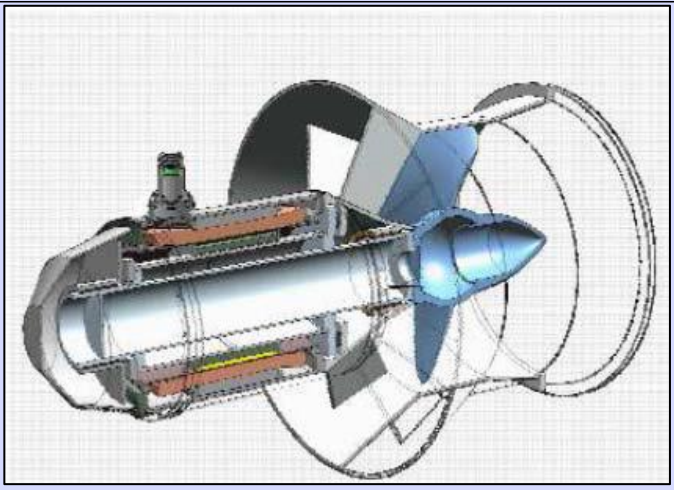
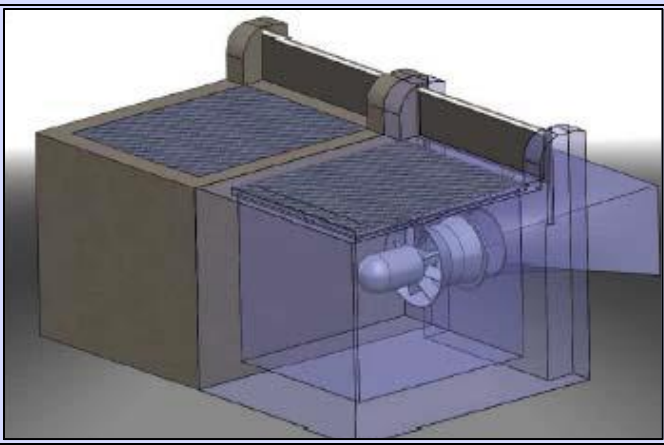
<td>
Bulb turbine drawing</td>
<td>
Runner installation</td>
</tr>
<tr>
<td>
Installation at Wu Jin Xia, China</td>
<td>

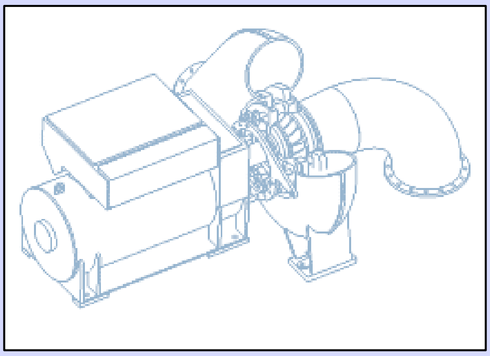
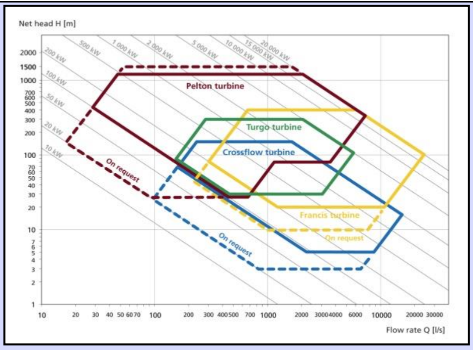
Turbine range</td>
</tr>
</table>

Turbine Name	**BULB TURBINE**
Company name	**Voith Hydro Holding GmbH & Co. KG**
Company Address	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel	+49 7321 37 0
Company E-mail	info.voithhydro@voith.com
Website	www.voithhydro.com
Turbine Description	Voith Bulb turbines are used primarily for low heads and high flows. These units can achieve higher full-load efficiencies and flow capacities than vertical Kaplan turbines.
Pressure Head Range	2 m to 30 m
Flow Range	Not given
Power Range	1 MW to 80 MW
Illustrations, Photos and Applicable Graphs	 *Bulb turbine*  *Bulb turbine computer illustration*  *Cross section of a Bulb turbine*  *Turbine range*

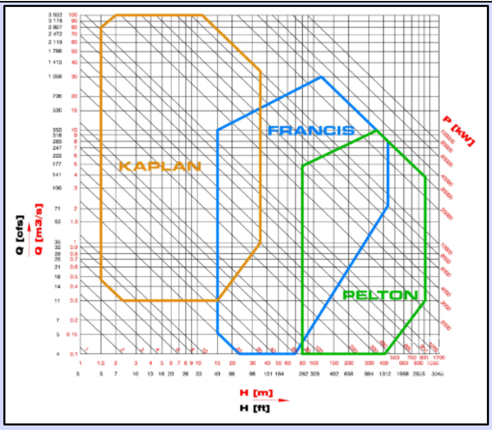
Turbine Name	**MINIHYDRO**	
Company name	**Voith Hydro**	
Company Address	Jeremy A. Smith Manager, Small Hydro	
Company Tel	717-792-7868	
Company E-mail	Jeremy.smith@voith.com	
Website		
Turbine Description	The concept is under development but will be appropriate for low head applications.	
Pressure Head Range	2 m to 10 m	
Flow Range	1 m^3/s to 14 m^3/s	
Power Range	Not available	
Illustrations, Photos and Applicable Graphs	 *Turbine schematic*	
		

	Turbine application

Turbine Name	**FRANCIS TURBINE**
Company name	**Wasserkraft Volk AG**
Company Address	Am Stollen 13 D-79261 Gutach GERMANY
Company Tel	+49 7685-9106-0
Company E-mail	mail@wkv-ag.com
Website	www.wkv-ag.com
Turbine Description	This turbine has a high peak capacity, compact design and low maintenance, with bearings rated for more than 100 000 operating hours.
Pressure Head Range	Up to 300 m
Flow Range	Not given
Power Range	Up to 20 000 kW
Illustrations, Photos and Applicable Graphs	 *Francis turbine room*  *Francis turbines manufacturing*

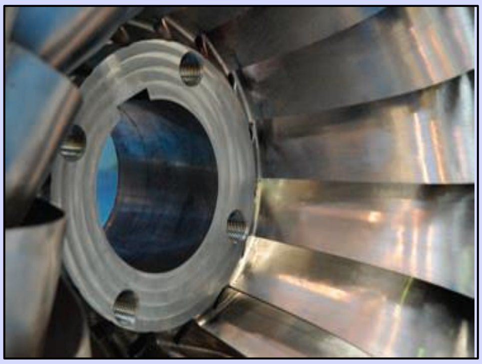
	 *Typical turbine drawing*	 *Wasserkraft Volk turbine ranges*

Turbine Name	**FRANCIS TURBINE**	
Company name	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))	
Company Address	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA	
Company Tel	+27 21 552 9993	
Company E-mail	karenr@sciontechnologies.co.za	
Website	www.mavel.cz	
Turbine Description	Mavel Francis turbines are milled from a single block of forged steel and can be applied to medium heads and medium flow ranges.	
Pressure Head Range	15 m to 440 m	
Flow Range	0.1 m^3/s to 30 m^3/s	
Power Range	20 kW to 30 MW	
Illustrations, Photos and Applicable Graphs	 *Francis runner*	 *Francis turbine manufacturing*

	 *Typical layout*	 *Turbine range*

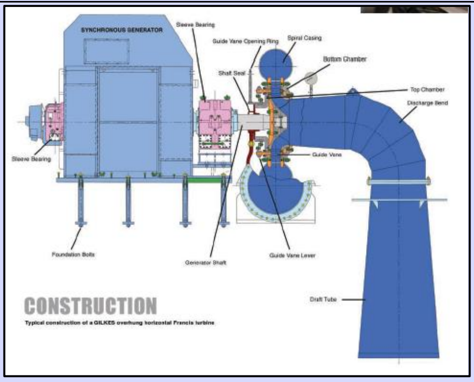
Turbine Name	**FRANCIS TURBINE**
Company name	**Gilbert Gilkes & Gordon Ltd**
Company Address	Canal Head North Kendal Cumbria LA9 7BZ UK
Company Tel	+44 (0) 1539 720028
Company E-mail	enquiries@gilkes.com
Website	www.gilkes.com
Turbine Description	This turbine can be supplied as a horizontal or vertical unit and directs water through a series of moveable guide vanes to the turbine runner, from where it is discharged through a draft tube to the tailrace.
Pressure Head Range	Up to 400 m
Flow Range	0.05 m^3/s to 40 m^3/s
Power Range	Up to 20 000 kW

Illustrations, Photos and Applicable Graphs

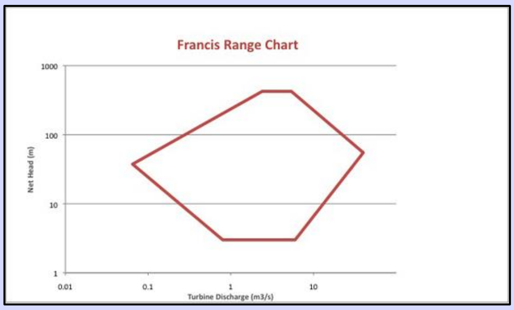


Francis runner

Francis turbine

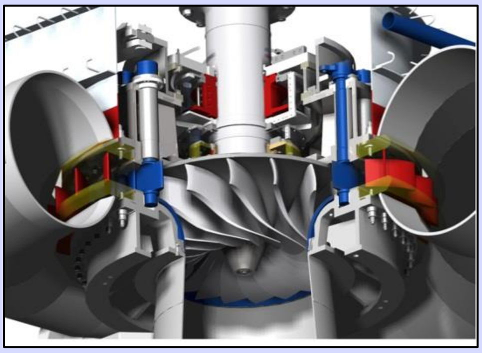
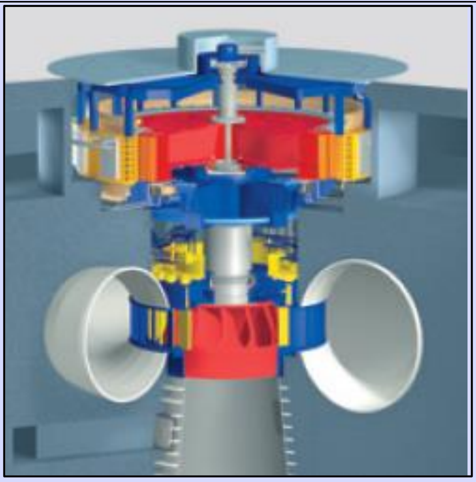
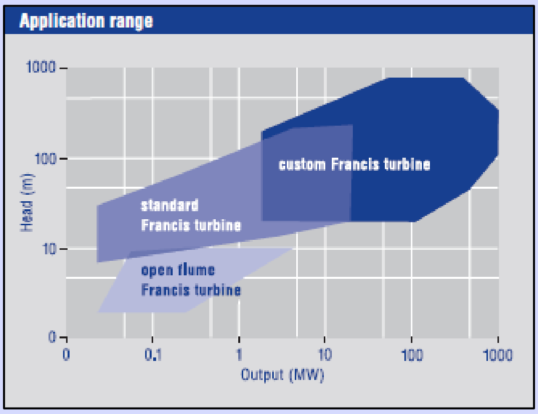


Typical layout

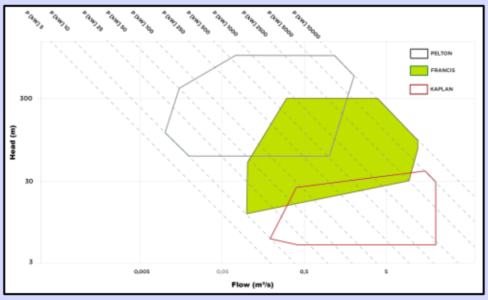


Turbine range

Turbine Name	**FRANCIS TURBINE**
Company name	**Voith Hydro Holding GmbH & Co. KG**
Company Address	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel	+49 7321 37 0
Company E-mail	info.voithhydro@voith.com
Website	www.voithhydro.com
Turbine Description	The Voith Francis turbines are used primarily for medium heads and large flows. These units run at high specific speeds and are therefore compact. Standardized designs can be ordered for small installations.
Pressure Head Range	3 m to 95 m
Flow Range	Not given
Power Range	5 kW to 1 000 MW

Illustrations, Photos and Applicable Graphs	 *Francis turbine runner*	 *Turbine layout*
	 *Cross section of a Francis turbine*	 *Turbine range*

Turbine Name	**FRANCIS TURBINE**
Company name	**Tamanini Hydro S.r.l**
Company Address	Salita ai Dossi, 5 – 38123 Trento (TN) ITALIA
Company Tel	+39 0461 945307
Company E-mail	stefania@tamanini.it
Website	http://tamanini.it/en/ http://www.tamanini-sa.com/
Turbine Description	The Tamanini Francis turbine is specifically designed to provide a high efficiency, running at low-maintenance cost and is easily installed.
Pressure Head Range	15 m to 300 m

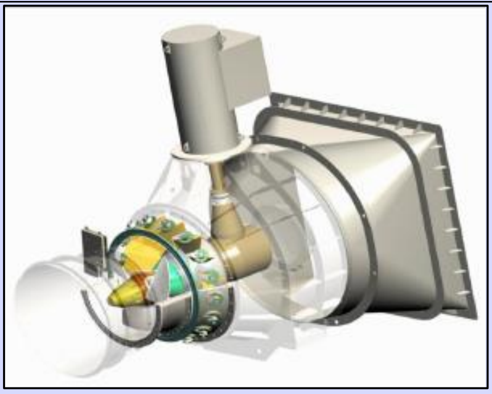
<table>
<tr><td>Flow Range</td><td colspan="2">0.2-10.0 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">10 kW to 10 000 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>
Francis turbine installation</td><td>
Francis runner</td></tr>
<tr><td>

Turbine range</td><td>
Turbine manufacturing</td></tr>
</table>

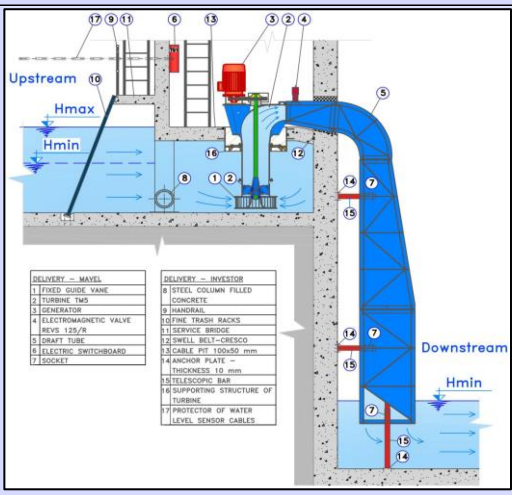
Turbine Name	**SIPHON-TYPE TURBINE**
Company name	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel	+27 21 552 9993
Company E-mail	karenr@sciontechnologies.co.za
Website	www.mavel.cz
Turbine Description	Mavel Micro turbines are designed to function with low head and work on the principle of siphoning water over a weir. Turbines can be placed in parallel.
Pressure Head Range	1.5 m to 6 m
Flow Range	0.15 m^3/s to 4.5 m^3/s (per turbine)
Power Range	1 kW to 180 kW

Illustrations, Photos and Applicable Graphs

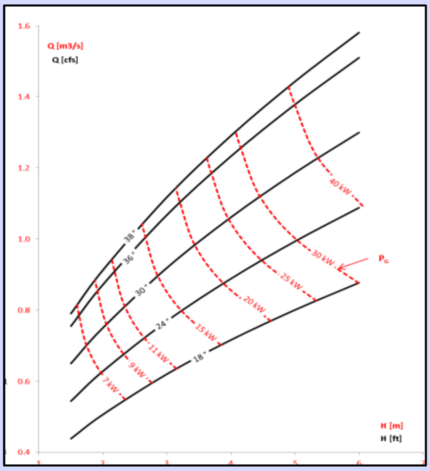
Turbine runner for Palmiet, South Africa



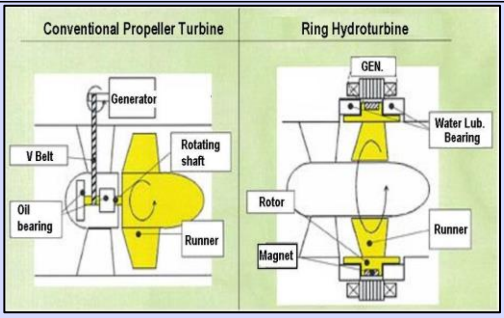
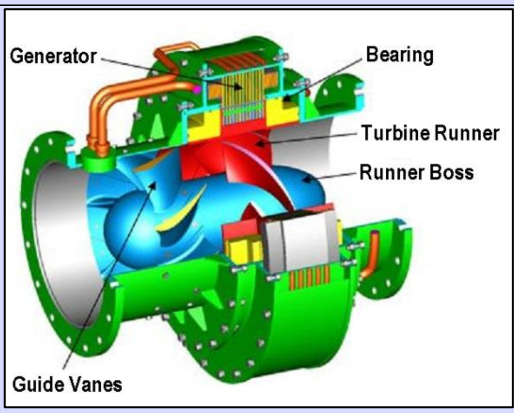
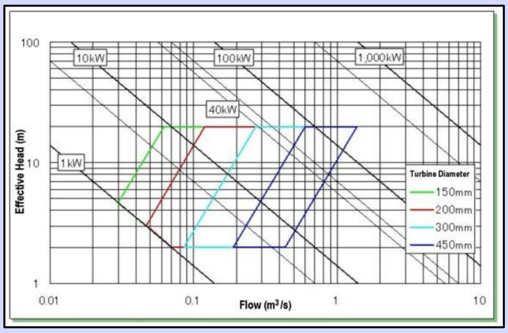
Turbine layout

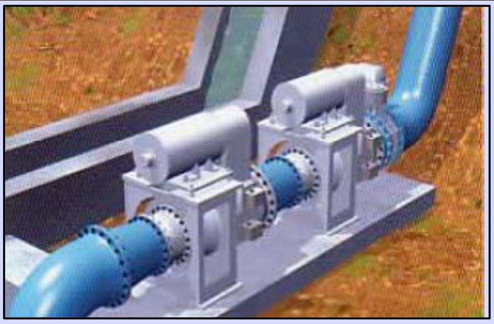


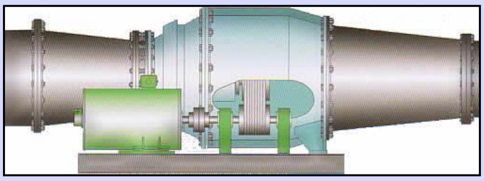
Construction drawing of a Syphon turbine



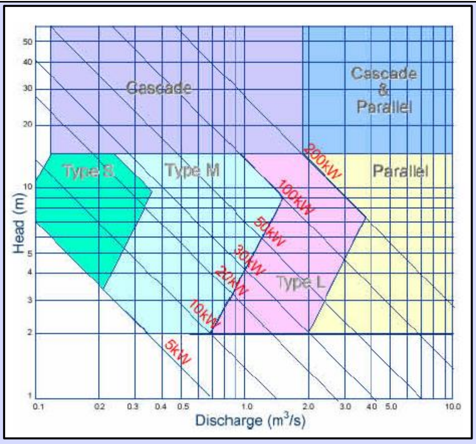
Turbine range (MT5)

Turbine Name	**RING HYDROTURBINE**
Company name	**Kawasaki Plant Systems Ltd.**
Company Address	1-14-5, Kaigan, Minato-ku Toyo JAPAN 8315
Company Tel	+81-3-3435-2111
Company E-mail	Not given
Website	www.khi.co.jp
Turbine Description	This high efficiency inline system is easily installed in small spaces and has requires little maintenance.
Pressure Head Range	3 m to 30 m
Flow Range	0.14 m³/s to 2.8 m³/s
Power Range	20 to 500 kW
Illustrations, Photos and Applicable Graphs	 *Ring hydroturbine*  *Ring and propeller comparison*  *Turbine layout*  *Turbine ranges*

Turbine Name	**HYDRO E-KIDS**
Company name	**Toshiba International Corporation Pty Ltd**
Company Address	66-2, Horikawa-Cho Saiwai-Ku Kawasaki 212-8551 JAPAN
Company Tel	+81-44-548-3406
Company E-mail	Hydro-eKIDS@toshiba-eng.co.jp
Website	http://www.tic.toshiba.com.au/product_brochures_and_reference_lists/ekids.pdf
Turbine Description	In order to improve the economic viability, Toshiba have developed a new concept to improve the manufacturing and construction efficiency of hydro turbine and generator sets for small scale hydroelectric power generation, through a mass production approach.
Pressure Head Range	2 m to 15 m
Flow Range	0.1 m^3/s to 3.5 m^3/s
Power Range	5 to 200 kW
Illustrations, Photos and Applicable Graphs	 *Turbines in parallel*  *Turbines in series*

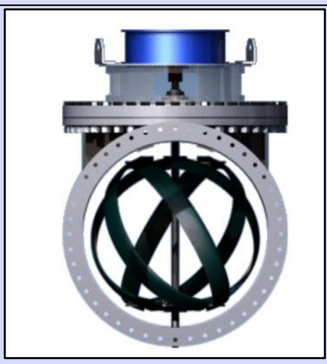


Turbine layout

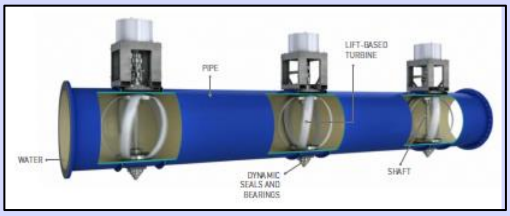


Turbine ranges

Turbine Name	**LUCIDPIPE POWER SYSTEM**
Company name	**LucidEnergy**
Company Address	108 NW 9th Avenue Suite 201C Portland USA
Company Tel	+1 574-238-5415
Company E-mail	Josh.kanagy@lucidenergy.com
Website	www.lucidenergy.com
Turbine Description	These spherical turbines are installed inline in large diameter pipes. A number of turbines can be installed in series and can operate across a wide range of head and flow conditions.
Pressure Head Range	0.5 m to 10 m head drop through turbine; pressure head in the pipe can be higher
Flow Range	1 m^3/s to 5.6 m^3/s
Power Range	14 kW to 100 kW
Illustrations, Photos and Applicable Graphs	

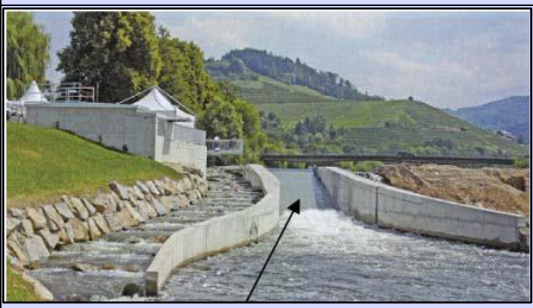
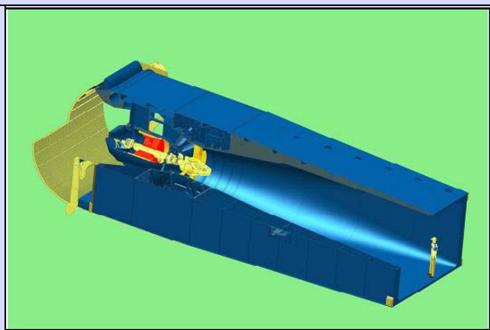


Computer-generated drawing of turbine



Three Lucidpipe turbines in series

	 *Turbine in pipe*	 *Installed turbine*

Turbine Name	**MOVABLE POWER HOUSE**
Company name	**Ossberger Canada**
Company Address	4839 Brébeuf Montreal, Qc Canada
Company Tel	(514) 525-8430
Company E-mail	
Website	http://www.hsi-hydro.com/cd/
Turbine Description	In addition to the Cross Flow turbine, Ossberger has recently developed a Kaplan turbine / generator package for specific low head applications called the "Movable Power House".
Pressure Head Range	1 m to 8 m
Flow Range	1 m^3/s to 25 m^3/s
Power Range	350 kW to 2 000 kW
Illustrations, Photos and Applicable Graphs	 *Movable power house installation*  *Turbine*

	 *Turbine construction*	 *Turbine construction*

Turbine Name	**PUMP AS TURBINE**
Company name	**Andritz**
Company Address	Penzinger Strasse 76 Vienna AUSTRIA 1141
Company Tel	+43 (1)891 00 0
Company E-mail	hydro@andritz.com
Website	www.andritz.com
Turbine Description	This turbine utilizes a centrifugal pump in reverse to generate electricity in closed lines. Advantages of this turbine include cost-effectiveness, availability of spare parts and ease of installation
Pressure Head Range	3 m to 80 m
Flow Range	0.03 m^3/s to 6 m^3/s
Power Range	30 kW to 10 000 kW

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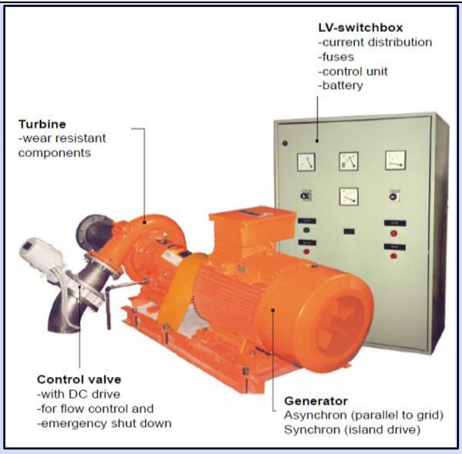
<tr>
<td rowspan="2">Illustrations, Photos and Applicable Graphs</td>
<td>
Installed turbines</td>
<td>

Turbine components</td>
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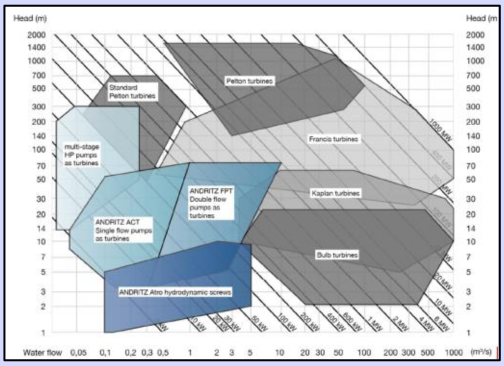
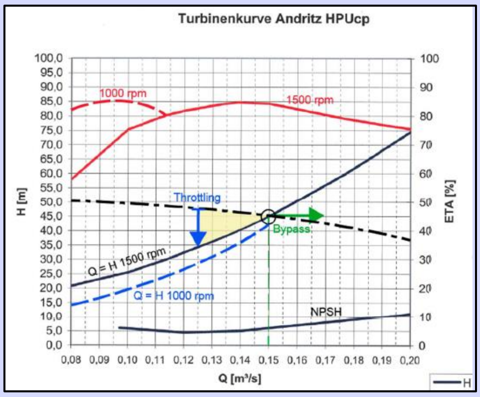
<td>

Turbine range</td>
<td>

Turbine curve</td>
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