ENERGY GENERATION USING LOW HEAD HYDROPOWER TECHNOLOGIES

Report to the
Water Research Commission

by

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Front cover picture courtesy Jacques van Delft

Executive Summary

In the execution of this study attention was firstly given to identify the available low head hydropower technologies, followed by the identification of sites where the technologies can be implemented. A detailed description of the analyses of a potential WWTW site is provided. A pilot plant was constructed showcasing the application potential at low head installations.

Defining low head power generation

Low head hydropower generation refers to electricity generated from a relatively low pressure head normally found in rivers or irrigation canals, and according to Campbell (2010) is applicable to sites with less than 5 metres of head. This definition is however negated by the definition reflecting that heads up to 30 m should be identified as low head (ESHA, 2004). For the purposes of this report, low head installations include all installations up to 30 m head.

Turbine types

Turbines are broadly divided into two groups: impulse- and reaction type turbines. Impulse type turbines are more suited to high head applications where reaction type turbines are widely used for low head sites. Information of the potential technologies were obtained and for each technology a data sheet was compiled and provided in **Appendix A**.

Potential sites for installation of low head hydropower technologies

The potential sites where low head hydropower technologies can be installed in South Africa are grouped as follows:

- Dams and barrages (retrofitting);
- Rivers;
- Irrigation systems (canals and conduits); and
- Urban areas (industrial and urban discharge, WTW, WWTW, storm water systems and WDS).

Pilot plant

A pilot plant was constructed at Zeekoegat WWTW. This is a 3 kW installation utilizing a locally made Kaplan type impeller configuration, depicted in **Figure i**. The pipework allows for two flow configurations: (i) through the bottom outlet or (ii) siphoning over the dam wall. The electricity is used on site for lighting and improvement of water quality through aeration of the final effluent.

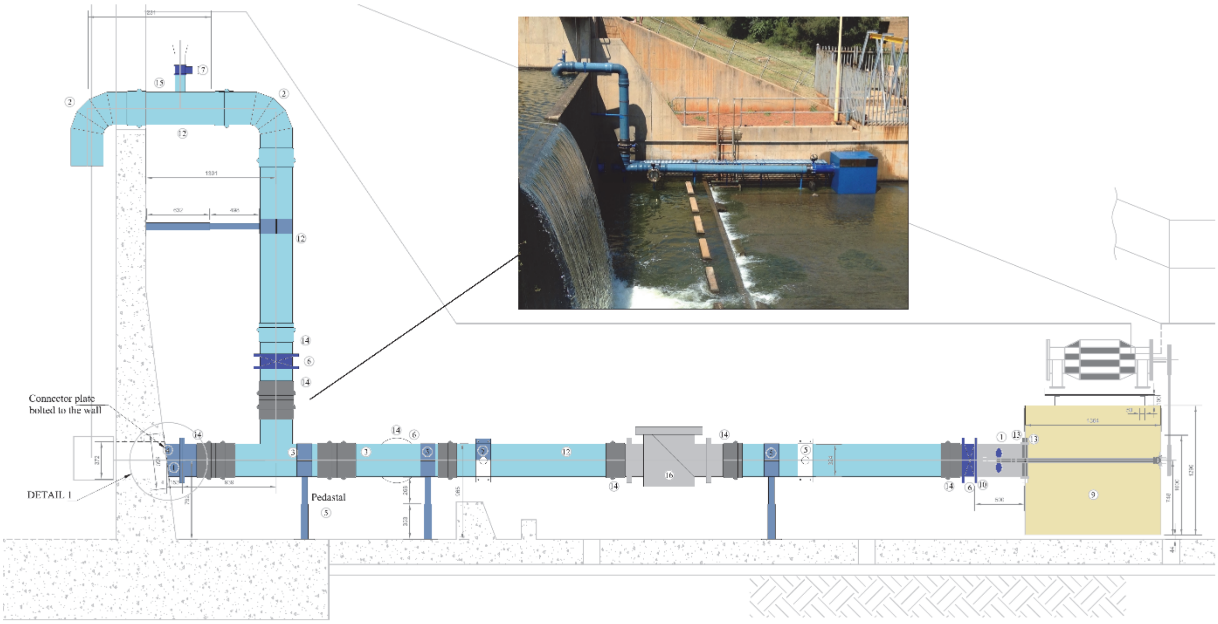

Figure i: Zeekoegat pilot Low Head installation

Recommendations

The study illustrated that there is significant potential for the development of low-head hydropower in both the perennial streams, at dams and barrages and within existing water supply (i.e. urban and agricultural scheme) and wastewater treatment infrastructure.

It is recommended that:

- A South African definition for the grouping of hydropower size be developed;
- The process to qualify as independent energy suppliers should be revisited;
- Other technical solutions and technologies be implemented to create more interest and commitment to hydropower generation;
  - Other types of low head installations be constructed to showcase the technology at wastewater treatment works;
  - a canal system be equipped with kinetic turbines for demonstrative purposes; and
  - an example be installed of retrofitting of hydropower technology on existing low head dams.
- Guidelines be developed that could be used by designers of WWTW and irrigation systems assisting in the design and implementation of generating facilities from the planning stage of the infrastructure; and that the
- Implementation of new developments should be showcased to display the contribution to the power situation in South Africa.

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List of Symbols and Abbreviations

Symbol/abbreviation	Description	Unit
AADD	average annual daily demand	Ml/d
AEP	annual energy production	
ALF	annual load factor	
BA	basic assessment	
BHA	British Hydropower Association	
BOT	build, operate and transfer	
BOTT	build, operate, train and transfer	
C_h	cost of hydropower project	R
CPI	consumer price index	
c_u	unit cost	R/kW
D	diameter of penstock or pipe	m
DEA	Department of Environmental Affairs	
DME	Department of Minerals and Energy	
DoE	Department of Energy	
DWA	Department of Water Affairs	
DWS	Department of Water and Sanitation	
EBP	Eskom Build Programme	
EE & EDS	Energy Efficiency and Energy Demand Side Management	
EIA	environmental impact assessment	
EPC	energy production cost	
ESHA	European Small Hydropower Association	
ESP	electricity services providers	
EU	European Union	
F_d	discount cost factor	
FSL	full supply level	
g	gravitational acceleration	m/s^2
GDP	gross domestic product	
GWS	Government Water Schemes	
H	effective pressure head	m
h_f	friction loss	m
h_l	secondary losses	m
HRM	Hydropower Retrofitting Model	
i	discount rate or escalation rate	%
I	electrical current	A
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 cost	R
MAR	mean annual runoff	
MSA	Municipal Services Act	

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
P_1	pressure at Station 1	N/m^2
P_2	pressure at Station 2	N/m^2
PPA	power purchase agreement	
PPP	public private partnership	
PRS	pressure reducing station	
PRV	pressure reducing valve	
PV	solar photovoltaic	
Q	flow rate through the turbine	m^3/s
RE	renewable energy	
REBID	Renewable Energy Bidding	
REFIT	Renewable Energy Feed-In Tariff	
REIPPP	Renewable Energy Independent Power Producer Procurement	
ROE	return on equity	
SAIPPA	South African Independent Power Producers Association	
SANCOLD	South African National Committee on Large Dams	
SHE	small hydroelectric	
SLA	service level agreement	
SP	Service Provider	
t	time actually worked	h
T	theoretical time	h
USBR	United States Bureau of Reclamation	
V	potential difference	V
v_1	velocity of the flow at Station 1	m/s
v_2	velocity of the flow at Station 2	m/s
WSA	water services authority	
WSP	water services provider	
WTS	water transfer scheme	
WUL	water use licence	
WWTW	wastewater treatment works	
Z_1	elevation of the water above datum line, at Station 1	m
Z_2	elevation of the water above datum line, at Station 2	m
η	hydraulic efficiency of the turbine	%
λ	friction coefficient of penstock or pipe	

Glossary of Terms

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 in a calendar year.
Assets	:	Items of value owned by or owed to a business.
Availability factor	:	The percentage of time a plant is available for power production.
Backup Generation Service	:	An optional service for customers with demands greater than or equal to 75 kW who wish to enhance their distribution system reliability through contracting with the company for the use of portable diesel or gas-fired backup generators. The service provides for backup generation if customers should ever experience a distribution-related outage.
Base Load Generation	:	Those generating facilities within a utility system that are operated to the greatest extent possible to maximize system mechanical and thermal efficiency and minimize system operating costs.
Base Load Unit/Station	:	Units or plants that are designed for nearly continuous operation at or near full capacity to provide all or part of the base load. An electric generation station normally operated to meet all, or part, of the minimum load demand of a power company's system over a given amount of time.
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.
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.
Cavitation	:	Noise or vibration causing damage to the turbine blades as a results of bubbles that form in the water as it goes through the turbine which causes a loss in capacity, head loss, efficiency loss, and the cavity or bubble collapses when they pass into higher regions of pressure.
Circuit breaker	:	A switch that automatically opens to cut off an electric current when an abnormal condition occurs.

Connection Charge	:	An amount to be paid by a customer in a lump sum or in instalments for connecting the customer's facilities to the supplier's facilities.
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 instant 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.
Demand Interval	:	The period of time during which the electric energy flow is averaged in determining demand, such as 60-minute, 30-minute, 15-minute, or instantaneous.
Depreciation	:	Charges made against income to provide for distributing the cost of depreciable plant less estimated net salvage over the estimated useful life of the asset in such a way as to allocate it as equitably as possible to the period during which such services are obtained from the use of the facilities. Among the factors to consider are: wear and tear, decay, inadequacy, obsolescence, changes in demand and requirements of public authorities.
Direct current (DC)	:	Electric current which flows in one direction.
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 relative low voltage as compared with transmission lines.
Draft Tube	:	A water conduit, which can be straight or curved depending upon the turbine installation that 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.
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.
Flywheel	:	A heavy mass of steel spinning with a turbine and generator adding inertia to the rotating system. Fast changes in load or water supply are smoothed out to create a more uniform rotating speed, thus maintaining 50 Hz.
Generator	:	A rotating machine that converts mechanical energy into electrical energy.
Gigawatt (gW)	:	One gigawatt equals one billion (1 000 000 000) watts, one million (1 000 000) kilowatts, or one thousand (1 000) megawatts.
Gigawatt-Hours (gWh)	:	One gigawatt-hour equals one billion (1 000 000 000) watt-hours, one million (1 000 000) kilowatt-hours, or one thousand (1 000) megawatt-hours.
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 in either feet or meters, between the head water level and the tail water level.
Headwater	:	The water level above the powerhouse.
Hertz	:	1 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.
Induction Generator	:	A generator which must be part of a larger system to be controlled. The induction generator is regulated by the electrical inertia and frequency of the larger power system.
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 instant of greatest load, usually determined from the readings of indicating or graphic meters.
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.
Load Curve	:	A curve on a chart showing power (kilowatts) supplied, plotted against time of occurrence, and illustrating the varying magnitude of the load during the period covered.
Load Dump	:	A bank of resistors (heaters) which absorb surplus energy from a generator. A load dump is controlled by a governor to maintain a constant total load on a generator.
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, in percent, also may be derived by multiplying the kilowatt-hours (kWh) in the period by 100 and dividing 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 percent ((10 000 kWh/720 hours/21 kW)*100).

Load Management	:	Economic reduction of electric energy demand during a utility's peak generating periods. Load management differs from conservation in that load-management strategies are designed to either reduce or shift demand from on-peak to off-peak times, while conservation strategies may primarily reduce usage over the entire 24-hour period. Motivations for initiating load management include the reduction of capital expenditure (for new power plants), circumvention of capacity limitations, provision for economic dispatch, cost of service reductions, system efficiency improvements or system reliability improvements. Actions may take the form of normal or emergency procedures.
Load Shifting	:	Involves moving load from on-peak to off-peak periods. Popular applications include use of storage water heating, storage space heating, cool storage and customer load shifts to take advantage of time-of-use or other special rates.
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.
Network	:	A system of transmission or distribution lines cross-connected and operated as to permit multiple power supply to any principal point on it.
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.
Overspeed	:	A speed higher than the normal operating speed. A turbine/generator in overspeed will produce harmful power surges (unless the main breaker acts to put the generator off line) and prolonged operation at overspeed can result in bearing failure and destruction of rotating parts.
Penstock	:	A closed conduit or pipe for conducting water to the powerhouse.

Reaction Turbine	:	A machine which converts the energy of water under pressure to motion. A pressurized case contains the water, which must turn the runner in order to reduce down 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.
Reserve Margin	:	The difference between net system capability and system maximum load requirements (peak load or peak demand).
RPM	:	Revolution per minute.
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 pressurized water, either by a jet of water (impulse turbine) or by reducing the pressure of the water (reaction turbine).
Service Area	:	Geographical area in which a utility system is required or has the right to supply electric service to ultimate consumers.
Single-Phase Service	:	Service where the facility (e.g. house, office or warehouse) has two energized wires coming into it. Typically serves smaller needs of 120V/240V. Requires less and simpler equipment and infrastructure to support and tends to be less expensive to install and to maintain.
Specific Speed	:	A relationship between rotating speed, power, and head which serves to compare turbines or pumps of different sizes. Also a means of classifying geometrically similar machines.
Step-Down	:	To change electricity from a higher to a lower voltage.
Step-Up	:	To change electricity from a lower to a higher voltage.
Substation	:	An assemblage of equipment for the purposes of switching and/or changing or regulating the voltage of electricity. Service equipment, line transformer installations or minor distribution and transmission equipment are not classified as substations.
Surplus Energy	:	Generated energy that is beyond the immediate needs of the producing system.
Synchronous Generator	:	A generator which is capable of regulating its own frequency (speed). It can therefore operate in isolation as a single source of supply to a system.
Tailrace	:	The channel that carries water away from a dam.
Tailwater	:	The water downstream of the powerhouse.
Tariff	:	A schedule of prices or fees.

Three-Phase Service	:	Service where the facility (e.g. manufacturing plant, office building or warehouse) has three energized wires coming into it. Typically serves larger power needs of greater than 120V/240V. Usually required for motors exceeding 7 kW or other inductive loads. Requires more sophisticated equipment and infrastructure to support and tends to be more expensive to install and maintain.
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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1 INTRODUCTION

1.1 STUDY BACKGROUND

The Kyoto Protocol to the United Nations Convention on Climate Change (United Nations, 1998) brought attention to the development of new renewable energy technology facilities including the small hydropower (SHP) installations. Hydropower is now recognized world-wide as a robust and well tested renewable energy technology in the electricity generation sector. Modern hydropower installations can convert up to 95 percent of the energy from moving water into electricity.

In South Africa, mainly due to relative scarcity of surface water, there is a prevailing perception that the potential for conventional hydropower development is rather low. However, the country's dam facilities store about 65 percent of the total mean annual surface runoff re-evaluated at 49 210 million m^3 (DEA, 2012). At present only seven dam facilities are equipped with hydropower generation plants, the largest being the Gariep hydropower plant situated on the Orange River having an operational capacity of 360 MW (the larger pumped storages are excluded as these are not considered "green" and installed for a peak supply only). In South Africa there are almost 5000 registered dams of all sizes providing water mainly for the irrigation and urban/rural water users (classification as in 2009 provided in **Table 1-1**).

Table 1-1: SA dams registered according to size class (SANCOLD, 2009)

Dam size class	Number	% of total
Small (5 m to 12 m)	3 232	73
Medium (12 m to 30 m)	1 033	23
Large (30 m and higher)	192	4
Total	4 457	100

Typically, dam facilities are built for various purposes; including flood control, irrigation of agricultural land, urban/rural water supply, stock watering, recreation and hydropower. Most of the early dams built in SA prior to the Second World War were to supply primarily the irrigation boards. Over time the main purpose of a dam might change according to the type of water demand.

The largest quantities of raw water made available for irrigation and municipal economic sectors are delivered through extensive water supply and wastewater disposal infrastructure installations (e.g. weirs/intake structures, pipelines, canals, chutes, etc.). This may provide accessible and economical low head hydropower (2-30 m, according to ESHA (2004), as per **Table 1-2**) that is hidden within the existing irrigation or urban/rural water supply water supply infrastructure.

Table 1-2: Scheme classification according to head (ESHA, 2004)

Classification	Head (m)	Typical turbine type
High head	>100	Pelton, Francis, etc.
Medium head	30-100	Francis, Kaplan, etc.
Low head	2-30	Pelton, crossflow, hydroengine, hydraulic screw, waterwheel, hydrokinetic, vortex and siphon

1.2 STUDY OBJECTIVES

A scoping study by Van Vuuren et al. (2013) on low head hydropower potential in South Africa was concluded in July 2013 and the results of that investigation indicated significant potential for the development of low-head hydropower in urban systems, irrigation schemes and South African rivers (including small dams and weirs) and this is graphically depicted in **Figure 1-1**.

The study noted that the potential would not necessarily be significant with regard to the contribution to Eskom's national grid. However, low head hydropower could be significant in reducing electricity demand at localised sites, including raw water and wastewater treatment facilities. It could also be a significant contributor to rural electrification, a persisting challenge in South Africa (Van Vuuren et al., 2013).

The scoping study report commented that "the owners and administrators of water supply and wastewater treatment schemes do not have essential conscience and relevant know-how about the hydropower energy which might be hidden in the schemes they are operating" (Van Vuuren et al., 2013).

The research work compiled in this report, together with the *Conduit Hydropower Development Guide* (Van Vuuren et al., 2014b) on in-line hydropower, are aimed at making administrators and operators more aware of the means and ways of identifying and evaluating the low-head hydropower potential within their systems, together with the benefits of generating even small amounts energy from own sources.

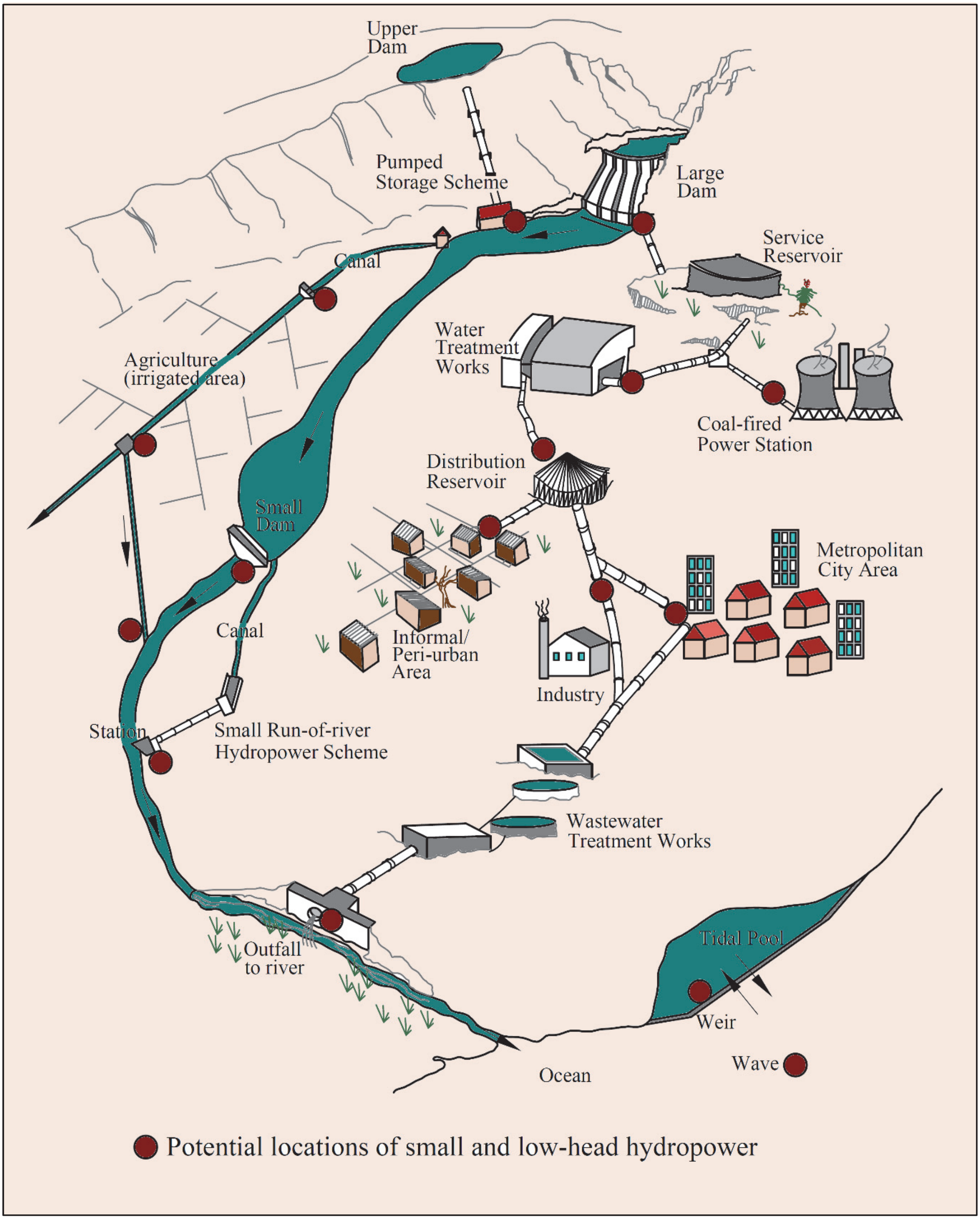


Figure 1-1: Low head hydropower potential

The key objective of this report is to discuss the development of low head hydropower in the South African context. The study is focused mainly on the investigation of existing irrigation, river flow and wastewater disposal infrastructure administered by water users' associations (WUAs), Government Water Schemes (GWS), local authorities and water utilities. These administrators are responsible for extensive water infrastructure where low head hydropower potential can be found.

2 STRIVING TOWARDS SUSTAINABLE POWER GENERATION

The following section provides an overview of the current and forecasted energy situation in South Africa, with a special focus on the potential of hydropower generation.

2.1 ENERGY SITUATION IN SOUTH AFRICA

2.1.1 BACKGROUND

Until fairly recently, electricity supply in South Africa has not received much attention from users. This could perhaps be attributed to the success with which Eskom used to provide an uninterrupted supply of electricity to the South African grid, until 2008 when the serious problems in the supply of electricity started. Presently, South Africa is facing an energy crisis which places additional importance on harvesting all available feasible renewable energy resources.

Worldwide there is still a vast dependence on fossil fuels to generate electricity, the most abundant fossil resource being coal (Lloyd and Subbarao, 2009). Eskom's document 'Understanding Electricity' (Eskom, 2013a) indicates that in South Africa, approximately 90% of electricity provided is generated in coal-fired power stations. The relative abundance, availability and the historically low cost in mining the coal, allowed electrification and supply of electricity to most of the people in South Africa. The Department of Minerals and Energy (DME, 2003), as a custodian of energy generation, together with the national regulator NERSA, have to reconcile the demand for electricity and at the same time maintain an acceptable cost to most of consumers. Another task is to keep a sustainable margin in generating capacity between demand and supply. The result is that coal will remain economically viable and will continue to be the most attractive source of energy in South Africa from a financial perspective for many more years. To secure this in the future, the environmental and sustainability perspectives need to be explored and evaluated against the relative environmental cost of coal (Evans et al., 2009).

2.2 CURRENT SOURCES OF ENERGY IN SOUTH AFRICA

The most recent figures for the breakdown of GWh produced in South Africa by the different electricity generation technologies were found in a report published by Statistics South Africa (2012). This report reflected electricity generation in South Africa in 2011. A total of 240 528 GWh was produced.

Eskom generates 95% of South Africa's electricity with the remaining 5% made up by a small group of private individuals who generate mainly for their own use (DME, 2007). Eskom owns 11 coal-fired power stations (with two more currently under construction), a nuclear power station, two pumped storage schemes (with a third under construction), six hydroelectric power stations, one wind farm (with one under construction) and four open cycle gas-fired turbines which are used only for peak demands (Eskom, 2012a).

Figure 2-1 shows the net maximum generating capacity mix of the different technologies.

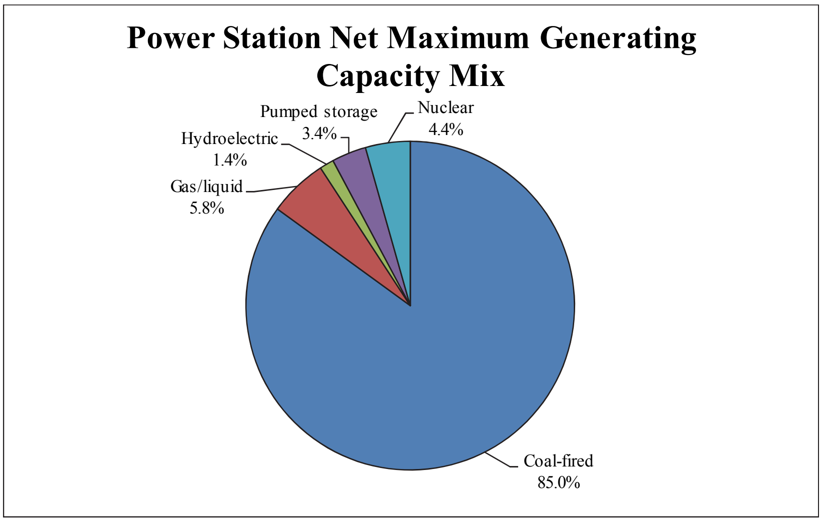


Figure 2-1: Power station net maximum generating capacity mix (Eskom, 2012a)

2.2.1 ELECTRICITY PRICE INCREASES

For many years, the average increase in electricity tariffs in the country was below inflation. Since April 2008, electricity tariff increases have been significantly above inflation every year, as illustrated in **Figure 2-2**. The main reason for the significant hike in electricity prices is because electricity generation has been subsidised for many years. It was therefore supplied at below cost to consumers. However, this practice is not sustainable and electricity prices need to become cost-reflective to support a sustainable industry in future (Eskom, 2012b).

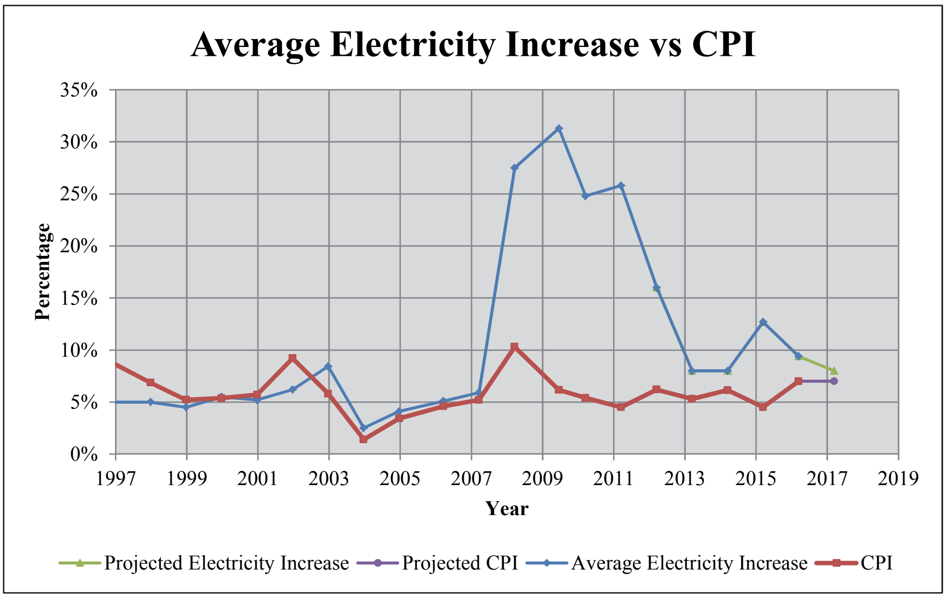


Figure 2-2: Electricity increases in South Africa (Eskom, 2007; National Treasury, 2012; Eskom 2013b)

3 AN OVERVIEW OF HYDROPOWER

3.1 INTRODUCTION

The following section will provide background information on various conventional and unconventional types of hydropower. Hydropower size classification, the potential for hydropower development in South Africa and the advantages of hydropower over other energy generation methods will also be discussed.

3.2 CONVENTIONAL TYPES OF HYDROPOWER

Normally one would associate hydropower generation with large dams and associated generating facilities; however, hydropower can be generated in various ways. The common denominator in all schemes is flowing and falling water (Natural Resources Canada, 2004). The following sections will describe the different types of conventional hydropower schemes, including: storage schemes; run-of-river schemes and pumped storage schemes.

3.2.1 STORAGE SCHEMES

Conventional hydropower depends on water from a reservoir that can provide power when needed, either to meet a fluctuating demand or a peak load. Dams are associated with significant environmental impacts and are normally only constructed for large-scale projects, as dam construction makes small schemes economically unfeasible.

However, small schemes may be retrofitted, or planned, in dams that are built for other purposes, like flood control, irrigation, recreation or water abstraction. In some cases, electricity can be generated with the discharges associated with the dam's fundamental use or ecological flows (ESHA, 2004).

3.2.2 RUN-OF-RIVER SCHEMES

Run-of-river schemes involve the diversion of either a portion or all of a river flow through a turbine to generate electricity; or turbines are installed directly in a river channel (Harvey et al., 1993). Therefore, the hydropower plant can only use the water that is available in the natural river flow.

In some irrigation canal systems, turbines can be installed to generate electricity, either through diversion or in the canal system itself. These systems will normally consist of high-flow, low-head installations (ESHA, 2004).

3.2.3 PUMPED STORAGE SCHEMES

Pumped storage schemes are used to generate peak-time electricity. During off-peak hours water is pumped to an upper dam and when peak-time electricity is needed this water is released through turbines and released into a lower dam. More energy is required in the pumping phase than energy generated and this makes these systems net energy consumers (Egré and Milewski, 2002).

However, some recent projects have utilised hybrid systems where pumped storage is combined with a renewable energy, like wind power, with high generation randomisation. These schemes use the upper dam of a pumped storage system as a battery while renewable energy is generated. The stored water is then released through the turbines when electricity is needed (Bueno and Carta, 2006).

3.3 UNCONVENTIONAL TYPES OF HYDROPOWER

According to Van Dijk et al. (2012), there are four areas with energy-generation potential in the water-supply and -distribution systems, as shown in **Figure 3-2** and discussed below**:**

1. Dam releases
2. Water-treatment works (raw water)
3. Potable water at reservoirs (PRV)
4. Potable water at pressure-reducing stations (PRSs) in the supply network

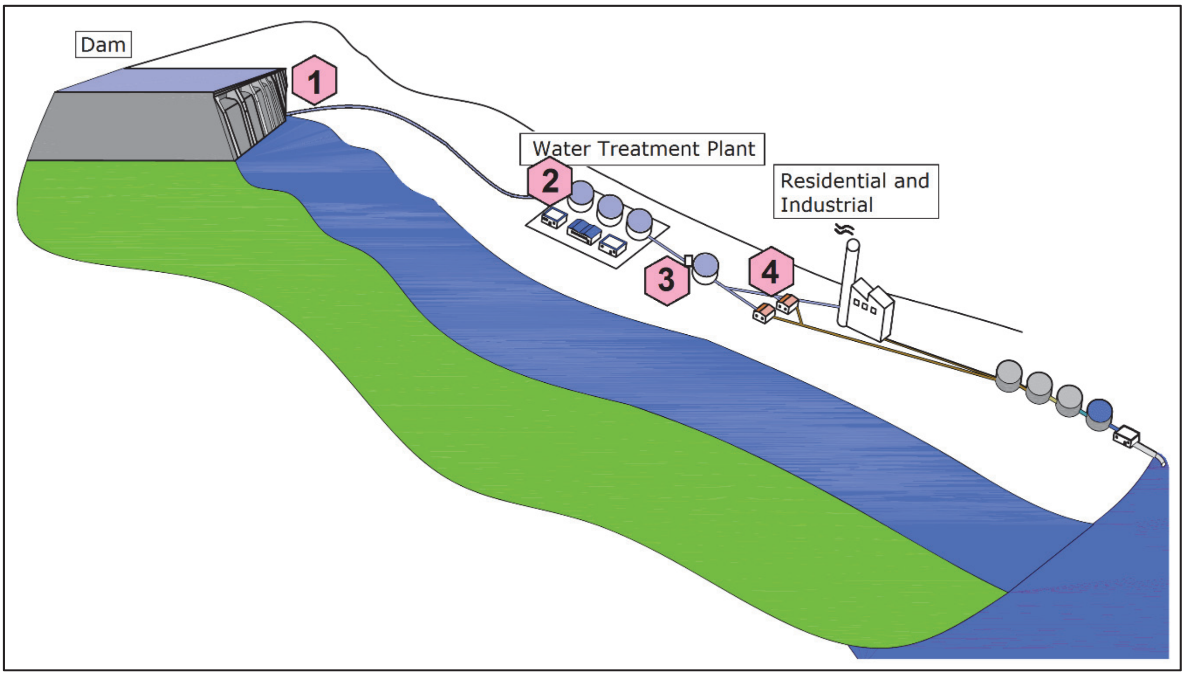


Figure 3-1: Potential energy-generation locations in WDS (Van Dijk et al., 2012)

There are generally eight areas with typically lower head energy-generation potential. These are shown in **Figure 3-2** and summarised below:

1. Dam releases (low head dams)
2. Run-of-river schemes
3. Irrigation canals
4. Weirs
5. Urban areas (pipelines and stormwater systems)
6. Industrial outflows
7. Wastewater treatment plants
8. Oceans and tidal lagoons

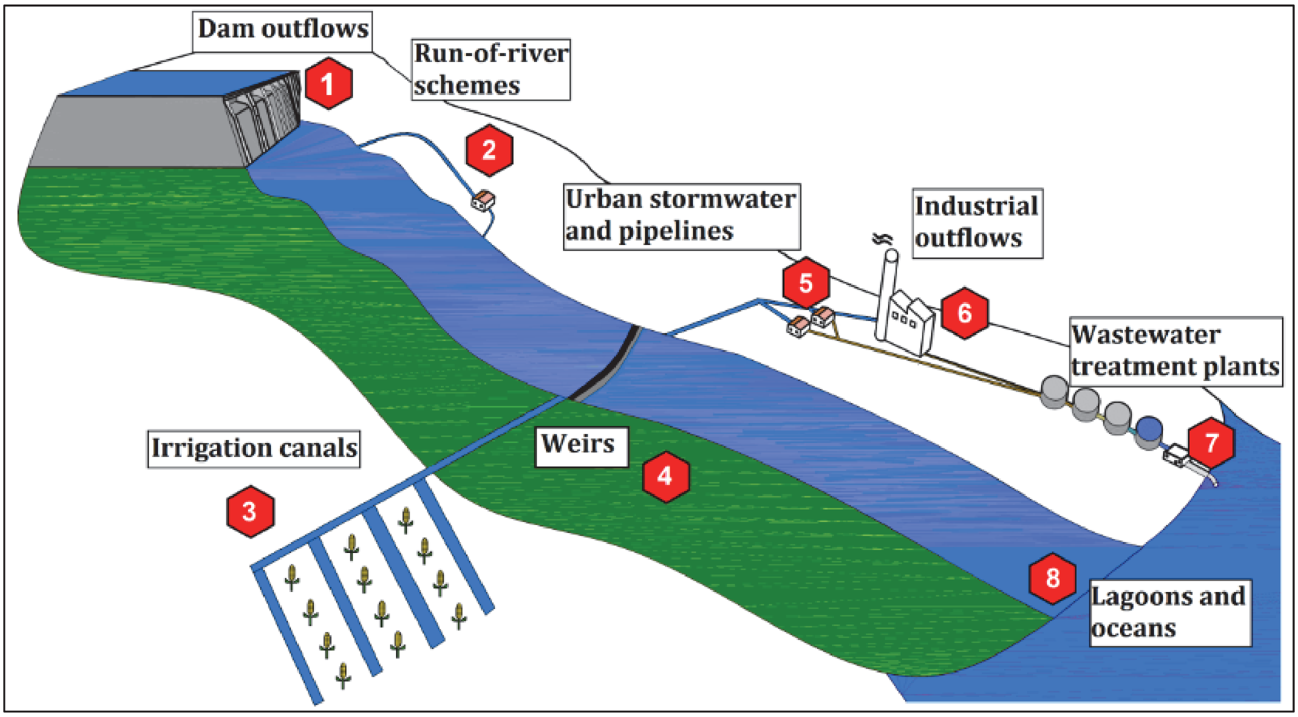


Figure 3-2: Potential low head energy-generation locations

3.4 ADVANTAGES OF HYDROPOWER

Hydropower has the following advantages over other forms of energy production in terms of economic, social, and environmental impacts:

- Firstly, hydropower is a form of clean renewable and sustainable energy as it makes use of the energy in water due to flow and available head, without actually consuming the water itself. Unlike the burning of coal, oil and natural gas, it does not emit any atmospheric pollutants such as carbon dioxide, sulphurous oxides, nitrous oxides or particulates such as ash (Frey and Linke, 2002).
- Secondly, hydropower schemes often have very long operational lifetimes (50 years or more) and high efficiency levels (70% to 90%) (BHA, 2005).

- Operating costs per annum can be as low as 1% of the initial investment costs (Oud, 2002).

A fourth advantage is that hydropower schemes often have more than one purpose. Hydropower through water storage can help with flood control and supply water for irrigation or consumption, and dams constructed for hydropower can also be used for recreational purposes (Frey and Linke, 2002).

Different forms of hydropower, including reservoir, pumped storage and run-of-river systems of different sizes, are available and can be used for different forms of electricity generation (IHA, 2005).

3.5 HYDROPOWER SCHEME SIZE CLASSIFICATION

Presently, there is no universally accepted classification system for hydropower scheme sizes (Jonker Klunne, 2012). In some cases, all installations smaller than 20 MW, or even 25 MW, are referred to as 'small', although 10 MW is common. According to Taylor and Upadhyay (2005) 'mini-hydro typically refers to schemes below 1 MW, micro-hydro below 100 kW and pico-hydro below 5 kW'. However, it seems that in the South African context, the classification given in **Table 3-1** tends to be the standard.

Table 3-1: Hydropower classification (Barta, 2002)

Category	Power output
Pico	Up to 20 kW
Micro	20 kW to 100 kW
Mini	100 kW to 1 MW
Small	1 MW to 10 MW
Macro (or large)	>10 MW

In addition to power-output classification, a scheme can also be categorised according to the type of layout, considering the type of hydropower, as well as the head (as described in **Table 1-2**).

This study focusses on low head installations, therefore sites with pressure drops of up to 30 m.

4 TYPICAL HYDROPOWER PLANT COMPONENTS

4.1 CIVIL WORKS

Conventional hydropower schemes consist of a number of structures or combinations of structures, depending on the type and layout of the scheme. The following civil components will normally be found: diversion structure, including dams, spillways, fish passes and residual flow arrangements and conveyance systems, including intakes, canals, tunnels, penstocks and powerhouses (ESHA, 2004).

4.1.1 DAM

Dams 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).

4.1.2 INTAKE

A water intake must direct the required amount of water into a canal, with as little head loss as possible. It is carefully planned to ensure that the full design flow is diverted to the turbine (Natural Resources Canada, 2004). The handling of debris and sediment is an important, but challenging aspect to consider. During the design phase it is important to consider operation and maintenance of the structure.

In a run-of-river or storage system, the location of the intake will depend on various factors, including submergence, geotechnical conditions, environmental concerns, and sediment and debris exclusion. It should have a trash rack, sediment trap, gate and a spillway for the diversion of excess water (ESHA, 2004; BHA, 2005).

4.1.3 TRASH RACK AND SEDIMENT TRAP

As the names imply, trash racks and sediment traps are structures to prevent debris and sediment from entering the turbine units. Traditionally trash screens consist of a combination of a floating boom placed across the flow path upstream of the intake to catch large debris and a panel with bars in front of the intake, with the bars spaced to allow raking of the screen. As the screen causes energy (head) loss, the bars should be installed with the maximum spacing to still prevent debris that could damage the turbine from passing through. Automatic cleaners can also be installed (BHA, 2005).

Although the trash rack will remove most of the large debris in the system, it will not eliminate sediment suspended in the water. Therefore, a sediment trap is installed downstream of the intake, to ensure that sedimentation does not occur in downstream structures or that the sediment does not damage the turbine. The sediment trap reduces the flow velocity and turbulence of the water and allows sedimentation to occur where it can be managed (ESHA, 2004).

4.1.4 CANALS AND TUNNELS

From the intake, water is conveyed to the penstock and ultimately the turbine using a system of canals or tunnels, or a combination. It is important to minimise the head losses in these conveyance structures, by providing smooth lining and regularly shaped conduits (ESHA, 2004).

4.1.5 PENSTOCK

A penstock is the pipe that carries water from the conveyance system to the turbine. A variety of materials (like plastics, steel, iron, fibreglass or concrete) and installation techniques (above or below ground) can be used for penstocks. The selected materials are determined by site layout, pipe diameter, ground conditions, budgetary constraints, etc. The penstock's diameter must be selected to minimise friction losses (which result in lost energy production). The pressure class should be taken to handle the maximum pressure, including possible surge pressures that might occur (ESHA, 2004).

4.1.6 POWERHOUSE

The purpose of the powerhouse is to support the turbines and electrical equipment, as well as to protect them from the weather. A powerhouse therefore has a substructure for support and a superstructure for protection. The superstructure contains all the operating equipment, including the turbines, generators, electrical control units, transformer and switching gear (Price and Probert, 1997). Powerhouses are normally constructed from concrete or other conventional building materials, but in the case of very small systems, might even be a prefabricated container. Space should be provided for easy maintenance and potential future expansion.

4.1.7 TAILRACE

A tailrace is used to convey the water from the turbine back to the river (Price and Probert, 1997). It is important to ensure that the tailrace is properly protected against erosion, and also that the tailrace will not allow water to rise into, and interfere with, the turbine runner (in the case of an impulse turbine) (ESHA, 2004).

4.2 TURBINE TYPES

A turbine uses the energy of moving water to generate electricity by converting the kinetic energy of the water into rotational energy used to power the generator (Paish, 2002).

Turbines can be classified according to their type of action as either impulse or reaction turbines (Loots, et.al. 2015). Impulse turbines are surrounded by air while reaction turbines are submerged in water (Paish, 2002). **Table 4-1** provides a summary of the classification of turbines. It should be noted that the heads proposed in this table are only for traditional uses and many manufacturers currently produce turbines with different head ranges than shown in **Table 4-1**. **Table 4-2** and **Table 4-3** provide more information on applicable flow and head ranges for a number of low head turbines.

Table 4-1: Groups of water turbines (Natural Resources Canada, 2004)

Turbine runner	High head	Medium head	Low head	Ultra-low head
	> 100 m	20-100 m	5-20 m	< 5 m
Impulse	Pelton Turgo	Cross-flow Turgo Multi-jet Pelton	Cross-flow Multi-jet Turgo	Water wheel
Reaction	-	Francis Pump-as-Turbine	Propeller Kaplan	Propeller Kaplan

Impulse turbines use runners that are rotated using water jets at high velocities. The three main types are the Pelton, Turgo and Cross-flow (or Banki) turbines. Pelton turbines usually have very good efficiencies (ESHA, 2004). Turgo turbines use smaller diameter runners to obtain similar results (Paish, 2002) and can operate at flows significantly lower than the design flow, giving them high flexibility. Cross-flow (or Banki-Michell) turbines have a lower efficiency than other turbines (ESHA, 2004).

Reaction turbines use the flow of water to generate upward hydrodynamic force that in turn rotates the runner blades. The most used reaction turbines are the propeller (or Kaplan) and the Francis turbine (Paish, 2002).

As this study is focussed on low head hydropower (up to 30 m of pressure head), an extensive list of a variety of low head turbine types from various manufacturers is summarised in **Table 4-2** and **Table 4-3** and included in **Appendix A**. The rest of **Section 4.2** will briefly describe the most commonly used types of low head turbines.

Table 4-2: List of low head impulse turbines

Turbine type	Supplier	Flow range	Head range (m)	Power (kW)
Pelton*	Powerspout	0.008-0.01 (m^3/s)	3-100	<1.6
Crossflow (Banki)*	IREM	0.01-1 (m^3/s)	5-60	<100
	Ossberger	0.04-13 (m^3/s)	2.5-200	15-3 000
	Wasserkraft Volk	1.5-150 (m^3/s)	Not given	<2 000
Hydroengine	Natel energy	1.1-10.1 (m^3/s)	< 6	50-500
Hydraulic (Archimedean) Screw*	Andritz	<10 (m^3/s)	<10	<500
	HydroCoil	<10 (m^3/s)	4-20	2-8
	3Helix Power	0.2-10 (m^3/s)	1-10	1.4-700
Waterwheel*	Hydrowatt	0.1-5 (m^3/s)	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 (m^3/s)	0.7-2	0.5-160
Steffturbine	Walter Reist	<0.4 (m^3/s)	2.5-5	10

* denotes turbines that are discussed in the rest of **Section 4.2**

Table 4-3: List of low head reaction turbines

Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power (kW)
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
	Energy systems	0.03-0.06	1-3	0.09-1
	Power Pal	0.04-0.13	1.5	0.2-1
	Tamanini	0.2-15	5-35	10-5 000
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
Turbinator	Clean Power AS	0.5-12	10-60	75-3 300
Francis*	Tamanini	0.2-10	15-300	10-10 000
	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
Siphon-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
Wave power	Voith	Not given	Not given	Not given

* denotes turbines that are discussed in the rest of **Section 4.2**

4.2.1 PELTON TURBINE

Pelton turbines function by directing one or more jets of water tangentially onto a runner with split buckets, as shown in **Figure 4-1**. The jet of water causes a force on the buckets, causing the buckets to rotate, resulting in torque on its shaft (Paish, 2002). After propelling the buckets, the water falls into the tailrace, ideally with almost zero remaining energy.

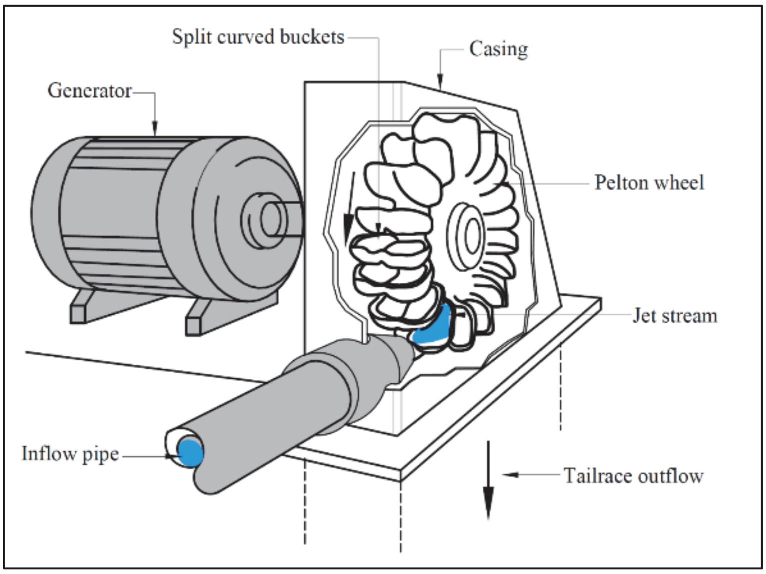


Figure 4-1: Typical Pelton turbine (Paish, 2002)

4.2.2 CROSS-FLOW TURBINE

Cross-flow turbines are constructed with two disks joined together using inclined blades. Water enters the turbine from the top and passes through the blades twice, as shown in **Figure 4-2**. After hitting the blades twice, the water ideally has almost no residual energy and falls into the tailrace (Paish, 2002). Thornbloom et al. (1997) consider an accurately designed cross-flow runner as one in which 'the water impinges on the top blade, is turned by the blade, and flows through the runner, just missing any shaft in the centre and impinges on a lower blade before exiting to the tailrace.'

The efficiency of a cross-flow turbine does not drop much when flow rates change. Therefore, cross-flow turbines are regularly used when large flow-rate variations are anticipated (Razak et al., 2010).

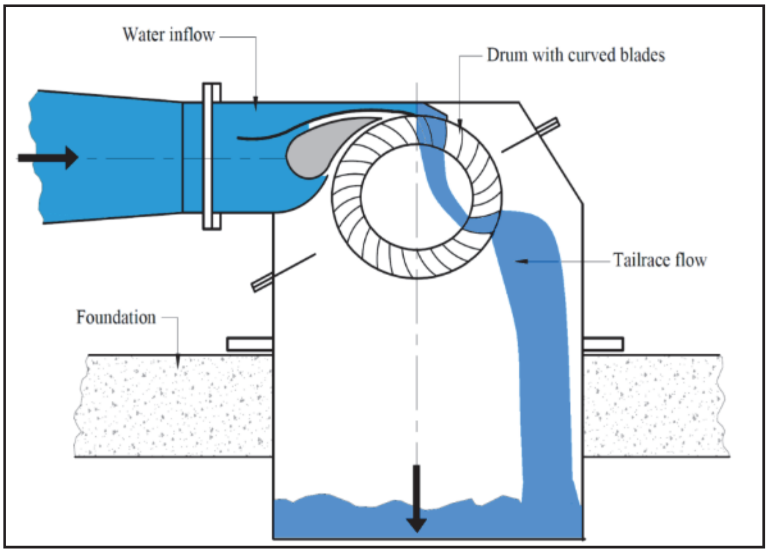


Figure 4-2: Typical cross-flow turbine (Paish, 2002)

4.2.3 HYDRAULIC SCREW TYPE TURBINE (ARCHIMEDEAN PRINCIPLE)

Screw-type turbines are based on the principle of an Archimedes screw pump in reverse that operates by utilising the hydrostatic pressure difference across the blades (Williamson et al., 2012). These turbines are used in low-head, high-flow applications and can generate up to 300 kW (International Energy Agency, 2010).

A study done by the Future Energy Yorkshire indicated that in terms of capital cost the Archimedes' screw turned out 22 percent cheaper than an equivalent Kaplan turbine (FEY, 2012). The screw type turbines are also reported to be less harmful to fish.

A schematic view of a screw type turbine installation is shown in **Figure 4-3.**

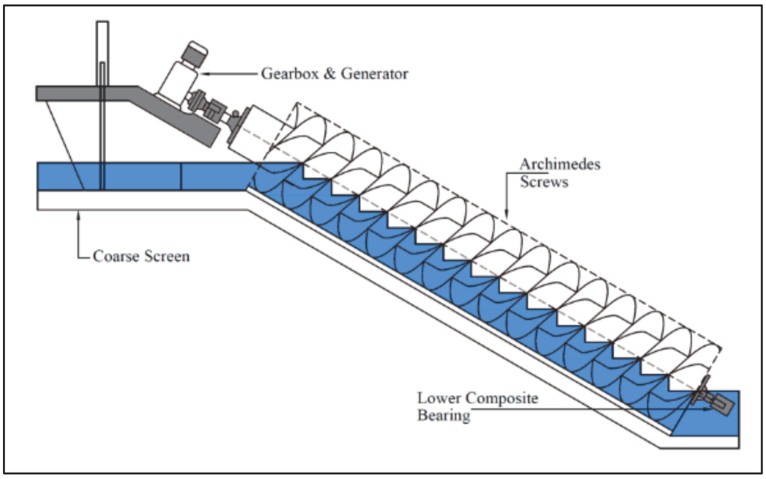


Figure 4-3: Screw type turbine design (Bouk, 2011)

4.2.4 WATER WHEELS

Water wheels have for many years been the traditional method of generating hydropower in small quantities. Even though they are less efficient than turbines, they can still be a practical option in certain cases, as they are simple to control, easy to construct and maintain and are aesthetically pleasing (Natural Resources Canada, 2004).

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

- The **Undershot wheel** is vertically mounted on top of the water surface. The wheel is turned by the water flowing underneath the wheel. **Figure 4-4** is a schematic of an undershot wheel.

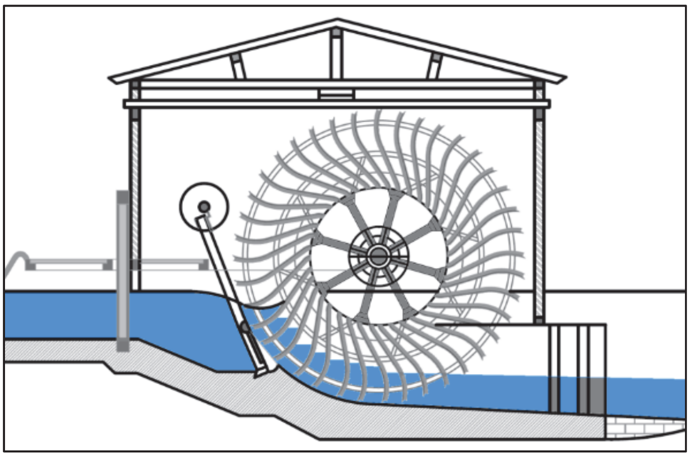


Figure 4-4: Undershot wheel (Muller, 2004)

- The **Breastshot wheel** receives energy from falling water which hits the blades at the centre height of the wheel. A breastshot wheel is shown in **Figure 4-5**.

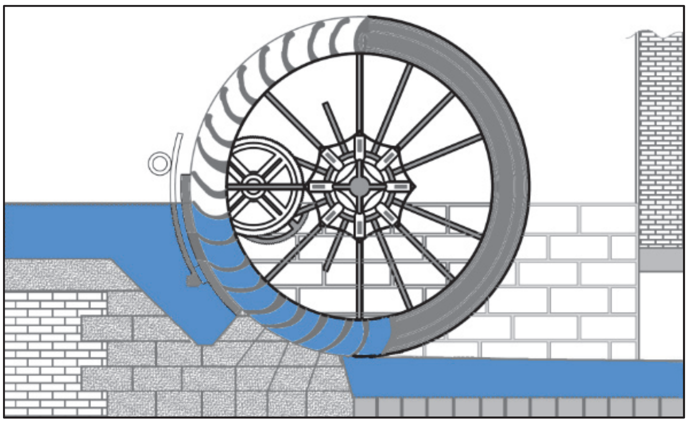


Figure 4-5: Breastshot wheel (Muller, 2004)

- An **Overshot wheel** works in much the same manner as the breastshot wheel, only with the water striking the blades near the top of the wheel. Such an installation is shown in **Figure 4-6.**

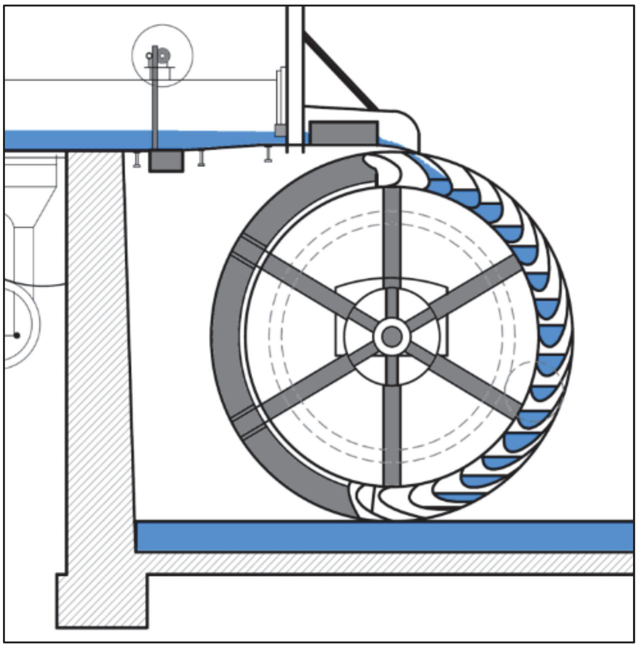


Figure 4-6: Overshot wheel (Muller, 2004)

4.2.5 HYDROKINETIC TURBINES

Hydrokinetic turbines generate electricity using the kinetic energy of the water in low head applications, instead of the potential energy due to hydraulic head, as in high pressure applications. These devices therefore capture energy from moving water, without requiring dams or diversions (Kumar et al., 2011).

Two basic rotors are currently being used by one of the leaders in hydrokinetic manufacturers, Hydrovolts. The Darrieus and Open Savonius rotors are shown in **Figure 4-7.** Most other hydrokinetic rotors work in a similar manner. These rotors can be placed horizontal or vertically.

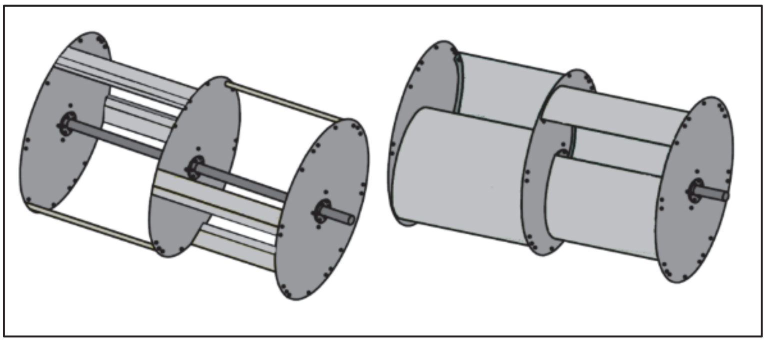


Figure 4-7: Darrieus (left) and Open Savonius (right) rotors (Hydrovolts, 2011)

4.2.6 KAPLAN, BULB AND PROPELLER TURBINES

Kaplan, bulb and propeller turbines use the axial flow of water to develop hydrodynamic forces that rotate the runner blades (Paish, 2002). Unlike with impulse turbines, the Kaplan turbine is completely submerged inside the conduit, as shown in **Figure 4-8**. Guide vanes are installed upstream of the turbine to create inlet swirl, as this ensures better efficiency.

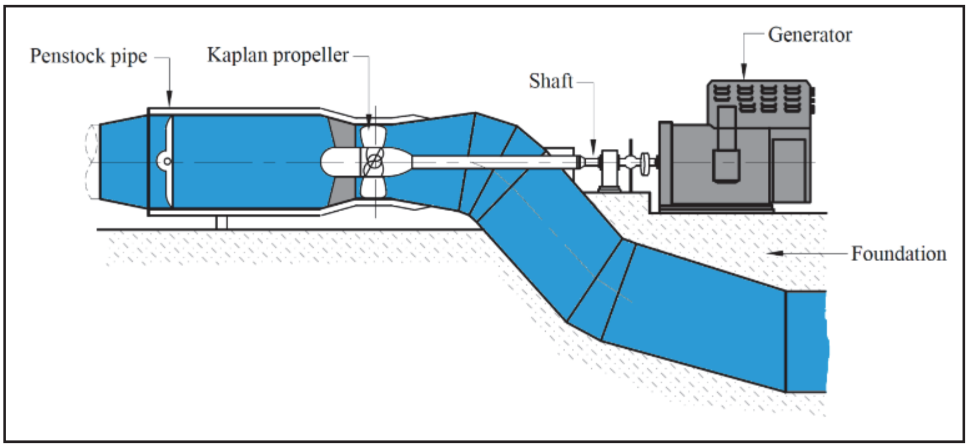


Figure 4-8: Typical Kaplan turbine (Paish, 2002)

4.2.7 FRANCIS TURBINE

A Francis turbine has radial runners that guide the water to exit at a different radius than the inlet radius. Francis turbines force the water to flow radially inwards into the runner and turned to emerge axially at the outlet, as shown in **Figure 4-9** (Paish, 2002).

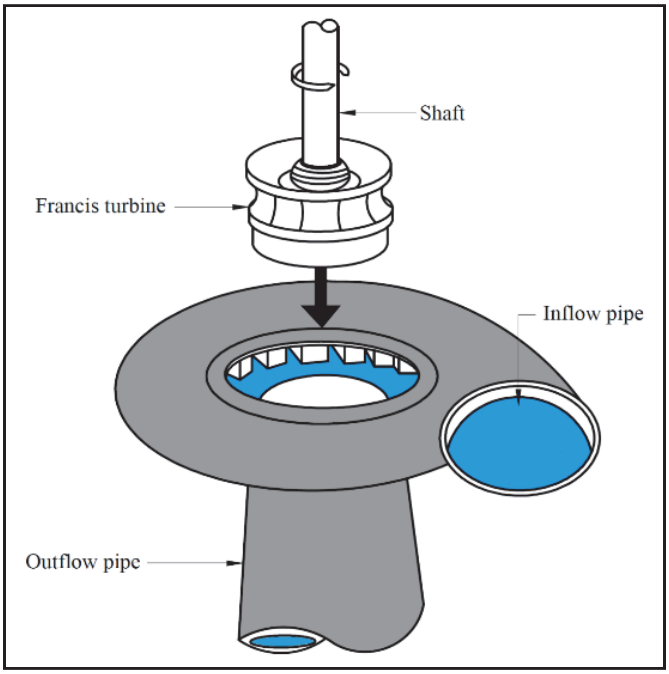
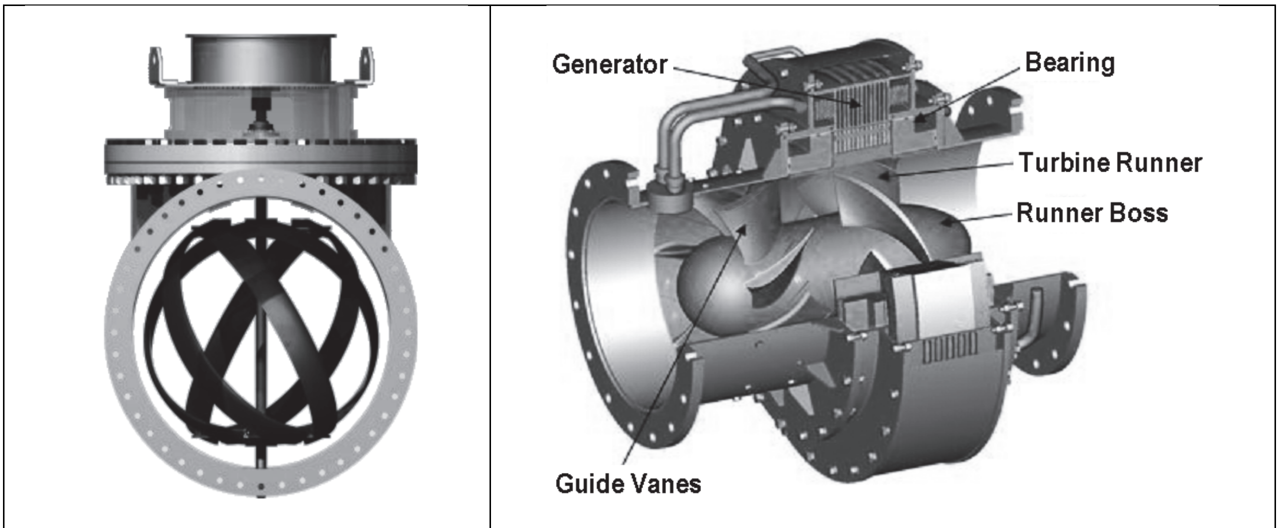


Figure 4-9: Francis turbine (Paish, 2002)

4.2.8 INLINE TURBINES

Recently the use of inline turbines has increased. These turbines include spherical and ring turbines (**Figure 4-10**) and are installed directly in the primary conduit of a pressurised system; they do not need to be installed in a bypass. These turbines can typically generate between 1 kW and 100 kW and are therefore applicable to pico- and micro-hydropower installations (Kanagy, 2011; International Energy Agency, 2010).



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

Figure 4-10: Examples of inline turbines

4.2.9 PUMP AS TURBINE (PAT)

Much research has been done recently on the use of reverse-engineered pumps that can be used as hydraulic turbines (**Figure 4-11**). A standard centrifugal pump is run in reverse to act as a turbine; this is an attractive option, especially in developing countries, because pumps are mass-produced, and therefore more readily available and cheaper than turbines (Williams, 2003). However, PATs generally operate at lower efficiencies than conventional turbines, especially at partial flows.

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

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

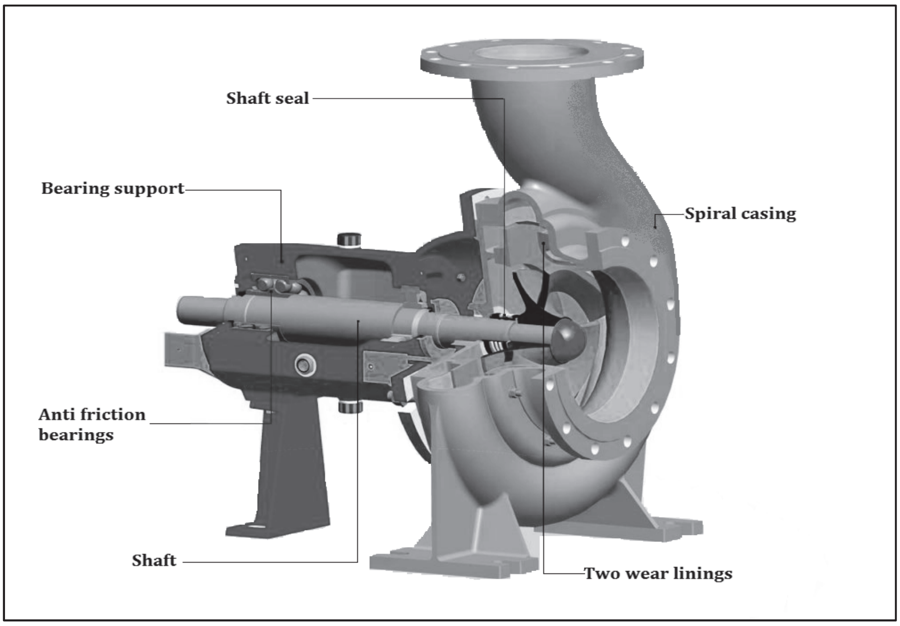


Figure 4-11: An example of a pump as turbine (Andritz, 2013)

4.2.10 TURBINE SELECTION

The key factors to consider in turbine selection and design are the net available head or effective pressure head across the turbine and the range of flow values which the turbine must be able to handle. These values are plotted on operational charts which give envelopes of limiting operational conditions for each type of turbine. Other factors to consider in turbine selection include specific speed, cavitation and efficiency (ESHA, 2004).

Another important factor to consider is flow-rate variation, as turbine efficiency might be severely impacted if high variation is experienced. For example, Francis and propeller-type turbines have high efficiencies at design flow, but very low efficiencies for other flow rates. On the other hand cross-flow and Pelton turbines can sustain high efficiencies over a wide range of flow rates.

Turbine selection charts and efficiency curves must be sourced from manufacturers and suppliers, as the applicability of turbines from various manufacturers differs significantly. **Appendix A** provides contact details of suppliers.

4.3 OTHER ELECTRICAL AND MECHANICAL EQUIPMENT

4.3.1 GENERATORS

The function of a generator is to convert the mechanical energy produced by the water flowing through the turbine to electrical energy. This is done by inducing a voltage in a coil of wire when the wire is moved through a magnetic field.

Generators can be grouped into two types: synchronous – and asynchronous generators. Synchronous generators are used in most power plants (Natural Resources Canada, 2004). They can run isolated from the grid (ESHA, 2004). Asynchronous (or induction) generators are usually applied in smaller systems, as they are more robust and less expensive than synchronous systems (Natural Resources Canada, 2004). However, they cannot generate high quality electricity if disconnected from the grid, as they cannot provide their own excitation current (ESHA, 2004). Therefore, asynchronous generators are generally connected to the grid.

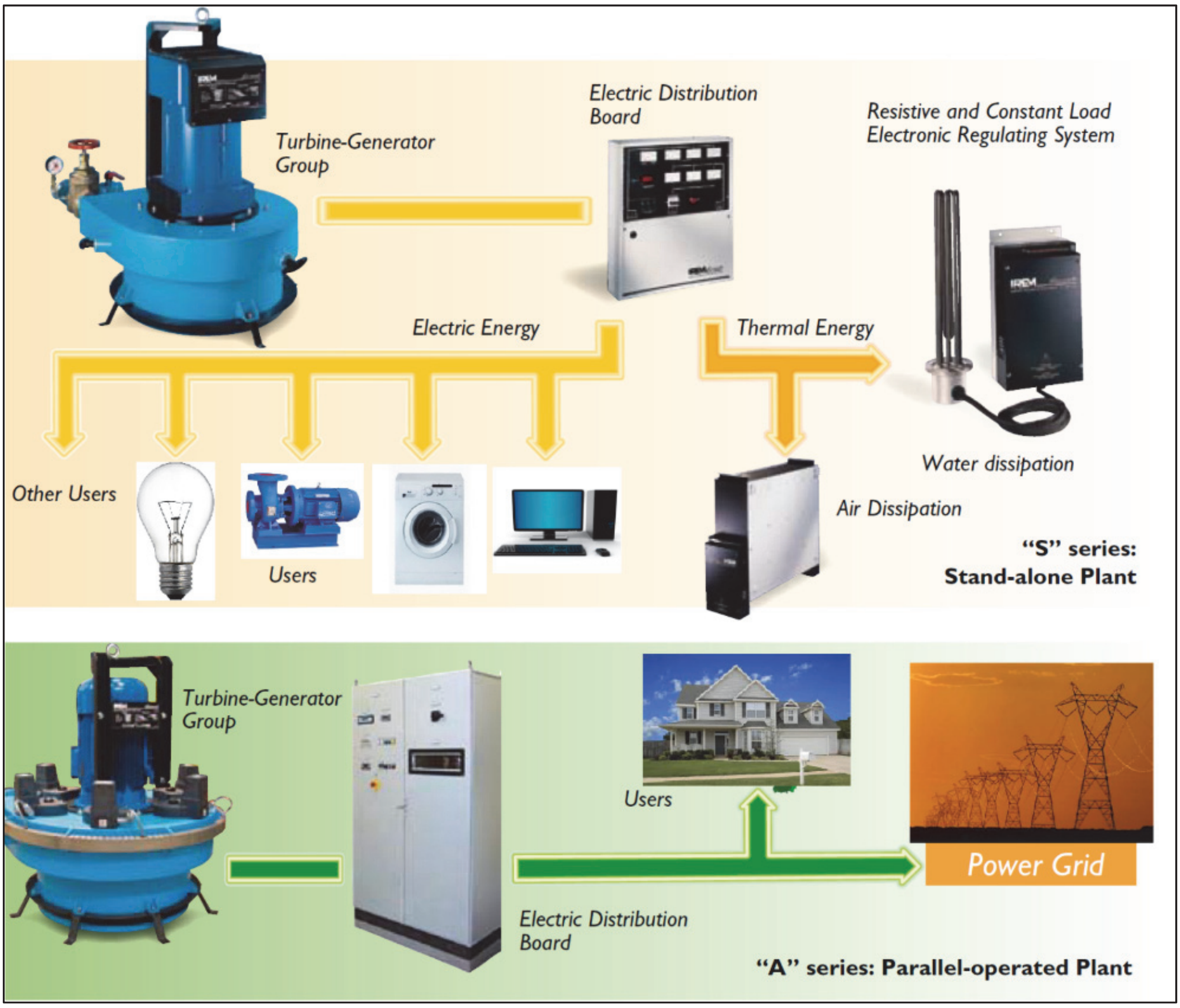


Figure 4-12: Diagram of grid-connected versus stand-alone installations (IREM, 2012)

4.3.2 DRIVERS

A drive system is needed in a hydropower system to ensure that electrical power is generated at a stable voltage and frequency. Therefore, it has to transmit power from the turbine to the generator shaft at the right speed and in the right direction. Typical drive systems include: direct drives; belts and pulleys; and gearboxes (Natural Resources Canada, 2004).

4.3.3 TURBINE CONTROL

Although turbines are designed for a certain net head and discharge, deviations in both flow and head occur and must be compensated for.

This is done by opening or closing control devices in the system to ensure that either the outlet power, the head in the system or the flow through the turbine remains constant (ESHA, 2004).

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

4.3.4 TRANSMISSION

Electricity is transported from the powerhouse to the users via electric cables (either overhead or underground). The size and type of the cables are determined by the amount of power to be transmitted and the distance between the plant and the users. For small systems, single-phase electricity may be sufficient. In larger systems a transformer or three-phase electricity is required to minimise losses (Natural Resources Canada, 2004).

5 FUNDAMENTALS OF HYDROPOWER POTENTIAL EVALUATION

5.1 PLANNING

When planning a hydropower plant, important information to be gathered includes: the available head; the proximity of the site to a grid connection; possible environmental impacts; regulatory requirements; public inquiry; construction requirements; electricity use; and cost implications of the planned system (Natural Resources Canada, 2004; ESHA, 2004; BHA, 2005).

It is also important to assess the organisational and technical capability of the future operators of a planned scheme. Micro-hydropower schemes are often installed in rural communities, far away from the skills centres of the cities. Therefore a sound management system should be an integral part of the planning phase (Harvey et al., 1993).

Harvey et al. (1993) proposes the following golden rule for feasibility phase planning: 'O[peration and] M[aintenance] first, plant factor second, engineering design last.' It is essential to include a full operation and maintenance study in the planning stages.

5.2 PRACTICABILITY OF SITES

The first step in planning a hydropower plant would be to identify potential sites. According to Natural Resources Canada (2004), '[t]he best geographical areas for (conventional) micro-hydropower systems are those where there are steep rivers, streams, creeks or springs flowing year-round, such as in hilly areas with high year-round rainfall.'

A hydropower scheme is dependent on both the flow through the system and the head drop through the system (Harvey et al., 1993). It is important to gather sufficient data to determine the design flow and head. Power and energy requirements should also be examined to determine the necessary capacity of the turbine and the applicability of the chosen site (Natural Resources Canada, 2004).

5.3 BASIC COMPONENTS

Conventional micro-hydropower systems typically include civil works, like dams, spillways, energy dissipating structures, intakes, de-siltation systems, channels, penstocks, powerhouses and tailraces.

The electromechanical components include turbines, generators, drive systems and controllers (ESHA, 2004). Electrical components consist of grid connections and the distribution network (Natural Resources Canada, 2004).

The basic components of a typical small hydropower system are illustrated in **Figure 5-1** (Natural Resources Canada, 2004).

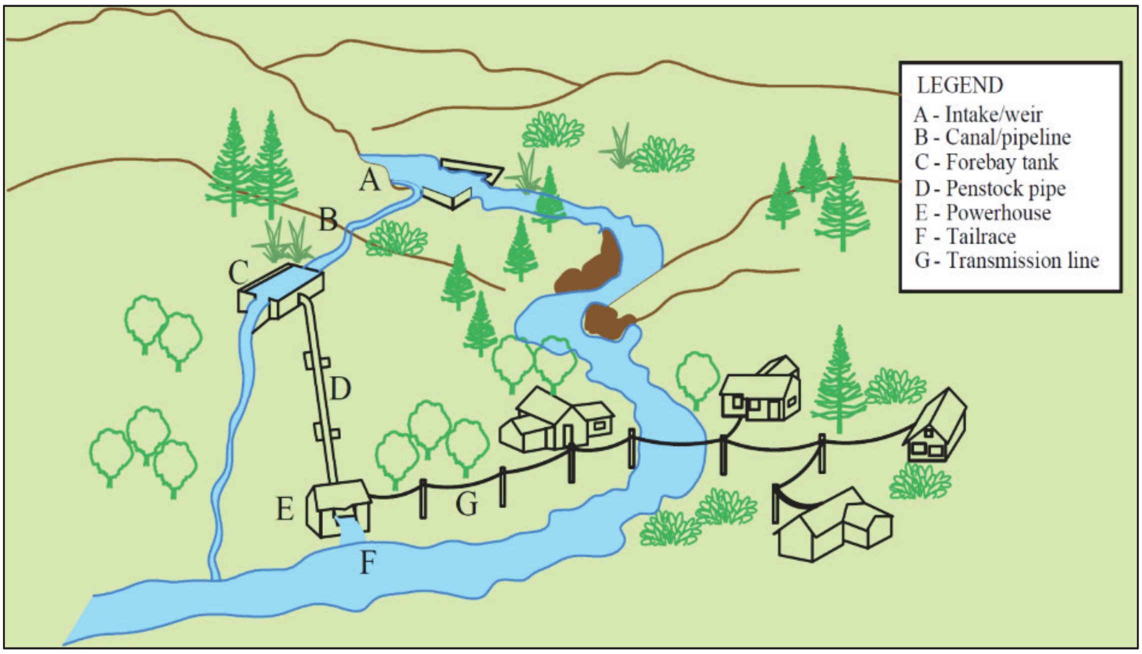


Figure 5-1: Typical run-of-river hydropower components (NRC, 2004)

5.4 POWER CAPACITY AND OUTPUT CALCULATIONS

5.4.1 RELEVANT EQUATIONS

Hydropower works on the principle that water pressure is used to rotate a mechanical shaft in the hydro turbine. This rotation is used to power a generator that converts the energy into electricity. The potential power output of a hydropower installation is directly proportional to the flow (m^3/s) and available pressure head (m), as illustrated in **Equation 5-1** (BHA, 2005):

$$P=\rho gQH\eta \qquad \textbf{Equation 5-1}$$

where:

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

However, the power produced by hydrokinetic turbines is based on the velocity of the water, instead of pressure head and flow. The general equation to determine power from these turbines has been adapted for metric units from Colorado Department of Agriculture (CDA) (2011):

$$\boldsymbol{P} = \mathbf{126.71} \times (\boldsymbol{A} \times \boldsymbol{v}^{\mathbf{3}})$$ **Equation 5-2**

With:

P= power (Watts)

A = area of the turbine in flow (m^2)

v = velocity (m/s)

Bernoulli's energy equation is based on the principle of conservation of energy and can be used to calculate the variation in pressure and velocity along any continuous streamline (Chadwick et al., 2004).

The energy equation, accounting for losses in the streamline, is shown in **Equation 5-3**, with the equations for friction and secondary losses given in **Equation 5-4** and **Equation 5-5**, respectively.

$$\frac{P_1}{\rho g}+\frac{V_1^{\ 2}}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^{\ 2}}{2g}+Z_2+h_{\mathrm{f}}+h_{\mathrm{l}}$$ **Equation 5-3**

where*:*

P_1 = pressure at Station 1 (N/m^2)

ρ = density of water (kg/m^3)

g = acceleration due to gravity (m/s^2)

v_1 = velocity of the flow at Station 1 (m/s)

Z_1 = elevation of the water above datum line, in the streamline at Station 1 (m)

P_2 = pressure at Station 2 (N/m^2)

v_2 = velocity of the flow at Station 2 (m/s)

Z_2 = elevation of the water above datum line, in the streamline at Station 2 (m)

h_{f} = friction loss (m)

h_{l} = secondary losses (m)

and

$$h_{\mathrm{f}}=\frac{\lambda L V^2}{2gD}$$ **Equation 5-4**

$$h_{\mathrm{l}}=\frac{KV^2}{2g}$$ **Equation 5-5**

where:

h_{f} = friction loss (m)

h_{l} = secondary losses (m)

λ = friction coefficient of penstock or pipe (m)

L = length of penstock (m)

v = velocity of water flow in penstock pipe (m/s)

g = acceleration due to gravity (m/s^2)

D = diameter of penstock or pipe (m)

K = secondary loss coefficient (K is normally 0.5 at inlet and 1 at outlet)

5.4.2 FLOW-DURATION CURVES

In order to determine the design flow rate to be used in the power equation, flow-duration curves have to be drawn. These curves indicate the probability of the amount of days per annum that a certain flow will be exceeded. **Figure 5-2** a typical example of flow-duration curve of a stream with fairly constant base flow and significant seasonal variation in peak flow (Natural Resources Canada, 2004; BHA, 2005).

Distribution system pipelines will have flow-rating curves correlating with system demand. However, system demand will vary daily, weekly and monthly, depending on peak water-use times of system users.

Flow duration curves in irrigation canals will depend on various factors, including the rainfall during a specific year, the type and season of crop irrigation and the times scheduled for flow in specific canals.

Flow duration curves at wastewater treatment plant outlets are normally fairly constant throughout the year, with higher flows occurring after storm events.

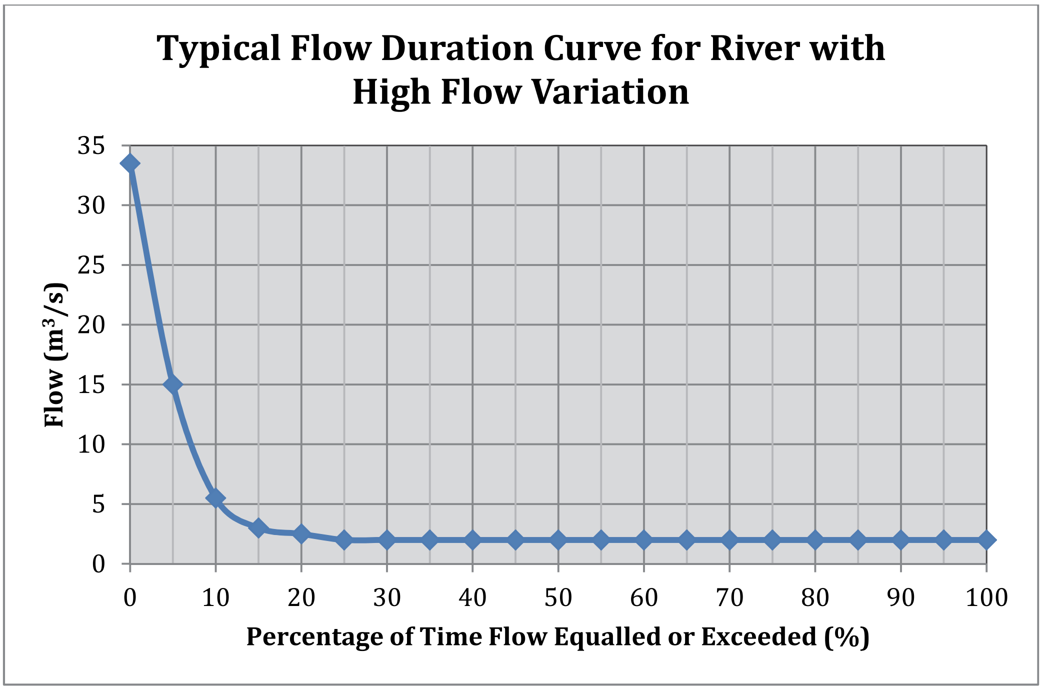


Figure 5-2: Flow-duration curve for high flow variation (NRC, 2004)

5.4.3 HYDROELECTRIC INSTALLATION CAPACITY UTILIZATION

To calculate the maximum amount of hydroelectricity that can be produced within each small scale hydroelectric category an Annual Load Factor (ALF) is determined from the historic data on similar installations or has to be based the local research or on assumed plant capacity utilization factor. Plant capacity utilization can be determined using **Equation 5-6:**

$$\boldsymbol{Utilization}\ (\%) = \frac{P \times t}{P \times T} \times 100 \qquad \textbf{Equation 5-6}$$

where:

P = capacity installed (kW)
t = time actually worked (hours)
T = theoretical time available (8 760 hours)

The uncertainty in choosing appropriate values of the ALF in determining annual plant production output is one of the critical issues in the feasibility assessment of a hydroelectric installation. The illustrative values of typical capacity utilization for the small scale hydroelectric categories are given in **Table 5-1**.

Table 5-1: Capacity utilization typical to small scale hydroelectric installations

Category	Installed capacity	Utilisation range (% p.a.)	Remarks
Pico	Up to 20kW	10 to 35	Determined from local research
Micro	20 kW to 100 kW	10 to 35	Determined from local research
Mini	100 kW to 1 MW	10 to 75	Determined from local research
Small	1 MW to 10 MW	35 to 85	Textbook general values

The gross electricity production which can be available from an installation depends on the choice of the Annual Load Factor (ALF), as shown in **Equation 5-7**:

$$\boldsymbol{Annual\ production\ output} = \boldsymbol{P} \times \boldsymbol{T} \times \boldsymbol{ALF} \qquad \textbf{Equation 5-7}$$

where:

P = capacity installed (kW)
T = theoretical time available (8 760 hours)
ALF = Annual Load Factor

The actual output achieved in any given year can be subjected to significant variation which in turn affects the capacity value of a hydroelectric installation.

5.4.4 HYDROPOWER OUTPUT COSTING

Power generation cost of mini and micro hydro projects in South Africa can be estimated using **Equation 5-8**:

$$\boldsymbol{C_h} = \boldsymbol{P} \times \boldsymbol{c_u} \qquad \textbf{Equation 5-8}$$

where:

C_h = cost of the hydropower plant
P = capacity installed (kW)
c_u = unit cost of power

and:

$$c_u = \frac{LCC}{F_d \times D \times 365}$$ **Equation 5-9**

where*:*

F_d = discounted cost factor = $\frac{(1+i)^n - 1}{i(1+i)^n}$

i = discount rate or project cost escalation rate

n = number of years

D = system's daily power demand

LCC = life cycle cost

Normally engineering projects incur not only capital cost, but also various revenue costs, maintenance costs and ultimately replacement costs over their lifetimes (see **Figure 5-3**). Therefore it is important to consider the value of all the components allowing for the relationship between the value of money and time.

The life-cycle cost (LCC) of a project includes all costs of constructing and operating a system over its full operating life (in present money value). LCC provides valuable information that will enable the comparison of projects with different expenditure patterns.

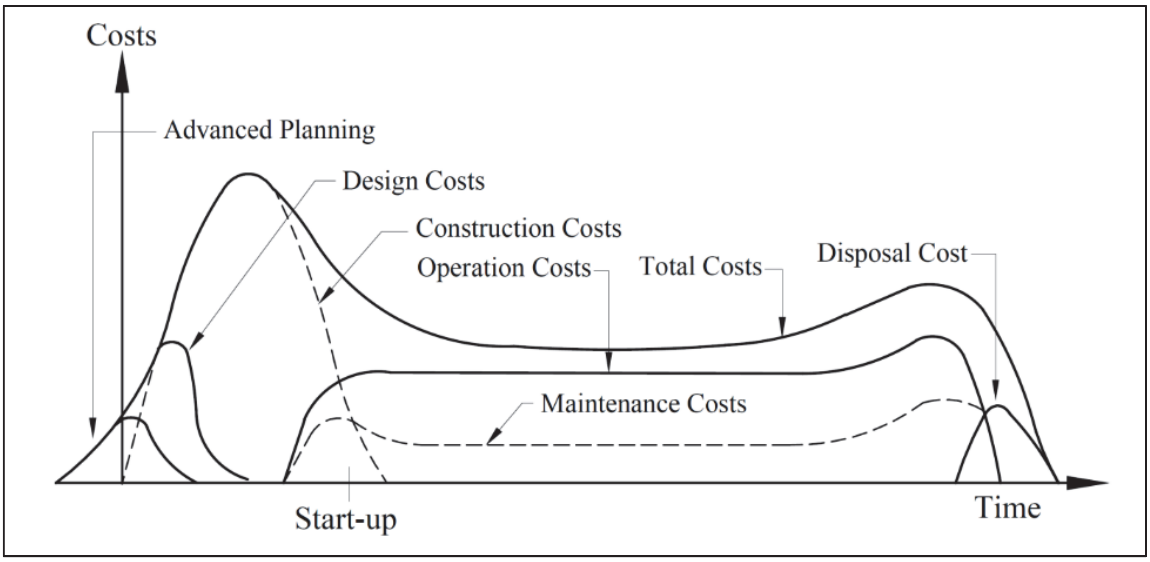


Figure 5-3: Representation of a hydroelectric system life-cycle profile

5.4.5 EFFICIENCY

The ratio between electricity output and input, at a specific time, is the electric power plant efficiency of a generator. The efficiency of a hydropower turbine can be calculated by comparing the actual power output with the theoretical output at 100% efficiency, as shown in **Equation 5-8.**

$$\eta = \frac{P_{\text{actual}}}{P_{\text{theoretical}}}$$ **Equation 5-10**

where:

η = hydraulic efficiency of the turbine (%)

P_{actual} = actual power output (W)

$P_{\text{theoretical}}$ = theoretical power output (W)

The actual electrical output of the turbine can be determined by multiplying the current of the electric flow by its potential difference (**Equation 5-9**):

$$P = IV$$ **Equation 5-11**

where:

P = electrical power output (W)

I = electrical current (A)

V = potential difference (V)

Harvey et al. (1993) proposes the following losses as typical system losses for a scheme operating at design flow (**Figure 5-4**).

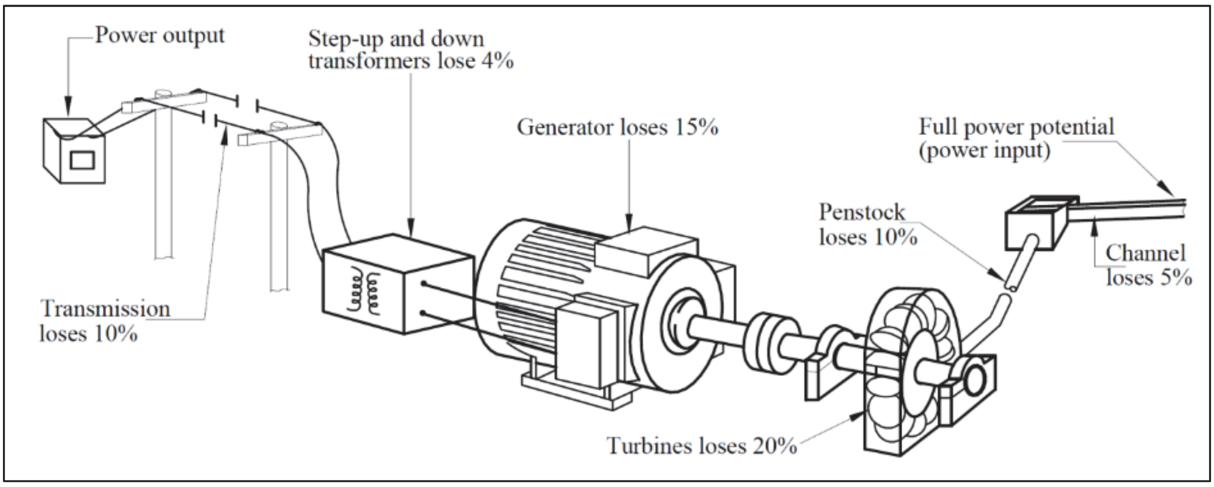


Figure 5-4: System losses (Harvey et al., 1993)

However, Natural Resources Canada (2004) proposes better efficiency ranges for turbines (**Table 5-2**). Currently most generators have efficiencies between 90% and 95%. The BHA (2005) states that micro-hydro system efficiency tends to be between 60% and 80%, with 70% considered a typical efficiency.

Table 5-2: Typical efficiencies of turbines and water wheels (NRC, 2004)

Prime mover	Efficiency range
Impulse turbines:	
Pelton	80-90%
Turgo	80-95%
Cross-flow	65-85%
Reaction turbines:	
Francis	80-90%
Pump-as-turbine	60-90%
Propeller	80-95%
Kaplan	80-90%
Waterwheels:	
Undershot	25-45%
Breastshot	35-65%
Overshot	60-75%

5.5 ENVIRONMENTAL CONSIDERATIONS

The potential environmental impacts of a hydropower scheme need to be studied and mitigated. According to ESHA (2004), the process followed will consider the identification and mitigation of all possible impacts during construction and operation on site, as well as downstream and upstream of the site and due to the transmission lines.

Van Vuuren et al. (2011) conducted an extensive investigation into the potential impacts of retrofitted hydropower. Considered aspects included: land-use and construction impact; temporary and permanent river-diversion impact; the impact of the type of power generation on releases; the impact on aquatic biodiversity; noise impact during construction as well as operation; visual impacts; and social impacts. All other impacts considered, 'there is one major positive environmental consequence in the form of greenhouse gas emission reductions which indirectly affects wildlife, nature and the general public' (Van Vuuren et al., 2011).

The expectations of the public with regard to environmental and social impacts of hydropower have grown significantly over time and are therefore becoming increasingly important (Klimpt et al., 2002). The general areas of consideration in terms of social aspects are:

- The cultural heritage of the site.
- Potential public health threats resulting from changes in downstream flow regimes or changes in the water quality.
- Public acceptance by the community and affected parties to increase buy-in and reduce vandalism.

- Impacts on downstream agricultural activities.
- The balance between community upliftment and the preservation of traditional ways of life.

The National Environmental Management Act (1998) and government Gazette of June 18, 2010 provide three schedules of activities which define whether a full EIA or Basic Assessment only is to be undertaken. The activities as scheduled are:

- GN 544 for Basic Assessment
- GN 545 for Environmental Impact Assessment (EIA)
- GN 456 for geographical activities

However, prior the actual implementation of a small scale low-head hydropower retrofit to existing infrastructure requires preparation of the Environmental Management Plan dealing primarily with the following issues:

- integrity of existing operation regime
- public health and safety
- air quality during construction
- noise management during construction
- water quality management during and post-construction
- waste management during construction
- disaster management
- environmental rehabilitation

6 PREVIOUS STUDIES ON HYDROPOWER POTENTIAL IN SOUTH AFRICA

6.1 INTRODUCTION

Worldwide, hydropower is the most established and reliable renewable energy technology. Traditionally, hydropower is used in large dams where the outlet flow is used to spin a turbine to generate electricity. However, South Africa has rather limited conventional water resources suitable for large-scale hydropower projects. Still, small hydropower has played a historically significant role in the implementation of electricity projects both in South Africa and the rest of the continent, with the first project in South Africa being a 300 kW station on Table Mountain in 1895 (Barta, 2002).

Unfortunately, many of the small-scale hydropower stations have fallen into disrepair. In many cases in South Africa, this was due to the availability of cheap and reliable electricity from Eskom at the time, but in others it was because of poor maintenance and general neglect (Jonker Klunne and Michael, 2010).

6.2 DME HYDROPOWER POTENTIAL BASELINE STUDY

An overall assessment of hydropower potential in South Africa was conducted in a baseline study in 2002 (Barta, 2002). The capacity of installed hydropower and future potential for hydropower development are summarised in **Table 6-1**.

Table 6-1: Assessment of hydropower according to feasible categories (Barta, 2002)

Hydropower category	**Installed capacity**	**Development potential**	
		Firm	**Long-term**
(Power output range)	**(MW)**	**(MW)**	**(MW)**
Pico (up to 20 kW)	0.02	0.10	60.20
Micro (20 kW to 100 kW)	0.10	0.40	3.80
Mini (100 kW to 1 MW)	8.10	5.50	5.00
Small (1 MW to 10 MW)	25.70	63.00	25.00
Subtotal for pico/micro/mini and small hydro	**33.92**	**69.00**	**94.00**
Large conventional hydropower (>10 MW)			
Run-of-river (e.g. direct intake weir)	-	1 200	150
Diversion fed (e.g. pipe, canal or tunnel)	-	3 700	1 500
Storage regulated head (e.g. barrage or dam)	653	1 271	250
Total for renewable hydropower in SA	**687**	**5 160**	**1 994**
Large pumped storages (>10 MW)	1 580	7 000	3 200
GRAND TOTAL (for all hydropower in SA)	**2 267**	**12 160**	**5 194**
Imported macro hydroelectricity (>10 MW)	800	1 400	35 000 (+)

* This table does not include the potential for development in distribution systems

6.3 THE AFRICAN HYDROPOWER DATABASE

An ‘African Hydropower Database’, with a section focusing on South African hydropower installations can be accessed on the Internet. **Figure 6-1** was retrieved from the database and shows all planned, existing and decommissioned sites in the country, as well as various potential sites (Jonker Klunne, 2016).

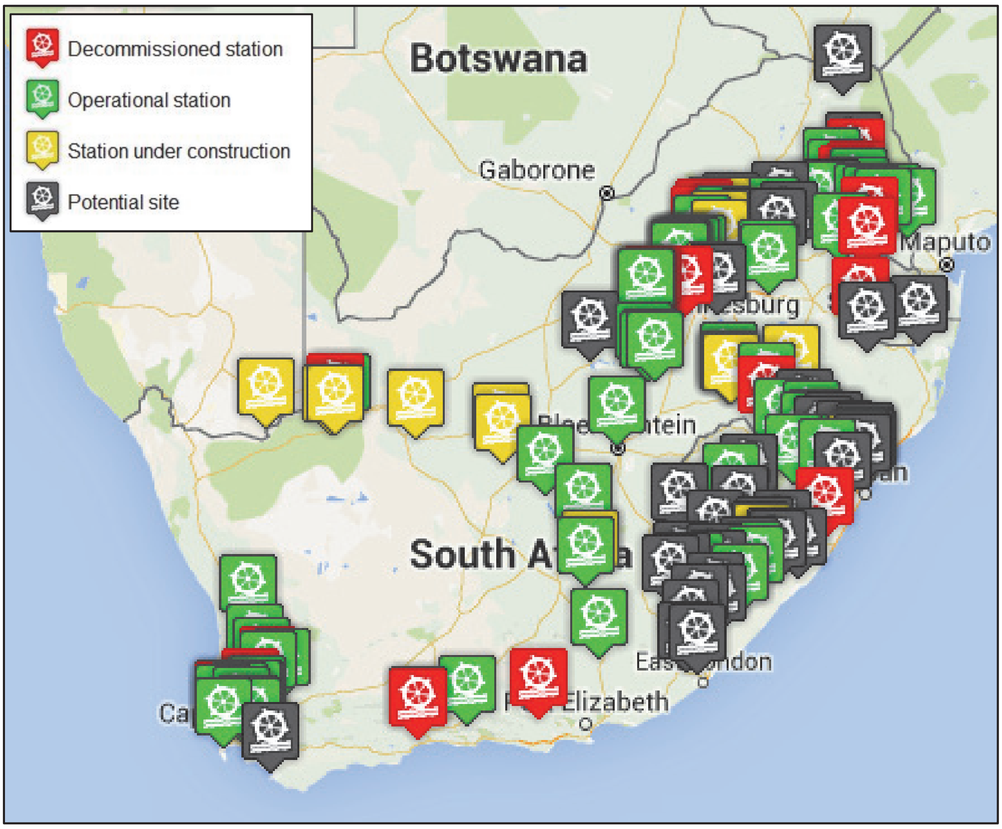


Figure 6-1: South African map indicating existing and potential hydropower sites (Jonker Klunne, 2016)

Van Vuuren et al. (2013), provided an estimate of the country-wide potential for low-head hydropower development listed in **Table 6-2**.

Table 6-2: Estimates of the country-wide potential for low-head hydropower development (Van Vuuren et al., 2013)

Low head hydropower location	Estimated potential (MW)	Hidden in existing infrastructure (MW)	Estimated potential "greenfield" conditions (MW)
Small (low-head) dams	5.70	5.70	As per new dams installed
Run-of-river schemes	39.50	17.00	22.50 +
Measuring weirs	0.30	0.30	As per new weirs installed
Irrigation schemes	5.50	5.50	No new developments envisaged
Wastewater Treatment Works (WWTW)	2.50	2.50	As per new works and rehab/upgrades
Urban storm water systems	0.10	0.10	Insignificant
Water transfer pipelines and canals	0.65	0.65	As per new transfers and rehab/upgrade
Industrial outfalls	0.25	0.25	As per new industry installed
Subtotal for inland hydropower	**54.50**	**32.00**	**22.50 +**
Tidal lagoons and harbours	26.50	As per further research	26.50
Wave energy systems	Unlimited	None	Unlimited

7 LOW HEAD HYDROPOWER ASSESSMENT MODEL

7.1 INTRODUCTION

One of the aims of this study was to develop a low head hydropower assessment model that can be used to identify low head hydropower potential in South Africa, as well as to provide proper guidance for the development of identified sites. A system of flow diagrams and tools has been compiled to identify and develop low head hydropower sites.

7.2 SYSTEMATIC APPROACH

A systematic approach must be followed when assessing hydropower potential to ensure that all relevant factors are considered. The procedure for determining hydropower potential is illustrated through a series of flow diagrams, whilst a tool developed in Microsoft Excel facilitates calculation of the factors that need consideration. **Chapter 8** will elaborate on the items in the flow diagrams. The development procedure has been divided into two phases that are split according to the type of hydropower turbine that will be applicable:

- Phase 1: Initial Investigation
- Phase 2A: Pre-feasibility Study for hydropower plants working with head and flow rate
- Phase 2B: Pre-feasibility Study for hydropower plants working with velocity
- Phase 3A: Feasibility Study for hydropower plants working with head and flow rate
- Phase 3B: Feasibility Study for hydropower plants working with velocity

Each phase has its own process flow diagram linked to the Low Head Hydropower Development Tool (LHHD Tool). Each item in the flow diagrams is also numbered and discussed in more detail in a paragraph with corresponding number in **Chapter 8**. Some of the aspects of the study will be required in both of the phases, but will be dealt with in increasing detail as the project progresses.

Subsequent project phases, dealing with detail design, construction, and operation and maintenance aspects, fall outside the scope of this document, but are also important to consider when designing a low head hydropower facility.

7.3 FLOW DIAGRAMS

7.3.1 PHASE 1 FLOW DIAGRAM

Phase 1 represents an initial investigation into hydropower potential in various low-head applications. The initial investigation is simply done to determine whether pressure head (m) or velocity (m/s) would be the critical factor to consider when determining hydropower potential, see **Figure 7-1**. This phase also redirects users with pipe systems to another WRC document, where conduit hydropower is discussed in depth (Van Vuuren et al., 2014b).

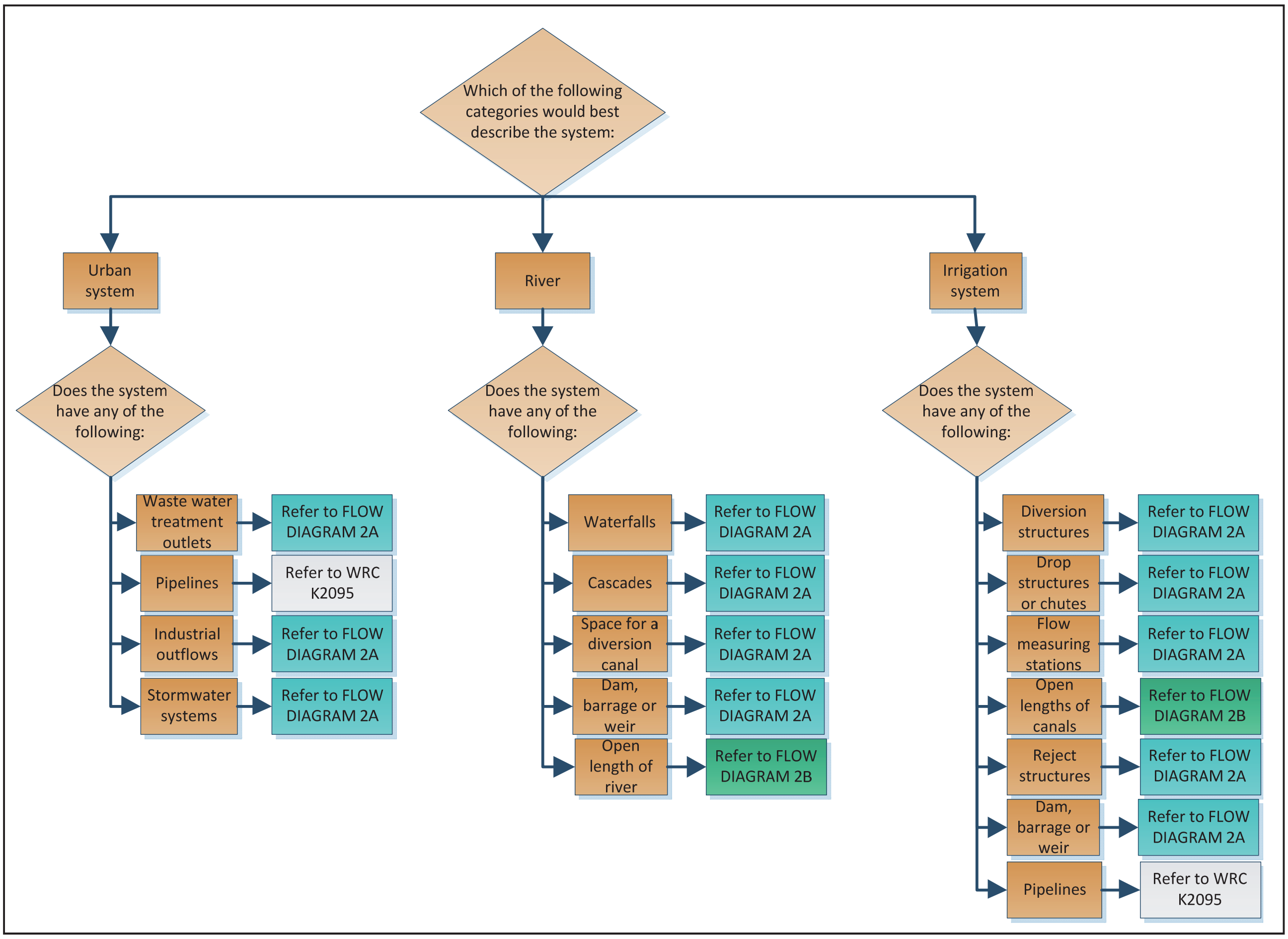


Figure 7-1: Phase 1 flow diagram

7.3.2 PHASE 2 FLOW DIAGRAMS

Phase 2 represents a pre-feasibility study and comprises various first-order analyses and studies. The purpose of this phase is to rapidly determine whether more in-depth studies will be worthwhile. **Figure 7-2** to **Figure 7-5** indicate the decision flow process for this phase. **Figure 7-2** and **Figure 7-3** indicate the process to follow for sites with elevation changes and **Figure 7-4**and **Figure 7-5** indicate the process for sites where velocity determines potential.

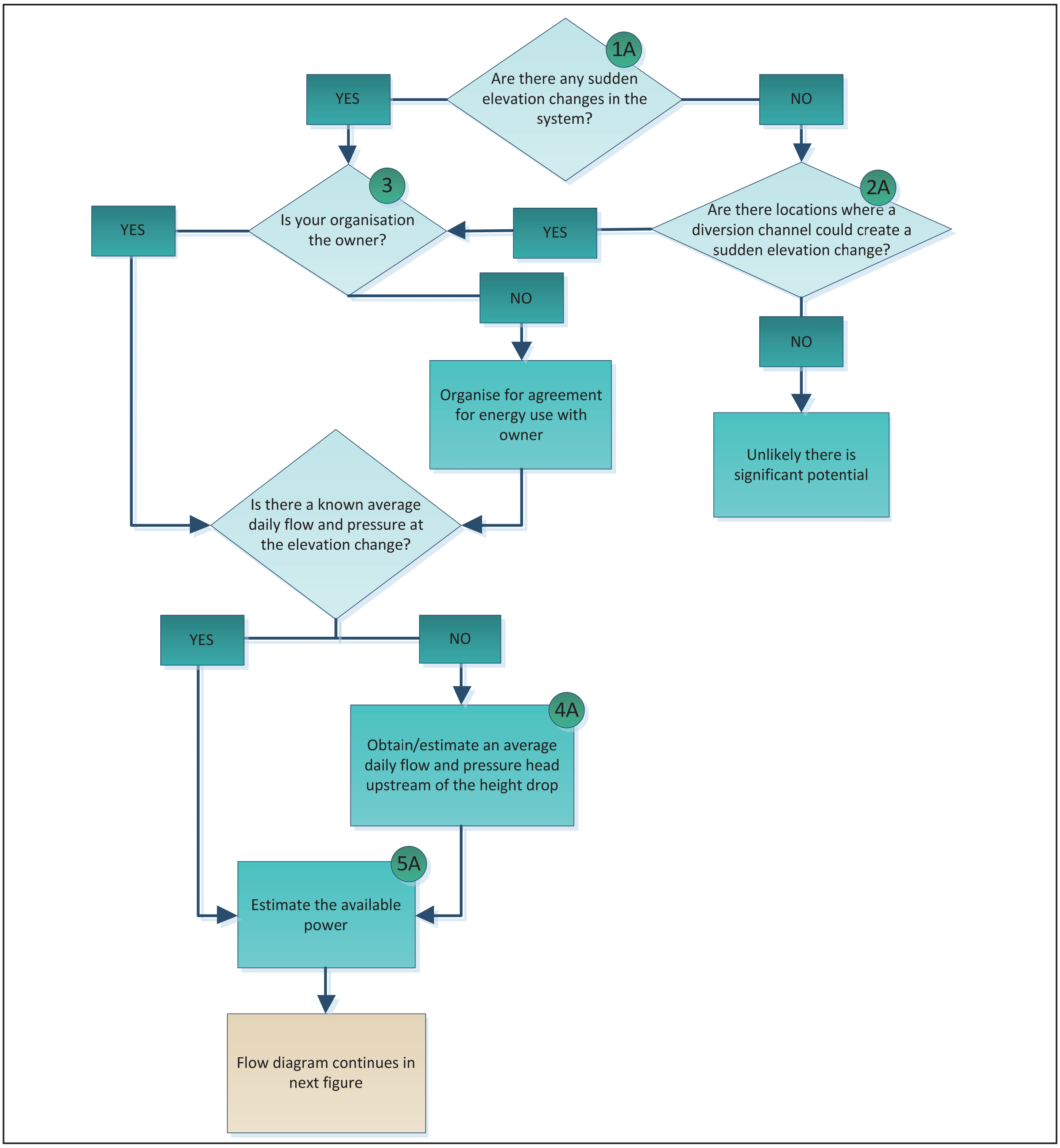


Figure 7-2: Phase 2A flow diagram Part 1

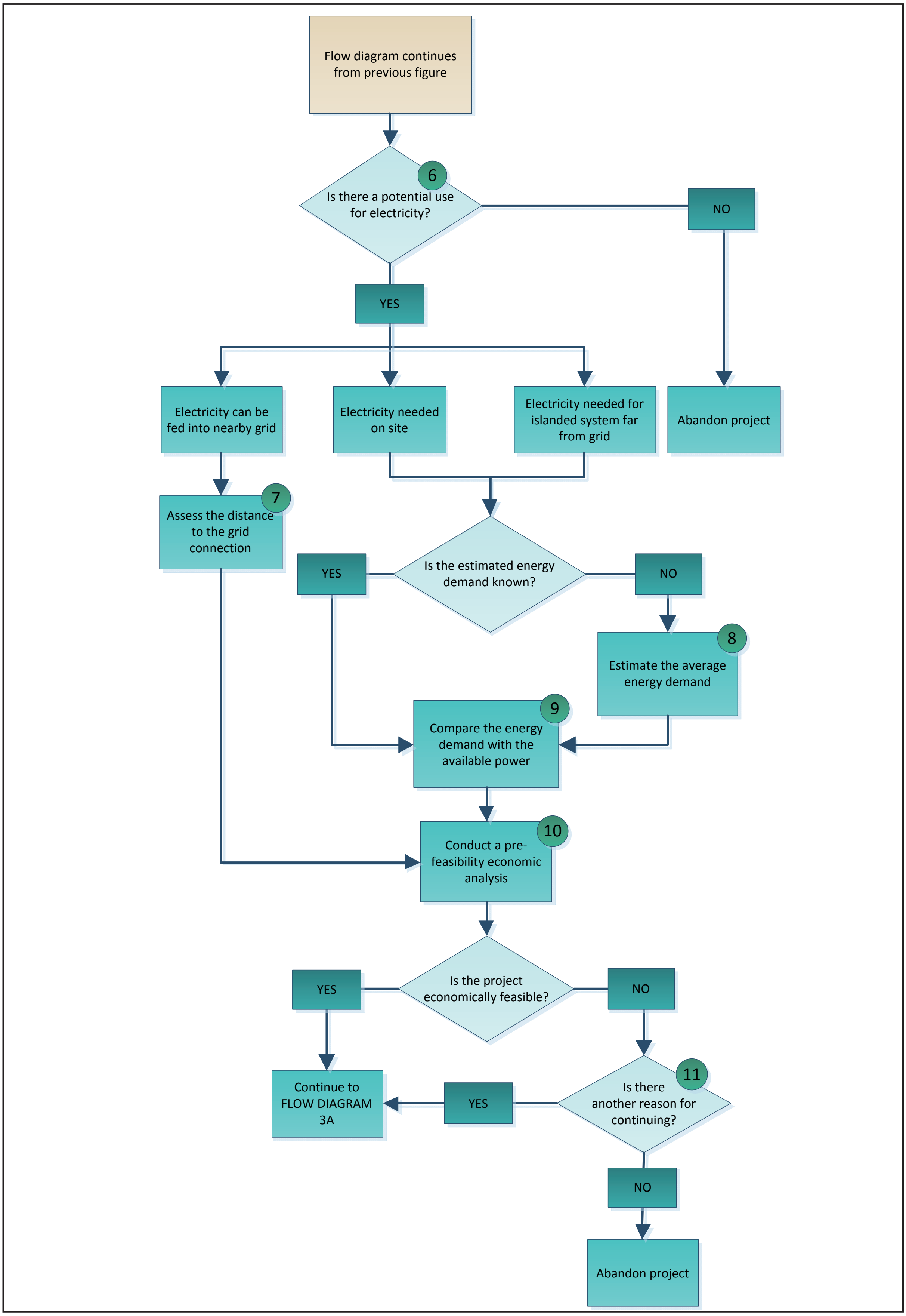


Figure 7-3: Phase 2A flow diagram Part 2

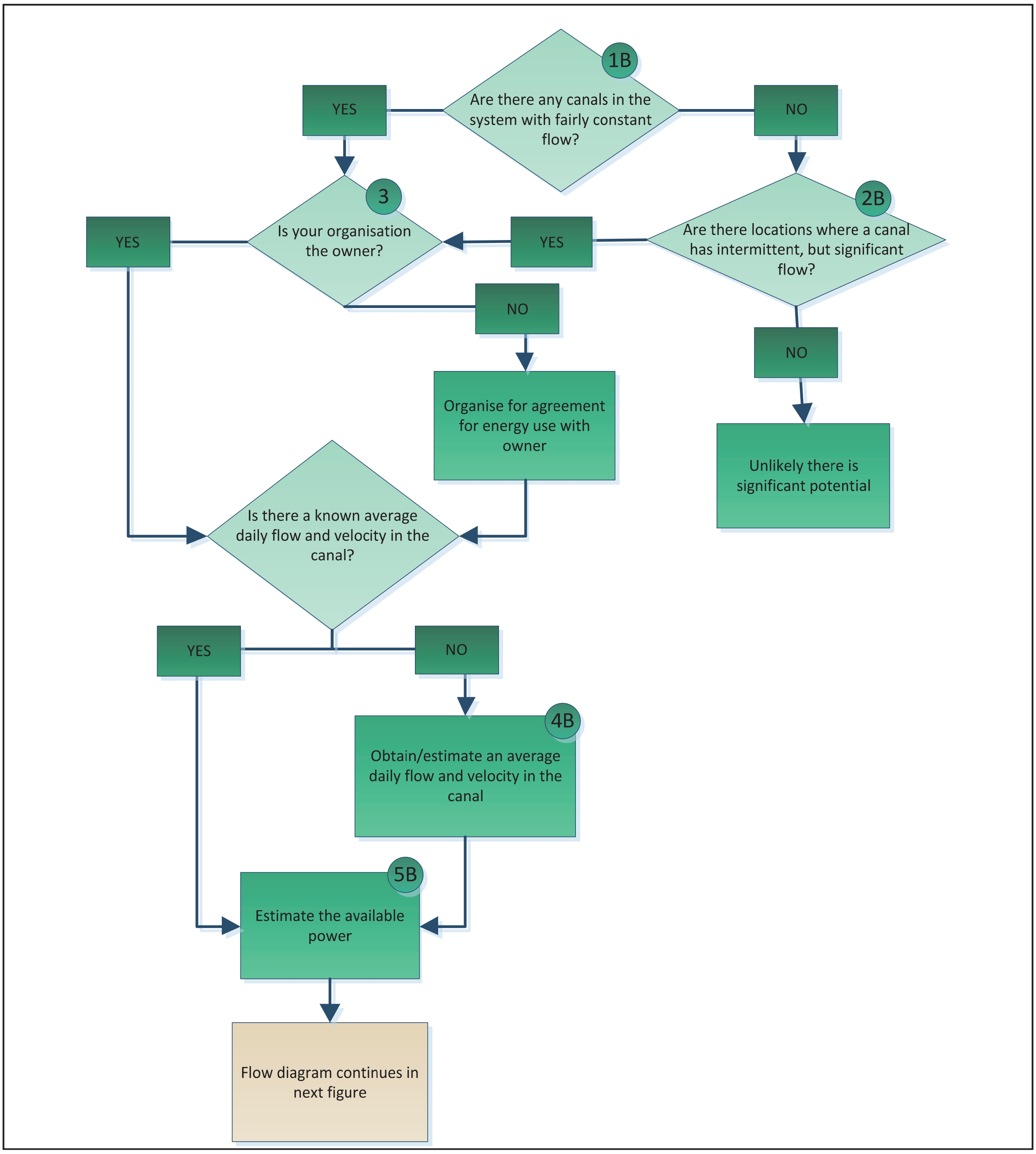


Figure 7-4: Phase 2B flow diagram Part 1

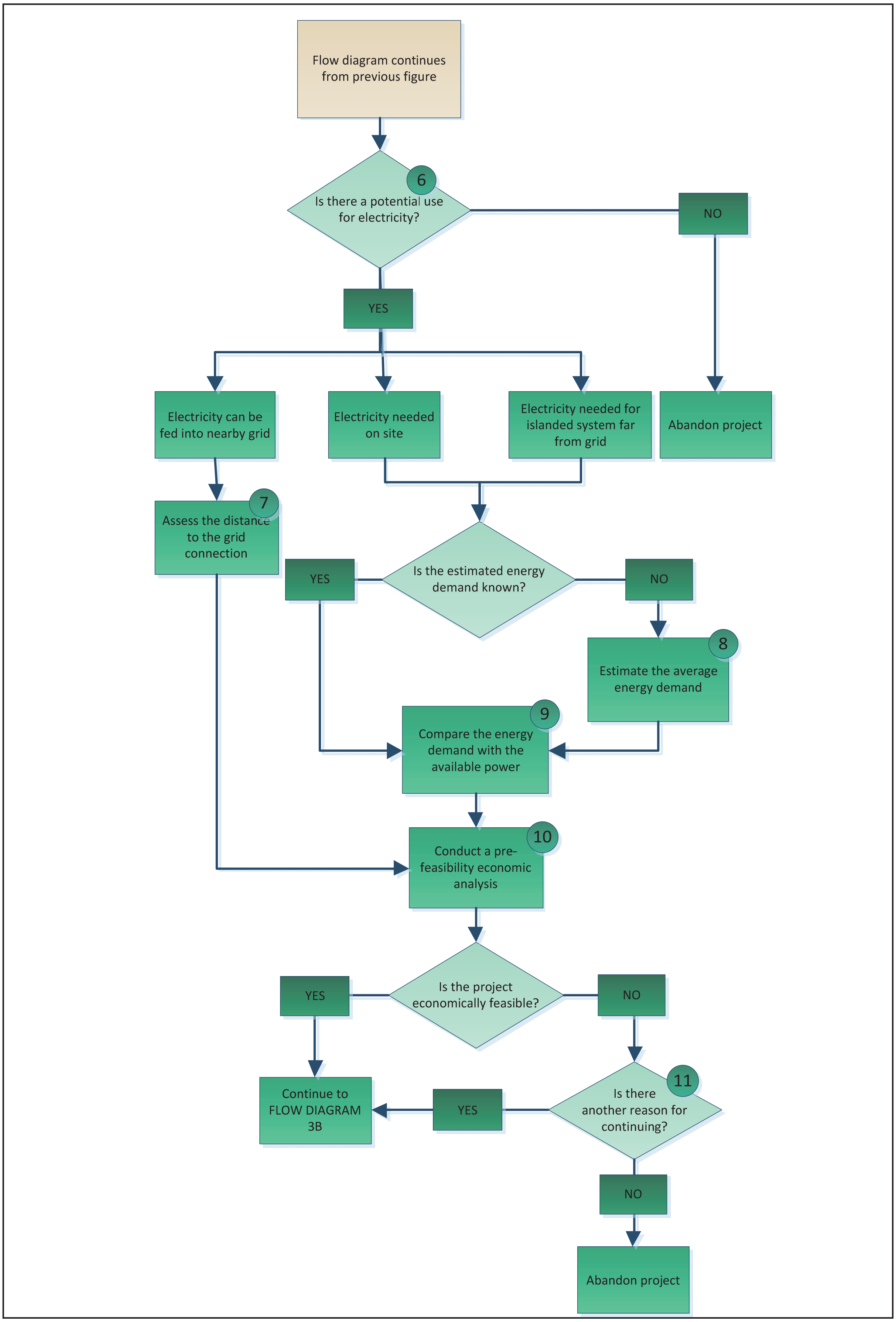


Figure 7-5: Phase 2B flow diagram Part 2

7.3.3 PHASE 3 FLOW DIAGRAMS

If Phase 1 indicates project viability, a more in-depth investigation can be done during the feasibility study of Phase 2. **Figure 7-6** to **Figure 7-9** illustrate the process to be followed during this stage. **Figure 7-6** and **Figure 7-7** indicate the process to follow for sites with elevation changes and **Figure 7-8** and **Figure 7-9** indicate the process for sites where velocity determines potential.

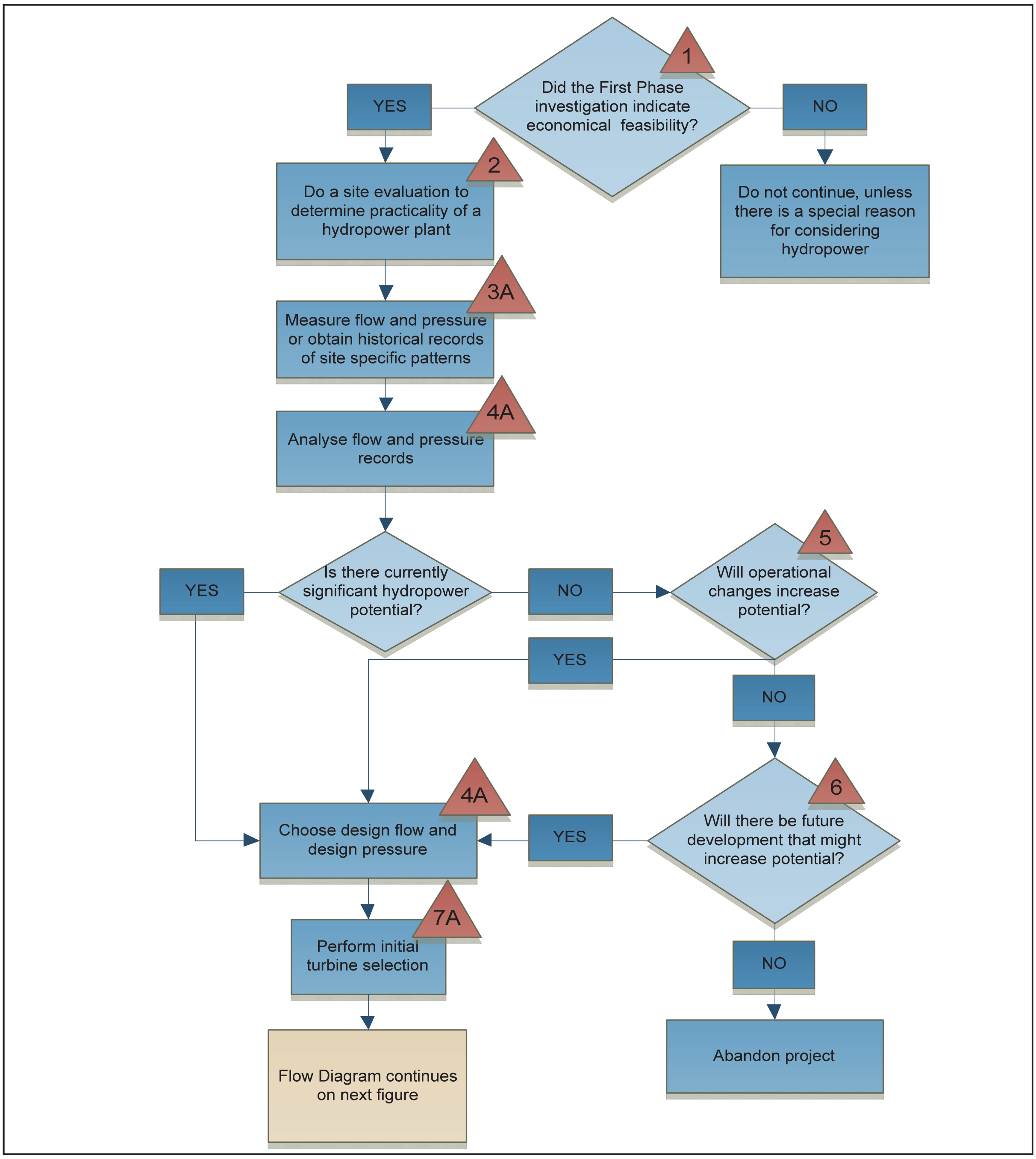


Figure 7-6: Phase 3A flow diagram Part 1

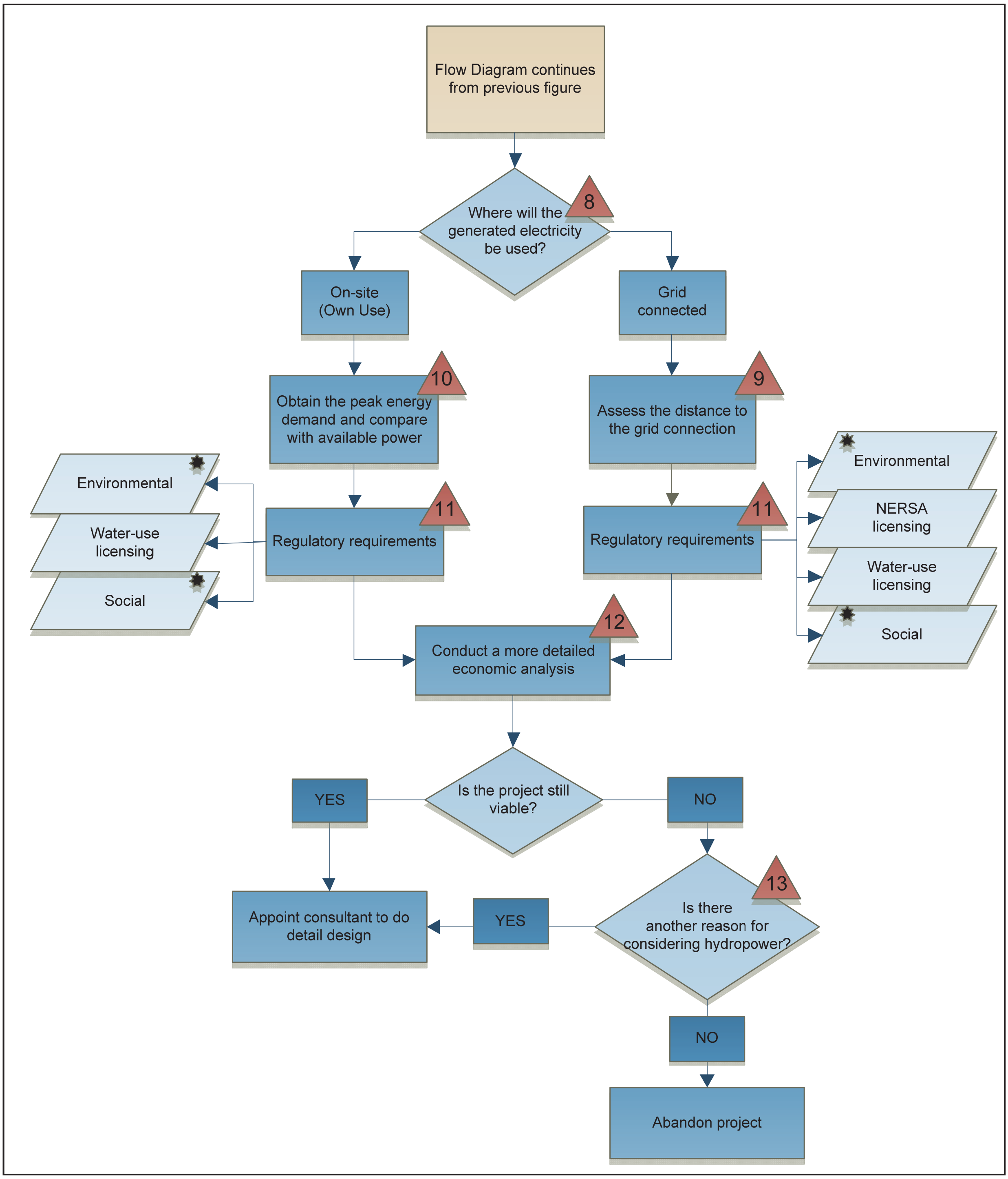


Figure 7-7: Phase 3A flow diagram Part 2 (✸ depicts specialist consultant input)

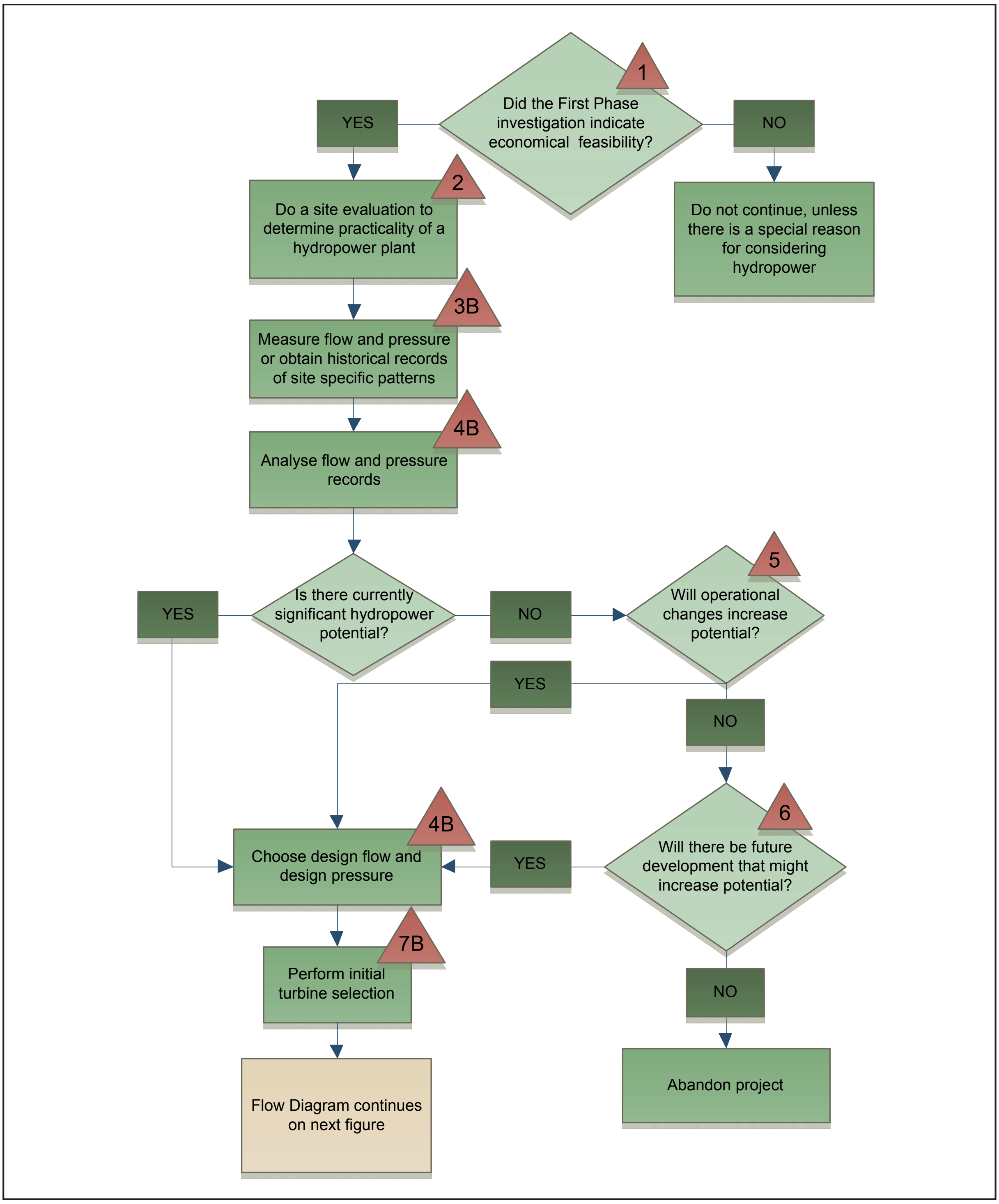


Figure 7-8: Phase 3B flow diagram Part 1

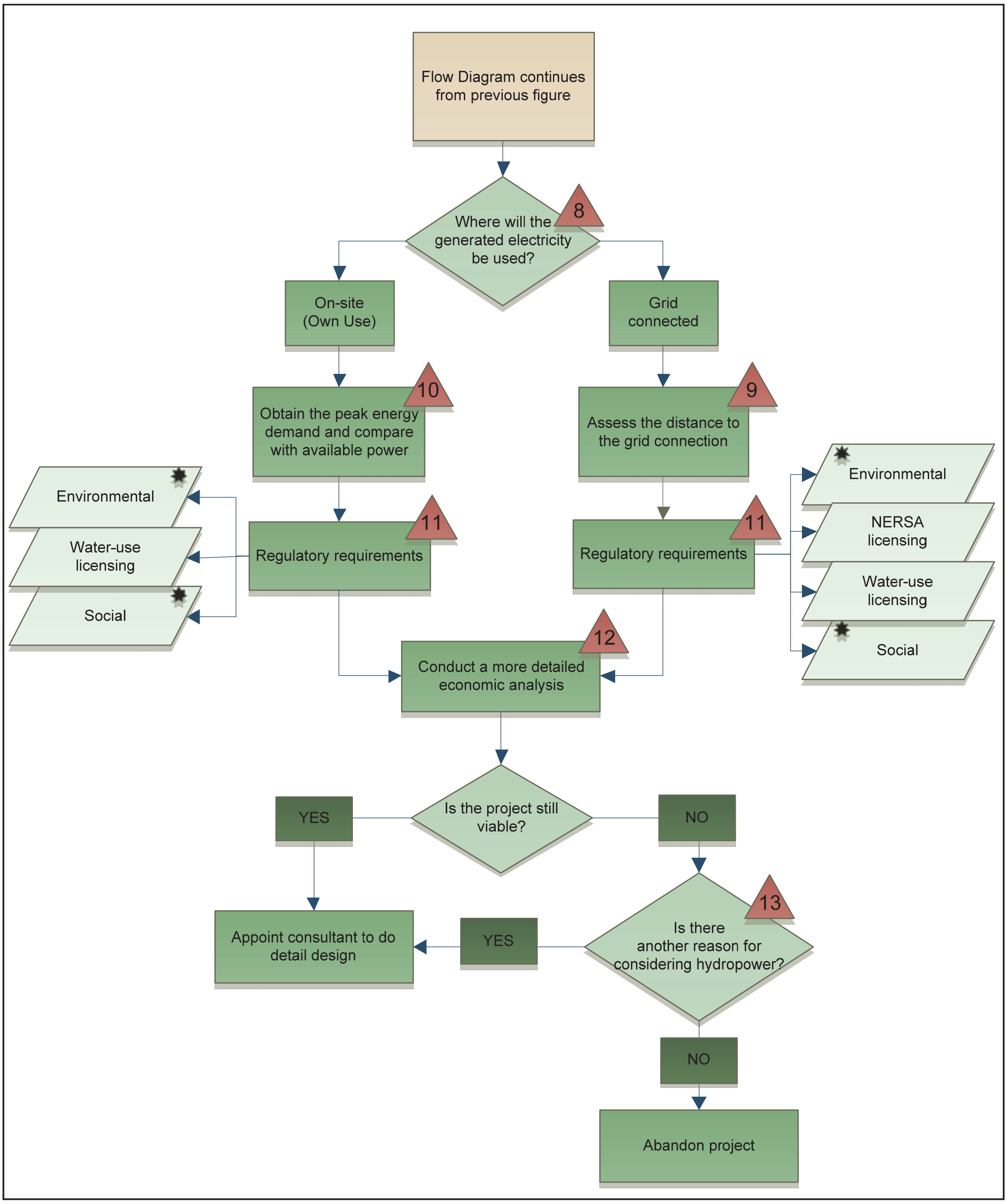


Figure 7-9: Phase 3B flow diagram Part 2 (✸ depicts specialist consultant input)

7.4 LOW HEAD HYDROPOWER DEVELOPMENT TOOL (LHHD TOOL)

The thought process and calculations of each phase are incorporated in a Low Head Hydropower Development Tool (LHHD Tool). This tool is in the form of a Microsoft Excel spreadsheet and aims to guide infrastructure owners or developers through the process (Phases 1 to 3) of low hydropower design by including all the calculations in a user-friendly format. The tools for all the phases have colour-coded value blocks to visually differentiate between different phases, input and output, as well as user-entered and default values. The colour-coding system is explained in **Table 7-1**.

Table 7-1: Colour-coding system for LHHD Tool

Colour coding	Description
Orange	Phase 1
Turquoise	Phase 2A
Mint green	Phase 2B
Light blue	Phase 3A
Light green	Phase 3B
Light yellow	User must enter values
Rose	User may edit default values if better information is available
Light purple	Results

7.4.1 PHASE 2 LHHD TOOL

The LHHD Tool for Phase 2 is divided into three sections, namely the Hydropower Potential Section, Economic Analysis Section and the Checklist Section.

7.4.1.1 Phase 2A potential calculator

The Hydropower Potential Section is shown in **Table 7-2**. The only input required in this section is the average flow, the static energy head and, if applicable, the distance to the grid connection and power demand. The output in this section includes the theoretically available power and the ratio of the energy demand vs. available energy, in the case of on-site or islanded systems.

Table 7-2: Phase 2A potential analysis LHHD Tool

PHASE 2A POTENTIAL ANALYSIS						
Power potential:						
Site name		Rooiwal WWTP				
Date of analysis		21/11/2013				
Average daily flow	(Q)	2	m^3/s			
Static head	(H)	8	m			
Fluid density	(ρ)	1,000	kg/m^3			
Gravitational acceleration	(g)	9.81	m/s^2			
Efficiency	(η)	70	%			
Annual operational percentage		60	%			
Theoretical available power	(P_{av})	**109.9**	kW			
Annual operational time		5,256	h			
Potential annual power		**577**	MWh/a			
Energy usage:						
Grid connected				**Islanded/on-site**		
Distance to grid connection			km	Maximum power demand	500	kW
				P_{av}/Maximum power demand	22.0	%
				Distance to islanded grid	0.5	km

7.4.1.2 Phase 2B potential calculator

The Hydropower Potential Section is shown in **Table 7-3**. The only input required in this section is the average velocity, applicable area of the turbine perpendicular to flow (height and diameter) and, if applicable, the distance to the grid connection and power demand. The output in this section includes the theoretically available power and the ratio of the energy demand vs. available energy, in the case of on-site or islanded systems.

Table 7-3: Phase 2B potential analysis LHHD Tool

PHASE 2B POTENTIAL ANALYSIS						
Power potential:						
Site name		Hartbees Irrigation Canal				
Date of analysis		21/11/2013				
Diameter of turbine	(D)	1.52	m			
Height of turbine	(H)	0.76	m			
Area of turbine	(A)	1.16	m^2			
Velocity	(v)	3	m/s			
Annual operational percentage		60	%			
Theoretical available power	(P_{av})	**4.0**	kW			
Annual operational time		5,256	h			
Potential annual power		**21**	MWh/a			
Energy usage:						
Grid connected				**Islanded/on-site**		
Distance to grid connection			km	Maximum power demand	5	kW
				P_{av}/Maximum power demand	79.0	%
				Distance to islanded grid	0.5	km

7.4.1.3 Phase 2 economic analysis

The Economic Analysis Section does not require any input, save the design life of the project, unless better information than the default values is available. The output from this section includes initial estimates of the net present value (NPV), internal rate of return (IRR) and payback period of the proposed project. It is important to note that the payback period was calculated considering inflation. **Table 7-4** provides an example of this section (the example is for Phase 2A, but 2B has exactly the same information).

Table 7-4: Phase 2A economic analysis LHHD Tool

PHASE 2A ECONOMIC ANALYSIS			
Power information			
Power rating		109.9	kW
Average daily flow	(Q)	2.0	m^3/s
Used pressure head	(H)	8	m
Design life		15	years
Cost			
Capital		7,001,075	R
Operation & maintenance percentage		1.00	% of capital cost
Annual operation & maintenance Cost		70,011	R
Annual operational percentage		60	%
Annual operational time		5,256	h
Planning		1,350	R/kW
Disposal percentage		1.00	% of capital cost
Disposal cost (present value)		70,011	R
Income			
Value of generated electricity		0.58	R/kWh
Revenue		0.00	R/kWh
Inflation			
Annual inflation of electricity		8.00	%
Annual inflation of O&M		6.00	%
Discount rate		6.00	%
Results			
Net present value of costs		-8,269,574	R
Net present value of income		5,853,560	R
Total NPV		**-2,416,014**	**R**
Internal rate of return		**1**	**%**
Payback period		**16**	**years**

7.4.1.4 Phase 2 checklist

The Checklist Section (**Table 7-5**) also does not require any input, but serves as a reference for the user to determine whether all the steps for the first phase have been considered.

Table 7-5: Phase 2 checklist LHHD Tool

PHASE 2ACHECKLIST	
Are there pressure reducing stations in the system?	
Are there other locations with excess pressure in the system?	
Is there a utilization agreement with the owner?	
Have the average daily flow - and pressure records been obtained?	
Has the estimated available power been calculated?	
Has the electricity use destination been established?	
For grid tie-in: Has the distance to the grid connection been measured?	
For islanded/on-site systems: Has the energy demand been determined?	
For islanded/on-site systems: Is the energy demand less than the available power?	
Has a pre-feasibility economic analysis been conducted?	
Is the project economically feasible?	
If not, is there another reason for continuing?	

If this phase indicates feasibility, the user should continue to Phase 3 of the LHHD Tool.

7.4.2 PHASE 3 LHHD TOOL

Phase 3 of the LHHD Tool is divided into 12 sections. Current and Future scenarios can be included for: the Hydropower Potential; Flow-Rating Curves; Energy Delivered; Turbine Selection; and Optimum Percentage Use Curves. The final two sections (Economic Analysis; and Checklist Sections) are applicable to the entire project and therefore incorporate both current and future scenarios.

7.4.2.1 Phase 3A potential calculator and associated graphs

The Hydropower Potential Section for Phase 3A can be seen in **Table 7-6**. The inputs required in this section are the measured values for flow and available head. The LHHD Tool accepts data of up to 35 000 data points. The LHHD Tool requires the data to be sorted from lowest to highest flow with corresponding pressure heads, with all data gaps removed. The number of used data points is also required.

Twenty-one data points corresponding to a 0% to 100% assurance of flow, (in 5% intervals) should be selected and entered into the allocated cells. If energy production is required for a specific percentage of time, this percentage (in multiples of 5%) should be entered into the 'Assurance of flow' cell to obtain the design flow. However, if the optimum flow, average flow or a user-defined flow is required, this cell should be left blank. If the average flow or a user-defined flow is required, it should be indicated by checking the applicable box.

Default values for fluid density, gravitational acceleration and turbine efficiency are provided, but if accurate values are known, they may be entered. The output values for this section are: an initial estimate of the design flow; design head; design power rating; and annual power generation.

Table 7-6: Phase 3A potential analysis LHHD Tool

PHASE 3A POTENTIAL ANALYSIS (CURRENT)							
Flow rating curve	Load factor (%)	Flow (m^3/s)	Head available (m)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100%	0	8	8592	0.0	0.000	0
	95%	0.000	8.0	8154	0.0	0.000	0
	90%	0.001	8.0	7716	0.0	0.302	0.008394305
	85%	0.059	8.0	7278	3.2	23.426	0.699769104
	80%	0.184	8.0	6840	10.1	69.100	2.861344084
	75%	0.310	8.0	6402	17.0	109.040	5.828482191
	70%	0.412	8.0	5964	22.6	134.978	9.722764041
	65%	0.553	8.0	5526	30.4	167.863	9.722764041
	60%	0.780	8.0	5088	42.9	218.123	9.722764041
	55%	0.959	8.0	4650	52.7	244.999	9.722764041
	50%	0.974	8.0	4212	53.5	225.260	9.722764041
	45%	0.981	8.0	3774	53.9	203.404	9.722764041
	40%	0.986	8.0	3336	54.2	180.740	9.722764041
	35%	0.992	8.0	2898	54.5	157.927	9.722764041
	30%	0.999	8.0	2460	54.9	135.036	9.722764041
	25%	1.009	8.0	2022	55.4	112.055	9.722764041
	20%	1.025	8.0	1584	56.3	89.228	9.722764041
	15%	1.105	8.0	1146	60.7	69.563	9.722764041
	10%	1.194	8.0	708	65.6	46.425	9.722764041
	5%	1.372	8.0	270	75.4	20.357	9.722764041
	0%	1.456	8.0	0	80.0	0.000	9.722764041
Optimum flow	55%	0.959	8.0	4650.0	52.7		155.2394503
Average flow		0.767	8.0	8592	42.2	362.249	
Chosen flow		0.037	8.0	8592	2.0	17.464	
Assurance of flow	70%	0.412	8.0	5964	22.6		
Design flow	**70%**	**0.412**	**8.0**	**5964**	**22.6**	**155.2**	

General input				Energy usage				
Fluid density	(ρ)	1000	kg/m^3	Grid connected		Islanded/on-site		
Gravitational acceleration	(g)	9.81	m/s^2	Distance	0.5 km	Max demand		kW
Efficiency	(η)	70	%			P_{av}/Max demand	0	%
Annual maintenance days		7	days			Distance to grid		km

PHASE 2 INPUT							
Site name	Rooiwal WWTW						
Data points	Load factor (%)	Date and time	Flow (m^3/s)	Head available (m)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)
13929	100.0000%	30/03/2012 13:45	0	8	8760	0.0	0.0
13928	99.9928%	30/03/2012 14:30	0	8	8759.371096	0.0	0.0
13927	99.9856%	30/03/2012 14:45	0	8	8758.742193	0.0	0.0

This section also generates various decision support graphs. These include a flow-rating curve (**Figure 7-10**), a potential energy curve (**Figure 7-11**), an initial turbine selection curve (**Figure 7-12**) and an optimum percentage use curve (**Figure 7-13**). These curves can be viewed in the four sections subsequent to the Hydropower Potential Section.

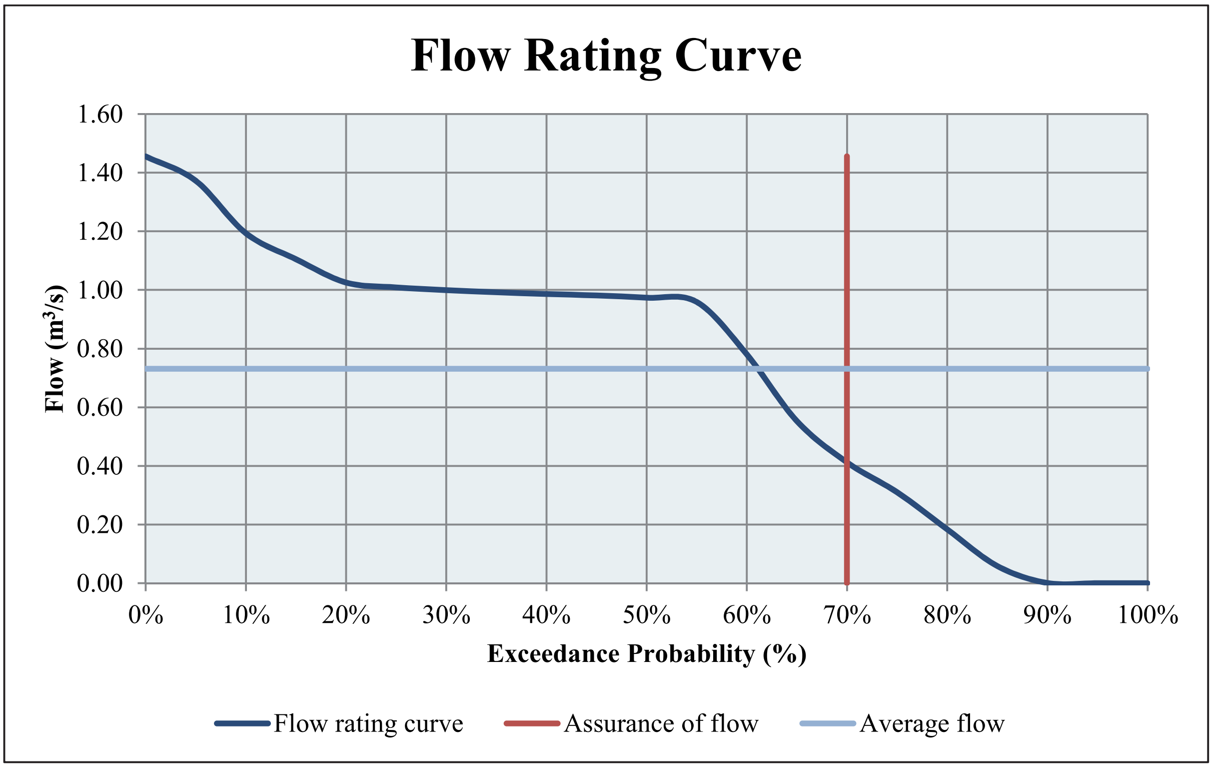


Figure 7-10: Phase 3A flow-rating curve LHHD Tool

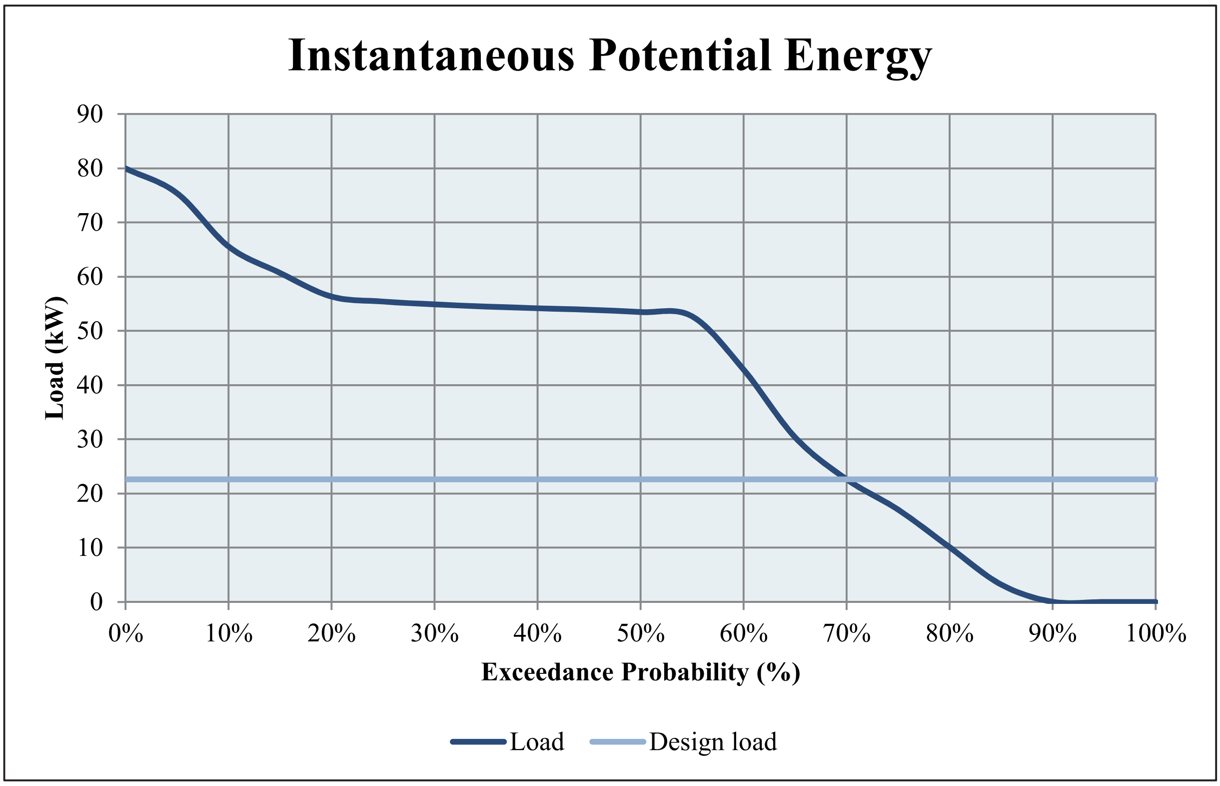


Figure 7-11: Phase 3A potential energy curve LHHD Tool

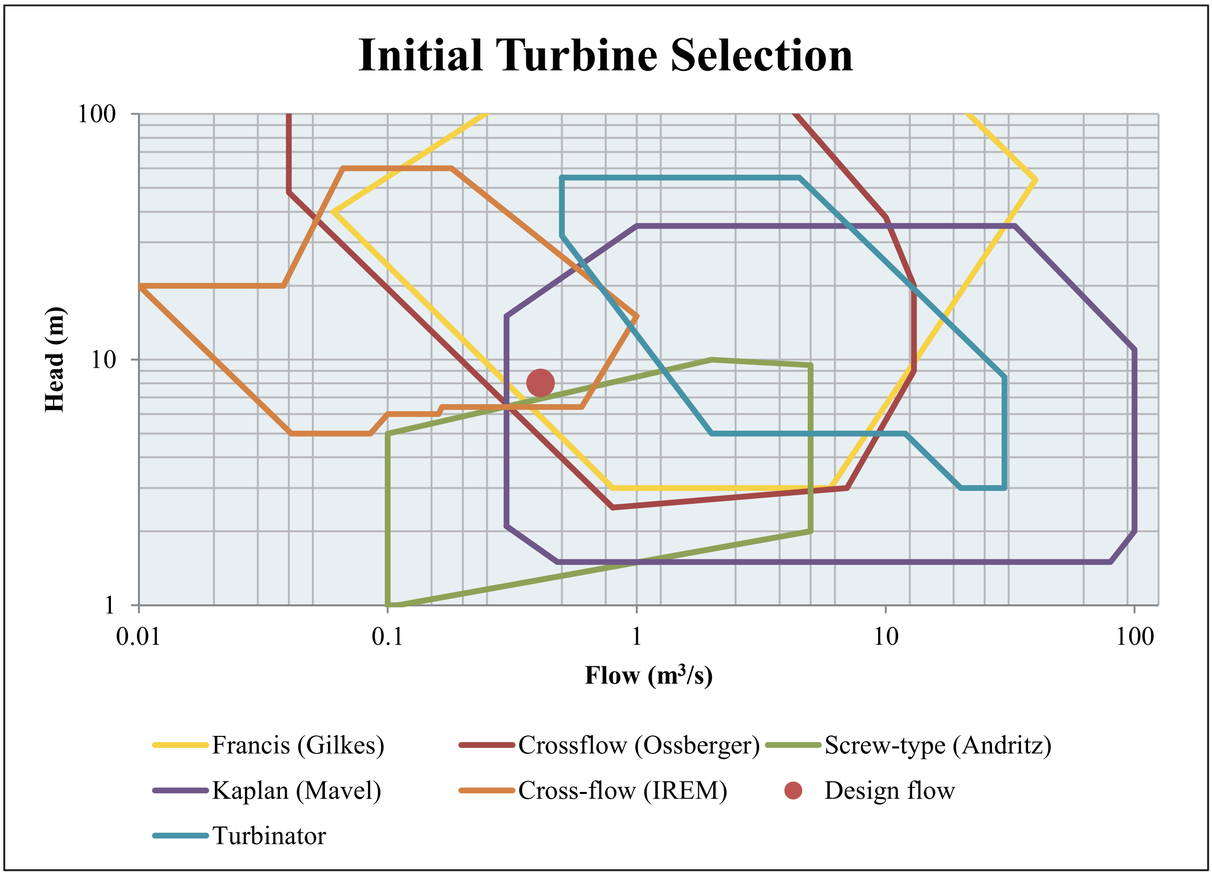


Figure 7-12: Phase 3A initial turbine selection LHHD Tool

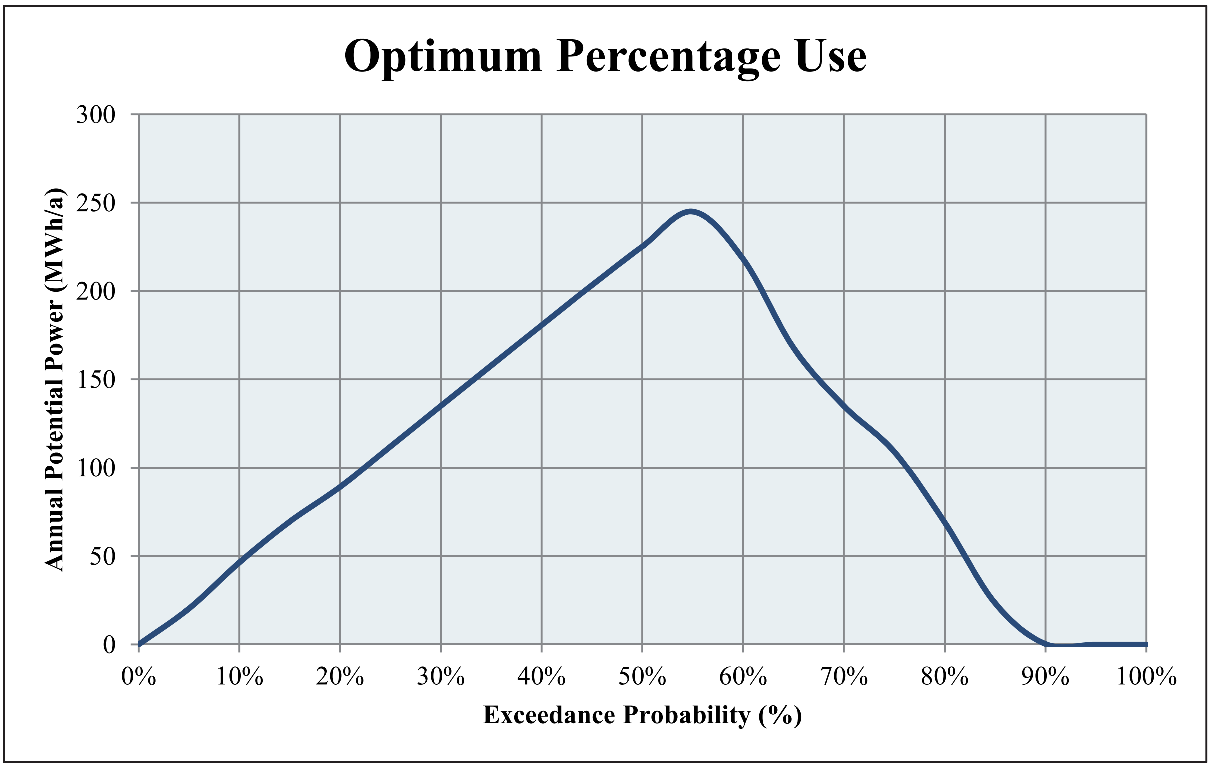


Figure 7-13: Phase 3A optimum percentage use curve LHHD Tool

7.4.2.2 Phase 3B potential calculator and associated graphs

The Hydropower Potential Section for Phase 3B can be seen in **Table 7-7**. The inputs required in this section are the measured values for velocity and available space for the height and diameter of a turbine. The LHHD Tool accepts data of up to 35 000 data points. The LHHD Tool requires the data to be sorted from lowest to highest velocity with all data gaps removed. The number of used data points is also required.

Twenty-one data points corresponding to a 0% to 100% assurance of velocity, (in 5% intervals) should be selected and entered into the allocated cells. If energy production is required for a specific percentage of time, this percentage (in multiples of 5%) should be entered into the 'Assurance of velocity' cell to obtain the design flow. However, if the optimum velocity, average velocity or a user-defined velocity is required, this cell should be left blank. If the average velocity or a user-defined velocity is required, it should be indicated by checking the applicable box.

The output values for this section are: an initial estimate of the design velocity; design power rating; and annual power generation.

Table 7-7: Phase 3B potential analysis LHHD Tool

PHASE 3B POTENTIAL ANALYSIS (CURRENT)							
Flow rating curve	Load factor (%)	Velocity (m/s)	Area (m^2)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100%	0.0	1.1552	8592	0.0	0.000	0
	95%	0.1	1.2	8154	0.0	0.001	3.14414E-05
	90%	0.2	1.2	7716	0.0	0.009	0.000282973
	85%	0.3	1.2	7278	0.0	0.029	0.00110045
	80%	0.4	1.2	6840	0.0	0.064	0.002861171
	75%	0.5	1.2	6402	0.0	0.117	0.005942431
	70%	0.6	1.2	5964	0.0	0.189	0.0135827
	65%	0.7	1.2	5526	0.1	0.277	0.0135827
	60%	0.8	1.2	5088	0.1	0.381	0.0135827
	55%	0.9	1.2	4650	0.1	0.496	0.0135827
	50%	1.0	1.2	4212	0.1	0.617	0.0135827
	45%	1.1	1.2	3774	0.2	0.735	0.0135827
	40%	1.2	1.2	3336	0.3	0.844	0.0135827
	35%	1.3	1.2	2898	0.3	0.932	0.0135827
	30%	1.4	1.2	2460	0.4	0.988	0.0135827
	25%	1.5	1.2	2022	0.5	0.999	0.0135827
	20%	1.6	1.2	1584	0.6	0.950	0.0135827
	15%	1.7	1.2	1146	0.7	0.824	0.0135827
	10%	1.8	1.2	708	0.9	0.604	0.0135827
	5%	1.9	1.2	270	1.0	0.271	0.0135827
	0%	2.0	1.2	0	1.2	0.000	0.0135827
Optimum velocity	25%	1.500	1.2	2022.0	0.5		0.21395896
Average velocity		2.000	1.2	8592	1.2	10.061	
Chosen velocity		3.000	1.2	8592	4.1	35.274	
Assurance of velocity	70%	0.600	1.2	5964	0.0		
Design velocity	**70%**	**0.600**	**1.2**	**5964**	**0.0**	**0.2**	

Turbine information				**Energy usage**			**Islanded/on-site**		
Turbine diameter	(D)	0.76	m	**Grid connected**			Max demand		kW
Turbine height in water	(H)	1.52	m	Distance	0.5	km	P_{av}/Max demand	0	%
Annual maintenance days		7	days				Distance to grid		km

PHASE 2 INPUT

Site name	Hartbeespoort Irrigation Canal						
Data points	Load factor (%)	Date and time	Velocity (m^3/s)	Area (m^2)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)
35044	100.0000%	30/03/2012 13:45	0	1.16	8760	0.0	0.0
35043	99.9971%	30/03/2012 14:30	0	1.1552	8759.750029	0.0	0.0
35042	99.9943%	30/03/2012 14:45	0	1.1552	8759.500057	0.0	0.0
35041	99.9914%	31/03/2012 16:15	0	1.1552	8759.250086	0.0	0.0

This section also generates various decision support graphs. These include a velocity-rating curve (**Figure 7-10**), a potential energy curve (**Figure 7-11**), an initial turbine selection curve (**Figure 7-12**) and an optimum percentage use curve (**Figure 7-13**). These curves can be viewed in the four sections subsequent to the Hydropower Potential Section.

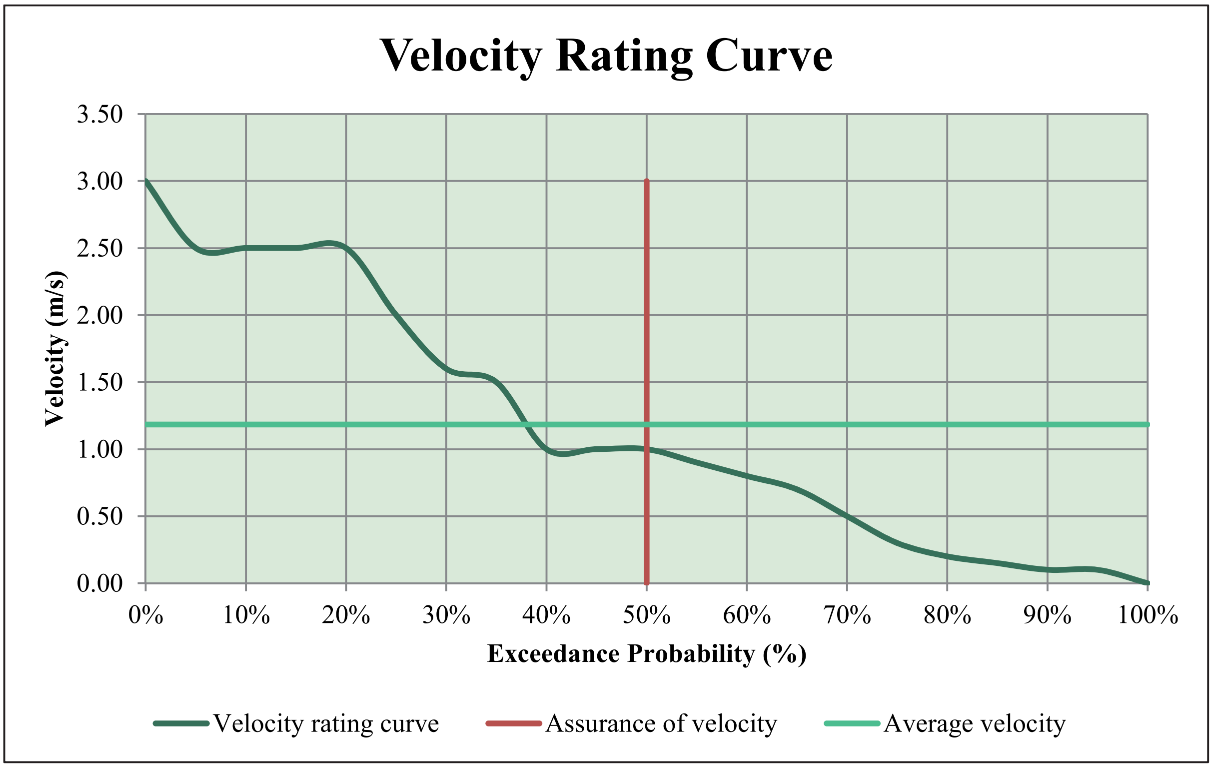


Figure 7-14: Phase 3A flow-rating curve LHHD Tool

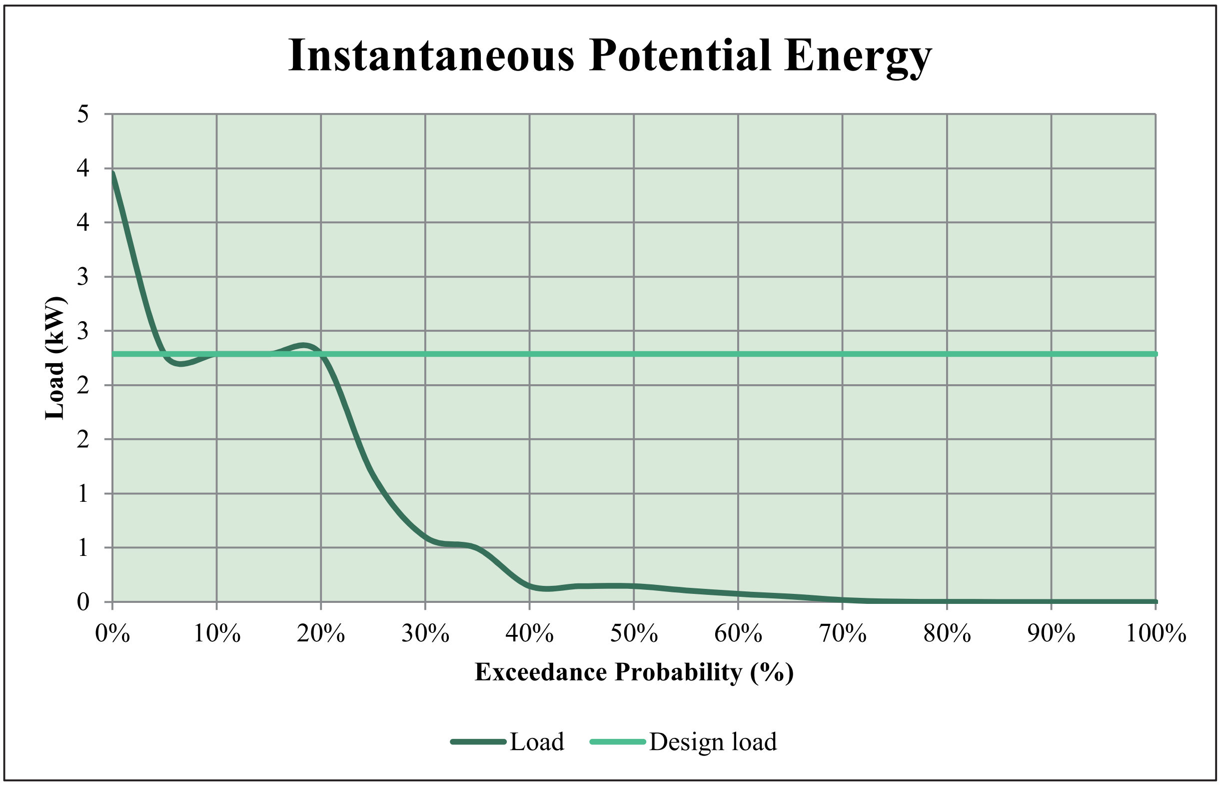


Figure 7-15: Phase 3A potential energy curve LHHD Tool

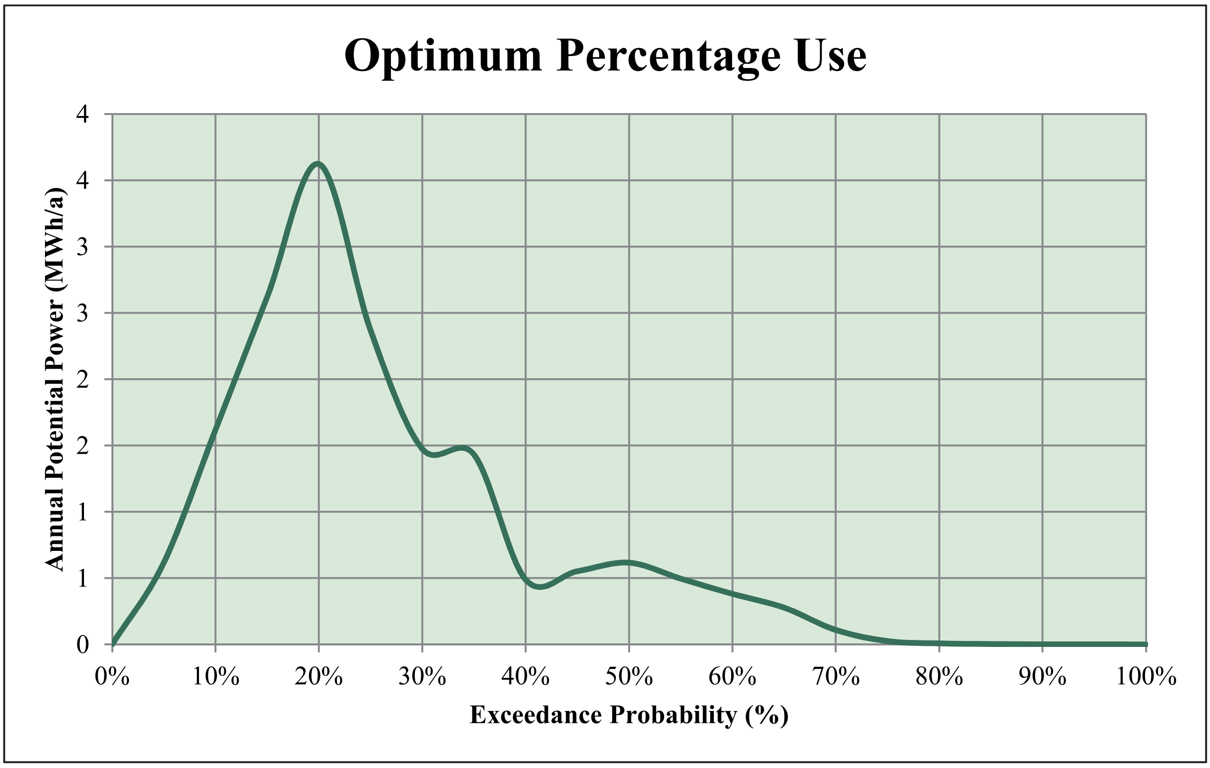


Figure 7-16: Phase 3A optimum percentage use curve LHHD Tool

7.4.2.3 Phase 3 economic analysis

The Economic Analysis Section has various default formulas, but information like turbine type, updated overall costs, design life and inflation rates have to be entered into the Tool. Also, if better information than the default values is available, the values should be altered to reflect the most accurate costs. The output in this screen includes an estimated net present value (NPV), internal rate of return (IRR) and payback period of the proposed project. **Table 7-8** shows the tool for Phase 3A, but Phase 3B looks similar, but with different turbine options and cost functions.

Table 7-8: Phase 3A economic analysis LHHD Tool

PHASE 3A ECONOMIC ANALYSIS				
Power information for current scenario				
Power rating			22.6	kW
Design flow	(Q)		0.412	m^3/s
Design flow corresponding head	(H)		8	m
Potential annual power			155	MWh/a
Turbine type			Crossflow	
Total Power information for future scenario				
Power rating			23	kW
Design flow	(Q)		0.412	m^3/s
Design flow corresponding head	(H)		8	m
Potential annual power			155	MWh/a
Turbine type			Crossflow	
Design life			15	years
Cost				
Initial planning cost (IPC)	% of total IPC			
Planning cost per MW installed (2012)			R 1,350,000	
Planning year			2013	
Planning cost per MW installed			R 1,350,000	
Legal and regulatory		3.0%	R 917	
Environmental and social assessment		27.0%	R 8,249	
Investigation and preliminary design		70.0%	R 21,387	
Subtotal		100.0%	**R 30,553**	
Capital expenditure (CEC)	% of total CEC			
Turbine			R 1,486,149	
Capital cost per MW installed (excl turbine) (2012)			R 13,300,000	
Construction year			2014	
Capital cost per MW installed (excl turbine)			R 13,300,000	
Preliminary and general		24.5%	R 73,747	
Access to site		0.5%	R 1,505	
Pipework and valves		6.5%	R 19,565	
Power station housing and tailrace		20.0%	R 60,201	
Electromechanical and controls		12.0%	R 36,121	
Transformer/transmission		12.5%	R 37,626	
Construction supervision		5.5%	R 16,555	
Contingencies		17.5%	R 52,676	
Disposal (present value (PV))		1.0%	R 3,010	
Subtotal		100.0%	**R 1,787,156**	
Additional capital expenditure due to expansion (PV)			R 0	
Year of expansion			2029	
Annual operation and maintenance cost (OMC)	% of CEC for component			
Civil items		0.25%	R 199	
Electrical and mechanical items		2.00%	R 30,445	
Transmission		0.80%	R 301	
Operation		0.40%	R 7,149	
Insurance		0.30%	R 5,361	
Subtotal (PV)			**R 43,456**	
Income				
Annual income for current scenario	R/kWh			
Average value of generated electricity		0.58	R 90,039	
Revenue			R 0	
Subtotal (PV)			**R 90,039**	
Annual income for future scenario	R/kWh			
Average value of generated electricity		0.58	R 90,039	
Revenue			R 0	
Subtotal (PV)			**R 90,039**	
Results				
Net present value of costs		-R 2,395,147		
Net present value of income		R 1,636,438		
Total NPV		**-R 758,708**		
Internal rate of return		**-0.36%**		
Payback period		**16**	**years**	

Inflation and maintenance factors over design life					
Year	**Annual Inflation**				**Maintenance factors**
	Electricity	**Operation**	**Maintenance**	**General**	
0	8.0%	5.3%	5.3%	5.3%	0.8
1	8.0%	5.1%	5.1%	5.1%	0.8
2	8.0%	6.0%	6.0%	6.0%	0.8
3	8.0%	6.0%	6.0%	6.0%	0.8
4	8.0%	6.0%	6.0%	6.0%	0.8
5	10.0%	6.0%	6.0%	6.0%	1
6	10.0%	6.0%	6.0%	6.0%	1
7	10.0%	6.0%	6.0%	6.0%	1
8	10.0%	6.0%	6.0%	6.0%	1
9	10.0%	6.0%	6.0%	6.0%	1
10	10.0%	6.0%	6.0%	6.0%	1
11	10.0%	6.0%	6.0%	6.0%	1
12	10.0%	6.0%	6.0%	6.0%	1
13	10.0%	6.0%	6.0%	6.0%	1
14	10.0%	6.0%	6.0%	6.0%	1
15	6.0%	6.0%	6.0%	6.0%	1.2
16	6.0%	6.0%	6.0%	6.0%	1.2
17	6.0%	6.0%	6.0%	6.0%	1.2
18	6.0%	6.0%	6.0%	6.0%	1.2
19	6.0%	6.0%	6.0%	6.0%	1.2
20	6.0%	6.0%	6.0%	6.0%	1.25
21	6.0%	6.0%	6.0%	6.0%	1.25
22	6.0%	6.0%	6.0%	6.0%	1.25
23	6.0%	6.0%	6.0%	6.0%	1.25
24	6.0%	6.0%	6.0%	6.0%	1.25
25	6.0%	6.0%	6.0%	6.0%	1.25
26	6.0%	6.0%	6.0%	6.0%	1.25
27	6.0%	6.0%	6.0%	6.0%	1.25
28	6.0%	6.0%	6.0%	6.0%	1.25
29	6.0%	6.0%	6.0%	6.0%	1.25
30	6.0%	6.0%	6.0%	6.0%	1.5
31	6.0%	6.0%	6.0%	6.0%	1.5
32	6.0%	6.0%	6.0%	6.0%	1.5
33	6.0%	6.0%	6.0%	6.0%	1.5
34	6.0%	6.0%	6.0%	6.0%	1.5
35	6.0%	6.0%	6.0%	6.0%	1.5
36	6.0%	6.0%	6.0%	6.0%	1.5
37	6.0%	6.0%	6.0%	6.0%	1.5
38	6.0%	6.0%	6.0%	6.0%	1.5
39	6.0%	6.0%	6.0%	6.0%	1.5
40	6.0%	6.0%	6.0%	6.0%	1.5
41	6.0%	6.0%	6.0%	6.0%	1.5
42	6.0%	6.0%	6.0%	6.0%	1.5
43	6.0%	6.0%	6.0%	6.0%	1.5
44	6.0%	6.0%	6.0%	6.0%	1.5
45	6.0%	6.0%	6.0%	6.0%	1.5
46	6.0%	6.0%	6.0%	6.0%	1.5
47	6.0%	6.0%	6.0%	6.0%	1.5
48	6.0%	6.0%	6.0%	6.0%	1.5
49	6.0%	6.0%	6.0%	6.0%	1.5
50	6.0%	6.0%	6.0%	6.0%	1.5

7.4.2.4 Phase 3 checklist

The Checklist Section (**Table 7-9**) for this phase does not require any input, but serves as a reference for the user to determine whether all the steps for the second phase have been considered.

Table 7-9: Phase 3A checklist LHHD Tool

PHASE 3A CHECKLIST	
Did the first phase indicate economic feasibility?	
If not, is there another reason for considering conduit hydro?	
Did the site evaluation show feasibility?	
Were flow - and pressure records measured/obtained?	
Were all gaps discarded?	
Were the values ranked from small to large flow with corresponding pressures?	
Was a percentage assigned to each flow (100% exceedance for min flow to 0% exceedance for max flow?	
Has the flow rating curve been populated?	
Has the hydropower potential been analysed?	
Is there currently significant potential?	
If not, will there be future develoment that might increase potential?	
Has a design flow and pressure been chosen?	
Has a first order turbine selection been done?	
For grid tie-in: Have all environmental aspects been considered and permission been obtained?	
For grid tie-in: Have licensing requirements been satisfied?	
For grid tie-in: Have all water use aspects been considered and permission been obtained?	
For grid tie-in: Have all social issues been addressed?	
For islanded/on-site systems: Have all environmental aspects been considered and permission been obtained?	
For islanded/on-site systems: Have all water use aspects been considered and permission been obtained?	
For islanded/on-site systems: Have all social issues been addressed?	
Has a pre-feasibility economic analysis been conducted?	
Is the project economically feasible?	
If not, is there another reason for continuing?	

8 DETAIL ACTIONS OF THE LOW HEAD HYDROPOWER ASSESSMENT MODEL

This Chapter serves to elaborate on the steps illustrated in the process flow diagrams of **Chapter 7** and to discuss the Low Head Hydropower Assessment Model (LHHAM) in greater detail. It should be noted that each item in the flow diagrams of **Chapter 7** has been numbered and a corresponding number in this chapter indicates discussion of that particular item.

8.1 FIRST PHASE: INITIAL INVESTIGATION

8.1.1 INTRODUCTION

Apart from conventional hydropower schemes in large dams, many opportunities exist for low head hydropower installations. Possible applications can be found in small dams, rivers, irrigation canals and in urban areas. The following sections will discuss potential site types with factors that may influence the feasibility of an installation at certain sites.

The initial investigation is simply done to determine whether pressure head (m) or velocity (m/s) would be the critical factor to consider when determining hydropower potential. This phase also redirects users with pipe systems to other WRC documentation, where conduit hydropower is discussed in depth (Van Vuuren et al., 2014b).

8.1.2 URBAN SYSTEMS

8.1.2.1 Wastewater treatment works

8.1.2.1.1 Description

Wastewater treatment works are viable sources of hydropower due to the high volume of water that generally flows from such facilities. The flow rates at these treatment works are fairly constant so that no dam or reservoir is required (Lam, 2008).

According to ESHA (2009), there are two opportunities for hydropower generation at wastewater treatment works: the first is before the treatment plant and the second is at the outflow of the plant (**Figure 8-1**).

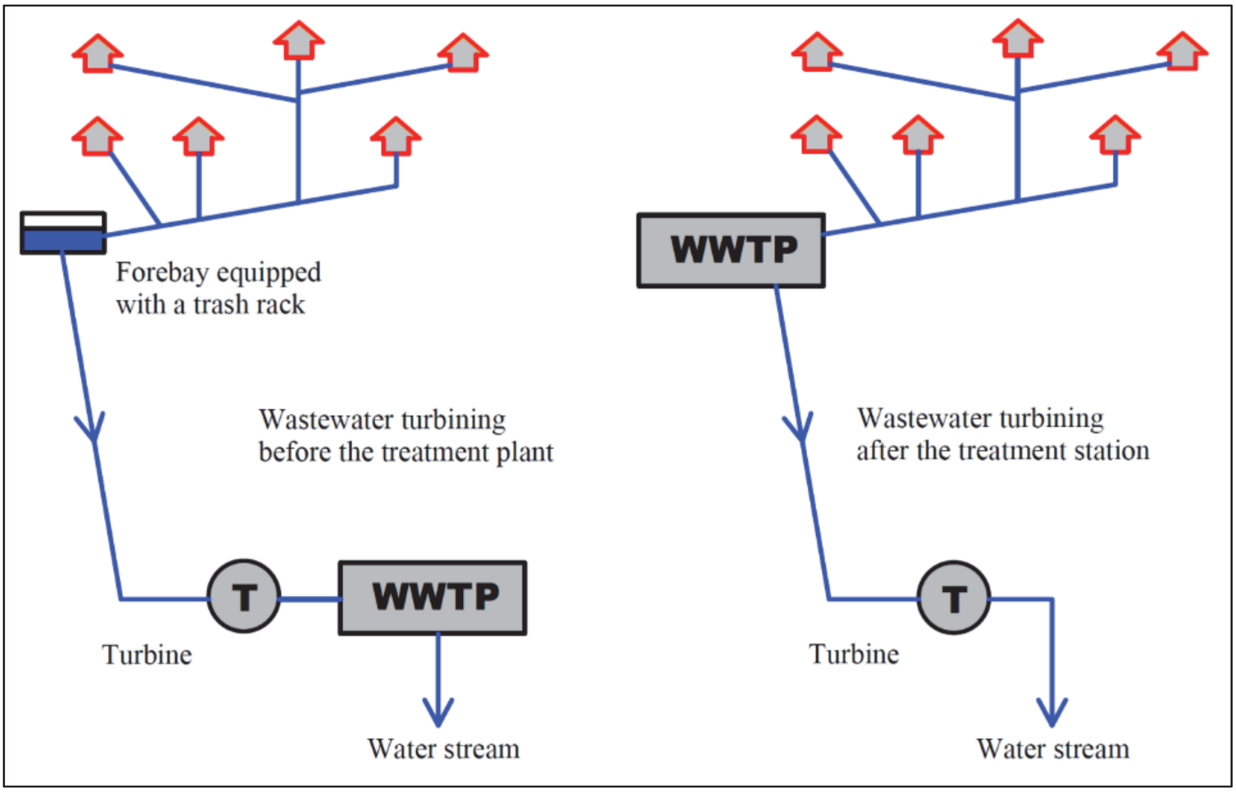


Figure 8-1: Wastewater treatment plant hydropower opportunities (ESHA, 2009)

If a hydropower plant is placed at the inflow of water treatment works, a forebay with trash rack should be included and the hydro plant should be situated as close as possible to the treatment plant, to maximise the operational head (ESHA, 2009).

The outflow from water treatment works is usually released into natural streams or manmade channels which transport the water to the river system downstream. These systems convey the water via gravity allowing all of the additional energy to be extracted.

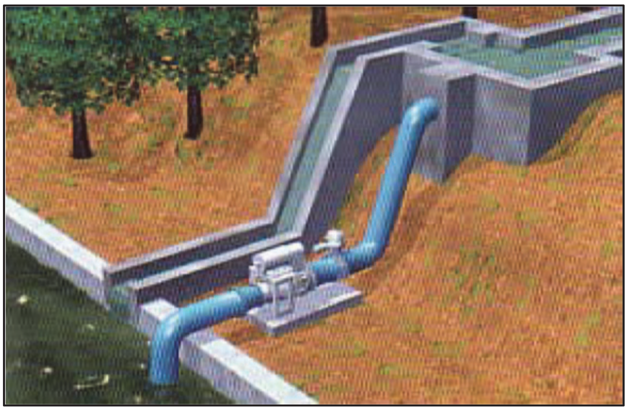
At these outlets a head difference from 1 m can be expected. Some of the analysed outlets have head differences of 8 m which combined with high flow rates have large electricity generation potential.

Something to note when designing hydropower plants at wastewater treatment works is the increased threat of corrosion. Treated wastewater may cause increased levels of corrosion when compared to other water sources (Lam, 2008).

At many of the wastewater treatment plants extensive civil work has been done at the outlets which in turn decreases the construction effort needed for a hydropower plant.

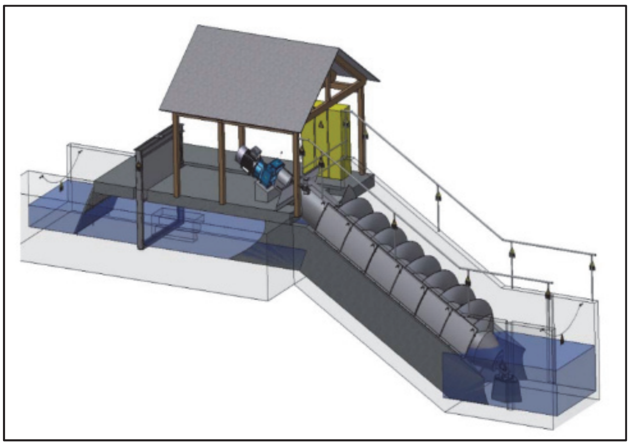
8.1.2.1.2 Typical layouts

Turbines can typically be installed at wastewater treatment plant outlets to utilise either some or the entire outflow. Depending on the available space and existing infrastructure on site a number of turbine options are available. This includes Archimedean screws (**Figure 8-2 (c)**), Kaplan or propeller turbines (**Figure 8-2 (a)**), hydroengine turbines (**Figure 8-2 (b)**) or siphon-type turbines.



(a) Hydro e-Kids (Toshiba, 2013)

(b) Hydroengine (Natel Energy, 2013)



(c) Archimedean screw (Mellacher & Fiedler, 2013)

Figure 8-2: Typical wastewater treatment plant turbine layouts

8.1.2.2 Pipelines

A WRC study (Van Vuuren et al., 2013) considers in detail the potential and application of hydropower plants in pipelines, specifically at high pressure points and pressure reducing stations in water distribution system. Similar installations may be possible at points with excess pressure, albeit lower pressure than investigated during that study.

Outlets of pipelines into canals or dams could also have potential for low head hydropower applications, even if pressure reducing measures were not deemed necessary.

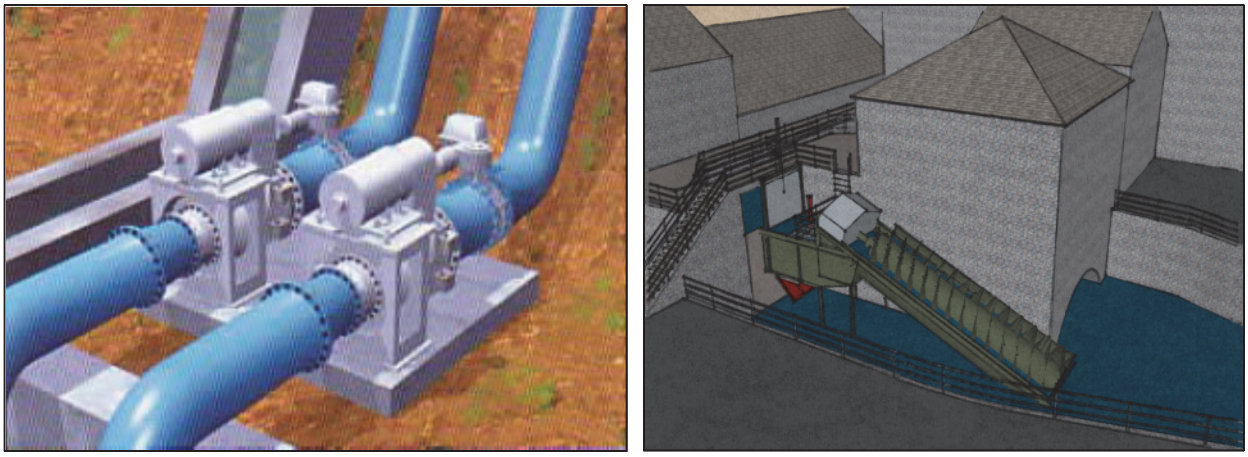
8.1.2.3 Industrial outflows

8.1.2.3.1 Description

Many commercial and industrial sites use significant amounts of water for cleaning or processing of materials. These sites may include breweries, dairy producers, vehicle manufacturers and many others. Turbines can potentially be installed at the return flow pipes or canals. Applicable turbines may include Archimedean screws, Kaplan turbines or Steff turbines, depending on the conditions on site.

8.1.2.3.2 Typical layouts

Typical layouts for hydropower generation at industrial outflows would normally be similar to wastewater treatment plant hydropower set-ups. Archimedean screws (**Figure 8-3 (b)**), Kaplan or propeller turbines (**Figure 8-3 (a)**), hydroengine turbines or siphon-type turbines are all possible options, depending on the layout and space on site.



(a) Hydro e-Kids in parallel (Toshiba, 2013) (b) Archimedean screw (3Helixpower, 2013)

Figure 8-3: Typical industrial outflow turbine layouts

8.1.2.4 Urban stormwater systems

Areas experiencing moderate to high rainfall are possible candidates for low head hydropower. In the hydropower potential formulation head is also a role player. Geographic areas containing small to significant elevation drops will serve to add needed potential.

Some cities in South Africa were forced to build intricate stormwater infrastructure to minimise the probability of damage to the area. Other areas are geographically situated where large volumes of runoff are generated either naturally or due to development. In these areas the foundation for the hydropower plants will already be built, which will decrease the civil works needed.

The most challenging facet will be to account for the irregularity of the stormwater resource (Bailey and Bass, 2009). Precipitation can vary from none to large volumes of water and can result in a low plant capacity factor. This low plant capacity factor implies that a relatively low amount of electricity is generated for a large capital expense (Bailey and Bass, 2009).

Another challenge is to incorporate the hydropower plant with the existing facility without compromising on the proficiency of the system and keeping the cost to a minimum. Underground systems will increase the capital outlay due to increased construction cost. To keep a project economically viable storm system revisions should be avoided or be accomplished as part of funded storm system upgrades or repairs (Bailey and Bass, 2009).

Due to the irregularity of storm events in South Africa, the installation of hydropower turbines is not recommended if a reliable energy supply is needed.

8.1.3 RIVER SYSTEMS

8.1.3.1 Run-of-river

8.1.3.1.1 Description

The potential for low-head hydropower development is commonly found within the range of micro-hydropower (i.e. up to or above the 100 kW installations, which can supply hydro energy to the small communities with agricultural/commercial/ manufacturing enterprises). Micro-hydro schemes are usually run-of-river installations, where there are no large water collection impoundments. Typically, a low weir structure is erected across a river to keep a fairly constant head of water with an intake structure situated behind the weir.

A channel/canal is typically feeding a fore bay tank connected to a pressurized pipe (i.e. a penstock). The design of such a system depends on the topology, water flow and costs of materials used in the structure associated with a micro hydropower scheme.

As micro-hydropower generally has no storage capacity it would be most important to determine and to predict a wide fluctuation in the river flows. An iterative numerical analysis of available data for the water course under consideration has to be conducted. If there is no flow data available for the proposed site, the flow information which might be available on a nearby stream within the same catchment, that can serve as a guiding pattern of river flows supported by a series of short field measurements. The flows are calculated month by month and averaged say over 3 to 5 years. The flows are then plotted against the percentage of time that the flow is exceeded compiling a flow-duration curve from which the energy potential at a given site can be determined

The distribution of seasonal precipitation around South Africa's land-mass is rather diversified making certain areas suitable and other areas not suitable for the development and operation of micro-hydropower. However, most of feasible potential of the micro and small scale hydropower is hidden within existing water supply infrastructure providing large quantities of raw and potable water to residential, industrial and agricultural establishments, in many cases by gravity.

Run-of-river schemes involve the diversion of either a portion or all of a river flow through a turbine to generate electricity; or turbines are installed directly in a river channel (Harvey et al., 1993). Therefore, the hydropower plant can only use the water that is available in the natural river flow.

8.1.3.1.2 Typical Layouts

Suitable sites for small-scale hydropower installations can vary from fast-flowing streams in mountains to wide rivers in lower areas. In some places existing infrastructure can be utilised for the construction of a hydropower plant, but in many cases entirely new construction would be required. The British Hydropower Association (BHA, 2005) proposes four common run-of-river hydropower installations (refer to **Figure 8-4**):

1. A canal-and-penstock setup: water is diverted from a stream to a canal; from the canal to a penstock; from the penstock to the turbine and then through a tailrace back to the river.
2. A variation on the first setup is to construct a penstock all the way from the diversion to the turbine, thereby omitting the canal.
3. Very low head schemes may make use of a diversion canal only; in many cases re-utilising an existing diversion canal.
4. A barrage may be developed, where the turbine is installed in a weir or right next to it, so that no diversion is required. These type of layouts can also be classified as weirs or even small dams.

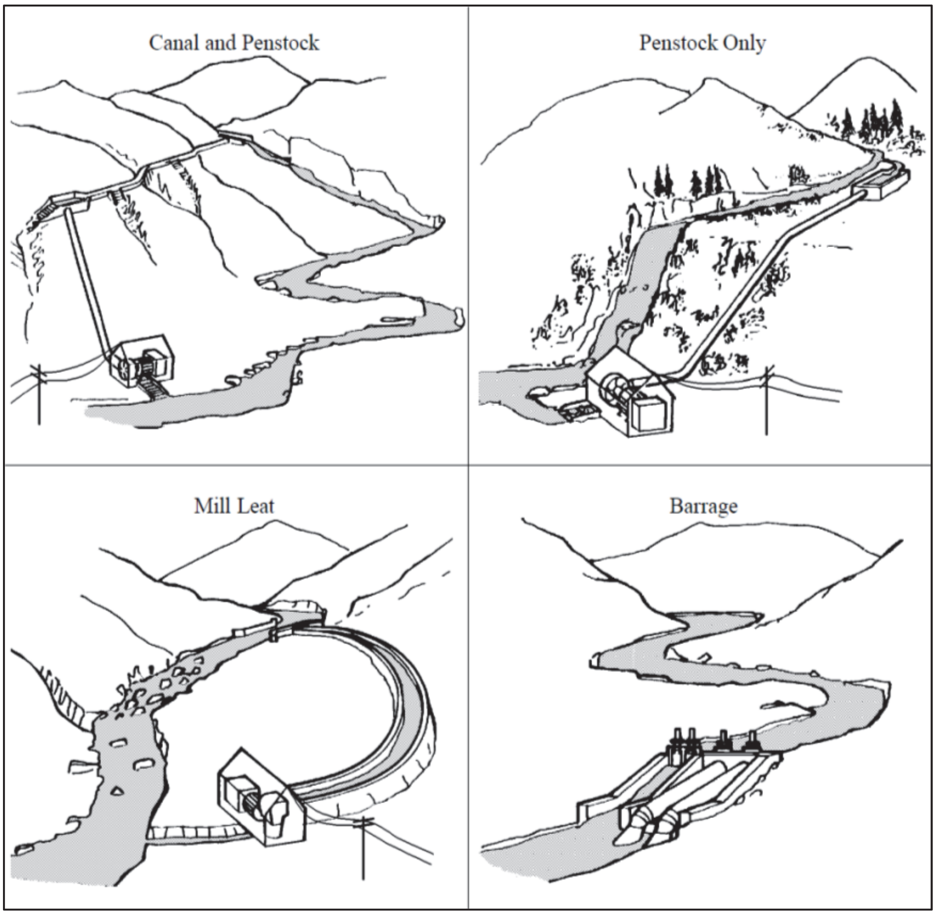


Figure 8-4: Run-of-river hydropower layouts (BHA, 2005)

8.1.3.2 DAMS, BARRAGES AND WEIRS

8.1.3.2.1 Description

There exists an opportunity to retrofit existing dams and reservoirs with hydropower plants. Instead of dams being constructed for the purpose of hydropower and then having different functions, reservoirs that are already in existence for other purposes can be fitted with hydropower plants in order to meet base or peak electricity demands. Obviously the application of this form of hydropower is limited as there are a fixed number of dams in existence, but the advantages are numerous because the energy is there waiting to be harnessed and additional environmental impacts are minimised.

Van Vuuren and Blersch developed a Hydropower Retrofitting Model (HRM) which is a comprehensive, logical and accurate model which can be used in the initial phases of a project to determine the feasibility of retrofitting hydropower onto an existing dam in South Africa (Van Vuuren et al., 2011). The aim of the model is not to generate an actual design but rather to ascertain financial, environmental and social feasibility at pre-feasibility level and make a recommendation about whether or not the project is worth further investigation.

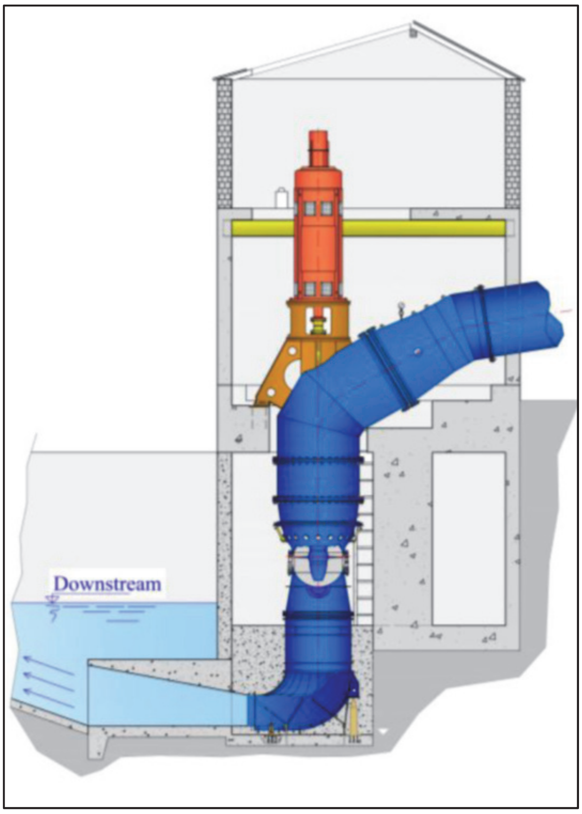
A typical hydropower project would require the consideration of technical, legislative, environmental, socioeconomic and financial aspects. Each of these has a role to play in the determination of feasibility at the early stages of a project. These aspects are successfully combined into a computer model (HRM) which requires only a few measurable inputs to produce a recommendation of viability. These include the costs of electromechanical components and civil works, legislative costs and general costs associated with any civil engineering project, which are successfully combined into a financial spreadsheet. All potential negative environmental and social impacts are listed for consideration and a method for weighting their importance and making a recommendation in their regard was developed. The model is comprehensive in that it includes all necessary costs and factors; and simple in that the inputs required by the user are minimal.

8.1.3.2.1 Typical Layouts

Typically, hydropower turbines will be built into new dams or retrofitted to existing infrastructure. Kaplan, bulb or propeller-type turbines (**Figure 8-5(a)** and **(b)**) would be most easily installed during dam construction. Siphon-type turbines (**Figure 8-5 (c)**) could be retrofitted to some low head dams.

(a) Kaplan (Alstom, 2013)

(c) Hydro e-kids as siphon (Toshiba, 2013)



(b) Vertical Kaplan (Mavel, 2013a)

Figure 8-5: Typical layout for turbines at low head dams

8.1.3.3 Measuring weirs

8.1.3.3.1 Introduction

Although large dams are normally associated with significant environmental impacts and only constructed for large-scale projects, there may exist many opportunities for using small dams and weirs for hydropower generation (Harvey et al., 1993).

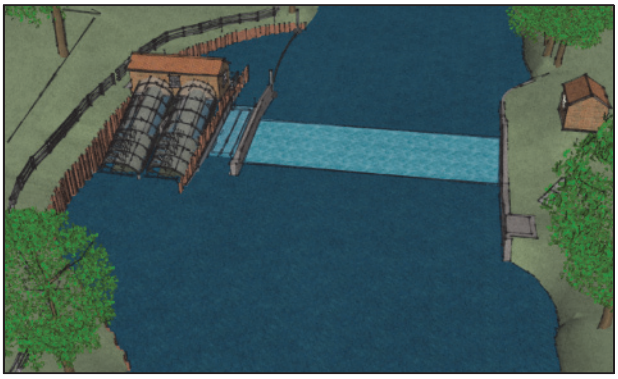
Measuring weirs provide a specific example of structures in many South African rivers where hydropower installations may be considered. The challenge at these sites would be to install a hydropower plant that does not affect the accuracy of the measuring weir.

Hydropower plants at dams and weirs will normally be built into the dam wall, or constructed right next to the dam with a short diversion. Siphon turbines or Archimedean screws can also be installed at many existing dams and weirs.

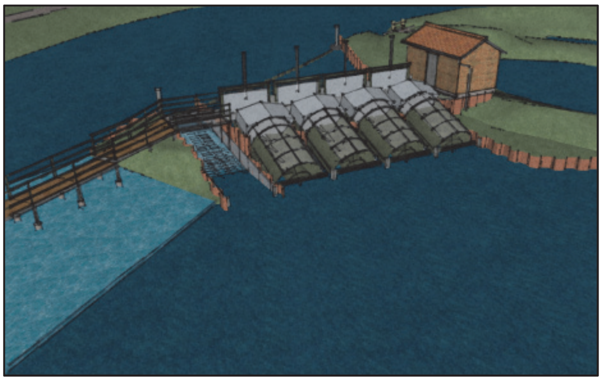
Small schemes may be retrofitted, or planned, at weirs that are built for other purposes, like flood control, measuring, irrigation, recreation or water abstraction.

8.1.3.3.2 Typical Layouts

Similarly to dams, hydropower turbines will be built into or retrofitted to weirs. Kaplan, bulb or propeller-type turbines (**Figure 8-6 (c)** and **(d)**) would be most easily installed during weir construction. Siphon-type turbines or Archimedean screws (**Figure 8-6 (a)** and **(b)**) could be retrofitted to some weirs, with some additional civil infrastructure required.

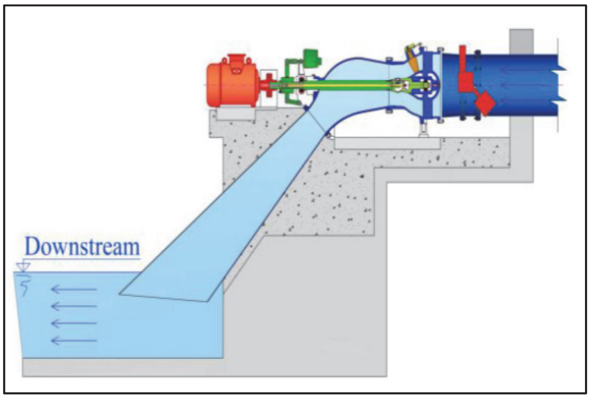


(a) Archimedean screw (3Helixpower, 2013)



(b) Archimedean screw (3Helixpower, 2013)

(c) Kaplan turbine (Alstom, 2013)



(d) Horisontal Kaplan (Mavel, 2013a)

Figure 8-6: Typical layouts of hydropower turbines at weirs

8.1.3.4 Open lengths on rivers

In some cases water wheels and hydrokinetic turbines can be installed along sections of natural rivers, if there is a need for electricity nearby and if it will not have a major impact on the river ecology, flow patterns and riverbed movement. The main drivers to determine suitability of these sites are flow volumes, flow velocities and reliability of flow. **Figure 8-11** an example of a hydrokinetic turbine.

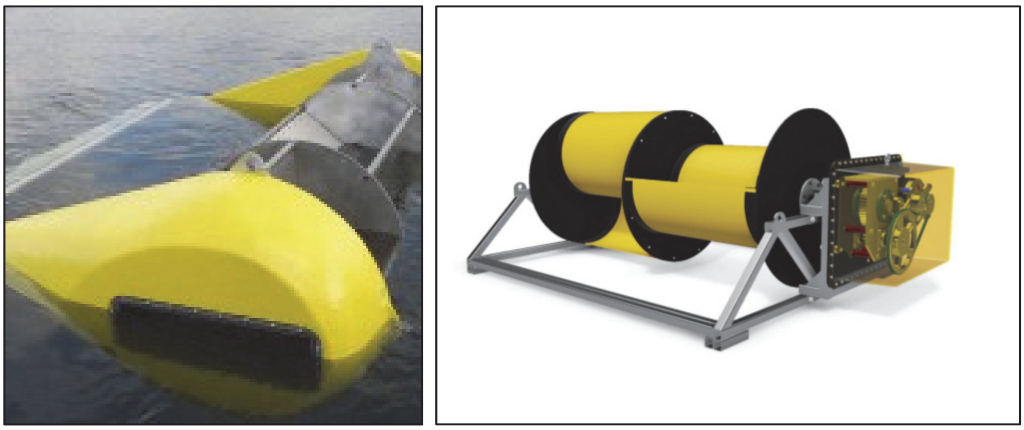


Figure 8-7: Hydrovolts hydrokinetic turbine (Hydrovolts, 2013)

Vehicle, cattle and pedestrian bridges may provide some opportunities for easy installation of very low head turbines in rivers. These structures can provide anchorage for various types of hydrokinetic turbines.

8.1.4 IRRIGATION SYSTEMS

8.1.4.1 Introduction

In some irrigation canal systems, turbines can be installed to generate electricity, either through diversion or in the canal system itself. These systems will normally consist of high-flow, low-head installations (ESHA, 2004).

The majority of the information for this section was extracted from reports on the development of water management programmes (WMPs) for 14 irrigation schemes in South Africa, administered by the Department of Water Affairs (DWA, 2013). Their contribution is acknowledged with gratitude.

8.1.4.2 Diversion structures

Many irrigation systems use diversion systems to canalise water from natural rivers to irrigation canals (**Figure 8-8**). These diversion structures may be ideal sites for the implementation of low head hydropower projects, firstly because the existing infrastructure can be used to lower construction cost and secondly because many diversion structures span right across rivers, allowing for the utilisation of all the flow for a hydropower plant (CDA, 2011).

Figure 8-8: Diversion structure in the Boegoeberg Irrigation Scheme (DWA, 2013)

Similarly to dams and weirs in rivers, turbines can be built into the diversion structure wall, or constructed right next to the structure. Siphon turbines or Archimedean screws can also be installed at many existing structures.

8.1.4.3 Concrete lined chutes and drop structures

According to the CDA (2011), chutes are regularly used for water transportation down hills. The chutes are normally concrete lined to prevent erosion of the in-situ material. Depending on the head available at a certain chute, it can either be bypassed using a pipe and conventional turbine or the existing structure can be used in conjunction with an Archimedean screw, Turbinator or similar turbine.

If the gradient is very steep, vertical drop structures are constructed. These drop structures can in many cases be used to house a turbine, typically a siphon turbine, Hydroengine or Kaplan turbine.

In South African irrigation schemes, bulk water sluices are normally put at the top of these structures, however, all bulk water sluices do not have significant downstream drops and therefore hydropower potential will vary significantly from site to site. **Figure 8-9** is an example of a sluice gate with no practical hydropower potential.

Figure 8-9: Sluice with almost no hydropower potential (DWA, 2013)

8.1.4.4 Flow measuring stations

Most irrigation canals have a number of flow measuring stations (**Figure 8-10**), some of which may provide an opportunity for pico hydropower generation. It is, however, important that flow through the measuring structure is not influenced, so as to guarantee effective readings.

Figure 8-10: Telemetry system at the Teebus canal

8.1.4.5 Open lengths on irrigation canals

In some cases water wheels and hydrokinetic turbines can be installed along sections of concrete lined canals, if there is a need for electricity nearby. The main drivers to determine suitability of these sites are flow volumes, flow velocities and reliability of flow. **Figure 8-11** shows the Teebus canal in the Fish River.

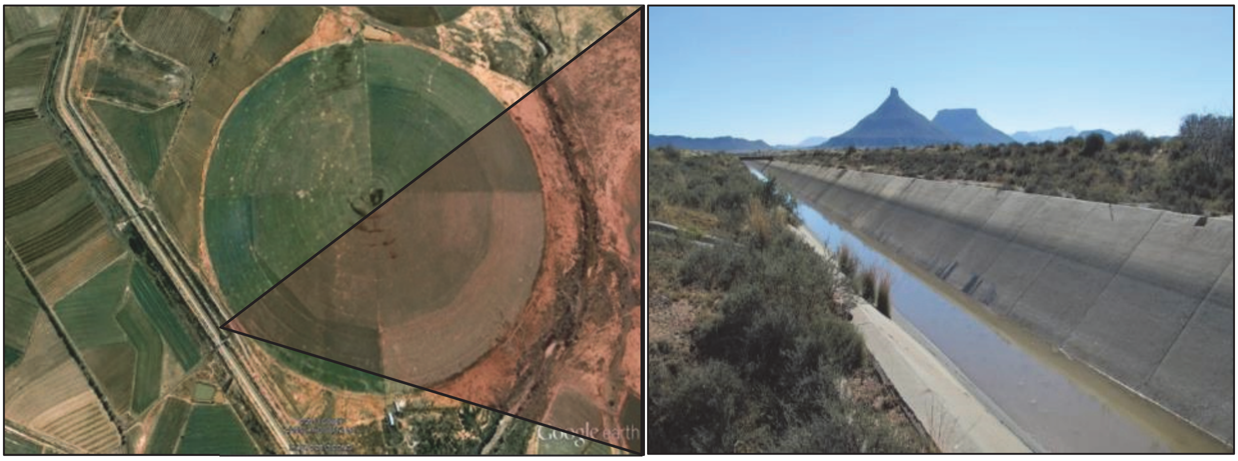


Figure 8-11: Google Earth image (Google Earth, 2013) and photo of the Teebus canal

Vehicle, cattle and pedestrian bridges (**Figure 8-12**) provide may provide many opportunities for easy installation of very low head turbines in irrigation canals. These structures can provide anchorage for various types of hydrokinetic turbines. The power produced by these turbines is based on the velocity of the water, instead of pressure head and flow.

Figure 8-12: Bridge across Teebus canal

8.1.4.6 Reject structures

Depending on how often reject structures (**Figure 8-13**) are used, they may provide an opportunity for hydropower generation using siphon turbines or Archimedean screws.

Figure 8-13: Typical reject structure (DWA, 2013)

8.1.4.7 Typical layouts

There are many different set-ups and variations of turbines that could be used for hydropower generation in irrigation systems. The type of turbine used, as well as the turbine set-up, depends on the existing infrastructure, flows and heads in the system. **Figure 8-14** shows a schematic layout of possible sites for different hydropower set-ups. Turbines that can typically be used include waterwheels, hydrokinetic turbines (**Figure 8-15 (b)**), vortex turbines, Archimedean screws (**Figure 8-15 (c)** and **(d)**), Kaplan or bulb turbines (**Figure 8-15 (a)**), siphon-type turbines and hydroengines.

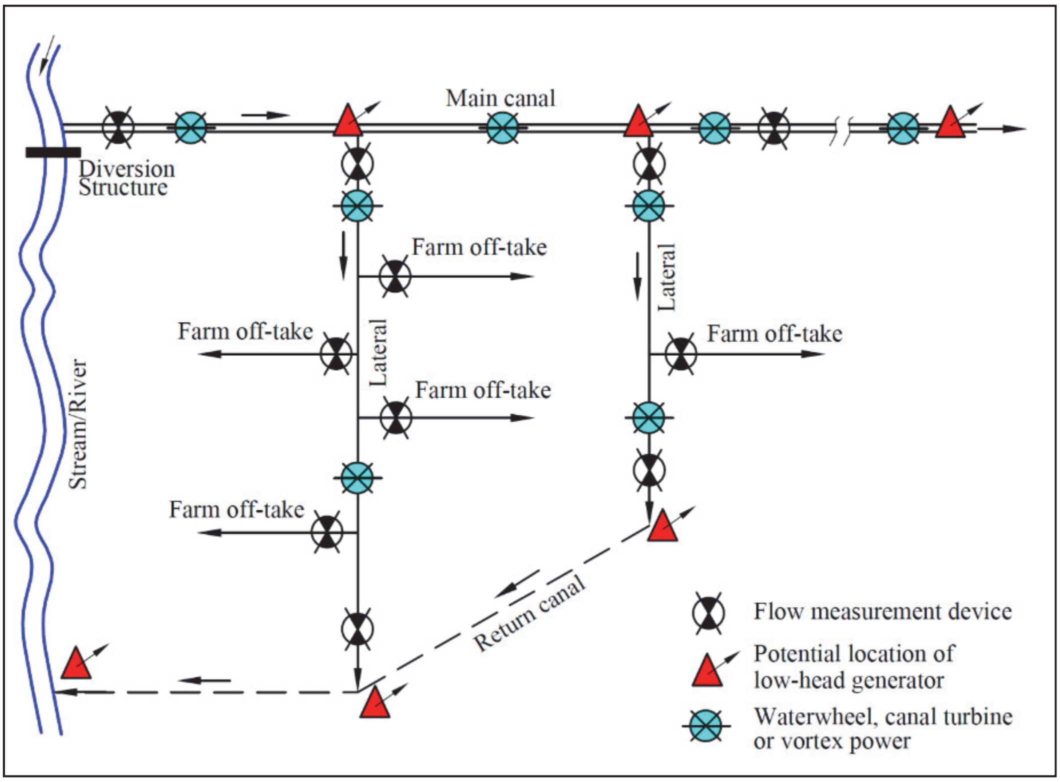
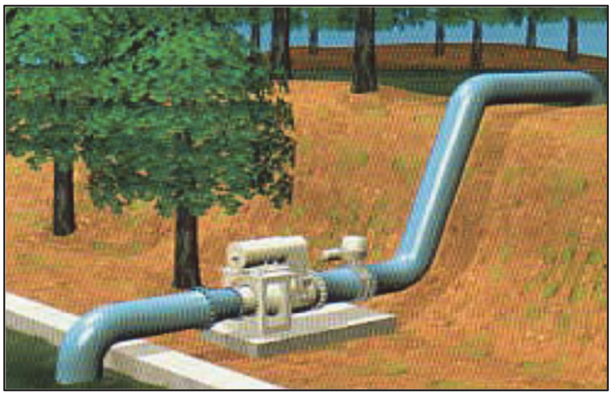
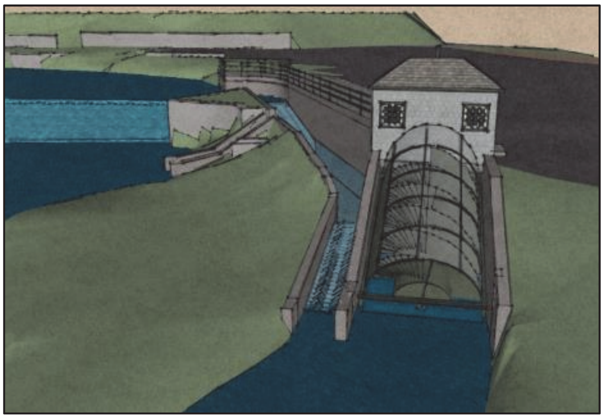


Figure 8-14: Schematic layout of irrigation scheme (adjusted from CDA, 2011)

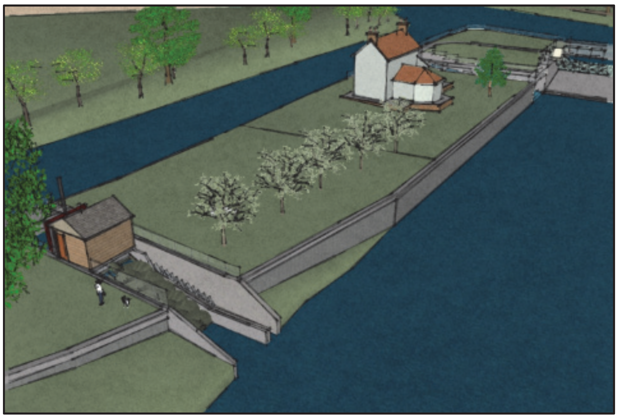


(a) Hydro e-Kids as siphon (Toshiba, 2013)

(b)Hydrokinetic turbine (Hydrovolts, 2013)



(b) Archimedean screw (3Helixpower, 2013)



(d) Archimedean screw (3Helixpower, 2013)

Figure 8-15: Typical layouts for turbines in irrigation schemes

8.2 SECOND PHASE: PRE-FEASIBILITY INVESTIGATION

8.2.1 INTRODUCTION

A pre-feasibility study should be performed on all potential sites, as valuable information on hydropower potential can be gathered by doing systematic desktop studies. The following sections discuss each of the aspects that should be considered before a full feasibility study is performed.

8.2.2 POTENTIAL SITES

The first task would be to determine whether there are any points with excess energy. Excess energy will generally be available between points in the network with significant elevation differences or, in the case of canals and rivers, where flow velocities are very high.

Therefore three important aspects to consider at this stage include: firstly, whether there are any points with sudden elevation changes in the system; secondly whether locations exist where a diversion channel could create sudden elevation changes; and thirdly, whether there are any locations where water flows regularly and at high velocities.

8.2.2.1 Sudden elevation changes 1A

Probably the easiest possible locations to identify for hydropower generation are locations with sudden elevation changes. These elevation changes can be: dam outlets, waterfalls or cascades in rivers, wastewater treatment plant outlets or irrigation canal drop structures, to name but a few.

8.2.2.2 Locations with consistent flow 1B

Another first order indication of hydropower potential is high velocity flow. Locations with regular, high velocity flow can be identified for development of hydrokinetic power plants. It should be noted that the formula used to determine hydrokinetic potential differs from the formula for conventional hydropower plants, and therefore a different LHHD Tool should be used for these applications.

8.2.2.3 Option of a diversion canal 2A

In some cases, a sudden elevation change is not present in the system, but a diversion channel at a flatter slope than the existing river or canal can create a sudden elevation change just before it reconnects with the stream. This can only be accomplished if sufficient space exists for such a diversion channel.

8.2.2.4 Locations with irregular, but significant flow 2B

In some cases, there may be locations in the system that do not experience constant flow, but that do have significant flow velocities, albeit at intermittent intervals. In most cases, these locations will not be feasible, unless the irregular flow can generate electricity to put into the national grid, or to power batteries for on-site use. A careful investigation should be performed to determine whether sites with sporadic flow are technically and economically feasible.

8.2.2.5 Obtaining permission from the owner 3

If the identified locations are not the property of the developer, permits for use should be obtained before effort is wasted on determining hydropower potential that cannot be used by the developer.

8.2.3 HYDRAULIC ANALYSIS

A pre-feasibility hydraulic analysis is done to obtain a first-order estimate of hydropower potential at a site.

8.2.3.1 Average flow and pressure 4A

For sites where elevation changes indicated hydropower potential, all available flow and pressure data should now be compiled to determine the design flow and head values, and estimates should be done where sufficient information is not readily available. At this stage, the annual average daily demand (AADD) can be used to calculate average flow and the average static head may be used as the pressure head, if other information is not known.

More detailed studies and flow and pressure measurements during different times of the day and seasons will be done in subsequent phases, if the outcome of the First Phase is positive. The average daily flow should be given in m^3/s and the pressure head given in metres (m). These values are used for the initial calculation of the power available at the specific point in the distribution system.

8.2.3.2 Average velocity 4B

For sites where velocity and frequency of flow indicated hydropower potential, all velocity data should now be compiled to determine the design velocity values, and estimates should be done where sufficient information is not readily available. At this stage, the average velocity may be used, if other information is not known. The available footprint of the turbine should also be estimated at this stage. More detailed studies and flow and velocity measurements during different times of the day and seasons will be done in subsequent phases, if the outcome of the First Phase is positive.

The area should be given in m^2 and the velocity in m/s. These values are used for the initial calculation of the power available at the specific point in the distribution system.

8.2.3.3 Power available (using flow and head) 5A

In order to obtain an initial estimate of the power potential at a specific site where flow and head are the drivers, the following formula (**Equation 8-1**), can be used:

$$P=\rho g Q H \eta \qquad \textbf{Equation 8-1}$$

where:

- P = mechanical power output (W) (calculated)
- η = hydraulic efficiency of the turbine (%) (use 70% in the First Phase)
- ρ = density of water (kg/m^3) (use 1 000 kg/m^3)
- g = gravitational acceleration (m/s^2) (use 9.81 m/s^2)
- Q = flow rate through the turbine (m^3/s) (use the average flow in the First Phase)

H = effective pressure head across the turbine (m) (use avg. head or 60% of static head)

8.2.3.4 Power available (using velocity) 5B

However, the power produced by hydrokinetic turbines is based on the velocity of the water, instead of pressure head and flow. The general equation to determine power from these turbines has been adapted for metric units from Colorado Department of Agriculture (CDA) (2011) (**Equation 8-2**):

$$\boldsymbol{P} = \mathbf{126.71} \times (\boldsymbol{A} \times \boldsymbol{v}^{\mathbf{3}}) \qquad \textbf{Equation 8-2}$$

with:

P= power (Watts)
A = area of the turbine in flow (m^2)
v = velocity (m/s)

8.2.4 ENERGY USE CONSIDERATIONS

8.2.4.1 Use of energy 6

Potential uses for electricity should be identified. It is important to note whether there are any settlements close to the site, or, if no settlements exist, whether generated electricity will be used on site or requires a grid connection. Generated energy can be used for one, or a combination of, the following options:

(a) Feeding electricity into an existing grid;
(b) So-called islanded systems that are far from an electricity grid; and/or
(c) Points in the network that need local lighting, security and telemetry.

8.2.4.2 Distance of site to energy users 7

If the generated electricity is to be connected to the grid, it is important to know how far the hydropower plant would be from the connection point. If the plant is far away from a grid connection, it might have a significant impact on the economic feasibility of the project.

8.2.4.3 Energy demand 8

Once potential users or uses have been identified for the generated electricity, the expected demand should be established. This can be done by either assessing current energy usage through measurement or electricity bills and estimation of future use.

8.2.4.4 Demand vs. energy potential

The energy potential and energy demand should be compared to determine whether the project has the potential to be feasible and whether further investigation should be undertaken.
This is especially true in the case of islanded systems or on-site usage, as insufficient hydropower potential would mean that additional sources of energy should also be utilised.

It is important to consider implementation of energy-efficiency measures to reduce demand. Energy efficiency may be increased by using low-energy lights and appliances and encouraging users to switch off unused or unnecessary lights and appliances.

8.2.5 PRE-FEASIBILITY ECONOMIC ANALYSIS

A pre-feasibility economic analysis is done using a life-cycle approach with roughly estimated values for both costs and income. It is proposed that at least the net present value (NPV) and internal rate of return (IRR) be calculated to estimate economic feasibility at this stage, using the formulas as indicated in the following paragraphs. The payback period may also be calculated, preferably considering inflation. However, it should not be used as the deciding factor in project selection. It should only be used as a tool for initial screening to supplement other methods, as it does not give sufficient information to stand alone as an evaluation tool (ESHA, 2004; Blank and Tarquin, 2004).

8.2.5.1 Net present value (NPV)

According to SANRAL (2013), this method is used to:

- 'select the best alternative among the mutually exclusive projects; and
- to help establish an overall economic viability of independent projects.'

The net present value (NPV) of a project is determined by subtracting the present worth of investment cost from all future benefits. A positive NPV would indicate an economically feasible project, with a higher value more advantageous than a lower value. The formula used for this method is (**Equation 8-3**) (from SANRAL, 2013):

$$NPV = PW(M_0+U_0) - PW(M_A+U_A) + PW(CS_A) - C_A \qquad \textbf{Equation 8-3}$$

where:

NPV	=	net present value of benefits
$PW(M_0+U_0)$	=	the present worth of facility maintenance costs and user costs of the null alternative

$PW(M_A + U_A)$ = the present worth of facility maintenance costs and user costs of a proposed alternative

$PW(CS_A)$ = consumer surplus gained through additional usage induced by the proposed alternative. This is equal to one-half of the benefit accruing to each existing journey multiplied by the number of induced trips.

C_A = investment (capital) cost that is required to implement the alternative *A'*

8.2.5.2 Internal rate of return (IRR)

This method can also be used to find the most viable between independent projects. The distinguishing feature of this method is that it shows the discount rate at which the project would break even. Future benefits and costs are calculated in the same way as for the NPV or B/C methods and discounted to the present using different rates until a rate is found where the returns and costs are equal. This rate is the internal rate of return. The higher the IRR, the more advantageous the project will be. The formula used for this method is (**Equation 8-4**, from SANRAL, 2013):

'$IRR = r$ When $PW(M_0+U_0)-PW(M_A+U_A)+PW(CS_A) = C_A$ **Equation 8-4**

where:

IRR = internal rate of return

r = rate at which the left-hand and right-hand sides of the equation are equal, resulting in an NPV of zero.

$PW(M_0+U_0)$ = the present worth of facility maintenance costs and user costs of the null alternative

$PW(M_A + U_A)$ = the present worth of facility maintenance costs and user costs of a proposed alternative

$PW(CS_A)$ = consumer surplus gained through additional usage induced by the proposed alternative.

C_A = investment (capital) cost that is required to implement the alternative'

8.2.5.3 Payback period

The payback method is used to calculate the time required for the initial investment to be offset by the resulting revenue of the scheme. The required time is called the payback, recovery or break-even period. The formula used for the calculation is (ESHA, 2004):

$$Payback\ period = \frac{investment\ cost}{net\ annual\ revenue}$$ **Equation 8-5**

Equation 8-5 does not incorporate the time value of money and only considers the life of the project until the payback point has been reached. However, other literature suggests that inflation may be included and that the payback period would then be the time taken to equate initial capital outlay and the present value of net annual cash flow (Blank and Tarquin, 2004).

Both sources agree that the payback period should not be used as the deciding factor in project selection. It should only be used as a tool for initial screening to supplement other methods, as it does not give sufficient information to stand alone as an evaluation tool (ESHA, 2004; Blank and Tarquin, 2004).

8.2.6 OTHER REASONS FOR LOW HEAD HYDROPOWER

In some cases, there might be reasons other than economic feasibility to justify the use of low head hydropower. These reasons include:

- Islanded systems which are not supplied from the national electricity grid.
- Locations far from the grid that need local lighting, security and telemetry.
- Areas where cable theft may be a problem.
- Areas that need additional peak-time electricity.
- Political reasons for developing greener renewable energy sources.

It may also be that operational changes can have a positive impact on the economic feasibility of a project. If this might be the case, a Phase 2 analysis would also be recommended.

8.2.7 OUTCOME OF PHASE 2

This phase requires a minimal amount of input information by the user. The main function of this phase is to obtain an initial estimate of potential power and the economic feasibility of a low head hydropower plant at a site. The outcome of this phase is a decision on the practicability of conducting a full feasibility study.

8.3 THIRD PHASE INVESTIGATION: FEASIBILITY

8.3.1 SECOND PHASE SUCCESSFUL

The first step during this phase is to critically consider the answers obtained during Phase 2. If Phase 2 indicates economic feasibility, or if there is another reason for considering hydropower at the site under investigation, the Third Phase study should commence.

8.3.2 SITE EVALUATION

After completing the desktop study and determining whether it would be theoretically possible to generate electricity at a given site, it would be necessary to visit the site and assess the practicability of a hydropower plant there.

Aspects to consider include space for the hydropower plant; safety of the turbine and other equipment from theft or vandalism; noise impact on the surroundings; and accessibility to the site during construction.

8.3.3 HYDRAULIC STUDY

8.3.3.1 Flow and pressure measurement 3A

A measuring weir is typically used for river flow measurement and the available head determined using the height difference between upstream and downstream water surfaces (BHA, 2005). At this stage, it would be unreasonable to expect long-term flow data, but longer record sets would lead to better estimation.

The data should be critically evaluated and all gaps should be discarded before continuing. Care should be taken not to discard zero values, unless it is known that faulty measuring equipment caused incorrect zero values to be recorded at certain times.

8.3.3.2 Velocity measurement 3B

A measuring weir is typically used for river flow measurement and the available head determined using the height difference between upstream and downstream water surfaces (BHA, 2005). At this stage, it would be unreasonable to expect long-term flow data, but longer record sets would lead to better estimation.

The data should be critically evaluated and all gaps should be discarded before continuing. Care should be taken not to discard zero values, unless it is known that faulty measuring equipment caused incorrect zero values to be recorded at certain times.

8.3.3.3 Design flow and associated power 4A

Power estimation can be done during the Feasibility Phase, using the additional information gathered. The following formula (with values as indicated in **Equation 8-6**), can be used:

$$\boldsymbol{P = \rho g Q H \eta} \qquad \textbf{Equation 8-6}$$

where:

P = mechanical power output (W) (calculated)

η = hydraulic efficiency of the turbine (%) (use 70% in the Feasibility Phase)

ρ = density of water (kg/m^3)

g = gravitational acceleration (m/s^2)

Q = flow rate through the turbine (m^3/s) (use the design flow)

H = effective pressure head across the turbine (m) (use the design head)

The design flow and head can be calculated by generating a flow-rating curve (**Figure 8-16**) and calculating the available power for different combinations of flow and associated head. The design flow and head are calculated in different ways, depending on the application of the generated energy. At this stage it should be decided whether the electricity generated by the hydropower plant should have a certain reliability of supply (for example, power should be reliable for 95% of the time), or whether the maximum possible annual amount of energy can be supplied to the grid.

If electricity should be supplied at a certain assurance level, the flow at that percentage may be used as the design flow, with its corresponding head. **Figure 8-16** shows an example of the flow for 80% reliability of supply. If the maximum potential is used, then the design flow and head will be the combination that generates the optimum potential annual power.

Table 8-1 is an example of a table used to obtain the optimum potential power and **Figure 8-17** is a graphical representation of the data. The annual potential power for a selected turbine capacity can be calculated by multiplying the potential power with the hours per year when that potential is available. The last column in **Table 8-1** is used to calculate this and **Figure 8-18** is a visual representation.

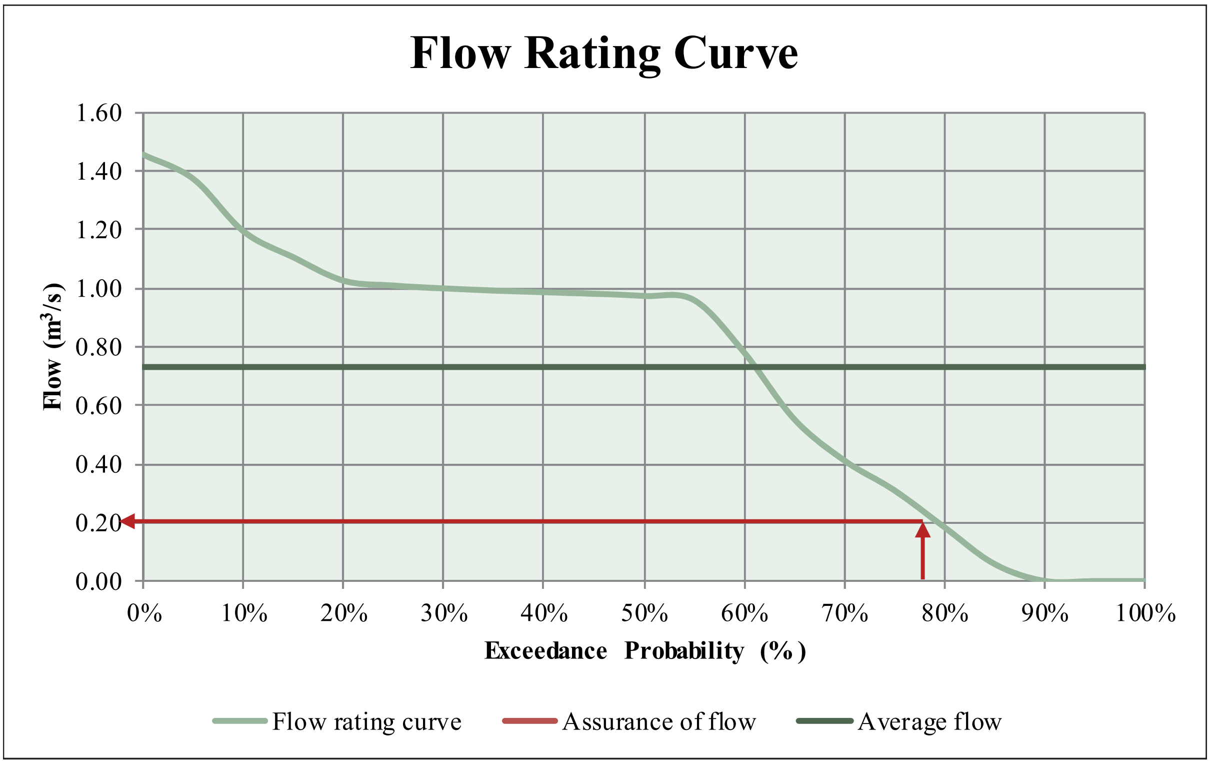


Figure 8-16: Example of a flow-rating curve with an 80% assurance of flow

Table 8-1: Example of a Phase 2 potential analysis

PHASE 2 POTENTIAL ANALYSIS							
Flowrating curve	Load factor (%)	Flow (m^3/s)	Head available (m)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100%	0	125	8592	0.0	0.000	0
	95%	0.000	123.4	8154	0.0	0.000	0
	90%	0.001	139.5	7716	0.7	5.257	0.146331973
	85%	0.059	143.9	7278	57.9	421.481	12.58574673
	80%	0.184	142.9	6840	180.5	1234.373	51.20306327
	75%	0.310	138.0	6402	293.8	1880.647	101.8631544
	70%	0.412	131.2	5964	371.2	2213.611	142.8251233
	65%	0.553	127.4	5526	483.7	2673.165	183.6336555
	60%	0.780	113.8	5088	609.8	3102.773	261.9793884
	55%	0.959	92.6	4650	609.9	2836.029	261.9793884
	50%	0.974	94.6	4212	632.5	2664.041	261.9793884
	45%	0.981	96.6	3774	651.0	2456.741	261.9793884
	40%	0.986	99.0	3336	670.6	2237.108	261.9793884
	35%	0.992	101.0	2898	688.3	1994.790	261.9793884
	30%	0.999	103.4	2460	709.2	1744.648	261.9793884
	25%	1.009	109.8	2022	760.6	1537.894	261.9793884
	20%	1.025	120.9	1584	851.4	1348.662	261.9793884
	15%	1.105	88.0	1146	667.8	765.326	261.9793884
	10%	1.194	97.1	708	795.7	563.354	261.9793884
	5%	1.372	85.8	270	808.2	218.204	261.9793884
	0%	1.456	82.6	0	825.4	0.000	261.9793884
Optimum flow	60%	0.780	113.8	5088.0	609.8		3897.989125
Average flow		0.767	111.6	8592	588.0	5052.294	
Chosen flow		0.037	50.4	8592	12.8	110.026	
Assurance of flow		0.000	0.0	0	0.0		
Design flow	**60%**	**0.780**	**113.8**	**5088**	**609.8**	**3898.0**	

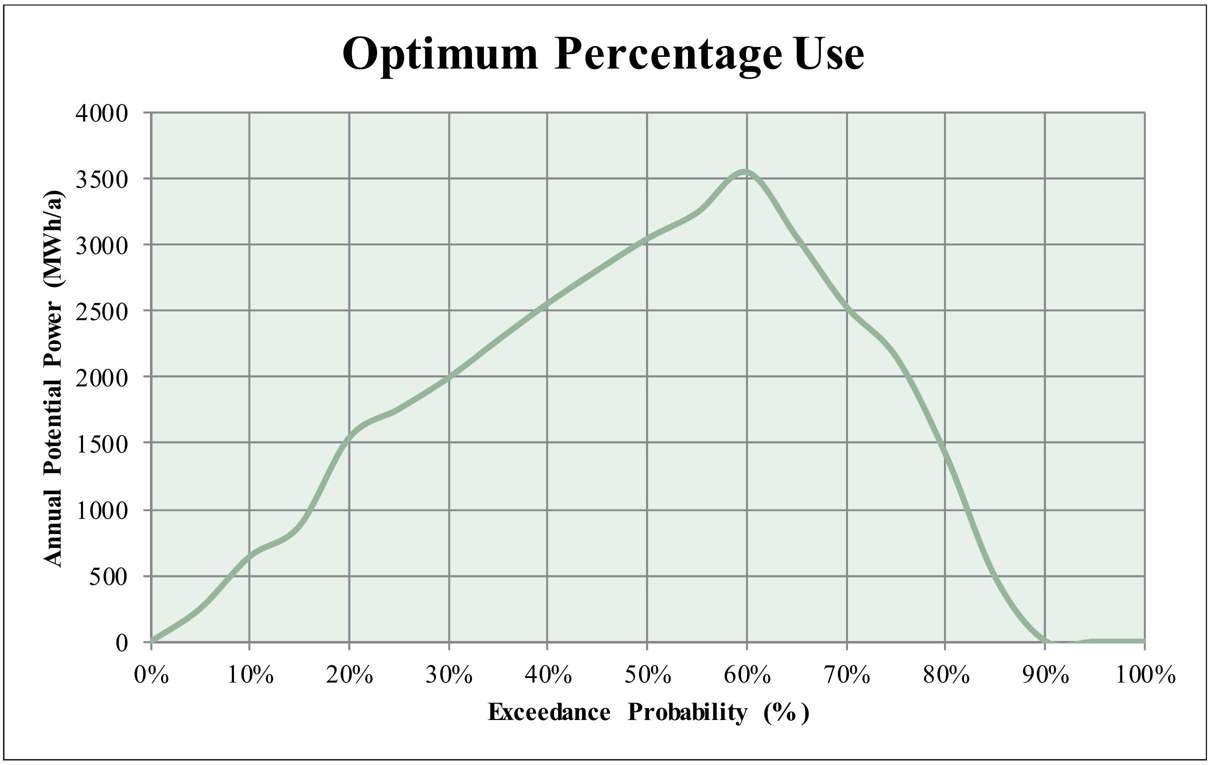


Figure 8-17: Example of an optimum percentage-use curve

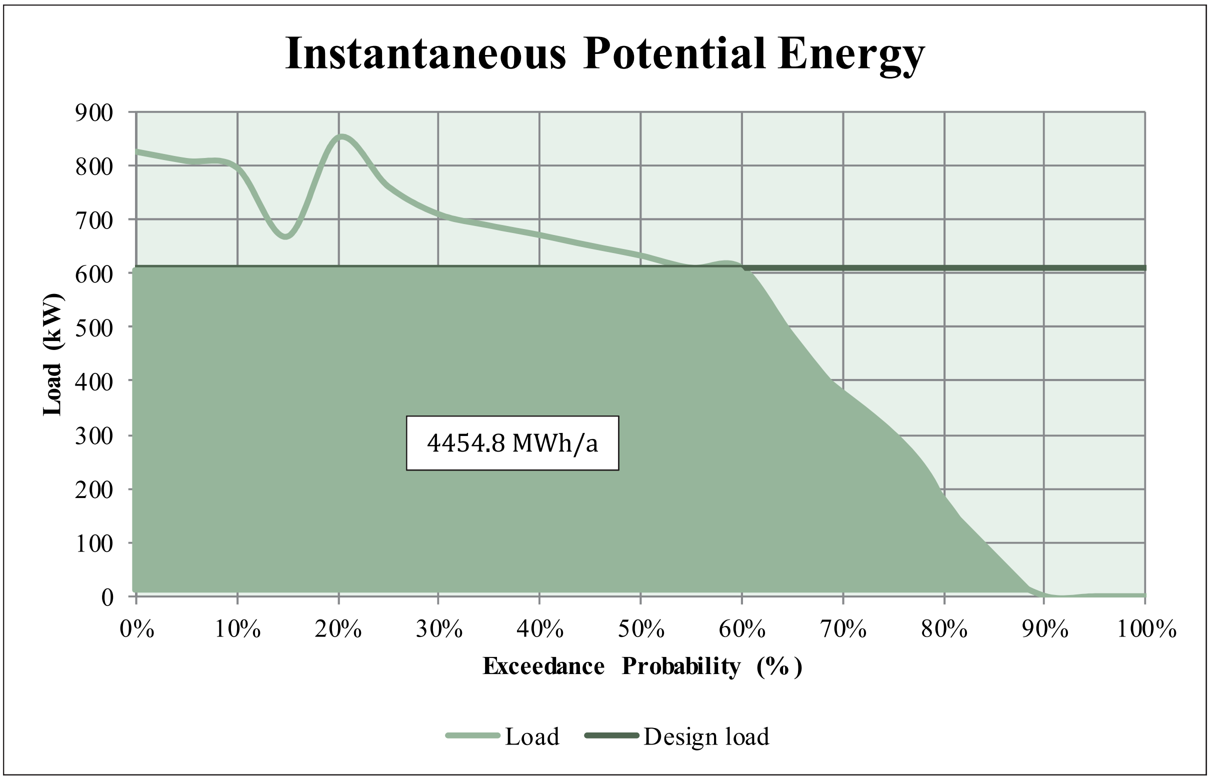


Figure 8-18: Example of an annual potential energy-calculation curve

8.3.3.4 Design velocity and associated power 4B

Power estimation can be done during the Feasibility Phase, using the additional information gathered. The power produced by hydrokinetic turbines is based on the velocity of the water, instead of pressure head and flow. The general equation to determine power from these turbines has been adapted for metric units from Colorado Department of Agriculture (CDA) (2011) (**Equation 8-7**):

$$\boldsymbol{P = 126.71} \times (\boldsymbol{A} \times \boldsymbol{v^3}) \qquad \textbf{Equation 8-7}$$

with:

P = power (W)
A = area of the turbine in flow (m^2)
v = velocity (m/s)

The design velocity can be calculated by generating a velocity-rating curve and calculating the available power for different velocities. The design velocity can be calculated in different ways, depending on the application of the generated energy. At this stage it should be decided whether the electricity generated by the hydropower plant should have a certain reliability of supply (for example, power should be reliable for 95% of the time), or whether the maximum possible annual amount of energy can be supplied to the grid.

If electricity should be supplied at a certain assurance level, the velocity at that percentage may be used as the design flow. **Figure 8-19** shows an example of the velocity for 50% reliability of supply.

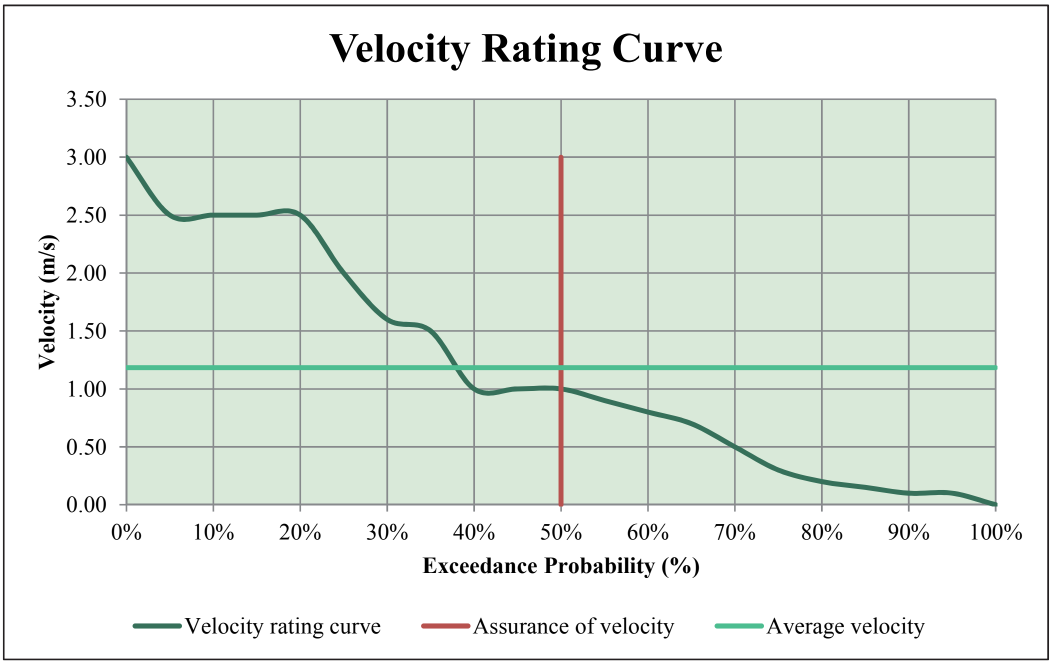


Figure 8-19: Example of a velocity rating curve

8.3.3.5 Operation of site within system

The site has to be evaluated as part of the larger system. The influence of a hydropower plant at the site should be investigated considering the main function of the system.

8.3.3.6 Future development

It may be that the current flow or velocity will not generate a significant amount of hydropower. If this is the case, an investigation should be carried out to determine whether future development that may increase the potential is planned. If so, the future values should be used in further analyses, or phasing of hydropower development should be considered.
If future development will decrease the hydropower potential, this should be noted and the economic feasibility analysis should be done with an applicable design life for current circumstances.

8.3.3.7 Turbine selection (using flow and head)

The design flow and head, together with the required power, can now be used for the initial selection of an appropriate turbine. The LHHD Tool includes a graph (**Figure 8-20**) to facilitate this process. If necessary, turbine suppliers (refer to **Appendix A**) may be contacted for more detailed information.

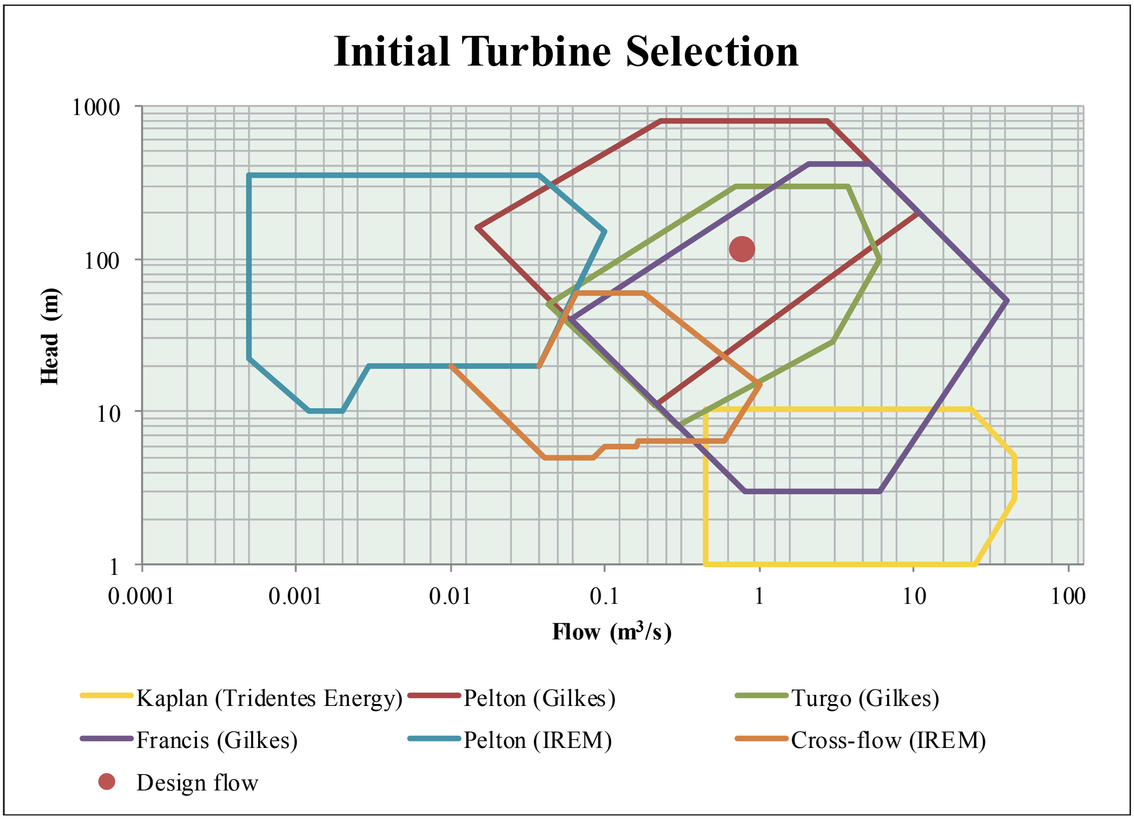


Figure 8-20: Example of an initial turbine-selection curve

8.3.3.8 Turbine selection (using velocity) 7B

The design velocity, together with the required power, can now be used for the initial selection of an appropriate turbine. Turbine suppliers (refer to **Appendix A**) may be contacted for more detailed information.

8.3.4 ENERGY USE CONSIDERATIONS

8.3.4.1 Use of energy 8

Potential uses for electricity should be identified. It is important to note whether there are any settlements close to the site, or, if no settlements exist, whether generated electricity will be used on site or requires a grid connection. Generated energy can be used for one, or a combination of, the following options:

- Feeding electricity into an existing grid;
- islanded systems that are far from an electricity grid; and/or
- Sites in the network that need local lighting, security and telemetry.

8.3.4.2 Distance of site to energy users

If the generated electricity is to be connected to the grid, it is important to know how far the hydropower plant would be from the connection point. If the plant is far away from a grid connection, it might have a significant impact on the economic feasibility of the project.

8.3.4.3 Energy demand vs. energy potential

Once potential users or uses have been identified for the generated electricity, the expected demand should be established. This can be done by either assessing current energy usage through measurement or electricity bills and estimation of future use.

The energy potential and energy demand should be compared to determine whether the project may be feasible and whether further investigation should be undertaken. This is especially true in the case of islanded systems or on-site usage, as insufficient hydropower potential would mean that additional sources of energy should also be utilised.

It is important to consider implementation of energy-efficiency measures to reduce demand. Energy efficiency may be increased by using low-energy lights and appliances and encouraging users to switch off unused or unnecessary lights and appliances.

8.3.5 FEASIBILITY STAGE REGULATORY ASSESSMENT

At this point, a regulatory assessment should be done, as it is important to consider the social and environmental aspects of the project. The following sections will deal with these points.

8.3.5.1 General

The development of a small or large hydropower either through the augmentation of existing hydraulic infrastructure or as a “greenfield” river installation must observe legal requirements particularly that of regulatory nature. However the extent of regulations applied will differ from case to case based on a project specific merit.

Since promulgation of the National Water Act (NWA) in 1998, the custodian of surface and ground water resources on behalf of the nation is the RSA’s Government, guided by the Constitution of the Republic of South Africa (South African Government, 1996).

The Government’s arm in dealing with all water issues in South Africa (e.g. strategy, policies, administration, O&M, etc.) is the Department of Water Affairs (DWA) through its several regional offices where the registration and licensing of water use is logged and processed.

Generally, any type of hydropower project development will face some or all of the obligations from the set given below:

- to obtain a water use permit from the DWA, needed by any user of the national water resources (Act 36/1998) for private enterprise purposes, Act 36/1998 sections to comply with: Section 21 (b), Section 21 (c), Section 21 (i) and Section 37 (1) (c) defining "*a power generation activity which alters the flow regime of a water resource*" as a controlled activity (NB: although the hydropower generation is a non-consumptive water use, no concession is given to this type of water use);
- to secure a permit of access allowing utilization of public/parastatal/private water engineering assets (i.e. dams, canals, pipelines, etc.) by an independent private entity if situated in a defined servitude;
- to scrutinize project proposal compared to the environmental impact assessment (EIA) (Act 73/1989 and Act 108/1998) requirements, particularly applicable for "greenfield" hydropower projects;
- to bring forward a suitable public private partnership (PPP) model (e.g. BOT, BOTT, lease contract, etc.) if the administrator/owner of a water source is the national government department or a parastatal utility (e.g. Eskom, Rand Water, etc.);
- to obtain a licence from the National Energy Regulator of SA (NERSA) to produce energy/electricity (obtaining of this license is subject to all other licenses/permits already granted);
- to arrange for a power purchase agreement (PPA) if produced hydro energy is not for in-house consumption; and
- to arrange and guarantee project finances

8.3.5.2 Legislative Requirements

The following legislative documentation is to be consulted in preparation of a small or large hydropower development proposal:

- **National Water Act (Act 36 of 1998) –** governs the way that the water resource is protected, used, developed, conserved, managed and controlled by means of registration and licensing of water resource use.
- **Water Services Act (Act 108 of 1997) –** provides a municipality with the status of a Water Services Authority in preparation of water services development plans (WSDP) involving planning and budgeting of future services development.
- **Municipal Systems Act (Act 32 of 2000)** – describes the processes that a municipality needs to undertake to ensure efficient and sustainable municipal services provision (Part 2: indicates whether municipal services, including water and electricity should be undertaken internally or externally).

- **National Environmental Management Act (Act 108 of 1998)** – makes provision for the Environmental Impact Assessment (EIA). Government Gazette (June 18/2010) provides for three levels of environmental assessment: GN456 for geographical activities; GN544 for basic assessment (BA) procedures and GN545 for EIA procedures.
- **Electricity Regulation Act (Act 4 of 2006)** – provides for the regulatory requirements on registration and licensing of electricity generation, transmission, distribution (reticulation), trading and import/export of electricity.

In addition to the above listed legislative documentation, several other relevant legislative documents might be necessary to consult while preparing small or large hydropower development proposal:

- National Water Amendment Act (Act 1 of 1999)
- Public Finance Management Act, 1999
- Strategic Framework for Water Services, 2003
- National Energy Regulator Act (Act 40 of 2004)
- National Energy Act, 2008
- Municipal Infrastructure Investment Framework, 2010
- Revised Strategic Plan of the DoE, 2011/12 to 2015/16 – enables the Minister of Energy to allow establishment of IPPs for the purpose of greater competition in the electricity generation sector, so as to increase the supply of electricity

Table 8-2: Regulatory Requirements for Development of Hydropower in SA

REGULATORY REQUIREMENTS FOR DEVELOPMENT OF ALL TYPES OF HYDROPOWER IN SA		
No.	**Requirement definition**	**Legal documentation to consult**
1.	**An Environmental Authorization** from the Provincial Department of Environmental Affairs (DEA), either through a Basic Assessment (BA) – or an Environmental Impact Assessment (EIA) process, needs to be attained if certain developmental activities are initiated that may affect the environment. The specific activities are listed in General Notices published in terms of the NEMA, and depending on the extent and type of the hydropower development, the development activities could be listed in either GN983, necessitating a BA process to be followed, or in GN984, requiring an EIA process to be followed. In some instances, the proposed development triggers geographical activities, such as when borders and or boundaries are crossed. These activities are listed in GN985.	**National Environmental Management Act 107 of 1998 (NEMA)** as amended. General Notices published in terms of Chapter 5 of the NEMA.
2.	**A Water Use Authorization** from the Regional Department of Water and Sanitation (DWS) or Catchment Management Agency if established, needs to be attained by a Developer if a water resource is impacted in any manner. One of two types of authorization could apply depending on the extent and type of the hydropower development:	**National Water Act 36 of 1998** as amended by **National Water Amendment Act 01 of 1999.** General Authorizations published in terms of section 39 of the National

	(i) registration in terms of a **General Authorization (GA)**by the DWS allows a potential user to use/abstract water without the need of a license; and **(ii)** registration and licensing in terms of the National Water Act. A full **Water Use Licensing Authorization process (WULA)** is complex and laborious, and it is recommended that an Environmental Management Practitioner be procured to support the Authorization process. Developers are to reference the latest DWS pricing strategy to determine the cost associated with water use, as well as the latest GA published in the Government Gazette to determine whether or not the planned development falls within the allowable activities of the GA.	Water Act (NWA). Pricing Strategy published in terms of the NWA.
	If conduit hydropower is considered, the Water Services Provider must confirm that water is available and that hydropower generation activities will not affect security of water supply. (in conventional hydropower projects this is addressed during the Authorization process)	
3.	An electricity generation license issued by the **National Energy Regulator of South Africa** (NERSA) is required in all instances where electricity is generated, unless electricity is generated purely for "own-use", for non-commercial islanded use and or for pilot initiatives. Electricity generation license requirements depend on the extent of the development, and the intended use of the electricity generated. Electricity distribution licenses, and or trading licenses might also be required, depending on the extent, type and use of the development. Developers are recommended to approach NERSA on a case by case basis to determine necessary licensing requirements.	**Electricity Regulation Act**, Act 4 of 2006 as amended (ERA); Electricity Regulation 2nd Amendment Bill; The Constitution, Act 108 of 1996; Municipal Structures Act, Act 117 of 1998 as amended Municipal Systems Act, Act 32 of 2000 General Notices published in terms of the ERA. The Department of Energy's 2011 Integrated Resource Plan 2010-2030; Also: NERSA's Standard Conditions for small-scale embedded generation within Municipal boundaries. Municipal Guidelines for Embedded Generation.

CONTRACTUAL REQUIREMENTS FOR DEVELOPMENT OF ALL TYPES OF HYDROPOWER IN SA	
No.	**Requirement definition**
1.	Proof of land ownership or permission to access land. For development purposes, land is either acquired, and the land use rights changed if necessary, or permission to use the land is acquired from the land owner, and a servitude registered in the name of the land user for the portion of land subject to development.
2.	Appropriate contracting mechanism between electricity generator, electricity distributor and electricity buyer; and could take on the form of either a Public Private Partnership approach, a Power Purchase Agreement approach, a Concession approach or another approach. The contracting mechanism will depend on the extent, type and the intended use of the electricity generated, as well as the mechanism and entity involved in procuring the electricity generated.

Note: These permits and or contracts would be required**, inter alia**, to determine the feasibility of a hydropower project, whether the project is commercially or socially driven.

8.3.5.3 Institutional Stakeholders in Development of Hydropower

- **Department of Water and Sanitation (DWS)** – this national department is a 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 override responsibility for the water services provided by the local authorities.
- **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 the natural resources.
- **Department of Energy (DoE)** – is responsible for ensuring exploration, development, processing, utilization and management of SA's mineral and energy resources. The energy development programmes presently implemented are:
  - (i) Eskom Build Programme (EBP)
  - (ii) Integrated National Electrification (INE)
  - (iii) Energy Efficiency and Energy Demand Side Management (EE & EDSM)
  - (iv) Renewable Energy Independent Power Producer Procurement (REIPPP)
- **National Energy Regulator of South Africa (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 relevant acts.
- **Eskom Holdings Limited** – is a public company and a state owned enterprise as per the Public Finance Management Act (Act 1 of 1999) administering and operating the National Electricity Grid. Eskom generates, transmits and distributes electricity to all sectors of SA's economy.
- **Electricity Services Providers (ESPs)** – are responsible for electricity distribution (reticulation) as per local authority functions which can be either embedded or outsourced to another entity.
- **Independent Power Producers (IPPs)** – by definition – "*any person in which an organ of state does not hold a direct or indirect controlling interest*". (SAIPPA, 2011)
- **Water Services Authorities (WSAs)** – are mandated with the constitutional responsibility for ensuring access, planning and regulating provision of water services within their area of jurisdiction. The licensing of water abstraction from a water resource and discharge of wastewater to the water source is another function with a WSA.
- **Water Services Providers (WSPs)** – WSPs have the operational responsibility for providing water and/or sanitation services (NB: Where the WSAs undertake any of these services onto themselves, they become also the WSPs).
- **Water User Associations (WUAs)** – several end water users typically form a WUA (mainly former Irrigation Boards). The users work together and care for their water

source. The main function of a WUA is to ensure fair and reliable water supply to its members, who are mostly irrigation or livestock farmers.

- **Water Utilities** (former Water Boards) – are state-owned WSPs providing both bulk services to more than one WSA and retail services on behalf of a WSA. The water utilities typically operate extensive infrastructure primarily bulk potable water supply or wastewater systems. There are at present some 20 WUs in SA.

8.3.5.4 Regulatory Requirements Important to Development of Hydropower

Internationally the development of hydropower is guided and regulated by the Hydropower Sustainability Assessment Protocol (IHA, 2010). This document has been compiled by the International Hydropower Association (IHA) and it is now recommended to the international public domain for appropriate development of all types and sizes of hydropower. The Protocol represents a globally applicable tool to enable guided assessment and demonstration of feasibility and sustainability of hydropower projects. This tool can be used during all stages of hydropower project development: early stage, preparation, implementation and operation.

Table 8-3: The Hydropower Sustainability Assessment Protocol (IHA, 2010) topics

Integrative perspective	Environmental perspective	Social perspective	Technical perspective	Economic/financial perspective
Demonstrated needs	Downstream flow regimes	Resettlement	Siting and design	Financial viability
Policies and plans	Erosion and sedimentation	Indigenous people	Hydrological resources	Economic viability
Governance	Water quality	Public health	Infrastructure safety	Project benefits
Integrated project management	Biodiversity and invasive species	Cultural heritage	Asset reliability and efficiency	Procurement
Source: www.hydroworld.com (Hydropower Review Worldwide: September/October 2011)				

The Protocol (2011) has not been tested and adopted yet in SA as it is necessary to compare and reconcile the Protocol's mechanisms with the country's current hydropower project development requirements considering regional/local circumstances.

In South Africa, due to almost forty years of absence in hydropower development, no specific programme has been devised for guided and sustainable development of hydropower. The projects presently being developed in SA are managed more or less according to the sequences given in **Table 8-4**.

Table 8-4: Pre-construction development stages of small hydropower (up to 10 MW)

Project stage	Project development stage	Regulatory requirements
Identification/Planning stage (one month)	**Project Identification/planning** – finding a suitable site and potential energy target market that lies within an acceptable distance from the project development site.	The Identification/planning stage may be coupled with the Pre-feasibility stage into "Pre-investment". This depends on availability of info from reports/surveys.
Pre-feasibility stage including applications for various permits (estimated lead time 3 to 6 months)	**Project pre-feasibility** – based on a relatively short investigation to establish the principal financial parameters verified by institutional, regulatory, technical and environmental requirements determined from the field investigation and consultations. The breakdown of essential costs and likely income streams of the proposed project will be determined and financial options leading to a successful project development will be identified. The costs of development are based on the conceptual design.	**(i)** water use permit from the DWA as per Act 36/1998 ; **(ii)** getting approved EIA as per Act 73/1989 and Act 108/1998; **(iii)** the access permit to the public water engineering assets (i.e. dams, canals, pipelines, etc.); and **(iv)** a proposal of suitable public-private partnership (PPP) procurement model;
Feasibility stage including essential hydrological and geological surveys (lead time 12 to 18 months)	**Project feasibility** (i.e. a bankable proposal) forming the core of the pre-investment activity. This stage will include a financial model based on a reasonable detailing of the technical, institutional, regulatory and environmental inputs and socio-economic issues. A potential developer of the proposed project should be able to present a bankable proposal to interested banking institution(s) leading to financial closure on the proposed project.	**(i) to (iv) as above** **(v)** National Energy Regulator SA (NERSA) licence needed (subject to all other licences already granted); and **(vi)** Funding arrangements (small scale hydroelectric schemes are not yet recognised as good banking propositions,
Note: After pre-construction stages the procurement, O&M and decommission stages are to follow.		

To illustrate an extent of development of a typical hydroelectric scheme **Table 8-5** shows a technical layout giving the key components required normally to erect a "greenfield" islanded hydropower scheme.

Table 8-5: Development layout and components of a typical hydroelectric scheme

Source of hydro-energy	Generator of hydro-energy		Transmission of hydro-energy
	Civil/mechanical items	Electrical/ electronic	
• Access to source • Diversion tunnel/ canal • Dam/weir/ barrage • Impoundment • Spillway • Outlets	• Access to generator • Headrace structure • Power station house • Turbine • Penstock • Surge device • Tailrace structure	• Generator • Controls • Security/safety	• Transformers • Transmission • Distribution
Notes: (i) If the development of hydro-energy is situated at the existing infrastructure the planning, design, costing and procurement of the items as headrace, turbine & generator, surge device, tailrace, controls & security, transformer, transmission & distribution are required to be attended, but the costs of source of hydro-energy are excluded from the conduit hydro-energy costing analysis. (ii) The costing of a project is based on the Life Cycle Costing methodology.			

The NWA (Act 36 of 1998) and Water Services Act (Act 108 of 1997) together with the National Water Amendment Act (Act 1 of 1999) are guiding the development and operation of SA's water resources and associated water supply infrastructure. However the ownership/administrative status of water resources asset(s) dictate what permit are needed with regard to a hydropower development.

Table 8-6 gives a summary on water use permits from the DWS and DEA.

Table 8-6: Summary on water use permits from DWS and DEA

Hydropower generation options		Water use permits	Remark on regulations to be observed and legislation consulted
Repair/rehab/ upgrade	DWA, WSA, WSP, WUA or private ownership	**Not required**	Hydroelectric plants built after promulgation of the NWA (Act 36 of 1998) would not need to apply for new permit, unless an increase of the flow needed by hydropower plant is considered.
Augmentation of existing water supply infrastructure	In-line closed conduits	**Water permit not normally required if not state's asset**	Refer to: (i) All regulations guiding the WSAs, WSPs, WUAs, and WUs (former Water Boards) (ii) Water Services Act (Act 108 of 1997) (iii) Municipal System Act (Act 32 of 2000)
	Low head hydropower		
	Small scale pumped storages		
Adding hydropower plants to existing non-powered dams	High head (>100 m)	**Water permit is required subject to possible exception**	Refer to: (i) NWA (Act 36 of 1998) (ii) <u>Fixed and variable charges</u> for a plant within the DWA's infrastructure R10/kW installed per annum and R0.01/kWh respectively; (iii) Typically EIA's Basic Assessment (GN 544) required
	Medium head (30 to 100 m)		
	Low head (2 to 30 m)		
Development of "greenfield" hydropower not associated with existing infrastructure	Run-of-river	**Water permit is required subject to possible exception**	Refer to: (i) NWA (Act 36 of 1998) (ii) <u>Fixed and variable charges</u> for a plant situated upstream/downstream of the DWA's infrastructure R5.00/kW installed per annum and R0.01/kWh respectively. (iii) Full EIA as per Act 73/1989 and Act 108/1998.
	Storage regulated hydropower		
	Pumped storage Schemes (PSS)		

<u>Notes on requirements with regard to environmental issues:</u>
(i) Repair/rehabilitation/upgrade of hydropower plant: No EIA or BA (GN 544) required.
(ii) Augmentation of existing water supply infrastructure: The Social Assessment component of BA (GN 544) is recommended to compile.
(iii) Adding hydropower equipment to existing non-powered dams: No EIA required.
(iv) Development of "Greenfield" hydropower: Full EIA required.

Table 8-7 illustrates a summary on the electricity generation permits from the National Energy Regulator of SA (NERSA).

Table 8-7: Summary on electricity generation permits from NERSA

Electricity generation option	Electricity generation licence requirements	Remarks
<u>Own use</u> This applies to ability in generating electricity for own use in addition to receiving electricity from a grid if capacity less than 1 MW is installed	**No generation licence required** 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 or distributed through a relevant power systems	Refer to: • Electricity Act 2006, Schedule 2. • Electricity Regulation 2nd Amendment Bill, 2011.
<u>Islanded use</u> This applies to a system(s) completely independent from any from any distribution/ reticulation grid	**No generation licence required if for non-commercial use**	Refer to: • Electricity Act 2006, Schedule 2. • Electricity Regulation 2nd Amendment Bill, 2011.
<u>Municipal grid connection</u> Electricity generated feeds into a municipal grid	**Generation licence required per power generation station**	Refer to: • Municipal by-laws & NERSA approved tariffs • WSAs MSA S78 outcome • SLA between WSA & WSP (if applicable) 1. SLA between municipality and electricity SP (if appl.)
<u>Eskom grid Connection</u> Electricity generated is fed directly into the Eskom grid	**Generation licence required per power generation station**	Refer to: 2. Renewable Energy IPP Procurement Programme (REIPPP)

8.3.6 FEASIBILITY PHASE ECONOMIC ANALYSIS

A feasibility phase economic analysis should be done with the additional information gathered during this phase. A life-cycle approach should be used. At this stage of the project, estimated values and functions will still be used for both costs and income, but all available information should be included, to render the analysis as accurate as possible. If future development will decrease the hydropower potential, this should be noted and the economic feasibility analysis should be done with an applicable design life for current circumstances.

It is proposed that at least the net present value (NPV) and internal rate of return (IRR) should be determined at this stage using the formulas as indicated in the following paragraphs. The payback period may also be calculated, preferably considering inflation. However, it should not be used as the deciding factor in project selection. It should only be used as a tool for initial screening to supplement other methods, as it does not give sufficient information to stand alone as an evaluation tool (ESHA, 2004; Blank and Tarquin, 2004).

8.3.6.1 Net present value (NPV)

According to SANRAL (2013), this method is used to:

- ‘select the best alternative among the mutually exclusive projects; and
- to help establish an overall economic viability of independent projects.’

The net present value (NPV) of a project is determined by subtracting the present worth of investment cost from all future benefits. A positive NPV would indicate an economically feasible project, with a higher value more advantageous than a lower value. The formula used for this method is (**Equation 8-8**) (from SANRAL, 2013):

$$'NPV=PW(M_0+U_0)-PW(M_A+U_A)+PW(CS_A)-C_A \qquad \textbf{Equation 8-8}$$

where:

NPV = net present value of benefits

$PW(M_0+U_0)$ = the present worth of facility maintenance costs and user costs of the null alternative

$PW(M_A + U_A)$ = the present worth of facility maintenance costs and user costs of a proposed alternative

$PW(CS_A)$ = consumer surplus gained through additional usage induced by the proposed alternative.

C_A = investment (capital) cost that is required to implement the alternative *A*’

8.3.6.2 Internal rate of return (IRR)

This method can also be used to find the most viable between independent projects. The distinguishing feature of this method is that it shows the discount rate at which the project would break even. Future benefits and costs are calculated in the same way as for the NPV or B/C methods and discounted to the present using different rates until a rate is found where the returns and costs are equal. This rate is the internal rate of return. The higher the IRR, the more advantageous the project will be. The formula used for this method is (**Equation 8-9**, from SANRAL, 2013):

$$'IRR = r \text{ When } PW(M_0+U_0)-PW(M_A+U_A)+PW(CS_A) = C_A \qquad \textbf{Equation 8-9}$$

where:

IRR = internal rate of return

r = rate at which the left-hand and right-hand sides of the equation are equal, resulting in an NPV of zero.

$PW(M_0+U_0)$ = the present worth of facility maintenance costs and user costs of the null alternative

$PW(M_A + U_A)$ = the present worth of facility maintenance costs and user costs of a proposed alternative

$PW(CS_A)$ = consumer surplus gained through additional usage induced by the proposed alternative.

C_A = investment (capital) cost that is required to implement the alternative’

8.3.6.3 Payback period

The payback method is used to calculate the time required for the initial investment to be offset by the resulting revenue of the scheme. The required time is called the payback, recovery or break-even period. The formula used for the calculation is (ESHA, 2004):

$$\text{Payback period} = \frac{\text{investment cost}}{\text{net annual revenue}} \qquad \textbf{Equation 8-10}$$

Equation 8-10 does not incorporate the time value of money and only considers the life of the project until the payback point has been reached. However, other literature suggests that inflation may be included and that the payback period would then be the time taken to equate initial capital outlay and the present value of net annual cash flow (Blank and Tarquin, 2004).

Both sources agree that the payback period should not be used as the deciding factor in project selection. It should only be used as a tool for initial screening to supplement other methods, as it does not give sufficient information to stand alone as an evaluation tool (ESHA, 2004; Blank and Tarquin, 2004).

8.3.7 OTHER REASONS FOR HYDROPOWER 13

As mentioned in the pre-feasibility stage, in some cases there might be reasons other than economic feasibility to justify the use of conduit hydropower. These reasons include:

- Islanded systems that are far from the national electricity grid.
- Locations that need local lighting, security and telemetry.
- Areas where cable theft may be a problem.
- Areas that need additional peak-time electricity.
- Political reasons for developing greener renewable energy sources.

If another reason for considering hydropower exists, the economic feasibility should not be the deciding factor for continuing the investigation.

8.3.8 OUTCOME OF PHASE 3

The function of Phase 3 is to determine feasibility of a proposed conduit hydropower plant, with as much detail and information as is available. This phase does not contain a detailed design. It does, however, include an initial estimation of the design flow and head, using measured data. The LHHD Tool also includes a graph to facilitate the initial selection of an appropriate turbine and a more detailed economic analysis than Phase 2. If this phase indicates feasibility, it is recommended that a consultant is appointed to implement a detail design.

9 CASE STUDY: ZEEKOEGAT WWTW LOW HEAD HYDOPOWER PLANT

9.1 INTRODUCTION

Various sites in Tshwane were investigated for their hydropower potential and many of the sites showed promise. The outlet of the Zeekoegat waste water treatment works (WWTW) will be discussed as a case study.

The Zeekoegat WWTW was chosen even though it did not present the highest hydropower potential and economic feasibility in the initial analyses, but is was envisaged to install a new type of turbine that could easily be retrofitted to the existing infrastructure at this site. The following paragraphs will discuss all the details related to the pilot plant installation at this site.

9.2 LOCATION

The Zeekoegat WWTW is situated in the north-east of Tshwane and it serves the eastern side of the Tshwane metropolitan area. The full plant layout can be seen in **Figure 9-1**. The water is then channelled underneath the road to the Roodeplaat Dam, as shown in **Figure 9-2** below.

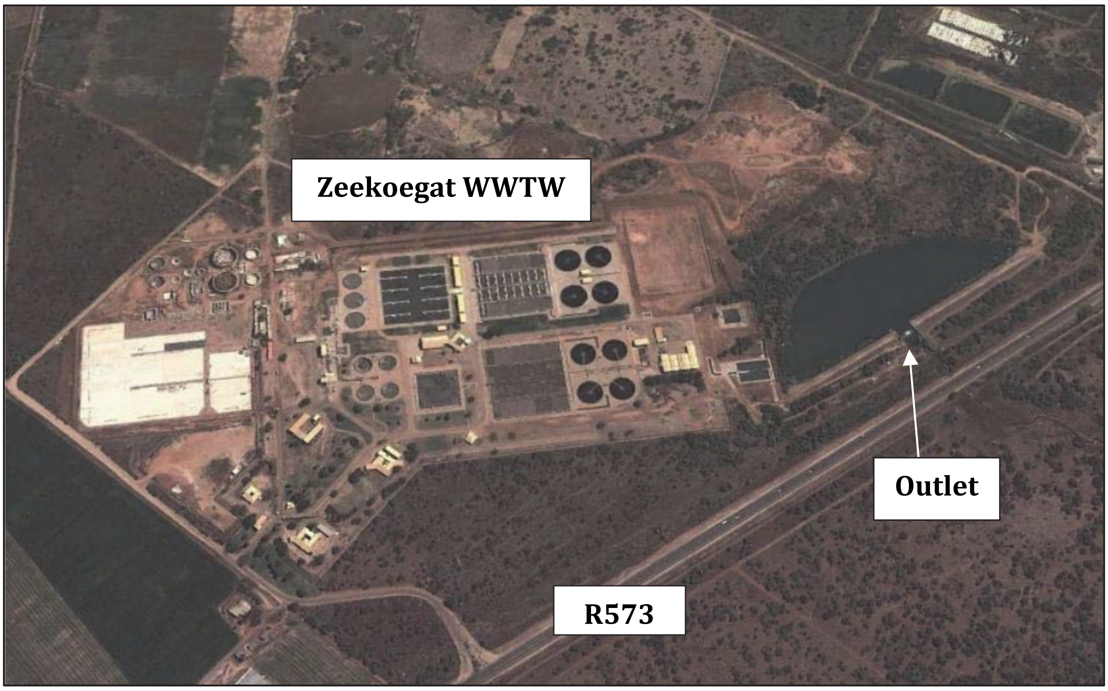


Figure 9-1: Zeekoegat WWTW layout

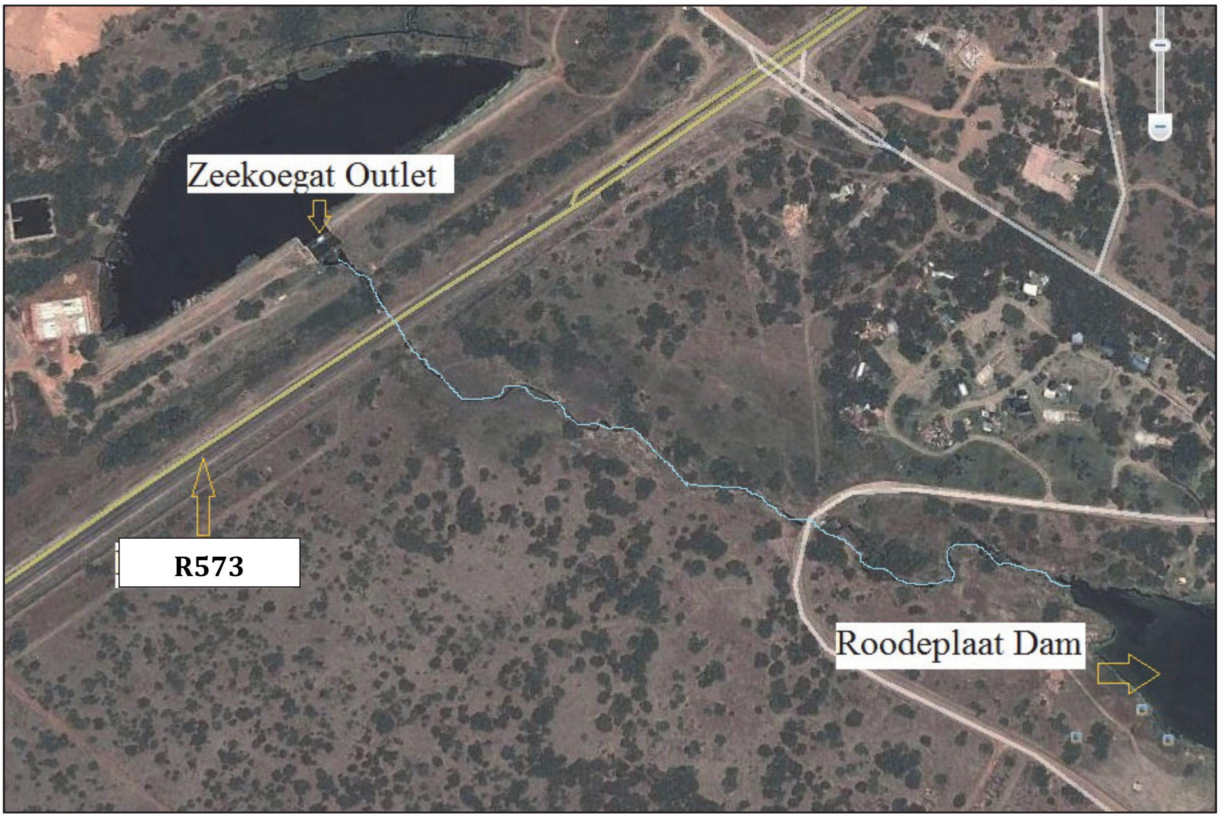


Figure 9-2: Zeekoegat WWTW connection to Roodeplaat Dam

9.3 DESCRIPTION OF THE OUTLET WORKS

The outlet structure at Zeekoegat WWTW is a dam wall, as shown in **Figure 9-3**. This structure was built to retain some water in the small dam at the plant, to make it a safe haven for birds to nest.

The advantage of this outlet dam is that it creates a further buffer between the inflow and outflow and thus results in an almost constant outflow.

Figure 9-3: Zeekoegat WWTW outlet structure

Figure 9-4 shows a three dimensional representation of the spillway.

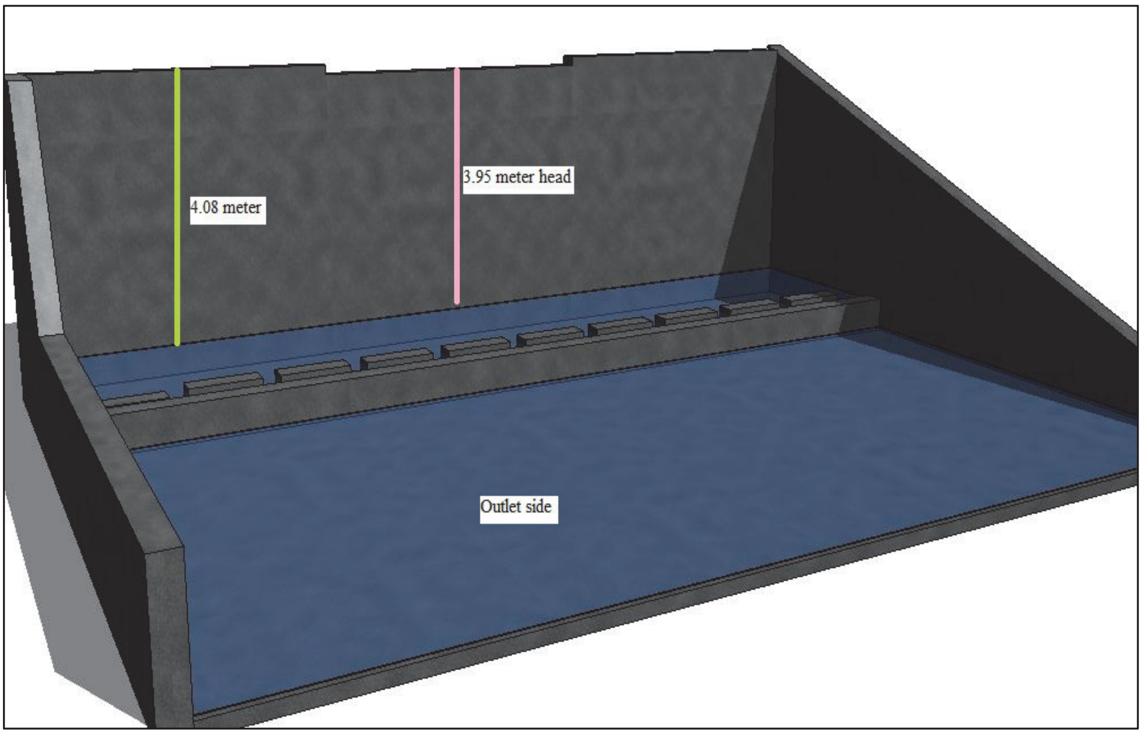


Figure 9-4: Zeekoegat WWTW outlet drawing

Detail drawings of the spillway were obtained from the City of Tshwane Metropolitan Municipality. They are shown in **Figure 9-5** to **Figure 9-9**.

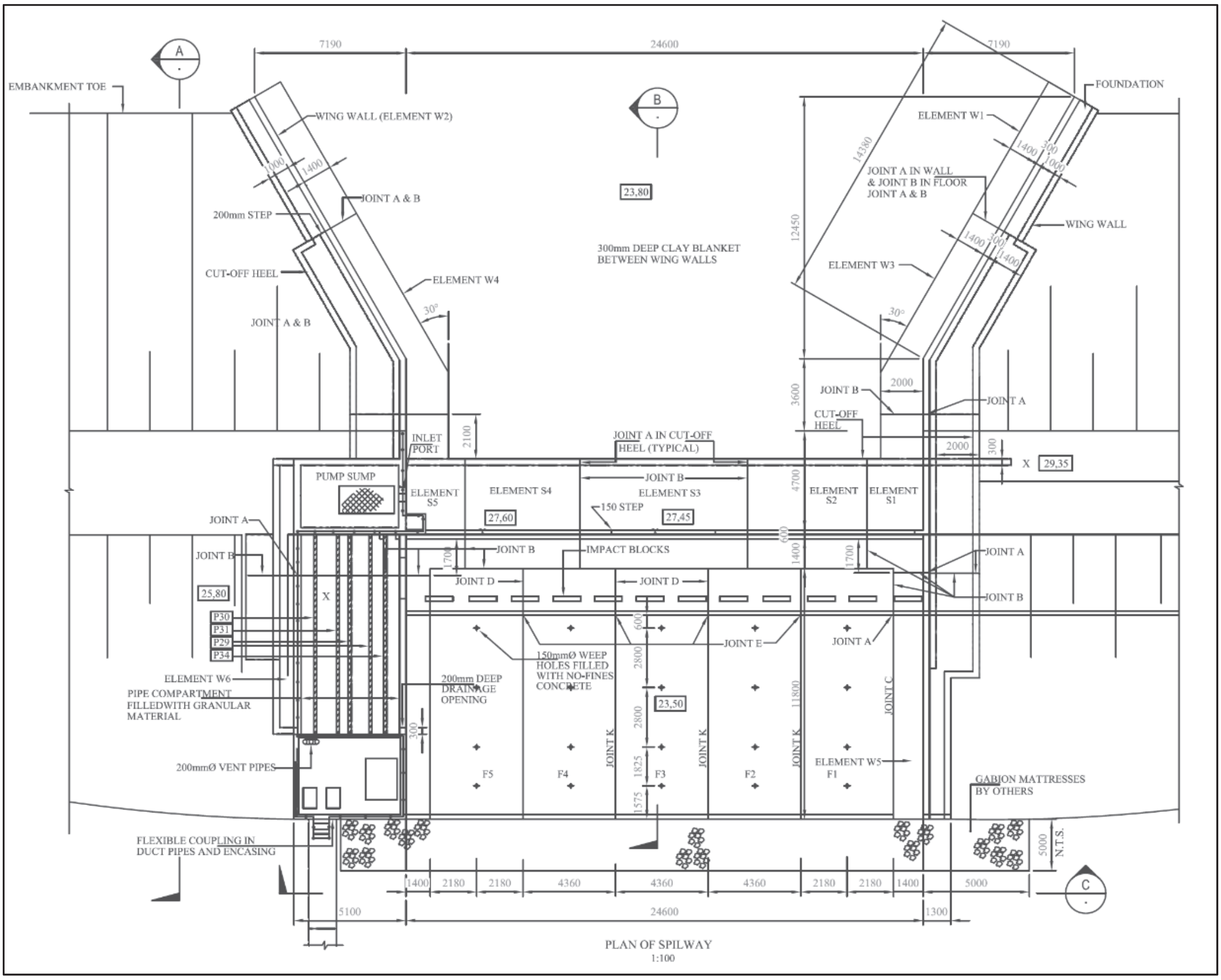


Figure 9-5: Zeekoegat WWTW outlet plan view

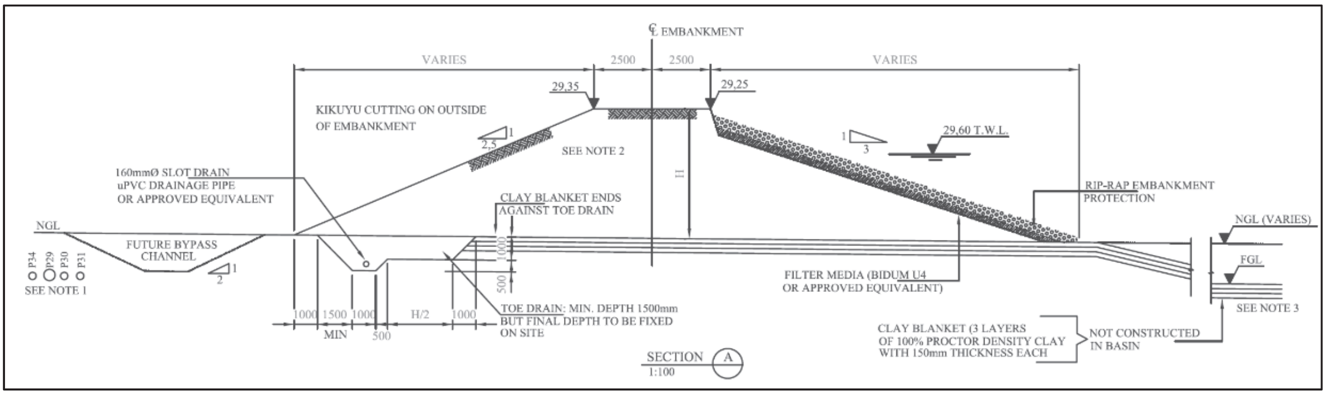


Figure 9-6: Zeekoegat WWTW outlet Section A

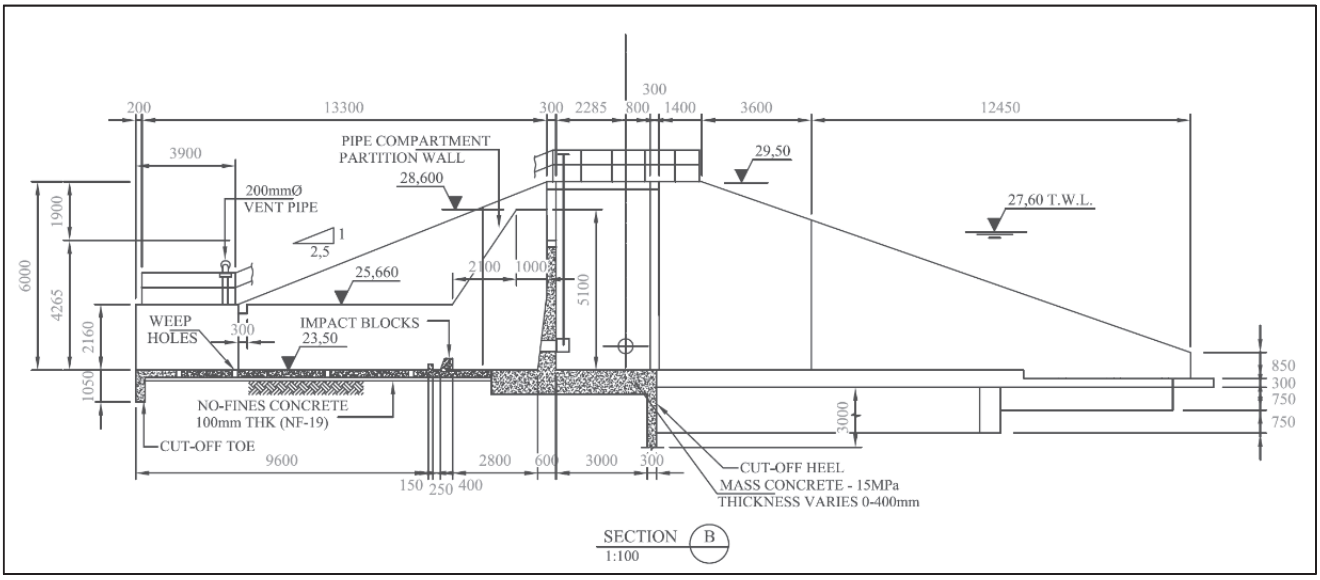


Figure 9-7: Zeekoegat WWTW outlet Section B

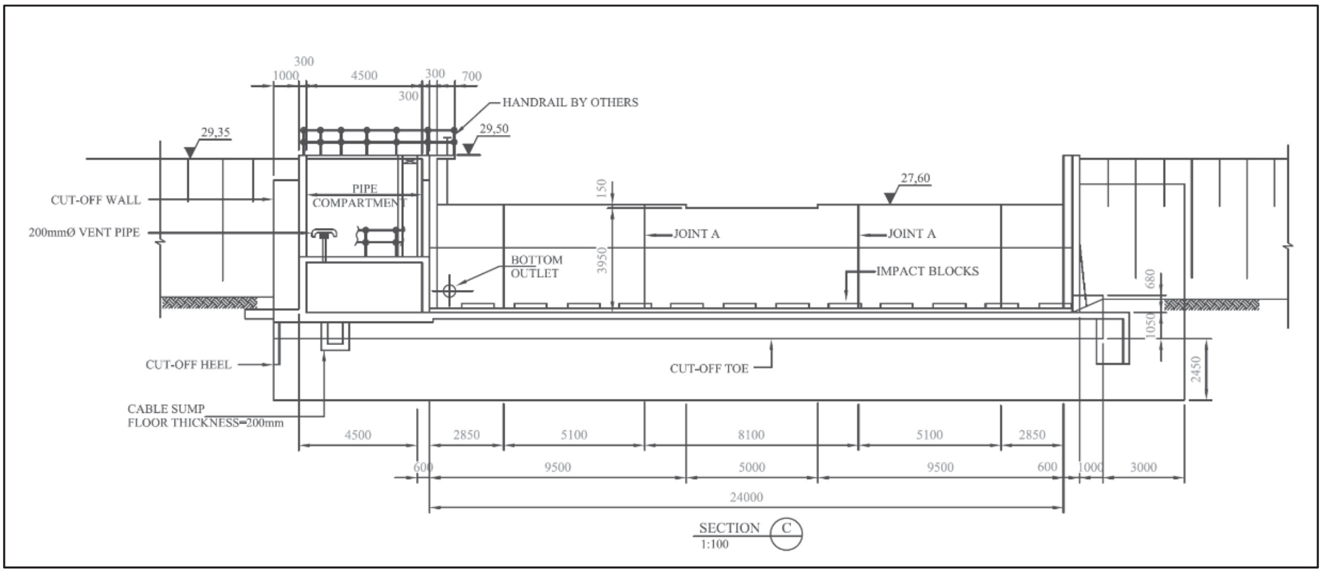


Figure 9-8: Zeekoegat WWTW outlet Section C

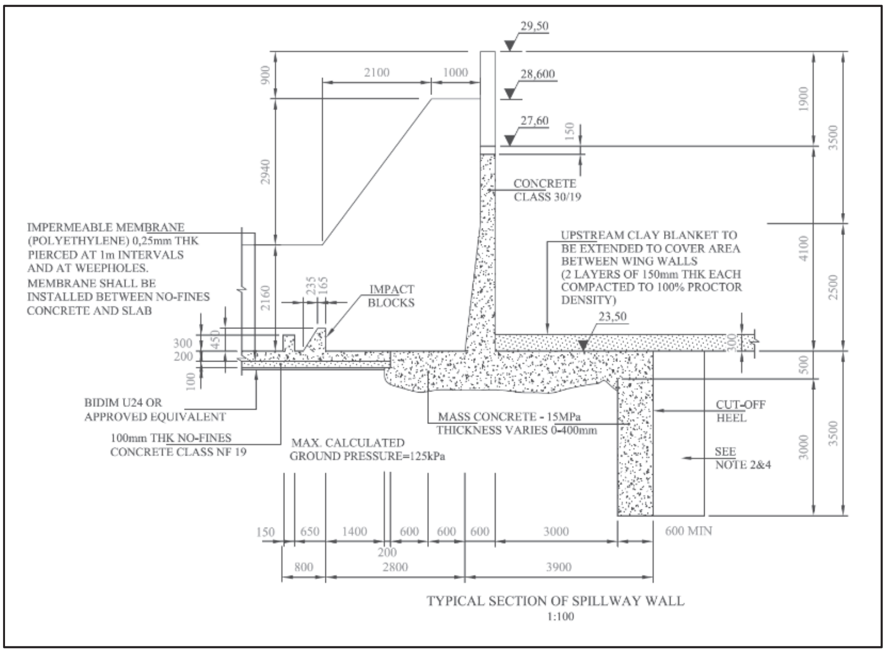
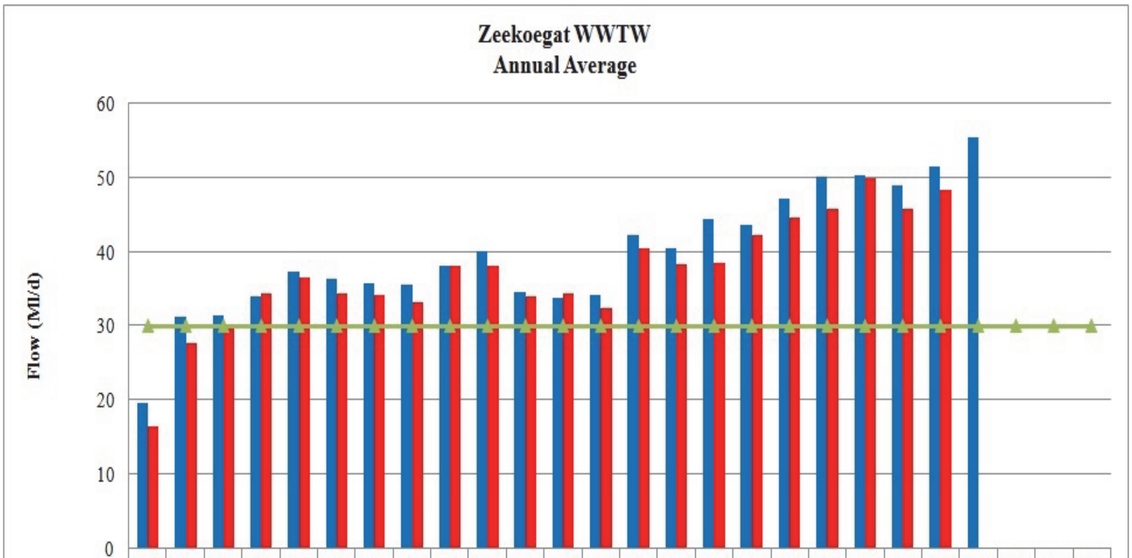


Figure 9-9: Zeekoegat WWTW outlet section of spillway wall

9.4 FLOW RATES

9.4.1 ANNUAL FLOW RATES

Flow data is collected on a daily basis by the plant operators to ensure that the plant runs according to design. This data was obtained and analysed to get an indication of the average flow, as well as the average dry weather flow. This was necessary because of rain water infiltration into the sewage system, which increases the flow significantly at times. The annual yearly dry weather flow rate for Zeekoegat shows a rise, but it can also be seen that the waste water works needs a capacity increase. Zeekoegat currently has a capacity of 30 Ml/day and it has a shortage of about another 30 Ml/day. The annual flow rate for Zeekoegat WWTW can be seen in **Figure 9-10**.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Average	19.6	31.2	31.5	34	37.3	36.4	35.8	35.6	38.2	40.2	34.7	33.9	34.3	42.2	40.6	44.4	43.6	47.3	50.2	50.3	49	51.5	55.5	0	0	0
ADDWF	16.6	27.8	30	34.4	36.6	34.4	34.2	33.2	38.2	38.1	34	34.4	32.5	40.6	38.3	38.6	42.3	44.6	45.9	50	45.8	48.4	0	0	0	0
Capacity	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

Figure 9-10: Zeekoegat WWTW annual average flow rate

9.4.2 MONTHLY FLOW RATES

The average monthly flow rate was also considered to appreciate the fluctuation in flow throughout the year. **Figure 9-11** shows the average flow rate for each month during the 2012/13 season and also the capacity of the waste water works.

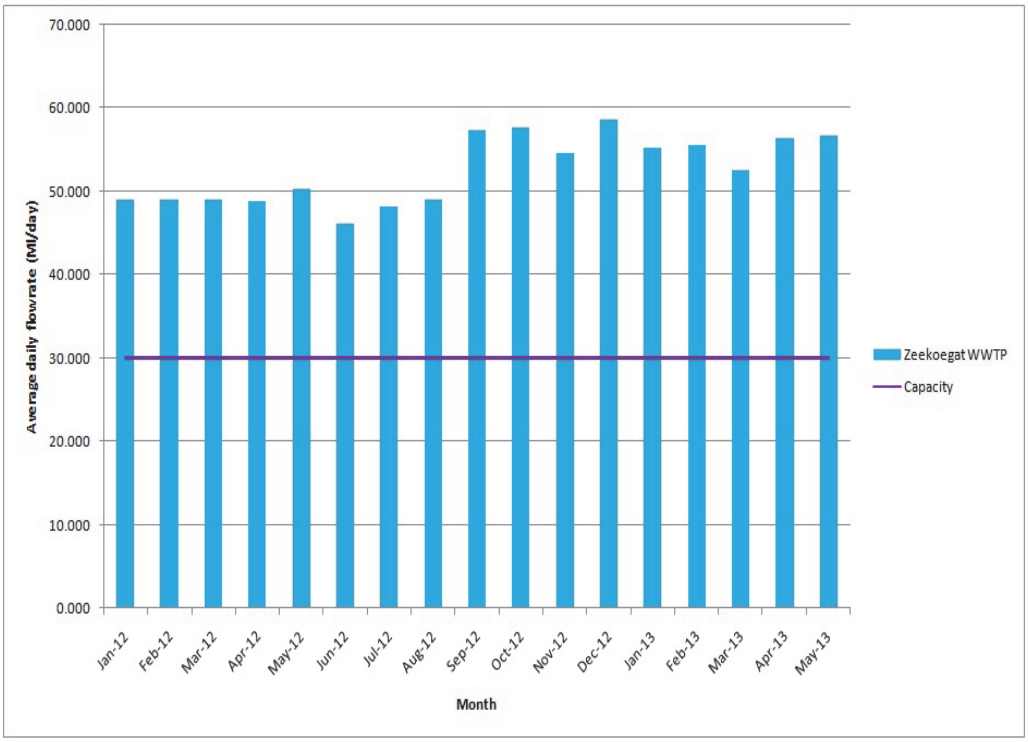


Figure 9-11: Zeekoegat WWTW monthly flow rate (Jan 2012-May 2013)

From **Figure 9-11** it is clear that that Zeekoegat WWTW operates above its capacity flow, thus making the average flow rate higher than the capacity flow rate; this will be incorporated into the analysis. This gives an even better understanding of the fluctuation in the flow rate over a year. The discharge values could now be used to calculate the estimated power the turbine can produce. The flow values that were used are: the lowest monthly flow the plant has had; the total average flow over the years; and the capacity flow. This will ensure that the turbine will stay economical even when at its lowest discharge.

9.4.3 DAILY FLOW RATES

The daily flow rate between May 2013 and April 2014 is shown in **Figure 9-12**. From this graph it is clear that a flow of at least 40 Ml/day was maintained for 98% of the year. The minimum flow in this year was 11 Ml/day, the Ml/day maximum was 136 Ml/day and the average was 63 Ml/day, which is about twice the actual capacity of the plant.

The peak values are also significant as this is the flow rate which will flow over the dam spillway and it needs to be ensured that the proposed hydropower plant is correctly installed above the water level during flood events.

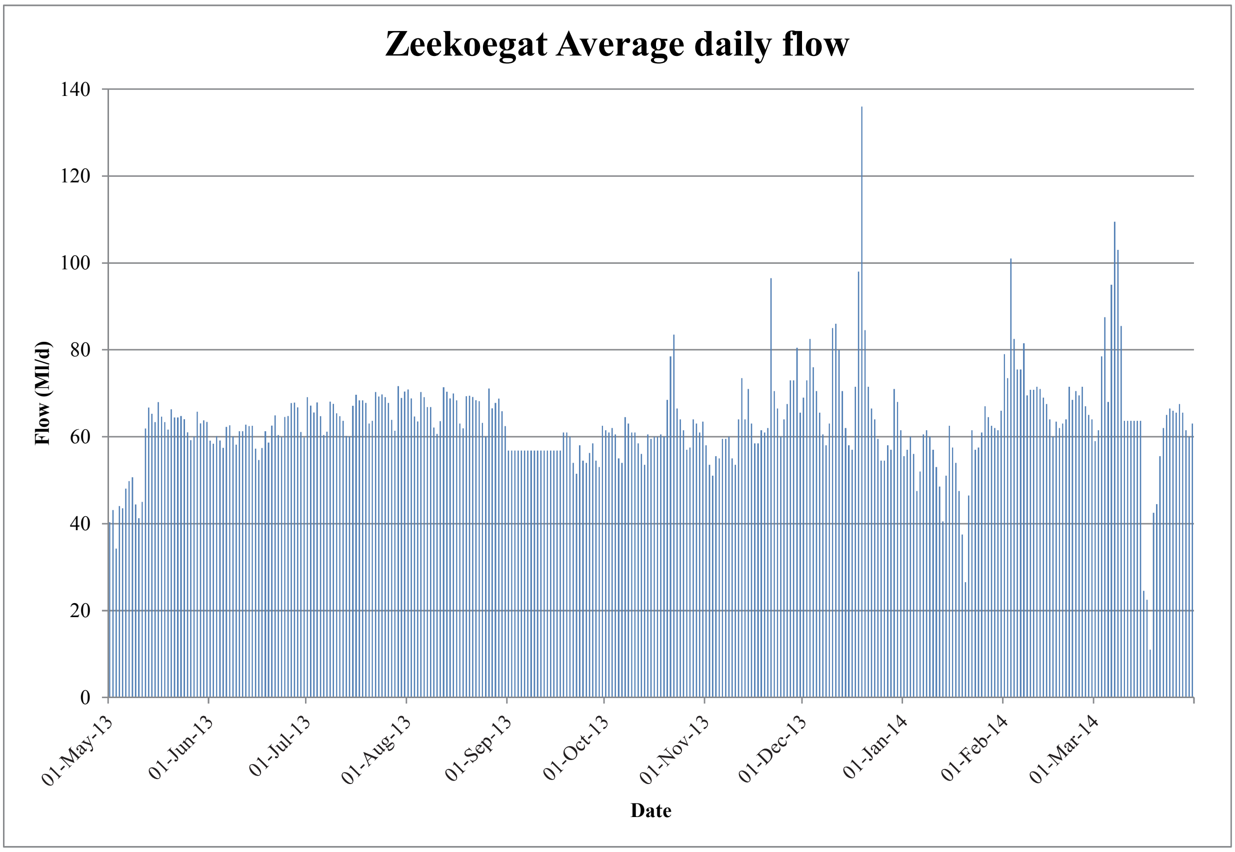


Figure 9-12: Zeekoegat WWTW daily flow rate

9.5 DATA LOGGING AT ZEEKOEGAT

9.5.1 EQUIPMENT

A water level logger was installed to water level fluctuations at the spillway. The following paragraphs provide a description of the technology used.

9.5.1.1 Hobo U30-GSM logger

The HOBO U30-GSM, see **Figure 9-13**, is a web-based, 15-channel data logging system for a broad range of energy and data monitoring applications. This system was installed in the turbine room and connected to two pressure transducers on the penstock.

Figure 9-13: Hobo U30 Data logger

9.5.1.2 Hobo U20 water level logger

The HOBO Water Level data loggers, see **Figure 9-14**, features high accuracy and are easy to use. This data logger was ideal for the recording of the water levels and temperatures just upstream of the weir. It is made of stainless steel and was lowered up to a position where the full variation in water surface level can be recorded.

Figure 9-14: Water level logger

9.5.2 RECORDED DATA

The outflow from the dam is measured at the sharp crested weir. The project team installed a water level sensor 1.0228 m below the middle weir level of the dam and measured the level of the flow over the dam for a period of one month (from 4 June to 4 July 2014) at two-minute intervals. More than 21000 data point were collected. A graph summarising the data is shown in **Figure 9-15**.

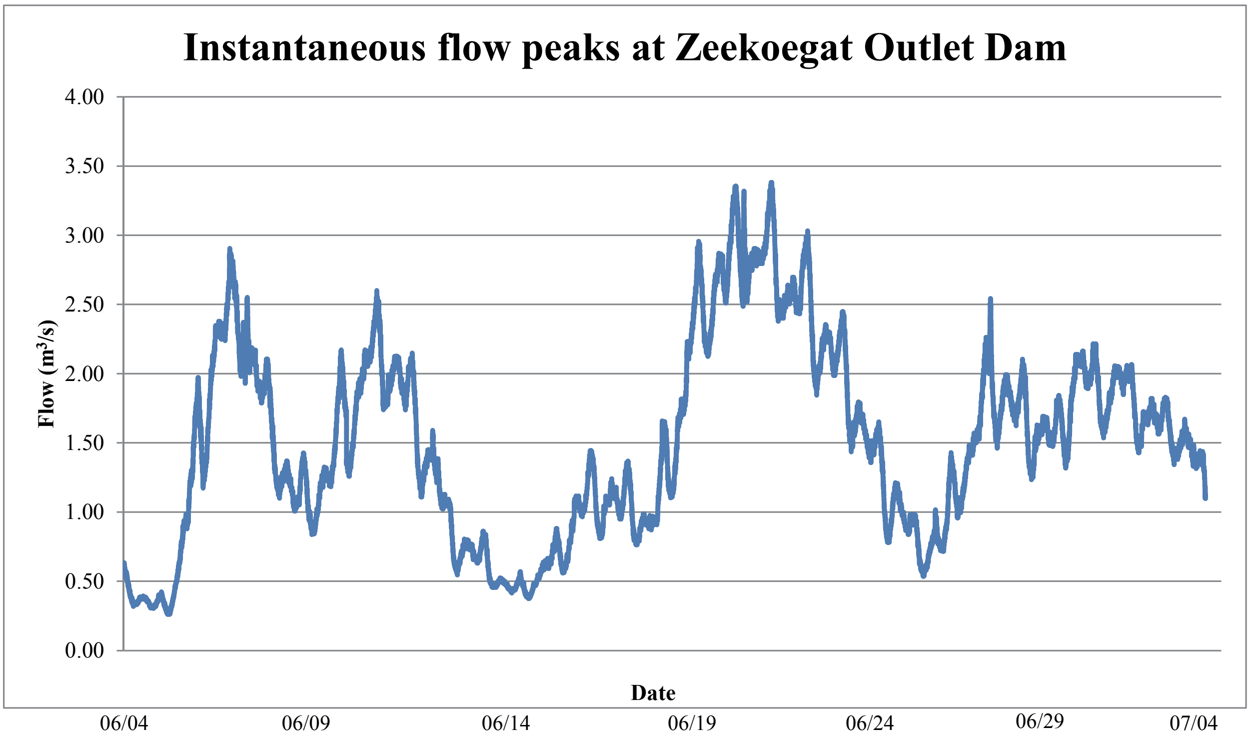


Figure 9-15: Instantaneous peak flow

A statistical analysis was done on the data and the summary is provided in **Table 9-1**.

Table 9-1: Zeekoegat instantaneous flow statistical analysis

Description of flow rate	Flow rate (m^3/s)
Lowest recorded	0.262
Highest recorded	3.382
Average	1.512
98 percentile	0.431
Standard deviation	0.698

The maximum capacity of the weir was determined as 107 m^3/s.

9.6 HYDROPOWER POTENTIAL ASSESSMENT

The power, in kilo-watts, was calculated using the minimum monthly flow that ever occurred, then the capacity flow rate of the plant now and lastly the average flow during 2013/2014 (**Table 9-2**). The potential power generation was calculated for different estimated efficiencies with an assumed usable design head of 3.5 m.

Table 9-2: Zeekoegat second order hydropower potential analysis (2013-2014)

Zeekoegat WWTW						
Description of flow rate	Flow rate (Ml/day)	Avg flow rate (m^3/s)	Efficiency (%)			
			60	70	80	
Lowest recorded	11	0.127	2.6	3.1	3.5	Power (kW)
Plant capacity	30	0.347	7.2	8.3	9.5	
Average	63	0.729	15.0	17.5	20.0	
98 percentile	40	0.463	9.5	11.1	12.7	

Two turbine options were considered. The first was utilising a siphon type turbine with Kaplan runner to suck the water over the spillway. The second was an axial flow propeller turbine utilising the bottom outlet.

9.7 TURBINE OPTIONS

9.7.1 MAVEL TM3 MICRO TURBINE

9.7.1.1 Turbine description

The TM3 Siphon turbine consists of four fixed blades connected directly to an asynchronous motor. The asynchronous motor serves as a pump to prime the siphon during start-up and an electromagnetic valve is used to stop the turbine. The turbine is connected to a draft tube that facilitates water flow from the turbine to the downstream outlet point. **Figure 9-16** and **Figure 9-17** illustrate the assembly of the siphon turbine and draft tube.

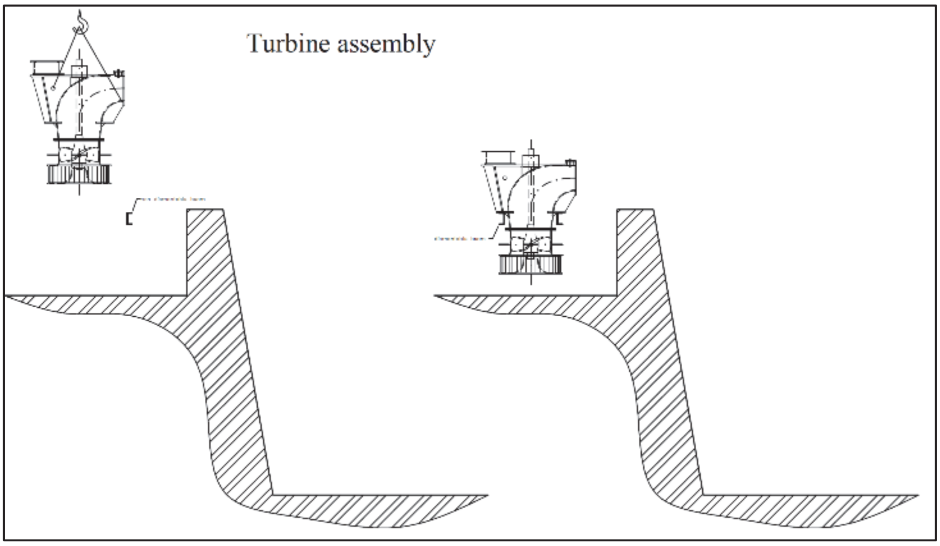


Figure 9-16: Mavel TM3 turbine assembly

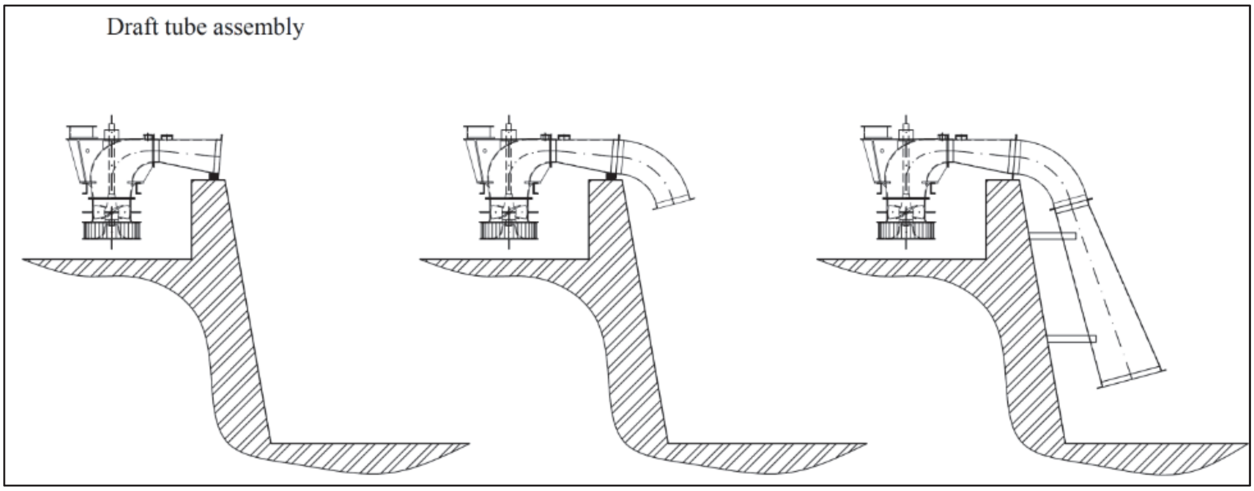


Figure 9-17: Mavel TM3 draft tube assembly

A Kaplan turbine runner (**Figure 9-18**) is used as it provides easy operation with minimum maintenance cost. All the components of the turbine are shown in **Figure 9-19**.

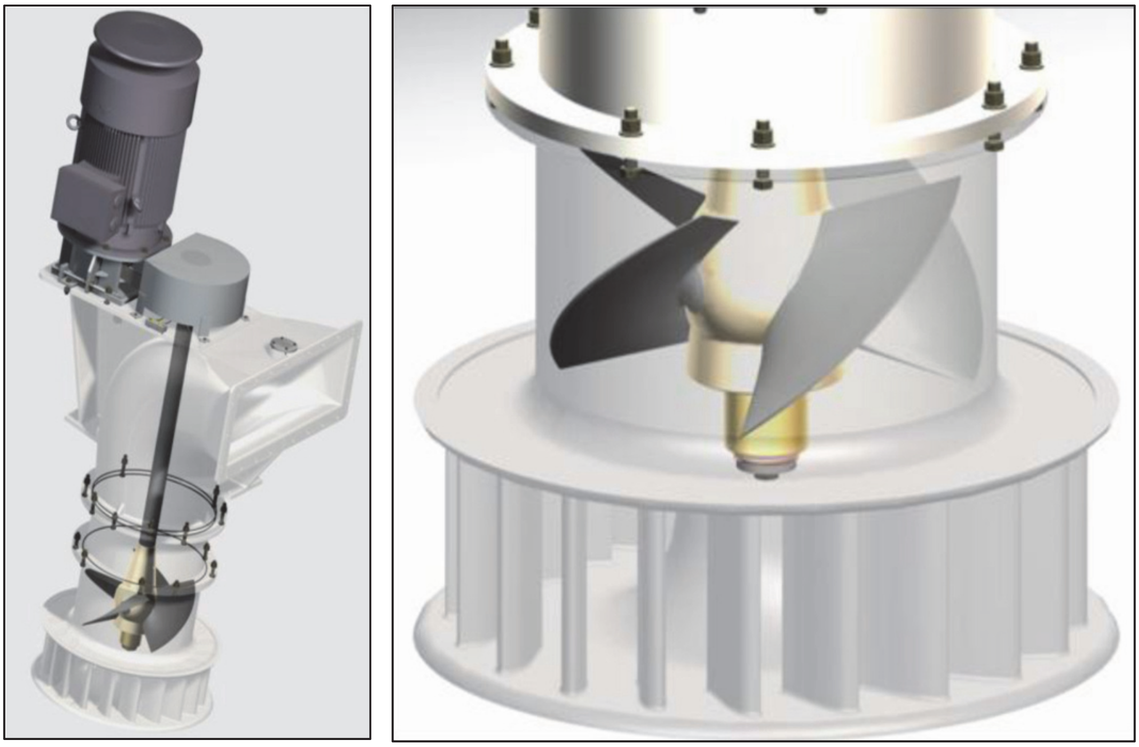


Figure 9-18: Mavel TM3 runner

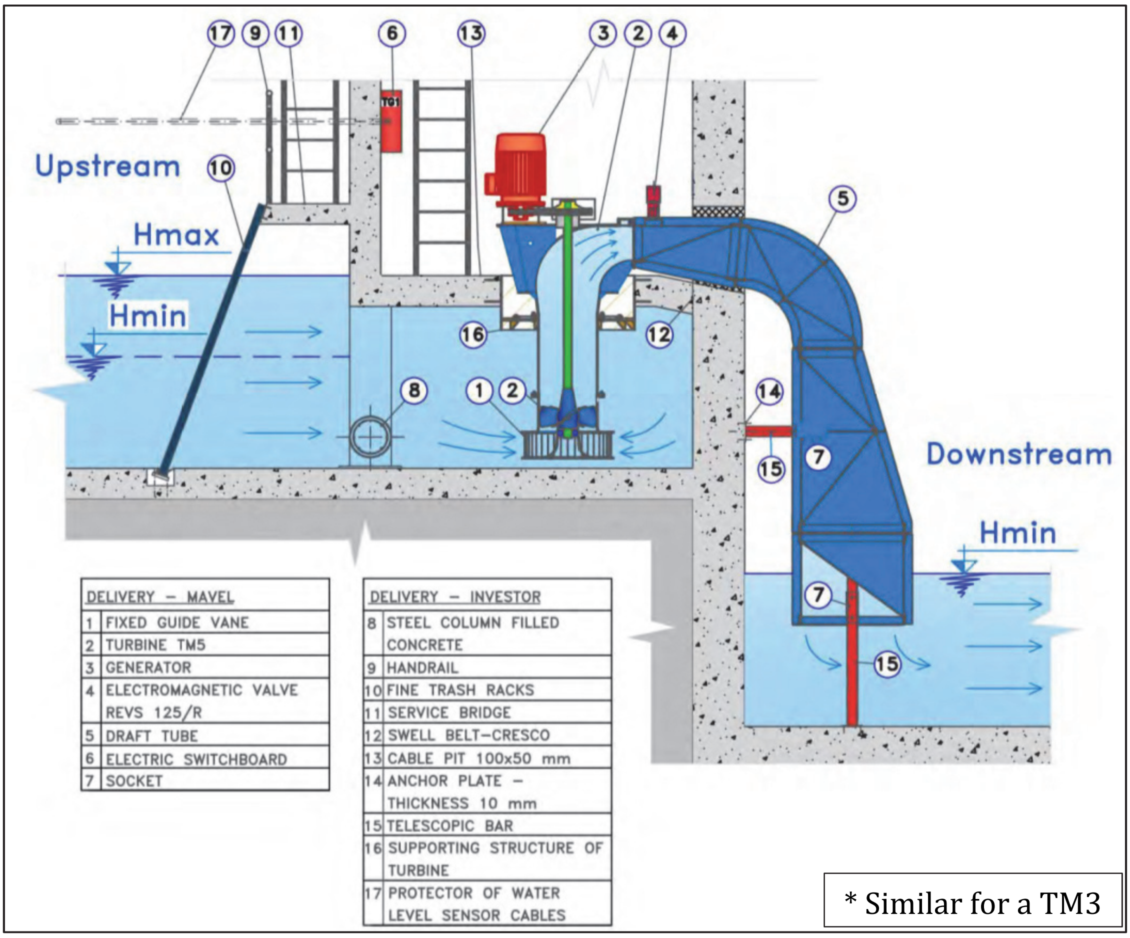


Figure 9-19: Mavel TM3 turbine descriptive diagram

9.7.1.2 Turbine selection curve

The selection curve for the TM3 turbine is shown in **Figure 9-20**. (The angles on the curve indicate the fixed angles to which the blades could be set.)

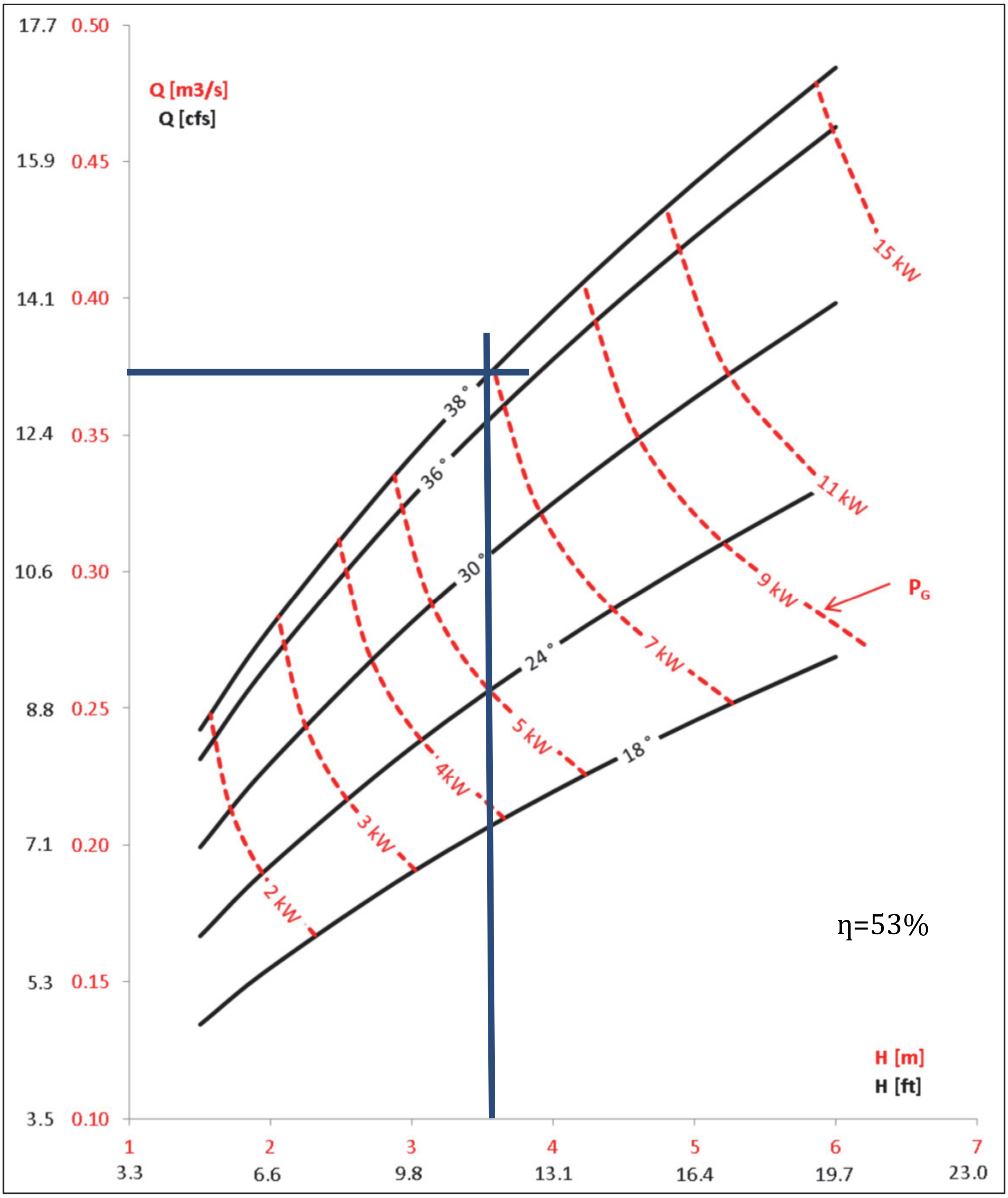


Figure 9-20: Mavel TM3 turbine selection diagram

9.7.1.3 Turbine-generator parameters

The turbine and generator parameters are described in **Table 9-3**.

Table 9-3: Mavel TM3 parameters

Turbine type	TM3
Number of units	1
Net head	3.6 m
Discharge per unit	0.37 m^3/s
Power output per unit	6.9 kW
Runner diameter	300 mm
Turbine speed	780 rpm
Type of generator	Asynchronous
Generator speed	780 rpm
Generator voltage	3 phase 400 V
Generator frequency	50 Hz

9.7.2 TOSHIBA HYDRO E-KIDS TURBINE

9.7.2.1 Turbine description

Toshiba's Micro Hydro turbines and generators are pre-set to ensure easy installation on a simple foundation (**Figure 9-21**). The turbines can be installed in series or parallel to facilitate flexibility of the system, as shown in **Figure 9-22**.

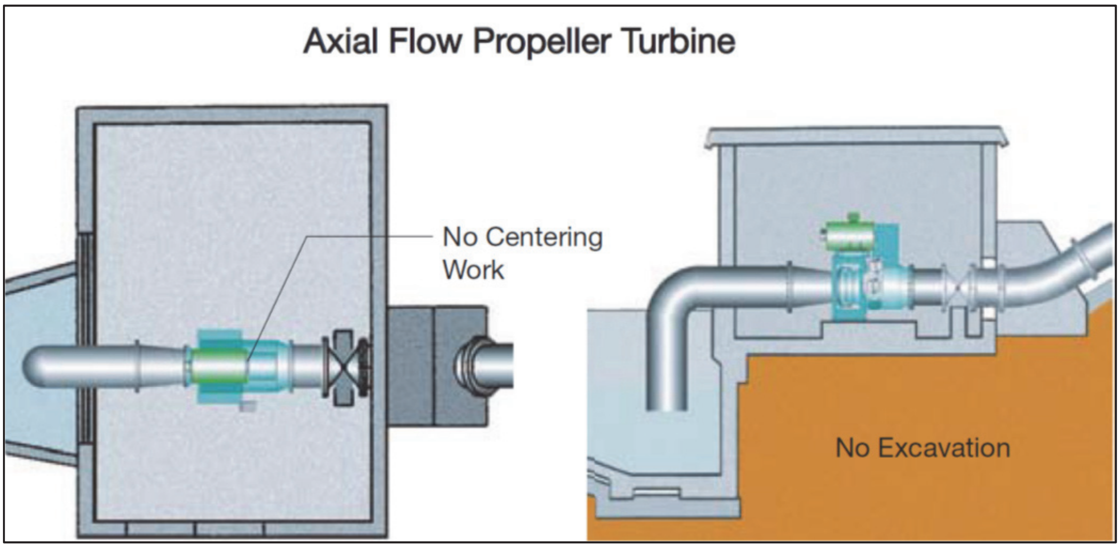
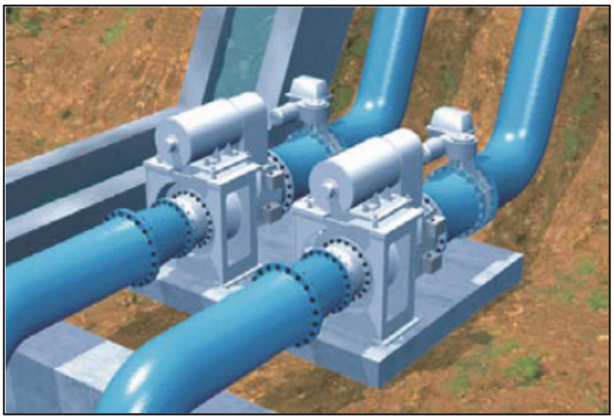


Figure 9-21: Toshiba Micro Hydro set-up



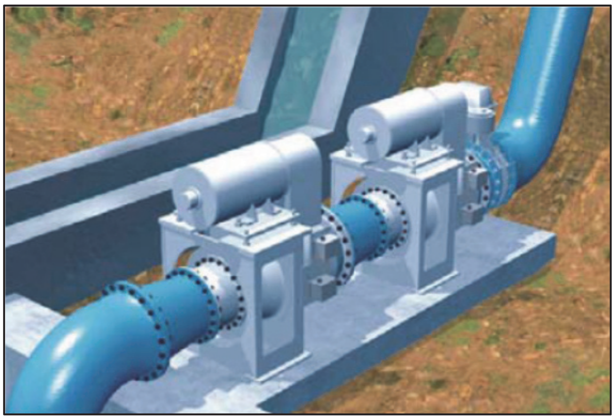


Figure 9-22: Toshiba Micro Hydro parallel and series configurations

The turbine is designed so that water runs past the shaft before reaching the runner. This will have some associated losses, but will also facilitate increased velocity at the runner. All the components of the turbine are shown in **Figure 9-23**.

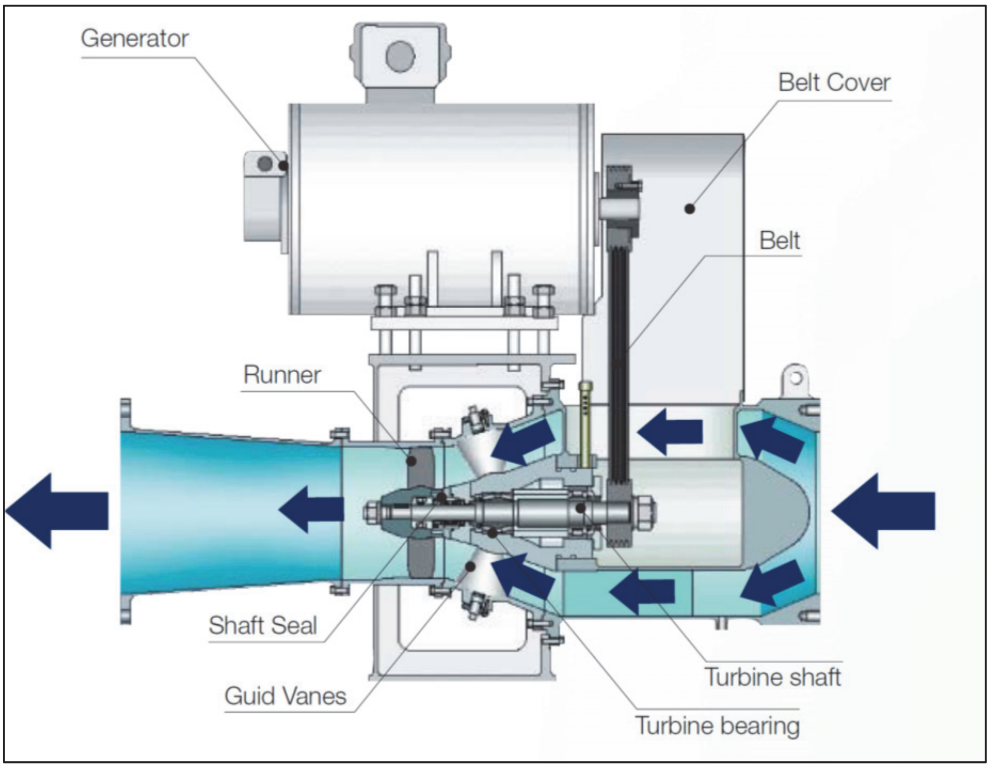


Figure 9-23: Toshiba Micro Hydro turbine descriptive diagram

9.7.2.2 Turbine selection curve

The selection curve for the Toshiba Micro Hydro series is shown in **Figure 9-24**. The M-type turbine is applicable for Zeekoegat site.

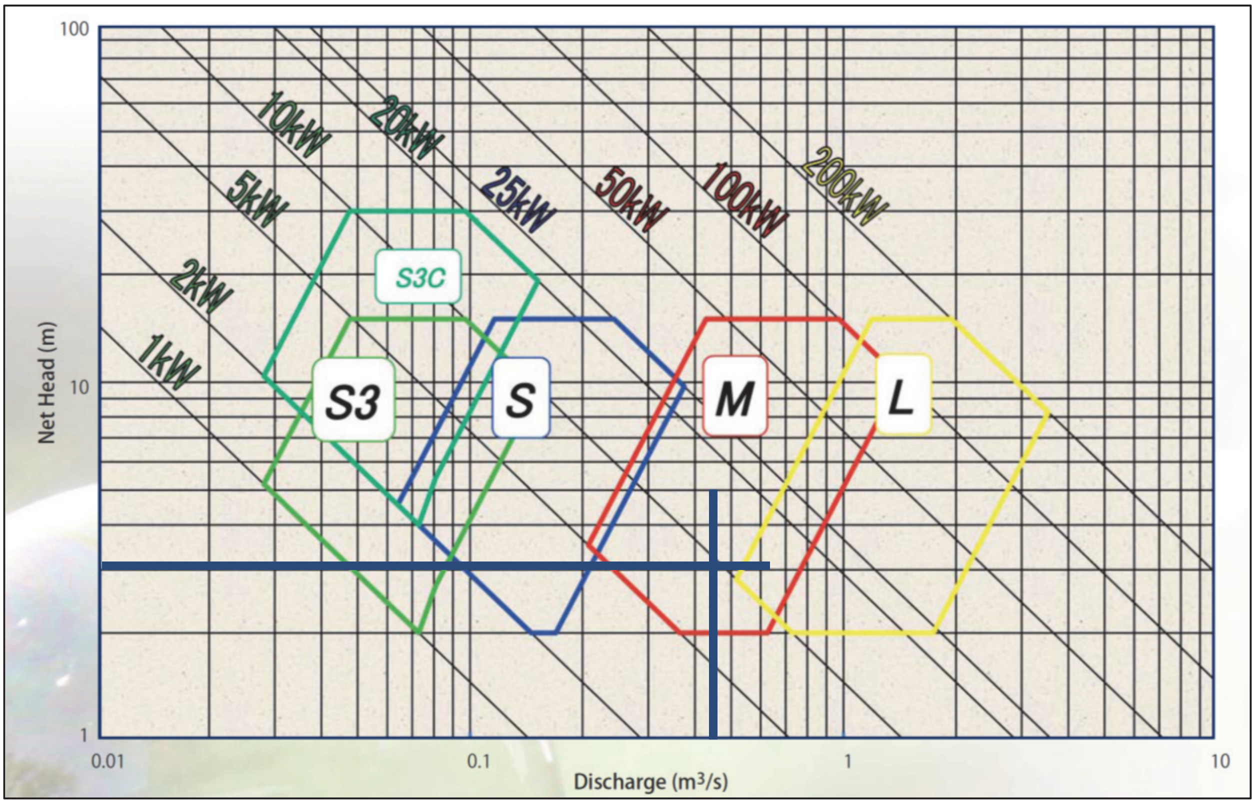


Figure 9-24: Toshiba Micro Hydro turbine selection diagram

9.7.2.3 Turbine-generator parameters

The turbine and generator parameters are described in **Table 9-4.**

Table 9-4: Toshiba turbine parameters

Turbine type	Micro Hydro (M-type)
Number of units	1
Net head	3.0 m
Discharge per unit	0.46 m^3/s
Power output per unit	9.5 kW
Type of generator	Asynchronous

9.7.3 TURBINE SELECTION

Based on the limited budget available it was decided to construct locally a Kaplan type turbine for Zeekoegat. It was further decided to test two types of configurations. The bottom outlet of the dam was utilized as one connection point. The second configuration was to construct a siphon pipe section over the wall.

9.8 TURBINE RETROFIT DESIGN

9.8.1 POSSIBLE TURBINE LOCATIONS

Both the Toshiba M-type turbine and the Mavel TM turbine could easily be retrofitted to the outlet spillway of the waste water treatment works. **Figure 9-25** shows a possible location for a turbine installed at bottom outlet of the spillway.

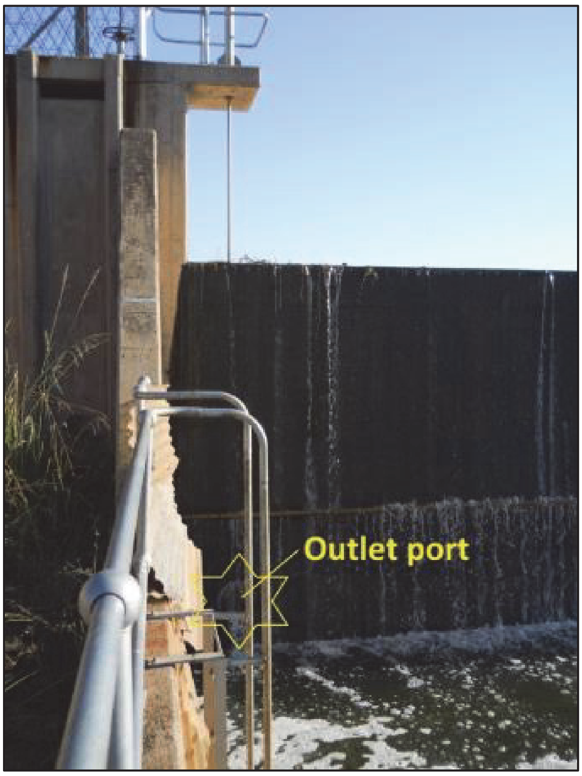


Figure 9-25: Turbine position

9.8.2 DAM SAFETY EVALUATION

As this is a classified (Category II) registered dam, any modifications made to the spillway required approval from DWS. The spillway capacity was reassessed and the impact of the proposed installation determined.

9.8.2.1 Introduction

A number of methods exist to determine extreme flooding events that are especially used for dam safety analysis. These methods are documented in SANCOLD (1991) and include:

- The **Regional Maximum Flood** (RMF) determination method was developed by Kovács by using the Francou-Rodier relationship. This relationship calculates the maximum expected flood by considering the area of the catchment and an empirically calculated K value that is region specific.

- The **Safety Evaluation Discharge** (SED) of a dam is used to perform an initial screening for dam spillway adequacy under extreme flood conditions. The SED is determined by scaling the Kovács region up or down when determining the RMF. The scaling of the RMF depends on the hazard potential rating of the dam, as well as the size class. However, for smaller dams many practitioners determine it as a proportion of the RMF or PMF, with the proportions dependent on hazard potential and size class of the dam.

- The **Recommended Design Discharge** (RDD) is the level pool peak discharge of a dam, with return period dependent on the size class and hazard potential of a dam. The spillway of the dam must be designed to accommodate the RDD without damage.

- The **Recommended Design Flood** (RDF) refers to a flood hydrograph (or hydrographs) that has a certain return period, depending on the hazard potential and size class of the dam. This flood must, after routing, be accommodated by the spillway of the dam without any damage.

- The **Probable Maximum Flood** (PMF) is a flood event with a close to zero exceedence probability. The PMF may be calculated using the Probable Maximum Precipitation (PMP) and applying this value to a deterministic technique, like the Unit Hydrograph Method or the Alternative Rational Method. It should be noted that for the PMF, factor $C_1=C_s+C_{pmax}+C_{vmax}$; $C_2=1$ and $F_t=1$.

- The **Safety Evaluation Flood** (SEF) is defined as the flood hydrograph that, after routing, may bring the dam to the point of failure but does not cause the dam to fail. The RMF as adjusted for the SED is one method of determining the SEF. However, for medium and large dams with high hazard potential and large dams with significant hazard potential, the PMF is used as the incoming hydrograph for the SEF. For smaller dams many practitioners determine it as a proportion of the RMF or PMF, with the proportions dependent on hazard potential and size class of the dam.

9.8.2.2 Defining catchment and catchment characteristics

The catchment area was determined using 1:50 000 Ortho Maps and Contours of the area upstream of the Zeekoegat outlet dam, as is shown in **Figure 9-26**.

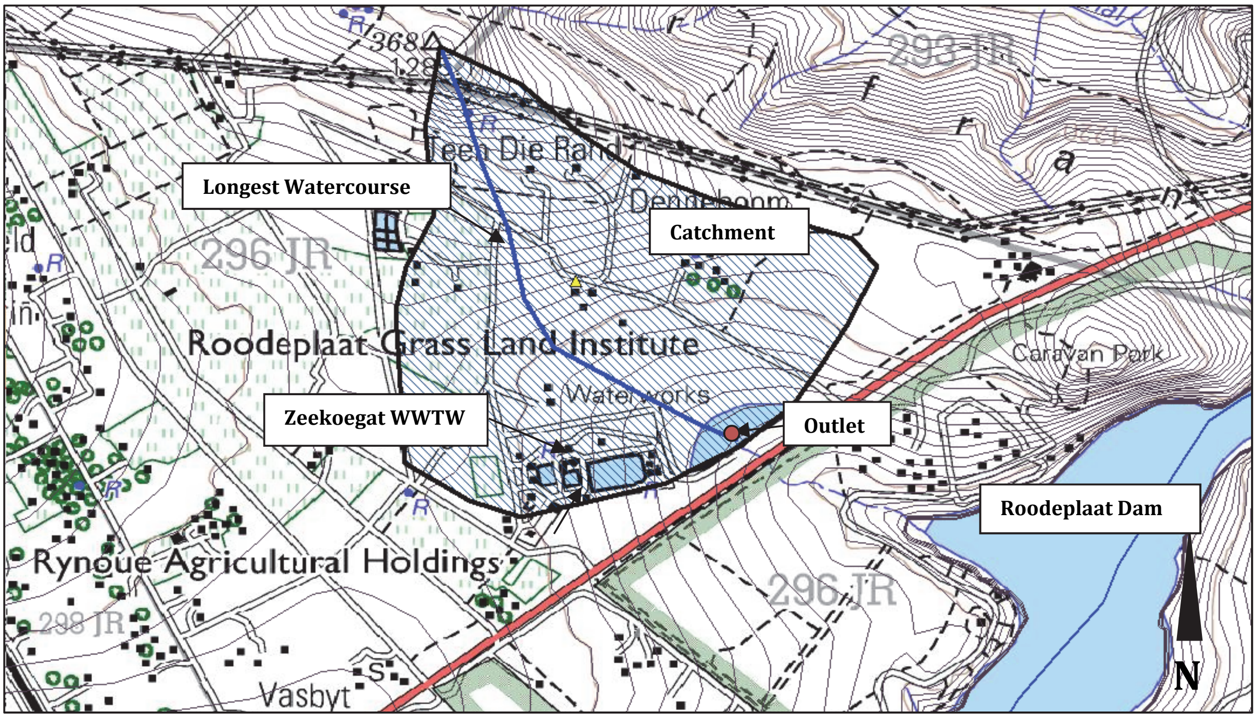


Figure 9-26: Definition of Catchment Area

No rainfall stations exist in the catchment area. Therefore, the mean annual precipitation (MAP) for the catchment was assumed to be the same as the Roodeplaat Tuin MAP.

The catchment's characteristics were determined rainfall data collected and the runoff calculations performed.

9.8.2.3 Runoff Calculation

The Utility Programs for Drainage software program was used for calculating the flood peaks using the deterministic and empirical methods applicable for catchments of this size. A summary of the calculated results is shown in **Table 9-5**.

The Rational Method was chosen as the catchment is very small (1.8 km^2) and therefore the regional methods will not necessarily be applicable.

Table 9-5: Summary of calculated peak flows from the natural catchment

Return period	Calculated peak flows (m^3/s)					
	2	5	10	20	50	100	RMF
Rational	10	14	19	24	32	41	
Alternative rational	9	16	22	28	36	43	
Unit hydrograph method	7	12	18	25	38	53	
Standard Design Flood		7	12	18	26	34	
Empirical			10	14	19	24	
Regional Maximum Flood					60	74	134

Routing through the dam was not considered as it is a small dam with limited storage capacity.

However, as the dam functions as the outlet of a wastewater treatment plant, the outflow from the plant also had to be considered to obtain a true peak outflow of the dam. Zeekoegat WWTW has the capability of choosing how much water to accept at the inlet works (all excess flow will gravitate to Rooiwal WWTW). Therefore the highest recorded instantaneous flow, of 3.4 m^3/s, which was experienced on 22 June 2014, was added to each of the calculated peak flows in the next paragraphs.

9.8.2.4 Extreme Flood Calculation for the Zeekoegat outlet dam

The Zeekoegat outlet dam can be considered a small dam with a significant hazard potential and can therefore be classified as a Category II dam by SANCOLD standards. Therefore, the following formulas (obtained from SANCOLD, 1991) were used for the calculation of different extreme flooding events (**Table 9-6**).

Table 9-6: Extreme Flood Calculations

Method	Applicable Formula	Flow (m^3/s)
Recommended Design Discharge (RDD)	100 year return period	44
Regional Maximum Flood(RMF△)		137
Safety Evaluation Discharge (SED)	RMF△	128
Recommended Design Flood (RDF)	100 year return period	43
Safety Evaluation Flood (SEF)	RMF△	128

Cullis (2007) documents various concerns with the factoring of the SED and SEF for smaller dams by scaling the Kovács region up or down when determining the RMF. Due to these concerns many practitioners revert back to the *Interim SANCOLD Guidelines on Safety in Relation to Floods* (SANCOLD, 1986). This document recommends SED and SEF values in terms of the PMF (or RMF). This is also used regularly for small and urban catchments. Alternative values for the SED and SEF are therefore proposed in **Table 9-7**.

Table 9-7: Alternative Values for the SED and SEF

Method	Applicable Formula	Flow (m^3/s)
Regional Maximum Flood(RMF)		137
Probable Maximum Flood (PMF)		109
SED and SEF as proportion of RMF	0.7xRMF	96
SED and SEF as proportion of PMF	0.5xPMF	54

As this is a Category II dam, it is proposed that a peak flow value of 96 m^3/s be used for the SED and SEF.

9.8.3 DESIGN DRAWINGS

As indicated due to budget constraints the initial design had to be altered. Initially the design was based on galvanised steel pipe which was changed to PVC pipe sections.

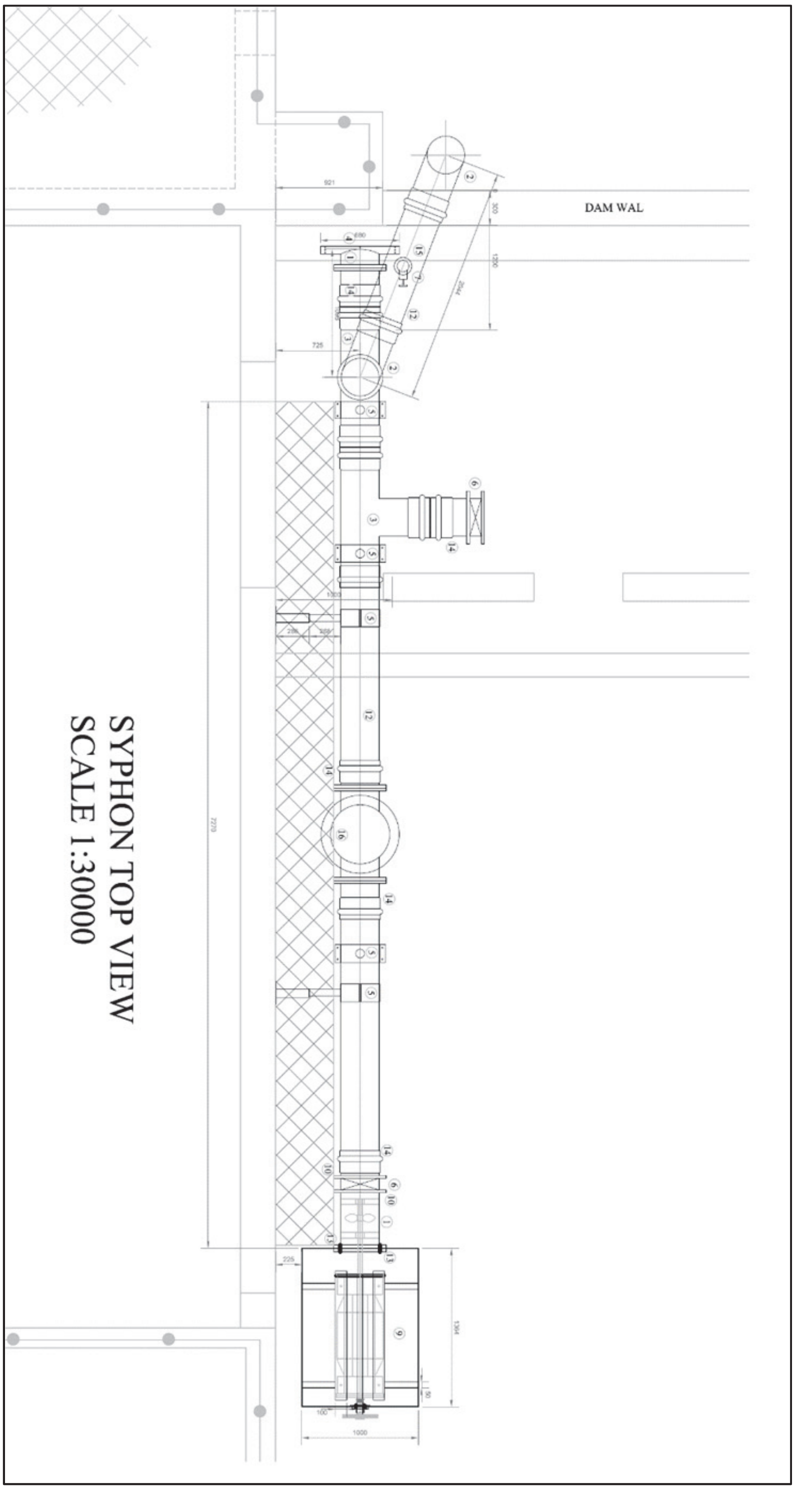


Figure 9-27: Top view of pipework of pilot plant installation

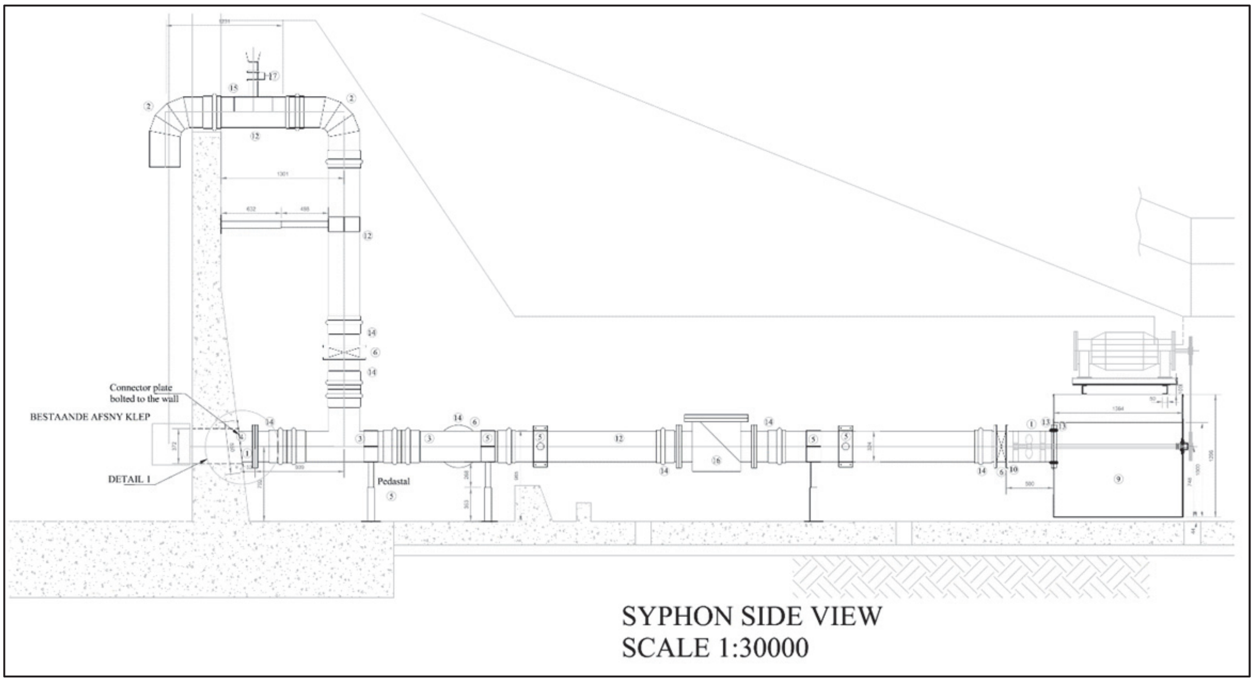


Figure 9-28: Side view of pilot plant installation

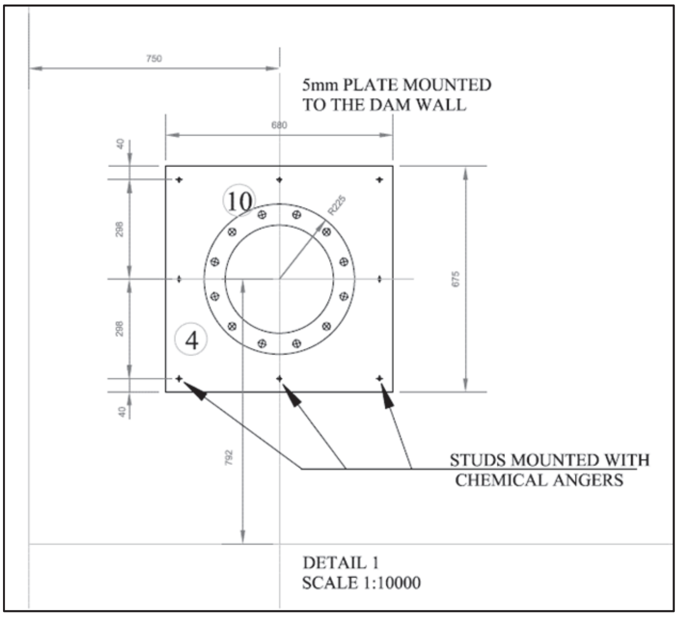


Figure 9-29: Mounting of pipework onto dam outlet

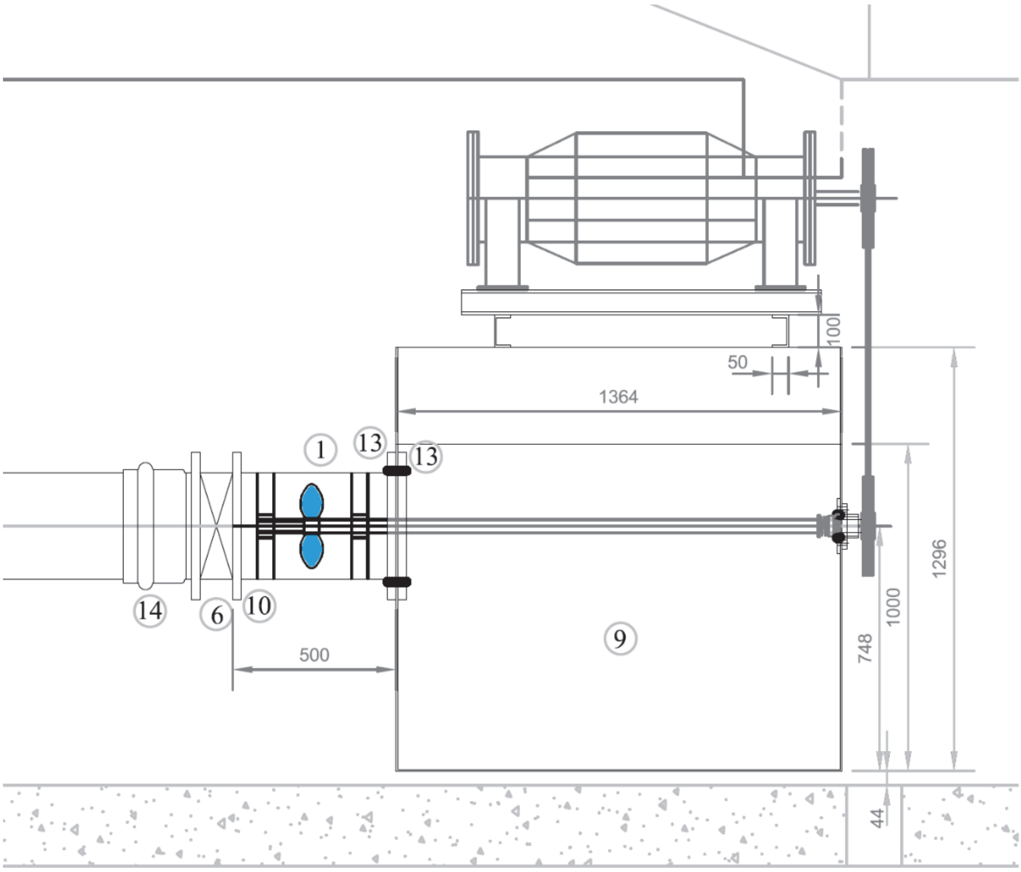


Figure 9-30: Turbine and generator installation

The final detailed drawing is included in **Appendix B.**

9.9 CONSTRUCTION OF HYDROPOWER PLANT

The entire hydropower plant was manufactured locally. The CoT personnel together with undergraduate students of the University of Pretoria constructed the plant.

The design drawings of the low head hydropower pilot plant at Zeekoegat Wastewater Treatment Works have been included in **Appendix B**. **Figure 9-31** shows the installation location prior to construction.

The installation consists out of a siphon pipeline over the crest of the dam wall, a secondary pipeline with a connection to the existing scour valve outlet, an inline low head propeller/Kaplan type turbine, a new scour point and several valves for operational purposes, as well as submerged tailrace chamber. A Bosch Unipoint T1 series 24v/28V 140-amp alternator was connected to the inline low head propeller/Kaplan type turbine an initial test has indicated an electrical power output of between 1 and 3 kW.

Further tests were conducted to investigate and calculate both the efficiency of the system and the turbine itself as well as calculating the maximum capacity of the installation and turbine. **Figure 9-32** to **Figure 9-52** gives a pictorial overview of the installation and testing of the Low head hydropower pilot plant at the Zeekoegat Wastewater Treatment Works.

Figure 9-31: Pilot plant installation location

Figure 9-32: Joing of pipework sections

Figure 9-33: Specials made to suite

Figure 9-34: Constructed pipe supports

Figure 9-35: Installing the offtake plate against dam wall

Figure 9-36: Pipework installation

Figure 9-37: Delivery of material to site

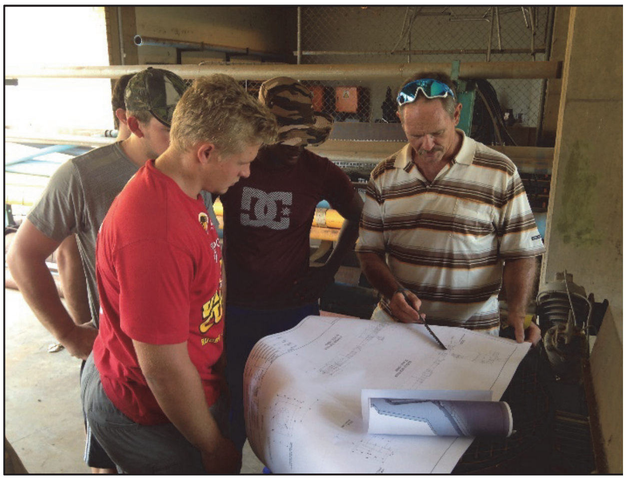


Figure 9-38: Reading construction drawings

Figure 9-39: Connection to existing scour point

Figure 9-40: Inline Kaplan/propeller Turbine

Figure 9-41: Measurements for connecting siphon

Figure 9-42: Siphon over dam crest

Figure 9-43: Tailrace chamber

Figure 9-44: Shaft operation during start-up

Figure 9-45: New scour point

Figure 9-46: Operation of Low Head installation

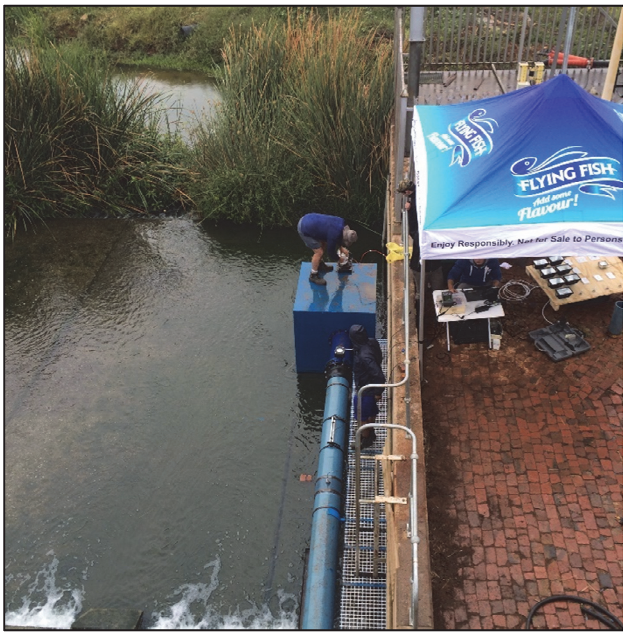


Figure 9-47: Testing of installation

Figure 9-48: Alternator during operation

Figure 9-49: Flow and pressure measurement set-up

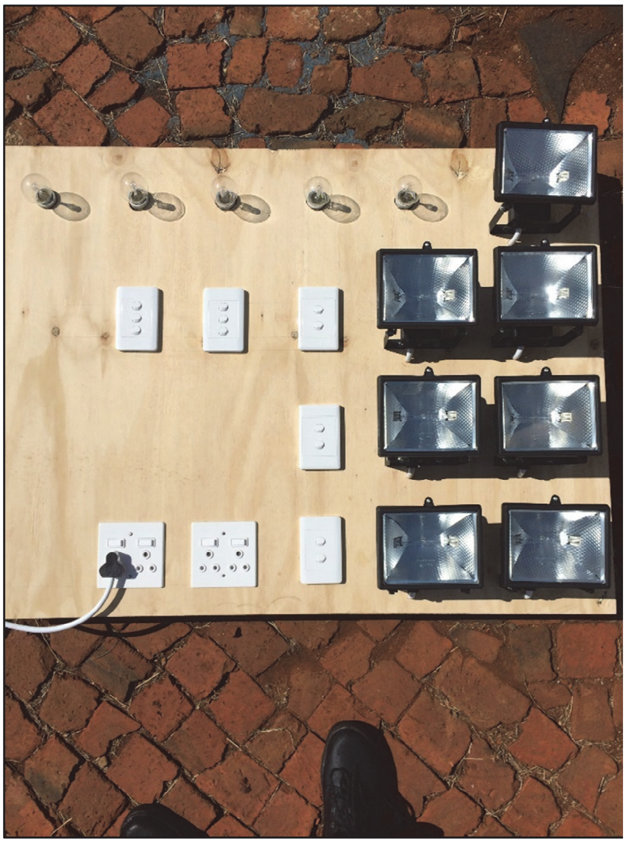


Figure 9-50: Energy dissapating board

Figure 9-51: Generating electricity with the Low Head installation

Figure 9-52: Zeekoegat WWTW – Low Head hydropower installation

9.10 TESTING PROCEDURE

To be able to determine the efficiency and thus the feasibility of the system a range of tests were performed. A range of flows were covered between 60 and 430l/s. This also led to an increased rotating speed of the turbine of between 0-833 rpm. The flow rate was varied to generate a varying data set of pressure, speed, and power as well as the overall system efficiency. From this data characteristic curves of the system were obtained such as the relationship between flow and pressure. The flow ranges were obtained by throttling the valves in such a manner to obtain a certain flow rate or pressure throughout the system.

The experimental tests to determine the energy generation potential of the low-head site was conducted three times on three different experimental layouts. The installation options investigated involved operating the bottom outlet in isolation, operating the siphon system in isolation and finally testing a combination of these two options.

The setup of the data recording instrumentation and the electrical configuration of the system is depicted in **Figure 9-53**.

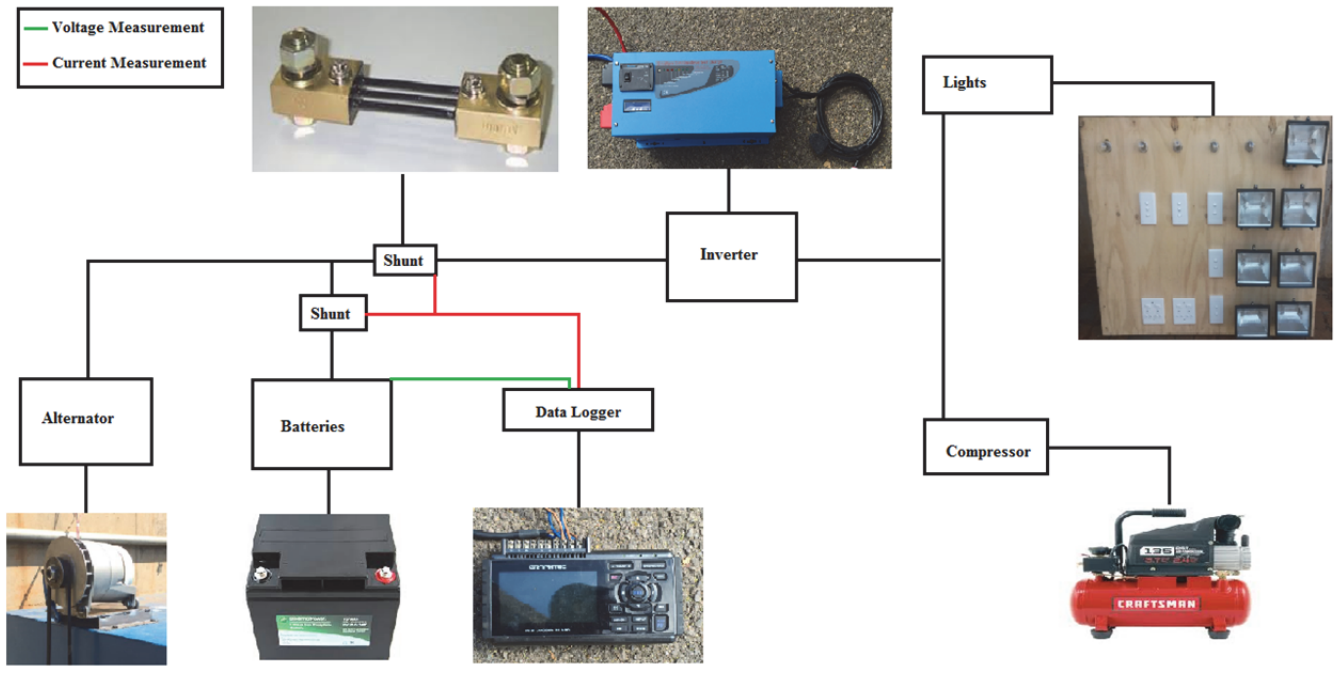


Figure 9-53: Electrical setup with recording instrumentation

The following steps were followed to determine the energy generation potential of each installation method:

1. Depending on the installation option being investigated, the required isolating valves were open to allow flow through the pipe network.

2. With the butterfly valve at the turbine closed, static pressure readings were obtained along the pipe at the locations as depicted in **Figure 9-54**.

3. The butterfly valve was open and water was allowed to flow through the runner and consequently rotate the alternator to generate energy.

4. With the system flowing at full capacity, the flow rate and corresponding velocity through the pipe network was recorded.

5. Pressure readings were also recorded along with the associated speed of the turbine shaft and alternator in RPM.

6. The alternator was connected to two 12 V batteries that were used to store the power produced by the alternator.

7. A Graphtec data logger was connected to the battery and was used to measure the current produced by the alternator and current drawn from the battery (during power dissipation) and the total system voltage.

8. Power was dissipated by turning on lights from **Figure 9-50** until the maximum power produced by the alternator was reached.

9. To determine the maximum power of the alternator, the power was dissipated until current was drawn from the battery. By subtracting the current drawn from the battery from the alternator current the current produced by the inverter was known.

10. This current was then multiplied by the system voltage to obtain the power produced by the system for that associated flow rate and installation method.

11. By slowly closing the hand wheel controlling the sluice gate which dictates flow through the network, the flow rate in the system was decreased in small increments of 10-15 l/s.

12. Steps 1-10 was repeated for each increment.

13. The flow rate was decreased until no power was generated by the alternator.

14. Once the minimum flow rate was reached, the hand wheel was once again slowly opened to increase the flowrate in the system in small increments of 10-15 l/s until the maximum flow rate was reached

15. Steps 1-10 was once again repeated for each increment.

16. Close the required valves and repeat step 1-15 for all installation options.

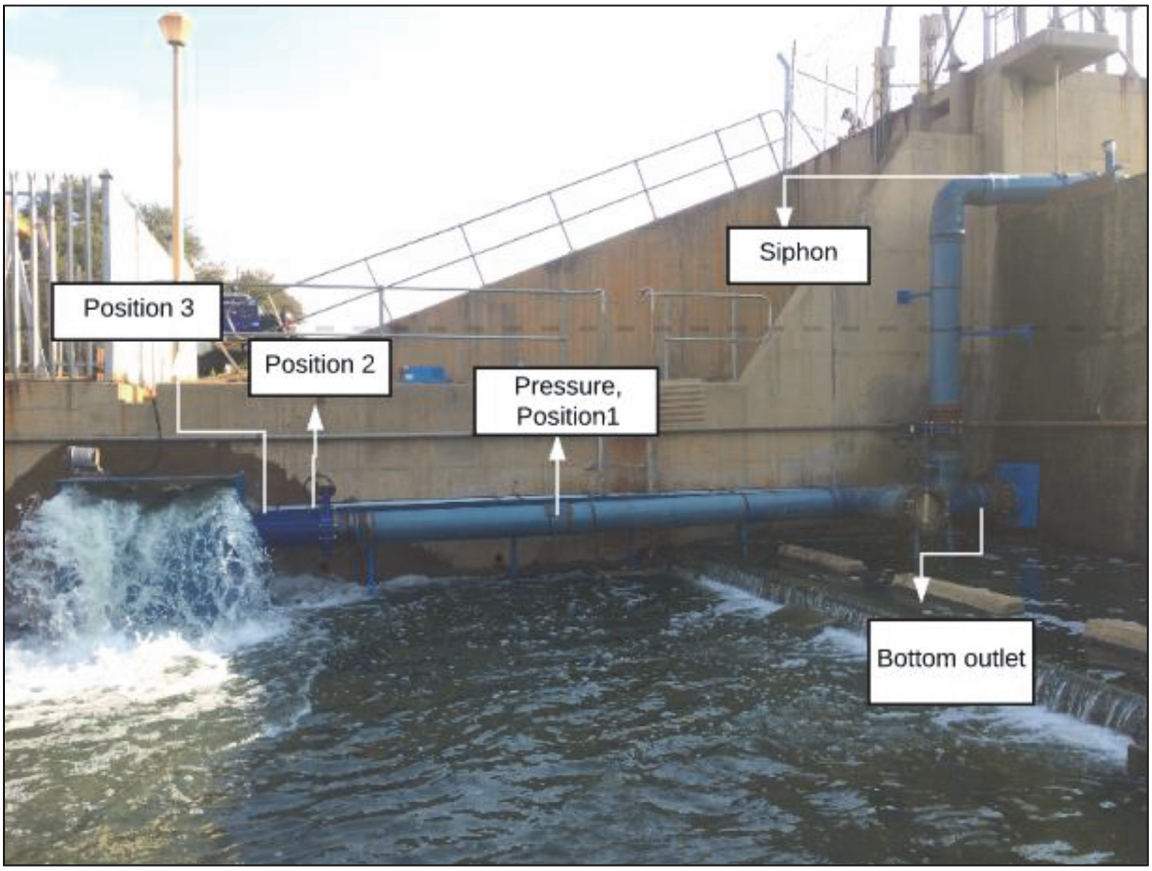


Figure 9-54: Measuring locations

9.11 ZEEKOEGAT LOW HEAD HYDROPOWER PLANT GENERATING CAPACITY

The main focus of the study was to demonstrate a technology by means of a pilot plant installation showcasing the opportunities which exist as existing water infrastructure which has the potential for hydropower generation.

By comparing the actual power produced to the theoretical power expected, it was possible to determine the efficiency of the system. A power curve, **Figure 9-55**, for one of the first sets of tests conducted indicated that for the flow rate of ±435 l/s approximately 1050 Watt could be generated. An efficiency of only 19 % as depicted in **Figure 9-56** was obtained during these tests.

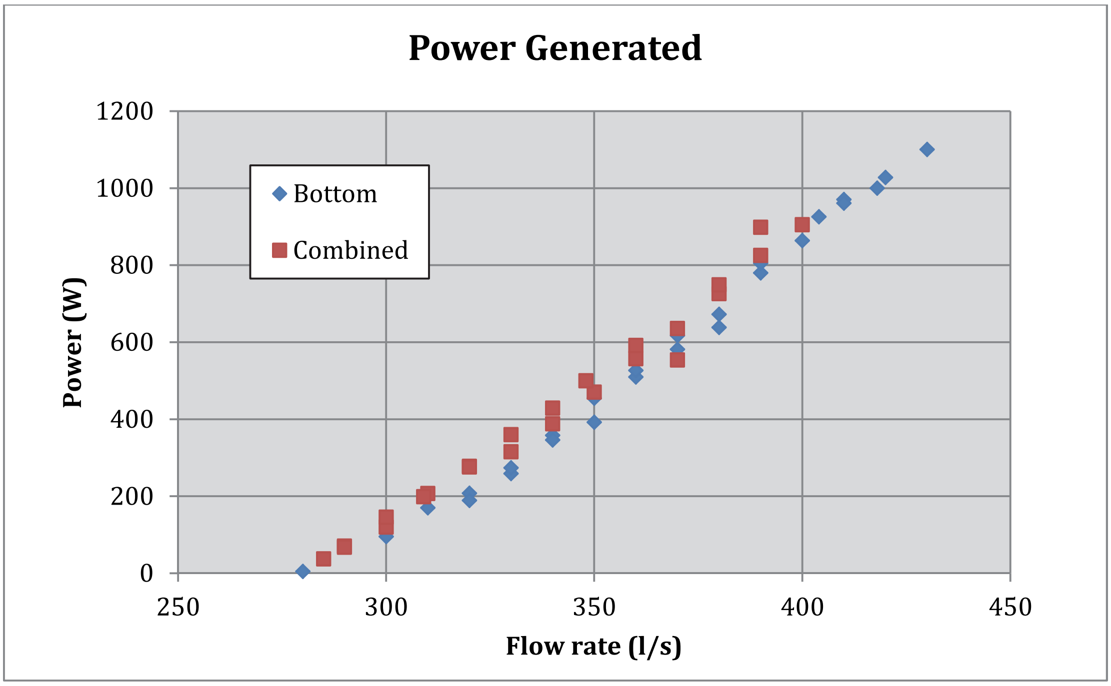


Figure 9-55: Power curve for hydropower plant setup

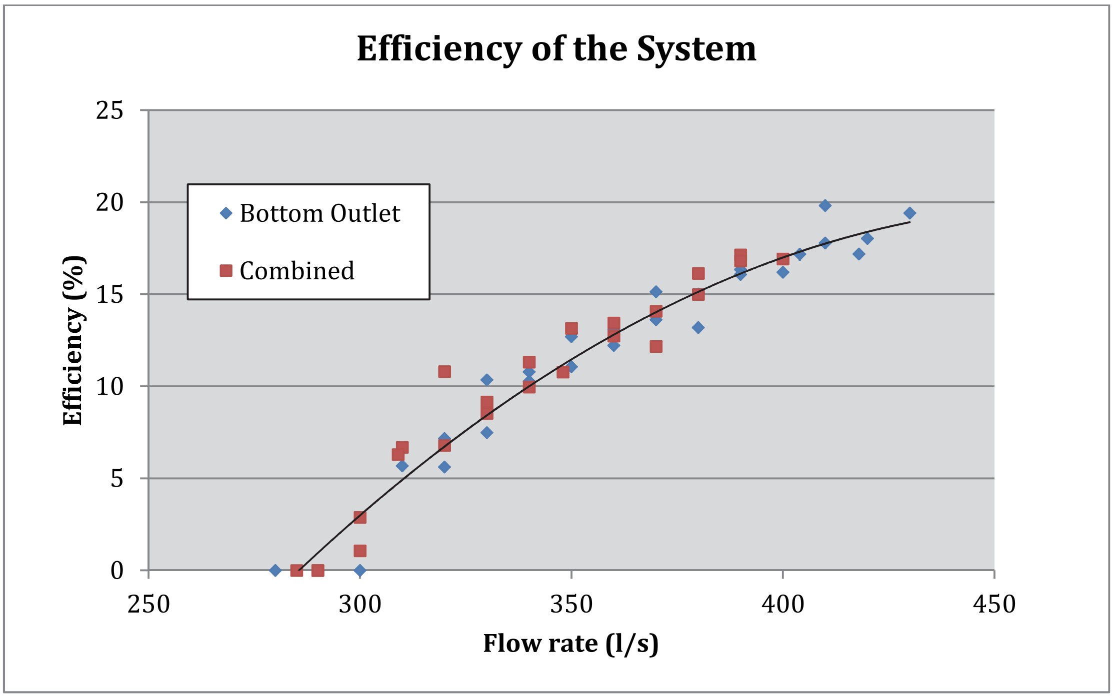


Figure 9-56: Efficiency curve

It was observed that there still existed a significant amount of energy in the waster after it has passed through the turbine runner. The pulley system was changed to enable more power to be extracted from the water and this resulted in an increased power generation of a maximum of 2.6 kW at the same flow rate of ±435 l/s.

The total cost of this installation was R130 000 and as shown in Figure 9-57 payback period would be in the order of 11 years. It is however believed that with small modifications the power generation could be further increased to approximately 4 kW.

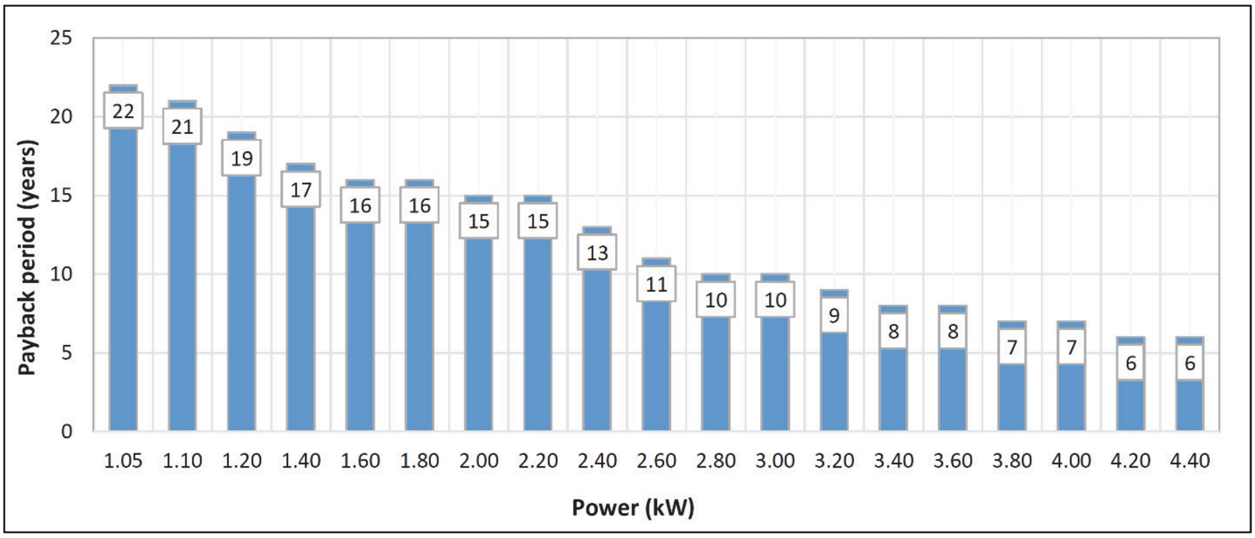


Figure 9-57: Payback period

9.12 USES FOR THE ELECTRICITY GENERATED AT ZEEKOEGAT

There are various possibilities for electricity use on site. The considered options included:

- Connecting to the grid and feeding the generated power back and utilizing this at any of the electricity intensive processes at the WWTW.
- Security fencing (electrified) in the area around the turbine.
- Lighting up of the site around the turbine, outlet and the road.
- Aeration of the outlet dam for further water quality improvements.
- Combination of the above.

Depending on the final generating capacity the power could be used for a number of functions on the site, i.e. lights at night and aeration during the day time.

The aeration of the water in the upstream dam was tested by linking an air compressor to the system and injecting air through a diffuser into the dam as shown in **Figure 9-58**.

Figure 9-58: Aeration of the dam using the generated hydro-electric power

10 CONCLUSIONS AND RECOMMENDATIONS

The study reflects that there is significant potential for the development of low-head hydropower in both the perennial streams and within existing water supply (i.e. urban and agricultural scheme) and wastewater treatment infrastructure. This potential is not necessarily significant with regard to the contribution to the Eskom's national grid, but is significant with regard to the potential reduction in electricity demand by the consumers. It provides a great opportunity for local municipalities to utilize their existing infrastructure and reduce their operational costs of for example the Waste Water Treatment Works.

The research work compiled in this report, is aimed at making the administrators and operators more aware of the means and ways of identifying and evaluating the low-head hydropower potential within their systems, together with the benefits generating even small amounts energy from own sources will have.

Introducing enhanced in-house energy generation will alleviate to some extent dependency of particularly the water supply utilities on the already stressed national grid and keep their energy costs lowered. The retrofitting of the low-head hydropower at existing infrastructure will to initiate the process of the water supply and wastewater system optimisation and revision of obsolete or insufficient regimes and procedures.

Micro and Pico hydropower is a proven technology with hydropower plants between 50 and 100 years old still operating today. A wide range of reaction and impulse turbines are available, each having a varying head and flow range, thus allowing for the selectin of a high efficiency hydropower plant. There a various locations where low head hydropower could be successfully installed as described in **Section 3**.

The following conclusions can be derived from the tests conducted on the low-head hydropower station at Zeekoegat:

- The low-head hydropower station constructed at the Zeekoegat WWTW managed to demonstrate the successful use of low-head hydro technologies to generate power in South Africa. The three different installation options investigated were all successful in generating sufficient flows to rotate the alternator and produce energy.
- It was identified as expected that the efficiencies of the low-head hydro power station are directly proportional to the flows through the system. Higher flow rates

produced faster turbine and alternator rotations which resulted in greater energy production.

- With small modifications the system could be further enhanced to increase the electricity output.
- Although payback periods are not excessive these could still be further reduced when opting for higher efficiency turbine systems. Connecting to the grid and not first through an inverter would also increase the generating potential and reduce payback periods.
- No negative environmental and social considerations were encountered or expected from the construction and operation of this low-head hydropower station.

It is recommended that:

- A South African definition for the grouping of hydropower size be developed;
- The process to qualify as independent energy suppliers should be revisited;
- Other technical solutions and technologies be implemented to create more interest and commitment to hydropower generation;
    - Other types of low head installations be constructed to showcase the technology at waste water treatment works;
    - a canal system be equipped with kinetic turbines for demonstrative purposes; and
    - an example of retrofitting of hydropower technology on existing low head dams be investigated.
- Guidelines be developed that could be used by designers of WWTW and irrigation systems assisting in the design and implementation of generating facilities from the planning stage of the infrastructure; and that the
- Implementation of new developments should be staged to show the contribution to the power situation in South Africa, be it small.

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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**
	> 100 m	**20-100 m**	**5-20 m**	**< 5 m**
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.

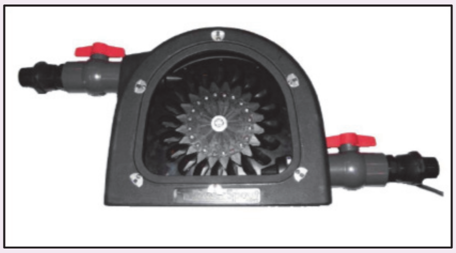
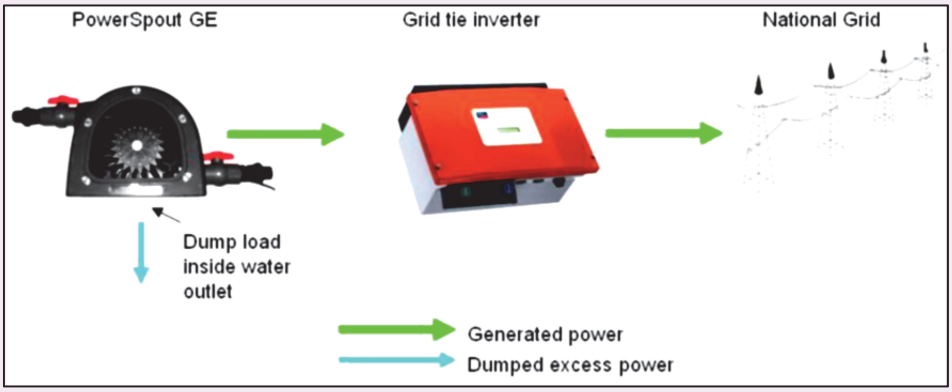
Table A2: Layout of Appendix A: Impulse turbines

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
	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

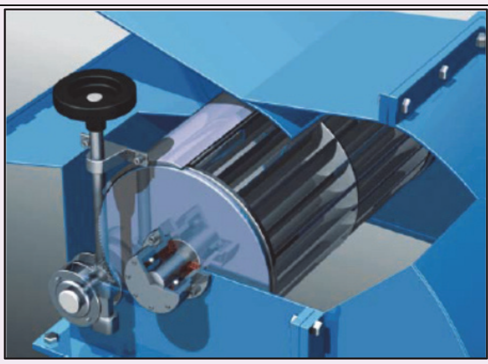
Table A3: Layout of Appendix A: Reaction turbines

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
Reaction	Kaplan	Mavel	0.3-150	1.5-35	30-20 000
Reaction	Kaplan	Voith	Not given	3-95	100-400 000
Reaction	Kaplan	Tamanini	0.2-15.0	5-35	10-5 000
Reaction	Kaplan	Power Pal	0.04-0.13	1.5	0.2-1
Reaction	Turbinator	Clean Power AS	0.5-12	10-60	75-3 300
Reaction	Bulb	Alstom	0.3-150	2-30	<130 000
Reaction	Bulb	Voith	2-30	Not given	1 000-80 000
Reaction	Bulb	Voith (MiniHydro)	1-14	2-10	Not given
Reaction	Francis	Wasserkraft Volk	Not given	<300	<20 000
Reaction	Francis	Mavel	0.1-30	15-440	20-30 000
Reaction	Francis	Gilkes	0.05-40	<400	<20 000
Reaction	Francis	Voith	Not given	3-95	5-1 000 000
Reaction	Francis	Tamanini	0.2-10	15-300	10-10 000
Reaction	Syphon-turbine	Mavel	0.15-4.5	1.5-6	1-180
Reaction	Inline Turbines	Kawasaki Ring	0.14-2.8	3-30	20-500
Reaction	Inline Turbines	Hydro E-Kids	0.1-3.5	2-15	5-200
Reaction	Inline Turbines	Lucidpipe Spherical	1-5.6	0.5-10	14-100
Reaction	Moveable Power House	Ossberger Canada	1-25	1-8	350-2 000
Reaction	Pump as turbine	Andritz	0.03- 6	3-80	3-10 000
Reaction	Wave power turbine	Voith	Not given	Not given	Not given

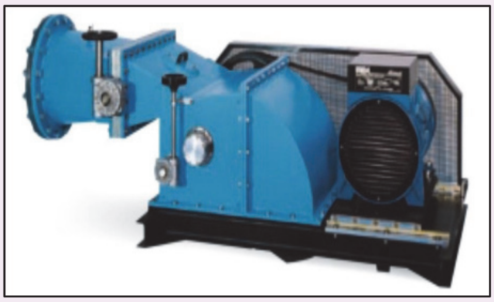
IMPULSE TYPE TURBINES

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*

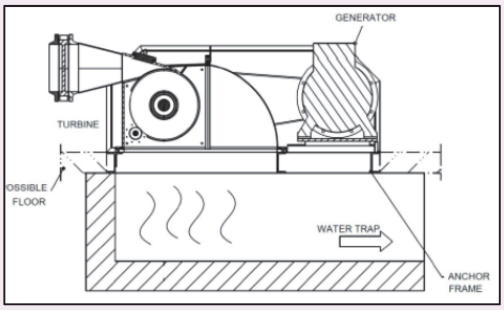
Turbine Name	**BANKI (CROSSFLOW) TURBINE**
Company name	**IREM SpA a Socio Unico**
Company Address	Via Abegg 75 Borgone Susa ITALY 10500
Company Tel	+39 011 9648211
Company E-mail	irem@irem.it
Website	www.irem.it
Turbine Description	The IREM Banki turbine is connected to a belt driven synchronous or 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	



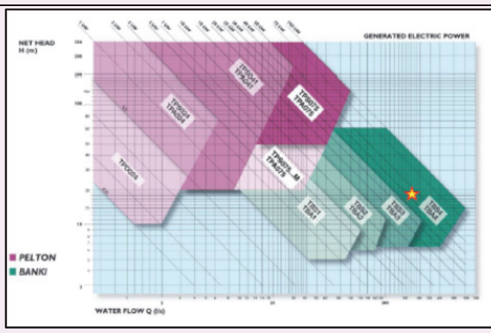
Banki runner



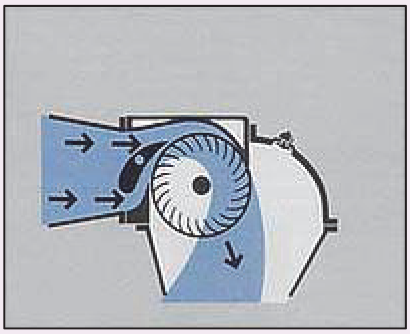
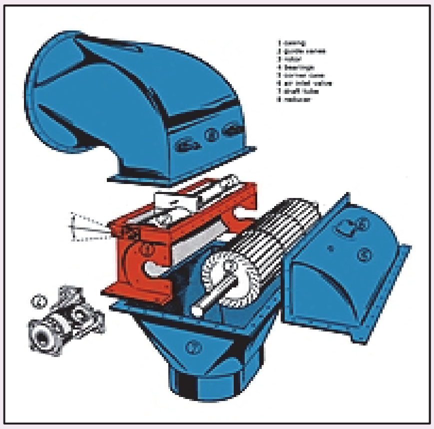
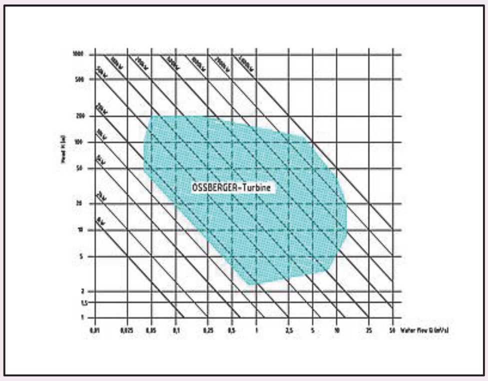
Banki turbine



Turbine set-up



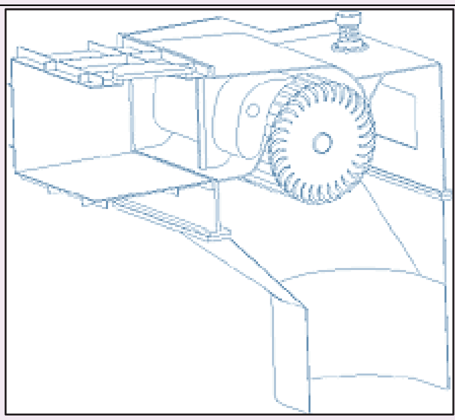
IREM turbine range

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*

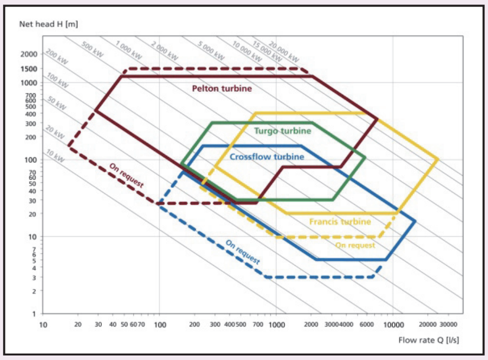
Turbine Name	**CROSSFLOW TURBINE**
Company name	**Wasserkraft Volk AG**
Company Address	Am Stollen 13 D-79261 Gutach GERMANY
Company Tel	+49 7685-9106-0
Company E-mail	mail@wkv-ag.com
Website	www.wkv-ag.com
Turbine Description	These turbines have high efficiencies down to 17% of design flow. They offer 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

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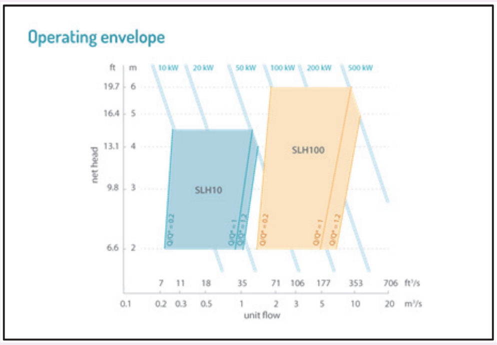
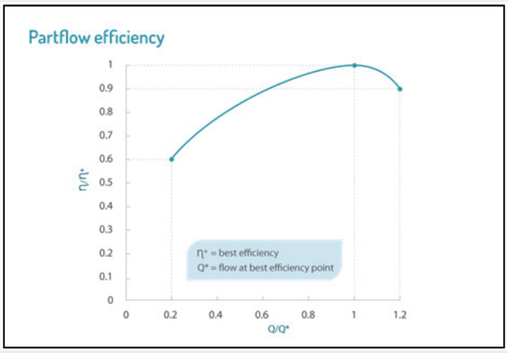
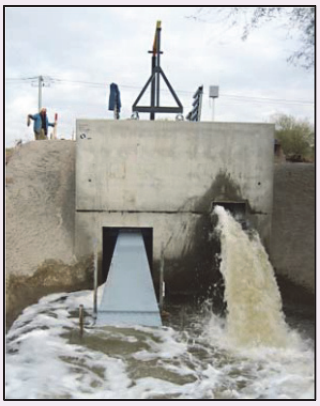
<tr><td>Turbine Name</td><td colspan="2">HYDROENGINE (SLH10 AND SLH 100)</td></tr>
<tr><td>Company name</td><td colspan="2">Natel Energy</td></tr>
<tr><td>Company Address</td><td colspan="2">2175 Monarch Street
Alameda, CA
94501</td></tr>
<tr><td>Company Tel</td><td colspan="2">(506)-984-3639</td></tr>
<tr><td>Company E-mail</td><td colspan="2">gia@natelenergy.com</td></tr>
<tr><td>Website</td><td colspan="2">www.natelenergy.com</td></tr>
<tr><td>Turbine Description</td><td colspan="2">Natel Energy's hydroengine is a unique design using the uplift created as water passes by curved blades.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">SLH10 & SLH100 – up to 6 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">SLH10 – up to 1.1 m^3/s
SLH100 – up to 10.1 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">SLH10 – up to 50 kW
SLH100 – up to 500 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>


Flow ranges</td><td>


Partflow efficiencies</td></tr>
<tr><td>

Hydroengine cross section</td><td>

Pilot installation</td></tr>
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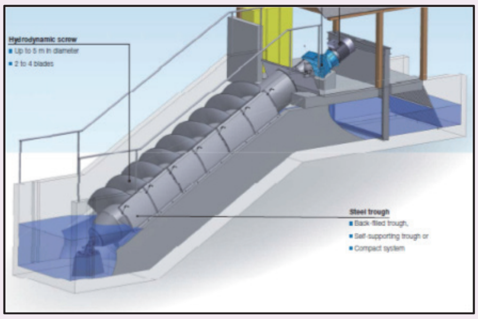
Turbine Name	**HYDRODYNAMIC SCREW**
Company name	**ANDRITZ Atro**
Company Address	Penzinger Strasse 76 Vienna AUSTRIA 1141
Company Tel	+43 (1)891 00 0
Company E-mail	hydro@andritz.com
Website	www.andritz.com
Turbine Description	This turbine is based on the Archimedean screw and is applicable to very 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

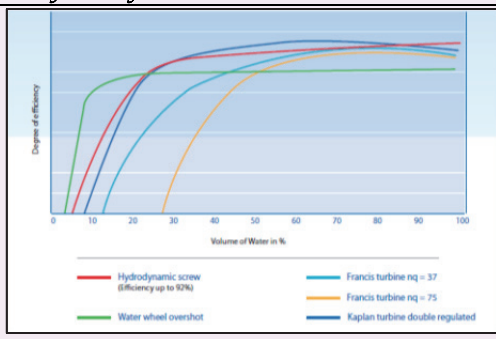
Illustrations, Photos and Applicable Graphs

Hydrodynamic Screw

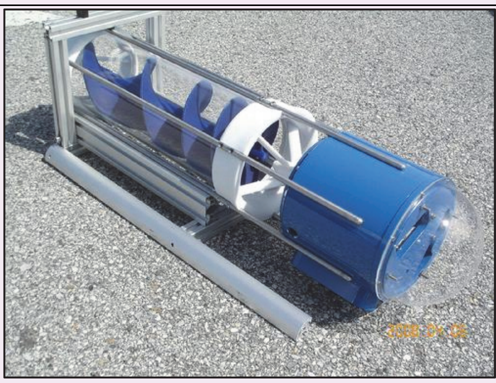
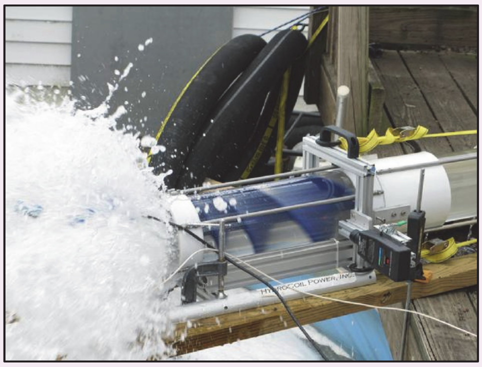
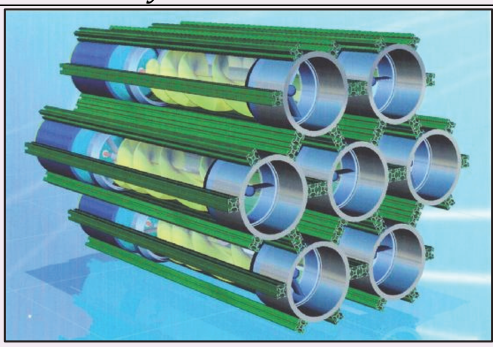
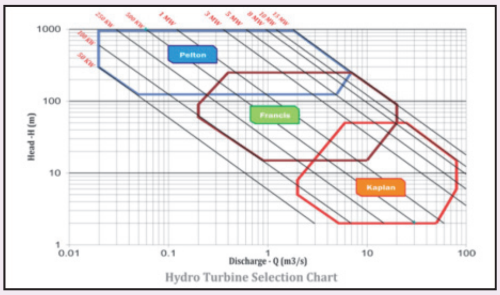
Hydrodynamic screw installation

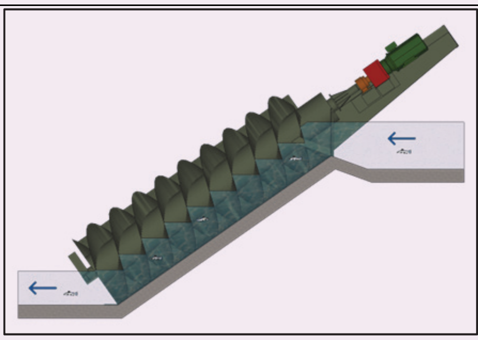
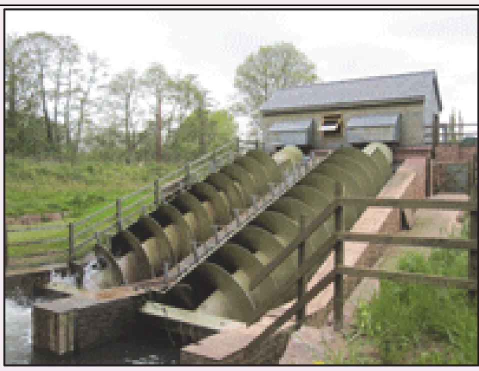
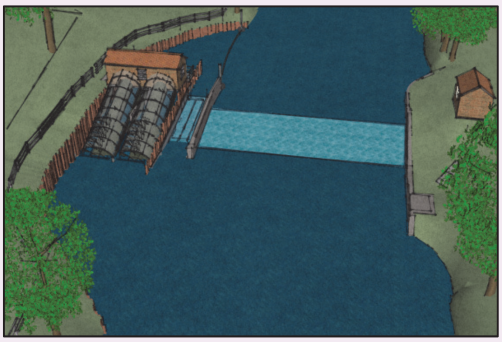


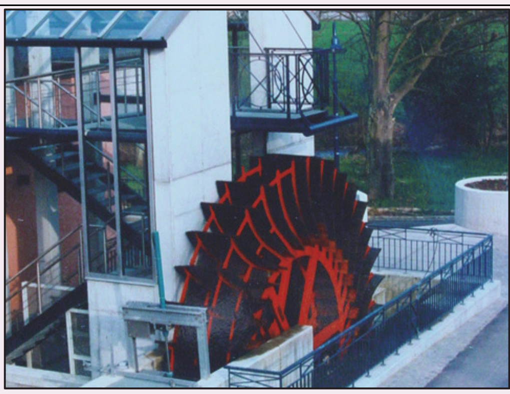
Typical layout

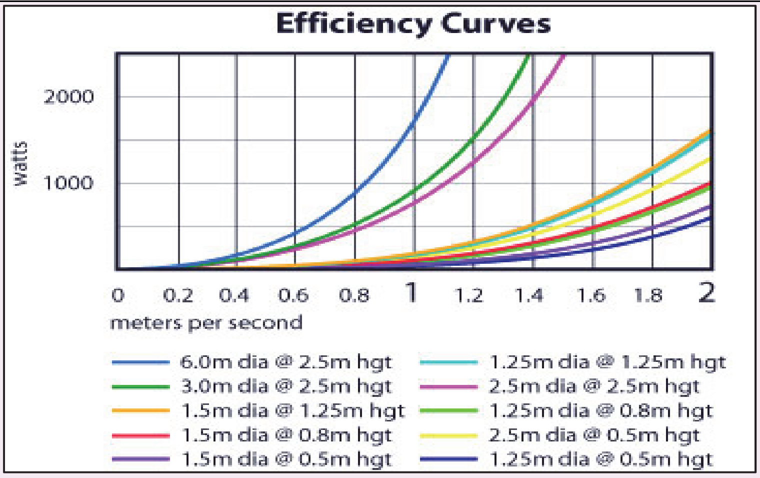


Turbine efficiency

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 10 m Breastshot – 1 m to 3 m
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*

Turbine Name	**HYDROKINETIC (Darrieus Water Turbine)**
Company name	**Alternative Hydro Solutions**
Company Address	Alternative Hydro Solutions Ltd Suite 421 323 Richmond Street East Toronto, Ontario M5A 4S7
Company Tel	416-368-5813
Company E-mail	sdgregory@althydrosolutions.com
Website	www.althydrosolutions.com
Turbine Description	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.
Pressure Head Range	0.1 m from bed for fast flow (> 1,3 m/s) 0.3 m for slow flow
Flow Range	Greater than 0.8 m/s
Power Range	1 kW to 4 kW
Illustrations, Photos and Applicable Graphs	 *Efficiency curves*
	 *Field installation*

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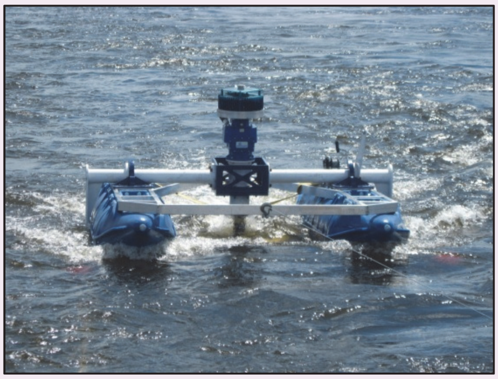
<tr><td>Turbine Name</td><td colspan="2">HYDROKINETIC (En Current Power Generation System)</td></tr>
<tr><td>Company name</td><td colspan="2">New Energy Corporation</td></tr>
<tr><td>Company Address</td><td colspan="2">3553 – 31 Street NW
Suite 473
Calgary, Alberta
T2L 2K7</td></tr>
<tr><td>Company Tel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


Field installation</td><td>


Underwater view</td></tr>
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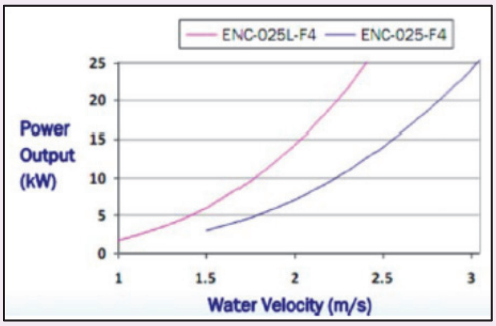
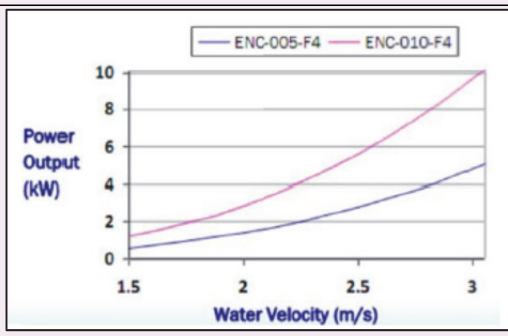
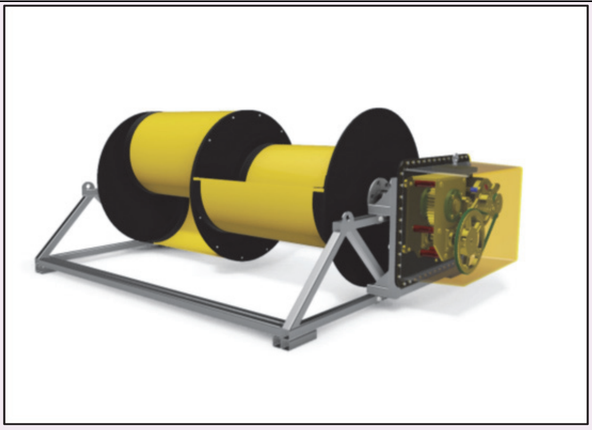
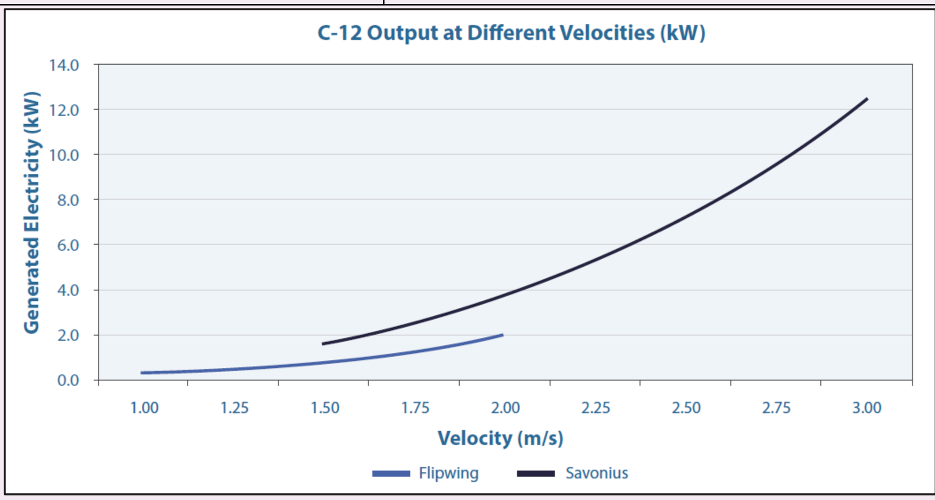
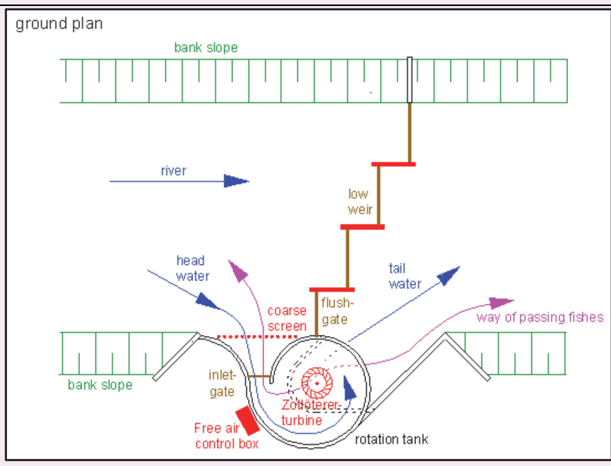


25 kW System</td><td>


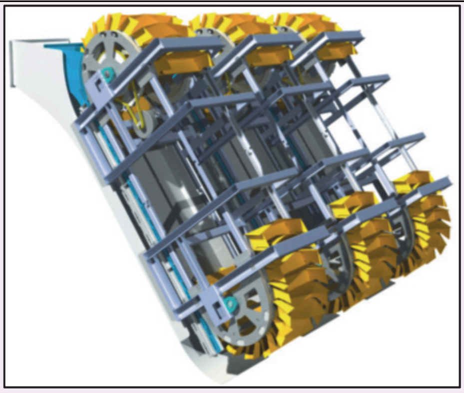
5 kW System</td></tr>
</table>

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*

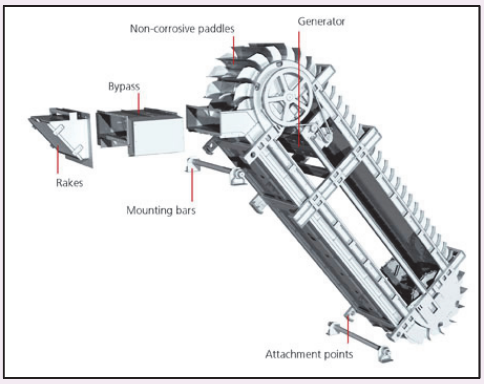
Turbine Name	**VORTEX POWER PLANT**
Company name	**Zotloeterer**
Company Address	A-3200 Obergrafendorf Wildgansstraße 5 AUSTRIA
Company Tel	0043-(0)2747-3106
Company E-mail	office@zotloeterer
Website	http://www.zotloeterer.com
Turbine Description	This power plant uses the rotational energy at the center 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*  *Plant installation*

Turbine Name	**STEFFTURBINE**
Company name	**Walter Reist Holding AG**
Company Address	WRH AG Industriestrasse 1 CH-830 Hinwil
Company Tel	+41 44 938 70 00
Company E-mail	info@steffturbine.com
Website	www.steffturbine.com
Turbine Description	The Steffturbine is the consistent further development of the technical principle of the overshot water wheel. It utilises a conveyor belt system.
Pressure Head Range	2.5 m to 5 m
Flow Range	Up to 0.4 m^3/s
Power Range	Up to 10 kW per turbine

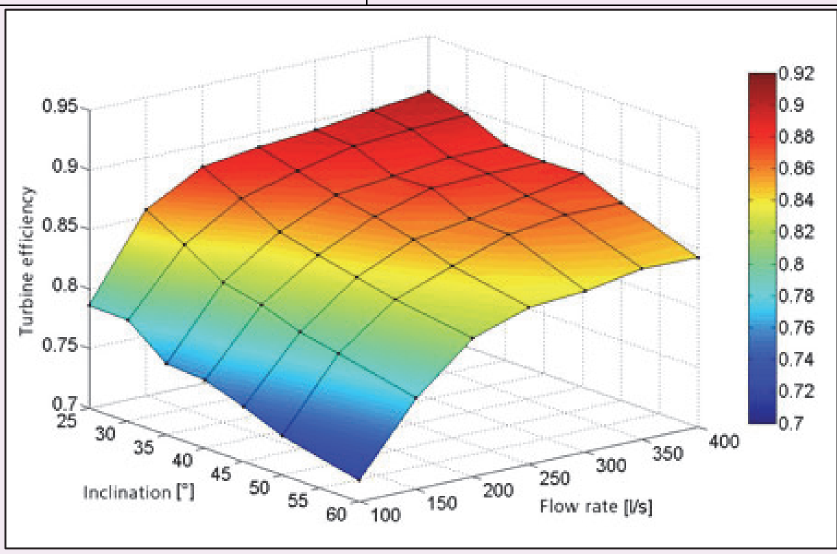
Illustrations, Photos and Applicable Graphs



Model

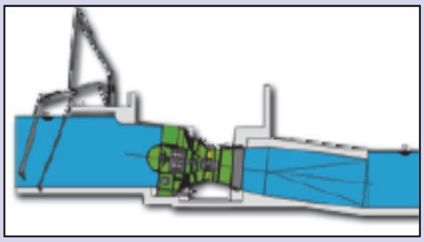
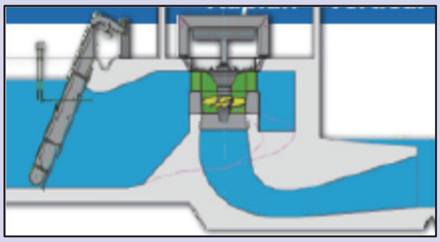
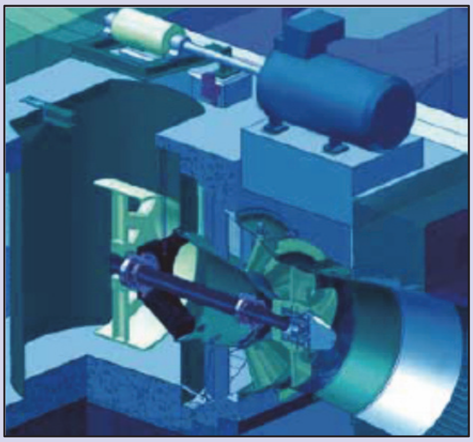
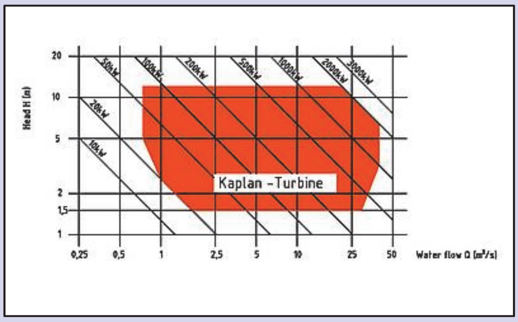


Steffturbine design



Efficiency

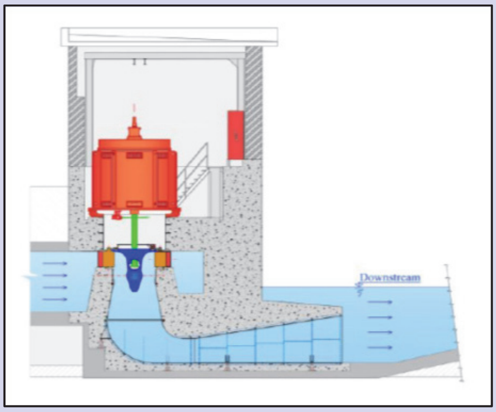
REACTION TYPE TURBINES

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*

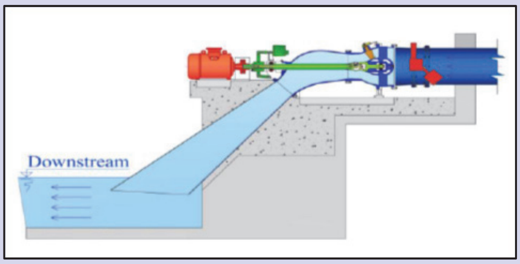
Turbine Name	**KAPLAN TURBINE**
Company name	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel	+27 21 552 9993
Company E-mail	karenr@sciontechnologies.co.za
Website	www.mavel.cz
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

Illustrations, Photos and Applicable Graphs

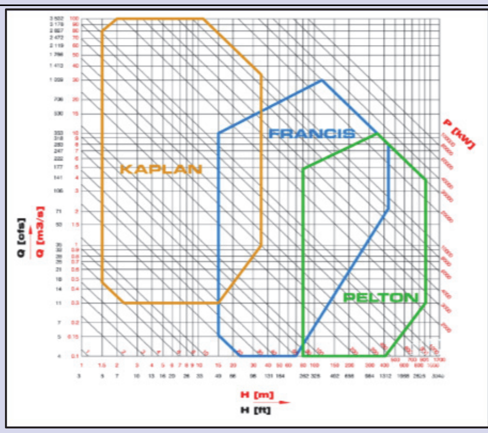
Kaplan turbine runner



Vertical Turbine layout



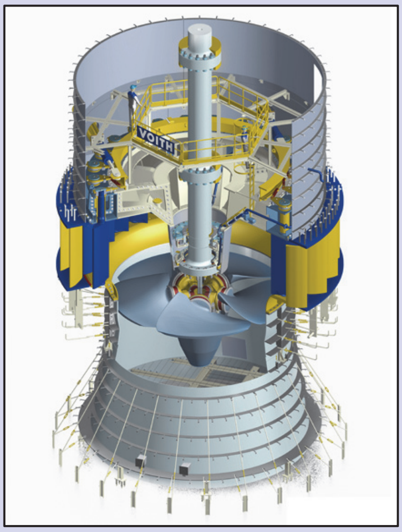
S-type turbine layout



Turbine range

<table>
<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">Voith Hydro Holding GmbH & Co. KG</td></tr>
<tr><td>Company Address</td><td colspan="2">Alexanderstrasse 11
89522 Heidenheim
GERMANY</td></tr>
<tr><td>Company Tel</td><td colspan="2">+49 7321 37 0</td></tr>
<tr><td>Company E-mail</td><td colspan="2">info.voithhydro@voith.com</td></tr>
<tr><td>Website</td><td colspan="2">www.voithhydro.com</td></tr>
<tr><td>Turbine Description</td><td colspan="2">Voith Kaplan turbines are designed to function with low head and high flow rates.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">3 m to 95 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">Not given</td></tr>
<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
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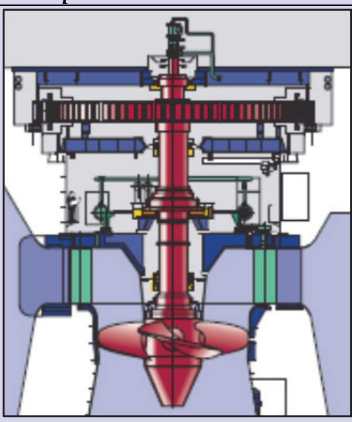

Cross section of a Kaplan runner
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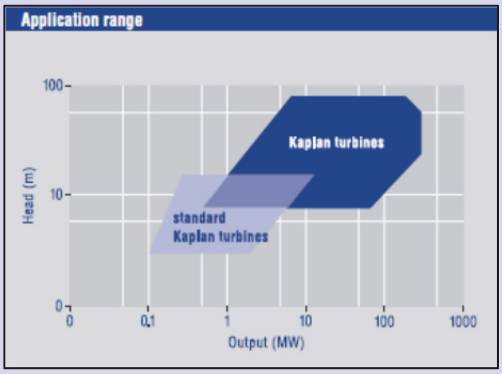

Turbine range
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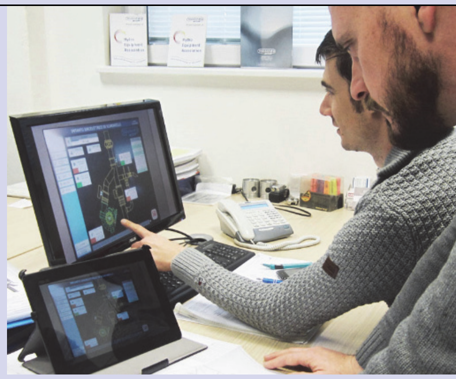
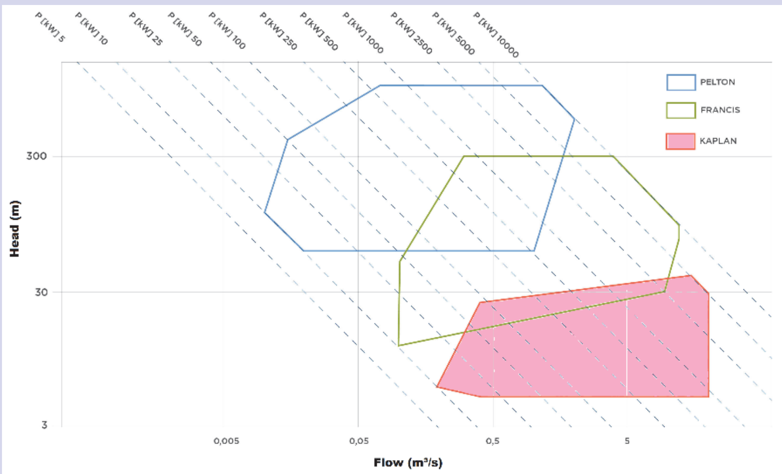
<tr><td colspan="3"></td></tr>
<tr><td>Turbine Name</td><td colspan="2">KAPLAN TURBINE</td></tr>
<tr><td>Company name</td><td colspan="2">Tamanini Hydro S.r.l</td></tr>
<tr><td>Company Address</td><td colspan="2">Salita ai Dossi,
5 – 38123
Trento (TN)
ITALIA</td></tr>
<tr><td>Company Tel</td><td colspan="2">+39 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>
<tr><td>Pressure Head Range</td><td colspan="2">5 m to 35 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.2-15.0 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">10 kW to 5 000 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>
Manufacturing</td><td>
Design of Kaplan Turbine</td></tr>
<tr><td colspan="2">

Turbine range</td></tr>
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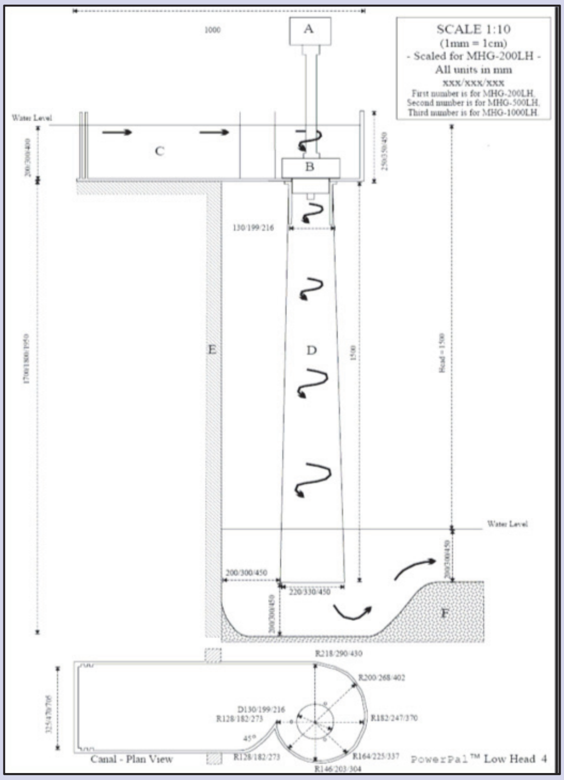
Turbine Name	**PROPELLOR TURBINE – (SMALL)**
Company name	**Power Pal**
Company Address	2-416 Dallas Road Victoria, BC V8V 1A9 CANADA
Company Tel	1-250-361-4348
Company E-mail	info@powerpal.com
Website	http://www.powerpal.com
Turbine Description	The Power Pal turbine is a very small, low head propeller type turbine set at the elevation of the incoming water.
Pressure Head Range	1.5 m
Flow Range	35 l/s to 130 l/s
Power Range	200 W to 1 kW
Illustrations, Photos and Applicable Graphs	see below

Illustrations, Photos and Applicable Graphs

Turbine

Turbine installation



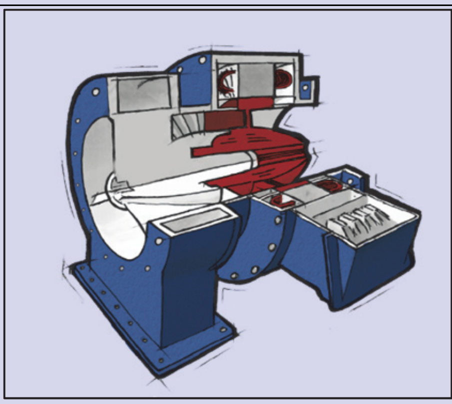
Internal schematic

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 m^3/s to 12 m^3/s
Power Range	75 kW to 3.3 MW

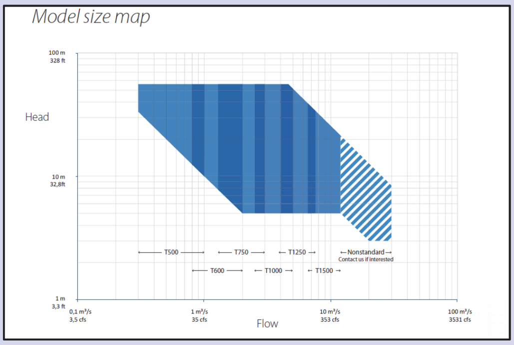
Illustrations, Photos and Applicable Graphs

Turbinator

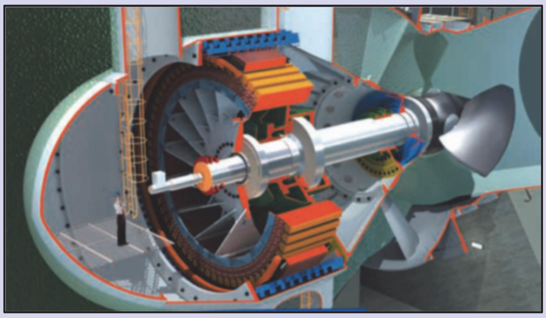
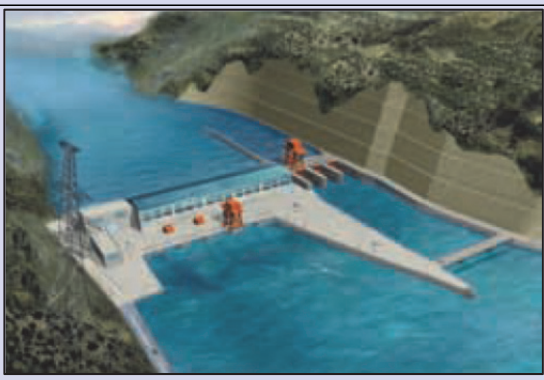
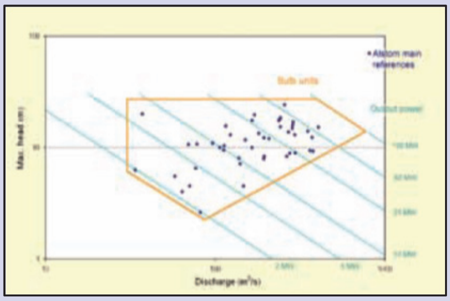
Turbine layout



Cross section of a Turbinator

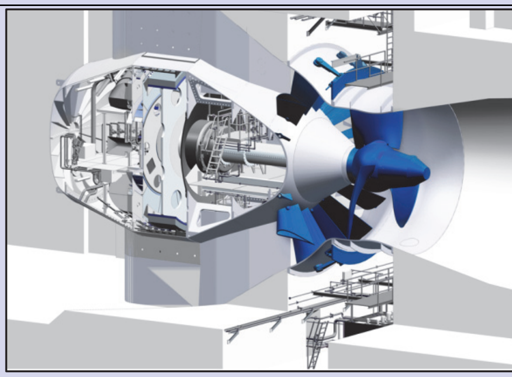


Turbine range

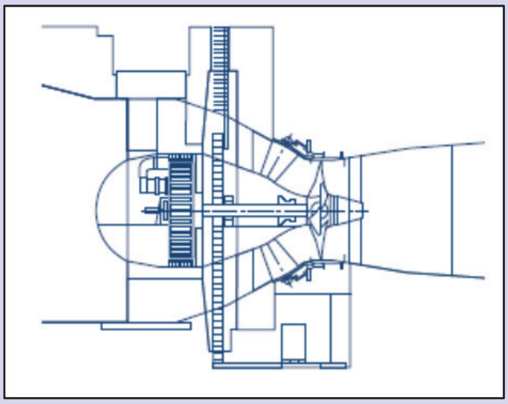
Turbine Name	**BULB TURBINE**
Company name	**Alstom**
Company Address	Country Club Estates 21 Woodlands Drive Woodmead SOUTH AFRICA
Company Tel	+27 11 518 8100
Company E-mail	Not given
Website	www.alstom.com
Turbine Description	Alstom design concepts ensure reliability in all operating circumstances 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
Illustrations, Photos and Applicable Graphs	 *Bulb turbine drawing*  *Runner installation*  *Installation at Wu Jin Xia, China*  *Turbine range*

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	

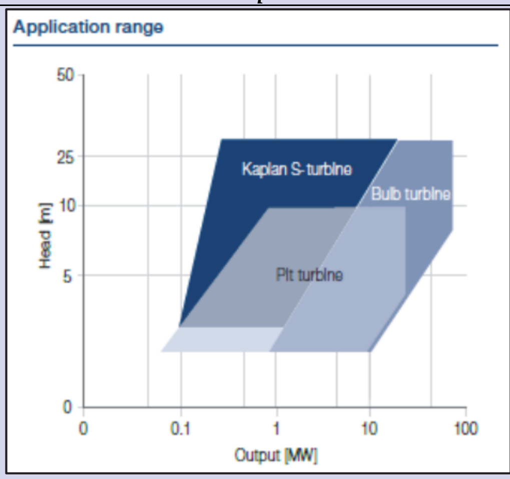
Bulb turbine



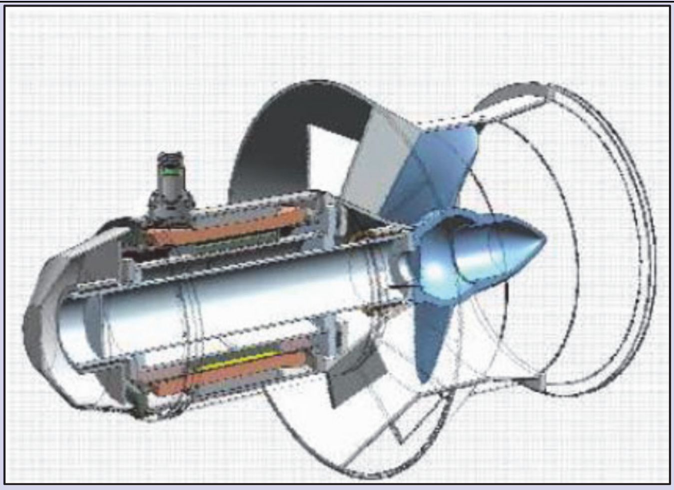
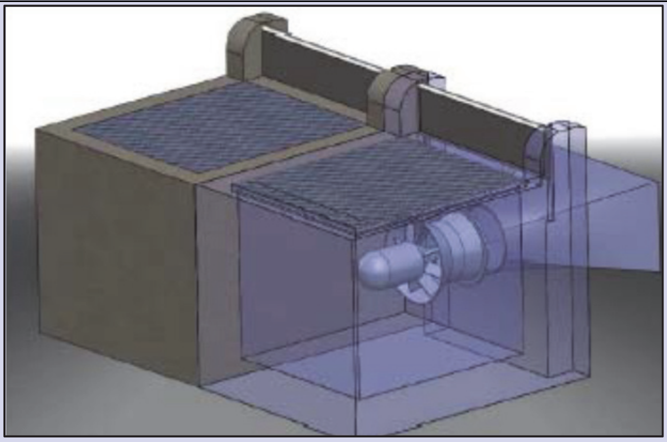
Bulb turbine computer illustration

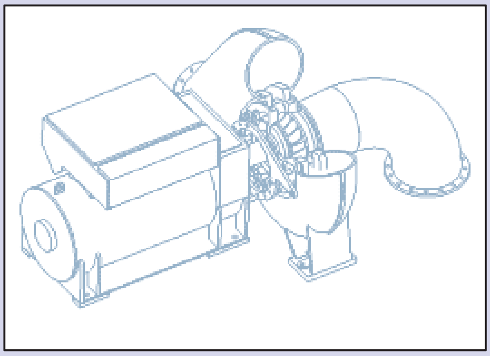
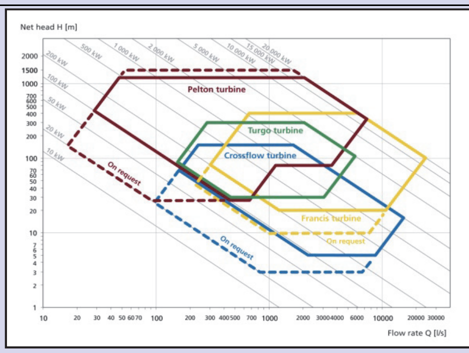


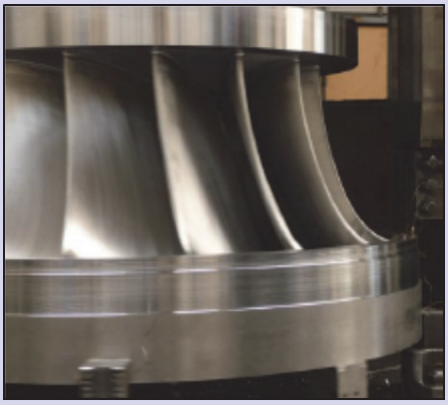
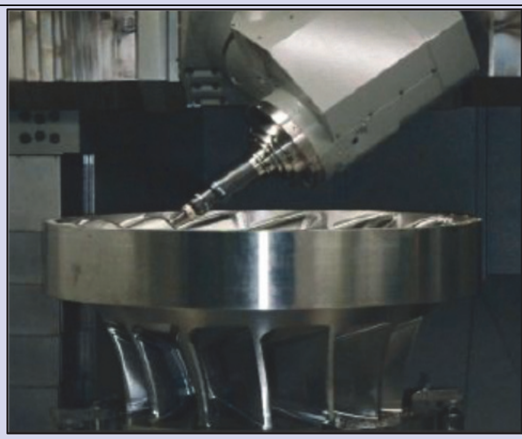
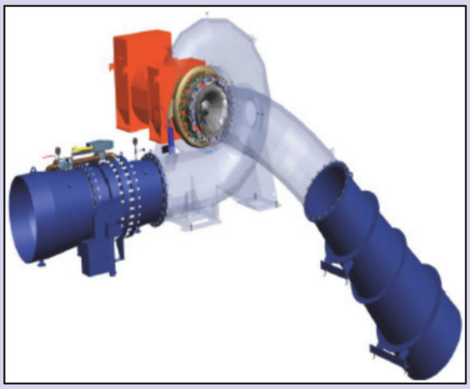
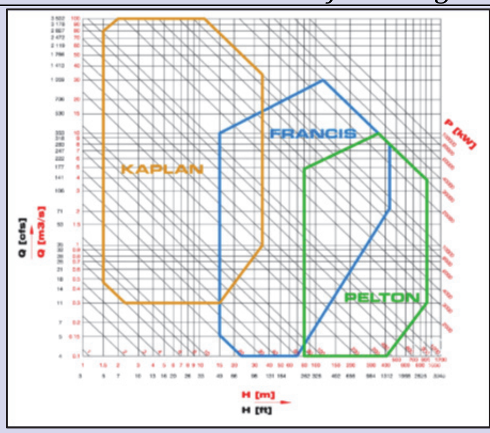
Cross section of a Bulb turbine



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*

<table>
<tr><th colspan="3"></th></tr>
<tr><td>Turbine Name</td><td colspan="2">FRANCIS TURBINE</td></tr>
<tr><td>Company name</td><td colspan="2">Mavel Hydro Turbines (Scion Technologies (South African Distribution))</td></tr>
<tr><td>Company Address</td><td colspan="2">Northbank 3rd Floor Northbank Lane
Century City, Cape Town
SOUTH AFRICA</td></tr>
<tr><td>Company Tel</td><td colspan="2">+27 21 552 9993</td></tr>
<tr><td>Company E-mail</td><td colspan="2">karenr@sciontechnologies.co.za</td></tr>
<tr><td>Website</td><td colspan="2">www.mavel.cz</td></tr>
<tr><td>Turbine Description</td><td colspan="2">Mavel Francis turbines are milled from a single block of forged steel and can be applied to medium heads and medium flow ranges.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">15 m to 440 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.1 m^3/s to 30 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">20 kW to 30 MW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>
Francis runner</td><td>
Francis turbine manufacturing</td></tr>
<tr><td>
Typical layout</td><td>

Turbine range</td></tr>
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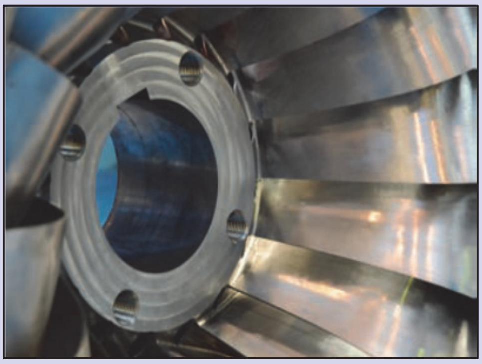
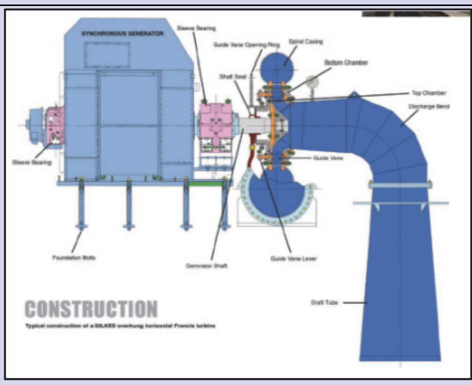
Turbine Name	**FRANCIS TURBINE**
Company name	**Gilbert Gilkes & Gordon Ltd**
Company Address	Canal Head North Kendal Cumbria LA9 7BZ UK
Company Tel	+44 (0) 1539 720028
Company E-mail	enquiries@gilkes.com
Website	www.gilkes.com
Turbine Description	This turbine can be supplied as a horizontal or vertical 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	

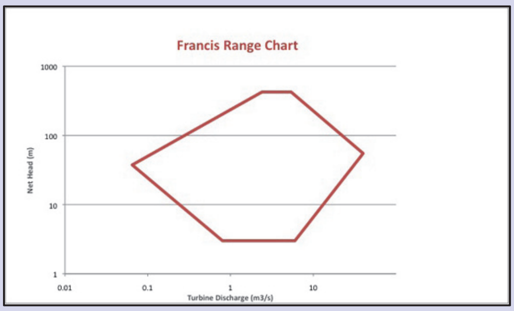


Francis runner

Francis turbine



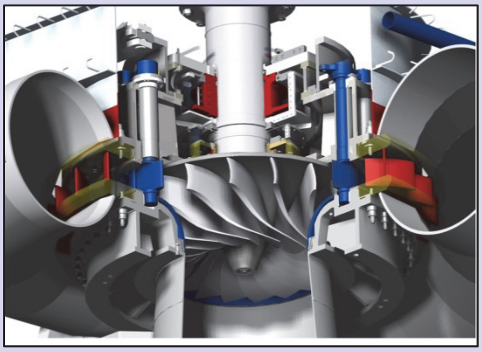
Typical layout



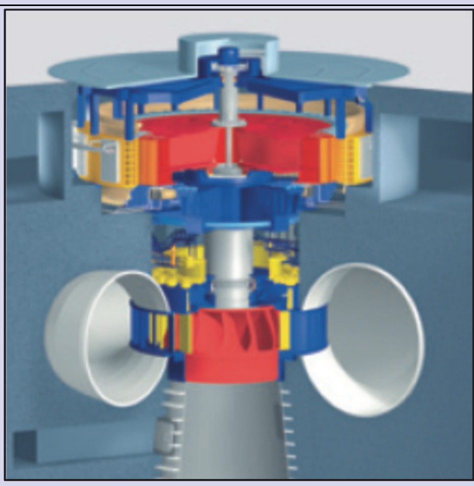
Turbine range

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	

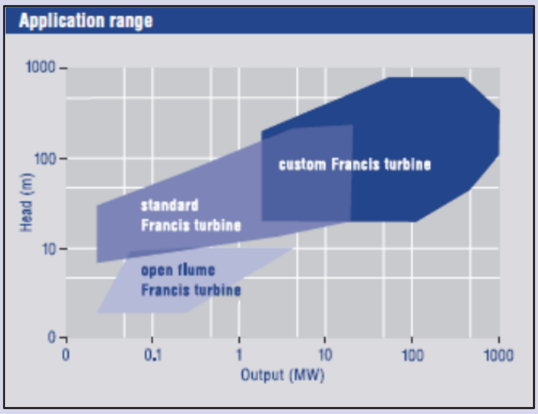
Francis turbine runner



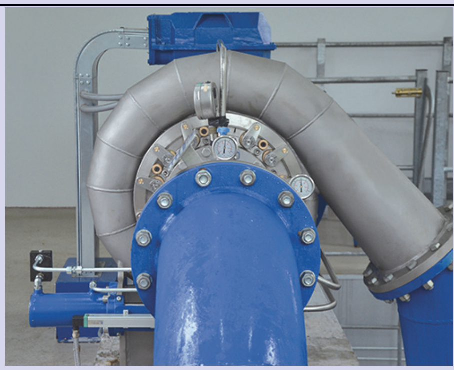
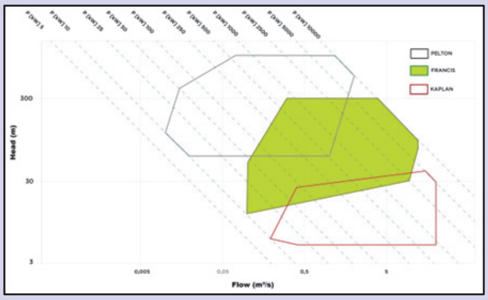
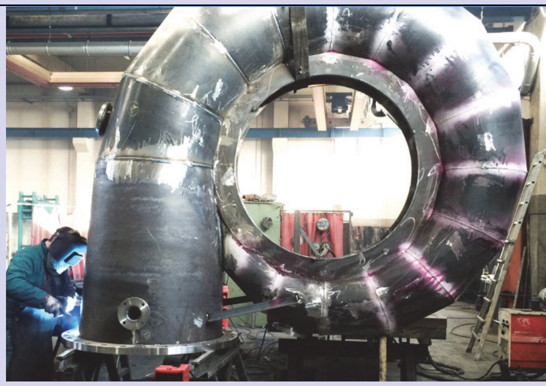
Turbine layout



Cross section of a Francis turbine



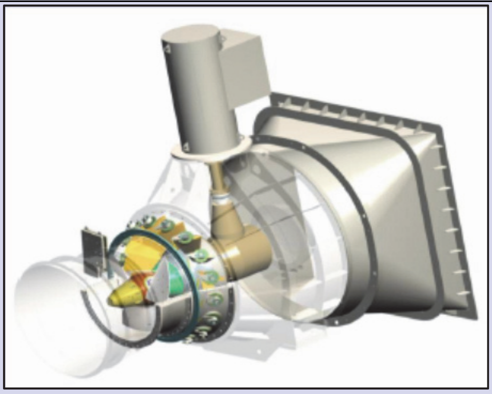
Turbine range

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
Flow Range	0.2-10.0 m^3/s
Power Range	10 kW to 10 000 kW
Illustrations, Photos and Applicable Graphs	 *Francis turbine installation*  *Francis runner*  *Turbine range*  *Turbine manufacturing*

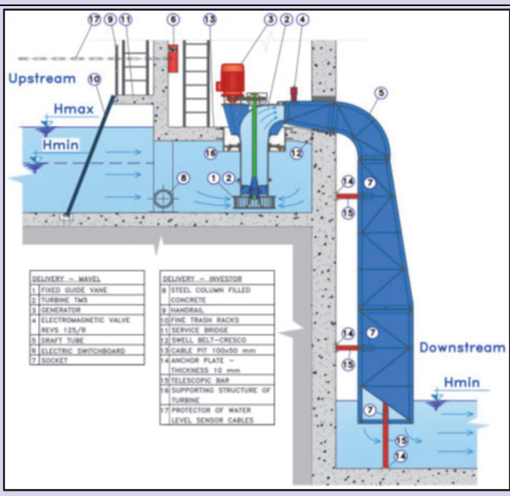
Turbine Name	**SIPHON-TYPE TURBINE**
Company name	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel	+27 21 552 9993
Company E-mail	karenr@sciontechnologies.co.za
Website	www.mavel.cz
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

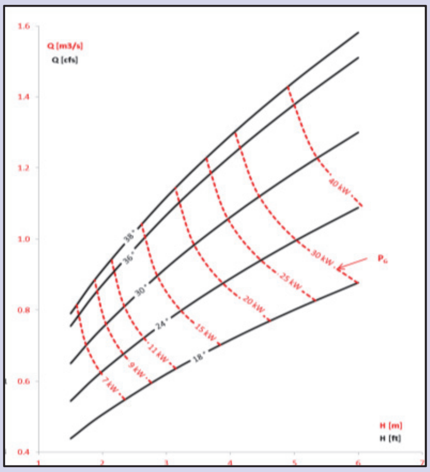
Turbine runner for Palmiet, South Africa



Turbine layout



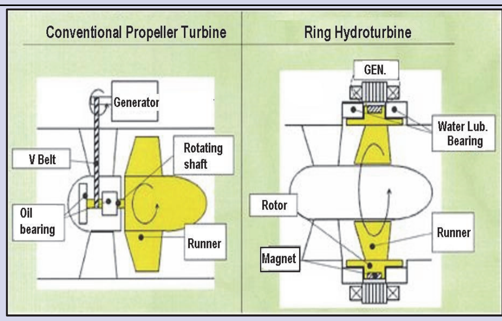
Construction drawing of a Syphon turbine



Turbine range (MT5)

<table>
<tr><th colspan="3"></th></tr>
<tr><td>Turbine Name</td><td colspan="2">RING HYDROTURBINE</td></tr>
<tr><td>Company name</td><td colspan="2">Kawasaki Plant Systems Ltd.</td></tr>
<tr><td>Company Address</td><td colspan="2">1-14-5, Kaigan, Minato-ku
Toyo
JAPAN
8315</td></tr>
<tr><td>Company Tel</td><td colspan="2">+81-3-3435-2111</td></tr>
<tr><td>Company E-mail</td><td colspan="2">Not given</td></tr>
<tr><td>Website</td><td colspan="2">www.khi.co.jp</td></tr>
<tr><td>Turbine Description</td><td colspan="2">This high efficiency inline system is easily installed in small spaces and has requires little maintenance.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">3 m to 30 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.14 m^3/s to 2.8 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">20 to 500 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>

Ring hydroturbine</td><td>



Ring and propeller comparison</td></tr>
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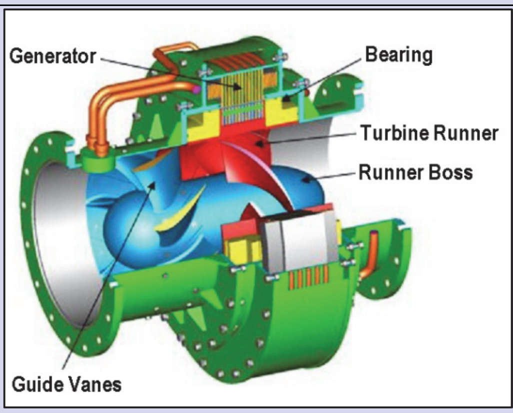
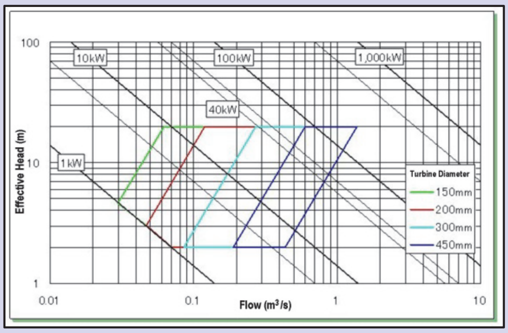


Turbine layout</td><td>



Turbine ranges</td></tr>
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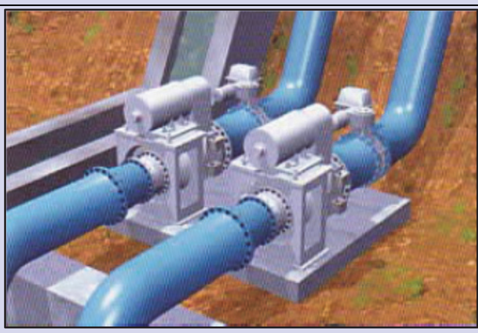
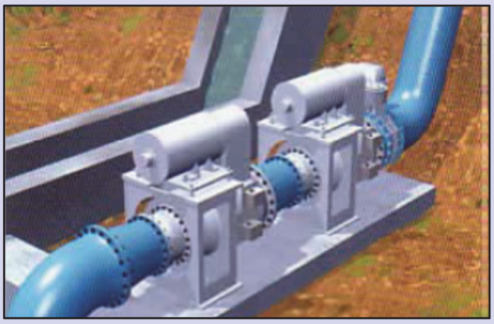
Turbine Name	**HYDRO E-KIDS**
Company name	**Toshiba International Corporation Pty Ltd**
Company Address	66-2, Horikawa-Cho Saiwai-Ku Kawasaki 212-8551 JAPAN
Company Tel	+81-44-548-3406
Company E-mail	Hydro-eKIDS@toshiba-eng.co.jp
Website	http://www.tic.toshiba.com.au/product_brochures_and_reference_lists/ekids.pdf
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 m³/s to 3.5 m³/s
Power Range	5 to 200 kW

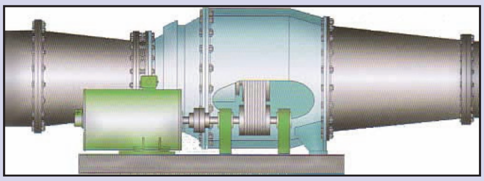
Illustrations, Photos and Applicable Graphs



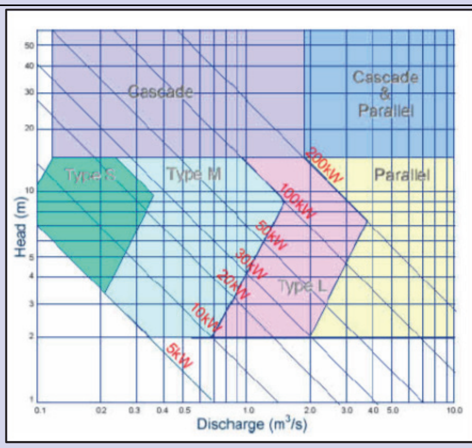
Turbines in parallel



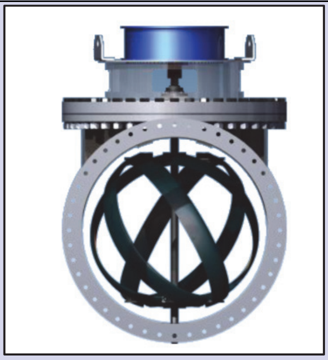
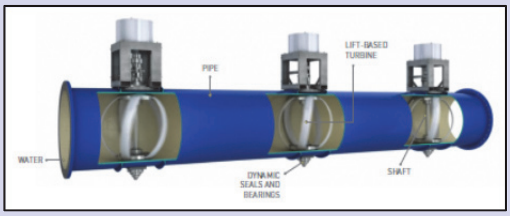
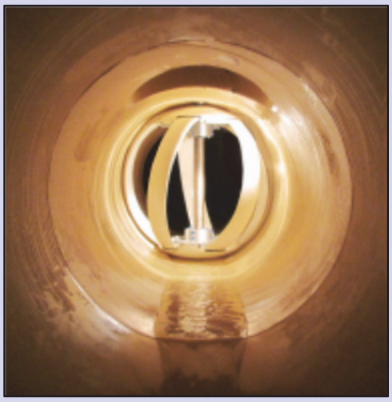
Turbines in series

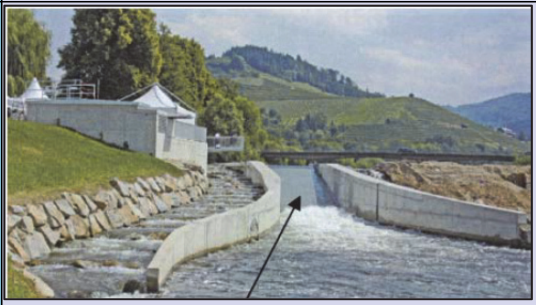
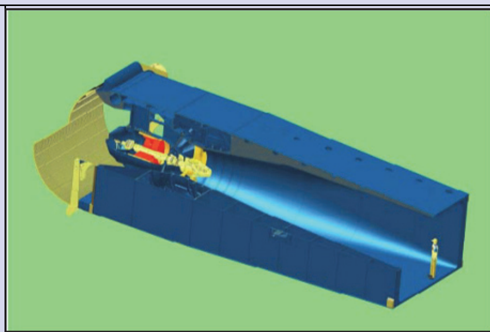
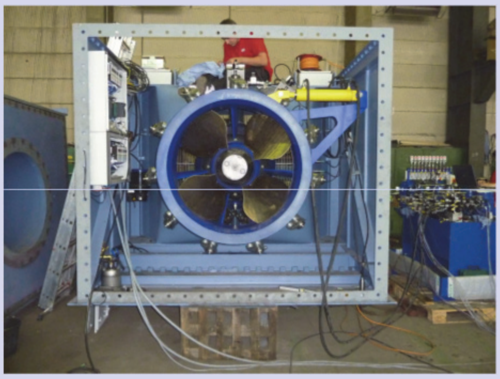


Turbine layout



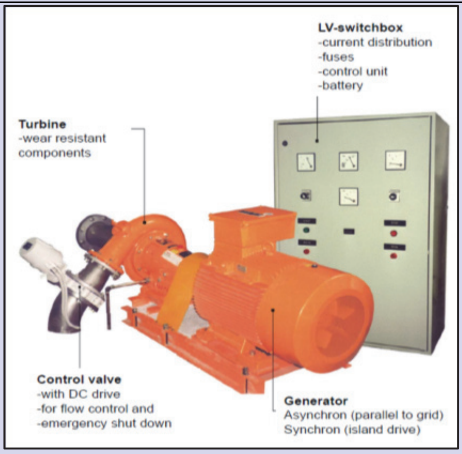
Turbine ranges

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*

<table>
<tr><td>Turbine Name</td><td colspan="2">PUMP AS TURBINE</td></tr>
<tr><td>Company name</td><td colspan="2">Andritz</td></tr>
<tr><td>Company Address</td><td colspan="2">Penzinger Strasse 76
Vienna
AUSTRIA
1141</td></tr>
<tr><td>Company Tel</td><td colspan="2">+43 (1)891 00 0</td></tr>
<tr><td>Company E-mail</td><td colspan="2">hydro@andritz.com</td></tr>
<tr><td>Website</td><td colspan="2">www.andritz.com</td></tr>
<tr><td>Turbine Description</td><td colspan="2">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</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">3 m to 80 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.03 m³/s to 6 m³/s</td></tr>
<tr><td>Power Range</td><td colspan="2">30 kW to 10 000 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs</td><td>

Installed turbines</td><td>



Turbine components</td></tr>
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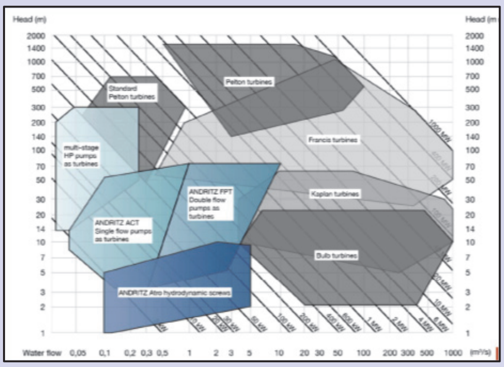
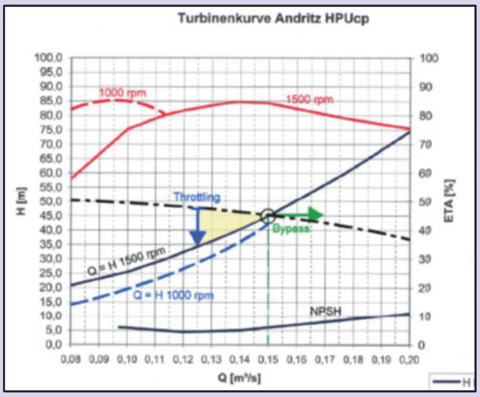


Turbine range</td><td>



Turbine curve</td></tr>
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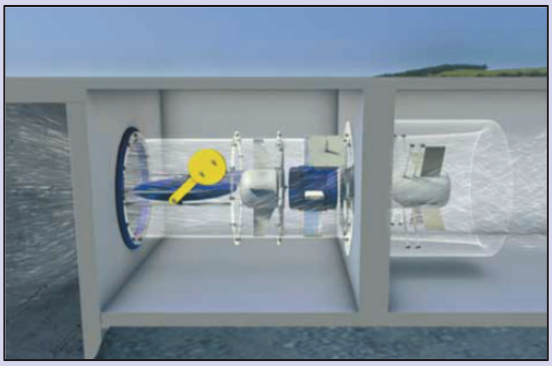
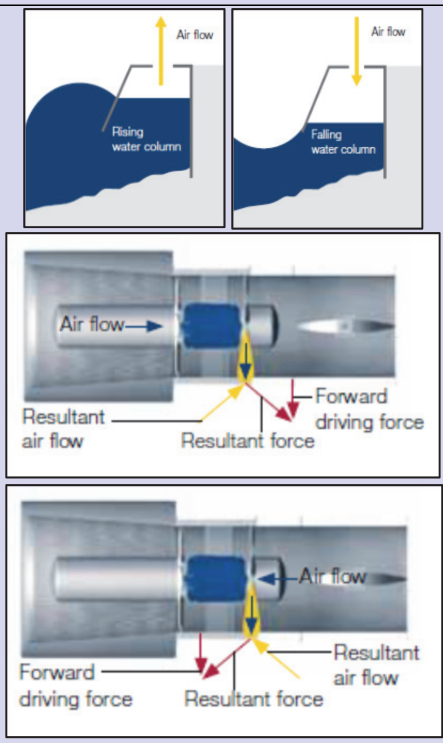
Turbine Name	**WAVEGEN**
Company name	**Voith Hydro Holding GmbH & Co. KG**
Company Address	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel	+49 7321 37 0
Company E-mail	info.voithhydro@voith.com
Website	www.voithhydro.com
Turbine Description	Wave power technology is considered new technology compared to hydropower and wind power. Voith Hydro Wavegen harnesses wave power and converts it into electricity using environmentally friendly technologies.
Pressure Head Range	Not given
Flow Range	Not given
Power Range	Not given

Illustrations, Photos and Applicable Graphs

Installed turbine



3-dimensional model of turbine



Turbine philosophy

APPENDIX B

Zeekoegat WWTW Design Drawing

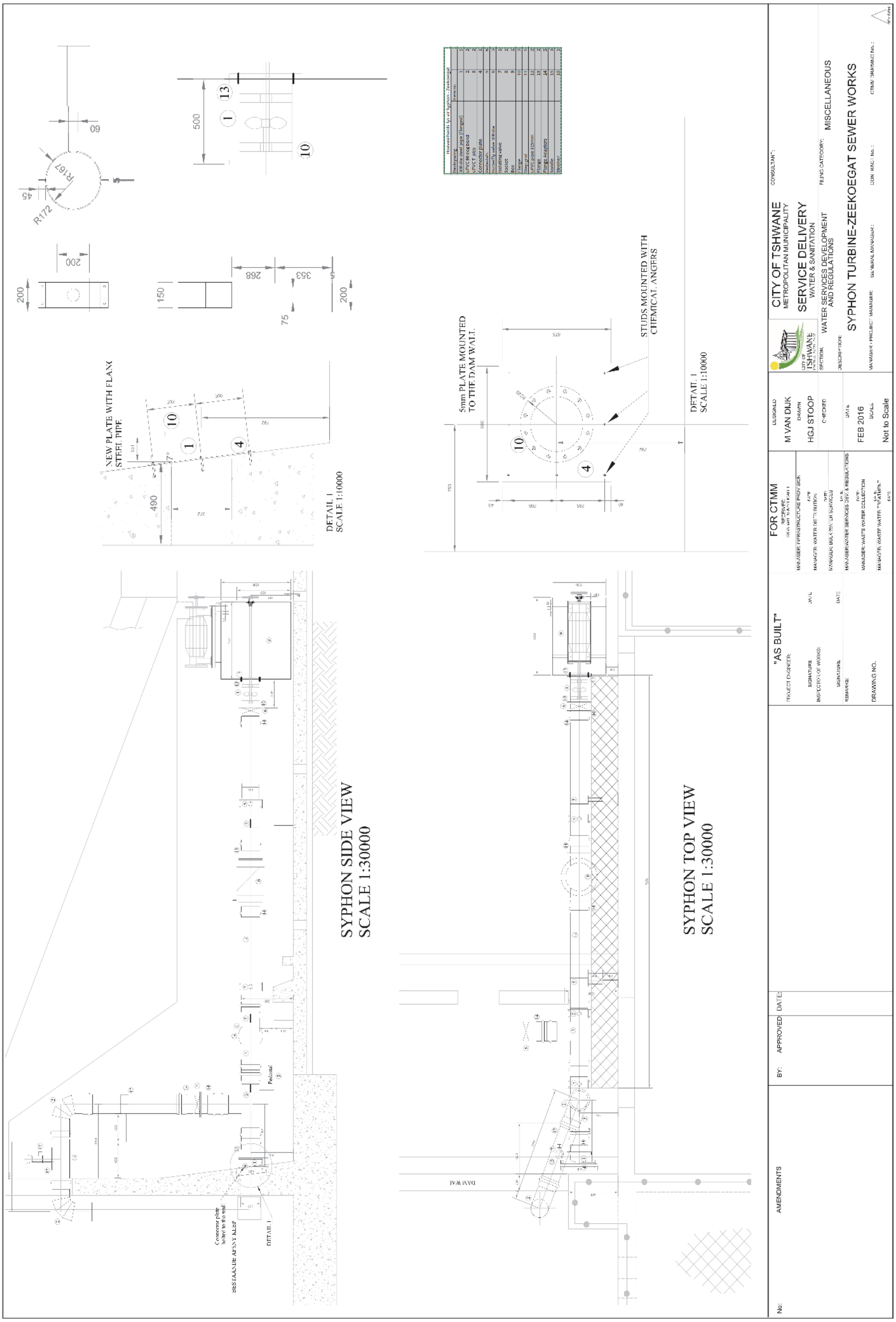


Figure B1: Pipework for turbine installation – Zeekoegat WWTW