Scoping study: Energy generation using low head hydro technologies

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Executive Summary

This report reflects the findings of the Scoping Study on "***Energy generation using low head hydro technologies***".

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 and finally the discussion of specific sites where the technology can be implemented.

Layman's reference to power generation

In this document reference to hydropower potential will be given in kilowatt (kW) or megawatt (MW) and depending on the availability of the facility during a given period (load factor) the energy can then be reflected as kilowatt hours (kWh) or megawatt hours (MWh). To bring this into perspective, 1 kWh could be used to boil water in a kettle for about a half an hour or provide 16 rooms with light.

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 is applicable to sites with less than 5 metres of head (Campbell, 2010). This definition is however negated by the definition reflecting that heads up to 30 m should be identified as low head (ESHA, 2004).

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. **Table i** indicates the different technologies for different operating heads associated with the specific turbine group.

Information of the potential technologies was obtained and for each a data sheet was compiled. The information is included in **Appendix A** and discussed in **Section 6.2**.

Table i: Scheme classification according to head (ESHA, 2004)

Classification	Head (m)
High head	>100
Medium head	30-100
Low head	2-30

Potential sites where low head hydropower can be generated

The potential sites where low head hydropower 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, storm water systems and WDS).

Table ii reflects the estimated hydropower potential in South Africa.

Table ii: Estimates of the country-wide potential for low-head hydropower development

Low head hydropower location	Estimated potential (MW)	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

Recommendations

The study illustrated that there is an untapped source of hydropower which should be harnessed. It also reflected that the hidden or unused potential in run-of-river generation; impoundments and irrigation schemes should be seen as priorities.

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 release more interest and commitment to hydropower generation;
    - pilot 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;
    - an example 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;
- Development of manuals to assist prospective small low-head hydropower developers/proponents for rural electrification in dealing with the technical, site evaluation, financial and regulatory aspects of such developments; and
- Detailed study be undertaken on the legislative and regulatory aspects of small hydropower especially for run-of river schemes; 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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LIST OF ABBREVIATIONS

Abbreviation	Description
AADD	average annual daily demand
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
CDA	Colorado Department of Agriculture
CPI	consumer price index
CSP	concentrated solar power
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy
DoE	Department of Energy
DWA	Department of Water Affairs
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
FSL	full supply level
GDP	gross domestic product
GWS	Government Water Schemes
HRM	Hydropower Retrofitting Model
IBT	inclining block tariff
IHA	International Hydropower Association
INE	Integrated National Electrification
IP	indexation price

IPP	independent power producer
IRP	integrated resource plan
IRR	internal rate of return
MAR	mean annual runoff
MSA	Municipal Services Act
NDC	network demand charge
NERSA	National Energy Regulator of South Africa
NMBMM	Nelson Mandela Bay Metropolitan Municipality
NPV	net present value
NWRI	National Water Resources Infrastructure
NWRS	National Water Resources Strategy
O&M	operation and maintenance
O-F S WTS	Orange-Fish Sundays Water Transfer Scheme
PPA	power purchase agreement
PPP	public private partnership
PRS	pressure reducing station
PRV	pressure reducing valve
PV	solar photovoltaic
RE	renewable energy
REBID	Renewable Energy Bidding
REFIT	Renewable Energy Feed-In Tariff
REIPPP	Renewable Energy Independent Power Producer Procurement
ROE	return on equity
RSC	reliability service charge
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
SLA	service level agreement
SWEC	Stellenbosch Wave Energy Converter
UK	United Kingdom

US	United States
USBR	United States Bureau of Reclamation
WMA	water management areas
WMP	water management programme
WSA	water services authority
WSP	water services provider
WTS	water transfer scheme
WUA	water users' association
WUL	water use licence
WWTP	wastewater treatment plant

LIST OF SYMBOLS

Symbol	Description	Unit
C_h	cost of hydropower project	-
c_u	unit cost	R/kW
D	diameter of penstock or pipe	m
F_d	discount cost factor	-
g	gravitational acceleration (typically 9.81 m/s^2)	m/s^2
H	effective pressure head	m
h_f	friction loss	m
h_l	secondary losses	m
i	discount rate or escalation rate	%
I	electrical current	A
K	secondary loss coefficient	-
L	length of penstock	m
LCC	life cycle cost	R
n	number of years	-
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
Q	flow rate through the turbine	m^3/s
t	time actually worked	h
T	theoretical time	h
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
Z_1	elevation of the water above datum line, in the streamline at Station 1	m
Z_2	elevation of the water above datum line, in the streamline at Station 2	m
η	hydraulic efficiency of the turbine	%
λ	friction coefficient of penstock or pipe	m
ρ	hydraulic efficiency of the turbine	%

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 usually expressed in kilowatts at a given instant or averaged over any 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 for the period during which 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. 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 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, to turn a generator. Examples are Pelton, Turgo and Crossflow turbines.
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.
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.
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 rapid closure of a valve 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.

1 INTRODUCTION

1.1 STUDY BACKGROUND

Energy is the lifeblood of worldwide economic and social development. When considering the current status of global energy shortages, the emphasis to reduce CO_2 emissions, development of alternative energy generation methods and growing energy consumption, it is clear that there is a need to change the way energy is created and used. The demand for energy increases continuously and those demands need to be met in order to stimulate worldwide development. Fossil fuels contribute a large majority of global energy, but due to the dangers of global environmental impacts, the expansion of fossil fuel as an energy source is in some cases resisted. This forces our current generation to focus on the development of renewable energy sources.

This project emanated from the need identified to focus on renewable energies. Hydropower contributes only 3% of global energy consumption which is only a fraction of its potential. Africa is the most underdeveloped continent with regard to hydropower generation with only 6% of the estimated potential exploited. This should not be seen as a burden, but rather as an opportunity.

In South Africa we are facing an energy crisis which places additional importance of harvesting all available feasible renewable energies. Rolling power cuts that hit the entire country at the start of 2008 made all citizens aware of the fact that demand for electricity is grossly outstripping supply. Energy experts say South Africa has moderate hydroelectric potential, and that the establishment of small hydroelectric projects around the country could help provide a sustainable future energy supply.

As described by Barta, unconventional hydropower development can take place in both rural and urban areas of South Africa, such as tapping hydropower from irrigation canals, water supply pipelines, deep mining undertakings, etc. (Barta, 2002).

It is believed that there are many untapped opportunities to generate electricity using hydropower technologies. Technologies have also improved over the last couple of decades which now allows the development of previously unfeasible sites.

Essentially there is a need for the review of technology available for a low-head hydropower generation, evaluation of small scale hydropower potential and proposals on how available energy may be extracted from existing hydraulic infrastructure operating in SA. The following objectives were set for this project:

1. Review the available low head hydro technologies.
2. Identifying potential sites for low head hydropower development in SA.
3. Reviewing the feasibility of generating low head hydropower systems.
4. Estimating the country wide potential for low head installations.th Africa.

It is believed that this report provides valuable insight into the current state of affairs with regard to available low head hydropower technologies and the potential application of these in South Africa

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its Parties by setting internationally binding emission reduction targets. This has brought attention to the development of new renewable energy technology facilities including the use of 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 operate at 95% efficiency converting the potential head into electricity.

In South Africa, mainly due to relative scarcity of surface water storage, there is a prevailing perception that the potential for the conventional hydropower development is rather low. However the country's 1082 dams store about 65 percent of the mean annual surface runoff (MAR) of 49 210 million m^3/a (WRC, 2005). At present only seven dams are equipped with hydropower generation plants, the largest being the Gariep hydropower plant situated on the Orange River with an operational capacity of 360 MW (pumped storages facilities are excluded as these are not considered "green" and installed for a peak power clipping). In South Africa there are almost 4 500 registered dams of all sizes providing water mainly for the irrigation and urban/rural water users (**Table 1-1**).

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

Dam size classification (height of wall)	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, dams are built for various purposes including flood control, irrigation of agricultural land, urban/rural water supply, stock watering, recreation and hydropower generation. Most of the dams built in SA prior to the Second World War, 1939, were primarily to supply the irrigation demands. Over time the main purpose of a dam might change according to the type of water demand.

According to the draft of the National Water Resource Strategy 2 (NWRS 2), water stored in all of our dams and the water drawn from dams and ground is made available to agriculture/irrigation (60%), municipal/domestic (27%), industrial (3%), power generation (2%), mining (2,5%), livestock and nature conservation (2,5%) economic sectors. The water for a forestation is represented as reduction in the surface runoff (3%) (DWA, 2012a). The largest quantities of raw water made available for irrigation and municipal economic sectors are delivered through extensive water supply and wastewater 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	See **Table 6-2** and **Table 6-3**

Note: This classification results in most of the dams in SA falling under low head installations

The study's main focus was to identify and evaluate the potential low head hydropower applications in existing irrigation systems, river systems and wastewater 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. Several irrigation schemes were studied in detail to determine low head hydro-electrical potential. Similarly the river flow gauging infrastructure (i.e. gauging weirs) and urban wastewater plants were investigated for low head hydropower potential. Various sites, with potential ranging from pico to small hydropower installations (as defined in **Table 1-3**), were identified.

Table 1-3: Categories of small hydroelectric capacity applications (Barta, 2010)

Hydropower category	Capacity in power output	Potential hydropower use either as a single source or in a hybrid configuration with other sources of renewable energy
Pico	Up to 20 kW	10 kW network to supply a few domestic dwellings
Micro	20 kW to 100 kW	100 kW network to supply small community with commercial/manufacturing enterprises
Mini	100 kW to 1 MW	1 MW to 10 MW network – electrical distribution will be at medium voltage ranging from 11 to 33 kV and transformers are normally needed. The generation must be synchronised with the grid frequencies (typically to 50 or 60 Hertz).
Small	1 MW to 10 MW	
NB: All installations above 10 MW are classified as macro (or large) hydropower plants		

Electricity – The basics you should know

Electricity is measured in units of power called watts (W).

- 1 000 watts = 1 kilowatt (kW)
- 1 kilowatt hour (kWh) = 1000W or 1 kW working for one hour
- Electricity is measured in kilowatt hours, and on the electricity bill each kilowatt hour is shown as a unit

All household appliances are rated in watts or kilowatts. This indicates how much electricity the appliance uses in a certain amount of time. For example, a 1 kW kitchen appliance uses one unit of electricity an hour. A 100 watt light bulb uses one unit of electricity every 10 hours. The average consumption of all households in South Africa is 1100 kWh/month according to Eskom.

In a typical home South African households, on average, electricity is used in the following ways:

- Space heating and cooling: 18%
- Lighting: 17%
- Fridges and freezers: 8%
- Cooking: 11%
- Consumer electronics: 5%
- Consumer electronics on standby mode: 15%
- Geysers: 24%
- Miscellaneous: 2%

As an example the installation of a 100 kW hydropower turbine would be equivalent to the average energy demand of 65 households in South Africa.

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 the uninterrupted electricity supply and moderate tariffs in South Africa has resulted in passive users. In 2008 this changed when shortages in the supply of electricity started to emerge.

Presently, South Africa is facing an energy crisis which amongst other reflects the 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 the cost of generation and transmission. Strategically it remains important to maintain a sustainable margin between the generating capacity and demand and supply. Coal will remain an economically viable generating option and will continue to be the most attractive source of energy in South Africa. To secure this the environmental and sustainability perspectives need to be explored and evaluated against the relative environmental cost of coal (Evans et al., 2009).

2.1.2 Current sources of energy in South Africa

Other than coal-fired power stations, electricity supply in South Africa is also generated by a nuclear power station, hydroelectric schemes, pumped storage schemes, open cycle gas turbines and wind farms. Recent figures for the breakdown of GWh produced in South Africa by the different electricity generation technologies, were reported by Statistics

South Africa (2012). This report reflected electricity generation in South Africa in 2011 when 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.

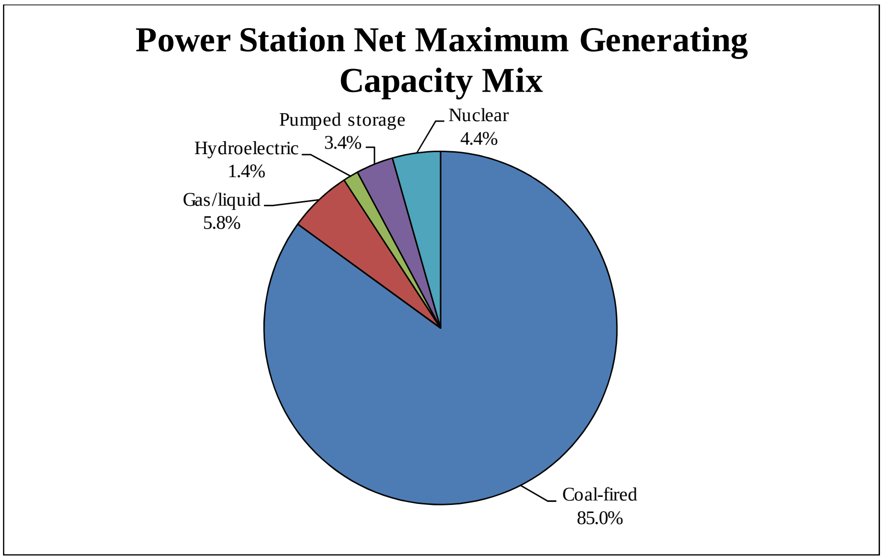


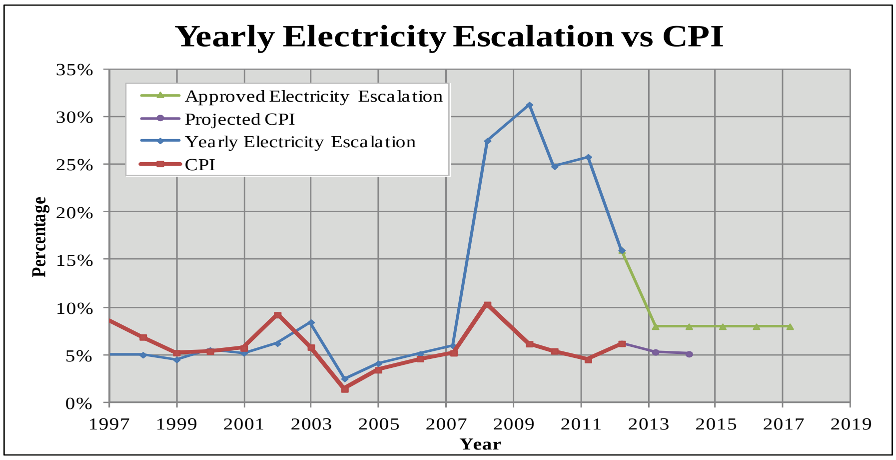
Figure 2-1: Power station net maximum generating capacity mix (Eskom, 2012a)

2.1.3 Electricity price increases

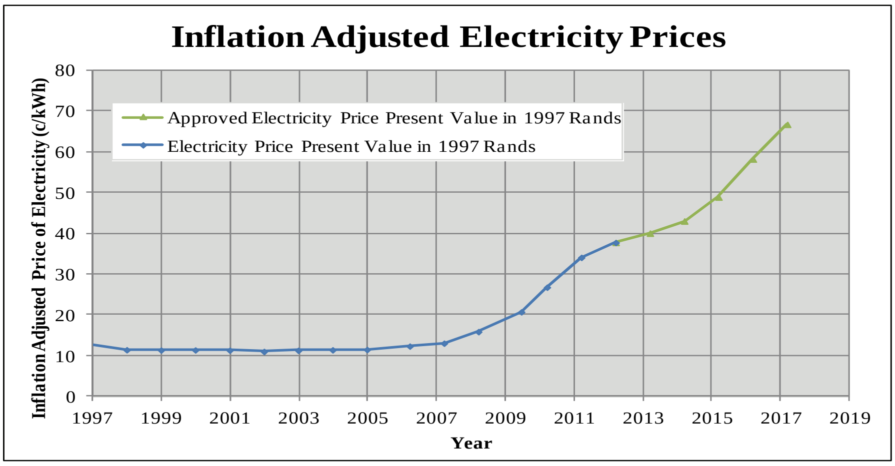
For many years, the average increase in electricity tariffs in the country was below inflation. Since April 2008, electricity tariff increases have been significantly above inflation every year, with inflation-adjusted prices increasing about threefold between 1997 and 2012, as illustrated in **Figure 2-2 (a)** and **(b)**. NERSA approved an average annual tariff increase of 8% for the five year period from April 2013 until April 2017. This will result in an average electricity tariff increase of more than 220% between 1997 and 2017 (Eskom, 2012b; Eskom 2012c; Eskom 2013b), as shown in **Figure 2-2 (c)**.

The main reason for the significant hike in electricity prices is because electricity generation has been subsidised for many years and supplied below cost to consumers.

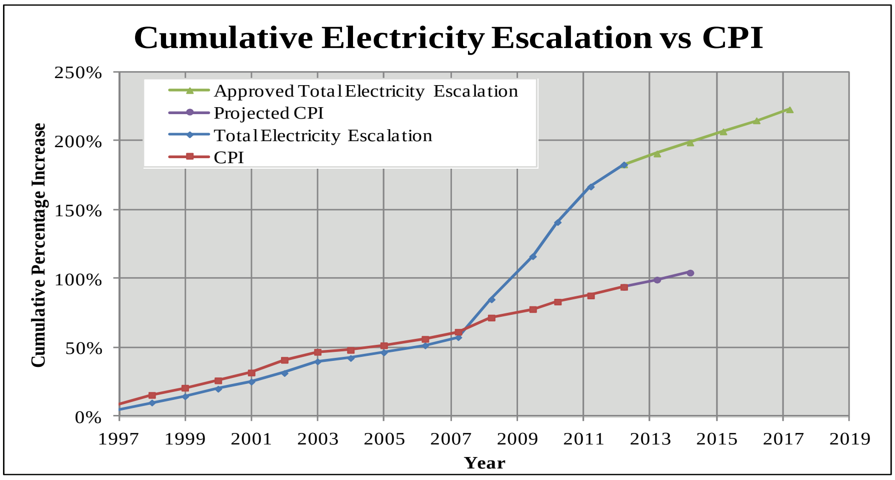
However, this practice is not sustainable and electricity prices need to become cost-reflective to support a future sustainable electricity supply industry (Eskom, 2012b).



(a)



(b)



(c)

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

The National Energy Regulator of South Africa (NERSA) announced its determination on Eskom's Multi Year Price Determination (MYPD3) application on 28 February 2013. NERSA allowed Eskom to raise tariffs by an average of 8% per annum for the next 5 years. For 2013/14, Eskom is permitted to recover R135 226 million from sales of 206 412 GWh at an average price of 65.51 c/kWh, increasing to 89.13 c/kWh in 2017/18.

The tariff increase will be implemented on 1 April 2013 for Eskom direct customers and on 1 July 2013 for municipalities. The various types of tariff structures are described in **Table 2-1.** Details of the tariff structure options can be found in *Eskom's Tariffs & Charges Booklet 2013/14* (Eskom, 2013c).

Table 2-1: Tariff structure options

Consumer type	Description
Nightsave Urban Large	Electricity tariff for high load factor urban$_p$ customers with a notified maximum demand (NMD) greater than 1 MVA.
Nightsave Urban Small	Electricity tariff for high load factor urban$_p$ customers with an NMD from 25 kVA up to 1 MVA.
Megaflex	Time of Use (TOU) electricity tariff for urban$_p$ customers with an NMD greater than 1 MVA able to shift load.
Miniflex	TOU electricity tariff for urban$_p$ customers with an NMD from 25 kVA up to 5 MVA able to shift load.
Business rate	Suite of electricity tariffs for commercial usage and for high consumption, non-commercial supplies such as churches, schools, halls, clinics, old-age homes or similar supplies in urban$_p$ areas an NMD of up to 100 kVA.
Public Lighting	Electricity tariff for public lighting or similar supplies where Eskom provides a supply for, and maintains, any street lighting or similar public lighting.
Residential tariffs (non-local authority and local authority) – Homepower bulk	Electricity tariff for residential bulk supplies, typically sectional title developments and multiple housing units, in urban$_p$ areas.

Table 2-1: Tariff structure options (continued)

Consumer type	Description
Residential tariffs (non-local authority and local authority) – Homepower standard HOMEPOWER	Suite of electricity tariffs for residential customers with conventionally metered supplies and also may be applied to supplies such as churches, schools, halls, clinics, old-age homes or similar supplies in urban$_p$ areas with an NMD of up to 100 kVA.
Residential tariffs (non-local authority) – Homelight HOMELIGHT	Suite of electricity tariffs based on the size of supply that provides a subsidy to low-usage single phase residential supplies in urban$_p$ and electrification areas.
Nightsave Rural NIGHTSAVE	Electricity tariff for high load factor rural$_p$ customers, with an NMD from 25 kVA at a supply voltage≤ 22 kV (or 33 kV* where designated by Eskom as rural$_p$).
Ruraflex RURAFLEX	TOU electricity tariff for rural$_p$ customers with dual and three-phase supplies with an NMD from 25 kVA with a supply voltage ≤ 22 kV (or 33 kV where designated by Eskom as rural$_p$).
Landrate LANDRATE	Electricity tariff for rural$_p$ customers with single, dual or three-phase conventionally metered supplies with an NMD up to 100 kVA with a supply voltage ≤ 500 V.
Landlight LANDLIGHT	An electricity tariff that provides a subsidy to low-usage single phase supplies in rural$_p$ areas, limited to 20A is only offered as a prepaid supply.

In cases where the electricity demand will be reduced, any economical evaluation will have to be based on discounting the development investment against the existing tariff structure.

2.2 REGULATORY REQUIREMENTS OF HYDROPOWER DEVELOPMENT

2.2.1 General

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

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 permits are logged and processed.

Generally, any type of hydropower development will have to adhere to 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 assets (i.e. dams, canals, pipelines, etc.) by an independent private entity if situated in a defined servitude;
- to scrutinize project proposal and compared to the environmental impact assessment (EIA) (Act 73/1989 and Act 108/1998) requirements, particularly applicable for "greenfield" hydropower projects;
- to propose 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 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 the generated energy is not for in-house consumption; and
- to arrange and guarantee project financing.

2.2.2 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. It also regulates the wastewater dischargers as well as irrigation flow with licensing requirements.
- **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.

2.2.3 Institutional stakeholders in development of hydropower

- **Department of Water Affairs (DWA) –** DWA is the custodian of all surface and ground water resources. It is primarily responsible for the formulation and implementation of policies governing the water sector.
- **Department of Environmental Affairs (DEA) –** 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 a balanced sustainable development through equitable distribution of benefits derived from the natural resources.
- **Department of Energy (DoE) –** DOE is responsible for ensuring exploration, development, processing, utilization and management of SA's mineral and energy resources. The energy development programmes currently being 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) –** NERSA is a regulatory authority established under the National Energy Regulator Act (Act 40 of 2004). NERSA regulates the Electricity, Piped-Gas and Petroleum industries as per the relevant acts.
- **Eskom Holdings Limited –** ESKOM 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) –** 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) –** 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)** – 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)** – 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) – Water Utilities (WUs) 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 20 WUs in SA.

2.2.4 Regulatory landscape for hydropower development

Internationally the development of hydropower is guided by the Hydropower Sustainability Assessment Protocol (IHA, 2010). This document has been compiled by the International Hydropower Association (IHA) and it is proposed that it be used to assist in the 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. The Hydropower Sustainability Assessment Protocol (the "Protocol") is a sustainability assessment framework for hydropower projects and operations. It outlines the important sustainability considerations for a hydropower project, and enables production of a sustainability profile for that project. The four Protocol assessment tools – Early Stage, Preparation, Implementation, and Operation – are designed to be standalone assessments applied at particular stages of the project life cycle. An assessment with one tool does not depend on earlier stage assessments to have been undertaken.

The assessment tools are designed to be applicable up to major decision points in the project life cycle, and are most effective where there are repeat applications to help guide continuous improvement measures. The assessment tools and associated decision points are shown in **Figure 2-3**. This tool can be used during all stages of hydropower project development: early stage, preparation, implementation and operation.

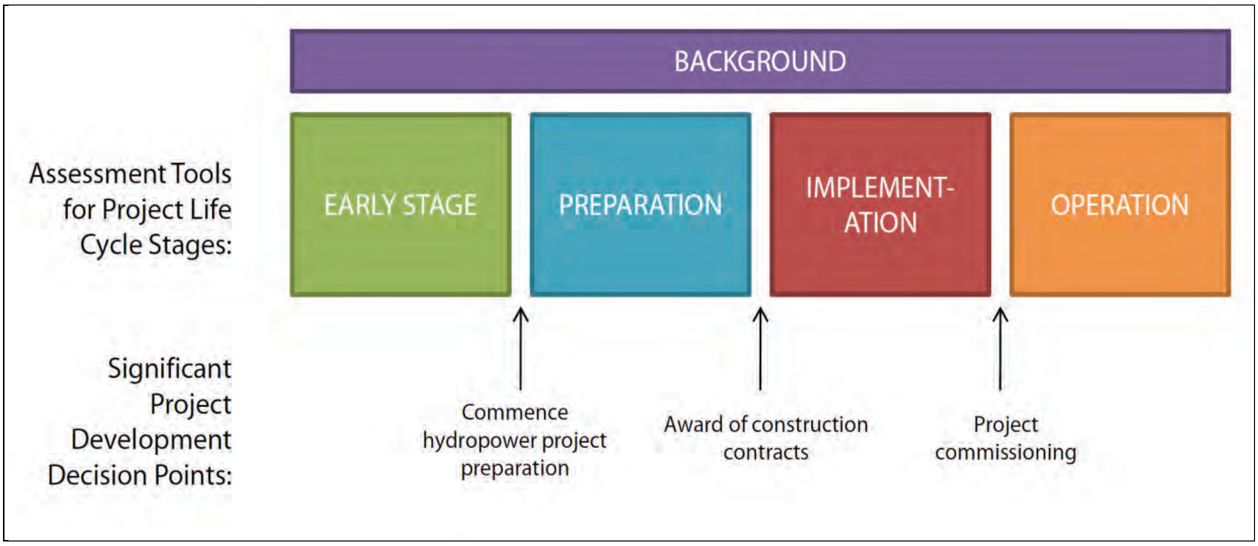


Figure 2-3: Protocol Assessment Tools and Major Decision Points (IHA, 2010)

Within each Protocol assessment tool is a set of topics important to forming a view on the overall sustainability of that project at that point in its life cycle. Topics, when taken together, provide the list of issues that must be considered to confidently form a view on the overall sustainability of a hydropower project at a particular point in its life cycle.

Table 2-2 shows the perspectives which are captured by the Protocol topics. It is recognised that an individual topic is not always neatly labelled as a particular perspective. For example, water quality may be typically seen as an environmental perspective, but poor water quality may have strongly negative social consequences. Some of the topics provide an integrative function across the other perspectives, for example Integrated Project Management.

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

Table 2-2: Topics included in the Hydropower Sustainability Assessment Protocol (IHA, 2010)

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

In South Africa, due to almost forty years of absence in hydropower development, resulted in a lack of a programmes guiding the sustainable hydropower development. The typical development stages of projects in SA is shown in **Figure 2-4**. The projects presently being developed in SA are managed more or less according to the sequences given in **Table 2-3**.

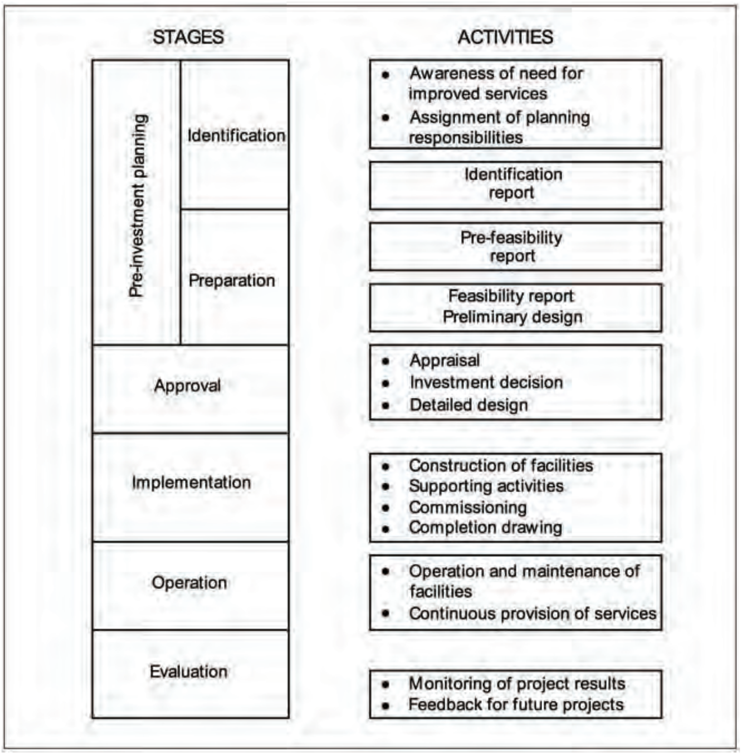


Figure 2-4: Development stages of water infrastructure projects (CSIR, 2005)

Table 2-3: Pre-construction development stages of small hydropower (up to 10 MW)

Project stage	Project development stage	Regulatory requirements
Identification/ Planning stage	**Project Identification/planning** – finding a suitable site and potential energy target market that lies within an acceptable distance from the 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	**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	**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 applicable licences (Water Affairs, etc.) 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.		

Table 2-4 illustrates the extent of development of a typical hydroelectric scheme, listing the key components normally required to erect a "greenfield" islanded hydropower scheme.

Table 2-4: Development layout and components of a typical hydroelectric scheme

Potential source of hydro-energy	Generation of hydro-energy		Transmission of hydro-energy
	Civil/mechanical items	Electrical/ electronic items	
• 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 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) dictates what permits are needed for hydropower development. **Table 2-5** gives a summary on water use permits from the DWA and DEA.

Repair, rehabilitation or upgrading of hydroelectric plants built before 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. These could be plants owned by DWA, WSA, WSP, WUA or private ownership.

Table 2-5: Summary on water use permits from DWA and DEA

<table>
<tr><th colspan="2">Hydropower generation options</th><th>Water use permits</th><th>Remark on regulations to be observed and legislation consulted</th></tr>
<tr><td rowspan="3">Augmentation of existing water supply infrastructure</td><td>In-line closed conduits</td><td rowspan="3">Water permit not normally required if not state's asset</td><td rowspan="3">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)</td></tr>
<tr><td>Low head hydropower</td></tr>
<tr><td>Small scale pumped storages</td></tr>
<tr><td rowspan="3">Adding hydropower plants to existing non-powered dams</td><td>High head (>100 m)</td><td rowspan="3">Water permit is required subject to possible exception</td><td rowspan="3">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</td></tr>
<tr><td>Medium head (30 to 100 m)</td></tr>
<tr><td>Low head (2 to 30 m)</td></tr>
<tr><td rowspan="3">Development of "greenfield" hydropower not associated with existing infrastructure</td><td>Run-of-river</td><td rowspan="3">Water permit is required subject to possible exception</td><td rowspan="3">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.</td></tr>
<tr><td>Storage regulated hydropower</td></tr>
<tr><td>Pumped storage Schemes (PSS)</td></tr>
<tr><td colspan="4"><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.</td></tr>
</table>

Table2-6 illustrates a summary on the electricity generation permits from the National Energy Regulator of SA (NERSA).

Table 2-6: Summary on electricity generation permits from NERSA

Electricity generation option	Electricity generation licence requirements	Remarks
Own use **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.
Islanded use **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.
Municipal grid connection **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) • SLA between municipality and electricity SP (if appl.)
Eskom grid Connection **Electricity generated is fed directly into the Eskom grid**	**Generation licence required per power generation station**	Refer to: • Renewable Energy IPP Procurement Programme (REIPPP)

2.2.5 Independent Power Provider (IPP) Procurement Programme

The DoE used the powers mandated to them by the Electricity Regulation Act (Act 4 of 2006) and on August 3, 2011 issued the first order of the renewable energy capacity of a 3 725 MW allocated entirely to Independent Power Providers under the new procurement programme. This programme is based on a competitive bidding process intended to be implemented in several phases that will manifest from the bidding process outcomes.

Between 2011 and 2012 the DoE received 79 project proposals during the first and second bidding window which closed in March 2012. The total RE capacity potential amounted to more than 3 200 MW. From a rather large number of proposals only 19 preferred bidders were selected to develop a potential capacity of a 1 044 MW. Among the preferred projects were one concetrated solar power (CSP), nine solar photovoltaic (PV) projects, seven onshore wind projects, and two small scale hydropower projects. The preferred small scale hydropower projects included Stortmelk Hydro Project with proposed capacity of a 4.3 MW situated on the Ash River in the Free State province and the Neusberg Hydro-electric Project to install 10 MW hydropower capacity on the Orange River in the Northern Cape province. The compliance criteria framework for the renewable energy projects potential bidders as originally published by the DoE is given in **Table** 2.7.

Table 2-7: RE Independent Power Producer Procurement (REIPPP) Programme

Renewable Energy Independent Power Producers Procurement Programme (REIPPPP)	
Original REIPPPP (August 2011):	3 725 MW (by 2016)
• Large projects (1 MW to 140 MW)	3 625 MW
(i) hydropower allocation	75 MW
(ii) other RE technologies total allocation	3 550 MW
• Small projects (1 MW to 5 MW)	100 MW
(i) no allocation for hydropower	not defined
(ii) other RE technologies total allocation	100 MW
Extended REIPPPP (October 2012)	3 200 MW (by 2020)
• Large projects (1 MW to 140 MW)	3 100 MW
(i) hydropower allocation	60 MW
(ii) other RE technologies total allocation	3 040 MW
• Small projects (1 MW to 5 MW)	100 MW
(i) no allocation for hydropower	not defined
(ii) other RE technologies total allocation	100 MW
Note: 3rd bidding window is open until August 19, 2013 with remaining capacity 1165,6 MW left over from the Original REIPPPP Large Projects allocation of 3 625 MW.	

3 AN OVERVIEW OF HYDROPOWER

3.1 INTRODUCTION

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

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).

3.2 CONVENTIONAL TYPES OF HYDROPOWER

Hydropower generation is normally associated with large dams and associated generating facilities; it can also be generated in various other ways. The common denominator in all hydropower schemes is flowing and falling water (Natural Resources Canada, 2004). The following types of conventional hydropower schemes are discussed below:

- storage schemes;
- run-of-river schemes; and
- pumped storage schemes.

3.2.1 Storage schemes

Conventional hydropower depends on a water supply 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, although a necessity in a water scarce country such as SA. Usually hydropower development is an added benefit to the construction of the dam for other purposes.

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 by installing turbines directly in a river channel (Harvey et al., 1993).

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 for peak clipping. During off-peak hours water is pumped to an upper dam and when peak-time electricity is needed this water is released via turbines to 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 reserve while renewable energy is generated, typically with wind turbines. The stored water is then released through the turbines when electricity is needed (Bueno and Carta, 2006).

3.3 UNCONVENTIONAL TYPES OF HYDROPOWER

3.3.1 High head 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 listed 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

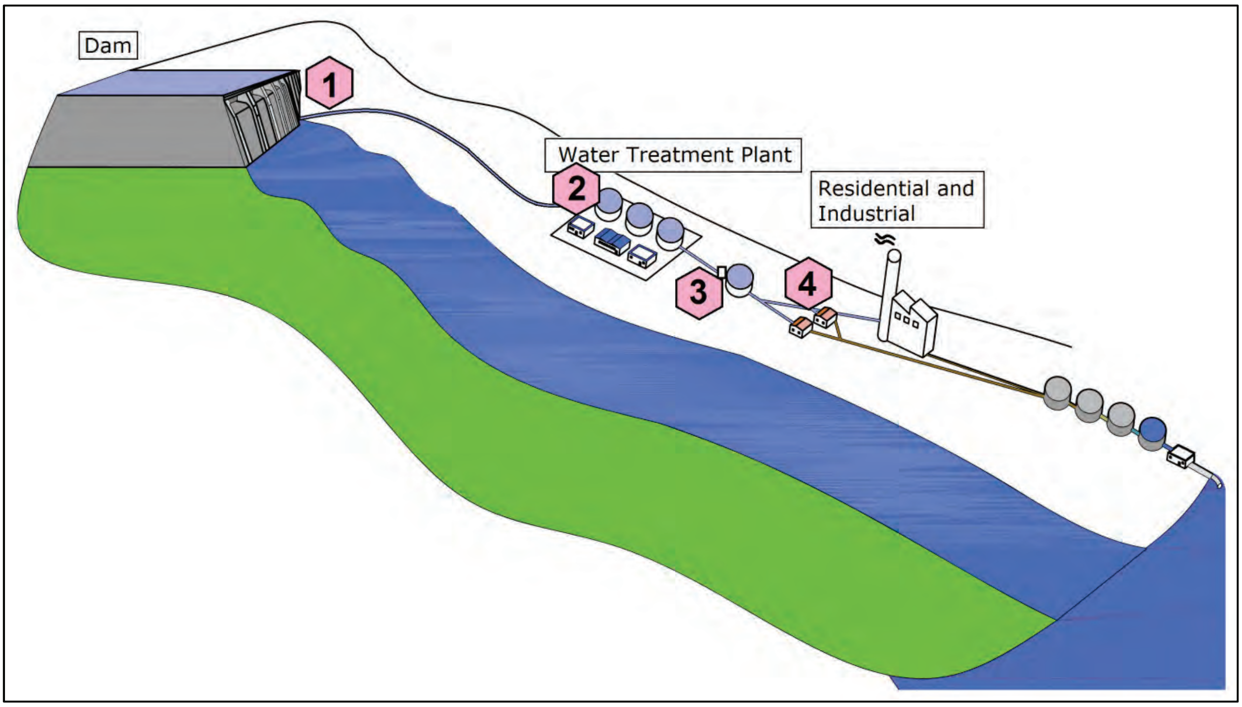


Figure 3-1: Potential energy-generation locations in WDS (Van Dijk et al., 2012)

3.3.2 Low head hydropower

There are generally eight areas with low 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

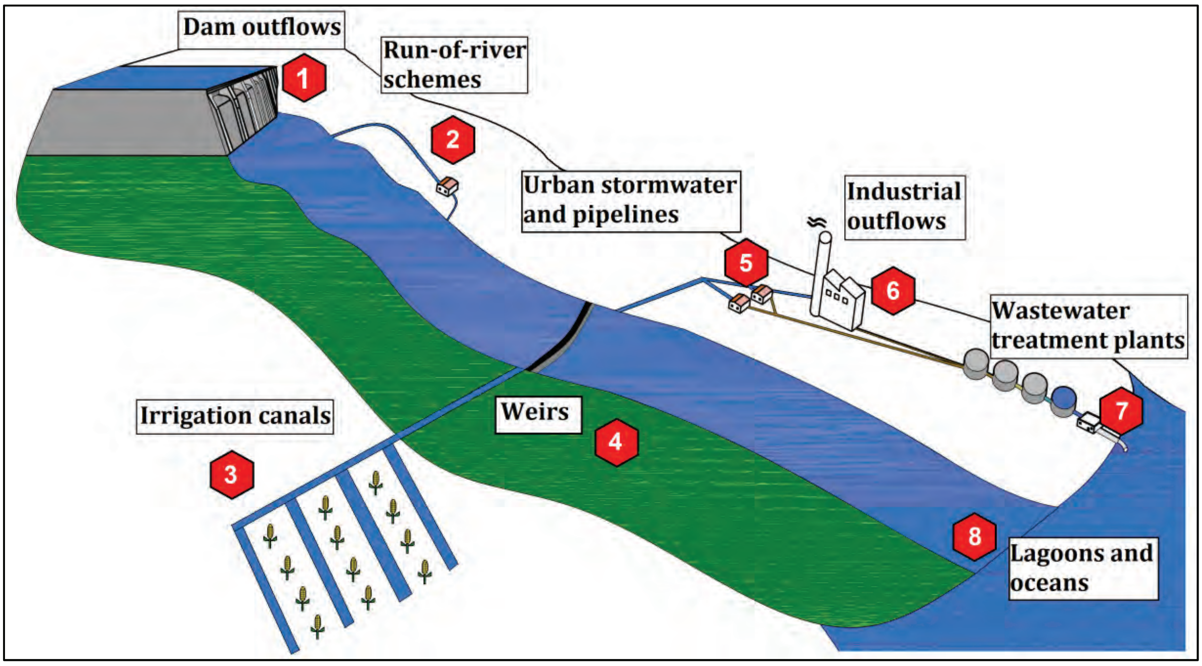


Figure 3-2: Potential low head energy-generation locations

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 a very long operational life (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).

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 focuses on low head installations, with pressure heads of up to 30 m.

4 PREVIOUS STUDIES ON HYDROPOWER POTENTIAL IN SOUTH AFRICA

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).

An overall assessment of hydropower potential in South Africa was conducted in a baseline study in 2002. The information collected in this study "enabled the formation of a much needed hydropower potential database for the future reference and planning of water resources development in South Africa" (Barta, 2002). The capacity of installed hydropower and future potential for hydropower development are summarised in **Table 4-1**.

Table 4-1: 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

An 'African Hydropower Database', with a section focusing on South African hydropower installations can be accessed on the Internet. **Figure 4-1** was retrieved from the database and shows all planned, existing and decommissioned sites in the country, as well as various potential sites (Jonker Klunne, 2013). Most of these sites would be classified as low head, based on the set classification in **Table 1-2**.

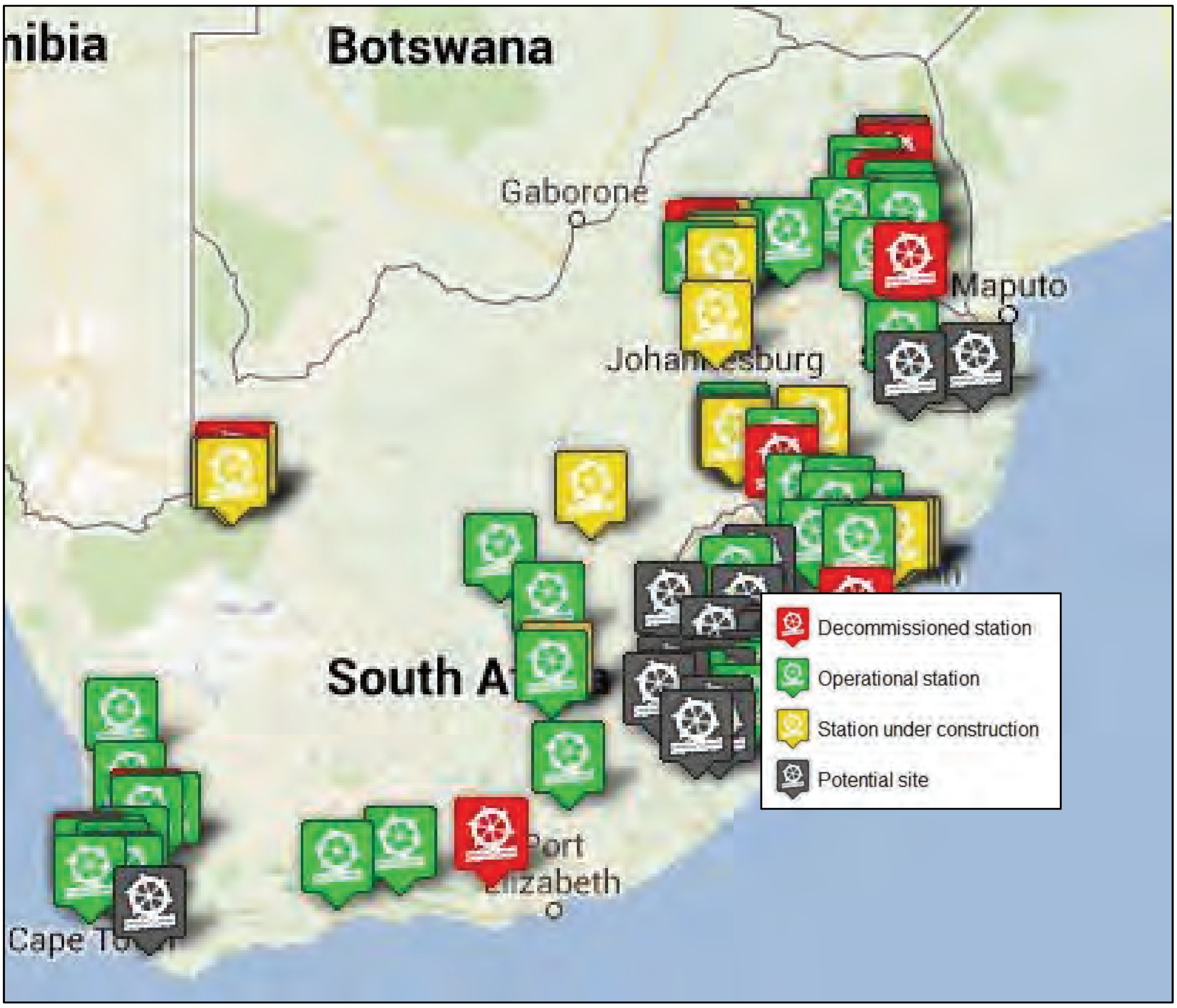


Figure 4-1: South African map indicating existing and potential hydropower sites (Jonker Klunne, 2013)

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: 'Operation and Maintenance 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 and 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

In conventional micro-hydropower systems the civil works could include dams, spillways, energy dissipating structures, intakes, de-siltation systems, channels, penstocks, powerhouses and tailraces. The electromechanical components normally consists of 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).

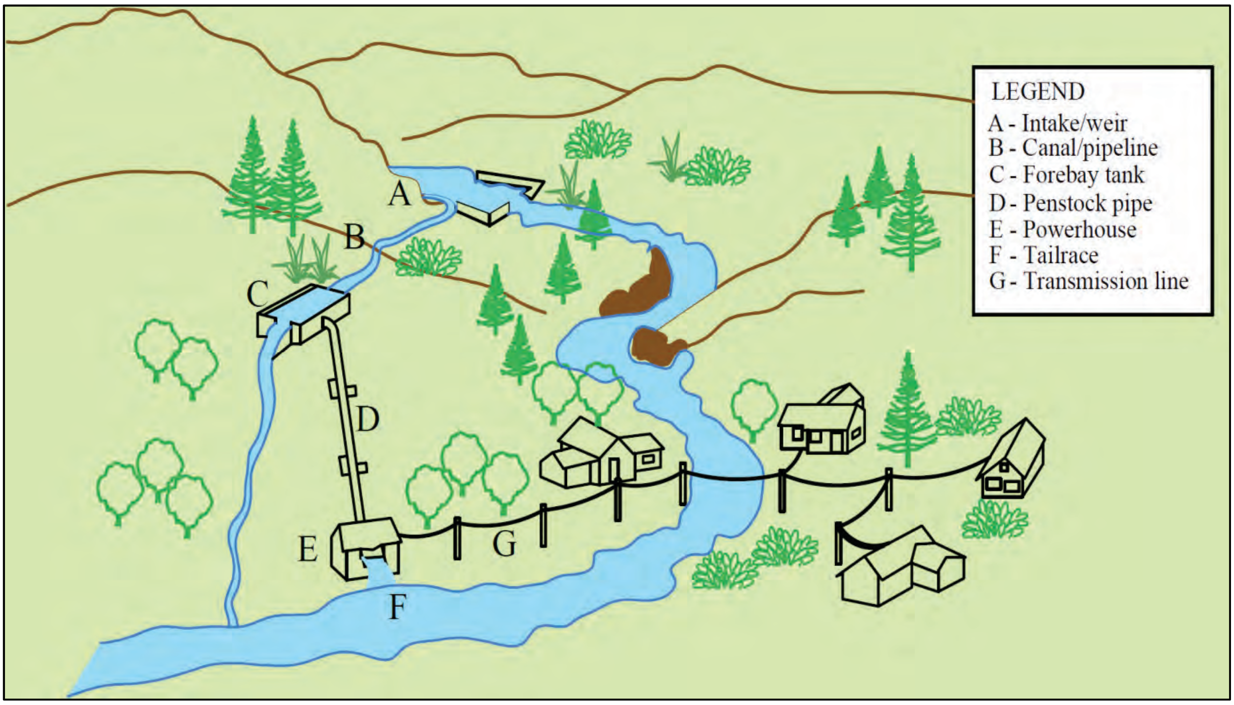


Figure 5-1: Typical run-of-river hydropower components (Natural Resources Canada, 2004)

5.4 POWER CAPACITY AND OUTPUT CALCULATIONS

5.4.1 Relationship for the calculation of hydropower potential

Hydropower works on the principle that water pressure and discharge is used to rotate a mechanical shaft of a hydro turbine. This rotation is used to power a generator that converts the mechanical 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):

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

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 converted to metric units based on the relationship produced by Colorado Department of Agriculture (CDA) (2011):

$$P = 126.71 \times (A \times v^3)$$ **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 along a 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.

$$\frac{P_1}{\rho g}+\frac{V_1^{\,2}}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^{\,2}}{2g}+Z_2+h_f+h_l$$ **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

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

$$h_l = \frac{K V^2}{2g}$$ **Equation 5-5**

where:

h_f = friction loss (m)

h_l = secondary losses (m)

λ = friction coefficient of penstock or pipe

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 calculation, the flow-duration curves have to be derived. These curves indicate the probability of the amount of days per annum that a certain flow will be exceeded. **Figure 5-2** is a typical example of a 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 the peak time based demand characteristics of the 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.

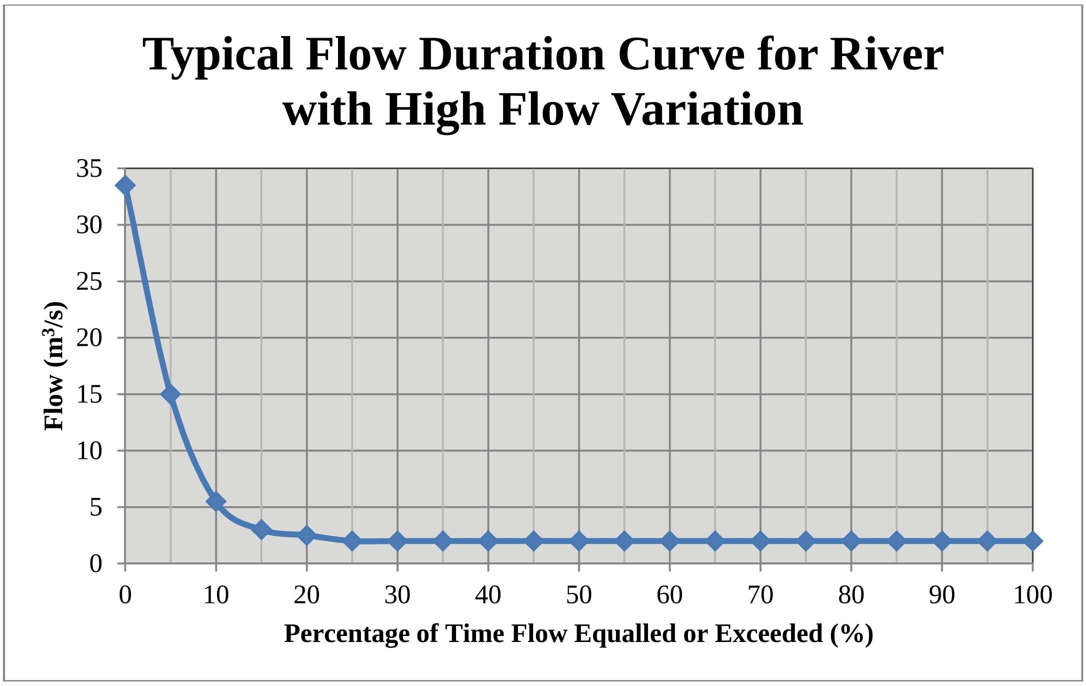


Figure 5-2: Flow-duration curve for high flow variation (Natural Resources Canada, 2004)

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 flow 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:**

$$\boldsymbol{Utilization}\ (\%) = \frac{\boldsymbol{Pt}}{\boldsymbol{PT}} \times \mathbf{100} \qquad \textbf{Equation 5-6}$$

where*:*

P = capacity installed (kW)

t = time actually worked per annum (hours)

T = theoretical time available per year (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**. The two important aspects which play a role in determining ALF is the <u>demand</u> for electricity and the <u>production</u> of energy.

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

Category	Installed capacity	Utilisation range, ALF (% p.a.)	Remarks
Pico	Up to 20 kW	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 depends on the choice of the ALF, as shown in **Equation 5-7**:

$$\boldsymbol{Annual\ production\ output} = (\boldsymbol{P})(\boldsymbol{T})(\boldsymbol{ALF})$$ **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 power production 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**:

$$\boldsymbol{C_h} = \boldsymbol{Pc_u}$$ **Equation 5-8**

where*:*

C_h = cost of the hydropower plant (R)

P = capacity installed (kW)

c_u = unit cost of power (R/kW)

and:

$$\boldsymbol{c_u} = \frac{\boldsymbol{LCC}}{(\boldsymbol{F_d})(\boldsymbol{D})(\boldsymbol{365})}$$ **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 (kW)

LCC = life cycle cost (R)

Engineering projects incur capital cost, various revenue costs, maintenance costs, operational costs and replacement costs and can create revenue over their lifetimes (see **Figure 5-3**). Therefore it is important to consider the value of all the cost components and incorporate the time value of money. 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 terms). LCC provides the basis which enables the comparison of projects with different expenditure patterns.

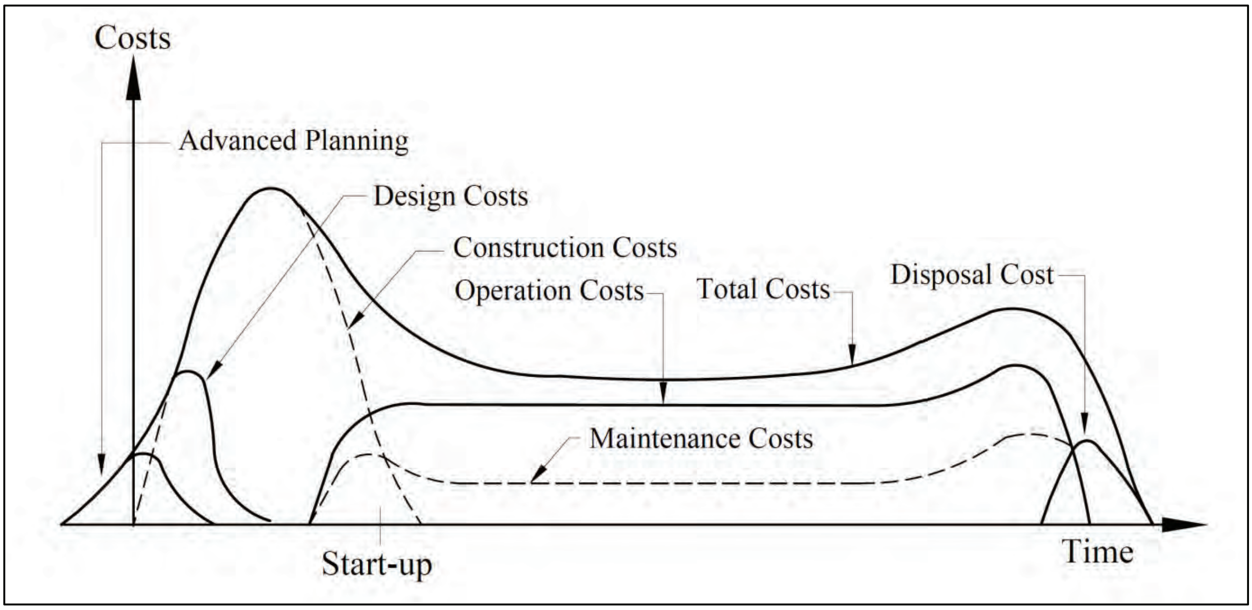


Figure 5-3: Representation of a hydroelectric system life-cycle profile

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 5-10.**

$$\eta = \frac{P_{actual}}{P_{theoretical}}$$ **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 (voltage) (**Equation 5-11**):

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

where:

P = electrical power output (W)

I = electrical current (A)

V = potential difference (V)

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

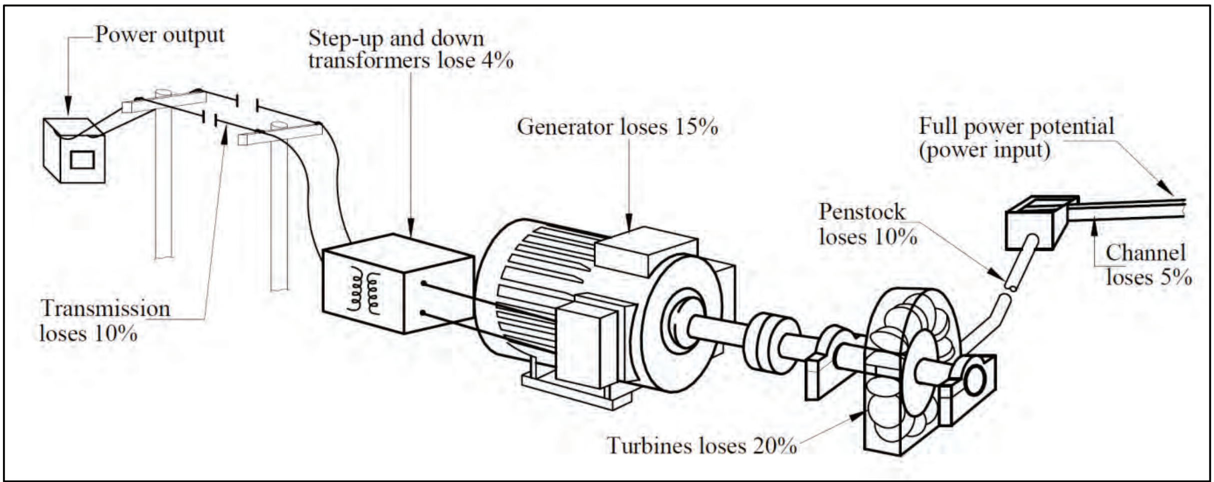


Figure 5-4: System losses (Harvey et al., 1993)

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 hydraulic efficiencies of turbines and water wheels (Natural Resources Canada, 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 reviewed and mitigated. According to ESHA (2004), the assessment will consider the identification and mitigation of all possible impacts during construction and operation, as well as the downstream and upstream impacts of the site and 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 and is becoming increasingly important (Klimpt et al., 2002). The general areas for consideration in terms of social impacts 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; and
- 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 just a Basic Assessment is to be undertaken. The activities as scheduled:

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

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

- 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; and
- environmental rehabilitation.

6 TYPICAL HYDROPOWER PLANT COMPONENTS

6.1 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: dams, diversion structure, spillways, fish passes and residual flow arrangements and conveyance systems, including intakes, canals, tunnels, penstocks and powerhouses (ESHA, 2004).

6.1.1 Impoundments/dams

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 could be associated with significant environmental impacts and are normally only constructed for large-scale projects, as dam construction makes small hydropower schemes economically unfeasible (ESHA, 2004). Hydropower could however be included to provide an added benefit to the main purpose of the dam.

6.1.2 Intake structures

The intake structure 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 are important, but challenging aspects 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).

6.1.3 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).

6.1.4 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).

6.1.5 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).

6.1.6 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.

6.1.7 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).

6.2 TURBINE TYPES

6.2.1 Introduction

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. Impulse turbines are experiencing atmospheric pressure while reaction turbines are experiencing hydrostatic pressure, i.e. submerged in water (Paish, 2002). **Table 6-1** provides a summary of the classification of turbines.

Table 6-2 and **Table 6-3** provide more information on applicable flow and head ranges for a number of low head turbines.

Table 6-1: 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

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 that shown in **Table 6-1**.

6.2.2 Impulse turbines

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

6.2.3 Reaction turbines

Reaction turbines use the flow and pressure drop to generate hydrodynamic force that turns the runner blades. The most used reaction turbines are the Kaplan (propeller) and the Francis turbine (Paish, 2002).

This study focuses 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 6-2** and **Table 6-3** and included in **Appendix A**. The rest of **Section 6.2** will briefly describe the most commonly used types of low head turbines. The colour scheme correlates with **Appendix A** for easy reference of the available turbines.

Table 6-2: List of low head impulse turbines

Turbine group	Turbine type	Supplier	Flow range	Head range (m)	Power (kW)
Impulse	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
	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
	Hydroengine	Natel energy	1.1-10.1 (m^3/s)	< 6	50-500
	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 detail in **Section 6.2**

Table 6-3: List of low head reaction turbines

Turbine group	Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power (kW)
Reaction	Kaplan*	Ossberger	1.5-60	1.5-20	20-35 00
		Mavel	0.3-150	1.5-35	30-20 000
		Voith	Not given	3-95	100-400 000
		Energy systems	0.03-0.06	1-3	0.09-1
		Power Pal	0.04-0.13	1.5	0.2-1
	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
	Pump as turbine*	Andritz	0.03-6	3-80	3-10 000
	Francis*	Wasserkraft Volk	Not given	<300	<20 000
		Mavel	0.1-30	15-440	20-30 000
		Gilkes	0.05-40	<400	<20 000
		Voith	Not given	3-95	5-1 000 000
	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
	Turbinator	Clean Power AS	0.5-12	10-60	75-3 300
	Moveable Power House	Ossberger Canada	1-25	1-8	350-2 000
	Siphon-turbine	Mavel	0.15-4.5	1.5-6	1-180
	Wave power	Voith	Not given	Not given	Not given

* denotes turbines that are discussed in detail in **Section 6.2**

6.2.4 Pelton turbine

Pelton turbines function by directing one or more jets of water tangentially onto a runner with split buckets, as shown in **Figure 6-1**. 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.

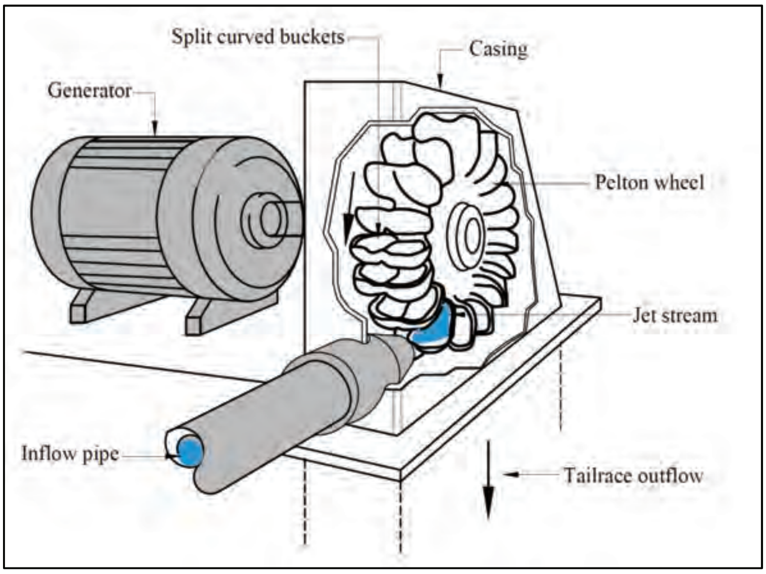


Figure 6-1: Typical Pelton turbine (Paish, 2002)

6.2.5 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 6-2**. 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).

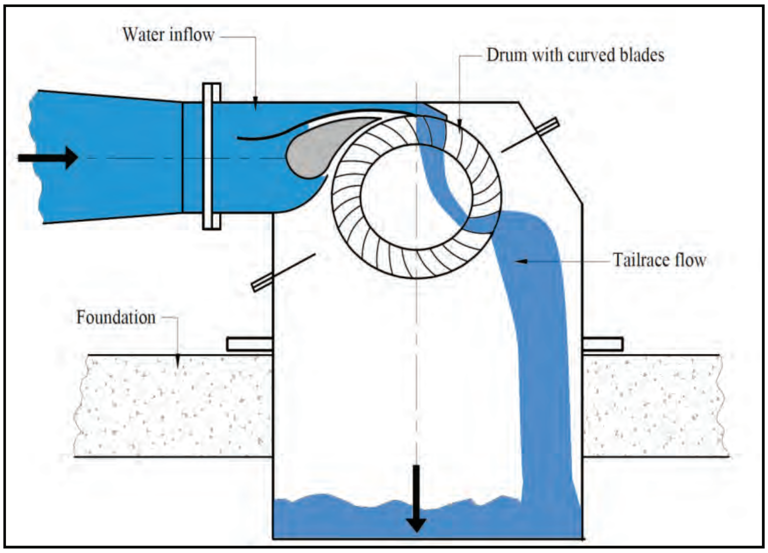


Figure 6-2: Typical cross-flow turbine (Paish, 2002)

6.2.6 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 6-3.**

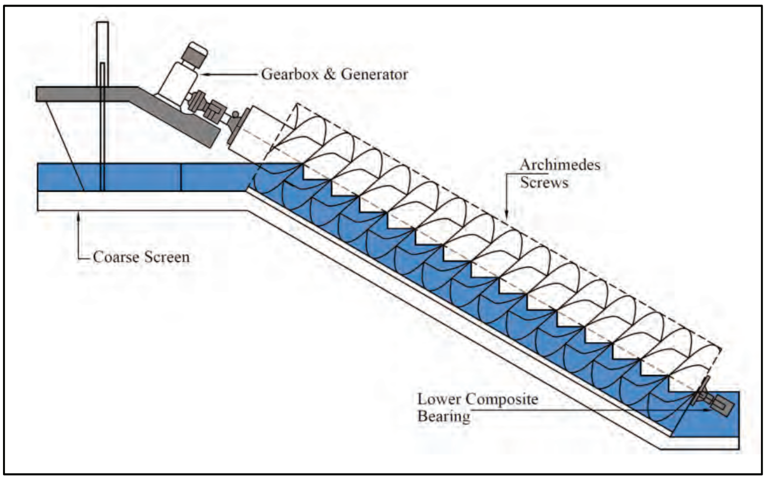


Figure 6-3 Screw type turbine design (Bouk, 2011)

6.2.7 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 6-4** is a schematic of an undershot wheel.

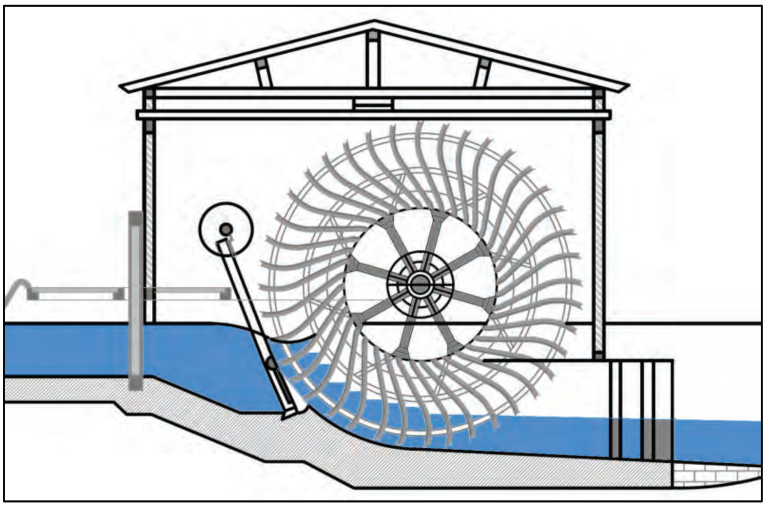


Figure 6-4 Undershot wheel (Muller, 2004)

- 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 6-5**.

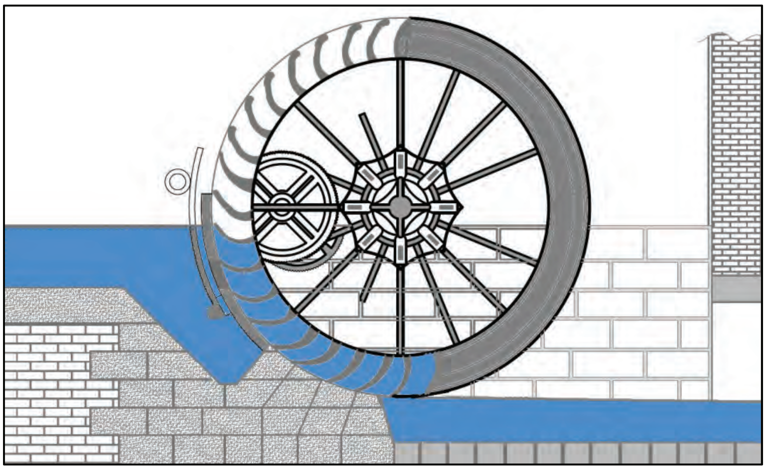


Figure 6-5 Breastshot wheel (Muller, 2004)

- 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 6-6.**

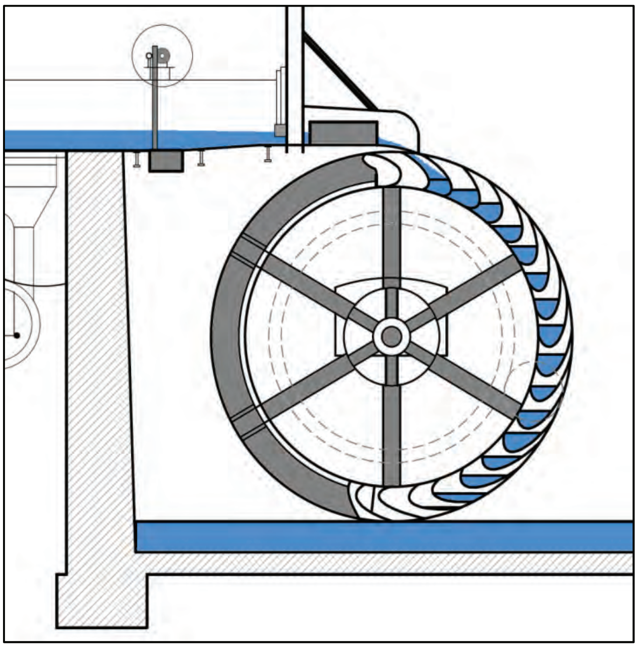


Figure 6-6 Overshot wheel (Muller, 2004)

6.2.8 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 6-7.** Most other hydrokinetic rotors work in a similar manner. These rotors can be placed horizontal or vertically.

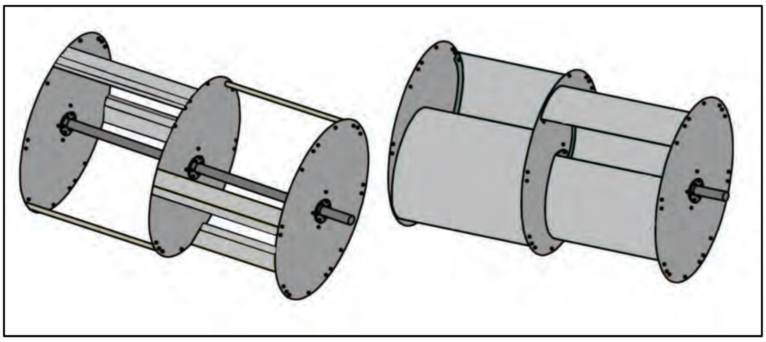


Figure 6-7 Darrieus (left) and Open Savonius (right) rotors (Hydrovolts, 2011)

These rotors are placed below the water surface. **Figure 6-8** shows how the Hydrovolt turbine works once installed.

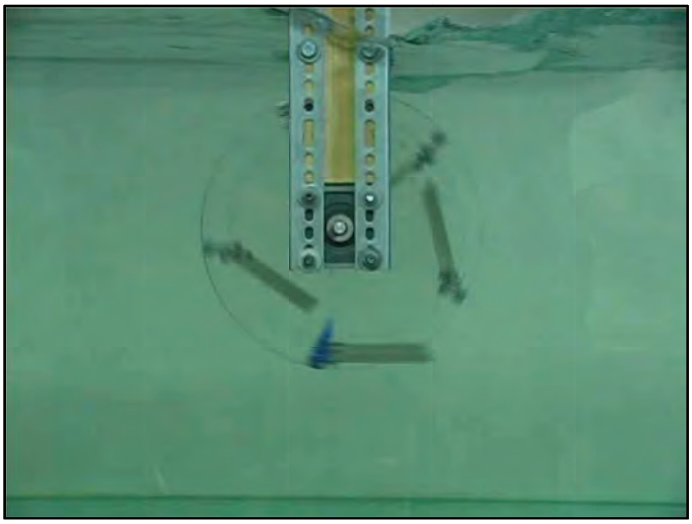


Figure 6-8 Underwater view of hydrokinetic turbine (Hydrovolts, 2011)

6.2.9 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 6-9**. Guide vanes are installed upstream of the turbine to create inlet swirl, as this ensures better efficiency.

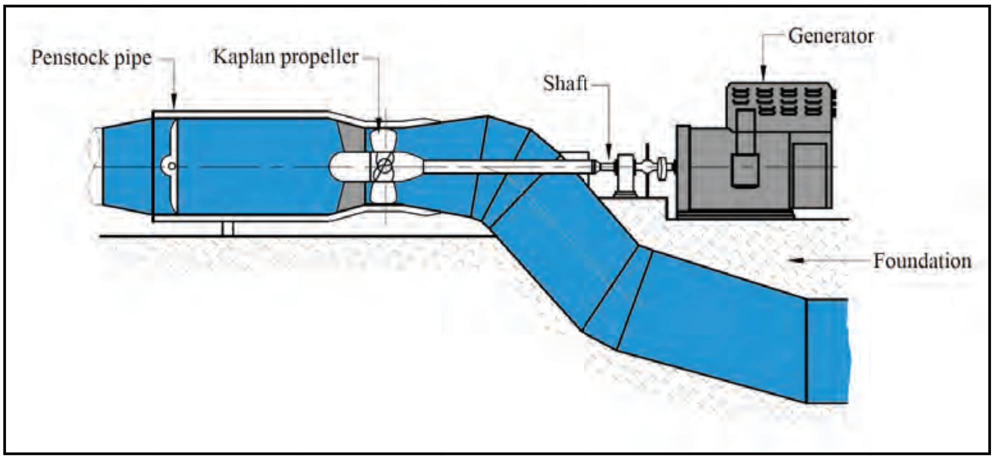


Figure 6-9: Typical Kaplan turbine (Paish, 2002)

6.2.10 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 6-10** (Paish, 2002).

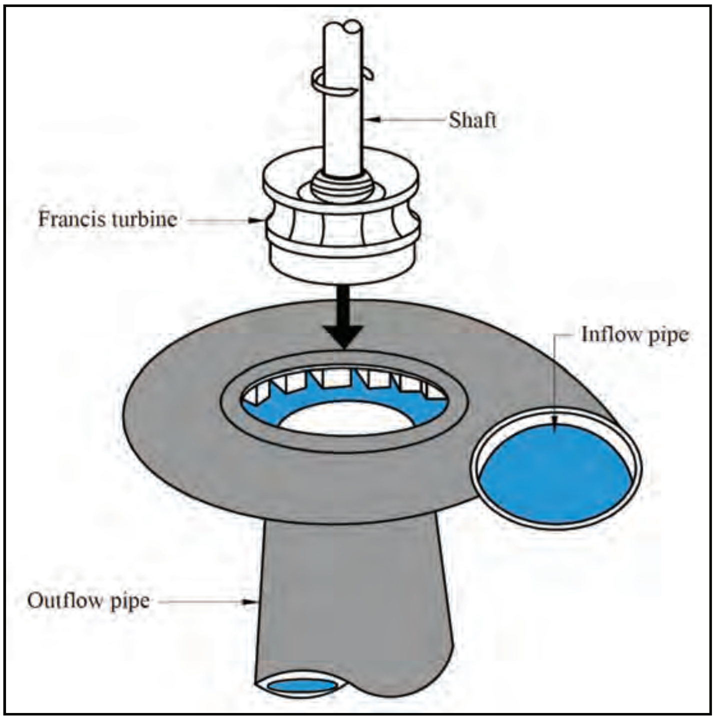
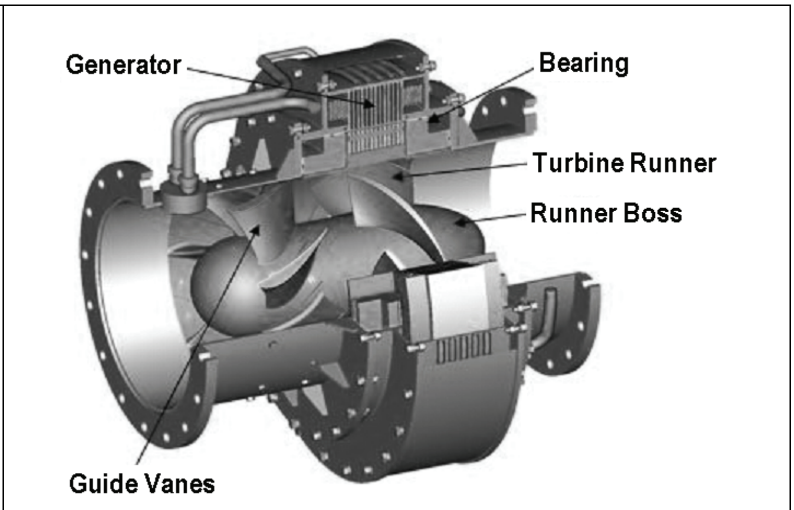


Figure 6-10: Francis turbine (Paish, 2002)

6.2.11 Inline turbines

Recently the use of inline turbines has increased. These turbines include spherical and ring turbines (**Figure 6-11**) 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 6-11: Examples of inline turbines

6.2.12 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 6-12**). 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

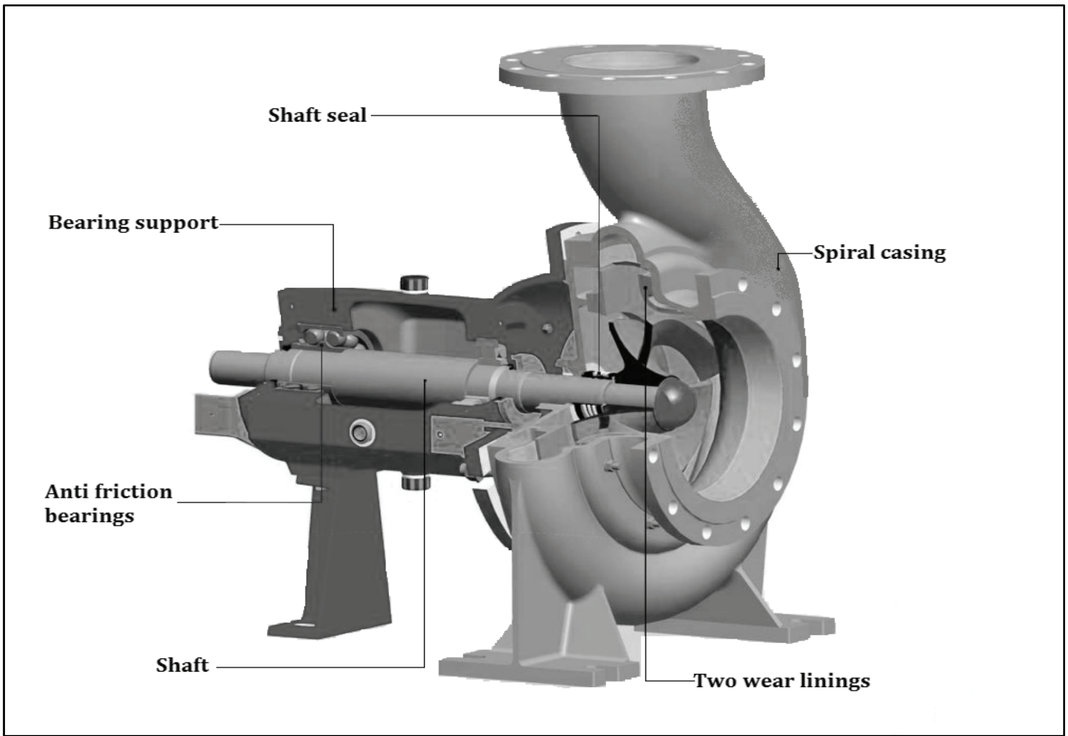


Figure 6-12: An example of a pump as turbine (Andritz, 2013)

6.2.13 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.

6.3 OTHER ELECTRICAL AND MECHANICAL EQUIPMENT

6.3.1 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.

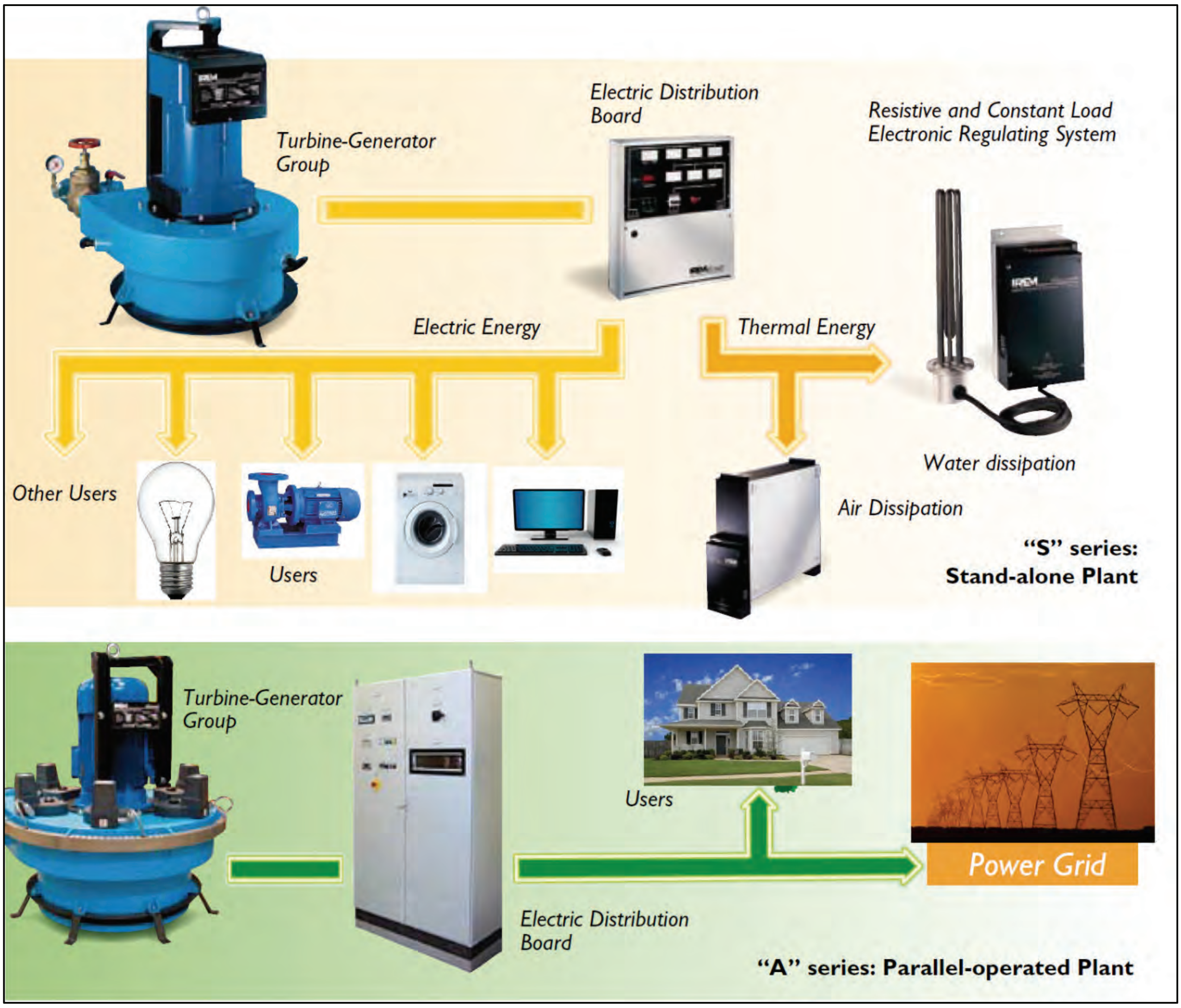


Figure 6-13: Diagram of grid-connected versus stand-alone installations (IREM, 2012)

6.3.2 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).

6.3.3 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).

6.3.4 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).

7 POTENTIAL LOCATIONS FOR LOW HEAD HYDROPOWER

7.1 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.

7.2 HYDROPOWER POTENTIAL AT DAMS AND BARRAGES

7.2.1 Introduction

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.

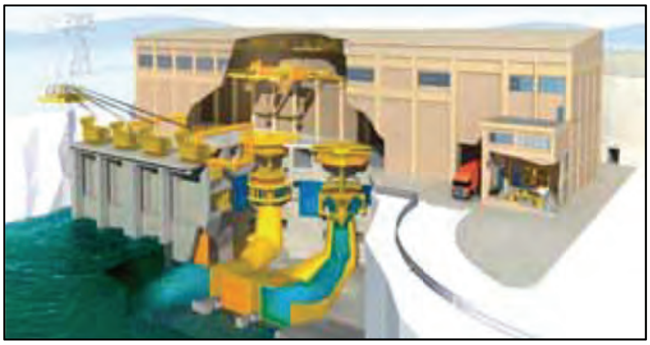
Van Vuuren and Blersch developed a Hydropower Retrofitting Model (HRM) which is a comprehensive, logical and accurate model which can be used in the initial phases of a project to determine the feasibility of retrofitting hydropower onto an existing dam in South Africa (Van Vuuren et al., 2011). The 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.

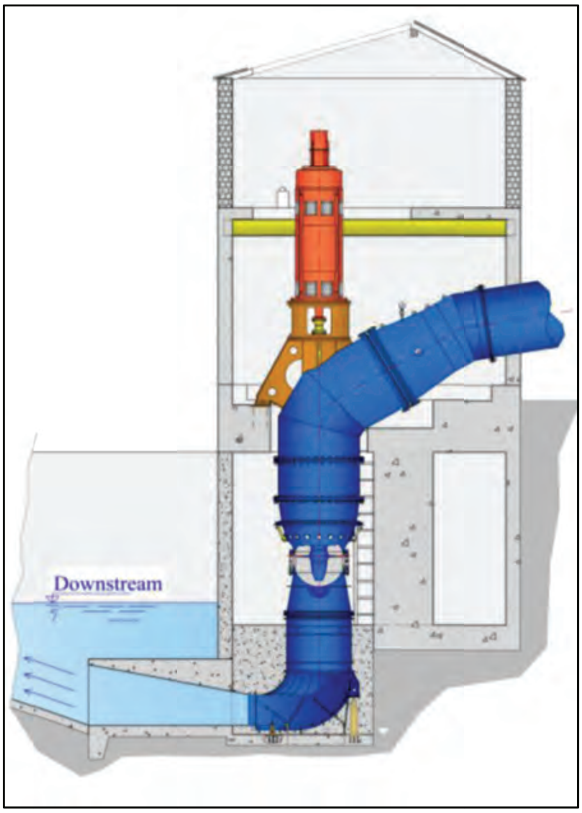
7.2.2 Typical Layouts

Typically, hydropower turbines will be built into new dams or retrofitted to existing infrastructure. Kaplan, bulb or propeller-type turbines (**Figure 7-1(a)** and **(b)**) would be most easily installed during dam construction. Siphon-type turbines (**Figure 7-1 (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 7-1: Typical layout for turbines at low head dams

7.2.3 Potential hydropower at South African dams

A study was conducted by Thompson (2012) to determine the hydropower potential of South African dams based on historical flow and dam level data. **Table 7-1** and **Table 7-2** show the "low head" dams, analysed in the study, classified according to the power producing abilities for river releases (environmental reserve releases) and total outflows, with 80% reliability factors.

As this study was only done considering historical flow and water levels and spillage was also not included, the classification should only serve as a guideline. Further detailed investigation will be needed to determine the exact potential in the country. The Hartbeespoortdam is discussed as an example in **Chapter** 8. From this example it is clear that the actual potential could in many cases be more than indicated in the tables below.

The study was done considering both total outflow and river releases separately, as river releases will produce less energy than the total outflow will but with better ALF. It will also be easier to capture.

Table 7-1: Total river release classification (extracted from Thompson & Van Dijk, 2012)

Total river releases classification			
Pico	**Micro**	**Mini**	**Small**
< 10 kW	**10 - 100 kW**	**100 kW - 1 MW**	**1 MW - 10 MW**
Bospoort Dam	Buffelskloof Dam	Albert Falls Dam	Bloemhof Dam
Calitzdorp Dam	De Mistkraal Dam	Clanwilliam Dam	Vaal Dam
Craigieburn Dam	Grootdraai Dam	Driel Barrage	
Da Gama Dam	Hazelmere Dam	Flag Boshielo Dam	
Dap Naude Dam	Hluhluwe Dam	Hartbeespoort Dam	
Doornrivier Dam	Klaserie Dam	Midmar Dam	
Floriskraal Dam	Klipfontein Dam	Roodekopjes Dam	
Gamkapoort Dam	Klipvoor Dam	Vaalharts Storage Weir	
Gubu Dam	Loskop Dam		
Heyshope Dam	Ntshingwayo Dam		
Jericho Dam	Ohrigstad Dam		
Kleinplaas Dam	Phalaborwa Barrage		
Korentepoort Dam	Spitskop Dam		
Krugersdrift Dam	Theewaterskloof Dam		
Longmere Dam	Vygeboom Dam		
Luphephe Dam	Welbedacht Dam		
Middelburg Dam	Witklip Dam		
Nooitgedacht Dam	Wriggleswade Dam		
Nwanedzi Dam			
Nzhelele Dam			
Roodeplaat Dam			
Tonteldoos Dam			
Vaalkop Dam			
Waterdown Dam			

Table 7-2: Total outflow classification (extracted from Thompson and Van Dijk, 2012)

Total outflow classification			
Pico	**Micro**	**Mini**	**Small**
< 10 kW	**10 - 100 kW**	**100 kW - 1 MW**	**1 MW - 10 MW**
Albasini Dam	Buffeljags Dam	Albert Falls Dam	Bloemhof Dam
Allemanskraal Dam	Buffelskloof Dam	Boskop Dam	Vaal Dam
Armenia Dam	Dap Naude Dam	Clanwilliam Dam	
Bospoort Dam	Darlington Dam	De Mistkraal Dam	
Buffelspoort Dam	Eikenhof Dam	Driel Barrage	
Calitzdorp Dam	Hazelmere Dam	Flag Boshielo Dam	
Craigie Burn Dam	Hluhluwe Dam	Grootdraai Dam	
Da Gama Dam	Kalkfontein Dam	Hartbeespoort Dam	
Doorndraai Dam	Klaserie Dam	Jericho Dam	
Doornrivier Dam	Klerkskraal Dam	Kleinplaas Dam	
Egmont Dam	Klipfontein Dam	Loskop Dam	
Elandskuil Dam	Klipvoor Dam	Midmar Dam	
Floriskraal Dam	Middelburg Dam	Ntshingwayo Dam	
Gamkapoort Dam	Nooitgedacht Dam	Phalaborwa Barrage	
Glen Alpine Dam	Ohrigstad Dam	Roodekopjes Dam	
Groothoek Dam	Saulspoort Dam	Roodeplaat Dam	
Gubu Dam	Spitskop Dam	Theewaterskloof Dam	
Hartebeestkuil Dam	Vaalkop Dam	Vaalharts Storage Weir	
Heyshope Dam	Waterdown Dam	Vygeboom Dam	
Klipdrift Dam	Witklip Dam	Welbedacht Dam	
Koppies Dam	Wriggleswade Dam		
Korentepoort Dam			
Kosterrivier Dam			
Kromellenboog Dam			
Krugers Post			
Krugersdrift Dam			
Longmere Dam			
Luphephe Dam			
Marico-Bosveld Dam			
Miertjieskraal Dam			
Morgenstond Dam			
Nqweba (V.Rynevelds)			
Nwanedzi Dam			
Nzhelele Dam			
Rhenosterkop Dam			
Rietspruit Dam			
Rustfontein Dam			
Tonteldoos Dam			
Vlugkraal Dam			
Westoe Dam			

Table 7-3 provides a summary of total potential in “low head dams” (as classified in **Table 1-2**), considering either 50% or 80% reliability of flow. It is assumed that these dams would all be classified as low head. Annual power generation potential is also shown for the different scenarios. This is untapped potential which will not affect the yield of the water resource.

Table 7-3: Low head hydro potential in dams (extracted from Thompson, 2012)

Description	Energy potential	
	50th percentile	80th percentile
Power (MW) using total outflow	7.65	6.56
GWh/year using total outflow	33.51	45.98
Power (MW) using river outflow	5.70	2.18
GWh/year using river outflow	24.94	9.56
Note: The above estimates are based on the river releases (i.e. ecosystem releases) downstream of a dam as recorded by the DWA at listed dams. If the actual physical parameters are available (e.g. water head, sizes of outlets, flow time series, etc.) many listed dams in Table 7-1 will classify for the small scale hydropower retrofit with capacities between 100 kW and 10 MW.		

Barta (2011) evaluated the small scale hydropower potential for some 185 state administered dams using the basic hydraulic parameters concluding that very moderate potential capacity of 55 MW exists primarily for the retrofit installations between 300 kW and 3 MW at 62 suitable dams. The installation of this hydropower capacity will enable the DWA in reduction of its overall electricity demand on the national grid by between 170 and 360 GWh per annum. The same exercise has been done for 20 suitable municipal dams (i.e. dams administered by the local authorities) and a small scale hydropower potential determined at some 8 MW allowing thus the municipal electricity demand to be reduced by between 35 and 50 GWh per year.

From the detailed hydropower potential analysis compiled for the Hartbeespoort Dam (also listed in Table 7-2) Ottermann and Barta (2012) determined that the small scale hydropower potential is more than three times higher than the original estimate (from 1,2 MW to 5,7 MW).

7.3 HYDROPOWER POTENTIAL IN RIVERS

7.3.1 Run-of-river schemes

7.3.1.1 The micro hydro theory

The potential for low-head hydropower development is commonly found within the range of micro-hydropower category (i.e. up to 100 kW installations, which can supply hydro energy to the small communities with agricultural/commercial/ manufacturing enterprises). Micro-hydro schemes are usually run-off-river installations, where there are 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 system depends on the topology, water flow and costs of materials used in the structure associated with a micro hydropower scheme. 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).

As run-of-river installations has no storage capacity, it is most important to determine and to predict the river flows. If there is no flow data available for the proposed site the flow information which might be available on the nearby stream within the same catchment, 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 than plotted against the percentage of time that the flow is exceeded compiling a flow-duration curve (see **Figure 5-2**) from which it can be determined what the energy potential at a given site is.

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 run-of-river micro-hydropower.

7.3.1.2 Typical layouts of run-of-river schemes

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 7-2**):

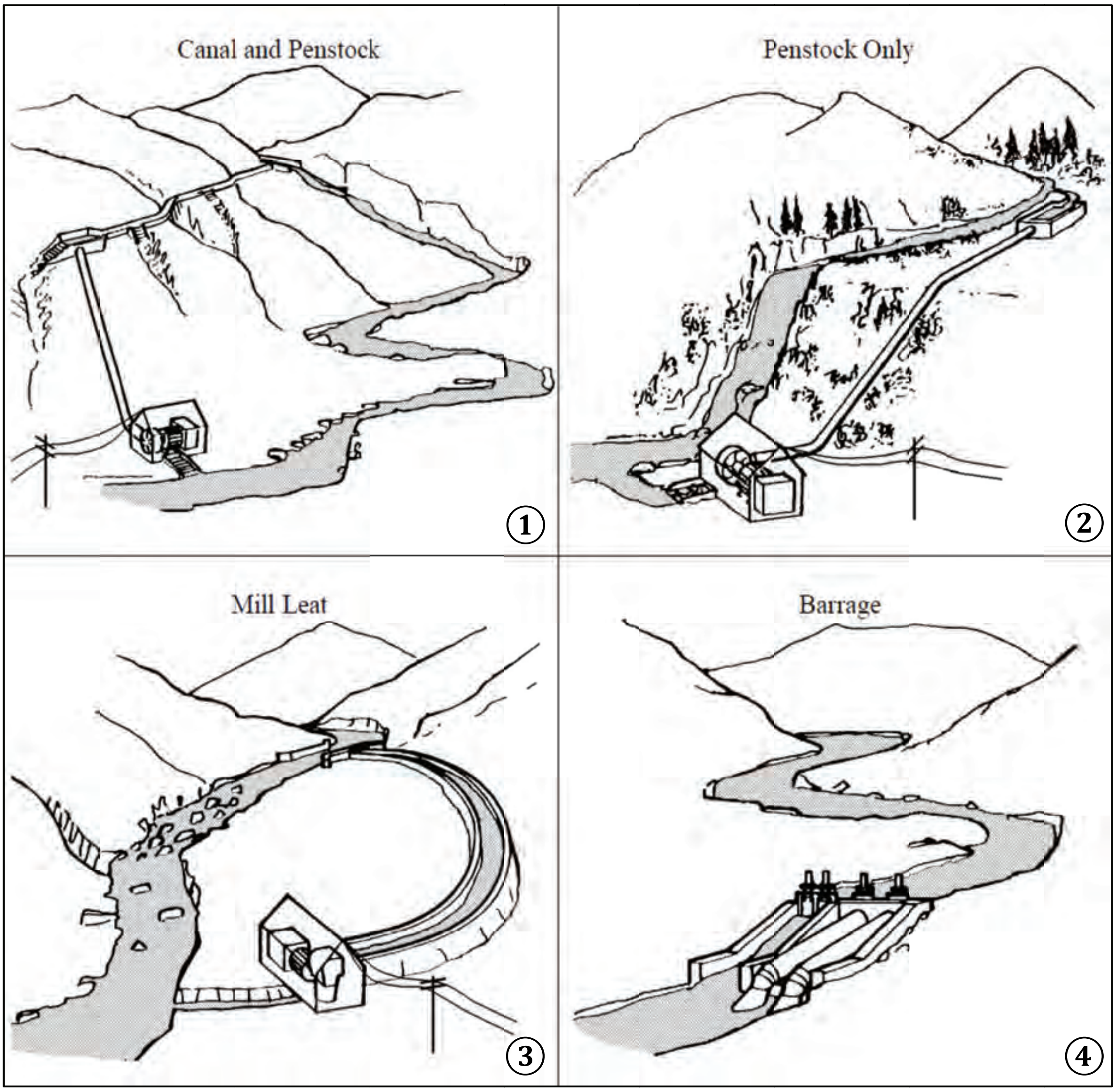


Figure 7-2 Run-of-river hydropower layouts (BHA, 2005)

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 types of layouts can also be classified as weirs or even small dams.

7.3.1.3 Potential of run-of-river schemes

Determining the total potential for development of the run-of-river schemes in the country's river systems falls outside the scope of this study. Theoretically there are many suitable sites available for the run-of-river schemes mainly around the high precipitation regions of South Africa as shown in **Figure 7-3**. Ballance et al. (2000) concluded from the geographic information systems analysis of hydropower potential in South Africa that the steeper and more humid slopes of the eastern escarpment, and parts of the southern escarpment near Cape Town, showed the best potential for both micro- and macro-hydropower. From the modelling hydropower study it had been concluded that the annual energy output potential is in order of 100 GWh for the micro-hydropower and 10 000 GWh for the macro-hydropower from available water resources.

The rural areas of the Eastern Cape (see **Table 7-4**) and KwaZulu-Natal provinces are enriched with a good potential for development of particularly run-of-river hydropower schemes. However, environmental legislation and licensing requirements make it difficult to obtain approval for development of this potential. In the regional context many potential sites can be developed for energy generation only if in a tandem with the development and/or optimizing new and/or existing community water supply systems.

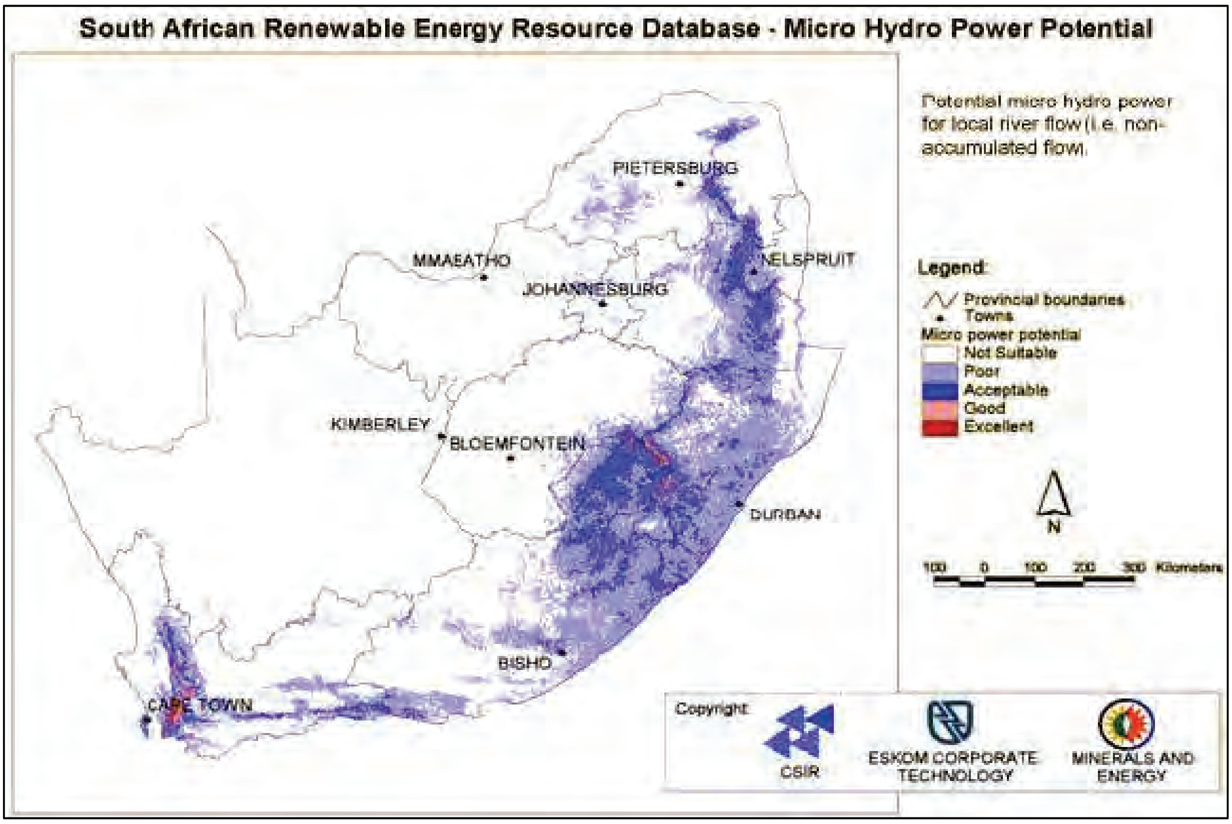


Figure 7-3: Run-of-river hydropower potential (Muller, 1999)

Table 7-4: Examples of the small run-of-river “greenfield” sites in the Eastern Cape

Site name	River	Estimated potential (MW)	Geographical location*		Remarks on purpose of development
			Longitude	Latitude	
All Saints	Xuka	3,0	28^{0}04’30”	31^{0}39’05”	Water supply plus hydro
Fraser Falls	Mkosi	1,5	29^{0}43’00”	31^{0}24’45”	Run-of-river hydro
Indwe Poort	Indwe	2,0	27^{0}26’10”	30^{0}25’00”	Run-of-river hydro
Mt Fletcher	Tina	2,0	28^{0}33’00”	30^{0}40’00”	Existing small dam
Tiyanapoort	Mgwali	7,0	28^{0}25’00”	30^{0}25’00”	Water supply plus hydro
Mbombo	Tina	10,0	28^{0}05’00”	31^{0}04’48”	Water supply plus hydro
NB: *Please note that the geographical location is approximate only.					

7.3.2 Measuring weirs as potential sites for low head hydropower installations

7.3.2.1 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).

The first gauging weirs designed specifically to measure flow in South Africa were completed in 1904 in the old Transvaal Province. Almost without exception all the gauging weirs built in South Africa until the mid 70's were compound sharp crested structures. The first compound Crump weir was built in the Great Fish River in October 1977. An example of a typical South African gauging weir is shown in **Figure 7-4**.

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.

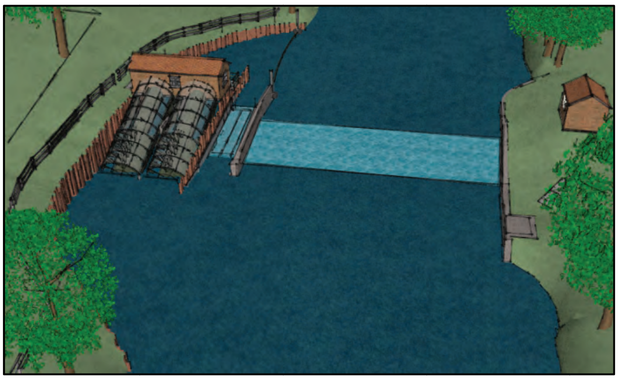
Hydropower plants at dams and weirs will normally be built into the dam wall, or constructed right next to the dam with a short diversion. Siphon turbines or Archimedean screws can also be installed at many existing dams and weirs.

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

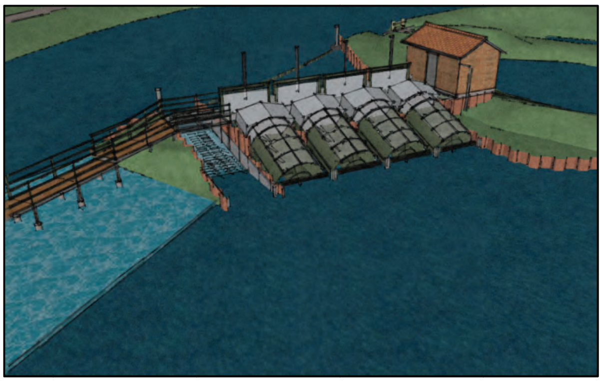
Figure 7-4: Typical measuring structure/weir

7.3.3 Typical layouts at gauging structures

Hydropower turbines will be built into or retrofitted to weirs. Kaplan, bulb or propeller-type turbines (**Figure 7-5 (c)** and **(d)**) would be most easily installed during weir construction. Siphon-type turbines or Archimedean screws (**Figure 7-5 (a)** and **(b)**) could be retrofitted to some weirs, with some additional civil infrastructure required.

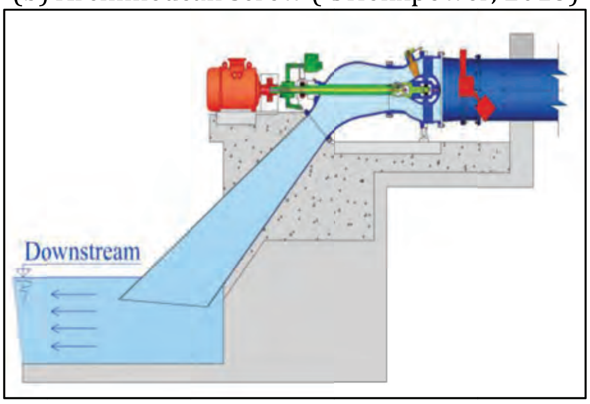


(a) Archimedean screw (3Helixpower, 2013)



(b) Archimedean screw (3Helixpower, 2013)

(c) Kaplan turbine (Alstom, 2013)



(d) Horisontal Kaplan (Mavel, 2013a)

Figure 7-5: Typical layouts of hydropower turbines at weirs

7.3.4 Potential energy at gauging structures

Today flow is measured at more than 800 river flow gauging stations and at more than 200 dams in South Africa. More than 55% of these stations include components at which flows are gauged with compound sharp crested weirs and more than 25% are gauged with compound Crump weirs.

In the following analysis a measuring weir was selected to demonstrate the hydropower potential. This analysis process can basically be applied at any structure where there is a drop in head and a flow of water.

The example which was selected is a measuring weir in the Great Fish River. The gauging weir is Q9H018 – Great Fish River @ Matomela (see **Figure 7-6**).

Figure 7-6: Measuring weir Q9H018 – Great Fish River @ Matomela

This station has recorded flows from 1 August 1969 until 30 June 2013. **Figure 7-7** shows the historical average daily flow rates of the data record. The approximately 16 000 days of recorded flow indicated only ±2.5% of the time zero flows. The average flow (excluding the missing data values) is 10.7 m^3/s with the maximum being 1 258 m^3/s. It is however of more value if the frequency of a specific flow rate is investigated. **Figure 7-8** depicts the frequency of historical occurrences of the daily flow rates. At a frequency of 80% the average flow rate is 2.8 m^3/s and at 50% it is 5.35 m^3/s.

Table 7-5: Theoretical hydropower potential

Parameter	Hydropower potential based on averaged flow	Hydropower potential based on 80% reliability	Hydropower potential based on 50% reliability	Units
Average head	1.5	1.5	1.5	m
Average flow rate	6.557	2.8	5.35	m^3/s
Efficiency	0.75	0.75	0.75	%
Potential power	72.37	30.90	59.04	kW
Annual potential		216 558	258 612	kWh

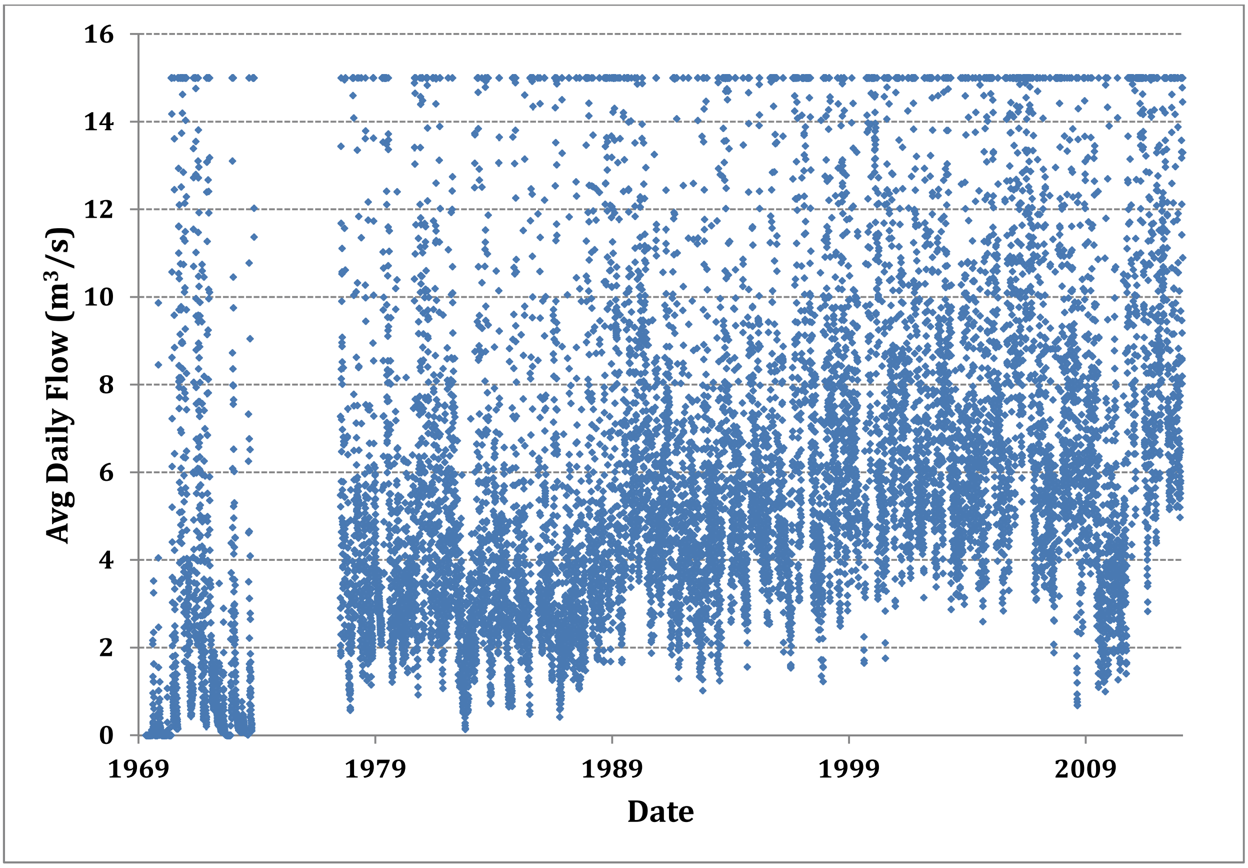


Figure 7-7: Historical average daily flow rates at Q9H018 (limited to 15 m^3/s)

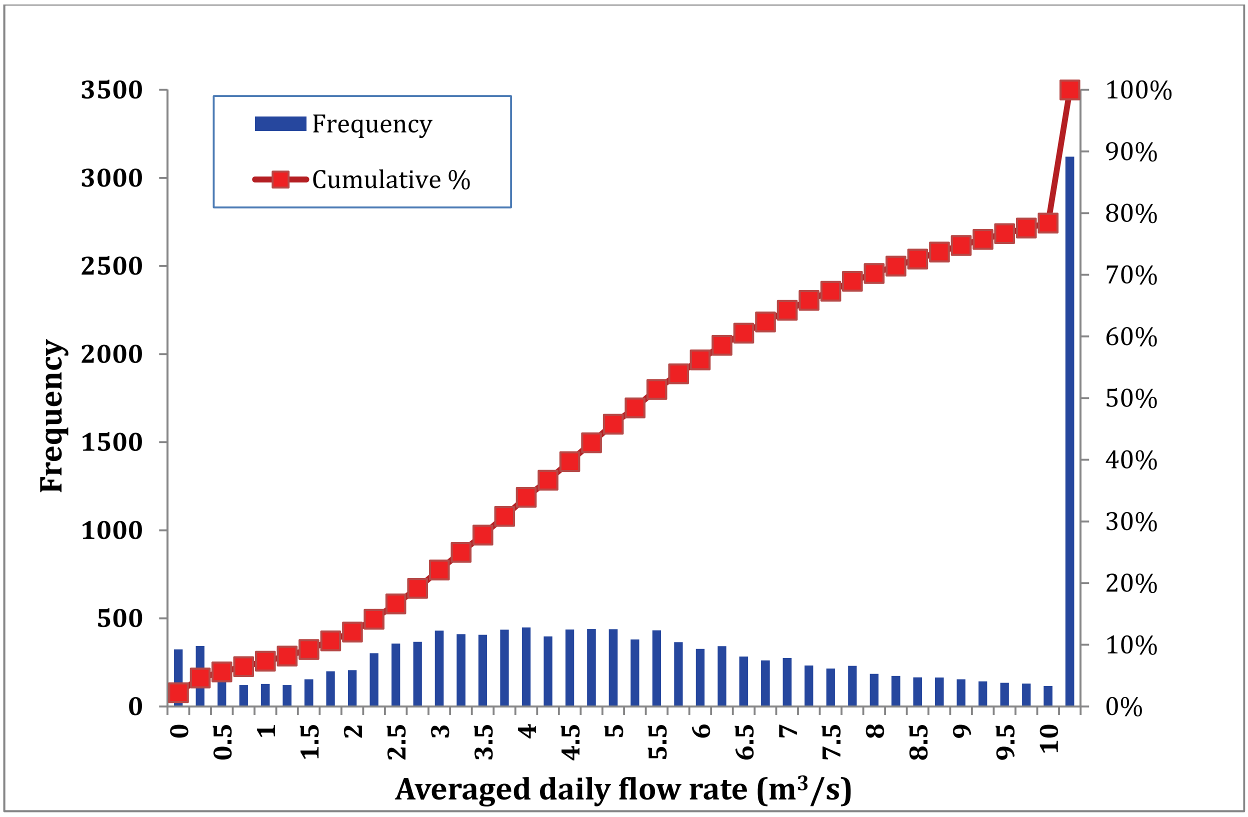


Figure 7-8: Histogram of average daily flow rates of Q9H018

7.4 IRRIGATION SYSTEMS AS POTENTIAL SITES TO GENERATE LOW HEAD HYDROPOWER

7.4.1 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.

7.4.2 Diversion structures coupled with irrigation systems

Many irrigation systems use diversion systems to canalise water from natural rivers to irrigation canals (**Figure 7-9**).

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 7-9: 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.

7.4.3 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 7-10** is an example of a sluice gate with no practical hydropower potential.

Figure 7-10: Sluice with almost no hydropower potential (DWA, 2013)

7.4.4 Bridges

Vehicle, cattle and pedestrian bridges (**Figure 7-11**) 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 7-11: Energy dissipating structure (at bridge) in Teebus canal (Orange-Fish Transfer Scheme)

7.4.5 Flow measuring stations

Most irrigation canals have a number of flow measuring stations (**Figure 7-12**), 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 7-12: Flow gauging telemetry system at the Teebus canal (Orange-Fish Transfer Scheme)

7.4.6 Reject structures

Depending on how often reject structures (**Figure 7-13**) are used, they may provide an opportunity for hydropower generation using siphon turbines or Archimedean screws.

Figure 7-13: Typical reject structure (DWA, 2013)

7.4.7 Open lengths on irrigation canals

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 7-14** shows the Teebus canal in the Fish River.

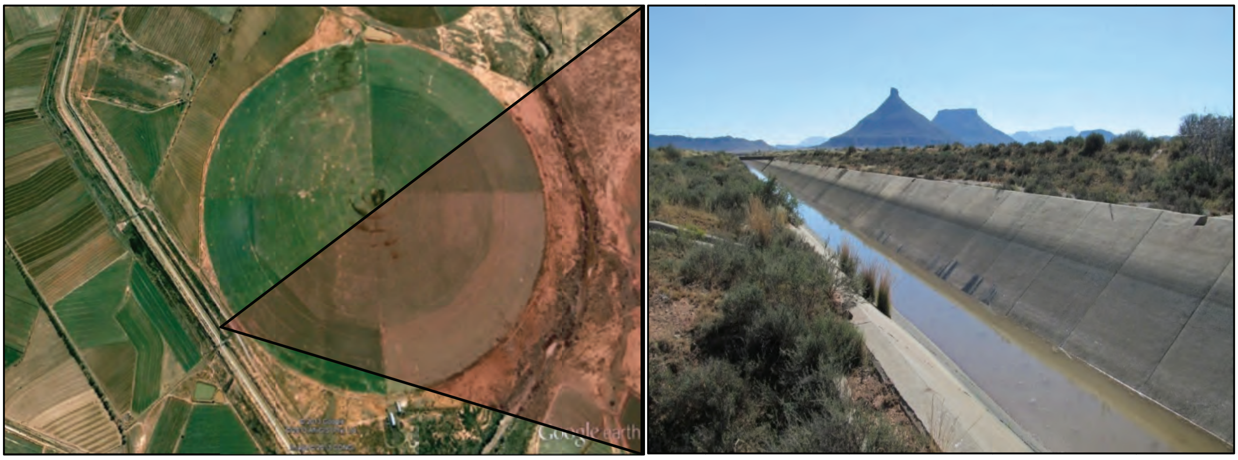


Figure 7-14: Google Earth image (Google Earth, 2013) and photo of the Teebus canal

7.4.8 Siphons

Siphons are underground pipes constructed to convey water underneath dry water courses, preventing damage to the canal structure (**Figure 7-15**). There is generally no excess energy available at these structures, and therefore the hydropower potential is negligible.

Figure 7-15: The inlet to a siphon on the Sand River canal system (DWA, 2013)

7.4.8.1 Typical layouts of low head hydropower installations in irrigation infrastructure

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 7-16** shows a schematic layout of possible sites for different hydropower set-ups.

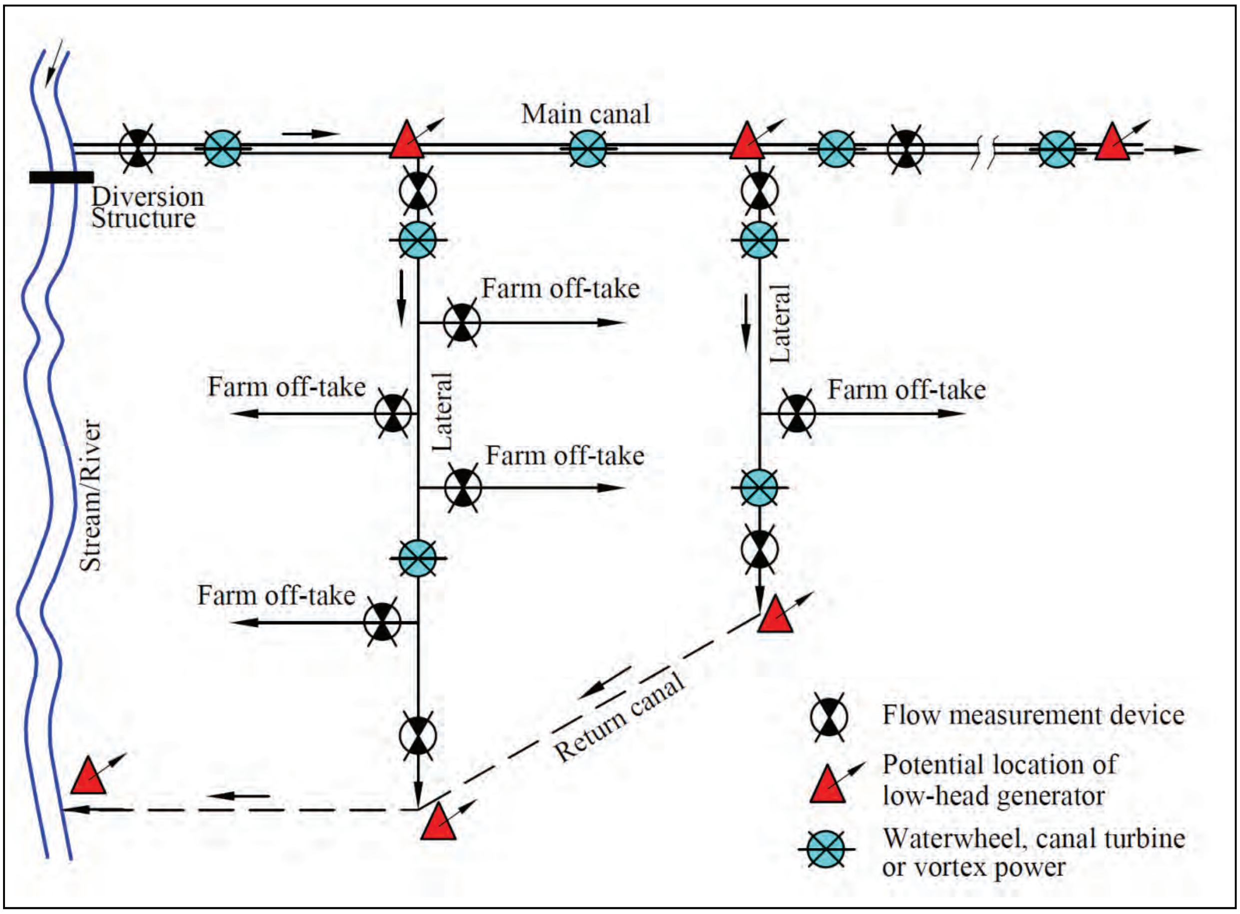
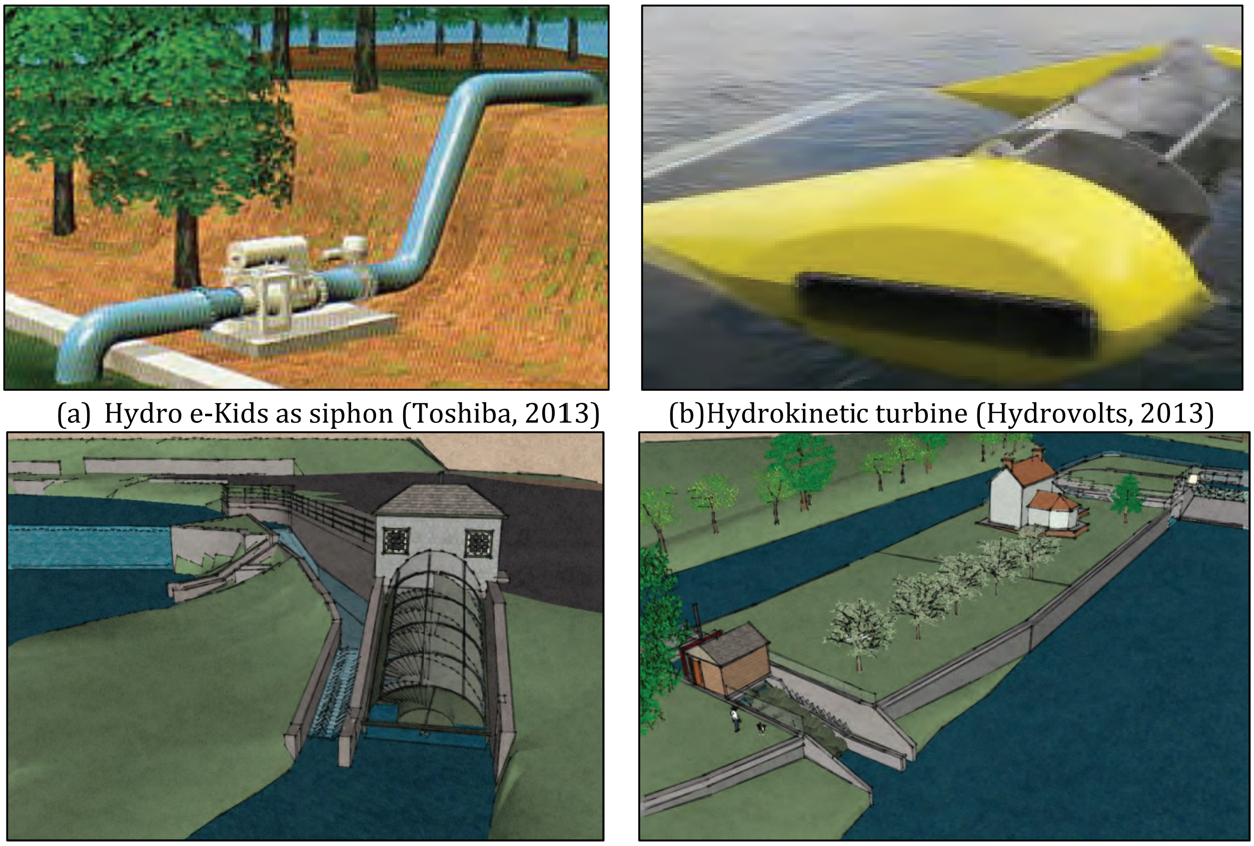


Figure 7-16: Schematic layout of irrigation scheme (adjusted from CDA, 2011)

Turbines that can typically be used include waterwheels, hydrokinetic turbines (**Figure 7-17 (b)**), vortex turbines, Archimedean screws (**Figure 7-17 (c)** and **(d)**), Kaplan or bulb turbines (**Figure 7-17 (a)**), siphon-type turbines and hydroengines.



(a) Hydro e-Kids as siphon (Toshiba, 2013) (b)Hydrokinetic turbine (Hydrovolts, 2013)

(b) Archimedean screw (3Helixpower, 2013) (d) Archimedean screw (3Helixpower, 2013)

Figure 7-17: Typical layouts for turbines in irrigation schemes

7.4.9 Potential hydropower in irrigation infrastructure

The Department of Water Affairs (DWA) is the custodian of some 72 irrigation schemes scattered around South Africa situated administratively within 19 Water Management Areas (WMA). On request the DWA provided information input on 14 operating irrigation schemes (DWA, 2013). Four of the most significant irrigation schemes were investigated in detail to determine the potential for hydropower within existing irrigation infrastructure. The schemes investigated were:

- Boegoeberg Irrigation Scheme
- Kakamas Irrigation Scheme
- Lower Fish Irrigation Scheme
- Lower Sundays Irrigation Scheme

The potential assessment of irrigation canals will be based on information from 14 irrigation schemes for which water management programs (WMPs) have recently been developed. The schemes are shown in **Figure 7-18**. Two of the schemes (Boegoeberg and Kakamas) were used to illustrate potential in South Africa's irrigation systems.

All the information for this section was extracted from reports on the development of water management programmes (WMPs) for these two irrigation schemes, commissioned by the Department of Water Affairs (DWA, 2013). Their contribution is acknowledged with gratitude.

Figure 7-18: Location of the 14 irrigation schemes where WMPs have been developed (DWA, 2013)

7.4.10 Boegoeberg Irrigation Scheme

7.4.10.1 Overview

This scheme is situated on the Orange River in the Northern Cape and consists of a dam and an irrigation canal distribution system with sluice gates. A description of the various structures in the Boegoeberg irrigation scheme is provided in **Table 7-6**, with some examples of structures given in **Figure 7-19**.

The number of items (or, in the case of canals or pipelines, kilometres) per structure type were summarised and the capacity for hydropower generation was estimated for each type of structure in the scheme, as shown in **Table 7-7**. Potentially appropriate turbines were also indicated in this table.

Table 7-6: Description of infrastructure in the Boegoeberg Irrigation Scheme (DWA, 2013)

Type of structure	Description
Main canals	The major, concrete lined canals that form the backbone of the irrigation system.
Secondary canals / pipelines	Includes small secondary canals and pipelines that convey water from the main canal to irrigation properties not adjacent to the canal.
Aqueducts	Elevated canal structures constructed to convey water over dry water courses, supported on tie beams.
Siphons	Underground pipes constructed to convey water underneath dry water courses, preventing damage to the canal structure (**Figure 7-19(a)**).
Flow measuring structures	Permanent structures constructed to measure the volume of water that passes the measuring point, (parshalls, sharp crested weirs, etc.)
Bulk water sluices	Sluices situated in the waterway, used to control the flow of water downstream of the control point.
Property sluices	Water from off takes that are serving the irrigation properties is controlled by sluices and the volume of water is measured by a parshall.
Reject structures	Water diversion structures that are used to divert excess water back to the river, i.e. water that is more than the maximum flow capacity of the downstream section of the canal.
Vehicle bridges	Bridges that were constructed and which allow direct access for vehicles and equipment over the canal where no alternative route exists.
Foot bridges	Smaller bridges that were constructed to allow access for people and farm workers to either side of the canal without safety risks.
Diversion structures	Structures used to divert water from one part of the scheme to another (**Figure 7-19 (b)**).

(a) Siphon inlet b) Diversion to Gariep canal

Figure 7-19: Boegoeberg irrigation scheme infrastructure (DWA, 2013)

Table 7-7: Hydropower potential estimation for the Boegoeberg irrigation scheme

Type of structure	Total items	Maximum flow rate	Canal area	Velocity	Suitable type of turbine	Power per site	Number of potential sites	Capacity
	No.	m^3/s	m^2	m/s	Description	kW	No.	kW
Boegoeberg main canal (km)	174	15.18	4	3.80	waterwheels, vortex & hydrokinetic turbines	13.9	17	241.00
Northern Orange canal (km)	40	2	1.5	1.33	waterwheels, vortex & hydrokinetic turbines	0.2	4	0.90
Gariep canal (km)	38	2	1.5	1.33	waterwheels, vortex & hydrokinetic turbines	0.2	4	0.86
Rouxvill West canal (km)	8	0.4	1.5	0.27	waterwheels, vortex & hydrokinetic turbines	0.0	1	0.00
Secondary canals/pipes (km)	62	potential estimated			not applicable	0.0	0	0.00
Aquaducts	15	potential estimated			hydrokinetic turbines	2.0	5	10.00
Siphons	68	potential estimated			not applicable	0.0	0	0.00
Flow measuring structures	30	potential estimated			very low-head equipment	0.1	10	1.00
Bulk water sluices	64	potential estimated			hydroengines, siphon turbines, Kaplan by Ossberger	150.0	2	300.00
Property sluices	769	potential estimated			hydrodynamic screws	2.0	10	20.00
Reject structures	26	potential estimated			hydroengines, siphon turbines, Kaplan by Ossberger	10.0	5	50.00
Vehicle/foot/cattle bridges	543	potential estimated			included in previous calculations	0.0	0	0.00
Estimated total of low-head hydropower capacity								**623.76**

7.4.11 Kakamas Irrigation Scheme

7.4.11.1 Overview

The Kakamas Irrigation Scheme has two weirs, primary irrigation conveyance infrastructure which diverts water from the Orange River into the scheme and a canal distribution system which delivers the water ordered by the irrigators at their farm turnouts through a number of sluice gates. **Table 7-8** provides a description of the structure types found in the Kakamas irrigation scheme

The number of items (or, in the case of canals or pipelines, kilometres) per structure type were summarised or estimated and the capacity for hydropower generation was estimated for each type of structure in the scheme, as shown in **Table 7-9**. Potentially appropriate turbines were also indicated in this table.

Table 7-8: Description of infrastructure within the Kakamas irrigation scheme (DWA, 2013)

Type of structure	Description
Main canals	The major, concrete lined canals that form the backbone of the irrigation system (**Figure 7-20 (a)**).
Secondary canals / pipelines	Includes small secondary canals and pipelines that convey water from the Main Canal to irrigation properties not adjacent to the canal.
Aqueducts	Elevated canal structures constructed to convey water over dry water courses, supported on tie beams.
Siphons	Underground pipes constructed to convey water underneath dry water courses, preventing damage to the canal structure
Flow measuring structures	Permanent structures constructed to measure the volume of water that passes the measuring point, (parshalls, sharp crested weirs, etc.)
Bulk water sluices	Sluices situated in the waterway, used to control the flow of water downstream of the control point.
Property sluices	Water from off takes that are serving the irrigation properties is controlled by sluices and the volume of water is measured by a parshall.
Reject structures	Water diversion structures that are used to divert excess water back to the river, i.e. water that is more than the maximum flow capacity of the downstream section of the canal (**Figure 7-20 (b)**).
Diversion structures	Structures used to divert water from one part of the scheme to another (**Figure 7-20 (c)**).

(a) The Northern main canal

(b) Reject structure

(c) Diversion structure

Figure 7-20: Examples of structures in the Kakamas irrigation scheme (DWA, 2013)

Table 7-9: Hydropower potential estimation for the Kakamas irrigation scheme

Type of structure	Total items	Maximum flow rate	Canal area	Velocity	Suitable type of turbine	Power per site	Number of potential sites	Capacity
	No./km	m^3/s	m^2	m/s	Description	kW	No.	kW
North main canal 1 (km)	17.4	7.45	4*	1.86	waterwheels, vortex & hydrokinetic turbines	1.6	2	2.85
North main canal 2 (km)	7.2	4.09	4*	1.02	waterwheels, vortex & hydrokinetic turbines	0.3	1	0.20
South main canal 1 (km)	9.3	6.81	4*	1.70	waterwheels, vortex & hydrokinetic turbines	1.3	1	1.16
South main canal 2 (km)	0.7	4.43	4*	1.11	waterwheels, vortex & hydrokinetic turbines	0.3	0	0.02
South main canal 3 (km)	6.35	3.16	1.5*	2.11	waterwheels, vortex & hydrokinetic turbines	0.9	1	0.56
South main canal 4 (km)	6.9	2.07	1.5*	1.38	waterwheels, vortex & hydrokinetic turbines	0.2	1	0.17
South main canal 5 (km)	9.35	0.84	1.5*	0.56	waterwheels, vortex & hydrokinetic turbines	0.0	1	0.02
Paarden Island main canal (km)	11.24	1*	1.5*	0.67	waterwheels, vortex & hydrokinetic turbines	0.0	1	0.03
Alheit main canal (km)	5.794	1*	1.5*	0.67	waterwheels, vortex & hydrokinetic turbines	0.0	1	0.02
Augrabies main canal 1 (km)	0.5	7.85	4*	1.96	waterwheels, vortex & hydrokinetic turbines	1.9	0	0.10
Augrabies main canal 2 (km)	4.9	5.25	4*	1.31	waterwheels, vortex & hydrokinetic turbines	0.6	0	0.28
Renosterkop main canal (km)	3.32	2*	1.5*	1.33	waterwheels, vortex & hydrokinetic turbines	0.2	0	0.07
Concrete secondary canals (km)	68.9	potential estimated			not applicable	0.0	0	0.00
Stormwater and subsurface drainage canals(km)	44	potential estimated			not applicable	0.0	0	0.00
Pipes (km)	23	potential estimated			spherical turbines, ring turbines, hydro e-kids	10.0	2	23.00
Tunnels	2	potential estimated			spherical turbines, ring turbines, hydro e-kids	10.0	2	20.00
Aquaducts	4	potential estimated			hydrokinetic turbines	2.0	1	2.00
Siphons	40	potential estimated			not applicable	0.0	0	0.00
Flow measuring structures	12	potential estimated			very low-head equipment	2.0	4	8.00
Bulk water sluices	8	potential estimated			hydroengines, siphon turbines, Kaplan by Ossberger	150.0	1	150.00
Property sluices	500	potential estimated			hydrodynamic screws	2.0	8	16.00
Reject structures	32	potential estimated			hydroengines, siphon turbines, Kaplan by Ossberger	10.0	7	70.00
Diversion structures	5*	potential estimated			hydroengines, siphon turbines, Kaplan by Ossberger	10.0	2	20.00
Estimated total of low-head hydropower capacity								**314.48**

* denotes estimated areas, flow rates or number of structures

7.5 URBAN AREAS

7.5.1 Wastewater treatment works

7.5.1.1 Introduction

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 7-21**).

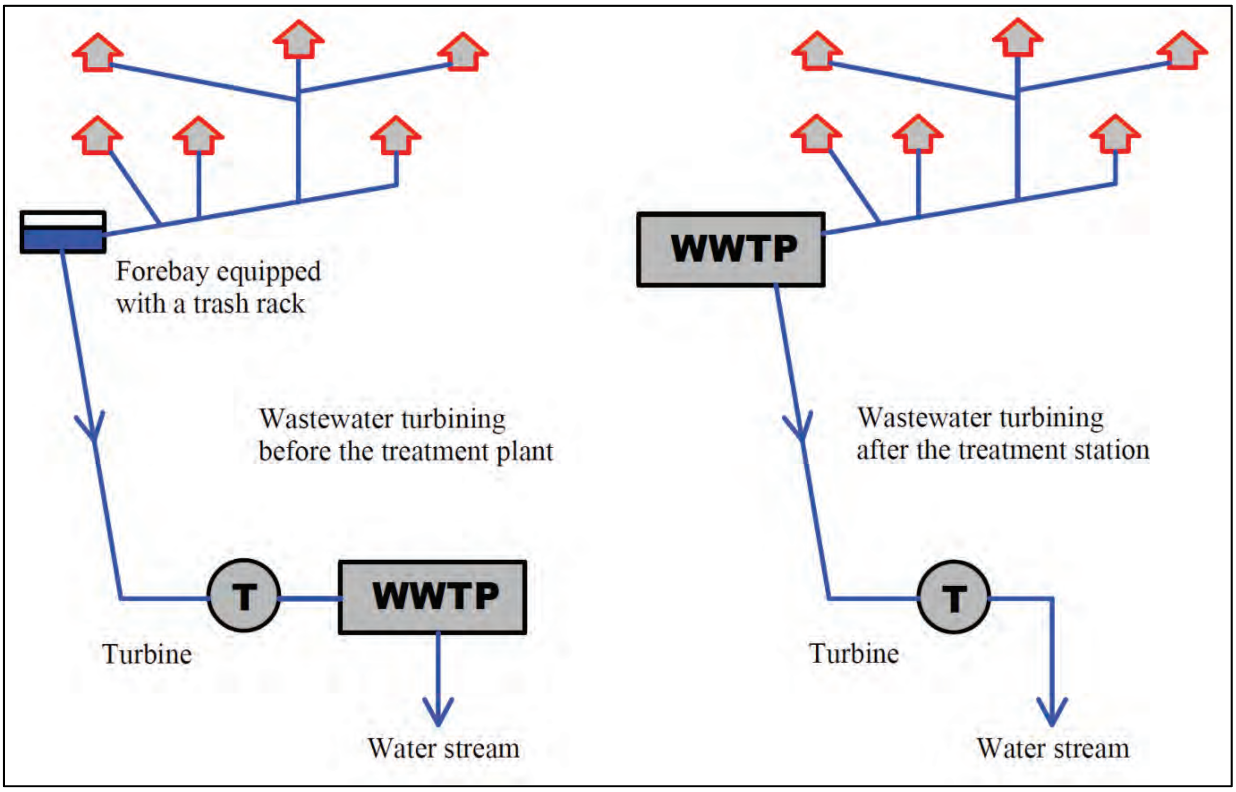


Figure 7-21: Wastewater treatment plant hydropower opportunities (ESHA, 2009)

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.

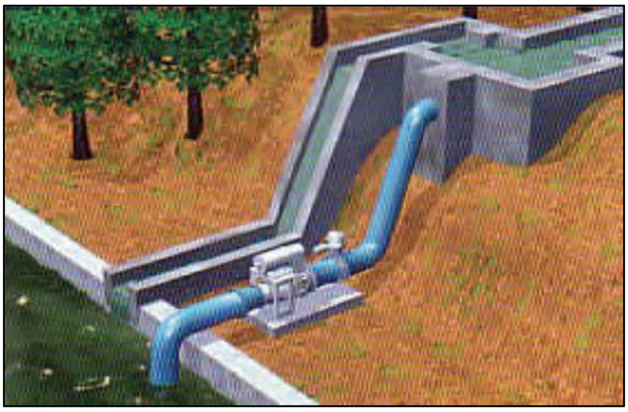
At these outlets a head difference from 1 m can be expected. Some of the analysed outlets have head differences of 8 m which combined with high flow rates have large electricity generation potential.

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).

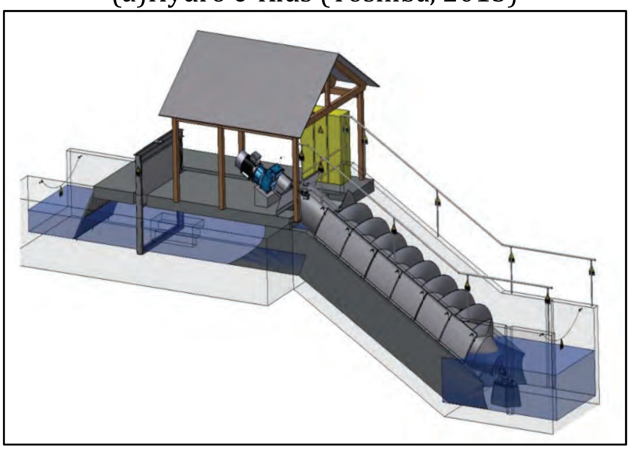
At many of the wastewater treatment plants extensive civil work has been done at the outlets which in turn decreases the construction effort needed for a hydropower plant.

7.5.1.2 Typical layouts of WWTW setups

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 7-22 (c)**), Kaplan or propeller turbines (**Figure 7-22 (a)**), hydroengine turbines (**Figure 7-22 (b)**) or siphon-type turbines.



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



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

(b)Hydroengine (Natel Energy, 2013)

Figure 7-22: Typical wastewater treatment plant turbine layouts

7.5.1.3 Potential

The Department of Water Affairs (DWA) releases Green Drop Reports annually for all nine South African provinces. The data from the 2012 reports were used to roughly estimate country-wide potential at wastewater treatment plants. The complete analysis is shown in **Appendix B.** A summary of all facilities with capacity of more than 25 Ml/day, grouped per province, is given in **Table 7-10**, with a more detailed look at all the wastewater treatment plants in Gauteng shown in **Table 7-11.**

For this study, a conservative approach was adapted, with a system efficiency of 80% and available head of 4 m. Using these values and the average flow in the country's macro wastewater treatment plants, it is estimated that about 1.6 MW of exploitable power exists, with a 99% load factor. Sensitivity analyses were done assuming available heads between 1 m and 8 m. These analyses are included in **Appendix B**. Two case studies are discussed in **Chapter** 8 and the actual measured potential at these sites are more than indicated using the initial assumptions of this section.

Table 7-10: Country-wide hydropower potential of macro wastewater treatment plants (extracted from DWA, 2012b)

Province	Total design capacity Ml/day	Total daily inflows Ml/day	Design potential kW	Design potential MWh/a	Operational potential kW	Operational potential MWh/a
Eastern Cape	212	163	59	513	77	666
Free State	204	124	45	389	74	639
Gauteng	2309	2388	867	7495	839	7247
KwaZulu Natal	652	487	177	1530	237	2047
Limpopo	28	27	10	83	10	88
Mpumalanga	56	36	13	111	20	176
North West	123	92	33	289	45	386
Western Cape	711	589	214	1849	258	2231
Northern Cape	64	25	9	78	23	201
Country-wide potential considering macro sites			**1428**	**12338**	**1583**	**13680**
Note: it is assumed that the inflows are equal to outflows at all plants						

Table 7-11: Hydropower potential of macro wastewater treatment plants in Gauteng (extracted from DWA, 2012b)

WWTP	Total design capacity Ml/day	Operational percentage of design capacity	Total daily inflows Ml/day	Design potential power kW	Design potential annual power MWh/a	Operational potential power kW	Operational potential annual power MWh/a
City of Johannesburg							
Driefontein	35	97%	34	11	93	11	96
Goudkoppies	150	89%	133	42	365	48	412
Bushkoppies	200	105%	209	66	574	64	549
Northern Works	450	98%	443	141	1216	143	1236
Olifantsvlei	200	103%	205	65	563	64	549
Subtotal	**1035**		**1024**	**325**	**2812**	**329**	**2843**
City of Tshwane							
Baviaanspoort	62	87%	54	17	149	20	170
Daspoort	60	63%	38	12	104	19	165
Klipgat	55	74%	41	13	112	17	151
Rietgat	28	74%	21	7	57	9	77
Rooiwal East	45	78%	35	11	96	14	124
Rooiwal North	150	107%	160	51	440	48	412
Sandspruit	20	56%	11	4	31	6	55
Sunderland Ridge	65	110%	71	23	196	21	179
Zeekoegat	30	17%	5	2	14	10	82
Subtotal	**515**		**436**	**139**	**1198**	**164**	**1415**
Ekurhuleni Metropolitan							
Anchor	35	121%	42	13	115	11	95
Dekema	36	78%	28	9	77	11	99
Hartebeesfontein	45	129%	58	18	159	14	124
Olifantsfontein	105	83%	87	28	239	33	288
Rondebult	36	64%	23	7	63	11	99
Vlakplaats	83	157%	130	41	357	26	228
Waterval	155	124%	192	61	528	49	426
Welbedacht	35	188%	66	21	181	11	96
Subtotal	**530**		**626**	**199**	**1719**	**168**	**1454**
Emfuleni Local							
Leeukuil	38	122%	46	15	127	12	104
Rietspruit	36	92%	33	11	91	11	99
Sebokeng	100	144%	144	46	396	32	275
Subtotal	**174**		**223**	**71**	**614**	**55**	**478**
Mogale City Local							
Flip Human	50	56%	28	9	77	16	137
Percy Stewart	27	63%	17	5	46	9	74
Subtotal	**77**		**45**	**14**	**123**	**24**	**212**
Total	**2331**		**2354**	**748**	**6466**	**741**	**6401**
Note: it is assumed that the inflows are equal to outflows at all plants							

7.5.2 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.

7.5.3 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.

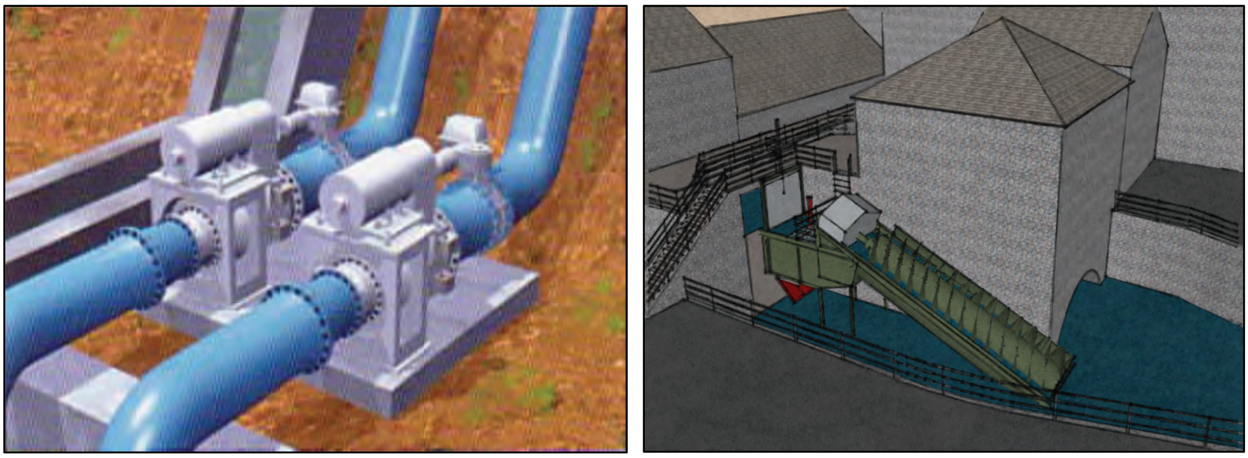
7.5.4 Industrial outflows

7.5.4.1 Introduction

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.

7.5.4.2 Typical layouts

Typical layouts for hydropower generation at industrial outflows would normally be similar to wastewater treatment plant hydropower set-ups. Archimedean screws (**Figure 7-23 (b)**), Kaplan or propeller turbines (**Figure 7-23 (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 7-23: Typical industrial outflow turbine layouts

7.5.4.3 Potential

The preliminary investigations indicate that there could be hydropower potential at some of the larger consumers. As an example the top 70 consumers in the City of Tshwane has a total AADD of ±74 000 kl (see **Figure 7-24**). The consumers include industries such as SAB, Nestle, Transnet; educational institutions such as University of Pretoria, UNISA, TUT; large businesses such as Department of Public Works, ABSA, SABS, Telkom, etc. All of these large consumers could have a potential hydropower

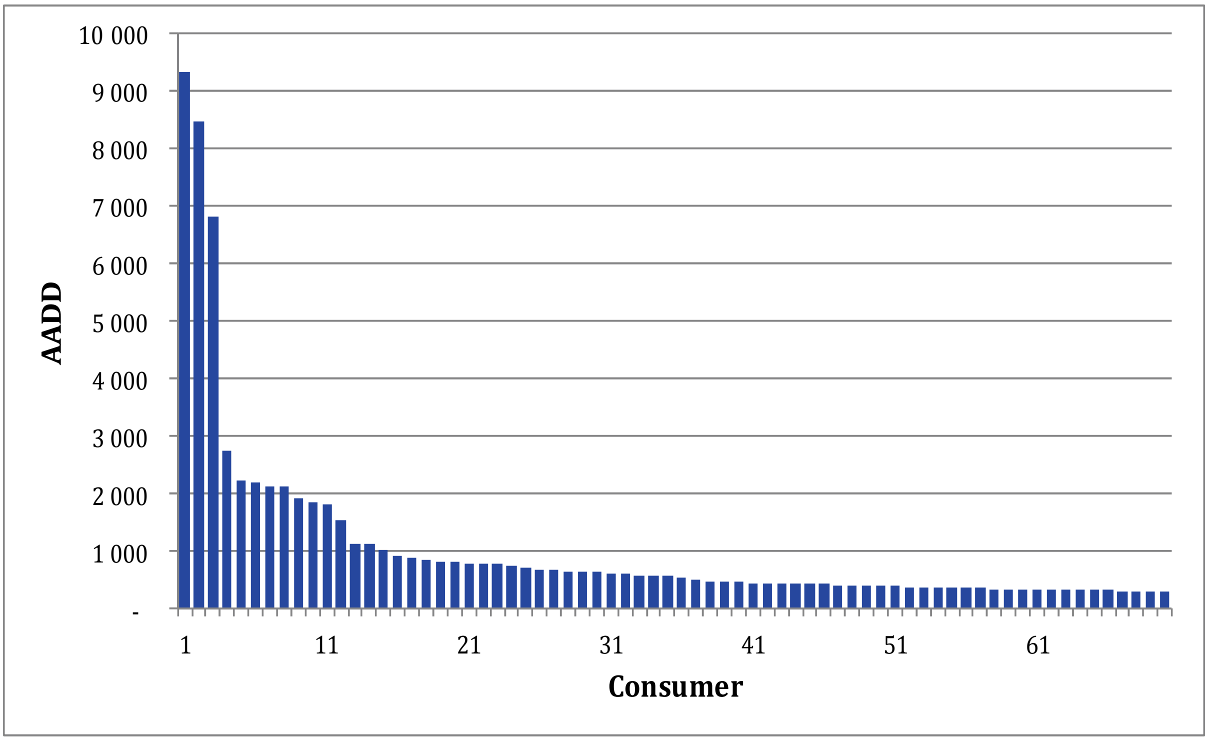


Figure 7-24: Large consumers in the City of Tshwane

There could be potential hydropower generation opportunities on the water supply side as well on the outflows from these larger consumers. The minimum residual pressure head based on the City of Tshwane Guidelines is 35 m for industries and businesses. These consumers may not require such high pressures and thus there could be opportunity for first converting some of this excess pressure into hydro electricity before consumption. These could typically be 10-20 kW hydropower turbine units depending on the pressure head available, resulting in between R45 000 and R90 000 per annum worth of clean renewable energy.

Certain industries and businesses return a significant portion of their water demand as effluent into the sewerage system. In some cases there could be a head difference between the outflow point and the receiving sewer system. This would then also provide an opportunity to install a low head turbine.

7.5.5 Tidal lagoons and oceans

7.5.5.1 Introduction

Hydropower generation utilising tidal energy is also a growing industry. Low-head turbines and wheels are used to extract energy from unconstrained, reversible water currents, found in oceans and tidal estuaries (Gorlov, 2002).

However, as the conventional hydropower development on the inland rivers and dams of South Africa is only resurrecting itself after decades of absence, the ocean energy development is in a total infancy in this country. To date no significant physical development can be accounted for. However the research of ocean energy potential and suitable energy abstraction technologies has been carried out for many years mainly by the Stellenbosch University Ocean Energy Research Group with the laboratory support from the Coastal Engineering and Port Infrastructure on the CSIR in Stellenbosch.

Nurick (1986) presented an overview of ocean energy; its broad potential and application of technologies suitable to South Africa's coastline conditions. By definition the renewable forms of ocean energy indirectly descend from solar energy manifesting on the surface of the Earth into the following energy forms:

- tidal energy – gravitational forces exerted by the moon and the sun
- ocean thermal energy – ocean surface acting as the collector of solar energy
- wave energy – generated by the wind over the ocean surface
- current energy – circulating current system generated by the prevailing global winds
- salinity gradients – interface between salt solutions of different concentrations

Internationally, to date tidal and wave energy are really only two systems successfully used in harnessing ocean energy on a commercial scale. The other systems are gradually surfacing from obscurity through a process of modern renewable energy technology applications.

The South African coastline, although fairly long (some 3 000 km long), is not endowed with the best tidal conditions (i.e. difference between high and low tide), but the average annual wave power is measured as high as a 50 kW per metre of the coastline (i.e. metre of wave crest).

7.5.5.2 Typical layouts

Figure 7-25 shows a typical layout for a wave power turbine installation and **Figure 7-26** shows an actual 300 kW installation in Northern Spain.

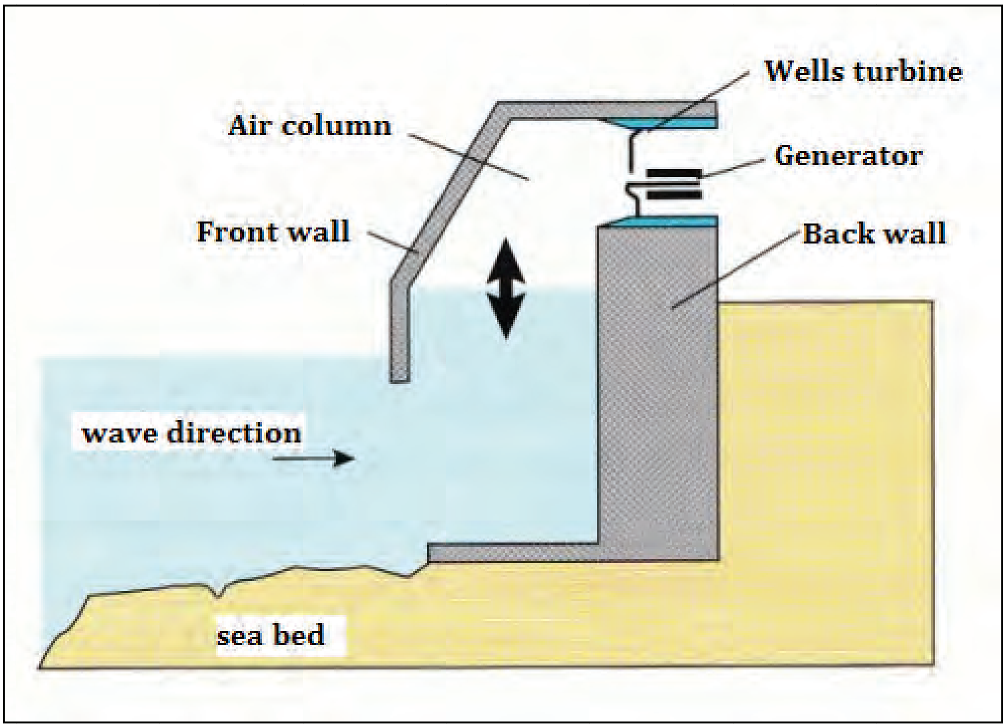


Figure 7-25: Example illustrating principles of a small wave power system (Hedberg, 2013)

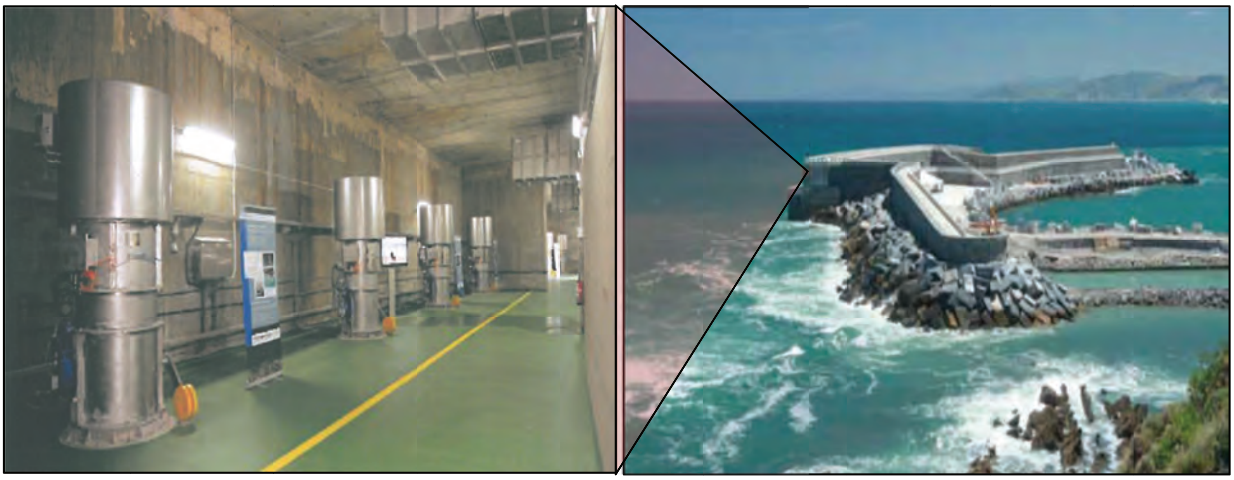


Figure 7-26: 300 kW Oscillating water column Mutriku wave power plant in Spain (Voith, 2011)

7.5.5.3 Potential

Retief and Muller (1986) outlined a status of research and application of wave energy development on selected sites of the Cape Peninsula. The Stellenbosch Wave Energy Convertor (SWEC) with a 770 MW potential capacity has been introduced and proposed for a site some 60 km north of Cape Town.

The power conversion output has been estimated at about 3 000 GWh per annum to be available ultimately to the national electricity grid. Nothing of this proposal has been implemented, however students studying coastal engineering and harbour infrastructure practiced with this proposal for the last thirty years. The physical model of the SWEC is well and functioning in the CSIR laboratory in Stellenbosch near Cape Town.

In the meantime, the national electricity utility Eskom conducted a series of site-specific studies particularly in the sphere of wave conditions and suitable technology possible for wave energy conversion in South Africa. In other parts of the world, research and technology application of small-scale ocean energy projects are increasing considerably with wave and tidal energy conversions topping the commercial research and manufacturing. Similarly to the sentiments that have surfaced in the sphere of inland hydropower (looking into energy extraction from existing or newly built infrastructure), ocean energy development tends to focus on existing breakwaters and harbour infrastructure (UK research is in the frontline of countries focusing on this subject).

Internationally, the main focus in ocean energy conversion is primarily within the sphere of wave energy which is being investigated in a number of EU countries, also in Canada, China, India, Japan, Russia and the US.

Tidal energy and tidal current projects are focused on primarily in countries with exceptionally tidal energy resources, such as the UK, Ireland, Italy, the Philippines, Japan and parts of US. In South Africa, the US-based Independent Power Producer Hydro Alternative Energy is contemplating to install an undersea power generation demonstration of about 8 MW (some R155 million) off the eThekwini (Durban in the KwaZulu-Natal Province) coast to utilise the energy potential of the Agulhas current.

Although ocean energy resources along the South African coastline are significant and highly sustainable, it should be noted that the implementation process of ocean energy conversion is lacking behind international development trends.

7.5.6 Summary of country-wide low head hydropower potential

Table 7-12 provides a conservative estimate of total low head hydropower potential in South Africa.

Table 7-12: Summary of country-wide low head hydropower potential

Low head hydropower location	Hydropower capacity range per site or scheme (kW)	Medium to long term capacity potential (MW)
Small (low head) dams	5 to 20 kW per small dam	5.70
Dams (low head)	300 kW and 3 MW	55.00
Run-of-river schemes	50 kW to a few MW per scheme	39.50
Measuring weirs	1 to 5 kW per weir	0.30
Irrigation canals	300 to 600 kW per scheme	5.50
Wastewater treatment works	5 to 200 kW per WWTW	2.50
Urban stormwater systems	Rather insignificant but at specific sites 1 to 5 kW	0.10
Conveyance pipelines	10 to 30 kW per pipeline	0.65
Industrial outflows	5 to 10 kW per site	0.25
Tidal lagoons and harbours	300 kW to several MW*	26.50
Wave energy systems	18 to 40 kW per metre wave crest offshore along the SA coastline	Unlimited as per new technology
*NB: 770 MW energy convertor tidal plant is planned to be installed some 60 km north of Cape Town.		

8 EXAMPLES OF EXISTING AND POTENTIAL LOW HEAD HYDROPOWER INSTALLATIONS

8.1 HARTBEESPOORT DAM

From a collaborative effort between the DWA's National Water Resources Infrastructure (NWRI), National Treasury, Eskom and the DoE some twenty national dam facilities were identified as potential for a small hydropower retrofit. An estimate of overall potential generation capacity is about 20 MW from evaluated dams. Ottermann and Barta (2012) compiled a pre-investment study for the Hartbeespoort Dam, one of the dam facilities on the DWA's list. The following excerpt from the study illustrates the main characteristics and costs concluded in the study.

The Hartbeespoort Dam is situated in the Crocodile River where it passes through the Magaliesberg mountain range north of Johannesburg and about 40 km west of the Tshwane Metropolitan area. The DWA is the owner of the dam and manages its water resource as an integral part of the Crocodile-west Water Supply System and the Limpopo Water Management Area. Administratively the Hartbeespoort Dam is situated in the North-West Province, but its catchment area is primarily within Gauteng Province. The natural runoff is highly modified through urbanization including Centurion, Midrand, Tembisa, Sandton, Randburg, Krugersdorp and parts of central Johannesburg, Edenvale and Kempton Park.

In total about 3.5 million people or 1,1 million households reside in the dam catchment representing about 28% of Gauteng's total population and up to 15% of South Africa's total GDP. This highlights the importance of the catchment and Gauteng's role in managing sustainable socio-economic development for its people. The construction of a dam was originally considered around 1902 to serve irrigation and some domestic water needs along the banks of the Crocodile River. However, the dam facility was commissioned only in 1923 together with a small hydropower plant attached to it.

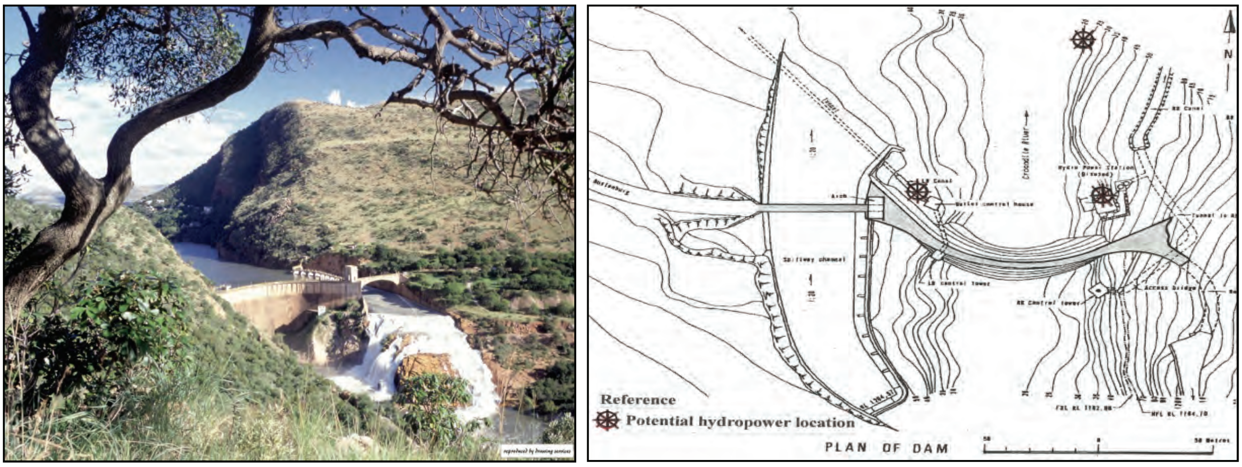


Figure 8-1: The Hartbeespoortdam

Figure 8-1 illustrates a general view of the dam wall and spillway and the plan with potential locations of small hydropower sites. The dam impoundment has a surface area of 20 km^2 and some 56 km of shoreline, which is now well covered by urban housing. High levels of nutrients resulted in eutrophication of the dam and associated blooms of algae and hyacinths are serious concerns for the sustainable water use in and below the dam.

To determine the potential for hydropower generation, a flow-duration curve was established using actual flow measurements over the past 32 years at the gauging weir (A2H083) downstream of the Hartbeespoort Dam. The river gauging station provides the most important data for the evaluation of hydropower generating potential. It comprises river releases and spills from the dam on a daily basis from 1980 to date (32 years of daily flows).

Downstream allocations released to river, currently include Brits domestic and industrial uses, releases for the old irrigation furrows abstracted at a downstream weir and transfers to Vaalkop dam, if required during dry years. These are constant releases which can be used for non-consumptive hydropower generation. In addition, 10% of the dam's yield is currently unallocated and most likely to be released permanently to river for downstream economic development. Additional seasonal spills are also available for peak hydropower generation.

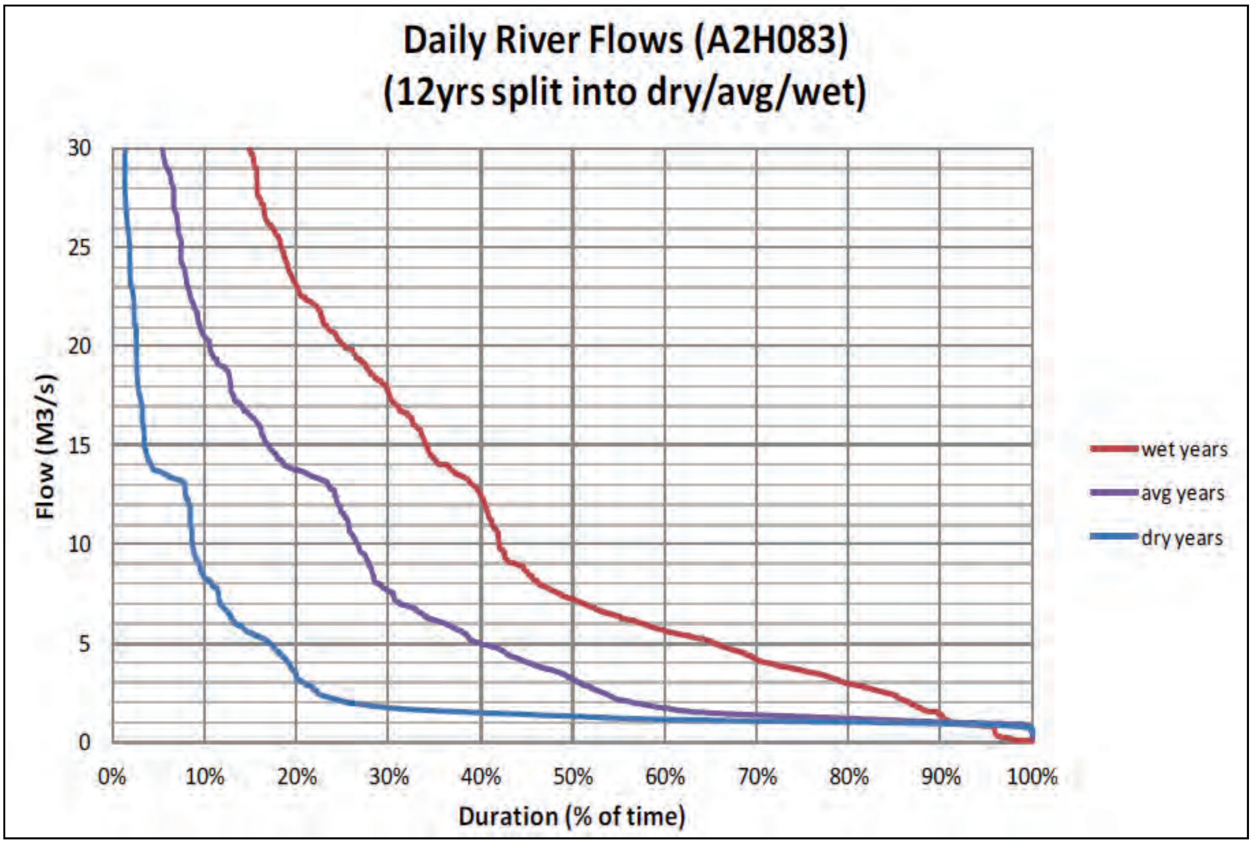


Figure 8-2: Flow-duration curve for gauging station A2H083 (Otterman and Barta, 2012)

Figure 8-2 indicates that:

- A 1.5 MW turbine can effectively run daily for peak rate periods (6hrs) and partially for standard rate periods;
- during dry years, it may be required to draw down about 2% of storage capacity, but this is unlikely, considering the artificial inflows from wastewater treatment works of 6.4 m^3/s;
- A 4.2 MW turbine can effectively run daily for peak periods during wet years; and
- further analysis of the rainy season will indicate the seasonal utilization during dry years

Hydrological analyses indicate that artificial runoff has already increased the MAR at the Hartbeespoort dam by over 50% from 163 million m^3 per annum in 1923 to 217 million m^3 per annum in 2010. If this trend continues, the flow duration curve will further move to the right and increase the level of assurance for power generation. This will specifically improve the base flows and allow a higher percentage of turbine utilization.

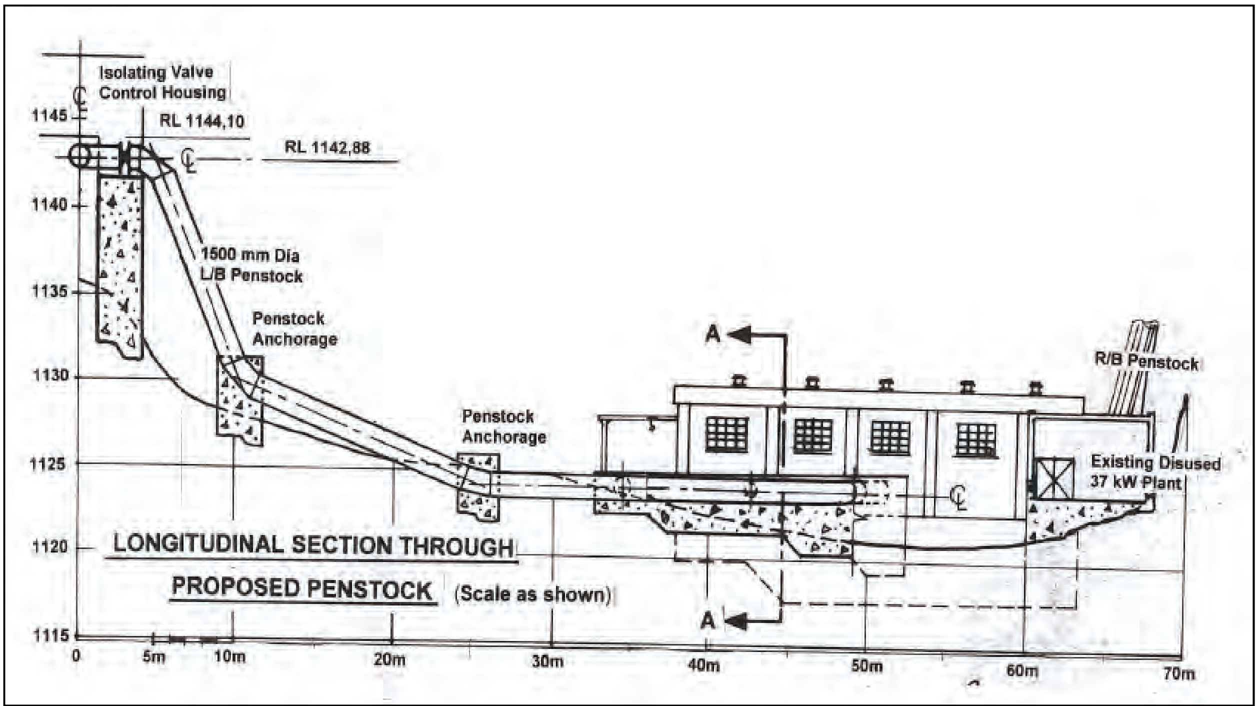


Figure 8-3: The conceptual sectional-view design showing a left bank penstock feed and turbines plant

Based on a preliminary design of the hydropower installation and costing of the installation, the following financials were derived, indicating the viability of retrofit hydropower installation at the Hartbeespoort Dam:

Cost-Benefit Summary for 2012 time basis:

(i) EPC Cost = **R98m** (R17 220 per installed kW)

(ii) Annual Operating Cost at NPV = **R1.72m** (R110/kWh)

(iii) Life-time levelised Cost at NPV = **R0.52/kWh** (break-even tariff)

(iv) Annual Income at NPV = **R16m** per annum

(v) Payback period = 13 years

(vi) Return on equity (ROE):

(vii) Without draw-down of dam FSL:

- At **90c/kWh** (the weighted average RuraFlex tariff), the IRR = **16%**
- At **103c/kWh** (NERSA tariff cap for hydropower), the IRR = **20%**

(viii) With draw-down of dam FSL:

- At **90c/kWh** (the weighted average RuraFlex tariff), the IRR = **21%**
- At **103c/kWh** (NERSA tariff cap for hydropower), the IRR = **25%**

From the above cost-benefit summary it is obvious that adding small hydropower to the Hartbeespoort Dam could advance the water-energy nexus in South Africa and stimulate more similar developments.

The DWA's Sakhile Project (WP 9233) conducted in 2008 evaluated field asset values of some 320 medium and large dams. The sizeable potential for hydropower has been identified and some 70 dams which can be retrofitted with the installations ranging between 300 kW and 3 MW. The estimate of some 55 MW of overall generation capacity can be developed with an estimated cost of about R 1 000 million within the next five years. Estimated annual hydroelectricity output is in order of 410 GWh saving in this way on CO_2 emissions by some 364 500 t/annum.

8.2 EXAMPLES OF HYDROPOWER DEVELOPMENTS IN RIVERS

8.2.1 RUN-OF-RIVER SCHEME: FISH RIVER NEAR COOKHOUSE

An example of an existing run-of-river scheme in South Africa can be found on the banks of the Fish River near Cookhouse in the Eastern Cape. Here, a farmer used a defunct irrigation pipe to divert water from the river, through a 315 kW Ossberger turbine and back into the river downstream of the turbine. The generated power is used mainly for a number of fixed centre pivot irrigation systems, but also for the farm's workshop and residence.

Water is diverted from the Fish River, through a 650 m long, 1.4 m diameter pipe (**Figure 8-4**), with a capacity of 2.5 m^3/s, that was installed in 1912 as irrigation pipe, but was decommissioned in 1974 after flood damage to the intake. The water falls 15.3 m to the Ossberger turbine (**Figure 8-5**), which has a maximum system efficiency of 84%. A trash rack was installed upstream of the turbine (**Figure 8-5**) to remove any debris from the water before it flows through the turbine. An Ossberger frequency regulator was installed to ensure a constant frequency of 50 hertz (**Figure 8-5**) (Botha, 2013).

Figure 8-4: Penstock to Ossberger turbine (Botha, 2013)

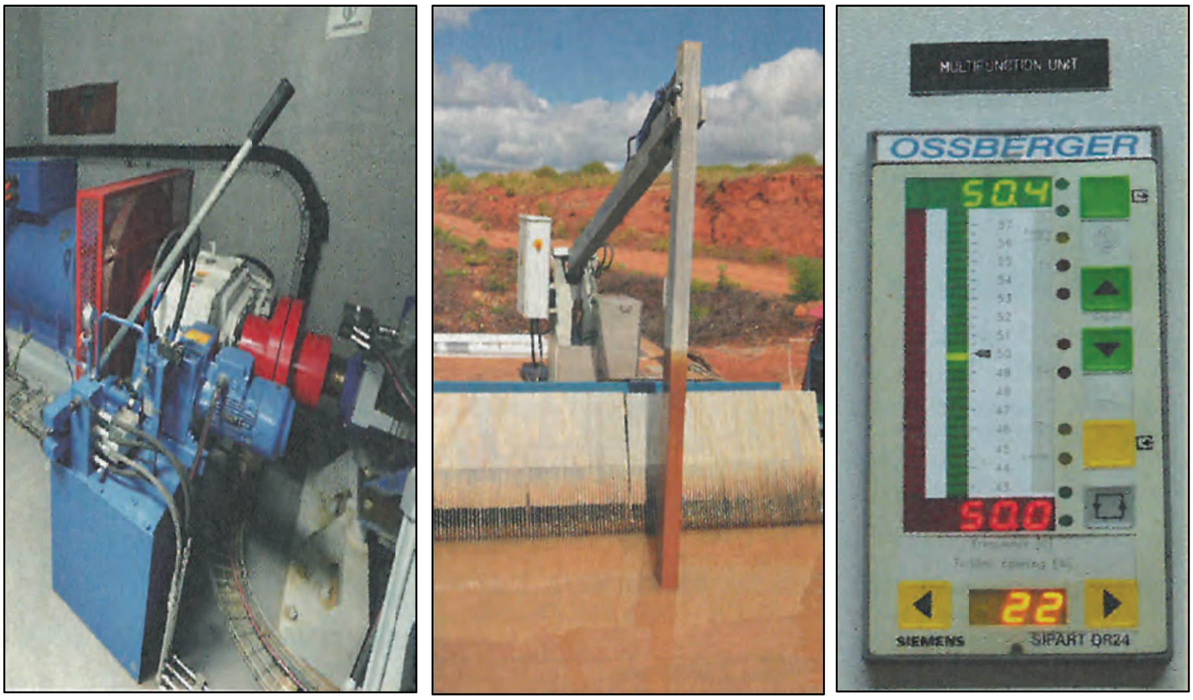


Figure 8-5: Ossberger turbine, trash rack and frequency regulator (Botha, 2013)

8.2.2 WEIRS – PROPOSED HYDROPOWER DEVELOPMENT AT NEUSBERG GAUGING WEIR

The Neusberg weir in the Orange River was identified in 2009 as a suitable site for a hydropower plant. A consortium has since been established and the project has been awarded preferred bidder status in the second round of the Renewable Energy Independent Power Producer Procurement (REIPP) Programme (West, 2013).

Figure 8-6: Neusberg Weir (DWA, 2013)

Both an environmental authorisation and a water use licence (WUL) were required for this scheme, as it has a significant construction component and water is abstracted from a natural resource. As water supply to the Kakamas irrigation scheme and flow gauging were the main functions of the weir, The Department of Water Affairs (DWA) only approved the WUL application after it was established that these functionalities would not be negatively impacted by the proposed hydropower plant.

As shown in **Figure 8-7**, the proposed scheme will have a capacity of 10 MW and will consist of an offtake weir (**Figure 8-8**), a 130 m long inlet canal, an inlet structure with radial gate, a 1.4 km long canal waterway, powerhouse and tailrace canal with a crump weir to measure return flow to the river.

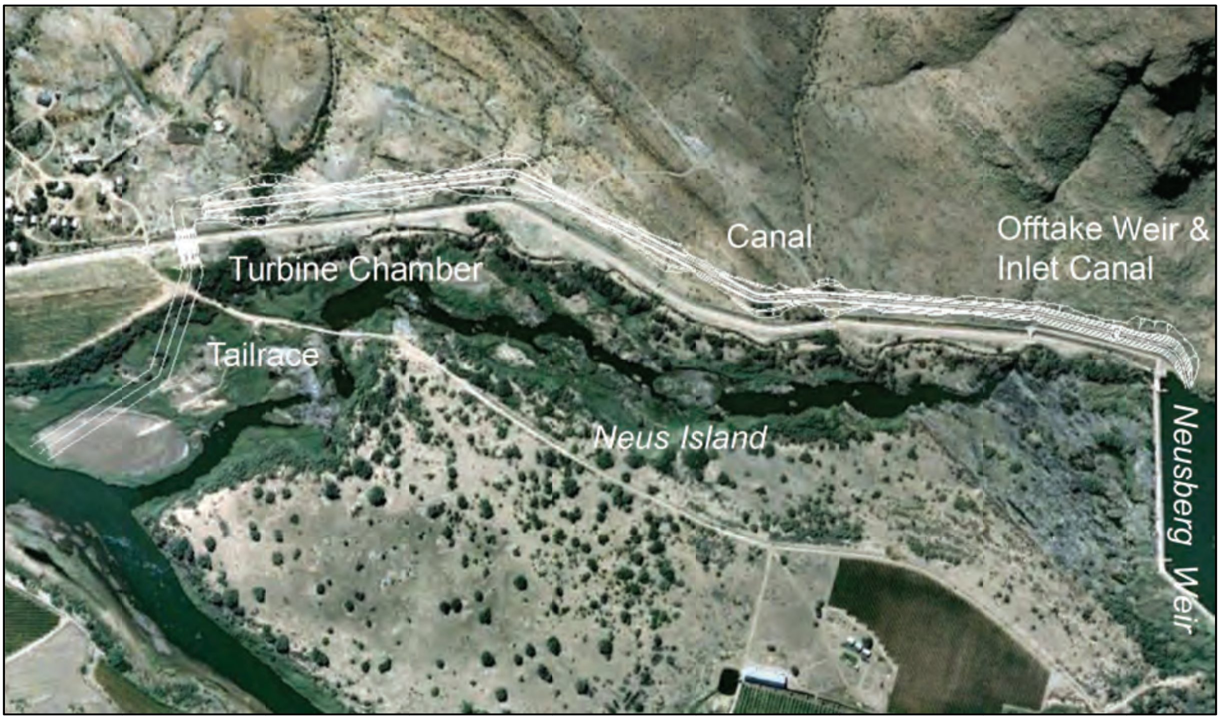


Figure 8-7: Proposed layout of Neusberg hydropower plant (West, 2013)

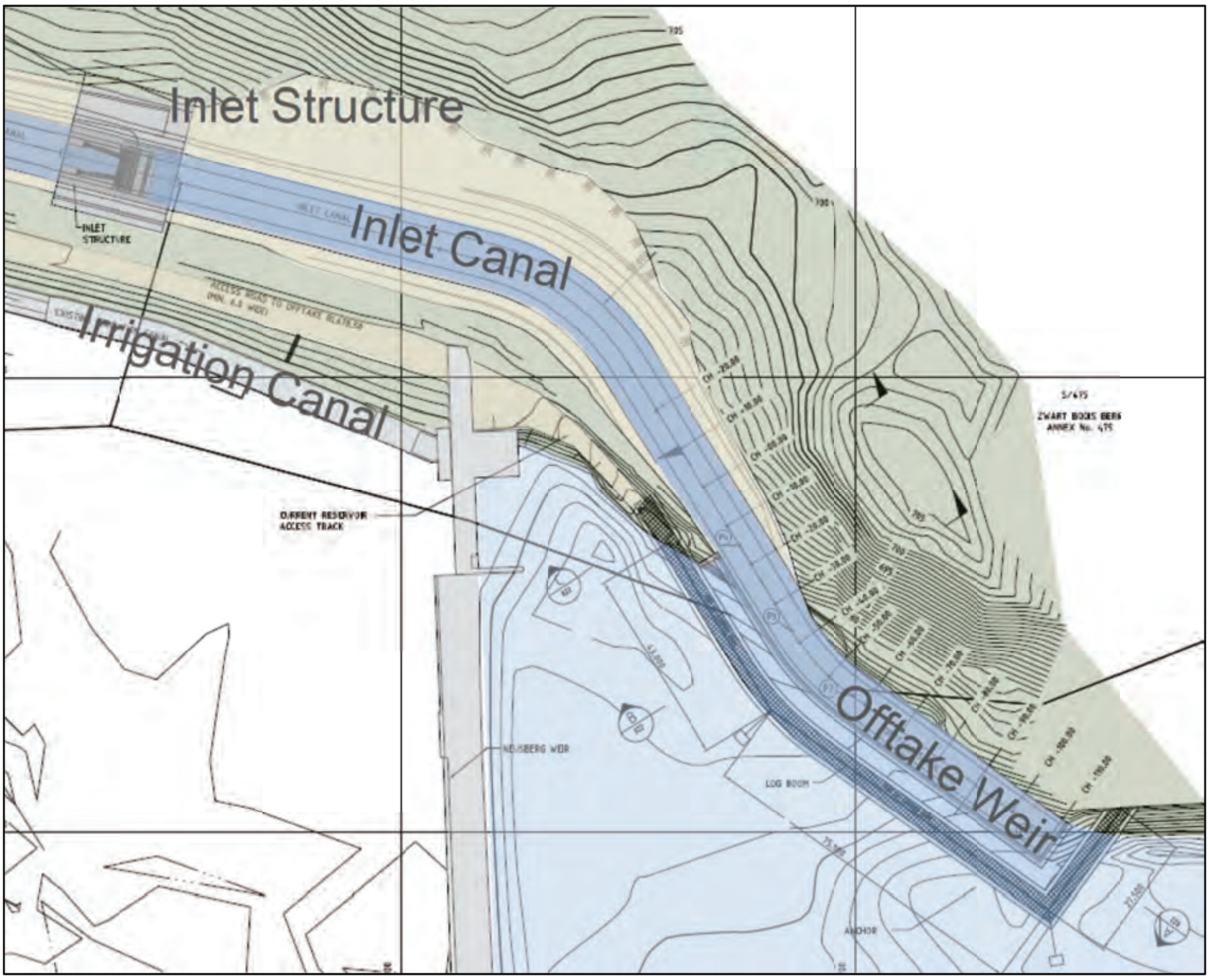


Figure 8-8: Proposed layout of Neusberg offtake weir and inlet canal (West, 2013)

8.3 IRRIGATION SYSTEMS

8.3.1 Orange-Fish-Sundays Water Transfer Scheme (O-F S WTS) & irrigation system

The O-F S WTS is situated in the Eastern Cape Province. For more than a century due to favourable climate conditions and suitable alluvial/flood plain soils, extensive irrigation activities were taking place particularly in the Great Fish and Sundays river basins. Before the large Gariep Dam storage on the Orange River was completed in 1971 and the Fish-Sundays river basins were connected by the Orange Fish Tunnel in 1975, the irrigation farmers were entirely dependent on water supplies from the four local major dams (i.e. Grassridge, Kommanddrift, Lake Arthur and Darlington dams). The diminishing capacities of existing major dams due to siltation and the frequent acute shortages of water for irrigation were decisive reasons for building of the O-F S WTS in 1978.

At present the DWA's administered O-F S WTS supports the Lower Fish and Lower Sundays Water User Associations (WUAs) and provides water supplies as far as to the Nelson Mandela Bay Metropolitan Municipality (NMBMM). The O-F S WTS is a complex system comprising of several hydraulic facilities, such as dams/barrage/weirs connected by the tunnels and canals equipped by siphons and cascaded chutes. Water for irrigation is abstracted along the banks of the Fish and Sundays rivers and along the irrigation canals. The whole scheme operates as a gravity flow system.

The total annual raw water allocation from the Gariep Dam presently stands at 651 million m^3 (20.6 m^3/s) of which some 207 million m^3 per annum (6.5 m^3/s) share is made available to the NMBMM for the urban water use. A constant firm yield from local water resources is estimated at 25 million m^3 per annum (0.82 m^3/sec) for the O-F S WTS. The flows experienced by this scheme are highly sustainable and substantial for more than 90 percent of the theoretically available time.

The pre-feasibility (i.e. pre-investment) analysis of nine most viable small hydroelectric (SHE) sites selected from the larger number of similar sites including irrigation gravity canals and a gravity pipeline had been compiled for the SA Central Energy Fund (2008). All nine selected sites have been found technically, environmentally and economically viable to be included in the feasibility evaluation and eventual procurement development.

All potential hydropower sites identified as suitable for development represent in principle an augmentation of existing hydraulic structures situated, in this specific case, along some 200 km of the O-F S WTS.

The sites selected are those with the highest potential capacity and least augmentation requirements in adjusting existing infrastructure (primarily low civil costs). The installations proposed for further analysis were investigated according to the similarities in augmentation activities.

(i) refurbishment/upgrading of existing SHE plants at the **Orange Fish Tunnel Shaft 7** (31^{0}22’26’’S; 25^{0}39’15’’E) of envisaged installed capacity of 6.9 MW;
(ii) augmentation of existing **Little Fish River Chute** (32^{0}48’40’’S; 25^{0}37’’50’’E) and **Schoenmakers River Chute** (33^{0}04’35’’S; 25^{0}34’00’’E) of envisaged installed capacity 4 MW and 2 MW respectively;
(iii) augmentation of existing **Grassridge Dam** (31^{0}46’08’’S; 25^{0}28’10’’E) and **Darlington Dam** (33^{0}44’26’’S; 24^{0}35’15’’E) of envisaged installed capacity 2 MW and 4 MW respectively as well as augmentation of **De Mistkraal Dam** (32^{0}58’04”S; 25^{0}40’19”E) of estimated hydropower capacity up to 2 MW;
(iv) augmentation of existing **Elandsdrift Barrage** (32^{0}31’43”S; 25^{0}45’22”E) in adding hydropower equipment with envisaged capacity of 2 MW;
(v) retrofitting in-line conduit hydropower at the **Nooitgedagt Water Treatment Works** (33^{0}31’51”S, 25^{0}37’45”E) of a capacity envisaged at 1 MW;
(vi) low head hydropower at the **Scheepersvlakte Balancing Dam** (33^{0}27’15”S; 25^{0}37’29”E) and at **several irrigation infrastructure sites** adopting screw turbines and waterwheels in generating energy for regional/local consumption.

There are numerous benefits to be gained from the establishment of overall anticipated install capacity of 25 MW in whatever way proposed SHE sites will be developed. The sites may be developed as self-standing installations or as a group of installations forming a regional hydroelectric scheme under management of one utility umbrella. In either case the overall annual energy production (AEP) will be able to off-set Eskom coal-based production annually by some 195 GWh (i.e. less annual losses) and enable CO_2 reduction of some 150 000 t/annum.

It is also anticipated that the proposed SHE plants will be mainly utilised for peaking rather than base load generation. Technically, the overall installed capacity will provide primarily for spinning reserve, frequency balance and voltage support. It is estimated that the lead time in developing of SHE installations will be about two years and service of each plant between 20 to 30 years along with the dams and canals to which the SHE plants are to be attached. In this way the national facilities will be inevitably better utilised and its maintenance can be supported from the sales of hydroelectricity. The hydroelectricity generated from new plants will become a pre-requisite to economic and social development in the rural areas of the region. The farmers will be able to plan for economic expansion of their businesses if additional energy is made available in that region. The urban areas of the NMBMM will have a choice between "dirty" and "green" energy.

Table 8-1: Hydropower potential in the Orange-Fish-Sundays WTS (Central Energy Fund, 2008)

Type of augmentation	Potential hydropower site	Estimated capacity (MW)	Direct benefits from development	
			Energy output (GWh/annum)	CO_2 reduction per annum (tons)
Refurbishment/ upgrade	Orange Fish Tunnel (Shaft 7)	6.9	42.0	32 430
Hydropower augmentation – conventional type	Little Fish River Cascade Chute	4	32.2	28 690
	Schoenmakers River Chute	2	16.1	14 345
Existing dam facility augmentation (retrofit)	Grassridge Dam	2	16.1	14 345
	Darlington Dam	4	32.2	28 690
	Elandsdrift Dam	2	12.4	11 072
	De Mistkraal Dam	1	5.8	5 146
	Scheepersvlakte Balancing Dam	Marginal	Marginal	Marginal
In-line conduit hydropower	Nooitgedagt Water Treatment Works	1	5.8	5 146
Totals for whole Water Transfer Scheme		22.9	162.6	139 864
*Note: There is a good potential for a micro hydropower on both incoming and out coming flows either for waterwheel(s) or a hydraulic screw.				

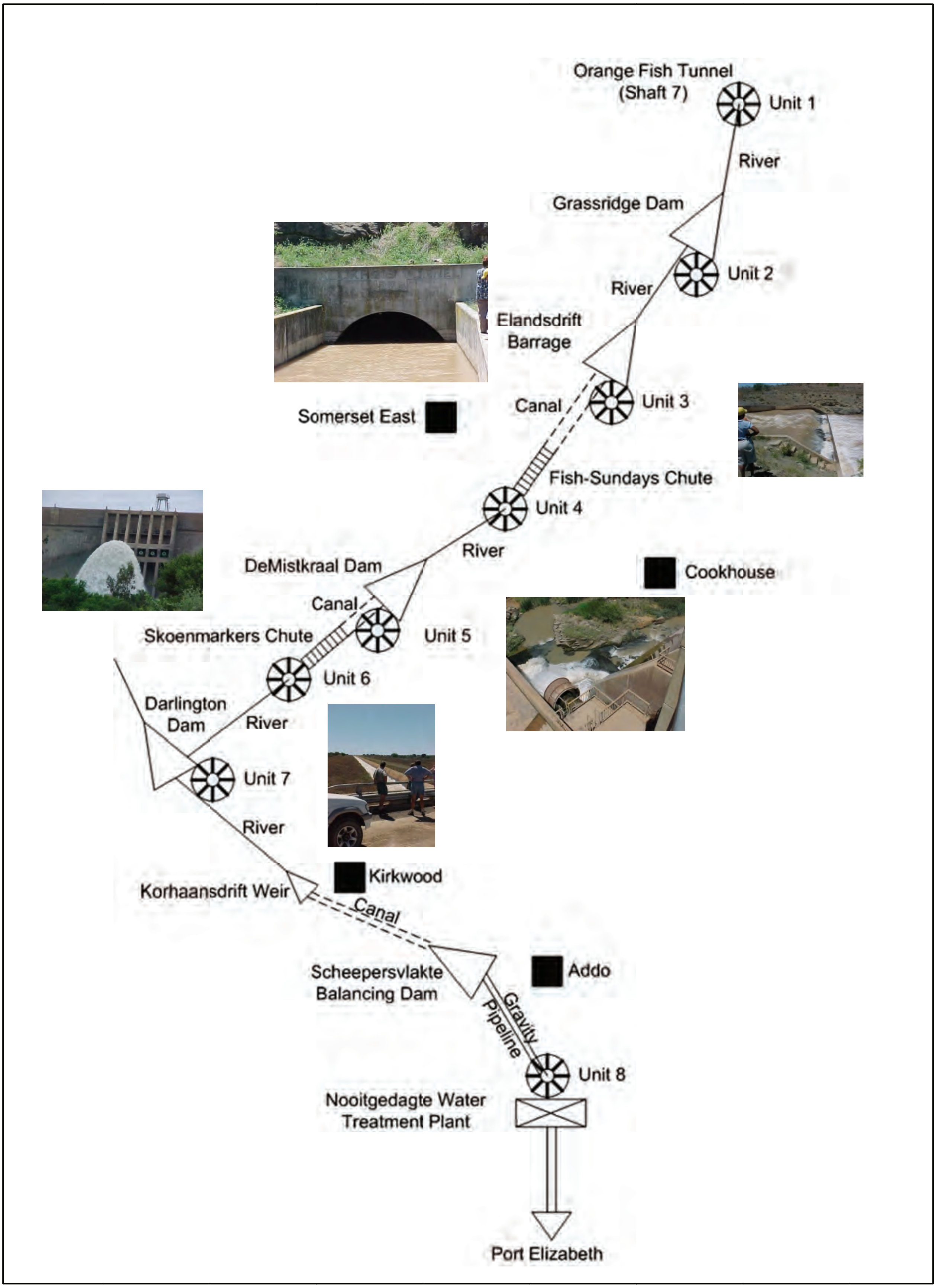


Figure 8-9: General layout of O-F S WTS hydropower potential

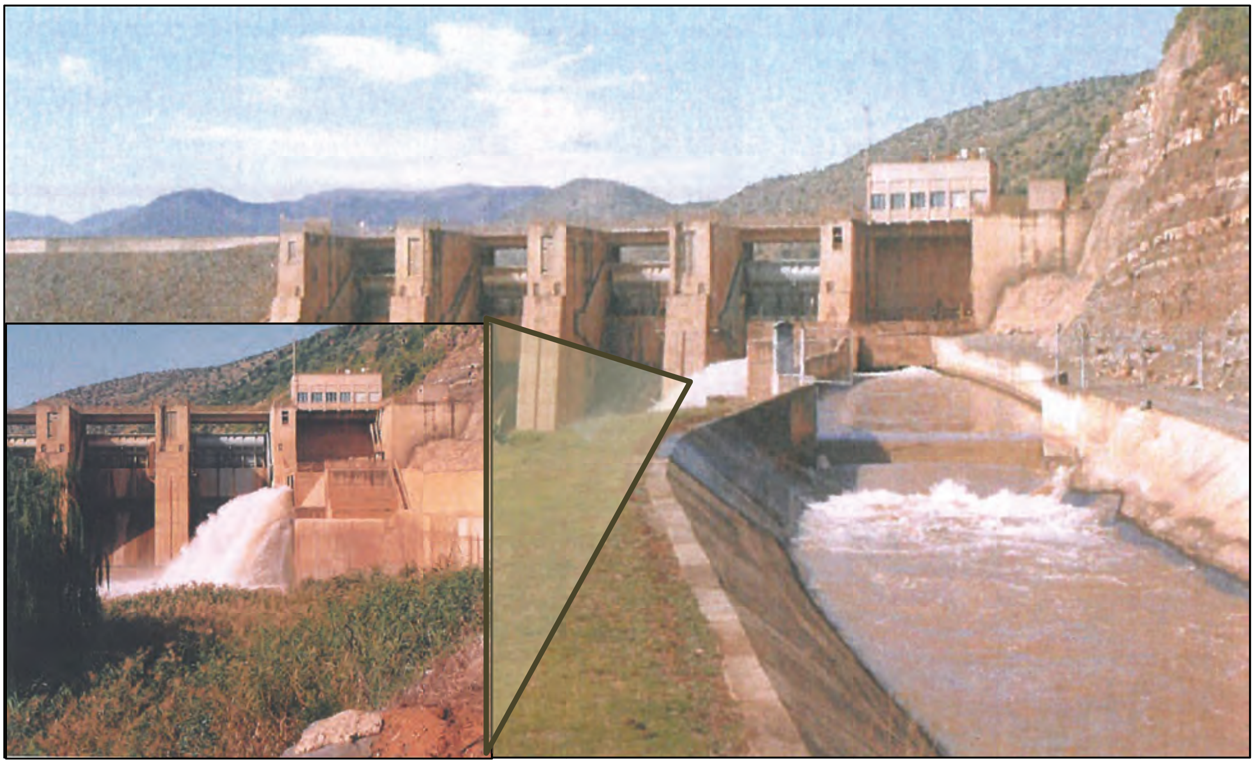


Figure 8-10: Elandsdrift Barrage (Barta, 2008)

8.4 URBAN

8.4.1 WASTEWATER TREATMENT PLANTS

8.4.1.1 Rooiwal

The Rooiwal wastewater treatment plant is located north of Pretoria on the Apies River. The plant receives sewage from eastern, central and western areas of Tshwane. It was constructed next to the Rooiwal power station in 1950 and currently has a capacity of 235 M*l*/d.

The Rooiwal premise has been split up into three works:

- Rooiwal West with a 40 M*l*/d biological trickling filter facility.
- Rooiwal East with a 45 M*l*/d biological trickling filter facility.
- Rooiwal North with a 150 M*l*/d biological nutrient removal activated sludge plant.

The plant on average operates at full capacity hence in 2011 the upgrading of this facility was commissioned to increase the capacity as well as the efficiency of the plant. The upgrade of the plant includes two 40 M*l*/d extensions on the Rooiwal North plant and a 60 M*l*/d extension on the Rooiwal East works.

The outflow from Rooiwal North and West accumulates in a reservoir from where the overflow is channelled to the Apies River. Rooiwal East conveys the outflow to the power station next door and was therefore not included in the analysis. **Figure 8-11 (a)** shows the North and West reservoir with its spillway structure.

(a) Rooiwal North and West reservoir outlet

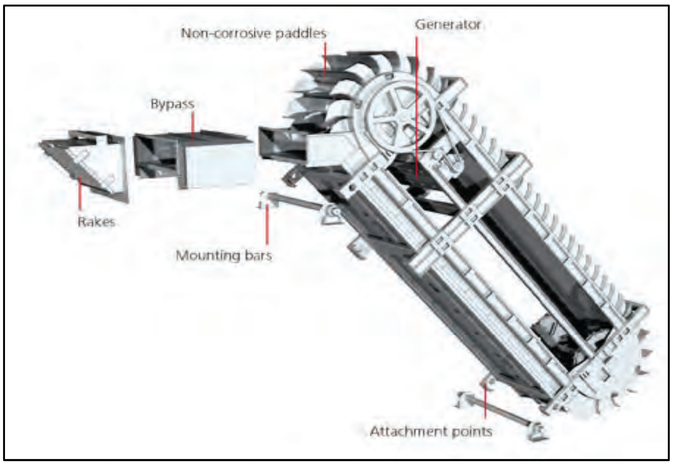
(b) Rooiwal North and West outflow

Figure 8-11: Rooiwal reservoir

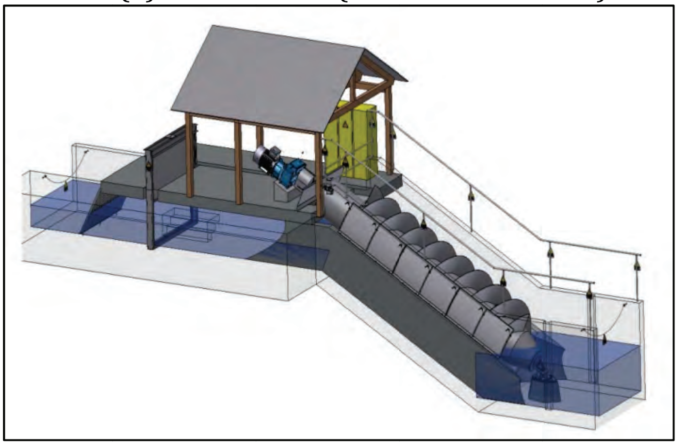
The outlet structure from the reservoir releases the water into a concrete channel which conveys the treated water to the Apies River. An approximate head difference of 8 metres is available in consort with the total outflow from the Northern and Western plants. The outlet structure can be seen in **Figure 8-11 (b)**.

Visible on **Figure 8-11 (b)** is the valuable energy currently going to waste. A conservative calculation indicates that 120 kW can be generated at this site utilising the outflow from the North and West plants (at 70 percent plant efficiency). The layout of the outlet structure can also assist in the incorporation of a hydropower plant reducing the installation costs. The upgrading of the facility will constitute a 40 percent increase in hydropower potential.

The recommended turbines for this site application are a hydrodynamic screw, Steffturbine or a Turbinator (refer to **Appendix A**). All three of these turbines are shown in **Figure 8-12**.



(a) Steffturbine (Steffturbine, 2013)



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

(b) Turbinator (Clean Power, 2013)

Figure 8-12: Possible turbine installations for Rooiwal WWTP

8.4.1.2 Zeekoegat

Zeekoegat wastewater treatment plant is located 40 km east of Pretoria with the outlet releasing treated water into the Pienaars River which flows into the Roodeplaat Dam. The current capacity of this plant is 35 Ml/d with an expansion project increasing the capacity with 40 Ml/d (Dungeni and Momba, 2010).

The treated water flows into a Dam on site which releases the treated water into the Pienaars River via a dam wall. The dam wall is shown in **Figure 8-13**. The available head is more than 4 metres and all the plant outflow flows into the dam on site. The plant currently runs at full capacity constituting approximately 11 kW (at 70 percent plant efficiency) with the upgrades increasing the potential to 23 kW.

Figure 8-13: Zeekoegat release

When incorporating a hydropower plant at this Dam wall the energy dissipaters should not be bypassed. Due to outflow from the plant flowing directly into a natural river, excessive velocities will cause excessive scouring. This has to be taken into account in the turbine selection.

The shape of the outlet structure lends itself to the use of a Siphon type turbine. These turbines take up little horizontal space allowing the outflow to still pass through the energy dissipaters. **Figure 8-14** indicates a typical Siphon turbine installation.

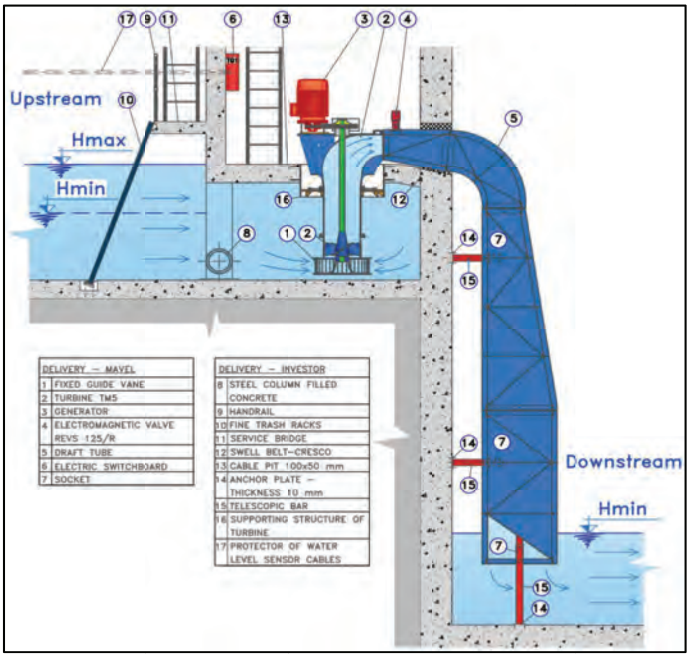


Figure 8-14: Siphon type turbine (Mavel, 2013b)

8.4.2 INDUSTRIAL OUTFLOWS

Teuteberg (2010) conducted a study to investigate the potential for hydropower generation at Roman Bay Sea Farm in Gansbaai. Roman Bay is an abalone farm that pumps large quantities of sea water from the ocean to holding tanks from where it circulates via gravity to various points on the farm, before being released back into the sea (**Figure 8-15**).

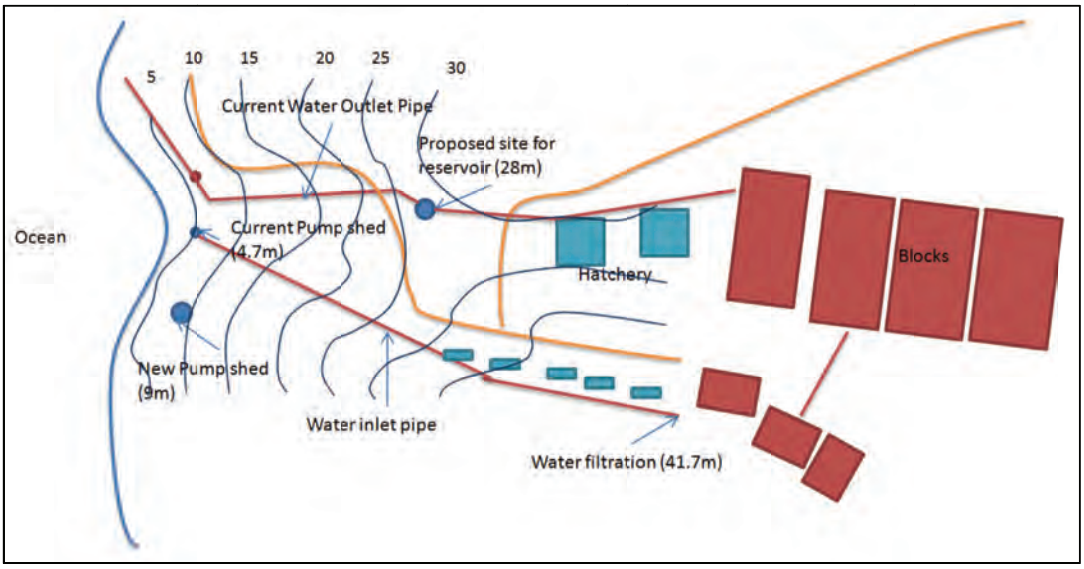


Figure 8-15: Roman Bay Sea Farm layout (Teuteberg, 2010)

It was estimated that around 97 kW of power could be generated at the existing pipe outlet (**Figure 8-16**), using the return flow of 0.52 m^3/s and 23 m of available head. Four concepts were considered for the site layout (**Figure 8-17**). Concept C was chosen and a KSB pump-as-turbine (PAT) was proposed, as it proved to be the most cost-efficient of a number of options due to its local content.

Figure 8-16: Roman Bay Sea Farm outlet pipe (Teuteberg, 2010)

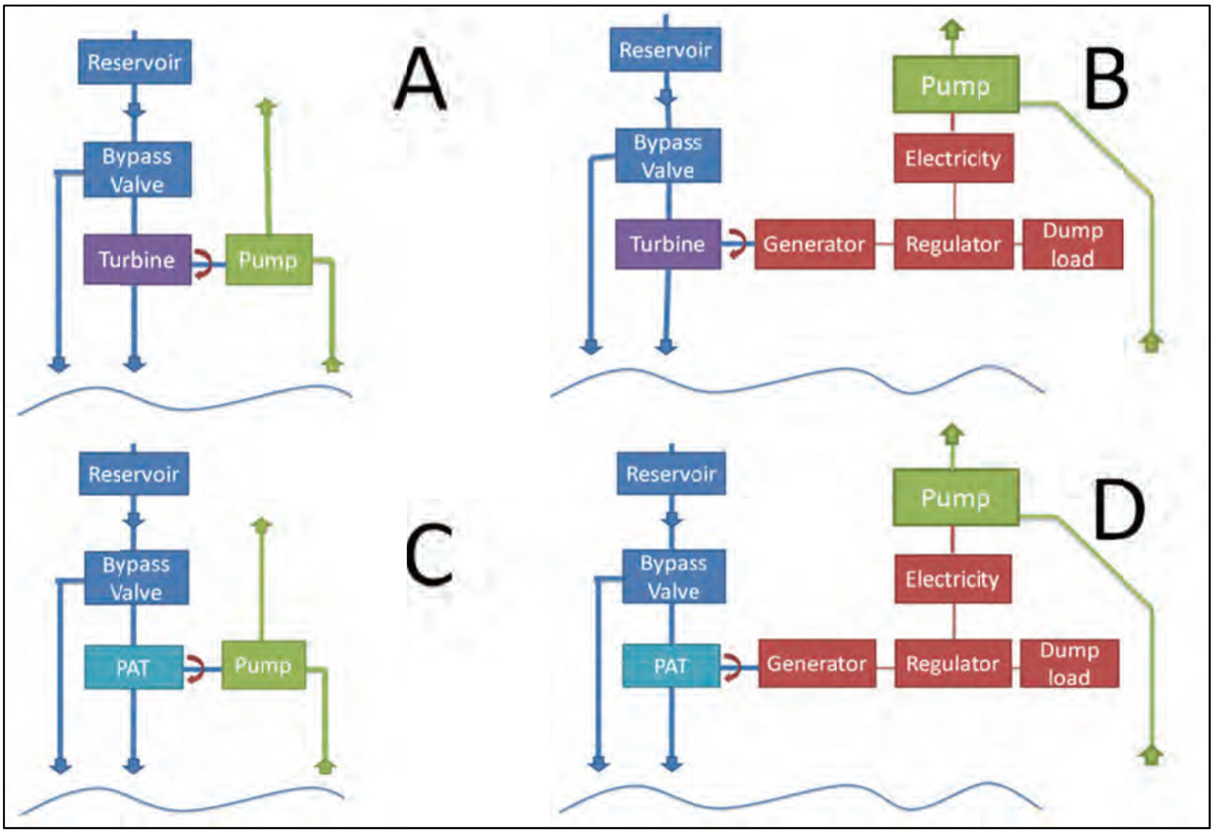


Figure 8-17: Roman Bay Sea Farm potential site layout concepts (Teuteberg, 2010)

9 CONCLUSIONS AND RECOMMENDATIONS

This report 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 on the overloaded national power generation capacity.

This report reflects that the retrofitting of hydropower (i.e. augmenting existing installations) to infrastructure has many advantages.

The research work compiled in this report, together with the WRC Project K5/2095 (i.e. in-line hydropower) are aimed to make 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.

Table 9-1 provides a summary of the estimated country-wide potential for low-head hydropower development, considering all the possible locations identified in this study.

The potential annual energy output from identified available capacity hidden in existing infrastructure as given in **Table 9-1** could produce between 35 and 115 GWh thus helping Eskom to deliver coal-fired electricity to other needy users. In implementing determined low-head hydropower potential, various job opportunities will be created in the manufacturing and operation/maintenance economic sectors. At present most, if not all, low-head hydropower equipment is available only from the European, Asian and North American manufacturing markets.

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.

Table 9-1: Estimates of the country-wide potential for low-head hydropower development

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
Dams (low head)	55.00	55.00	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

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 release more interest and commitment to hydropower generation;

    - pilot 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;
    - an example 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;
- Development of manuals to assist prospective small low-head hydropower developers/proponents for rural electrification in dealing with the technical, site evaluation, financial and regulatory aspects of such developments; and
- Detailed study be undertaken on the legislative and regulatory aspects of small hydropower especially for run-of river schemes; 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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Legislation

Electricity Act 2006

Electricity Regulation Act (Act 4 of 2006)

Municipal Infrastructure Investment Framework, 2010

Municipal Systems Act (Act 32 of 2000)

National Energy Act, 2008

National Energy Regulator Act (Act 40 of 2004)

National Environmental Management Act (Act 108 of 1998)

National Water Act (Act 36 of 1998)

National Water Amendment Act (Act 1 of 1999)

Public Finance Management Act, 1999

Revised Strategic Plan of the DoE, 2011/12 to 2015/16

Strategic Framework for Water Services, 2003

Water Services Act (Act 108 of 1997)

APPENDIX A

1 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 1-1** graphically indicates how the different turbine types are divided into the two categories.

Table 1-1: Groups of Water Turbines (Adapted from 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 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 1-2** and **Table 1-3** summarise the appendix layout, with turbines color-coded according to type, name and manufacturer.

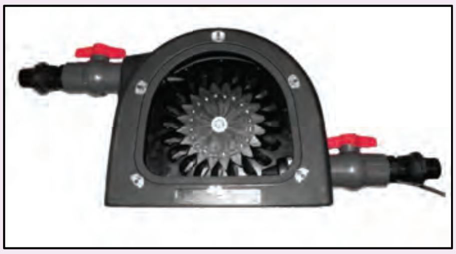
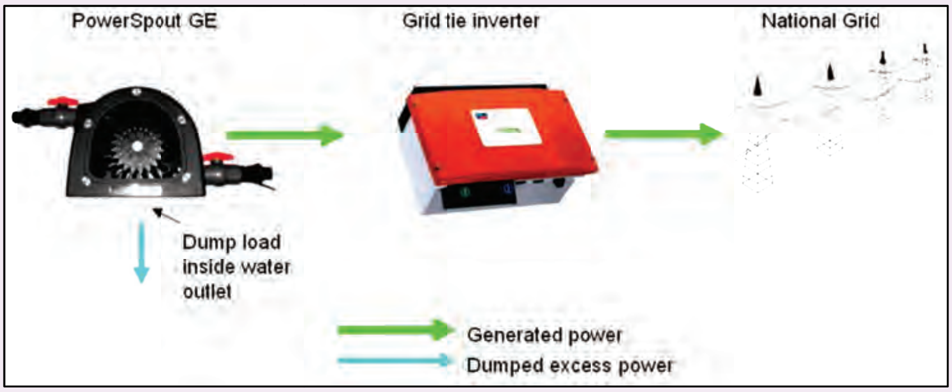
Table 1-2: Layout of Appendix B: impulse turbines

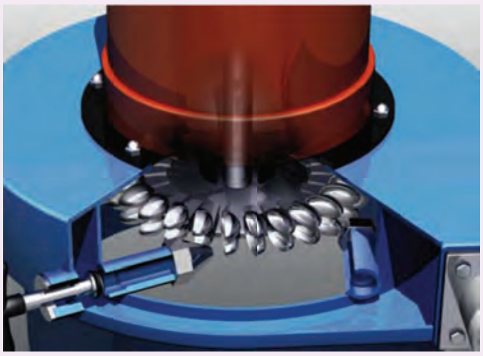
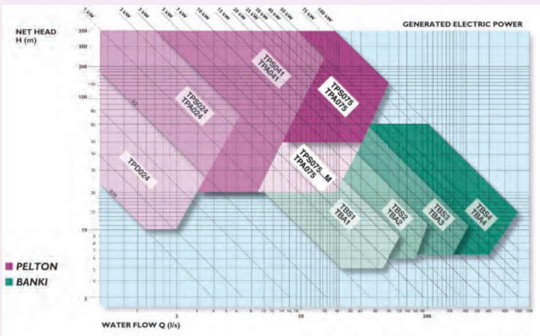
Turbine group	Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power (kW)
Impulse	Pelton	Powerspout	0.008-0.01	3-100	<1.6
		IREM	0.005-0.10	20-350	<100
	Crossflow	IREM	0.01-1	5-60	<100
		Ossberger	0.04-13	2.5-200	15-3 000
		Wasserkraft Volk	1.5-150	Not given	<2 000
	Hydroengine	Natel energy	1.1-10.1	< 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	2.5-5	10

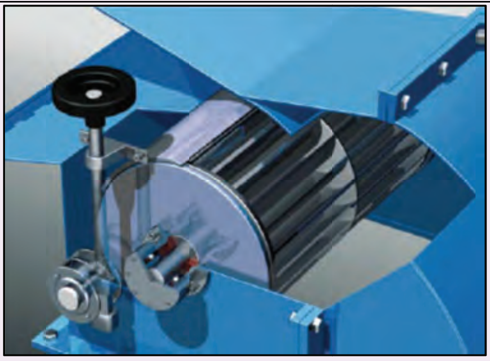
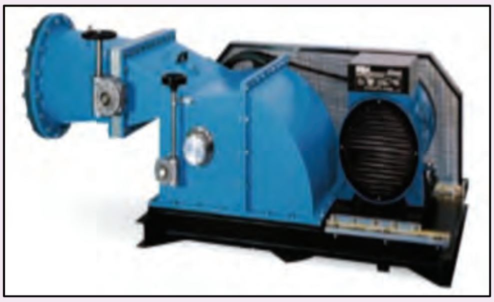
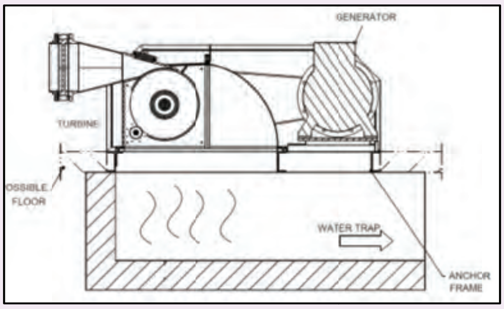
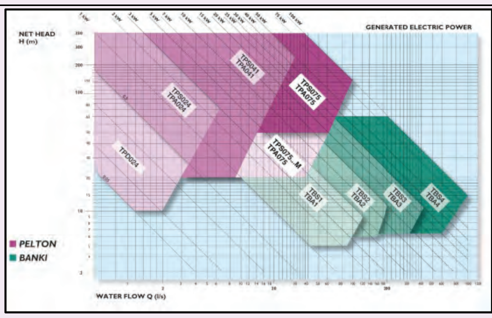
Table 1-3: Layout of Appendix B: reaction turbines

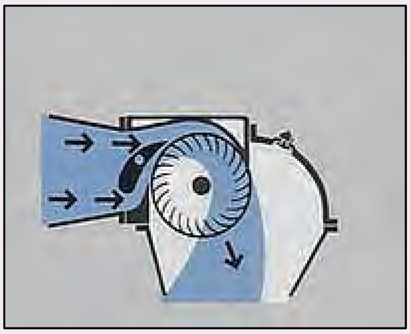
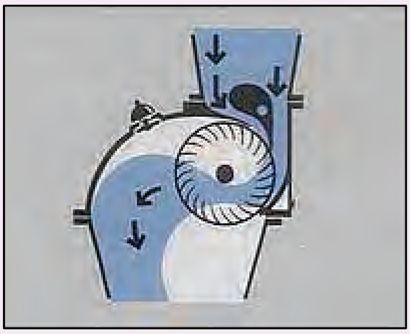
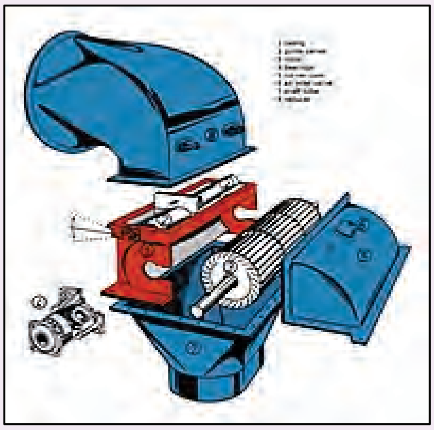
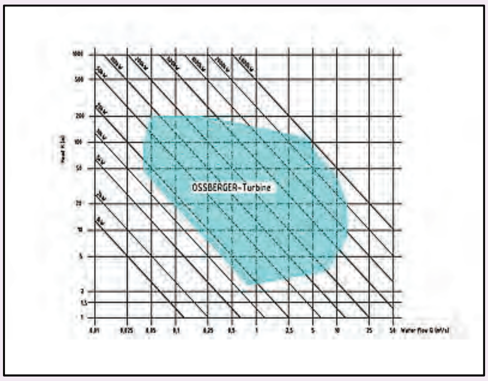
Turbine group	Turbine type	Supplier	Flow range (m^3/s)	Head range (m)	Power (kW)
Reaction	Kaplan	Ossberger	1.5-60	1.5-20	20-35 00
		Mavel	0.3-150	1.5-35	30-20 000
		Voith	Not given	3-95	100-400 000
		Energy systems	0.03-0.06	1-3	0.09-1
		Power Pal	0.04-0.13	1.5	0.2-1
	Turbinator	Clean Power AS	0.5-12	10-60	75-3 300
	Bulb	Alstom	0.3-150	2-30	<130 000
		Voith	2-30	Not given	1 000-80 000
		Voith (MiniHydro)	1-14	2-10	Not given
Reaction	Francis	Wasserkraft Volk	Not given	<300	<20 000
		Mavel	0.1-30	15-440	20-30 000
		Gilkes	0.05-40	<400	<20 000
		Voith	Not given	3-95	5-1 000 000
	Syphon-turbine	Mavel	0.15-4.5	1.5-6	1-180
	Inline Turbines	Kawasaki Ring	0.14-2.8	3-30	20-500
		Hydro E-Kids	0.1-3.5	2-15	5-200
		Lucidpipe Spherical	1-5.6	0.5-10	14-100
	Moveable Power House	Ossberger Canada	1-25	1-8	350-2 000
	Pump as turbine	Andritz	0.03-6	3-80	3-10 000
	Wave power turbine	Voith	Not given	Not given	Not given

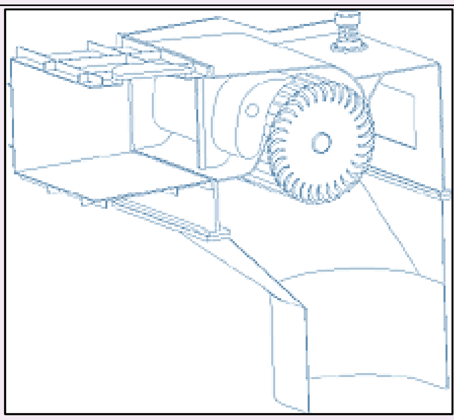
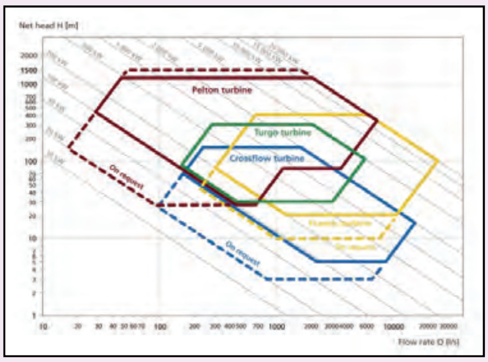
2 IMPULSE TYPE TURBINES

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 installation*  *Turbine set-up*

Turbine Name:	**PELTON TURBINE**
Company name:	**IREM SpA a Socio Unico**
Company Address:	Via Abegg 75 Borgone Susa ITALY 10500
Company Tel:	+39 011 9648211
Company E-mail:	irem@irem.it
Website:	www.irem.it
Turbine Description:	The buckets of Pelton turbines are made of precision cast stainless steel. All Pelton turbines are fitted with six nozzles controlled by special flow regulation valves, which help the efficiency of the system. The operation of the regulation valves may be manual or electric. The wheels are directly splined to the generator shaft, in order to improve the global output. All the revolving mechanical parts are in stainless steel. Operation can either be stand alone or grid-connected.
Pressure Head Range	20 m to 350 m
Flow Range	0.005 m^3/s to 0.1 m^3/s
Power Range	Up to 100 kW
Illustrations, Photos and Applicable Graphs:	 *Pelton turbine*  *Pelton turbine wheel*  *IREM turbine range*

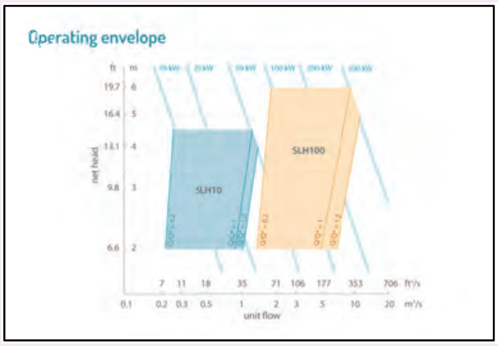
Turbine Name:	**BANKI (CROSSFLOW) TURBINE**
Company name:	**IREM SpA a Socio Unico**
Company Address:	Via Abegg 75 Borgone Susa ITALY 10500
Company Tel:	+39 011 9648211
Company E-mail:	irem@irem.it
Website:	www.irem.it
Turbine Description:	The IREM Banki turbine is connected to a belt driven synchronous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

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

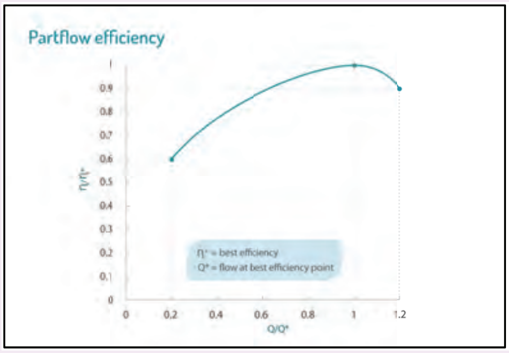
Turbine Name:	**CROSSFLOW TURBINE**
Company name:	**Wasserkraft Volk AG**
Company Address:	Am Stollen 13 D-79261 Gutach GERMANY
Company Tel:	+49 7685-9106-0
Company E-mail:	mail@wkv-ag.com
Website:	www.wkv-ag.com
Turbine Description:	These turbines have high efficiencies down to 17% of design flow. They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

Turbine Name:	**HYDROENGINE (SLH10 AND SLH 100)**
Company name:	**Natel Energy**
Company Address:	2175 Monarch Street Alameda, CA 94501
Company Tel:	(506)-984-3639
Company E-mail:	gia@natelenergy.com
Website:	www.natelenergy.com
Turbine Description:	Natel Energy's hydroengine is a unique design using the uplift created as water passes by curved blades.
Pressure Head Range	SLH10 & SLH100 – up to 6 m
Flow Range	SLH10 – up to 1.1 m³/s SLH100 – up to 10.1 m³/s
Power Range	SLH10 – up to 50 kW SLH100 – up to 500 kW

Illustrations, Photos and Applicable Graphs:



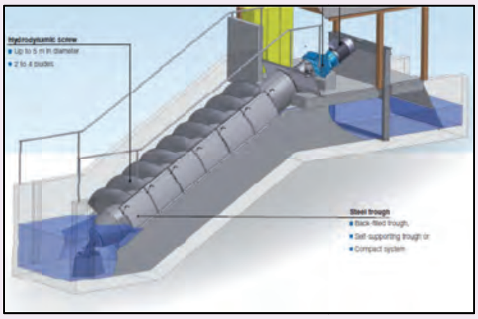
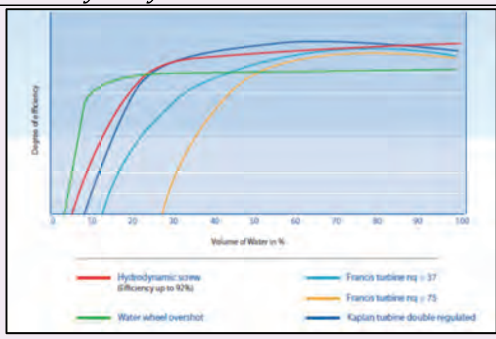
Flow ranges

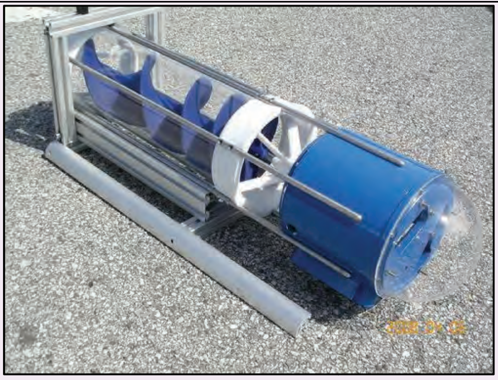
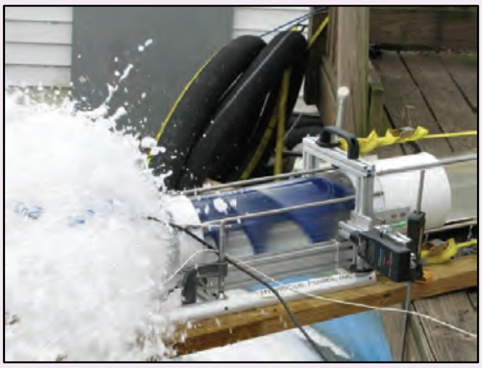
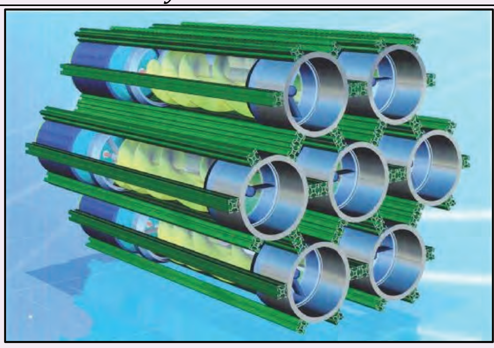
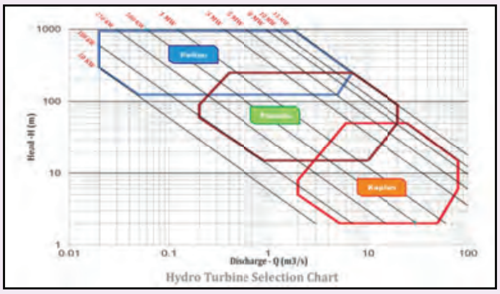


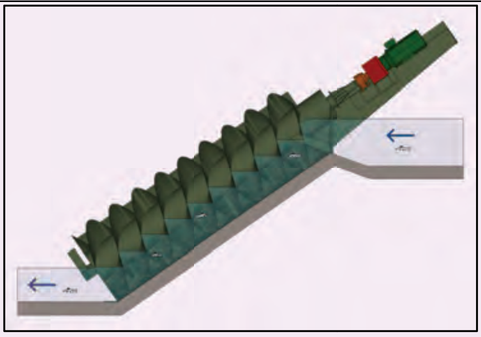
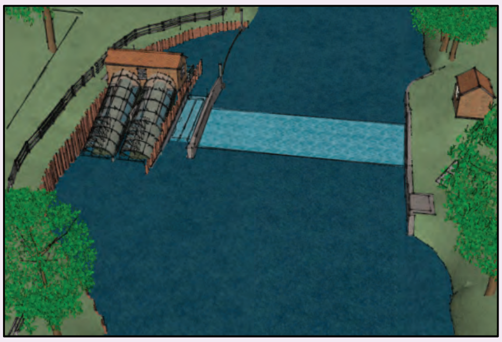
Partflow efficiencies

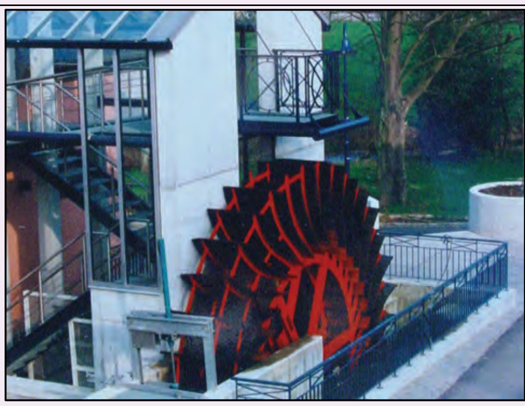
Hydroengine cross section

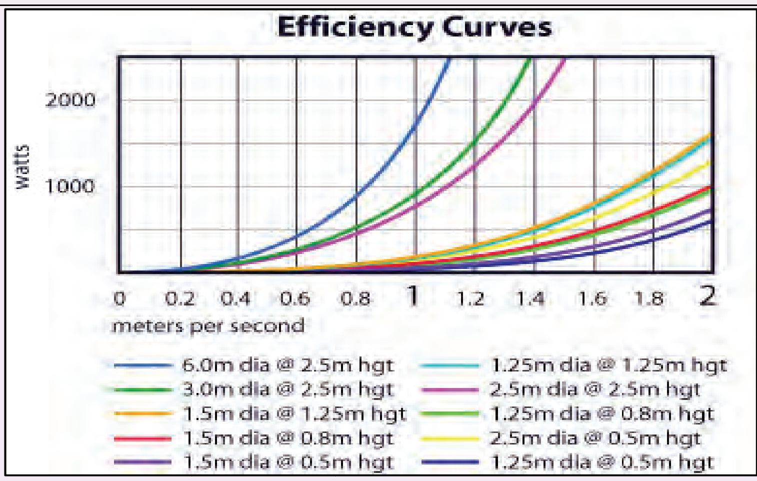
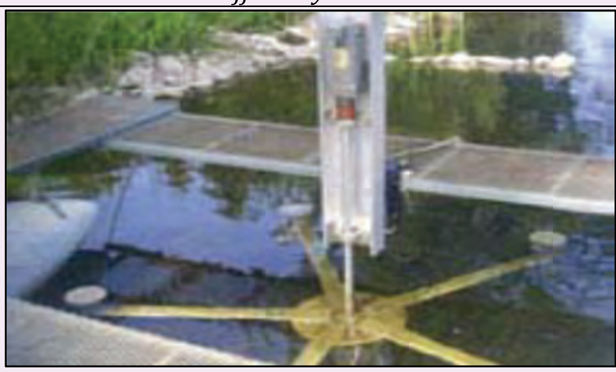
Pilot installation

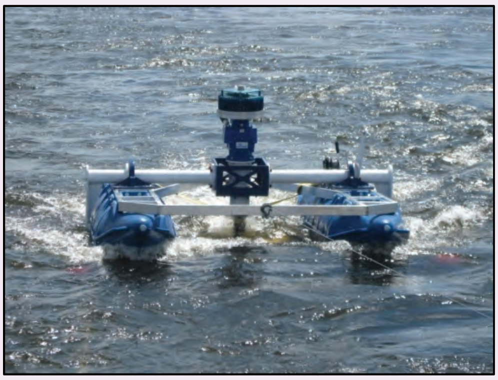
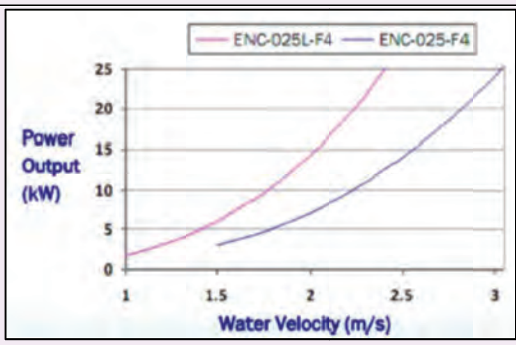
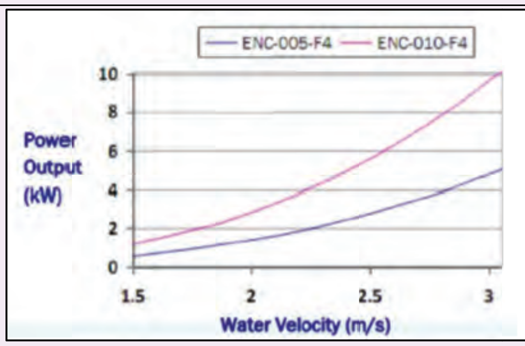
Turbine Name:	**HYDRODYNAMIC SCREW**
Company name:	**ANDRITZ Atro**
Company Address:	Penzinger Strasse 76 Vienna AUSTRIA 1141
Company Tel:	+43 (1)891 00 0
Company E-mail:	hydro@andritz.com
Website:	www.andritz.com
Turbine Description:	This turbine is based on the Archimedean screw and is applicable to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

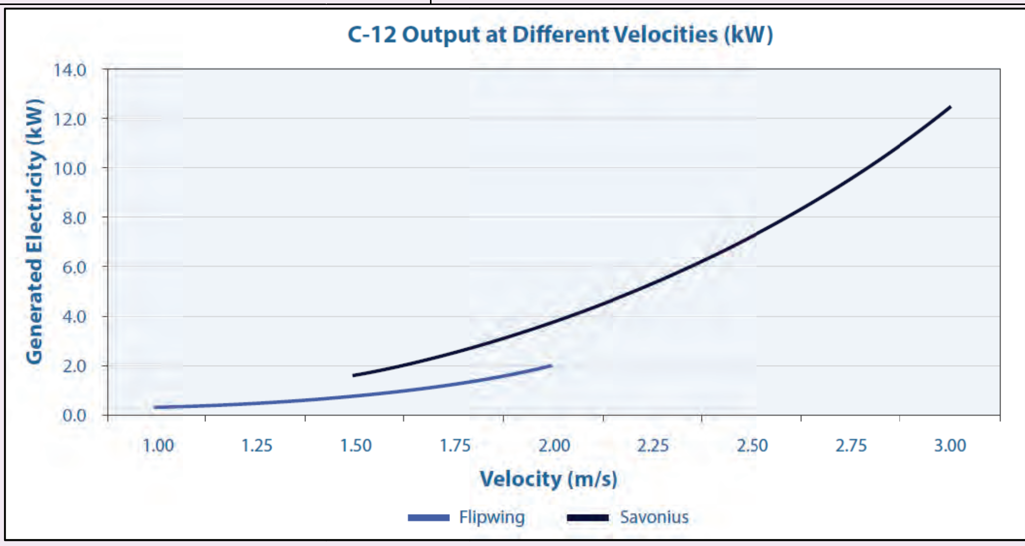
Turbine Name:	**HYDROCOIL TURBINE**
Company name:	**HydroCoil Power Inc. (HCP)**
Company Address:	1164 Saint Andrews Rd. Bryn MawR PA 19010 USA
Company Tel:	+1 610-520-4595
Company E-mail:	Hydrocoilpower.inc@att.net
Website:	www.hydrocoilpower.com
Turbine Description:	The turbine is comprised of approximately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

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

Turbine Name:	**WATERWHEEL**
Company name:	**HydroWatt**
Company Address:	Am Hafen 5 76189 Karlsruhe Germany
Company Tel:	+49 (0)721-831 86-0
Company E-mail:	info@hydrowatt.de
Website:	http://www.hydrowatt.de/sites/english/home.html
Turbine Description:	Hydrowatt of Germany, manufacturers both overshot and breastshot waterwheels.
Pressure Head Range	Overshot – 2.5 m to 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.
Depth requirements	0.1 m from bed for fast flow (> 1,3 m/s) 0.3 m for slow flow
Flow velocity Range	Greater than 0.8 m/s
Power Range	1 kW to 4 kW
Illustrations, Photos and Applicable Graphs:	 *Efficiency curves*
	 *Field installation*

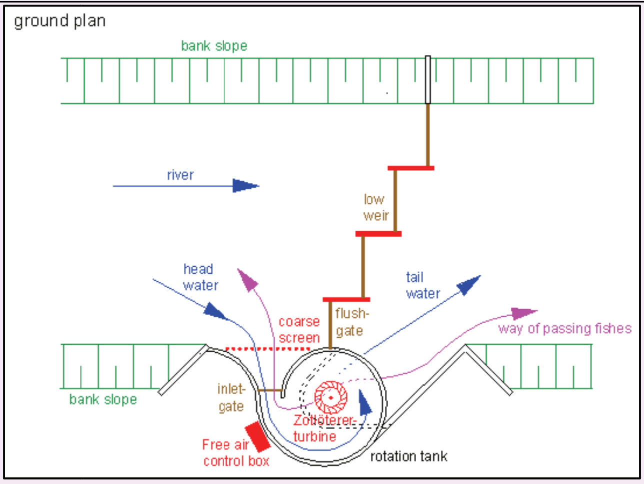
Turbine Name:	**HYDROKINETIC (En Current Power Generation System)**
Company name:	**New Energy Corporation**
Company Address:	3553 – 31 Street NW Suite 473 Calgary, Alberta T2L 2K7
Company Tel:	(403) 260-5240
Company E-mail:	info@newenergycorp.ca
Website:	www.newenergycorp.ca
Turbine Description:	New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

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

Turbine Name:	**VORTEX POWER PLANT**
Company name:	**Zotloeterer**
Company Address:	A-3200 Obergrafendorf Wildgansstraße 5 AUSTRIA
Company Tel:	0043-(0)2747-3106
Company E-mail:	office@zotloeterer
Website:	http://www.zotloeterer.com
Turbine Description:	This power plant uses the rotational energy at the centre of a vortex to turn a paddle type turbine.
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

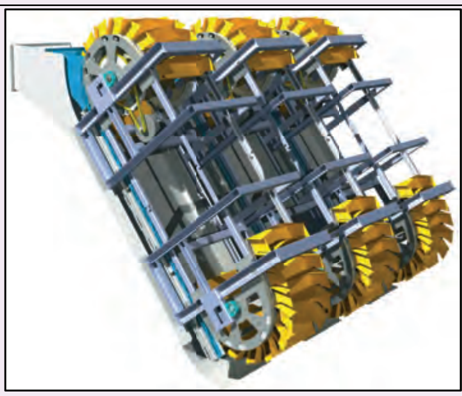
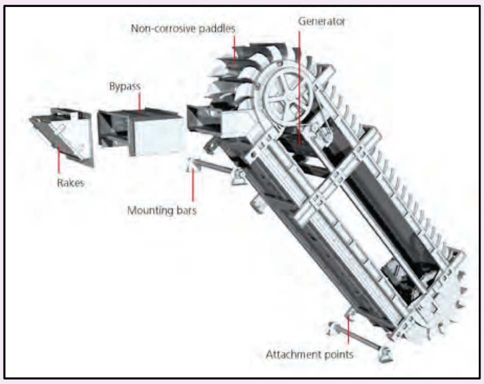
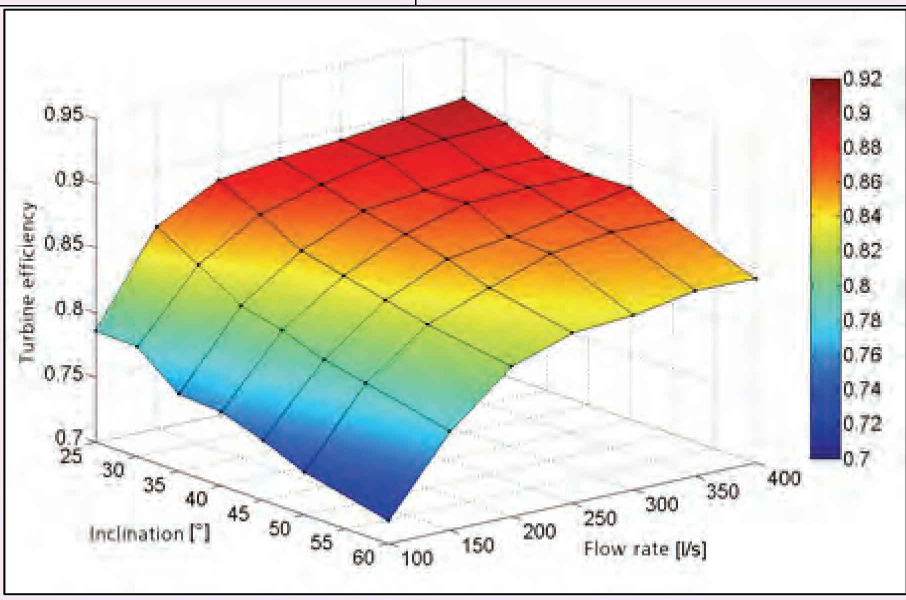
Illustrations, Photos and Applicable Graphs:

Turbine installation



Plant layout

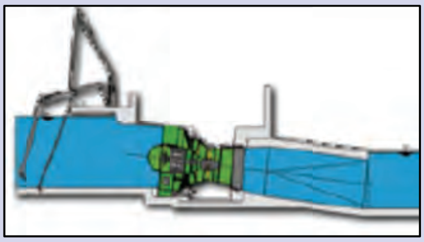
Plant installation

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*

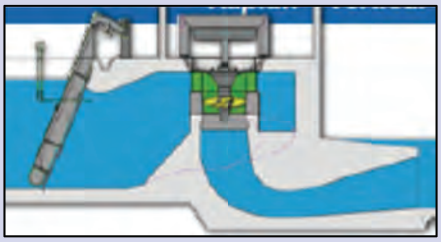
3 REACTION TYPE TURBINES

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

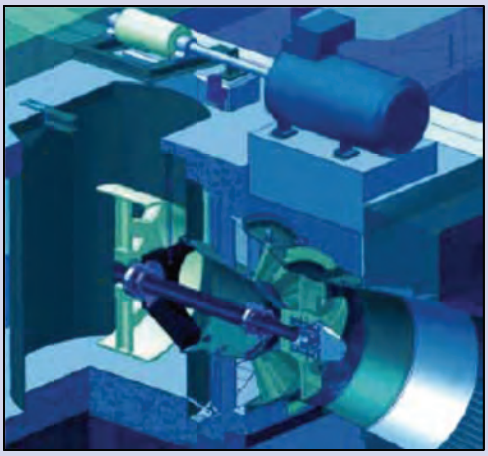
Illustrations, Photos and Applicable Graphs:



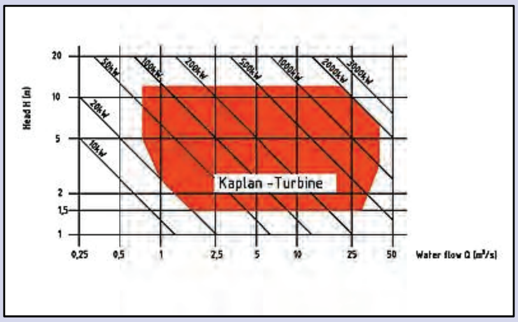
Inflow horizontal



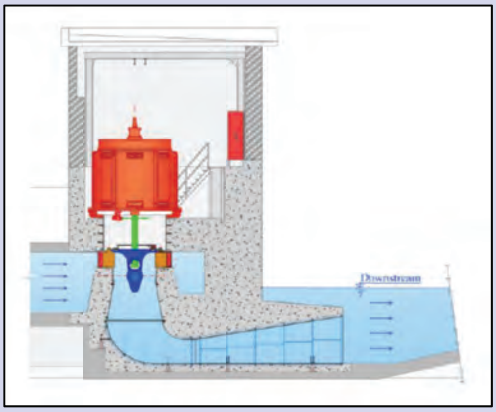
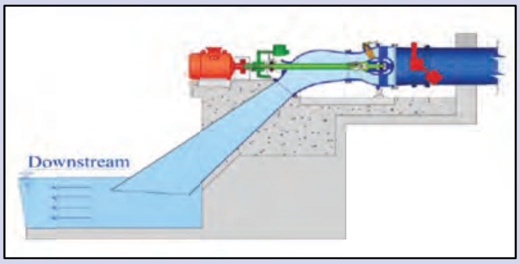
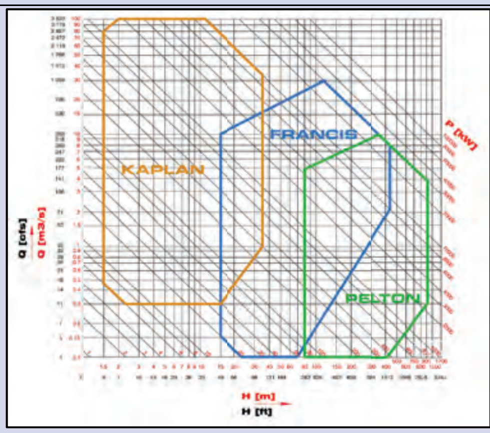
Inflow vertical

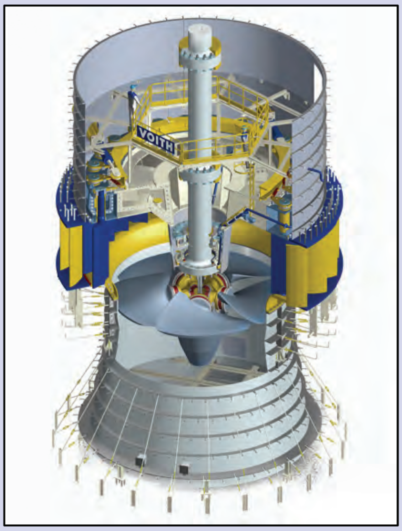
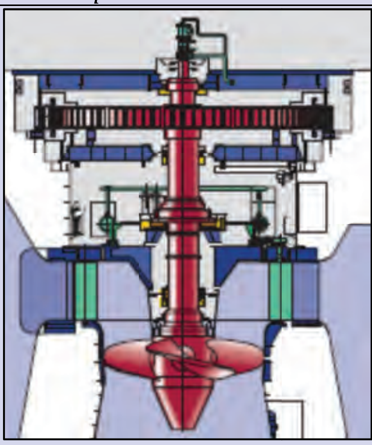
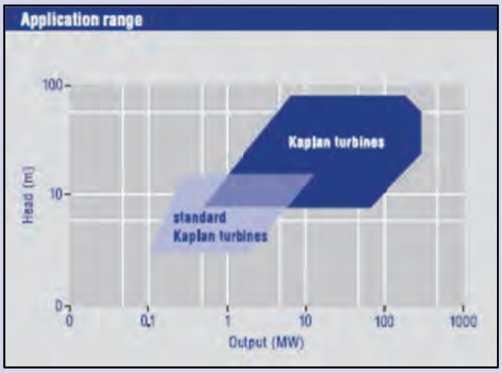


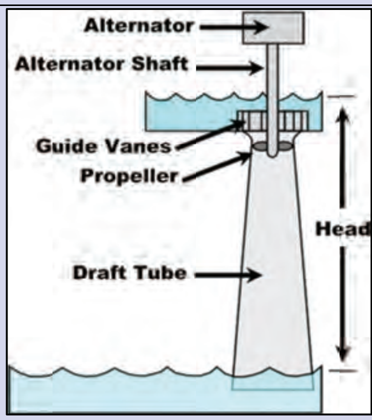
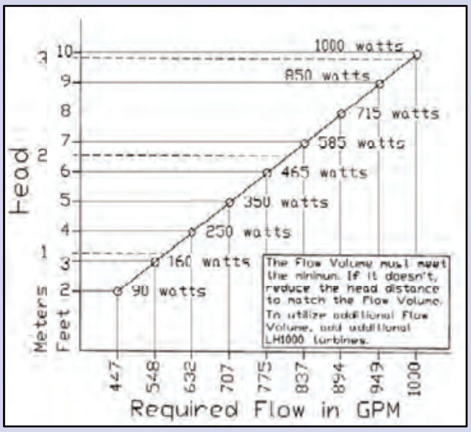
Computer generated view of Kaplan

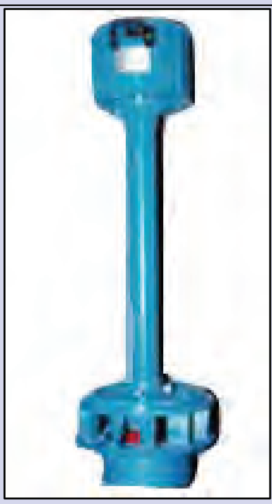
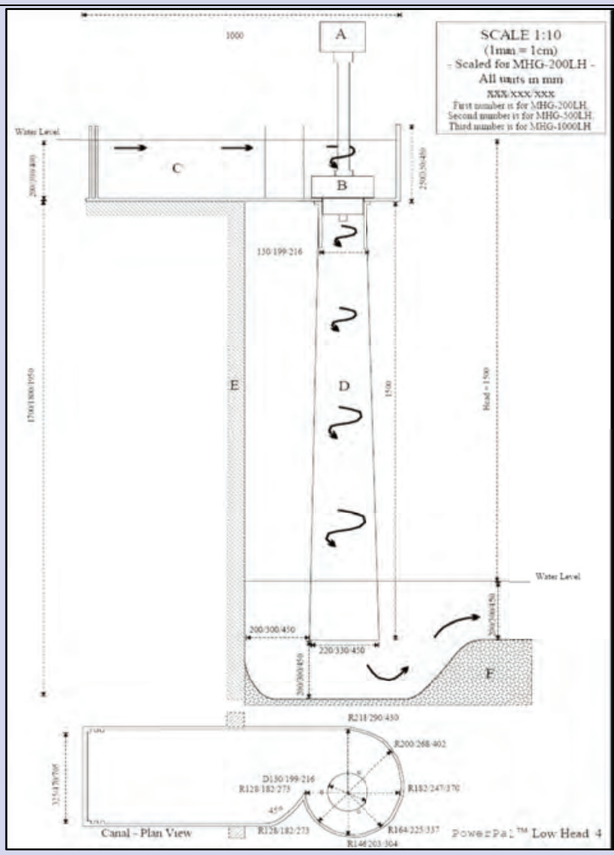


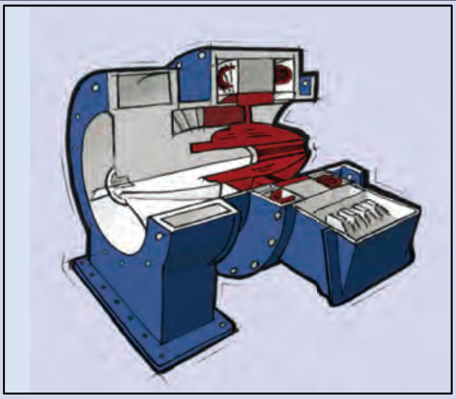
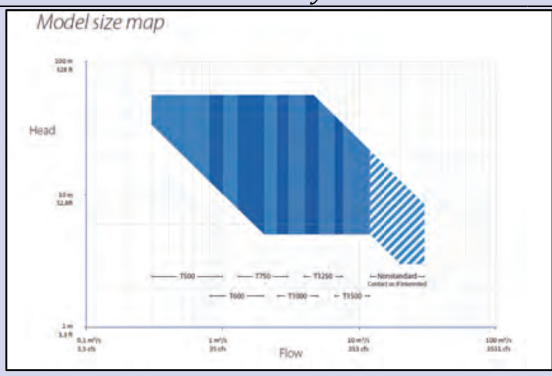
Turbine range

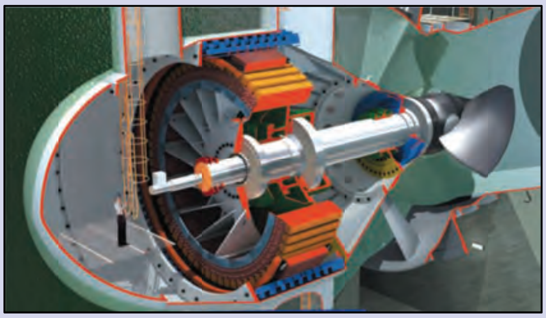
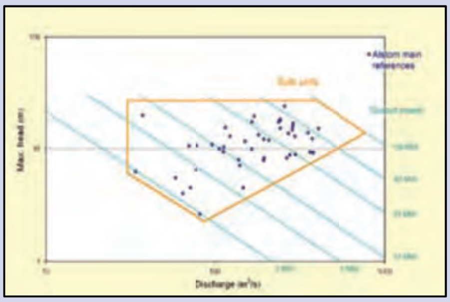
Turbine Name:	**KAPLAN TURBINE**
Company name:	**Mavel Hydro Turbines (Scion Technologies** (South African Distribution))
Company Address:	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel:	+27 21 552 9993
Company E-mail:	karenr@sciontechnologies.co.za
Website:	www.mavel.cz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

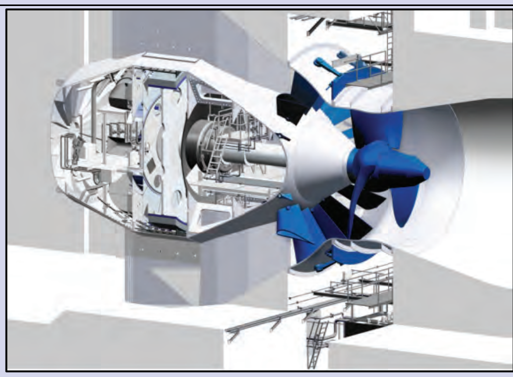
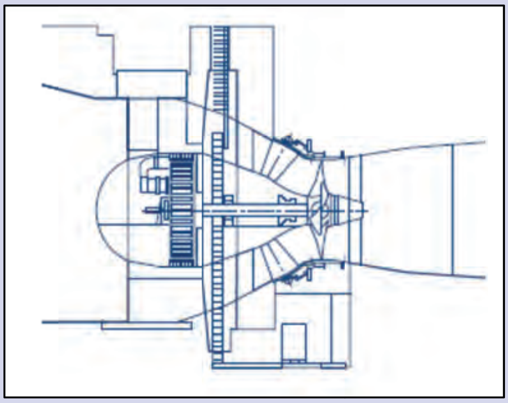
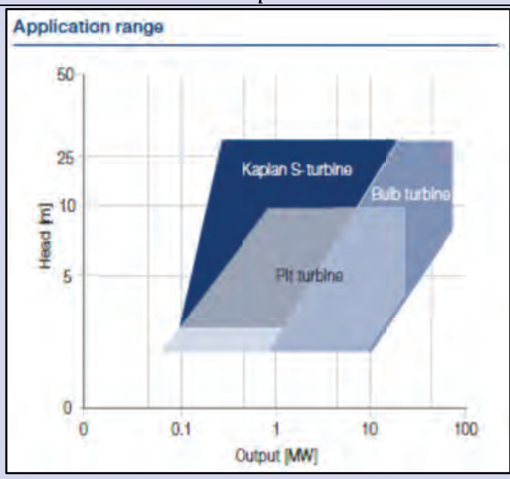
Turbine Name:	**KAPLAN TURBINE**
Company name:	**Voith Hydro Holding GmbH & Co. KG**
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel:	+49 7321 37 0
Company E-mail:	info.voithhydro@voith.com
Website:	www.voithhydro.com
Turbine Description:	Voith Kaplan turbines are designed to function with low head and high flow rates.
Pressure Head Range	3 m to 95 m
Flow Range	Not given
Power Range	100 kW to 400 MW
Illustrations and Applicable Graphs:	 *Kaplan turbine runner*  *Turbine layout*  *Cross section of a Kaplan runner*  *Turbine range*

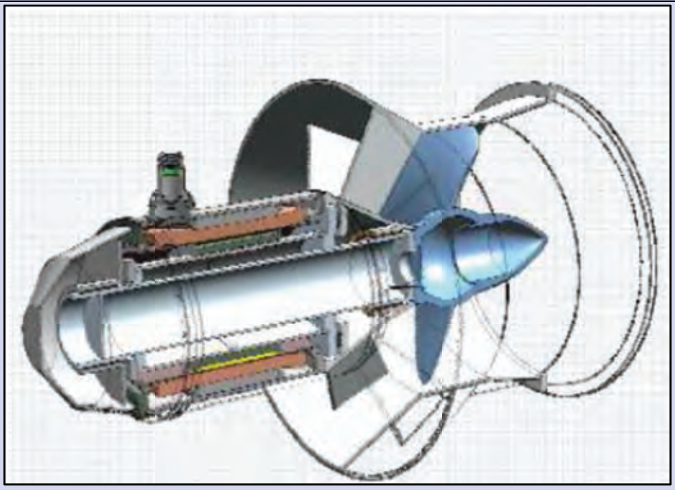
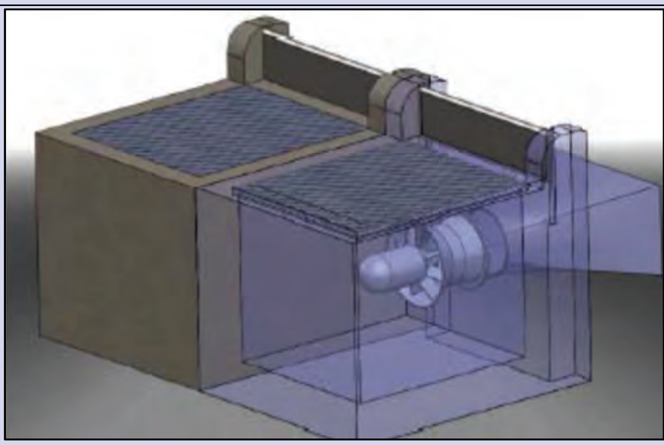
Turbine Name:	**PROPELLOR TURBINE – LH1000 (SMALL)**
Company name:	**Energy Systems and Design**
Company Address:	745 Waterford Rd Waterford, NB Canada E4E 5B4
Company Tel:	(506) 433-3151
Company E-mail:	hydropow@nbnet.nb.ca
Website:	http://www.microhydropower.com/
Turbine Description:	The LH1000 is a small propeller type turbine that uses a permanent magnet altenator.
Pressure Head Range	1 m to 3 m
Flow Range	30 l/s to 60 l/s
Power Range	90 W to 1 kW
Illustrations, Photos and Applicable Graphs:	 *Plan view*  *Side view*  *Turbine range*  *Turbine installation*

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:	 *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 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 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 and Applicable Graphs:	 *Bulb turbine*  *Bulb turbine computer illustration*  *Cross section of a Bulb turbine*  *Turbine range*

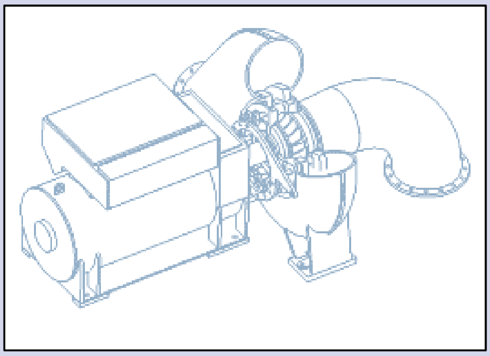
Turbine Name:	**MINIHYDRO**
Company name:	**Voith Hydro**
Company Address:	Jeremy A. Smith Manager, Small Hydro
Company Tel:	717-792-7868
Company E-mail:	Jeremy.smith@voith.com
Website:	
Turbine Description:	The concept is under development but will be appropriate for low head applications.
Pressure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

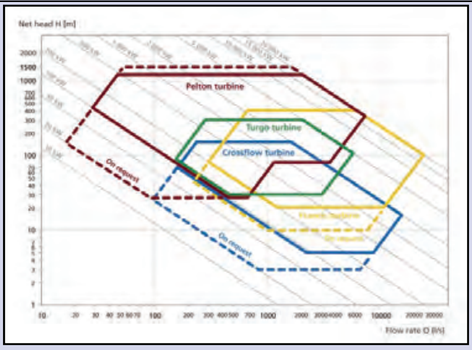
Illustrations and Applicable Graphs:

Francis turbine room

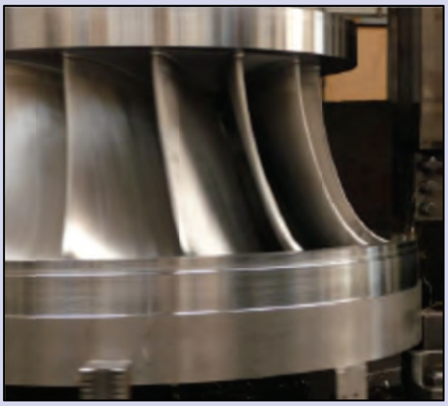
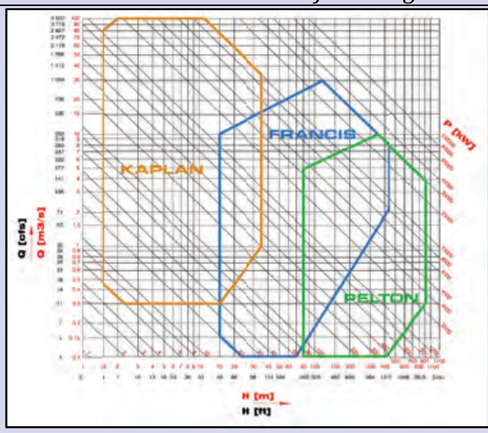
Francis turbines manufacturing



Typical turbine drawing

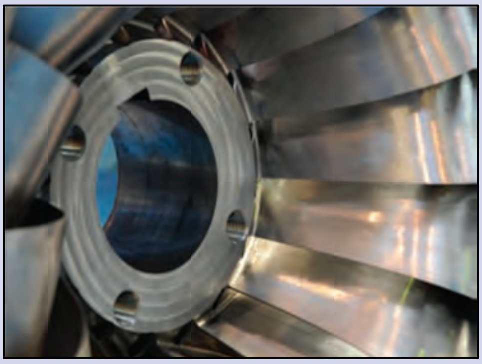


Wasserkraft Volk turbine ranges

Turbine Name:	**FRANCIS TURBINE**
Company name:	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address:	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel:	+27 21 552 9993
Company E-mail:	karenr@sciontechnologies.co.za
Website:	www.mavel.cz
Turbine Description:	Mavel Francis turbines are milled from a single block of forged steel and can be applied to medium heads and medium flow ranges.
Pressure Head Range	15 m to 440 m
Flow Range	0.1 m³/s to 30 m³/s
Power Range	20 kW to 30 MW
Illustrations, Photos and Applicable Graphs:	 *Francis runner*  *Francis turbine manufacturing*  *Typical layout*  *Turbine range*

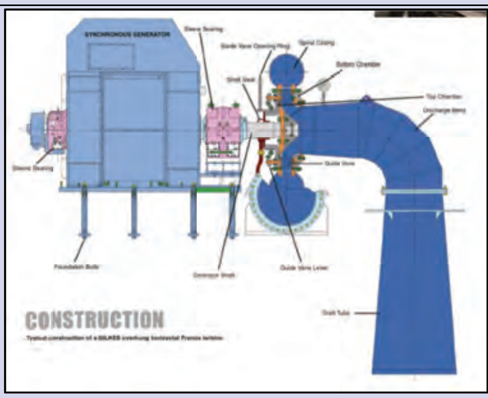
Turbine Name:	**FRANCIS TURBINE**
Company name:	**Gilbert Gilkes & Gordon Ltd**
Company Address:	Canal Head North Kendal Cumbria LA9 7BZ UK
Company Tel:	+44 (0) 1539 720028
Company E-mail:	enquiries@gilkes.com
Website:	www.gilkes.com
Turbine Description:	This turbine can be supplied as a horizontal or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

Illustrations, Photos and Applicable Graphs:

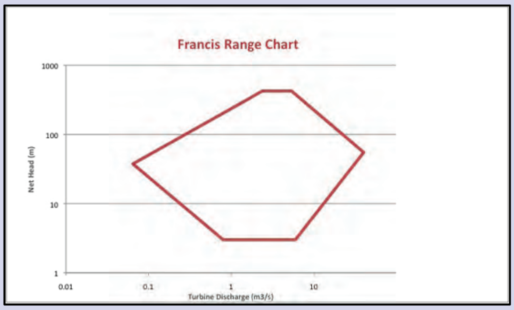


Francis runner

Francis turbine



Typical layout

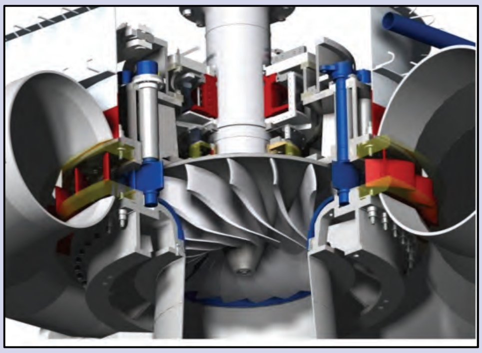


Turbine range

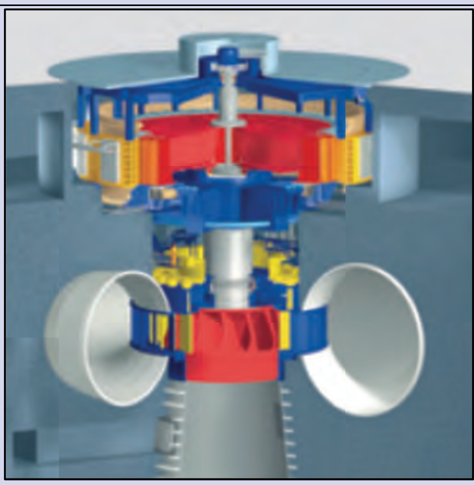
Turbine Name:	**FRANCIS TURBINE**
Company name:	**Voith Hydro Holding GmbH & Co. KG**
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel:	+49 7321 37 0
Company E-mail:	info.voithhydro@voith.com
Website:	www.voithhydro.com
Turbine Description:	The Voith Francis turbines are used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

Illustrations and Applicable Graphs:

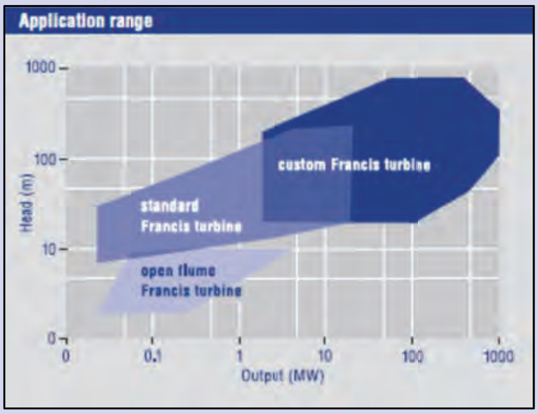
Francis turbine runner



Turbine layout



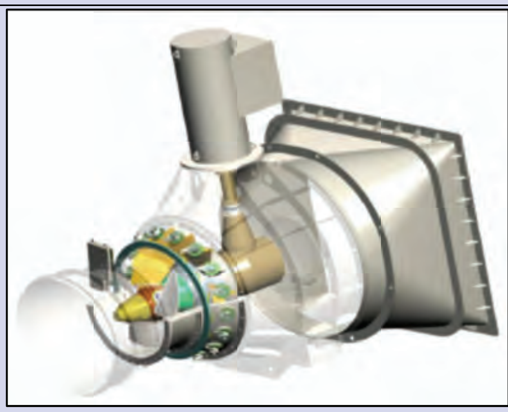
Cross section of a Francis turbine



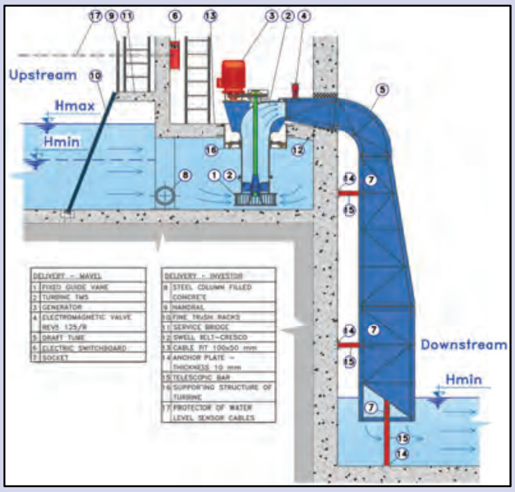
Turbine range

<table>
<tr><th></th><th></th></tr>
<tr><td>Turbine Name:</td><td>SYPHON-TYPE TURBINE</td></tr>
<tr><td>Company name:</td><td>Mavel Hydro Turbines (Scion Technologies (South African Distribution))</td></tr>
<tr><td>Company Address:</td><td>Northbank 3rd Floor Northbank Lane
Century City, Cape Town
SOUTH AFRICA</td></tr>
<tr><td>Company Tel:</td><td>+27 21 552 9993</td></tr>
<tr><td>Company E-mail:</td><td>karenr@sciontechnologies.co.za</td></tr>
<tr><td>Website:</td><td>www.mavel.cz</td></tr>
<tr><td>Turbine Description:</td><td>Mavel Micro turbines are designed to function with low head and work on the principle of syphoning water over a weir. Turbines can be placed in series.</td></tr>
<tr><td>Pressure Head Range</td><td>1.5 m to 6 m</td></tr>
<tr><td>Flow Range</td><td>0.15 m³/s to 4.5 m³/s (per turbine)</td></tr>
<tr><td>Power Range</td><td>1 kW to 180 kW</td></tr>
<tr><td>Illustrations and Applicable Graphs:</td><td>

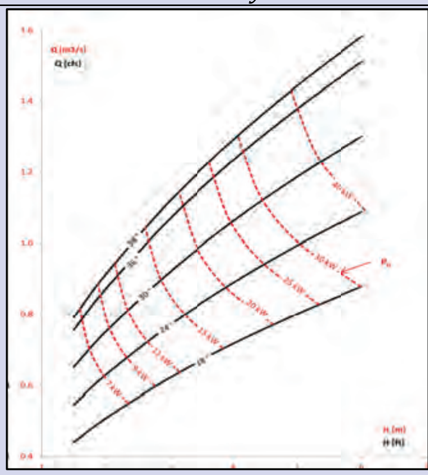
Turbine runner for Palmiet, South Africa



Turbine layout



Construction drawing of a Syphon turbine



Turbine range (MT5)

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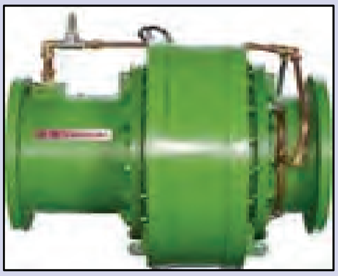
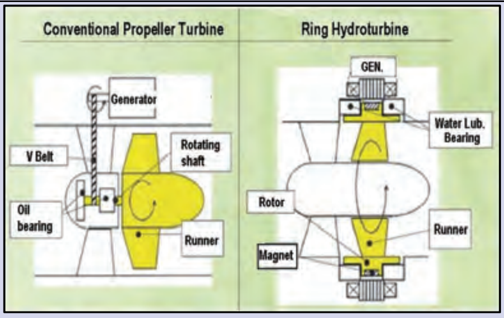
Turbine Name:	**RING HYDROTURBINE**
Company name:	**Kawasaki Plant Systems Ltd.**
Company Address:	1-14-5, Kaigan, Minato-ku Toyo JAPAN 8315
Company Tel:	+81-3-3435-2111
Company E-mail:	Not given
Website:	www.khi.co.jp
Turbine Description:	This high efficiency inline system is easily installed in small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

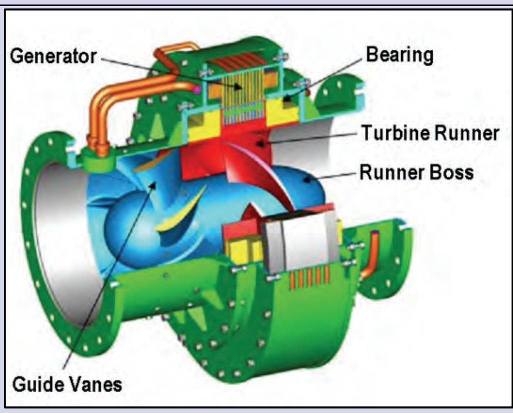
Illustrations and Applicable Graphs:



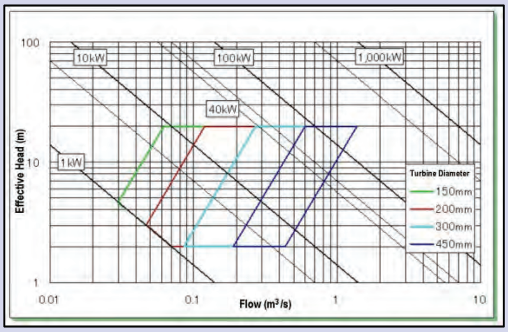
Ring hydroturbine



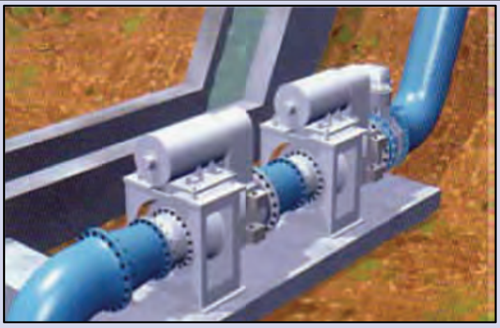
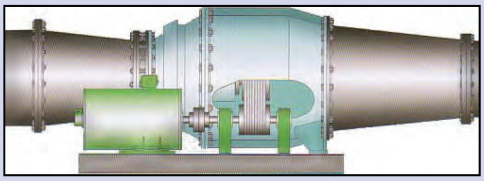
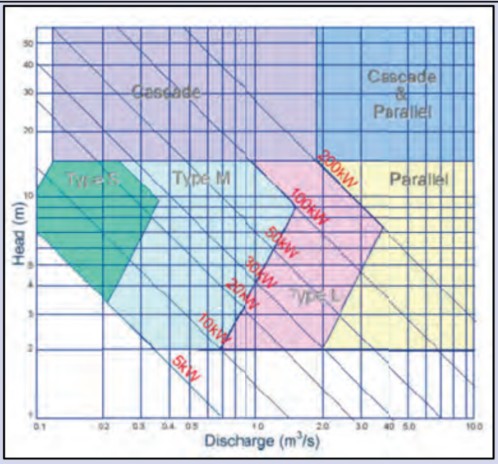
Ring and propeller comparison

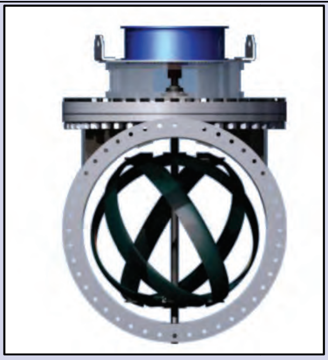
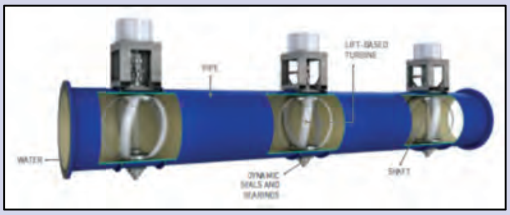


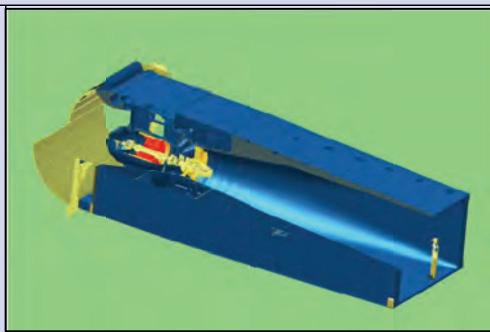
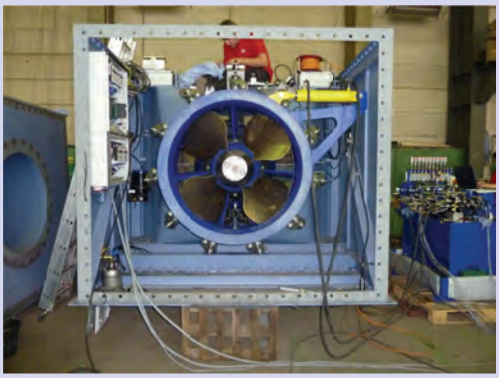
Turbine layout



Turbine ranges

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

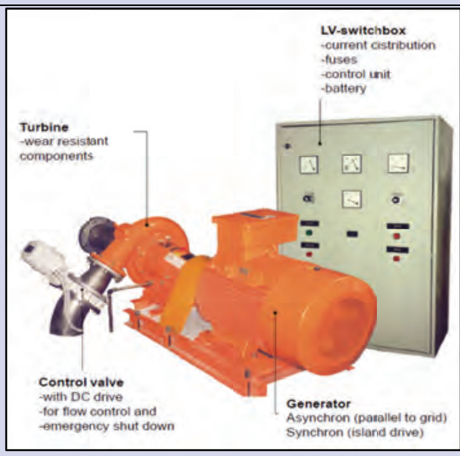
Turbine Name:	**LUCIDPIPE POWER SYSTEM**
Company name:	**LucidEnergy**
Company Address:	108 NW 9th Avenue Suite 201C Portland USA
Company Tel:	+1 574-238-5415
Company E-mail:	Josh.kanagy@lucidenergy.com
Website:	www.lucidenergy.com
Turbine Description:	These spherical turbines are installed inline in 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 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 m³/s to 25 m³/s
Power Range	350 kW to 2 000 kW
Illustrations, Photos and Applicable Graphs:	 *Movable power house installation*  *Turbine*  *Turbine construction*  *Turbine construction*

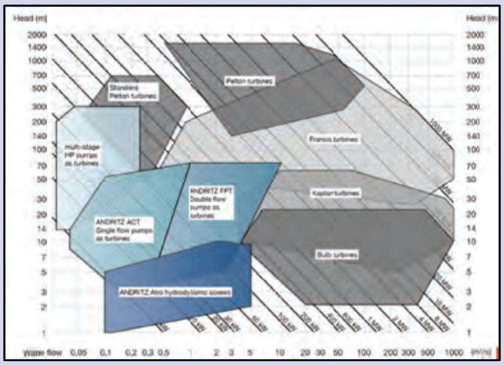
Turbine Name:	**PUMP AS TURBINE**
Company name:	**Andritz**
Company Address:	Penzinger Strasse 76 Vienna AUSTRIA 1141
Company Tel:	+43 (1)891 00 0
Company E-mail:	hydro@andritz.com
Website:	www.andritz.com
Turbine Description:	This turbine utilizes a centrifugal pump in reverse to generate electricity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

Illustrations, Photos and Applicable Graphs:

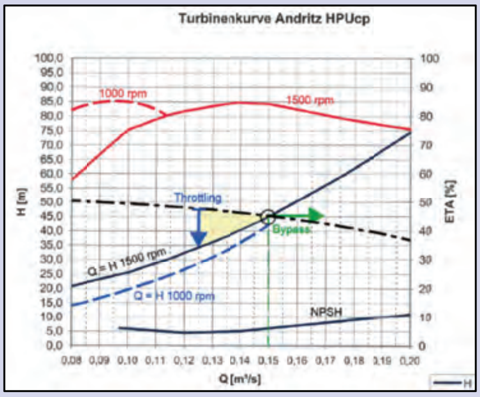
Installed turbines



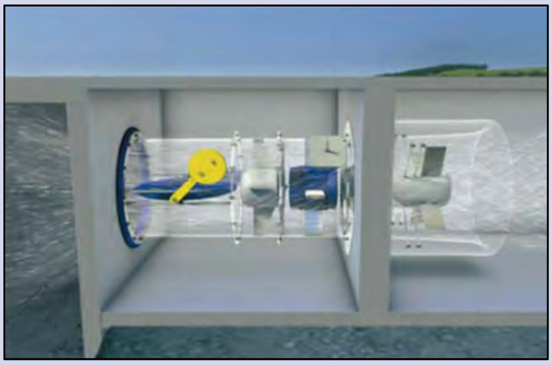
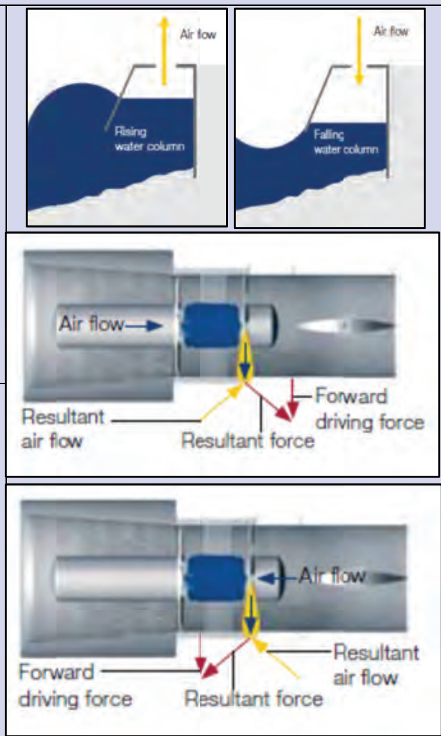
Turbine components



Turbine range



Turbine curve

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

Density	1000 kg/m^3
g	9.81 m/s^2
Efficiency	80%
Head	4 m

Province	**Eastern Cape**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	5.292	1.7525	0.64	5.50	1.92	16.61
Small	0.5 - 2 Ml/day	33.39	9.046	3.29	28.40	12.13	104.82
Medium	2 - 10 Ml/day	132.5	107.99	39.24	339.00	48.14	415.94
Large	10 - 25 Ml/day	84.6	55.5	20.17	174.23	30.74	265.58
Macro	> 25 Ml/day	212	163.4	59.37	512.95	77.03	665.51
Total				**122.69**	**1060.07**	**169.96**	**1468.46**

Province	**Free State**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.45	0	0.00	0.00	0.53	4.55
Small	0.5 - 2 Ml/day	34.73	5.044	1.83	15.83	12.62	109.02
Medium	2 - 10 Ml/day	129.8	21.6	7.85	67.81	47.16	407.47
Large	10 - 25 Ml/day	108.2	49.4	17.95	155.08	39.31	339.66
Macro	> 25 Ml/day	203.6	123.9	45.02	388.95	73.97	639.14
Total				**72.65**	**627.66**	**173.59**	**1499.85**

Province	**Gauteng**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1	0.71	0.26	2.23	0.36	3.14
Small	0.5 - 2 Ml/day	4.35	1.88	0.68	5.90	1.58	13.66
Medium	2 - 10 Ml/day	75.4	66.96	24.33	210.20	27.40	236.70
Large	10 - 25 Ml/day	170.5	143.82	52.25	451.48	61.95	535.23
Macro	> 25 Ml/day	2308.5	2387.5	867.46	7494.84	838.76	7246.84
Total				**944.98**	**8164.65**	**930.04**	**8035.57**

Province	**KwaZulu Natal**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	7.35	3.66	1.33	11.49	2.67	23.07
Small	0.5 - 2 Ml/day	37.84	20.3	7.38	63.73	13.75	118.79
Medium	2 - 10 Ml/day	123.58	62.52	22.72	196.26	44.90	387.94
Large	10 - 25 Ml/day	262.8	161.46	58.66	506.86	95.48	824.98
Macro	> 25 Ml/day	652	487.25	177.03	1529.58	236.89	2046.76
Total				**267.12**	**2307.91**	**393.70**	**3401.54**

Province	**Limpopo**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.52	0.06	0.02	0.19	0.55	4.77
Small	0.5 - 2 Ml/day	13.99	1.99	0.72	6.25	5.08	43.92
Medium	2 - 10 Ml/day	110.03	107.95	39.22	338.88	39.98	345.41
Large	10 - 25 Ml/day	11.7	8	2.91	25.11	4.25	36.73
Macro	> 25 Ml/day	28	26.5	9.63	83.19	10.17	87.90
Total				**52.50**	**453.61**	**60.04**	**518.72**

Province	**Mpumalanga**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.03	0	0.00	0.00	0.37	3.23
Small	0.5 - 2 Ml/day	23.88	13.7	4.98	43.01	8.68	74.96
Medium	2 - 10 Ml/day	136.27	93.44	33.95	293.33	49.51	427.78
Large	10 - 25 Ml/day	112.5	97.43	35.40	305.85	40.88	353.16
Macro	> 25 Ml/day	56	35.5	12.90	111.44	20.35	175.80
Total				**87.23**	**753.63**	**119.78**	**1034.93**

Province	**North West**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	0	0	0.00	0.00	0.00	0.00
Small	0.5 - 2 Ml/day	8.2	4.21	1.53	13.22	2.98	25.74
Medium	2 - 10 Ml/day	92.55	70.68	25.68	221.88	33.63	290.53
Large	10 - 25 Ml/day	80.3	51	18.53	160.10	29.18	252.08
Macro	> 25 Ml/day	123	92.2	33.50	289.43	44.69	386.12
Total				**79.24**	**684.63**	**110.47**	**954.47**

Province	**Western Cape**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	7.33	4.86	1.77	15.26	2.66	23.01
Small	0.5 - 2 Ml/day	48.68	33.43	12.15	104.94	17.69	152.82
Medium	2 - 10 Ml/day	157.76	96.53	35.07	303.03	57.32	495.24
Large	10 - 25 Ml/day	118.2	101.32	36.81	318.06	42.95	371.05
Macro	> 25 Ml/day	710.6	589	214.00	1848.99	258.18	2230.72
Total				**299.80**	**2590.28**	**378.80**	**3272.84**

Province	**Northern Cape**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	3.12	1.49	0.54	4.68	1.13	9.79
Small	0.5 - 2 Ml/day	22.56	8.68	3.15	27.25	8.20	70.82
Medium	2 - 10 Ml/day	54.5	23.82	8.65	74.78	19.80	171.09
Large	10 - 25 Ml/day	16	13.2	4.80	41.44	5.81	50.23
Macro	> 25 Ml/day	64	25	9.08	78.48	23.25	200.91
Total				**26.23**	**226.62**	**58.20**	**502.84**

Country-wide Total	**1952.44**	**16869.06**	**2394.59**	**20689.22**

Density	1000 kg/m^3
g	9.81 m/s^2
Efficiency	80%
Head	8 m

Province	**Eastern Cape**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	5.292	1.7525	1.27	11.00	3.85	33.23
Small	0.5 - 2 Ml/day	33.39	9.046	6.57	56.79	24.26	209.64
Medium	2 - 10 Ml/day	132.5	107.99	78.47	678.00	96.28	831.89
Large	10 - 25 Ml/day	84.6	55.5	40.33	348.45	61.48	531.15
Macro	> 25 Ml/day	212	163.4	118.74	1025.89	154.05	1331.02
Total				**245.39**	**2120.14**	**339.92**	**2936.92**

Province	**Free State**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.45	0	0.00	0.00	1.05	9.10
Small	0.5 - 2 Ml/day	34.73	5.044	3.67	31.67	25.24	218.05
Medium	2 - 10 Ml/day	129.8	21.6	15.70	135.61	94.32	814.94
Large	10 - 25 Ml/day	108.2	49.4	35.90	310.15	78.63	679.32
Macro	> 25 Ml/day	203.6	123.9	90.03	777.89	147.95	1278.28
Total				**145.29**	**1255.33**	**347.19**	**2999.69**

Province	**Gauteng**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1	0.71	0.52	4.46	0.73	6.28
Small	0.5 - 2 Ml/day	4.35	1.88	1.37	11.80	3.16	27.31
Medium	2 - 10 Ml/day	75.4	66.96	48.66	420.40	54.79	473.39
Large	10 - 25 Ml/day	170.5	143.82	104.51	902.96	123.90	1070.47
Macro	> 25 Ml/day	2308.5	2387.5	1734.92	14989.68	1677.51	14493.69
Total				**1889.97**	**16329.30**	**1860.09**	**16071.13**

Province	**KwaZulu Natal**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	7.35	3.66	2.66	22.98	5.34	46.15
Small	0.5 - 2 Ml/day	37.84	20.3	14.75	127.45	27.50	237.57
Medium	2 - 10 Ml/day	123.58	62.52	45.43	392.53	89.80	775.88
Large	10 - 25 Ml/day	262.8	161.46	117.33	1013.71	190.97	1649.96
Macro	> 25 Ml/day	652	487.25	354.07	3059.15	473.79	4093.52
Total				**534.24**	**4615.82**	**787.39**	**6803.09**

Province	**Limpopo**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.52	0.06	0.04	0.38	1.10	9.54
Small	0.5 - 2 Ml/day	13.99	1.99	1.45	12.49	10.17	87.83
Medium	2 - 10 Ml/day	110.03	107.95	78.44	677.75	79.96	690.81
Large	10 - 25 Ml/day	11.7	8	5.81	50.23	8.50	73.46
Macro	> 25 Ml/day	28	26.5	19.26	166.38	20.35	175.80
Total				**105.00**	**907.23**	**120.07**	**1037.44**

Province	**Mpumalanga**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.03	0	0.00	0.00	0.75	6.47
Small	0.5 - 2 Ml/day	23.88	13.7	9.96	86.01	17.35	149.93
Medium	2 - 10 Ml/day	136.27	93.44	67.90	586.65	99.02	855.56
Large	10 - 25 Ml/day	112.5	97.43	70.80	611.70	81.75	706.32
Macro	> 25 Ml/day	56	35.5	25.80	222.88	40.69	351.59
Total				**174.45**	**1507.26**	**239.57**	**2069.86**

Province	**North West**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	0	0	0.00	0.00	0.00	0.00
Small	0.5 - 2 Ml/day	8.2	4.21	3.06	26.43	5.96	51.48
Medium	2 - 10 Ml/day	92.55	70.68	51.36	443.76	67.25	581.07
Large	10 - 25 Ml/day	80.3	51	37.06	320.20	58.35	504.16
Macro	> 25 Ml/day	123	92.2	67.00	578.87	89.38	772.24
Total				**158.48**	**1369.26**	**220.94**	**1908.95**

Province	**Western Cape**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	7.33	4.86	3.53	30.51	5.33	46.02
Small	0.5 - 2 Ml/day	48.68	33.43	24.29	209.89	35.37	305.63
Medium	2 - 10 Ml/day	157.76	96.53	70.15	606.05	114.64	990.48
Large	10 - 25 Ml/day	118.2	101.32	73.63	636.13	85.89	742.11
Macro	> 25 Ml/day	710.6	589	428.01	3697.98	516.37	4461.43
Total				**599.60**	**5180.56**	**757.60**	**6545.67**

Province	**Northern Cape**	**Total design capacity**	**Total daily inflows**	**Design potential power**	**Design potential annual power**	**Operational potential power**	**Operational potential annual power**
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	3.12	1.49	1.08	9.35	2.27	19.59
Small	0.5 - 2 Ml/day	22.56	8.68	6.31	54.50	16.39	141.64
Medium	2 - 10 Ml/day	54.5	23.82	17.31	149.55	39.60	342.17
Large	10 - 25 Ml/day	16	13.2	9.59	82.87	11.63	100.45
Macro	> 25 Ml/day	64	25	18.17	156.96	46.51	401.82
Total				**52.46**	**453.24**	**116.40**	**1005.67**

Country-wide Total	**3904.88**	**33738.13**	**4789.17**	**41378.44**

Density	1000 kg/m^3
g	9.81 m/s^2
Efficiency	80%
Head	1 m

Province	Eastern Cape	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	5.292	1.7525	0.16	1.38	0.48	4.15
Small	0.5 - 2 Ml/day	33.39	9.046	0.82	7.10	3.03	26.20
Medium	2 - 10 Ml/day	132.5	107.99	9.81	84.75	12.04	103.99
Large	10 - 25 Ml/day	84.6	55.5	5.04	43.56	7.68	66.39
Macro	> 25 Ml/day	212	163.4	14.84	128.24	19.26	166.38
Total				**30.67**	**265.02**	**42.49**	**367.12**

Province	Free State	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.45	0	0.00	0.00	0.13	1.14
Small	0.5 - 2 Ml/day	34.73	5.044	0.46	3.96	3.15	27.26
Medium	2 - 10 Ml/day	129.8	21.6	1.96	16.95	11.79	101.87
Large	10 - 25 Ml/day	108.2	49.4	4.49	38.77	9.83	84.92
Macro	> 25 Ml/day	203.6	123.9	11.25	97.24	18.49	159.79
Total				**18.16**	**156.92**	**43.40**	**374.96**

Province	Gauteng	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1	0.71	0.06	0.56	0.09	0.78
Small	0.5 - 2 Ml/day	4.35	1.88	0.17	1.48	0.40	3.41
Medium	2 - 10 Ml/day	75.4	66.96	6.08	52.55	6.85	59.17
Large	10 - 25 Ml/day	170.5	143.82	13.06	112.87	15.49	133.81
Macro	> 25 Ml/day	2308.5	2387.5	216.86	1873.71	209.69	1811.71
Total				**236.25**	**2041.16**	**232.51**	**2008.89**

Province	KwaZulu Natal	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	7.35	3.66	0.33	2.87	0.67	5.77
Small	0.5 - 2 Ml/day	37.84	20.3	1.84	15.93	3.44	29.70
Medium	2 - 10 Ml/day	123.58	62.52	5.68	49.07	11.23	96.99
Large	10 - 25 Ml/day	262.8	161.46	14.67	126.71	23.87	206.25
Macro	> 25 Ml/day	652	487.25	44.26	382.39	59.22	511.69
Total				**66.78**	**576.98**	**98.42**	**850.39**

Province	Limpopo	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.52	0.06	0.01	0.05	0.14	1.19
Small	0.5 - 2 Ml/day	13.99	1.99	0.18	1.56	1.27	10.98
Medium	2 - 10 Ml/day	110.03	107.95	9.81	84.72	9.99	86.35
Large	10 - 25 Ml/day	11.7	8	0.73	6.28	1.06	9.18
Macro	> 25 Ml/day	28	26.5	2.41	20.80	2.54	21.97
Total				**13.13**	**113.40**	**15.01**	**129.68**

Province	Mpumalanga	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	1.03	0	0.00	0.00	0.09	0.81
Small	0.5 - 2 Ml/day	23.88	13.7	1.24	10.75	2.17	18.74
Medium	2 - 10 Ml/day	136.27	93.44	8.49	73.33	12.38	106.94
Large	10 - 25 Ml/day	112.5	97.43	8.85	76.46	10.22	88.29
Macro	> 25 Ml/day	56	35.5	3.22	27.86	5.09	43.95
Total				**21.81**	**188.41**	**29.95**	**258.73**

Province	North West	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	0	0	0.00	0.00	0.00	0.00
Small	0.5 - 2 Ml/day	8.2	4.21	0.38	3.30	0.74	6.44
Medium	2 - 10 Ml/day	92.55	70.68	6.42	55.47	8.41	72.63
Large	10 - 25 Ml/day	80.3	51	4.63	40.02	7.29	63.02
Macro	> 25 Ml/day	123	92.2	8.37	72.36	11.17	96.53
Total				**19.81**	**171.16**	**27.62**	**238.62**

Province	Western Cape	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	7.33	4.86	0.44	3.81	0.67	5.75
Small	0.5 - 2 Ml/day	48.68	33.43	3.04	26.24	4.42	38.20
Medium	2 - 10 Ml/day	157.76	96.53	8.77	75.76	14.33	123.81
Large	10 - 25 Ml/day	118.2	101.32	9.20	79.52	10.74	92.76
Macro	> 25 Ml/day	710.6	589	53.50	462.25	64.55	557.68
Total				**74.95**	**647.57**	**94.70**	**818.21**

Province	Northern Cape	Total design capacity	Total daily inflows	Design potential power	Design potential annual power	Operational potential power	Operational potential annual power
Size WWTP	**Description**	**Ml/day**	**Ml/day**	**kW**	**MWh/a**	**kW**	**MWh/a**
Micro	< 0.5 Ml/day	3.12	1.49	0.14	1.17	0.28	2.45
Small	0.5 - 2 Ml/day	22.56	8.68	0.79	6.81	2.05	17.71
Medium	2 - 10 Ml/day	54.5	23.82	2.16	18.69	4.95	42.77
Large	10 - 25 Ml/day	16	13.2	1.20	10.36	1.45	12.56
Macro	> 25 Ml/day	64	25	2.27	19.62	5.81	50.23
Total				**6.56**	**56.65**	**14.55**	**125.71**

Country-wide Total	**488.11**	**4217.27**	**598.65**	**5172.30**

Density	1000 kg/m^3
g	9.81 m/s^2
Efficiency	70%
Head	4 m

WWTP	Total design capacity Ml/day	Operational percentage of design capacity	Total daily inflows Ml/day	Design potential kW	Design potential annual power MWh/a	Operational potential power kW	Operational potential annual MWh/a
City of Johannesburg							
Driefontein	35	0.971	34	11	93	11	96
Ennerdale	8	0.875	7	2	19	3	22
Goudkoppies	150	0.887	133	42	365	48	412
Bushkoppies	200	1.045	209	66	574	64	549
Northern Works	450	0.984	443	141	1216	143	1236
Olifantsvlei	200	1.025	205	65	563	64	549
Subtotal	**1043.0**	**5.8**	**1031**	**328**	**2831**	**332**	**2865**
City of Tshwane							
Babelegi	2.3	0.757	2	1	5	1	6
Baviaanspoort	62	0.874	54	17	149	20	170
Daspoort	60	0.634	38	12	104	19	165
Ekangala	2.5	1	3	1	7	1	7
Godrich	5	0.968	5	2	13	2	14
Klipgat	55	0.741	41	13	112	17	151
Rayton	1.2	0	0	0	0	0	3
Refilwe	1.15	0	0	0	0	0	3
Rethaiseng	2.5	0	0	0	0	1	7
Rietgat	28	0.735	21	7	57	9	77
Rooiwal East	45	0.778	35	11	96	14	124
Rooiwal North	150	1.067	160	51	440	48	412
Sandspruit	20	0.561	11	4	31	6	55
Summersplace	0.3	0	0	0	0	0	1
Sunderland Ridge	65	1.096	71	23	196	21	179
Temba	12.5	0.807	10	3	28	4	34
Zeekoegat	30	1.657	50	16	137	10	82
Subtotal	**542.5**	**11.7**	**500**	**159**	**1373**	**172**	**1490**
Ekurhuleni Metropolitan							
Anchor	34.5	1.209	42	13	115	11	95
Benoni	16	0.706	11	4	31	5	44
Carl Grundling	5	0.76	4	1	10	2	14
Dekema	36	0.775	28	9	77	11	99
Daveyton	16	0.594	10	3	26	5	44
Esther Park	0.4	1.775	1	0	2	0	1
Hartebeesfontein	45	1.289	58	18	159	14	124
Herbert Bickley	12.5	1.352	17	5	46	4	34
Jan Smuts	9.1	1.209	11	3	30	3	25
J.P. Marais	15	1.067	16	5	44	5	41
Olifantsfontein	105	0.829	87	28	239	33	288
Rondebult	36	0.642	23	7	63	11	99
Rynveld	13	0.615	8	3	22	4	36
Tsakane	12	1.333	16	5	44	4	33
Vlakplaats	83	1.566	130	41	357	26	228
Waterval	155	1.239	192	61	528	49	426
Welbedacht	35	1.883	66	21	181	11	96
Subtotal	**628.5**	**18.8**	**719**	**229**	**1975**	**200**	**1726**
Emfuleni Local							
Leeukuil	38	1	46	15	127	12	104
Rietspruit	36	1	33	11	91	11	99
Sebokeng	100	1	144	46	396	32	275
Subtotal	**174**	**4**	**223**	**71**	**614**	**55**	**478**
Lesedi Local							
Heidelberg	8	1	9	3	25	3	22
Ratanda	5	1	6	2	15	2	14
Subtotal	**13**	**2**	**15**	**5**	**40**	**4**	**36**
Merafong Local							
Khutsong	8	1	5	2	15	2	21
Kokosi-Fochville	8	1	6	2	16	2	21
Oberholzer	8	1	4	1	12	3	22
Welverdiend	1	2	2	0	4	0	2
Wedela	3	2	5	2	15	1	8
Subtotal	**27**	**6**	**23**	**7**	**63**	**9**	**74**
Midvaal Local							
Meyerton	10	1	13	4	36	3	27
Oheni Muri	0	0	0	0	0	0	1
Vaal Marina	2	0	0	0	0	1	5
Subtotal	**12**	**1**	**13**	**4**	**36**	**4**	**34**
Mogale City Local							
Flip Human	50	1	28	9	77	16	137
Magaliesburg	1	0	0	0	1	0	3
Percy Stewart	27	1	17	5	46	9	74
Subtotal	**78**	**2**	**45**	**14**	**124**	**25**	**215**
Randfontein Local							
Randfontein	20	1	15	5	41	6	54
Subtotal	**20**	**1**	**15**	**5**	**41**	**6**	**54**
Westonaria Local							
Hannes van Niekerk	22	1	17	5	47	7	60
Subtotal	**22**	**1**	**17**	**5**	**47**	**7**	**60**
Total	**2560**	**52**	**2601**	**827**	**7144**	**814**	**7031**

Density	1000	kg/m^3
g	9.81	m/s^2
Efficiency	70%	
Head	4	m

WWTP	Total design capacity Ml/day	Operational percentage of design capacity	Total daily inflows Ml/day	Design potential power kW	Design potential annual power MWh/a	Operational potential power kW	Operational potential annual power MWh/a
City of Johannesburg							
Driefontein	35	97%	34	11	93	11	96
Goudkoppies	150	89%	133	42	365	48	412
Bushkoppies	200	105%	209	66	574	64	549
Northern Works	450	98%	443	141	1216	143	1236
Olifantsvlei	200	103%	205	65	563	64	549
Subtotal	**1035**		**1024**	**325**	**2812**	**329**	**2843**
City of Tshwane							
Baviaanspoort	62	87%	54	17	149	20	170
Daspoort	60	63%	38	12	104	19	165
Klipgat	55	74%	41	13	112	17	151
Rietgat	28	74%	21	7	57	9	77
Rooiwal East	45	78%	35	11	96	14	124
Rooiwal North	150	107%	160	51	440	48	412
Sandspruit	20	56%	11	4	31	6	55
Sunderland Ridge	65	110%	71	23	196	21	179
Zeekoegat	30	17%	5	2	14	10	82
Subtotal	**515**		**436**	**139**	**1198**	**164**	**1415**
Ekurhuleni Metropolitan							
Anchor	35	121%	42	13	115	11	95
Dekema	36	78%	28	9	77	11	99
Hartebeesfontein	45	129%	58	18	159	14	124
Olifantsfontein	105	83%	87	28	239	33	288
Rondebult	36	64%	23	7	63	11	99
Vlakplaats	83	157%	130	41	357	26	228
Waterval	155	124%	192	61	528	49	426
Welbedacht	35	188%	66	21	181	11	96
Subtotal	**530**		**626**	**199**	**1719**	**168**	**1454**
Emfuleni Local							
Leeukuil	38	122%	46	15	127	12	104
Rietspruit	36	92%	33	11	91	11	99
Sebokeng	100	144%	144	46	396	32	275
Subtotal	**174**		**223**	**71**	**614**	**55**	**478**
Mogale City Local							
Flip Human	50	56%	28	9	77	16	137
Percy Stewart	27	63%	17	5	46	9	74
Subtotal	**77**		**45**	**14**	**123**	**24**	**212**
Total	**2331**		**2354**	**748**	**6466**	**741**	**6401**

Note: it is assumed that the inflows are equal to outflows at all plants