



Conduit Hydropower Development Guide

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The publication of this report emanates from a project entitled: *Energy generation from distribution systems* (WRC Project No. K5/2095).

The outputs emanating from this study:

-  TT596/14 - Conduit Hydropower Pilot Plants
-  TT597/14 - Conduit Hydropower Development Guide (this report)
-  HydroAID DVD

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Executive Summary

Winston Churchill stated the following in his speech in November of 1936:

"The era of procrastination of half-measures, of soothing and baffling expedients, of delays, is coming to a close. In its place we are entering a period of consequence..."

His words were referring to the turbulent political situation at the time in the wake of devastating wars and costly errors, but they have developed new connotations and an even harder bite in the 21st century. This quote is now viewed as a stern warning to the leaders of today that the days of reckless living, in which decisions are based on short term beneficitation, is over. Seventy years after he uttered these prophetic words we are starting to realise what a 'period of consequence' means for the way we choose to live our lives as the earth, and its inhabitants, begin to feel the consequences of the decisions our forefathers made (Blersch and Van Vuuren, 2009).

Churchill's statement has become a mantra for environmental activists because it seems to eloquently summarise the environmental climate we live in. Since the industrial revolution, civilisation has boomed. Natural resources such as coal, water and wood have been used recklessly at the will of the consumer without always recognition of the fact that once a non-renewable resource is exhausted, there is no way of replenishing it. Electricity has been produced in the least expensive, but often most harmful, way - particularly in the case of coal-fired power stations - thus placing financial benefits above potential environmental harms which in many cases can be quite severe.

Energy is the lifeblood of worldwide economic and social development. When considering the current status of global energy shortages, the emphasis to reduce CO₂ emissions, development of alternative energy generation methods and the 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. Renewable energy is the way of the future and the potential for its development is of great magnitude.

South Africa is 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 and again in 2013 made all citizens aware of the fact that demand for electricity is grossly outstripping supply.

South Africa is acknowledged to be not particularly endowed with the best hydropower conditions as it might be elsewhere in Africa and the rest of the world. However, large quantities of raw and potable water are conveyed daily under either pressurized or gravity conditions over large distances and elevations.



An initial WRC scoping study highlighted the potential hydropower generation at the inlets to storage reservoirs. In South Africa there are 284 municipalities and several water supply utilities, mines, all owning and operating gravity water supply distribution systems which could be considered for small, mini, micro and pico scale hydropower installations.

Most of these water supply/distribution systems could be equipped with turbines or pumps as turbines, supplementing and reducing the requirements for pressure control valves. The hydro energy may be used onsite, supplied to the national electricity grid or feeding an isolated electricity demand cluster.

There are basically 5 areas where energy generation can occur in the water supply and distribution, as shown in **Figure i**.

- 1) Dam releases into bulk supply lines
- 2) At water treatment works (raw water) – the bulk pipeline from the water source can be tapped
- 3) Potable water – at inlets to service reservoirs where pressure reducing stations (PRS) are utilised to dissipate the excess energy
- 4) Distribution network – in the distribution network itself where excess energy is dissipated (typically with pressure reducing valves (PRV))
- 5) Treated effluent – cases where the treated effluent has potential energy based on its elevation above the discharge point.

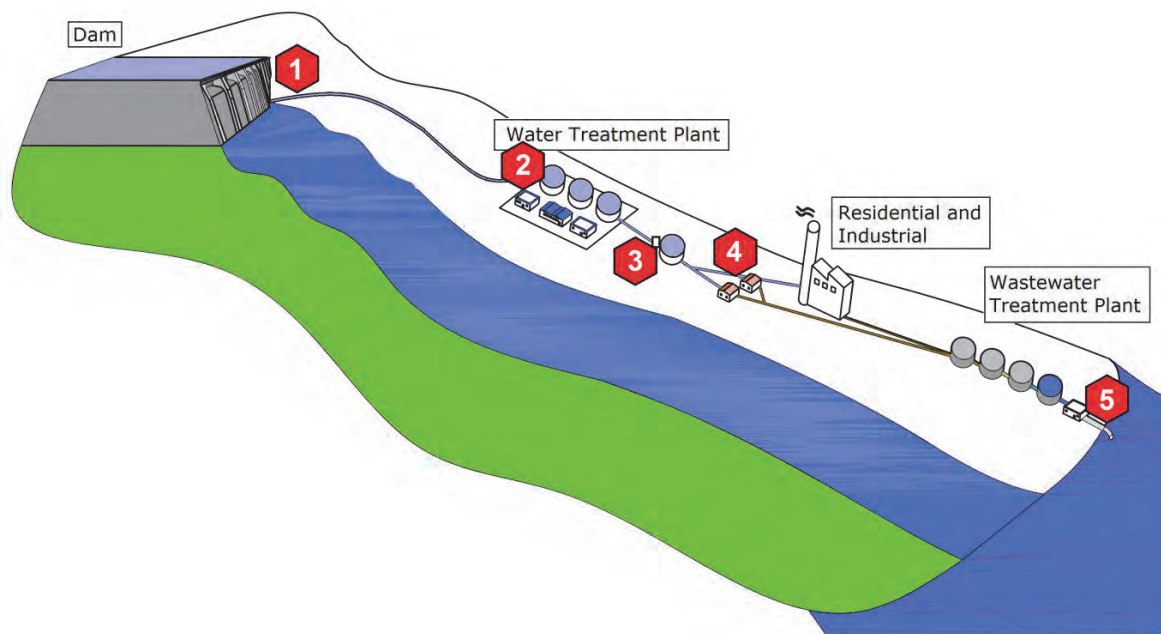


Figure i: Potential energy generation locations in WDS

Worldwide, hydropower is the most established and reliable renewable energy technology. Traditionally, hydropower is used in large dams where the outlet flow is turbinised to generate electricity.



Due to the exploitation of most large dams where this is economically viable, focus has shifted to the use of small scale, mini and micro hydropower as a way to generate electricity, primarily by retrofitting hydropower technology to existing water supply infrastructure.

Advantages of conduit hydropower development

There are numerous benefits provided by hydropower over other energy sources:

- 🔊 Hydroelectric energy is a continuously renewable energy source.
- 🔊 Hydroelectric energy is non-polluting - no heat or noxious gases are released.
- 🔊 Hydroelectric energy is detached from fossil fuel escalation and has low operating and maintenance costs, it is essentially inflation proof.
- 🔊 Hydroelectric energy technology is proven technology offering reliable and flexible operations.
- 🔊 Hydroelectric stations have a long life – many existing stations have been in operation for more than half a century and are still operating efficiently.
- 🔊 Hydropower stations achieve high efficiencies.
- 🔊 Hydropower offers a means of responding quickly to changes in load demand.
- 🔊 Hydropower can help with grid stability as water turbines can generate more rapidly energy than any other generation system.
- 🔊 Conduit hydropower uses the available water distribution infrastructure and thus as long as there is a demand, hydroelectric energy can be generated.
- 🔊 Conduit hydropower “piggy backs” onto existing water infrastructure resulting in a minimal environmental impact.

Conduit hydropower development procedure

It is important to understand the conduit hydropower development process which is different from conventional hydropower development. The following conduit hydropower development process diagram was compiled, which describes the general steps and methods required in the development of a hydropower installation, **Figure ii**.

Conduit hydropower Decision Support System

A Decision Support System (DSS) that facilitates the development process of a conduit hydropower plant was developed. The DSS assists in evaluation of the site, providing guidance on the data gathering procedure, describes the feasibility/economic analysis required, and guides the developer through the turbine selection and detail design aspects. A systematic approach must be followed when assessing hydropower potential in a distribution network to ensure that all relevant factors are considered. The procedure for determining hydropower potential is illustrated through a series of flow diagrams reflecting the different project phases, whilst a tool developed in Microsoft Excel facilitates calculation of all the factors that need consideration.





Figure ii: Conduit hydropower development process diagram

A three phased approach is adopted increasing in intricacy and level of detail required to provide informed decisions at the various stages:

- 🕒 First Phase: Pre-Feasibility Investigation (**Figure iii**)
- 🕒 Second Phase: Feasibility Study (**Figure iv**)
- 🕒 Third Phase: Detailed Design (**Figure v**)



Each phase has its own process flow diagram linked to the Conduit Hydropower Development Tool (CHD Tool). Some of the aspects are required in two or more of the phases, but is dealt with in increasing detail as the project progresses.

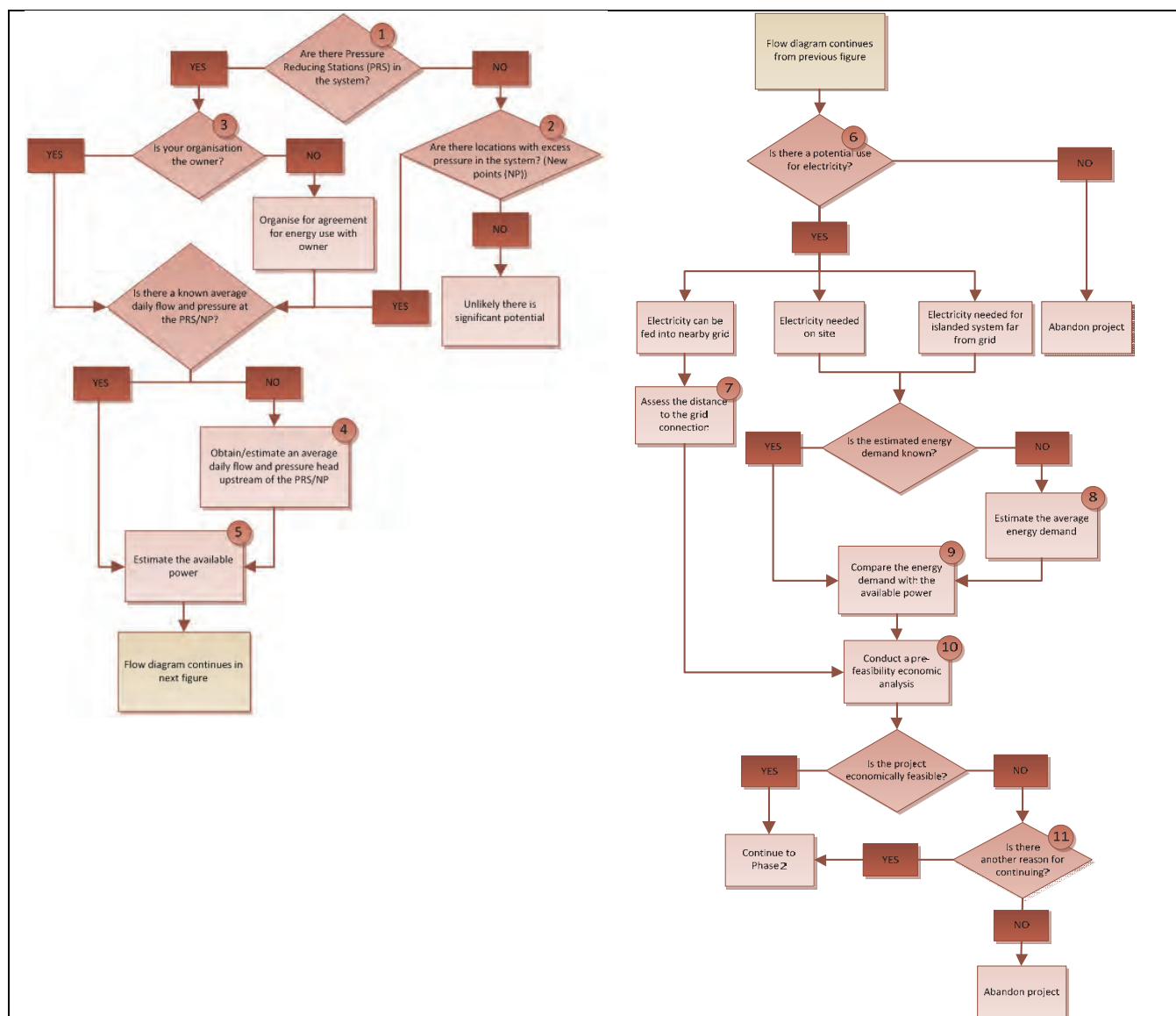


Figure iii: Phase 1 - Pre-Feasibility Investigation



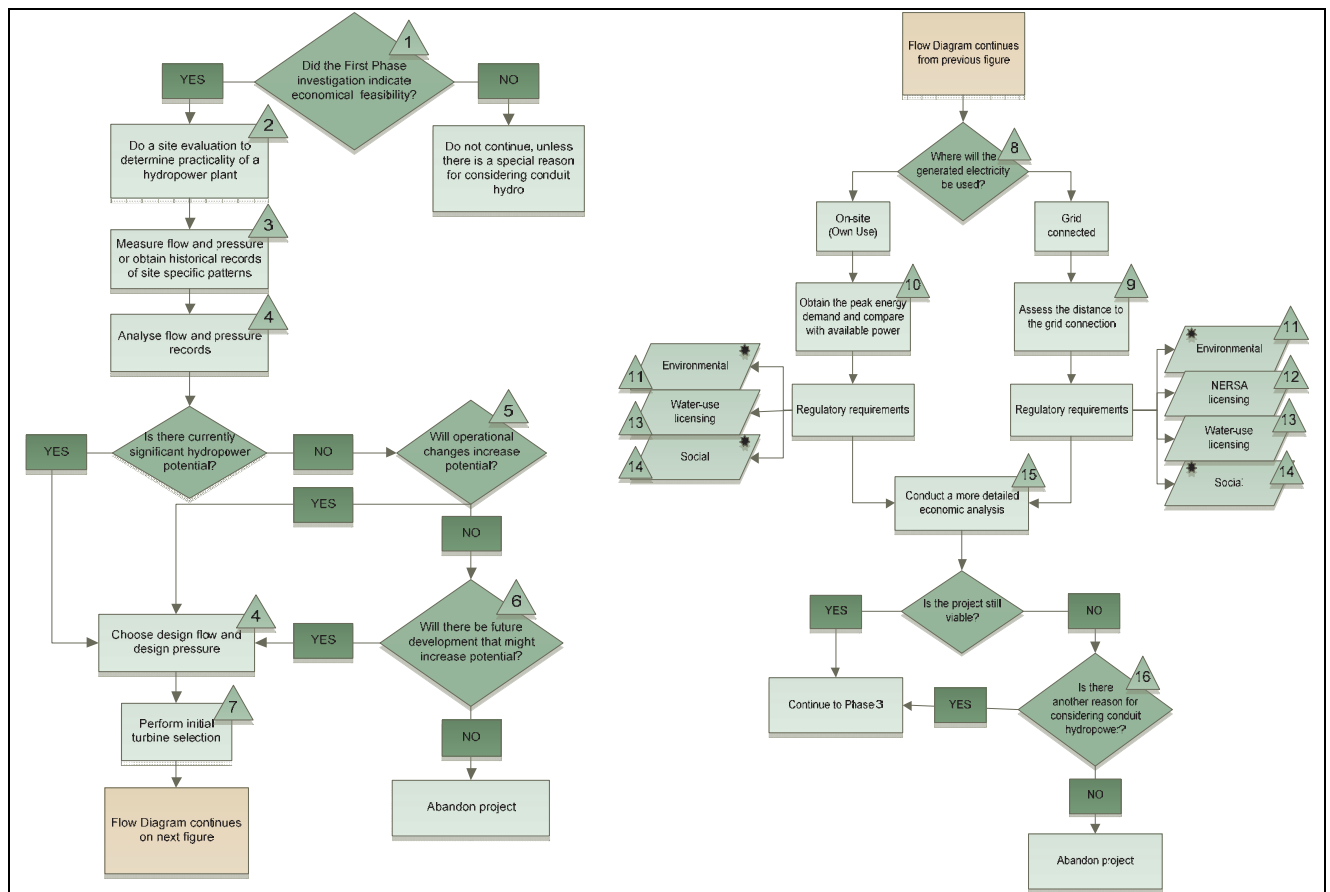


Figure iv: Phase 2 - Feasibility Study

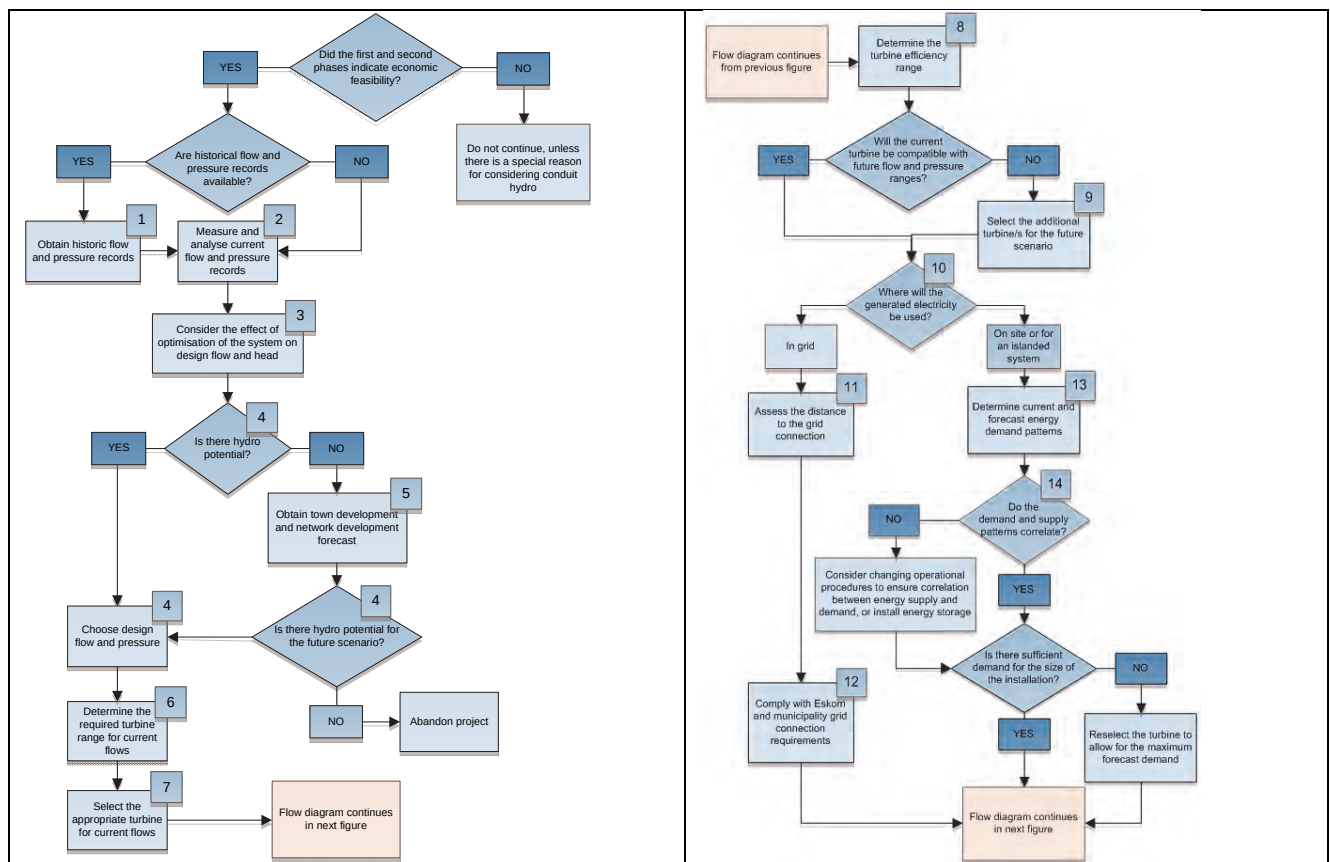


Figure v: Phase 3 - Detailed Design



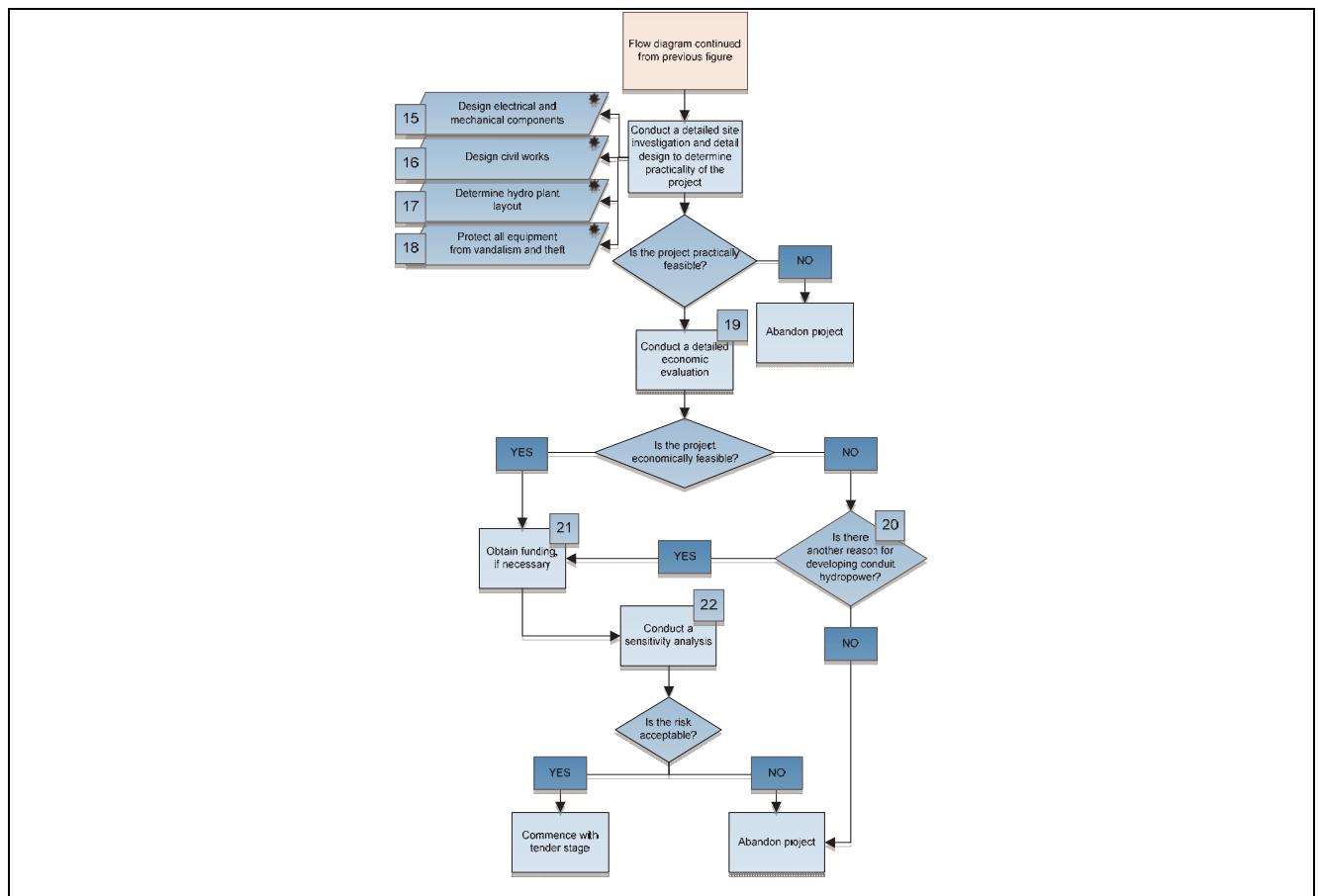


Figure v: Phase 3 - Detailed Design (continued)

Pilot plants installed

The application to install hydro electric turbines in a water distribution system is fairly new in South Africa and thus three pilot plants, listed in **Table i**, were constructed showcasing several of the intricacies in the development process and to demonstrate the technologies (**Figure vi**, **Figure vii** and **Figure viii**).

Table i: Conduit Hydropower Pilot Plants

Nr	Name	Owner	Turbine	Installed capacity (kW)	Use	Payback period (months)
1	Pierre van Ryneveld	City of Tshwane Metropolitan Municipality	Crossflow	14.9	Islanded – On site only	96 months
2	Brandkop	Bloemwater	Crossflow	96	Islanded – Supplying the Bloemwater head office	72 months
3	Newlands 2	Ethekwini Municipality	Pelton	2 x 1	Islanded and grid connected	n.a.



The development process as described in **Figure ii**, was followed to provide feasible full scale hydropower plants. The process of development was documented and recorded and is included on the **HydroAID** supporting DVD.



Figure vi: Pierre van Ryneveld hydropower installation



Figure vii: Brandkop hydropower installation





Figure viii: Newlands 2 Reservoir hydropower installation

This research study indicated that it is feasible and technically possible to generate energy from distributions systems. The hydropower development guidelines assist in identifying locations, selecting the turbine and determining the feasibility thereof. To assist in the feasibility calculations, showing that it is a viable investment cost functions have been developed. The practical aspects are demonstrated with the three constructed, operational pilot plants installations.

“As long as people use water, renewable hydroelectricity can be generated”

A number of complexities were identified:

- ☒ Low awareness from the general public and many decision makers about the advantages that hydropower generation has to offer.
- ☒ Lack of skilled small contractors to construct civil and mechanical components;
- ☒ High cost of control system;
- ☒ There are regulatory and legislative aspects which are “fuzzy” i.e. not well defined;
- ☒ Lack of local turbine manufacturers results in cost uncertainty due to volatile exchange rate;
- ☒ Complex hydraulic analyses required (networks analysis and dynamic simulations) to ensure correct turbine selection; and
- ☒ The novelty of the concept will require more convincing potential owners of infrastructure to implement.



HydroAID

The **HydroAID** supporting DVD contains information to assist the developer/designer of conduit hydropower sites in all the different development facets. The following is included on the DVD:

Literature

-  The British Hydropower Association's Guide to UK Mini-Hydro developments
-  Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries
-  Guide on How to Develop a Small Hydropower Plant
-  Layman's Guidebook on how to develop a small hydro site
-  Renewable Energy Technologies: Cost Analysis Series
-  State of the Art of Small Hydropower in EU-25
-  Hydropower Resource Assessment at Existing Reclamation Facilities
-  Canadian small hydropower handbook

Relevant South African documentation

-  Application for an Electricity Generation Licence in Terms of the Electricity Regulation ACT, 2006 (ACT No. 4 of 2006);
-  Application for a License or Registration of a Water Use (DWA);
-  Application for a Connection of a Generator to the Eskom Network; etc.

Software

Spreadsheet tools such as:

-  Generic Energy Study V1.06 (Microsoft Excel Spreadsheet)
-  Plant Cost Estimator V1.0 (Microsoft Excel Spreadsheet)
-  USBRHydroAssessmentToolVersion2.0 (Microsoft Excel Spreadsheet)
-  Conduit Hydropower Development Tool (CHD Tool) (Microsoft Excel Spreadsheet)
-  RETScreen® International - Small Hydro Project Analysis

Supplier information

Numerous catalogues of suppliers of turbine and other relevant appurtenances for hydropower development including: Andritz, Cla-Val, Cornell, Gilkes, Hydrovolt, IREM, Kawasaki, KSB, Lucid Energy, Mavel, Powerspout, Steffturbine, Tamanini, Toshiba, Cleanpower and Voith.



Pilot Plants

The development of the pilot plants is described in WRC Report TT596/14. In addition a gallery of photos (from construction to implementation), manuals, drawings and video clips are provided to assist in the development process.

WRC reports

-  TT596/14 - Conduit Hydropower Pilot Plants
-  TT597/14 - Conduit Hydropower Development Guide (this report) with Appendices
-  KV323/13 - Scoping study: Energy generation using low head hydro technologies
-  KV238/10 - A High Level Scoping Investigation into the Potential of Energy Saving and Production/Generation in the Supply of Water Through Pressurized Conduits



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APPENDICES

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LIST OF SYMBOLS AND ABBREVIATIONS

AADD	average annual daily demand
BA	basic assessment
BBEEE	Broad-Based Black Economic Empowerment
B/C	benefit/cost ratio
BHA	British Hydropower Association
BOO	build-own-operate
C_A	investment (capital) cost that is required to implement the alternative A
C_C	cross-flow turbine cost
C_{CC}	construction costs
C_{CE}	civil engineering design cost
CEC	capital expenditure cost
C_{Civil}	civil works cost
C_{CM}	construction management cost
$C_{Contingency}$	contingency cost
C_{CP}	commissioning cost of plant
C_D	system design costs
C_{DC}	documentation costs
C_{design}	design costs
C_E	electrical cost
C_{EM}	electro-mechanical cost
$C_{environmental\&social}$	costs of environmental and social assessment
C_{ES}	environmental impact scoping cost
$C_{E\&S}$	costs of environmental and social assessment
C_{F1}	Francis turbine cost (function 1)
C_{F2}	Francis turbine cost (function 2)
C_{F3}	Francis turbine cost (function 3)
C_{FixOM}	fixed annual operation and maintenance cost
C_G	generator cost
CHD Tool	Conduit Hydropower Development Tool
CHDSS	Conduit Hydropower Decision Support System
C_I	installation costs: this includes payment for casting, delivery and mounting of equipment within the civil works
$C_{installation}$	installation costs
$C_{investigation}$	investigation costs
C_{K1}	Kaplan turbine cost (function 1)
C_{K2}	Kaplan turbine cost (function 2)
C_L	licensing cost
C_{LCC}	life-cycle cost (Rand)
$C_{legal\®ulatory}$	legal and regulatory costs
C_{LF}	application and follow-up costs
C_{LR}	legal and regulatory package report cost
C_M	mechanical cost
C_{MC}	manufacturing costs
$C_{M\&C}$	mounting and connecting cost
$C_{M\&E}$	mechanical and electrical design cost
CO ₂	carbon dioxide



C_{OT}	cost of other turbine types
CoT	City of Tshwane
C_P	purchase costs: these include costs of materials and equipment
C_{PB}	project formulation baseline report costs
C_{PEL}	Pelton turbine cost
C_{PM}	project management costs
C_{Pr}	overall project cost
C_{Prop}	propeller turbine cost
$C_{purchase}$	purchase costs
$C_{P/T}$	Pelton or Turgo turbine cost
C_{QC}	quality control costs
C_S	start-up costs
C_{SA}	capital cost of the proposed alternative
C_{SC}	logistic support and control cost
C_{SE}	social benefit/dis-benefit evaluation
C_{SK}	Semi-Kaplan turbine cost
C_{ST}	transformer and switchyard cost
$C_{start-up}$	start-up cost
C_T	turbine cost
C_{TC}	equipment transport costs
C_{TE}	equipment transport costs
C_{TOR}	test and evaluation costs
C_{Trans}	transformer cost
$C_{Transmission}$	transmission cost
$C_{TransROW}$	transmission right-of-way cost
C_u	unit cost
C_{VarOM}	variable operation and maintenance cost
D	diameter of penstock or pipe (m)
Dem	system's daily demand (kWh or MWh)
DBSA	Development Bank of Southern Africa
DME	Department of Minerals and Energy (now DoE)
DoE	Department of Energy
d_r	discount rate or escalation rate
DSS	decision support system
EIA	environmental impact assessment
ESHA	European Small Hydropower Association
EUL	expected useful life
FC	fixed cost
F_v	final value
g	gravitational acceleration (m/s^2) (typically $9.81 m/s^2$)
H	effective pressure head (m)
HES	Hydropower Evaluation Software
h_f	friction loss (m)
h_l	secondary losses (m)
I	electrical current (A)
IHA	International Hydropower Association
IMQS	Infrastructure Management Query Station
IPC	initial planning cost



IPP	independent power producer
IRP	integrated resource plan
IRR	internal rate of return
K	secondary loss coefficient
L	length of penstock (m)
$LCOE$	levelised cost of electricity
L_T	transmission line length (miles)
LCC	life cycle cost
M	facility maintenance cost
M_0	facility maintenance cost of the null alternative
M_A	facility maintenance cost of the proposed alternative
n	number of years
N_T	number of turbines
NERSA	National Energy Regulator of South Africa
NPV	net present value of benefits
OMC	operation and maintenance cost
O&M	operation and maintenance
P	mechanical power output (W)
P_{actual}	actual power output of turbine (W)
$P_{\text{theoretical}}$	theoretical output at 100% efficiency (W)
P_1	pressure at Station 1 (N/m ²)
P_2	pressure at Station 2 (N/m ²)
PRS	pressure-reducing station
PRV	pressure-reducing valve
PW	present worth
PWOC	present worth of cost
Q	flow rate through the turbine (m ³ /s)
r	rate at which the left-hand and right-hand sides of the equation are equal, resulting in an NPV of zero
REBID	Renewable Energy Bidding (now REIPPPP)
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROI	return on investment
RUL	remaining useful life
SABS	South African Bureau of Standards
SANEDI	South African National Energy Development Institute
U_{cost}	user costs
U_0	user costs of the null alternative
U_A	user costs of the proposed alternative
USA	United States of America
USBR	United States Bureau of Reclamation
V	potential difference (V)
v	velocity of water in penstock or pipe (m/s)
v_1	velocity of the flow at Station 1 (m/s)
v_2	velocity of the flow at Station 2 (m/s)
VC	variable costs



WRC	Water Research Commission
Z_1	elevation of water above datum line, in the streamline at Station 1 (m)
Z_2	elevation of 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.
Annuity	:	An annuity is any continuing payment, usually annually, to repay an investment or loan.
Asset	:	In financial accounting, an asset is an economic resource. Anything tangible or intangible that is capable of being owned or controlled to produce value and that is held to have positive economic value is considered an asset.
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.
Debt	:	Capital raised from loans or borrowings.
Demand	:	The rate at which electric energy is delivered to or by a system, part of a system or a piece of equipment. It is expressed usually in kilowatts at a given instant or averaged over any designated period of time. The primary source of "demand" is the power-consuming equipment of customers.
Demand, Average	:	The demand on, or the power output of, an electric system or any of its parts over any interval of time, as determined by dividing the total number of kilowatt-hours by the number of units of time in the interval.
Demand Charge	:	That part of the charge for electric service based upon the electric capacity (kW) consumed and billed on the basis of billing demand under an applicable rate schedule.
Demand Interval	:	The period of time during which the electric energy flow is averaged in determining demand, such as 60-minute, 30-minute, 15-minute, or instantaneous.
Depreciation	:	Charges made against income to provide for distributing the cost of depreciable plant less estimated net salvage over the estimated useful life of the asset in such a way as to allocate it as equitably as possible to the period during which such services are obtained from the use of the facilities. Among the factors to consider are: wear and tear, decay, inadequacy, obsolescence, changes in demand and requirements of public authorities.
Direct current (DC)	:	Electric current which flows in one direction.



Distribution	:	The act or process of delivering electric energy from convenient points on the transmission system (usually a substation) to consumers. The network of wires and equipment that distributes transports or delivers electricity to customers. Electric energy is carried at high voltages along the transmission lines. For consumers needing lower voltages, it is reduced in voltage at a substation and delivered over primary distribution lines extending throughout the area where the electricity is distributed. For users needing even lower voltages, the voltage is reduced once more by a distribution transformer or line transformer. At this point, it changes from primary to secondary distribution.
Distribution Line	:	One or more circuits of a distribution system either direct-buried, in conduit or on the same line of poles or supporting structures, operating at relative low voltage as compared with transmission lines.
Draft Tube	:	A water conduit, which can be straight or curved depending upon the turbine installation, that maintains a column of water from the turbine outlet and the downstream water level. It takes the water from a turbine which is discharged at a high velocity, and reduces its velocity by enlarging the cross-section of the tube, to provide a gain in net head.
Efficiency	:	A percentage obtained by dividing the actual power or energy by the theoretical power or energy. It represents how well the hydropower plant converts the energy of the water into electrical energy.
Energy Charge	:	That part of the charge for electric service based upon the electric energy (kWh) consumed or billed
Feasibility study	:	An investigation to develop a project and definitively assess its desirability for implementation.
Flywheel	:	A heavy mass of steel spinning with a turbine and generator adding inertia to the rotating system. Fast changes in load or water supply are smoothed out to create a more uniform rotating speed, thus maintaining 50 Hz.
Generator	:	A rotating machine that converts mechanical energy into electrical energy.
Gigawatt (gW)	:	One gigawatt equals one billion (1 000 000 000) watts, one million (1 000 000) kilowatts, or one thousand (1 000) megawatts.



Gigawatt-Hours (gWh)	:	One gigawatt-hour equals one billion (1 000 000 000) watt-hours, one million (1 000 000) kilowatt-hours, or one thousand (1 000) megawatt-hours.
Governor	:	An electronic or mechanical device which regulates the speed of the turbine/generator by sensing frequency and either adjusting the water flow or adjusting a balancing load dump to keep a constant load on the turbine.
Head	:	Vertical change in elevation, expressed in either feet or meters, between the head water level and the tail water level.
Headwater	:	The water level above the powerhouse.
Hertz	:	1 electrical cycle per second. Usually 50 Hz is maintained.
Impulse turbine	:	A machine which converts the energy of a jet of water at atmospheric pressure into mechanical energy, usually used to turn a generator. Examples are the Pelton, Turgo and Crossflow turbine.
Independent Power Producer (IPP)	:	Any person who owns or operates, in whole or in part, one or more new independent power production facilities.
Induction Generator	:	A generator which must be part of a larger system to be controlled. The induction generator is regulated by the electrical inertia and frequency of the larger power system.
Inflation	:	A general rise in prices. An increase in a particular price may or may not be inflationary, depending on how it affects other prices and on how promptly it brings to market additional supplies of the product.
Instantaneous Peak Demand	:	The demand at the instant of greatest load, usually determined from the readings of indicating or graphic meters.
Kilowatt (kW)	:	One kilowatt equals 1 000 watts.
Kilowatt-Hour (kWh)	:	This is the basic unit of electric energy equal to one kilowatt of power supplied to or taken from an electric circuit steadily for one hour. One kilowatt-hour equals 1,000 watt-hours.
Load Curve	:	A curve on a chart showing power (kilowatts) supplied, plotted against time of occurrence, and illustrating the varying magnitude of the load during the period covered.
Load Dump	:	A bank of resistors (heaters) which absorb surplus energy from a generator. A load dump is controlled by a governor to maintain a constant total load on a generator.



Load Factor	:	The ratio of the average load in kilowatts supplied during a designated period to the peak or maximum load in kilowatts occurring in that period. Load factor, in percent, also may be derived by multiplying the kilowatt-hours (kWh) in the period by 100 and dividing by the product of the maximum demand in kilowatts and the number of hours in the period. Example: Load Factor Calculation - Load Factor = kilowatt-hours/hours in period/kilowatts. Assume a 30-day billing period or 30 times 24 hours for a total of 720 hours. Assume a customer used 10 000 kWh and had a maximum demand of 21 kW. The customer's load factor would be 66 percent $((10\ 000\ \text{kWh}/720\ \text{hours}/21\ \text{kW}) \times 100)$.
Load Management	:	Economic reduction of electric energy demand during a utility's peak generating periods. Load management differs from conservation in that load-management strategies are designed to either reduce or shift demand from on-peak to off-peak times, while conservation strategies may primarily reduce usage over the entire 24-hour period. Motivations for initiating load management include the reduction of capital expenditure (for new power plants), circumvention of capacity limitations, provision for economic dispatch, cost of service reductions, system efficiency improvements or system reliability improvements. Actions may take the form of normal or emergency procedures.
Load Shifting	:	Involves moving load from on-peak to off-peak periods. Popular applications include use of storage water heating, storage space heating, cool storage and customer load shifts to take advantage of time-of-use or other special rates.
Maximum Demand	:	The greatest demand that occurred during a specified period of time such as a billing period.
Megawatt (MW)	:	One megawatt equals one million (1 000 000) watts.
Network	:	A system of transmission or distribution lines cross-connected and operated as to permit multiple power supply to any principal point on it.
Off-Peak Energy	:	Energy supplied during periods of relatively low system demand as specified by the supplier.
On-Peak Energy	:	Energy supplied during periods of relatively high system demand as specified by the supplier.



Overspeed	:	A speed higher than the normal operating speed. A turbine/generator in overspeed will produce harmful power surges (unless the main breaker acts to put the generator off line) and prolonged operation at overspeed can result in bearing failure and destruction of rotating parts.
Penstock	:	A closed conduit or pipe for conducting water to the powerhouse.
Rated flow	:	The flow of a water course based on the mean flow of say certain months of the year for determining a hydropower plant with a specific load factor.
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	:	Measure of speed in 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 turbine.
Tailwater	:	The water conduit downstream of the powerhouse.
Tariff	:	A schedule of prices or fees.
Three-Phase Service	:	Service where the facility (e.g., manufacturing plant, office building or warehouse) has three energized wires coming into it. Typically serves larger power needs of greater than 120V/240V. Usually required for motors exceeding 7 kW or other inductive loads. Requires more sophisticated equipment and infrastructure to support and tends to be more expensive to install and maintain.
Transformer	:	An electromagnetic device for changing the voltage level of alternating-current electricity.
Transmission	:	The act or process of transporting electric energy in bulk from a source or sources of supply to other principal parts of the system or to other utility systems.
Turbine	:	A machine in which the pressure or kinetic energy of flowing water is converted to mechanical energy which in turn can be converted to electrical energy by a generator.
Water course	:	A natural channel in which water flows regularly or intermittently.
Water hammer	:	A change in penstock pressure caused by changing the speed of a column of water in a penstock. The result of a rapid valve closure can produce extremely high pressures capable of rupturing a penstock, while the results of extremely rapid valve opening can reduce pressures, causing potential water column separation and vacuum conditions. Water hammer is controlled by using slow acting valves, pressure relief valves, surge tanks or jet deflectors (on impulse machines).



1. BACKGROUND

Winston Churchill stated the following in his speech in November of 1936:

"The era of procrastination of half-measures, of soothing and baffling expedients, of delays, is coming to a close. In its place we are entering a period of consequence..."

His words were referring to the turbulent political situation at the time in the wake of devastating wars and costly errors, but they have developed new connotations and an even harder bite in the 21st century. This quote is now viewed as a stern warning to the leaders of today that the days of reckless living, in which decisions are based on immediate harms or gains, is over. Seventy years after he uttered these prophetic words we are starting to realise what a 'period of consequence' means for the way we choose to live our lives as the earth, and its inhabitants, begin to feel the consequences of the decisions our forefathers made (Blersch and Van Vuuren, 2009).

Churchill's statement has become a mantra for environmental activists because it seems to eloquently summarise the environmental climate we live in. Since the industrial revolution, civilisation has boomed. Natural resources such as coal, water and wood have been used recklessly at the will of the consumer without always recognition of the fact that once a non-renewable resource is exhausted, there is no way of replenishing it. Electricity has been produced in the least expensive, but often most harmful, way - particularly in the case of coal-fired power stations - thus placing financial benefits above potential environmental harms which in many cases can be quite severe.

Energy is the lifeblood of worldwide economic and social development. When considering the current status of global energy shortages, the emphasis to reduce CO₂ emissions, development of alternative energy generation methods and the growing energy consumption, it is clear that there is a need to change the way energy is created



"THERE'S A FOOT OF WATER IN THE LOUNGE
BUT STILL NO ELECTRICITY."



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 the 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.

Renewable energy is the way of the future and the potential for its development is of great magnitude. 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.**

South Africa is 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.

One of the major economic problems facing hydropower development in the past has been the low tariffs that Eskom has been willing to pay for renewable energy. With South Africa's high level of carbon emissions, reliance on coal and severe energy shortage, the government has been forced to reconsider the state of renewable energy tariffs in order to reach their target of 10 000 GWh of renewable energy by 2013 (Reuters, 2009). This prompted the announcement of a set of renewable energy feed-in tariffs by NERSA at the end of March 2009. The primary aim of these tariffs was to cover generation costs with allowance for a profit potential that is sufficiently attractive to stimulate investment (NERSA, 2009). The initial REFIT tariff for small hydropower was 94c/kWh which was however reduced by NERSA in March 2011 to 67.1 c/kWh. The Department of Energy (DoE) with the endorsement from NERSA introduced the Integrated Electricity Resource Plan (IRP) for South Africa 2010 – 2030. The IRP 2010 has been subjected to public scrutiny and comments and eventually the whole process manifested into a Final Policy Adjusted IRP 2010: New-build Technology Mix. The DoE subsequently allocated different capacities across various renewable energy technologies from the total development capacity of 3725 MW. The hydropower sector has been allocated overall capacity of 75 MW to be commercially operational by June 2014 based on a Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) where IPPs would competitively tender to implement projects.

An initial scoping investigation (Van Vuuren, 2010) highlighted the potential hydropower generation at the inlets to storage reservoirs. In South Africa there are 284 municipalities and several water supply utilities all owning and operating gravity water supply distribution systems which have some type of pressure dissipating system at the downstream end of the supply pipe.



There are basically 5 areas where energy generation can occur in the water supply and distribution, as shown in **Figure 1-1** (Van Dijk et al., 2012).

- 1) Dam releases into bulk supply lines
- 2) At water treatment works (raw water) – the bulk pipeline from the water source can be tapped
- 3) Potable water – at inlets to service reservoirs where pressure reducing stations (PRS) are utilised to dissipate the excess energy
- 4) Distribution network – in the distribution network itself where excess energy is dissipated (typically with pressure reducing valves (PRV))
- 5) Treated effluent – cases where the treated effluent has potential energy based on its elevation above the discharge point.

Worldwide, hydropower is the most established and reliable renewable energy technology. Traditionally, hydropower is used in large dams where the outlet flow is turbinised to generate electricity. Due to the exploitation of most large dams where this is economically viable, focus has shifted to the use of small scale, mini and micro hydropower as a way to generate electricity.

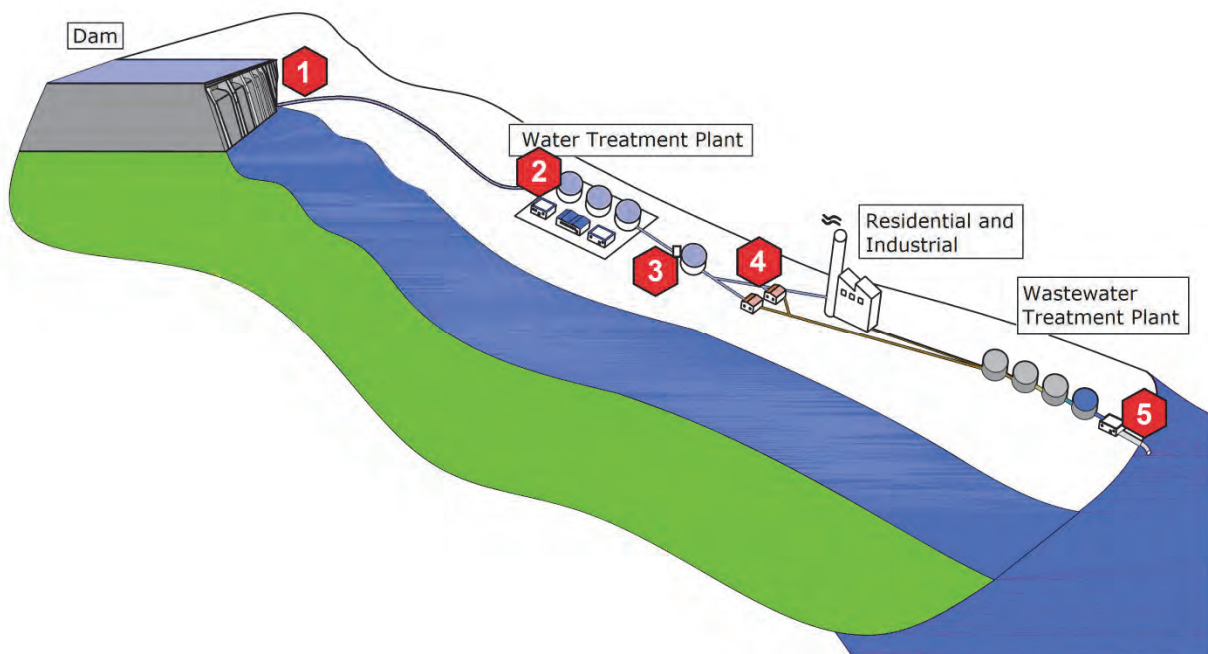


Figure 1-1: Location of energy generation potential (Van Dijk et al. 2012)

1.1 Hydropower potential and enabling environment in South Africa

The Integrated Resource Plan (IRP 2010) accepted and endorsed by the SA Government in the second half of 2011 set out eventually a path for the development of the renewable energy technologies in South Africa.



A “Request for Qualification and Proposals for New Generation Capacity under the IPP Procurement Programme” (August 2011) introduced the regulatory and capacity requirements for each renewable energy technology suitable for development in South Africa. The small scale hydropower (<10 MW) has been allocated 75 MW (2%) out of the total of a 3 725 MW (100%) to be implemented by 2016. A broad overview of the development potential based on the different types of hydropower categories are presented in **Table 1-1**:

Table 1-1: Development potential of different hydropower categories

Hydro-power category	Capacity in power output	Potential hydropower use either as a single source or in a hybrid configuration with other sources of renewable energy (e.g. solar, wind, biomass, etc.)	Extent of hydropower potential in South Africa
Pico	Up to 20 kW	10 kW network to supply a few domestic dwellings	Unlimited
Micro	20 kW to 100kW	100 kW network to supply small community with commercial/manufacturing enterprises	All 284 municipalities and rural settlements
Mini	100 kW to 1 000 kW	1 MW plant can offset about 150 000 tons of CO ₂ annually and will provide about 1 000 sub-urban households with reliable electricity supply.	Most of 1085 medium to large dam reservoirs are suitable for mini plants
Small	1 MW to 10 MW	1MW to 10MW network– distribution will be at medium voltage ranging from 11 to 33kV and transformers are normally needed. The generation is synchronized with a grid frequency (typically to 50 or 60 Hertz).	Several dam reservoirs and numerous bulk water supply systems – Water Transfer Systems
NB: All installations above 10 MW are classified as macro (or large) hydropower plants – limited potential but sizeable			

The Renewable Energy Feed-in-Tariff (REFIT) adopted by many countries world-wide has been dropped and replaced by a bidding process (REIPPPP) in South Africa placing the hydropower development opportunities into a disorder and the developers of this technology rather unprepared for the new development conditions. The REIPPPP requirements for qualification allows really only for those projects which were at the stage of feasibility (bankable) study in August 2011 and all projects smaller than 1 MW in capacity are to date excluded from the bidding process. This means that all developers of pico, micro and mini hydropower are to bear all development risks without guarantees during the whole procurement process.



2. ENERGY FROM WATER

2.1 Introduction

In a hydroelectric power station, water stored behind a dam wall, in a reservoir or in a river is conveyed to a hydraulic turbine, which is turned by the force of the water. The turbine drives a generator rotor, to which it is coupled by a shaft, thus generating electricity. After the water has completed its task, it is discharged back into the river or reservoir downstream of the power station, without consuming any amount of water.

2.1.1 Hydro power generation

Currently, just over one-third of the world's hydro potential is developed. Realistic hydro potential is greatest in Asia, followed by South America and then Africa. Africa's hydro potential is not evenly spread throughout the continent and varies from enormous hydro potential in countries such as the Democratic Republic of the Congo to water scarce countries such as South Africa.

The management of water supplies in South Africa has developed into a science to ensure that it is used to its full potential and to this end; unique partnerships have developed between Eskom and the Department of Water and Environmental Affairs.

In South Africa Eskom's hydroelectric power stations Eskom has three types of hydroelectric power stations; conventional reservoir (Gariep and Vanderkloof), run-of-river (Colley Wobbles, First and Second Falls and Ncora) and pumped storage schemes (Palmiet, Drakensberg and Ingula). Cape Town Metropolitan Municipality owns and operates the Steenbras pumped storage scheme.

2.1.2 Power generation in South Africa

Electricity, in the world of today, is a necessity for everyday life. Ensuring that all people have access to power is crucial for the economic development of any region or country.

Worldwide there is still a vast dependence on fossil fuels to generate electricity, the most abundant fossil resource being coal (Lloyd & Subbarao, 2009). Eskom's document 'Understanding Electricity' indicates that in South Africa, approximately 90% of electricity provided is generated in coal fired power stations. This is due to the relative abundance, availability and the low cost to mine coal in the country, thereby making other forms of electricity generation largely unfeasible. As stated by DME (2003), South Africa relies heavily on coal and has developed an "efficient, large-scale, coal-based power generation system that provides low-cost electricity" right across the country.



The result is that coal will remain economically viable and will continue to be the most attractive source of energy in South Africa from a financial perspective.

Other than coal fired power stations, electricity supplied in South Africa is also generated in nuclear power stations, hydroelectric schemes, pumped storage schemes, open cycle gas turbines and wind farms. The most recent figures for the breakdown of GWh produced in South Africa by the different electricity generating technologies were found in a report published by Statistics South Africa (2008). This report reflected electricity generation in South Africa in 2006. A total of 222 939 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. The locations as well as the installed capacities of the various power stations in South Africa are shown in **Figure 2-2**.

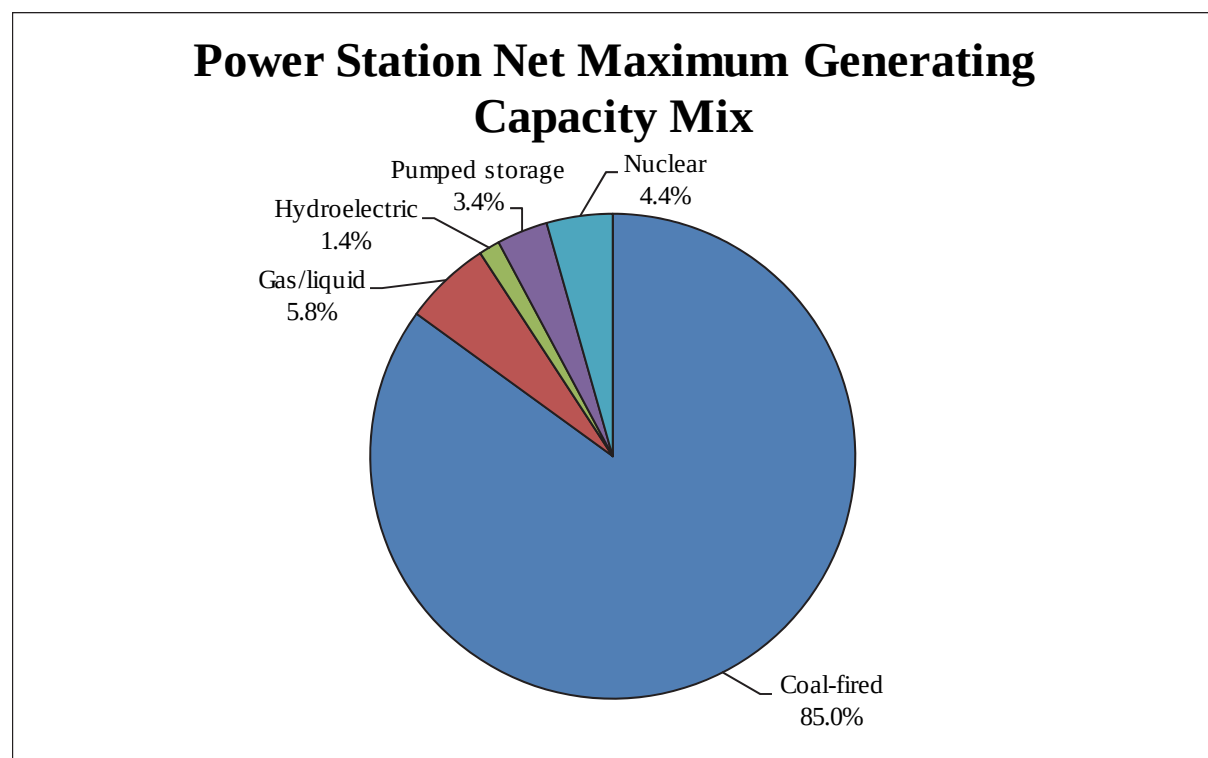
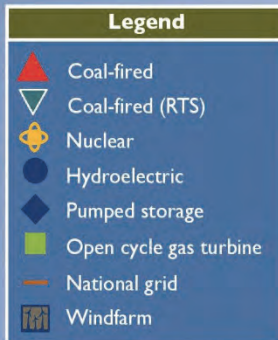


Figure 2-1: Power station net maximum generating capacity mix (Eskom, 2012a)





Base load stations	Return-to-service	Peak demand stations	New build
1 Arnot 2 100 MW 2 Duvha 3 600 MW 3 Hendrina 2 000 MW 4 Kendal 4 116 MW 5 Koeberg 1 930 MW 6 Kriel 3 000 MW 7 Lethabo 3 708 MW 8 Majuba 4 110 MW 9 Matimba 3 990 MW 10 Matla 3 600 MW 11 Tutuka 3 654 MW	12 Camden 1 600 MW 13 Grootvlei 1 200 MW 14 Kendal 1 000 MW	<i>Open cycle gas turbine</i> 19 Acacia 171 MW 20 Port Rex 171 MW 21 Ankerlig 592 MW 22 Gourikwa 444 MW <i>Distribution</i> 27 First Falls 6.4 MW 28 Second Falls 11 MW 29 Colley Wobbles 42 MW 30 Ncora 2.4 MW	<i>Base load</i> 24 Medupi 4 788 MW 32 Kusile 4 800 MW <i>Peak demand stations</i> 25 Ingula 1 332 MW 26 Gas 1 1 036 MW <i>Renewable energy</i> 31 Sere 100 MW <i>Renewable energy</i> <i>Windfarm</i> 23 Klipheuwel 3.2 MW

Figure 2-2: Location of Eskom's power stations in South Africa (Eskom 2008a; Eskom, 2012a)



As a result of higher than anticipated demand growth and limited investment in new power generation infrastructure over the last 15 years, Eskom's generation reserve margin has "decreased to 8%, well below the internationally accepted norm of 15%". The lower reserve margin means that the remaining generator units need to work harder to meet the demand for electricity" (ESKOM, 2008), increasing the likelihood of power failure or scheduling due to accelerated aging of the infrastructure.

With South Africa experiencing serious electricity shortages in recent years, it has become essential to step up the plans for future electricity development. The Cabinet approved the Integrated Resource Plan (IRP) for Electricity (2010 – 2030) as the basis for South African power generation for the next 20 years.

The approved plan is geared towards a low carbon future and aligned with the country's long-term mitigation scenarios in line with national government's aspiration. It is envisaged that 42% of the new build programme excluding the current committed Eskom build programme will be from renewable energy sources between 2011 and 2030 (ESKOM, 2011). By 2030, it is anticipated that the percentage of energy generated from CO₂ free sources (including nuclear energy) will be nearly 30% (ESKOM, 2011). South Africa has significant potential for renewable energy production in many forms as shown in **Figure 2-3**.

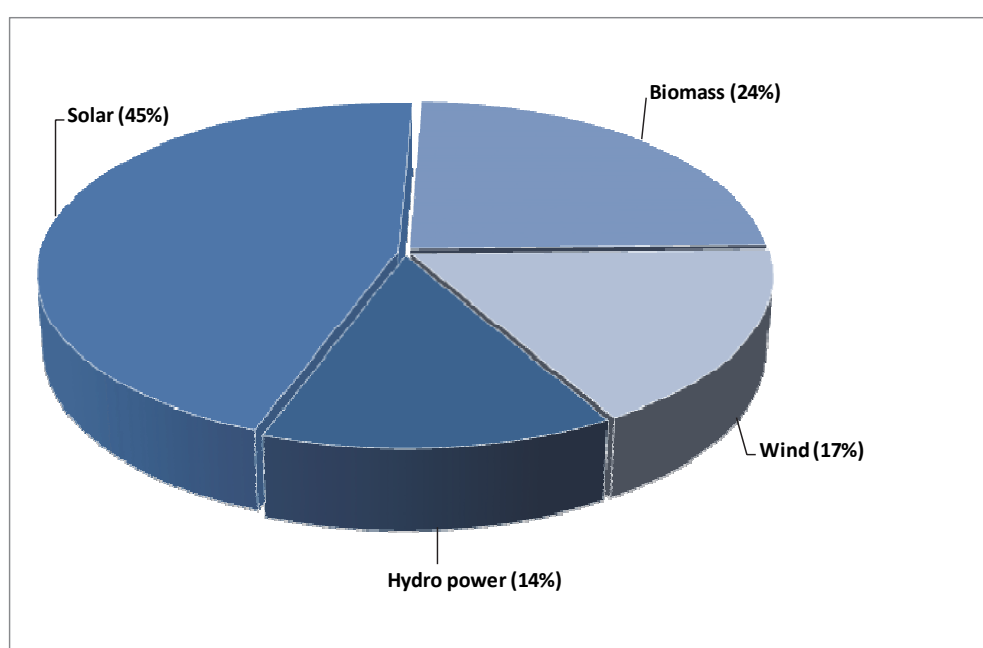


Figure 2-3: Percentage potential contribution of different forms of renewable energy (DME, 2003)

Although South Africa is a fairly dry country, there is potential for the development of all forms of **hydropower** in specific sites throughout the country, with the Eastern Cape and KwaZulu-Natal showing the greatest promise (DME, 2002 and DME, 2003).



It is estimated that there is a total technically feasible hydropower potential of 11 000 GWh/year and an economically feasible potential of 4 700 GWh/year. Of this small potential, 1 400 GWh/year is currently being exploited. South Africa's potential for small hydropower amounts to 880 GWh/year of which 16 MW is currently in operation at six different plants (IHA, 2006).

2.1.3 Overview of hydropower potential in South Africa

Any potential developer of hydropower in SA has a wide choice of hydropower types providing that the SA regulatory conditions are observed. The hydropower types appropriate for development in the SA are as follows:

- 🔍 rehabilitation/upgrade of existing hydropower scheme (some 8 MW is available around SA)
- 🔍 in-line/conduit hydropower from water distribution systems (at least 100 MW is feasible to develop)
- 🔍 run-of-river development (some 270 MW mainly in the Eastern Cape and KwaZulu/Natal)
- 🔍 storage regulated development (1 520 MW from existing and new dams + 5 200 MW "Greenfield")
- 🔍 Refrigerated water circulation at deep-level mines (unknown potential)
- 🔍 pump storage scheme – (Eskom identified several sites over above Ingula PS presently constructed)
- 🔍 tidal hydropower potential (at many locations around the SA coastline – full potential not available)
- 🔍 imported hydropower (up to capacity 36 400 MW mainly from the DRC and Zambia)

At present most lucrative and economic development of hydropower in South Africa is primarily within the spheres of rehabilitation/upgrade, in-line hydropower from the bulk water supply and distribution systems and the hydropower added to the existing storage regulated dams. To some extent there is also a significant hydro-energy potential at deep-level mines within specific locations in South Africa (Le Roux, 2013).

2.1.3.1 Water resources

South Africa is geographically and climatologically highly diversified country with the average annual precipitation of 450 mm and very high evaporation rates (up to 2000 mm/annum) in some areas (**Figure 2-4**). However the land areas situated in the north-east of the country between the mountainous rim of Drakensberg range and the Indian Ocean coastline are having average annual rainfall over 1000 mm. The place with highest annual rainfall (over 2000 mm) is situated in the Eastern Cape Province.



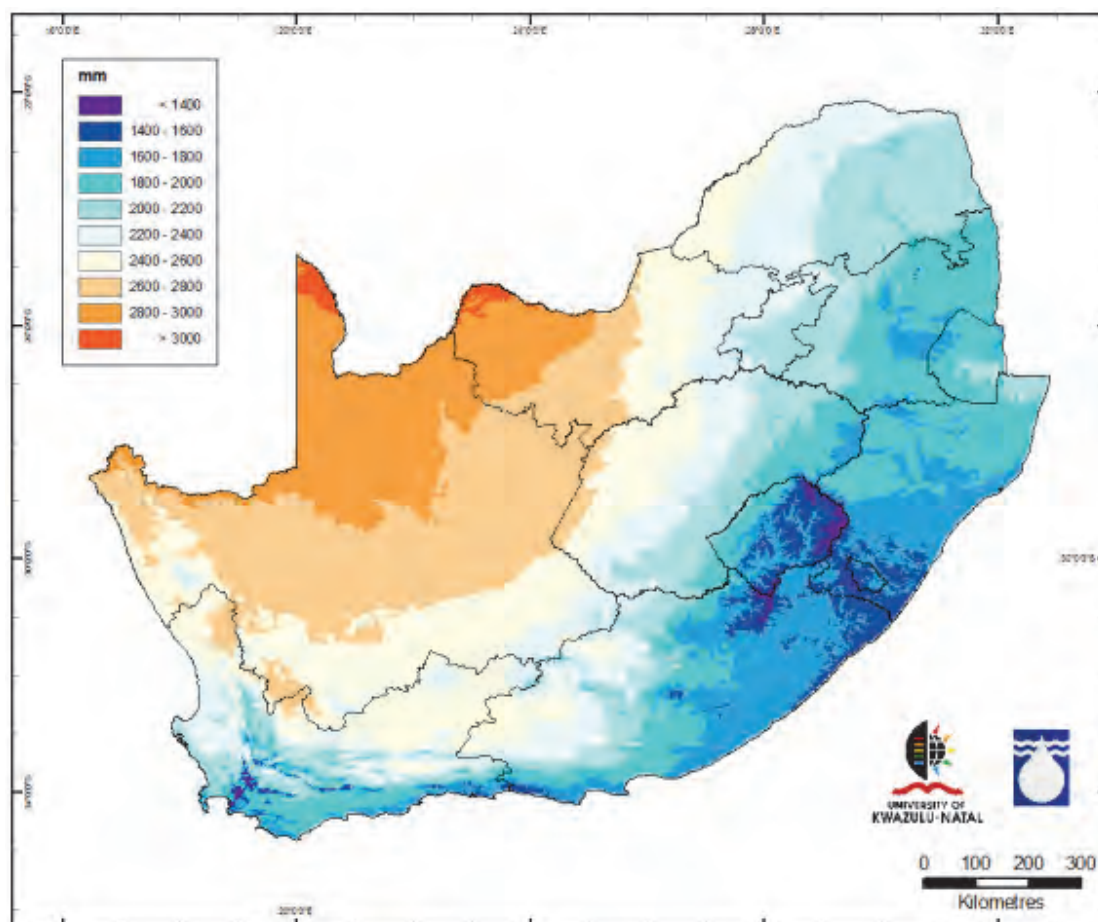


Figure 2-4: Water resources map of South Africa showing the rainfall regions

According to the recently compiled national water re-assessment (WR, 2005) South Africa's mean annual run-off is evaluated at 49 km³ and usable groundwater potential is estimated at 10 km³ per annum (25% less during drought conditions). Most of the exploitable run-off (some 20 km³/annum) is impounded in about 1 200 medium dams (between 15 and 30 m) and large dams (over 30 m) supplying the agricultural, urban industrial and residential areas. At present more than 300 South African dams are included in the world register of large dams.

2.1.3.2 Water Transfer Schemes

To overcome the imbalances between geographical water availability and demand for good quality of water a number of Water Transfer Schemes (WTS) have been developed in South Africa, mainly since 1970s. To date some twenty six WTSs were constructed and all of them are exclusively administered by the national Department of Water Affairs (DWA) together with the Trans-Caledon Tunnel Authority (TCTA) as an implementation agent for some latest water transfers schemes.



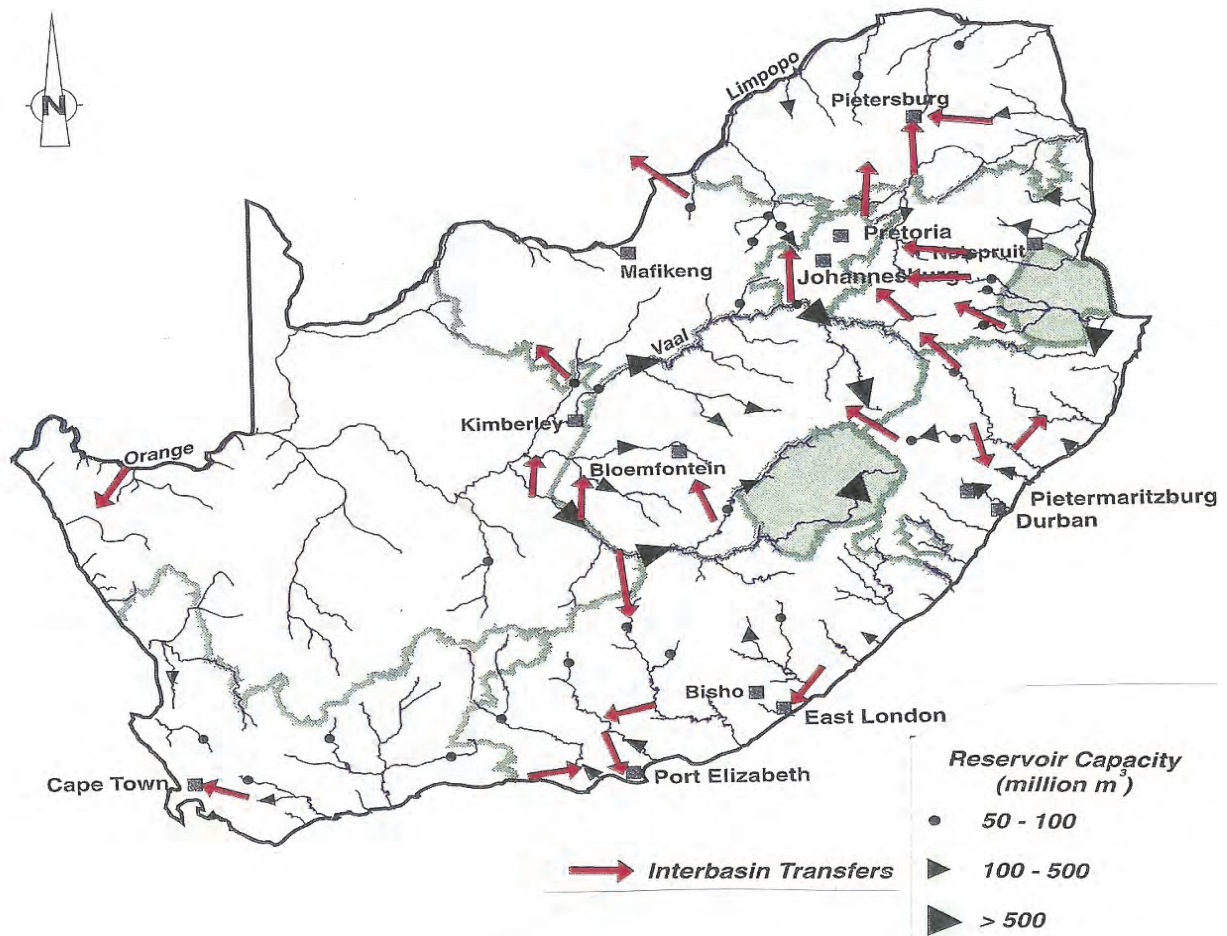


Figure 2-5: The location of foremost Water Transfer Schemes in South Africa (DWA, 1997)

The most recently built inter-basin WTS is the Phase 1 of the Lesotho Highlands Water Project (LHWP) which includes Muela Hydropower Station of a 72 MW capacity. The Phase 2 of the LHWP has been approved recently for development and will consist of the Polihali Dam (a CFR dam, 164 m high), gravity delivery tunnel with a hydropower plant situated at the tunnel outlet into the existing Katse Dam reservoir. Present flow from Lesotho to South Africa amounts to 25 m³/sec. Both LHWP's phases combined will supplement the South African bulk water supply systems with 40 m³/s by 2020.

Several existing WTSs are suitable besides transferring large quantities of water also for the energy generation at certain places where the water is conveyed by gravity. The most suitable are the LHWP (18 MW), Assegai to Vaal WTS (23 MW), Orange-Fish-Sundays (25 MW) and Usutu to Vaal WTS (5 MW).

2.1.3.3 Brief history of hydropower development in South Africa

Historically, the development of hydropower for electricity generation in South Africa has not been significant by the world-wide standards.



In the first half of 20th century between 1911 and late 1960s some 190 small scale hydropower plants with an overall capacity output of 23 100 kW were installed around South Africa. The range of these installations varied between 3 kW and 1000 kW of primarily the Francis turbine type with numerous Pelton and Turgo Impeller turbine arrangements also installed. The owners of these yester-year small plants were mainly the municipalities, farming enterprises and mines.

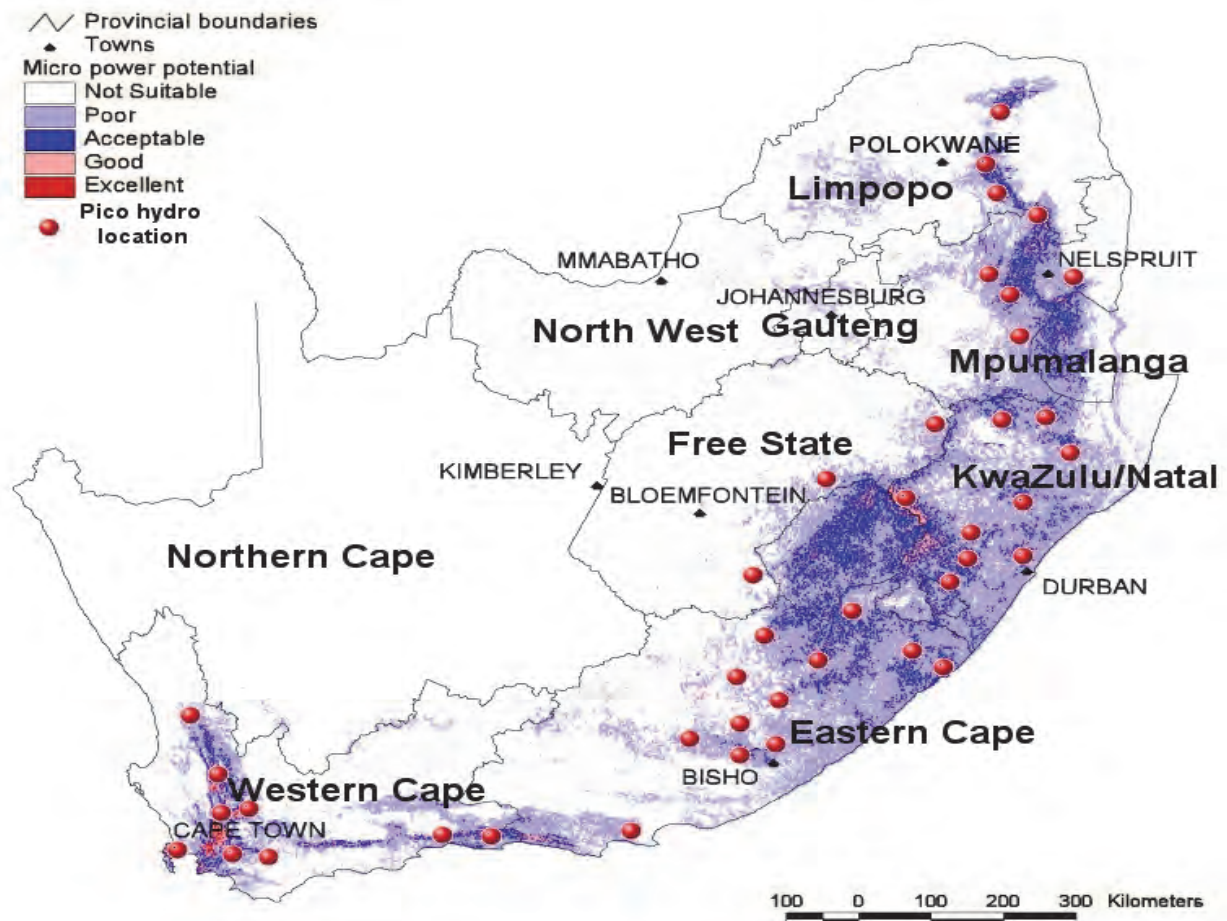


Figure 2-6: Yester-year distribution of small scale hydropower in South Africa (Barta, 2002)

There are still a few surviving yester-year small scale plants situated around South Africa either as out-of-operation plants at Mkhondo (Piet Retief) and Ceres municipalities or fully operational plants at Mashishing (Lydenburg Hydro) and Nelspruit (Friedenheim Hydro) municipalities. Several operational pico and micro hydropower installations (i.e. between say 2 kW and 30 kW) are situated mainly in the mountainous areas of the KwaZulu and Eastern Cape provinces electrifying primarily the farm establishments and old missionary mills. Most recently built new small scale hydropower installation, supplying the Sol Platje Municipality in the Free State province, is situated on the Ash River carrying flows of the LHWP into the Vaal Dam near Johannesburg.



2.1.3.4 Large hydropower (>10 MW) and pumped storages

The large hydropower development has also its history in South Africa and manifested over the years in installation of several significant hydroelectric plants developed together with the large dams. Two most significant large hydroelectric installations Gariep (360 MW) and Vanderkloof (240 MW) are situated on the Orange River in the Northern Cape Province. The smaller existing operational plants are all situated in the Eastern Cape Province namely the Mbashe (42 MW), First and Second Fall (6.4 and 11 MW) and Ncora (2.4 MW).

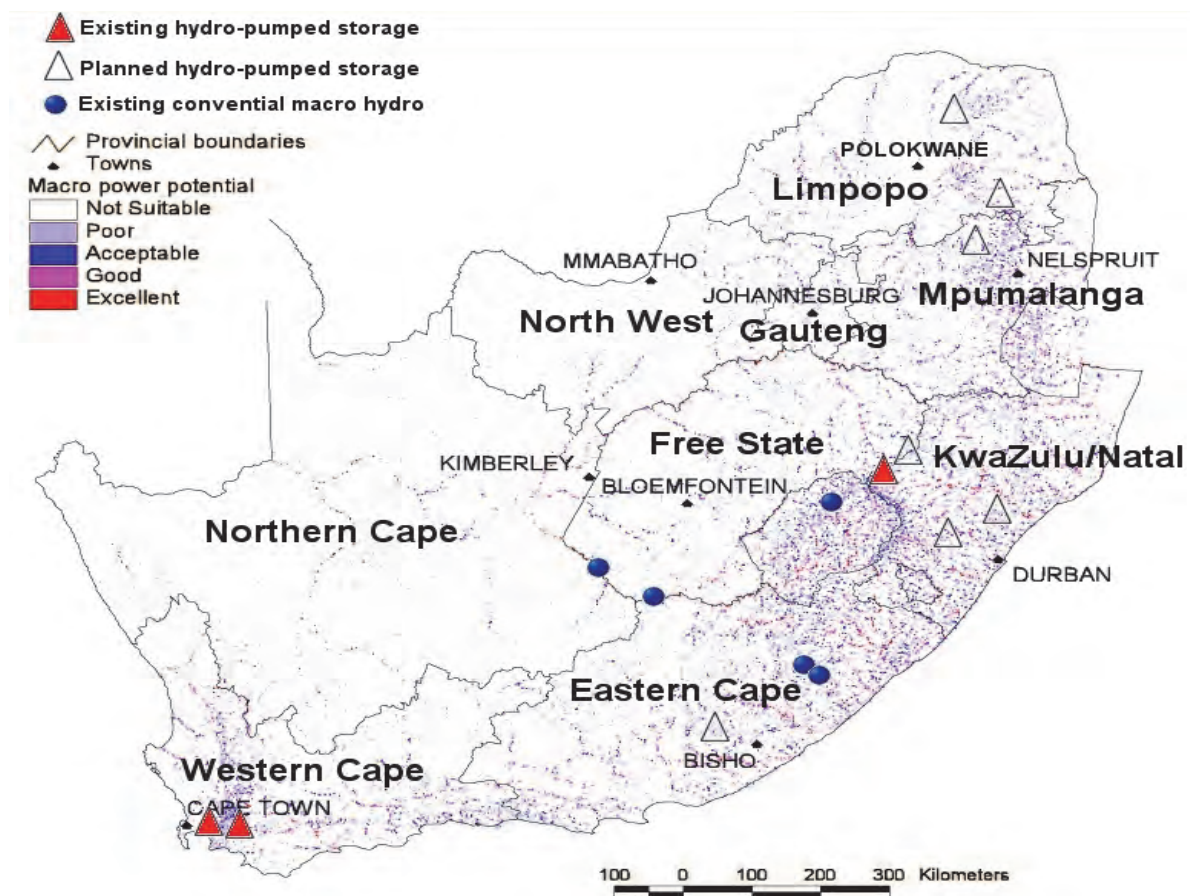


Figure 2-7: Distribution of large scale hydropower and pumped storages in SA (Barta, 2002)

The most peaking requirements of the electricity supply grid in South Africa are satisfied by the pumped storage hydropower installations. It takes typically 2 seconds of starting time and some 15 seconds to get a hydro-plant in a full load production. A pumped storage hydro plant consists of upper and lower dam storage reservoirs and water is pumped between lower and upper storages when the electricity is in a low demand, mostly during the night. The upper storage reservoir serves as ideal hydraulic energy storage (battery). There are at present 3 pumped storage hydro schemes in South Africa namely Steenbras PS (180 MW), Drakensberg PS (1000 MW) and Palmiet PS (400 MW).



The national electricity utility ESKOM is presently building Ingula PS scheme (four 333 MW pump turbines). The Tubatse 1500 MW pumped storage project is being planned for the Limpopo Province near Steelpoort. Another 5 suitable sites for PSs installations were found around South Africa.

2.1.3.5 Evaluation of hydropower potential in South Africa

Prior to the White Paper on Renewable Energy (November 2003) the first and most comprehensive evaluation on the overall potential of hydropower development in South Africa has been presented in the Baseline Study – Hydropower (September 2002) compiled for the national Department of Energy by the private sector consultants. The investigation focused in a fairly detailed way on the hydropower potential, challenges faced and evaluated the feasible opportunities in refurbishing and developing particularly the small scale (< 10 MW) installations within the borders of South Africa, Lesotho and Swaziland. The Baseline Study- Hydropower has been updated several times since 2002 with the last update (March 2010) verifying existing hydropower capacity and estimates of exploitable potential within various categories of hydropower feasible to exploit in South Africa.

Table 2-1: Evaluation of hydropower potential in South Africa

Hydropower size	Hydropower type	Installed capacity (MW)	Estimated potential (MW)
Macro (larger than 10 MW)	(i) Imported hydro	800	36 400
	(ii) Pumped storages	1 580	10 200
	(iii) Diversion fed hydro	-	5 200
	(iv) Dam storage regulated head	662	1 520
	(v) Run-of-river	-	270
Small hydro (1 MW to 10 MW)	As above (iv) and (v)	26	47
	Water Transfers Schemes	0.6	38
	Refurbishments of existing plants	8	16
Mini (100 kW to 1 MW)	As above (iv) and (v)	2.8	58
	Low-head at irrigation canals	0.1	60
Micro (< 100 kW)	As above (v) and waterwheels	0.6	8
Pico (up to 20 kW)	Most gravity water pipe systems	0.2	20
Subtotal for all types		3 080.3	53 837
Excl. imported hydro and including pumped storages		2 280.3	17 437
Total “green” hydro capacity (excl. imported hydro and pumped storages)			7 237

The Baseline Study acknowledged that South Africa is not particularly endowed with the best hydropower conditions as elsewhere on the continent of Africa.



However, this study highlighted that in South Africa there is next to some 5 000 MW of the “greenfield” hydropower also a significant hydropower potential dormant within particularly the water supply and distribution systems. The water infrastructure assets which allow for daily water transport (e.g. tunnels, pipelines, canals, etc.) or environmental water releases (e.g. from the large and medium dams) were identified as potential sources for the small scale hydroelectricity generation in now-a-day South Africa. The water management spheres where to look in South Africa for the hydropower potential.

Refurbishment/upgrading of existing installations mainly in ownership of various municipalities and the DWA (at least 70 GWh/annum).

- 🔧 Water Transfer Schemes (WTS) at the gravity flow components (at least 300 GWh/annum).
- 🔧 Adding hydropower sets to existing (new) dams, some 300 large to medium dams are suitable (at least 500 GWh/annum).
- 🔧 Municipal/water utility bulk supply and distribution networks (between 200 and 500 GWh/a)

2.1.3.6 Potential hydropower sites besides those already considered by other developers

The overall and specific evaluation of feasible hydropower development available within SA has been going on since 2002 as per the DME’s Base-line Study: Hydropower in South Africa (DME, 2002). Numerous potential sites are being investigated for a number of years by the private developers aspiring for the status of the IPPs. The details on the sites under investigation are not available due to commercial security reasons. The DoE and NERSA haven’t released the list of the REIPPPP hydropower submissions (an estimate is that of allocated 75 MW about 50% has been contested). Taking into consideration current circumstances it may be beneficial to focus on the sites as listed in **Table 2-2**.

Table 2-2: Potential hydropower sites

Hydropower site	Capacity (MW)	Type of development	Asset ownership	Estimated cost (R million)	Estimate of initial costs (R million)
A	4	Refurbishment	State	45	0.8
B	2	Conventional	State	30	2.0
C	1.5	Dam regulated	State	22	0.5
D	10	Run-of-river	District LA	250	12.0
E	5	Run-of-river	District LA	50	6.0
Notes: (i) The name and location details will be released after relevant choices are made. (ii) All above listed projects will all qualify for REIPPPP but PPA may be agreed on with the local communities and hydro energy sold privately providing that all relevant permits are obtained.					



2.2 Key advantages of hydropower

Hydropower has the following advantages over other forms of energy production in terms of economics, 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 et al., 2002).

Secondly, hydropower schemes often have very **long lifetimes and high efficiency** levels. Operation costs per annum can be as low as 1% of the initial investment costs (Oud, 2002).

A third 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 et al., 2002). Different forms of hydropower including reservoir, pumped storage and run-of-river systems of different sizes are available and can be used for different forms of electricity generation (IHA, 2005).

2.3 Hydropower concepts and systems

The basic concept of hydropower is that hydro turbines convert water pressure into mechanical shaft rotation which is then used to power an electric generator or some other form of electricity generating machinery. The basic mathematical relationship is that the potential power output is directly proportional to the flow through the turbine and the available pressure head. This can be stated as follows:

$$P = \eta \rho g Q H \quad \dots(2.1)$$

Where:

P	=	Mechanical power output (W)
η	=	Hydraulic efficiency of the turbine (%)
ρ	=	Density of water (kg/m ³)
g	=	Gravitational acceleration (9.81 m/s ²)
Q	=	Flow rate through the turbine (m ³ /s)
H	=	Effective pressure head across the turbine (m)

Electric power plant efficiency is defined as the ratio between the useful electricity output from the generating unit, in a specific time, and the energy value of the energy source supplied to the unit in the same time period. For electricity generation based on steam turbines 65% of all prime energy is wasted as heat.



The efficiency falls still further if fuels with lower energy content such as biomass are used to supply the plant. **Figure 2-8** shows the theoretical efficiency of converting various energy sources by a variety of methods into useful electrical energy and as is clear hydro has a high efficiency.

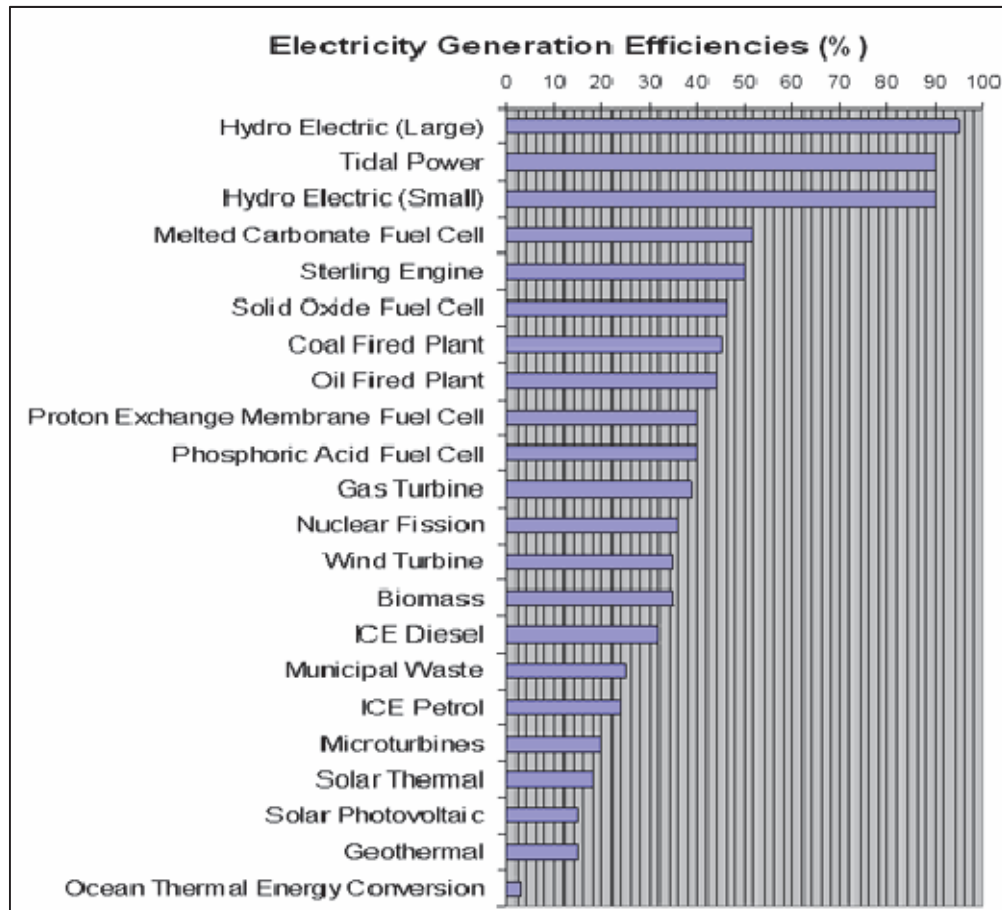


Figure 2-8: Theoretical efficiency of various energy sources (Eurelectric, 2013)

2.3.1 Definition of hydropower categories

The following section will provide background information on various conventional and unconventional types of hydropower options. 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).

2.3.1.1 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 (NRC, 2004). The following types of conventional hydropower schemes are discussed below:



 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).

 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).

 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).



2.3.1.2 Unconventional types of hydropower

High head hydropower

According to Van Dijk et al. (2012a), there are a number of areas with energy-generation potential in the water-supply and -distribution systems, as shown in **Figure 2-10** and listed below:

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

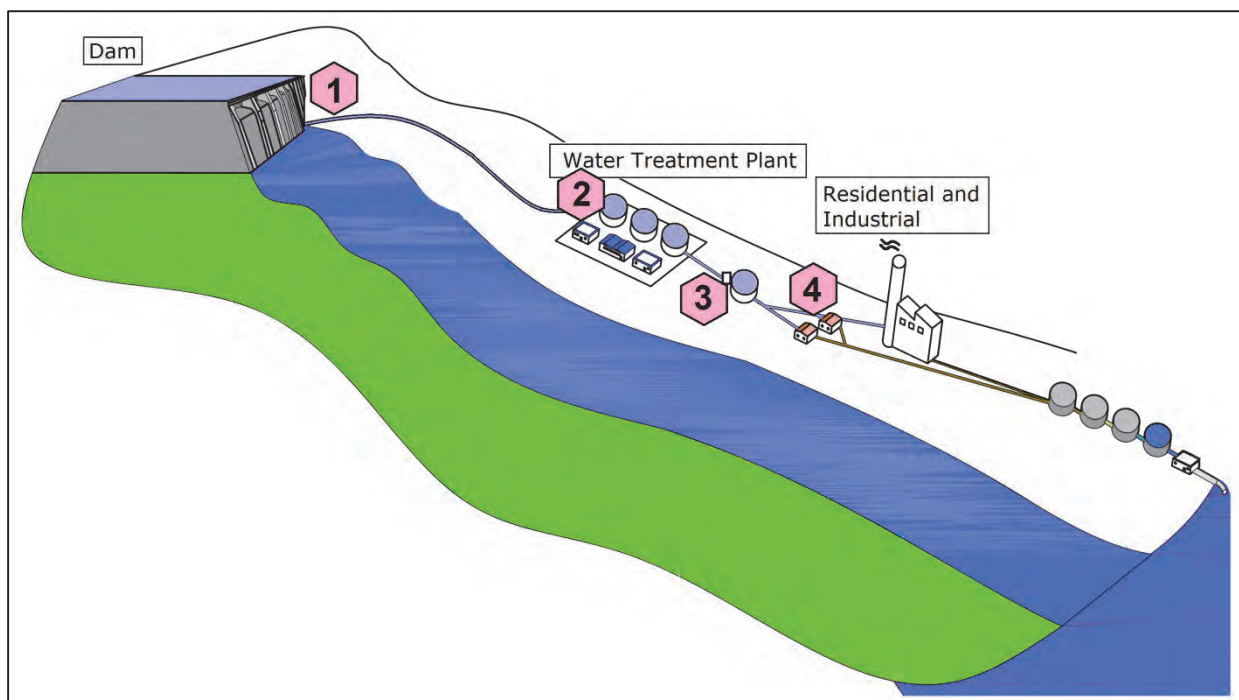


Figure 2-9: Potential energy-generation locations in WDS (Van Dijk et al., 2012a)

Low head hydropower

There are generally eight areas with low head energy-generation potential. These are shown in **Figure 2-10** 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



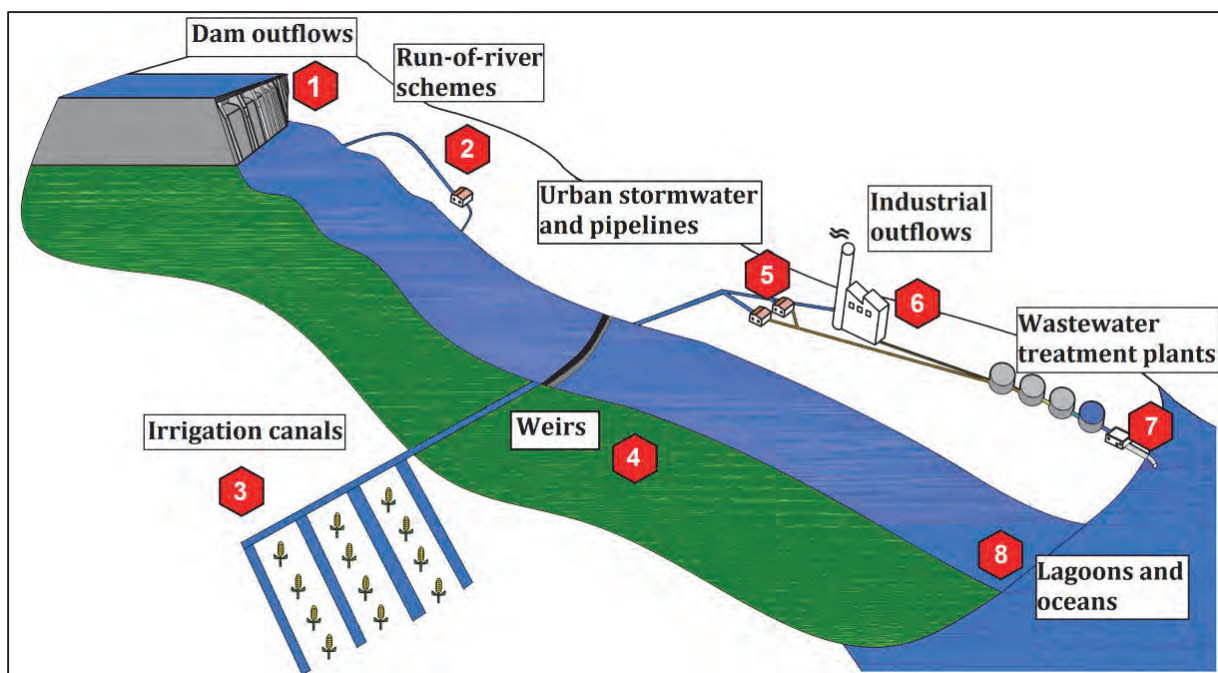


Figure 2-10: Potential low head energy-generation locations

2.4 Site selection and determining of hydropower potential

Hydropower works on the principle that water pressure is used to rotate a mechanical shaft in the hydro turbine. This rotation is used to power a generator that converts the energy into electricity. The potential power output of a hydropower installation is directly proportional to the flow (m^3/s) and available pressure head (m), as illustrated in **Equation 2.1** (BHA, 2005).

The critical parameters to obtain are the available pressure head and the flow rate.

2.4.1 Flow and pressure measurement

A measuring weir is typically used for river flow measurement and the available head determined using the height difference between upstream and downstream water surfaces (BHA, 2005). However, as the focus of this study is on conduit hydropower, flow and pressure measurement in pipes will be discussed in detail.

Flow in pipes can be measured using various types of meters. **Table 2-3** was adapted from Down (2002) and provides a summary of some typical flow meters and their applications. **Table 2-4** provides a comparison between the usefulness of the various flow meters in different circumstances (Down, 2002).



Table 2-3: Typical flow meters (Adapted from Down, 2002)

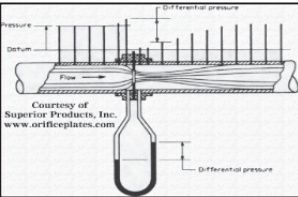
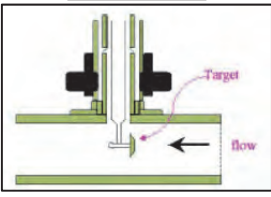
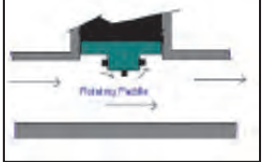
Flow-meter type	Description	Figures	Discussion
Differential flow meter	Based on differential pressure as a liquid passes through a flow restriction in the pipe. Orifice plates and venturis are typical examples.	 	Differential flow meters are seen as reliable instruments, but they have the disadvantage of restricting flow. Maintenance is necessary once or twice yearly to ensure that the opening has not become rougher or larger.
Target flow meter	These instruments have an object, or 'target' centred in the conduit that measures flow rate by the force imposed on the target.	 	This type of flow meter also causes a flow restriction, but less so than an orifice plate or venturi.
Propeller flow meter	Flow meters with axial vanes that spin at a rate correlating to flow rate can also be used.	 	These meters cannot be used in conduits with impurities or solids, as damage to the propeller must be avoided. However, in clean water they are very reliable and accurate if placed in a straight section.



Table 2-3: Typical flow meters (Adapted from Down, 2002) (continued)

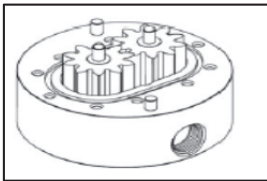
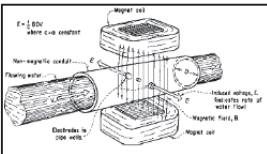
Flow-meter type	Description	Figures	Discussion
Volumetric flow meter	Volumetric meters measure flow by counting the filling and discharging of fixed volumes of liquid.	 	These meters are typically used for small quantities. As with other intrusive meters, erosion will occur with time.
Magnetic flow meters	Flow velocity is determined by a magnetic field.	 	These meters have to be used with conductive fluids and an electrically insulated pipe. This meter is not intrusive and therefore does not constrict flow.
Ultrasonic flow meters	This meter is clamped onto a pipe and emits an ultrasonic signal that is echoed from a particle in the water. The transit time is used to determine flow velocity.		These meters are lightweight and can be clamped to any pipe and removed again easily. This meter is not intrusive and therefore does not constrict flow.

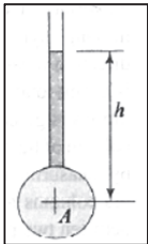
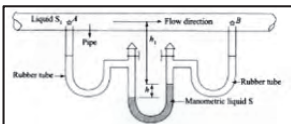
Table 2-4: Flow-meter selection (Down, 2002)

Flow-meter type	High viscosity	Particulate	Turbulence	Large flow turn-down
Differential	Poor	Poor-fair	Poor	Poor
Propeller	Poor	Poor	Fair	Very good
Volumetric	Very good	Fair	Good	Very good
Magnetic	Very good	Very good	Very good	Good
Ultrasonic	Very good	Very good	Very good	Fair



Pressure can be measured with a number of different instruments (**Table 2-5**). Bourdon and diaphragm transducers can be set to read gauge or absolute pressures and can be used with dial gauges or electronic logging systems (Gems Sensors and Controls, 2013).

Table 2-5: Typical pressure transducers (Ojha et al., 2010; Gems Sensors and Controls, 2013)

Pressure transducer type	Description	Figures	Discussion
Piezometer	This is one of the simplest forms of pressure measurement and consists of a glass tube inserted in the wall of a pipe and its other end is open to the atmosphere.		There are various limitations to this device, including the impracticality of reading very high pressure (due to the long tube necessary) or negative pressure (unless altered).
Manometer	These instruments use liquid columns for measuring pressure at a point, or differential pressure between two points or systems.		These devices can measure rapid pressure changes, large pressures and negative pressure.
Bourdon gauge	This type of gauge uses a hollow tube that changes its curvature as the liquid pressure changes. This in turn rotates the gauge dial.		These devices are commonly used, as they can measure positive and negative pressures accurately.
Diaphragm gauge	This type of gauge uses a diaphragm that deforms as pressure changes. This is transmitted to a pointer that records the pressure.		These devices are commonly used, as they can measure positive and negative pressures accurately.



2.4.2 Flow-duration curves

In order to determine the design flow rate to be used in the power equation, flow-duration curves have to be drawn. These curves indicate the probability of the amount of days per annum that a certain flow will be exceeded. Below are two typical examples of flow-duration curves. **Figure 2-11** shows a stream with a short seasonal variation between the base flow and maximum flow and **Figure 2-12** shows a river with more variation in flow during the year (NRC, 2004; BHA, 2005).

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

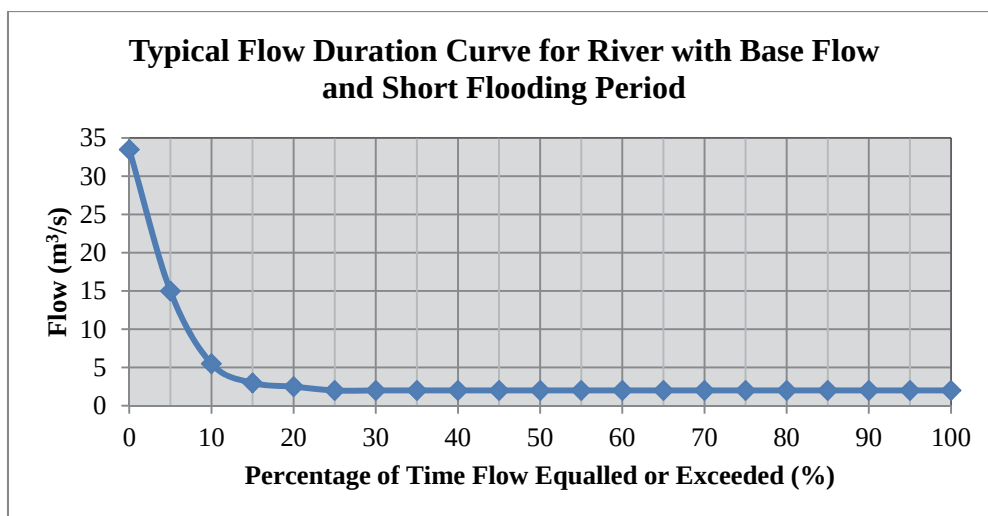


Figure 2-11: Flow-duration curve for river with base flow and short flooding period (NRC, 2004)

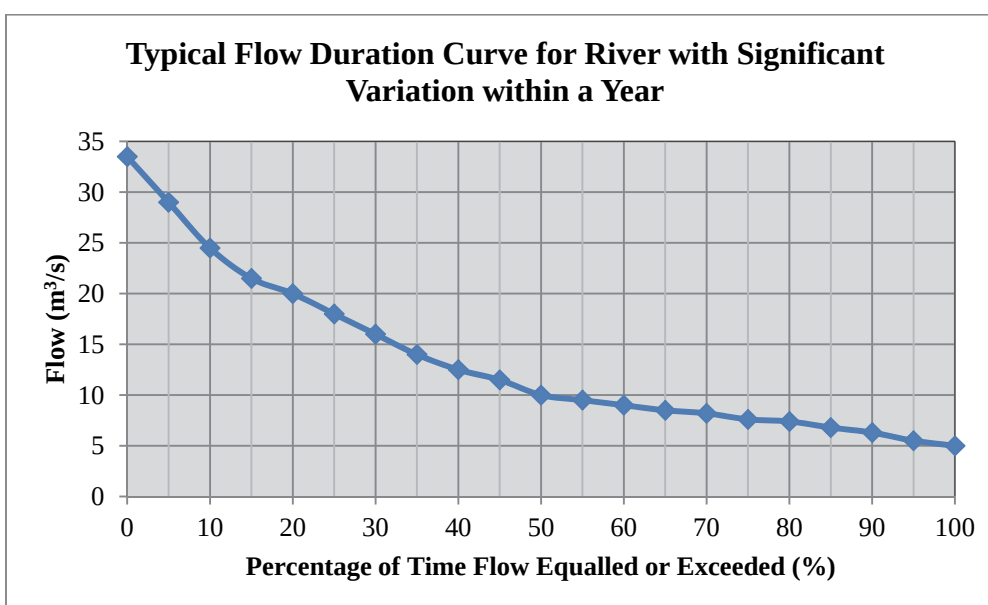


Figure 2-12: Flow-duration curve for low flow variation (NRC, 2004)



2.4.3 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 2.2**:

$$\eta = \frac{P_{\text{actual}}}{P_{\text{theoretical}}} \quad \dots(2.2)$$

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:

$$P = IV \quad \dots(2.3)$$

where:

P = electrical power output (W)

I = electrical current (A)

V = potential difference (V)

Harvey et al. (1993) proposes the following losses as typical system losses for a scheme operating at design flow (**Figure 2-13**).

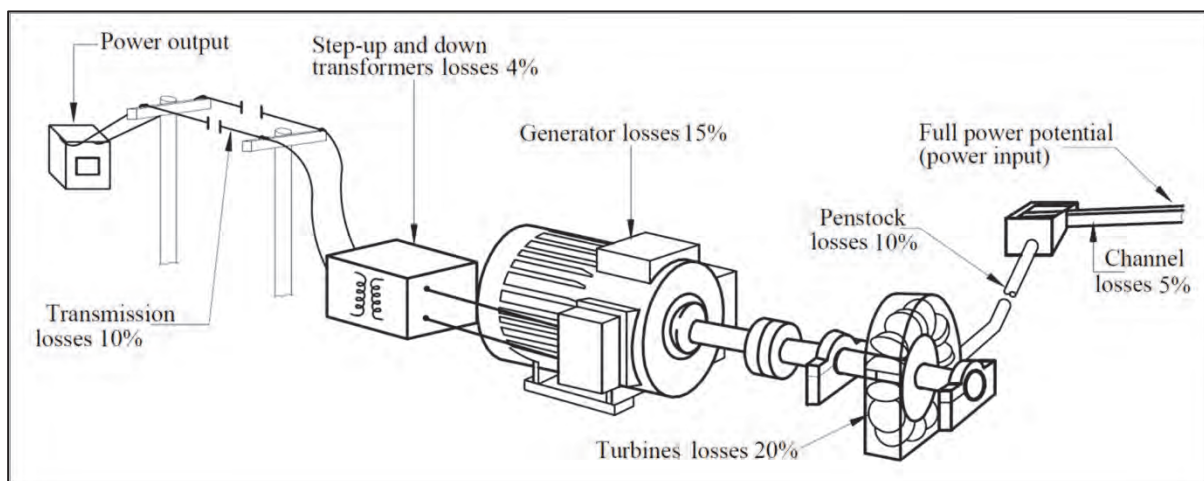


Figure 2-13: System losses (Harvey et al., 1993)



However, Natural Resources Canada (NRC, 2004) proposes better efficiency ranges for turbines see (**Table 2-6**) and ESHA (2004) proposes better efficiencies for small generators (**Table 2-7**). The British Hydropower Association (BHA, 2005) states that micro-hydro system efficiency tends to be between 60% and 80%, with 70% considered a typical efficiency.

Table 2-6: Typical efficiency of turbines and water wheels (NRC, 2004)

Prime mover	Turbine	Efficiency range
Impulse	Pelton	80-90%
	Turgo	80-95%
	Cross-flow	65-85%
Reaction	Francis	80-90%
	Pump-as-turbine	60-90%
	Propeller	80-95%
	Kaplan	80-90%

Table 2-7: Typical efficiencies of small generators (ESHA, 2004)

Rated power (kW)	Best efficiency (%)
10	91
50	94
100	95
250	95.5
500	96
1 000	97

2.5 Feasibility aspects of hydropower projects

2.5.1 Economic feasibility

The economics of a small hydro development are crucial in determining overall project feasibility. In some ways, the technical feasibility of a project is more readily established than the financial viability. To say that a project is feasible because a turbine can be installed in a bulk supply line to generate electricity, begs the question of whether it would make any sense to do so. The economic analysis is designed to answer this question and the financing plan is necessary to establish whether, or how, it can be done. This is described in detail in **Chapter 5**.



2.5.2 Environmental aspects

Every construction project that takes place in South Africa is subject to environmental regulations under the National Environmental Management Act of 1998. According to the act, plans for the construction of facilities or infrastructure for the generation of electricity which have a capacity of 20 MW or more or cover an area greater than one hectare, require the completion of an Environmental Impact Assessment (EIA) and are subject to regulations under the environmental authority of the province. If, however, the plant does not exceed the aforementioned limitations, only a Basic Assessment Report (BAR) is required. This is described in detail in **Chapter 4**.

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

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

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

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

2.5.3 Social aspects

As part of the environmental assessment phase, the interested and affected parties are identified and provided with opportunities to voice their concerns and objections with regard to the proposed project.

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

2.6 Turbines

Water turbines may depend on the impulse of the working fluid on the turbine blades or the reaction between the working fluid and the blades to turn the turbine shaft which in turn drives the generator. Several different types of turbines have been developed to optimise performance for particular water supply conditions.

In general, the turbine converts the kinetic energy of the working fluid, in this case water, into rotational motion of the turbine shaft. The Swiss mathematician Leonhard Euler showed in 1754 that the torque on the shaft is equal to the change in angular momentum of the water flow as it is deflected by the turbine blades and the power generated is equal to the torque on the shaft multiplied by the rotational speed of the shaft as shown in **Figure 2-14**.

Note that this result does not depend on the turbine configuration or what happens inside the turbine. All that matters is the change in angular momentum of the fluid between the turbine's input and output. Turbines convert the energy from falling water into rotational shaft power. They can be classified according to their type of action as either impulse or reaction turbines.

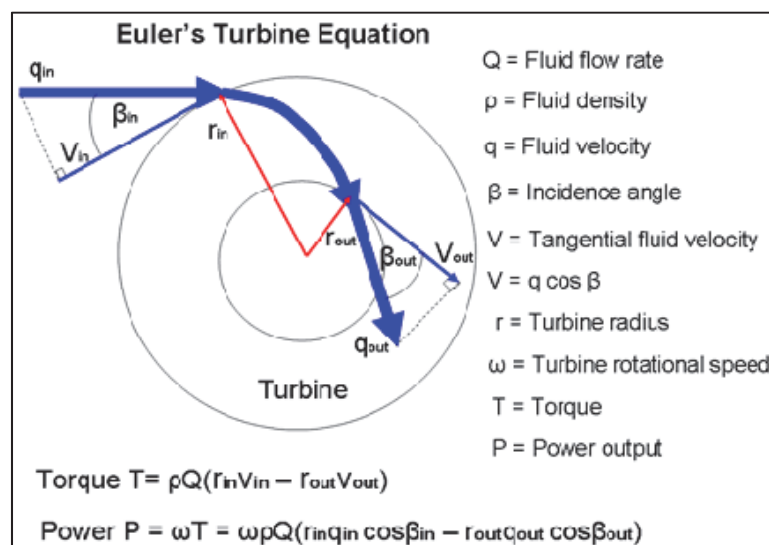


Figure 2-14: Euler's turbine equation (Electropaedia, 2013)



Impulse turbines make use of runners which operate in air by the action of a jet of water at a high velocity. There are three principal types including the Pelton, Turgo and Crossflow or Banki turbines. Pelton turbines are used only in high head applications, with ranges of above 50 m to almost 1 300 m, and usually have very good efficiencies (ESHA, 2004). Turgo turbines can operate using smaller diameter runners to obtain the same power output as a Pelton turbine (Paish, 2002). They operate at heads of between 50 and 250m and can operate at flows of 20 to 100% of the design flow which gives them a high degree of flexibility. The third type (Crossflow or Banki-Michell), are applicable over a wide range of heads (5 to 200 m) but have a lower efficiency than other turbines (ESHA, 2004).

Reaction turbines generate upward hydrodynamic forces to turn the runner blades by utilising oncoming flow. The most notable types are the Propeller or Kaplan and the Francis turbine (Paish, 2002). Kaplan turbines are used in low head applications of 2 to 40 m and are usually large as they are required to handle large flows in order to make such low head projects viable. Francis turbines are used in medium head situations of 25 to 350 m.

Turbine design is carried out by the manufacturer and does not fall within the engineer's scope of work on a hydropower project. This design includes sizing, layout of the turbine housing and, in the case of compact hydro, design of the electrical component. The 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. A summary of the applicability of each type of turbine is given in **Table 2-8**.

Table 2-8: Operational ranges of different turbines (ESHA, 2004)

Type of turbine	Head range (m)	Acceptance of flow variation	Acceptance of head variation	Maximum efficiency (%)
Kaplan/Propeller	2 - 40	High	Low	91 - 93
Francis	25 - 350	Medium	Low	94
Pelton	50 - 1 300	High	High	90
Crossflow	2 - 200	High	Medium	86
Turgo	50 - 250	Low	Low	85

In determining what turbine to use the prevailing flow and pressure conditions need to be determined. Different turbine types have different performance characteristics and each have their own advantages and disadvantages of use.



The variation in future predicted flow rate also affects the choice of turbine as it may be detrimental to turbine efficiency. The graph in **Figure 2-15** depicts the efficiencies of the most common turbine types. Certain turbines will have a high efficiency at a specific given design flow, but this will drop dramatically if lower flow rates are experienced. Other turbines, especially the crossflow and pelton turbines will maintain a good efficiency even at very low flow rates.

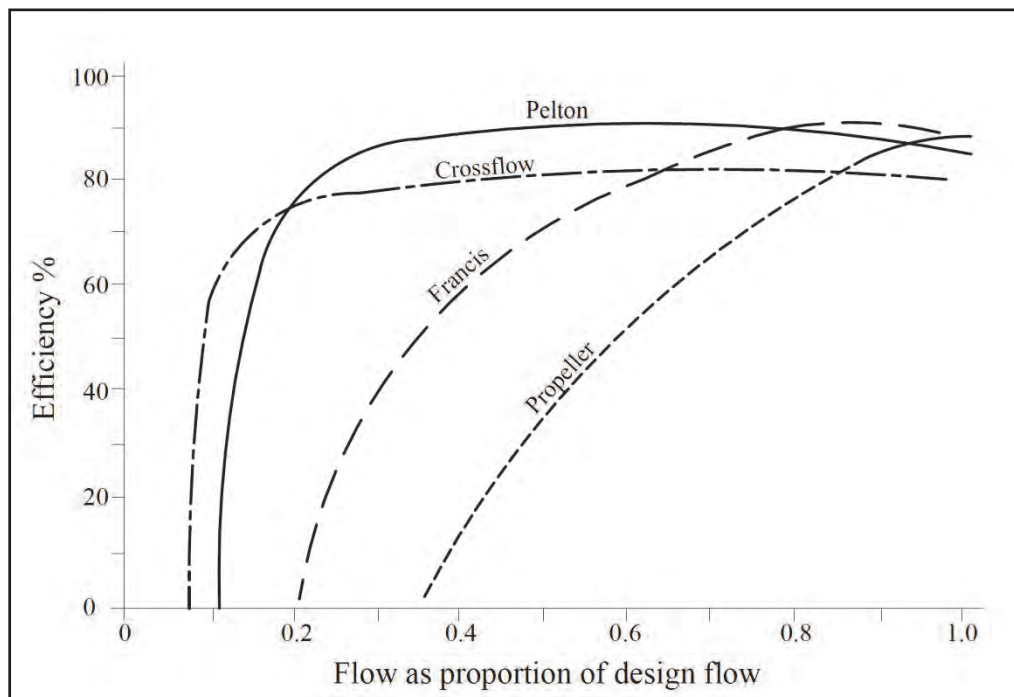


Figure 2-15: Part-flow efficiencies of different turbines (Paish, 2002)

2.6.1.1 Cross flow turbine

Razak et al (2010) concluded that cross-flow turbines are most preferable when there is large variation of flow rate due to cyclical change. As shown in **Figure 2-15** the efficiency of a crossflow turbine does not drop much when flow rates change. **Figure 2-16** shows that a crossflow turbine has a drum-like rotor with a solid disk at each end and gutter-shaped slats joining the two disks. A jet of water enters the top of the rotor through the curved blades, emerging on the far side of the rotor by passing through the blades a second time. The water is allowed to transfer some of its momentum on each passage through the rotor due to the shape of the blades, after which, now having little residual energy it falls away (Paish, 2002). Thornbloom et al (1997), considers 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.”



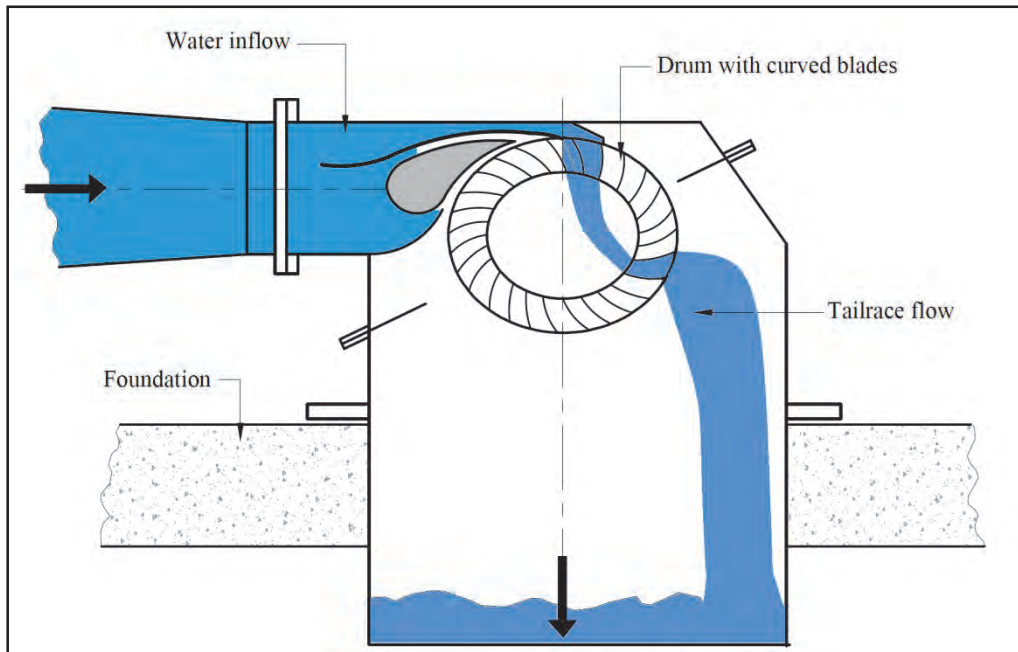


Figure 2-16: Side view of a crossflow turbine (Paish, 2002)

2.6.1.2 Pelton turbine

Figure 2-15 also shows that a pelton turbine performs relatively well at flow rates well below design flow. A typical single jet pelton wheel can be seen in **Figure 2-17**. In a pelton turbine one or more jets of water are directed tangentially onto a set of split curved buckets, connected to a wheel along its rim. The jet stream is directed inwardly, sideways and outwardly by the curved buckets, producing a force on the buckets that cause the wheel to turn resulting in a torque on its shaft (Paish, 2002). All of the head in the water flow is converted to kinetic energy at the nozzle. This kinetic energy then all goes into propelling the bucket. The deflected water then falls off into a discharge collector channel or weir. The water at the tailrace has no further energy to give and exit velocities are a minimum. The pelton wheel is a low specific speed device. The specific speed can be increased by adding additional nozzles (Gulliver & Arndt, 1991).



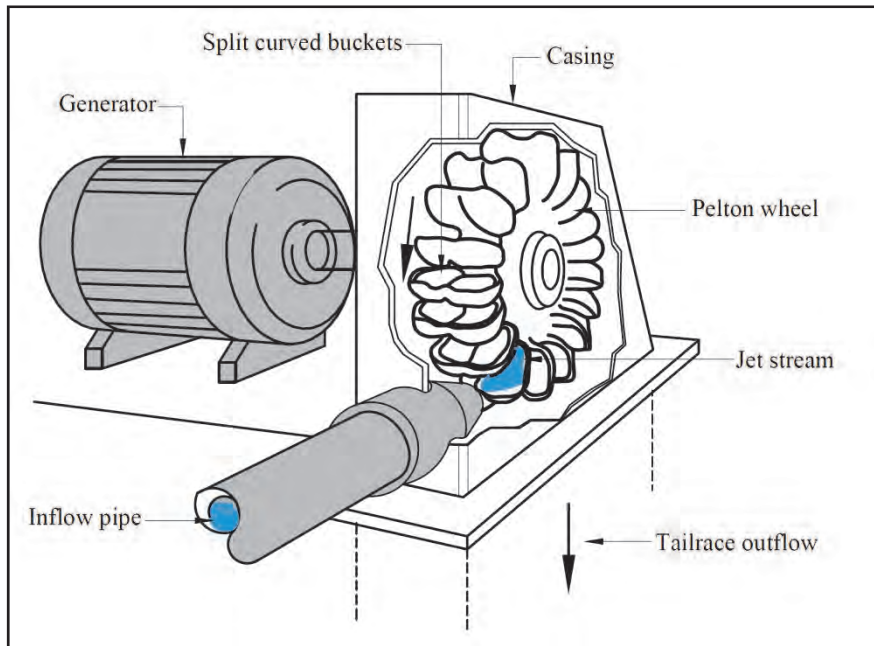


Figure 2-17: Pelton wheel turbine (Paish, 2002)

2.6.1.3 Turgo turbine

A turgo wheel functions very similar to a pelton wheel. The only difference is that in the turgo wheel the jet stream is directed obliquely onto the buckets and impinges several buckets instantaneously (Gulliver & Arndt, 1991). A typical turgo wheel turbine is depicted in **Figure 2-18**.

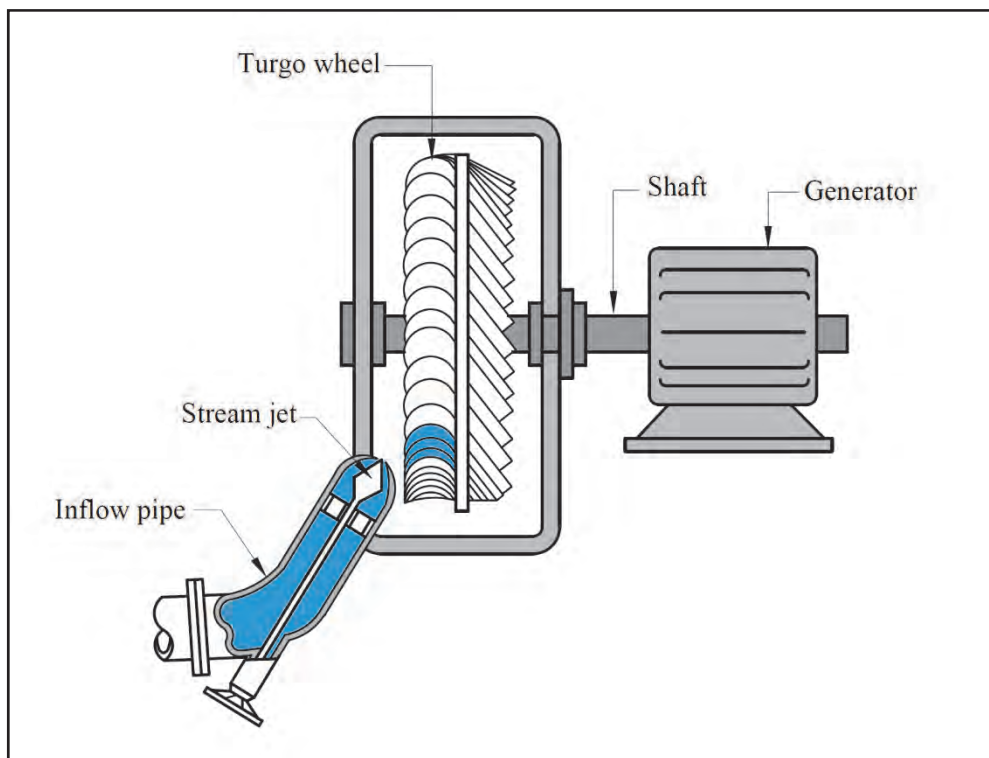


Figure 2-18: Turgo wheel turbine (Paish, 2002)



Paish (2002), highlighted that crossflow and pelton turbines are better suited for micro-hydro or smaller set-ups. Typically they function at high heads with low flow rates. These turbines have the following advantages:

- ☒ More tolerant of sand and other particles;
- ☒ Better access to working parts;
- ☒ No pressure seals or glands around the shaft;
- ☒ Easier to fabricate and maintain;
- ☒ Better part-flow efficiency.

Low specific speeds at low pressure heads make impulse turbines unsuitable for low pressure head circumstances.

2.6.1.4 Kaplan and propeller turbines

Kaplan and propeller type turbines are reaction turbines that operate on the axial-flow of water. They make use of the oncoming flow of water by developing hydrodynamic forces that propel the runner blades (Paish, 2002). The runner functions in a completely water-filled casing. To achieve good efficiency the water needs to be given a certain amount of swirl before meeting the turbine runner. Inlet swirl can be created by adding fixed guide vanes upstream of the runner. A Kaplan turbine has the advantage of adjustable blades. **Figure 2-19** shows the typical set-up of an axial-flow turbine.

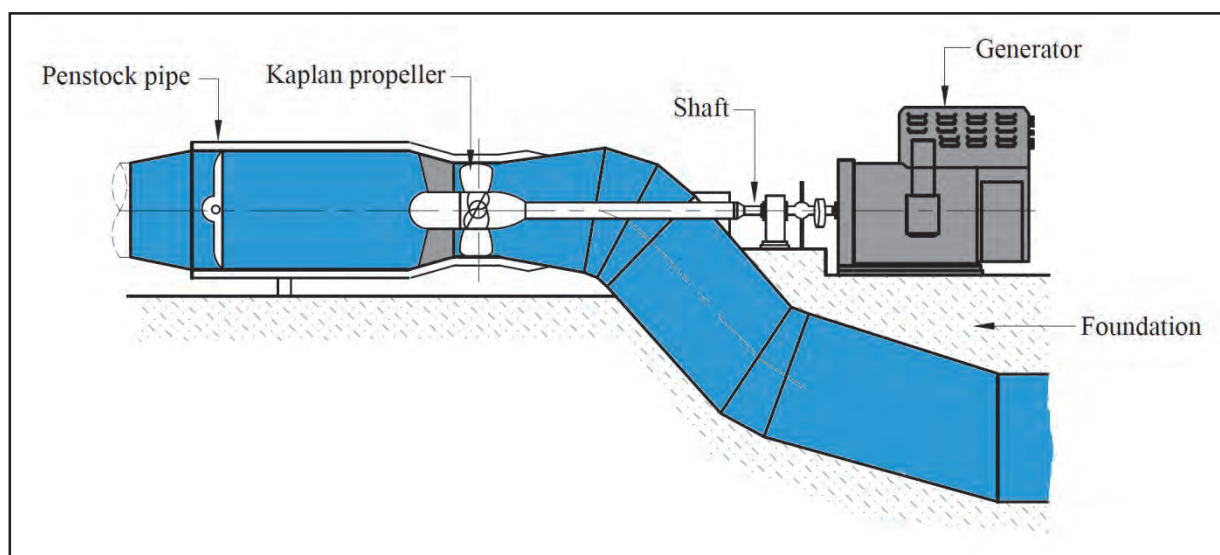


Figure 2-19: Axial-flow turbine fully embedded in water flow (Paish, 2002)



2.6.1.5 Francis turbine

Francis turbines are classified as radial or mixed-flow type. In radial or mixed-flow runners, the flow of water exits at a different radius than the radius at the inlet. If flow enters the runner with only radial and tangential components then it is a radial-flow device. In mixed-flow devices the flow enters with both radial and axial components. In a Francis turbine water flows radially inwards into the turbine runner and is turned to emerge axially as shown in **Figure 2-20**.

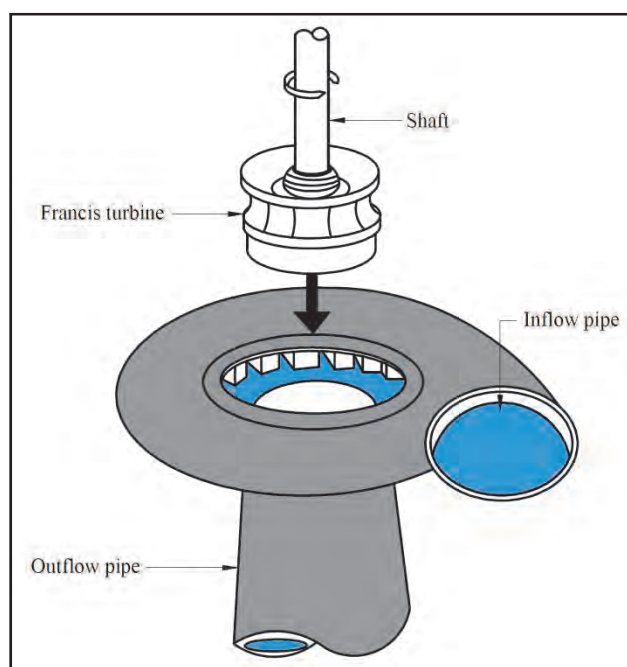


Figure 2-20: Mixed-flow Francis turbine in casing (Paish, 2002)

The most important advantage of reaction turbines is that they are able to harness extremely large flow rates. Reaction turbines are not ideal for pico or micro hydropower installations. The efficiency of reaction turbines drops far quicker when flow rates below designed flow rates are experienced. Reaction turbines are far more sophisticated than impulse turbines. Use is made of intricately profiled blades with carefully profiled casings. Reaction turbines are made far less attractive by these fabrication constraints, especially in developing countries, for use in pico and micro-hydro schemes (Paish, 2002).

2.6.1.6 Pump-as-turbine (PAT)

Much research has been done recently on the use of reverse-engineered pumps that can be used as hydraulic turbines. 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).



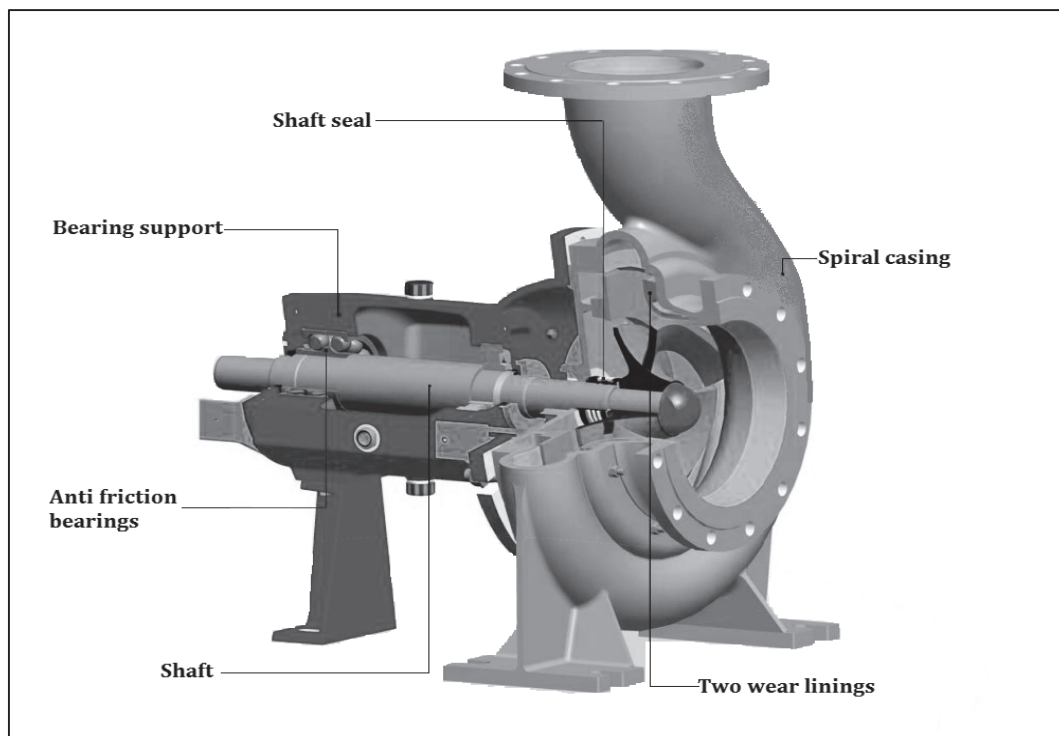
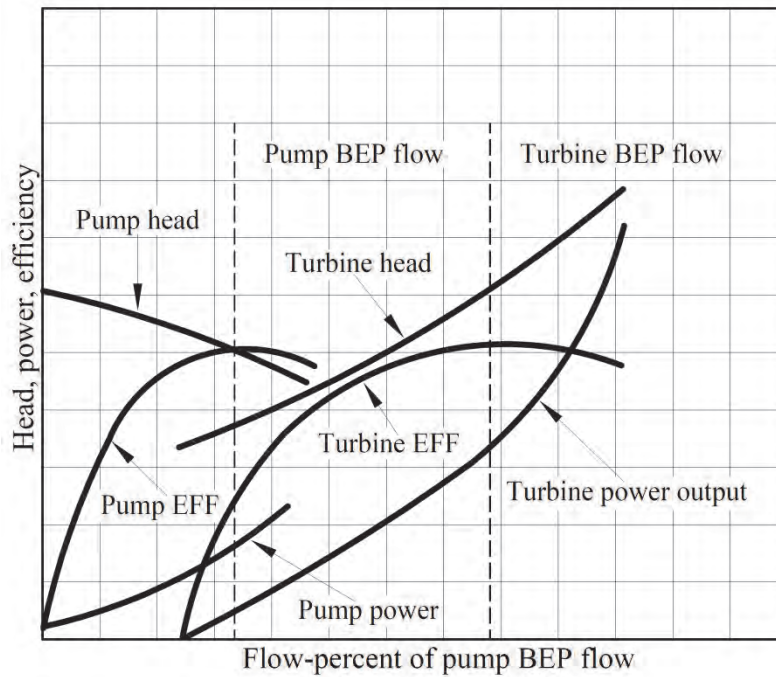


Figure 2-21: Pump-as-Turbine

There are important characteristics of pumps operated as turbines. A comparison of the characteristics of normal pump operation with the characteristics of the same pump operated as a turbine at the same speed is shown in **Figure 2-22**. The curves are normalized by the value of head, flow, efficiency and power at the pump BEP. Note that the location of the turbine BEP is at higher flow and head than the pump BEP. The ratio of the turbine capacity to the pump capacity at the BEP and the turbine head to the pump head at the BEP has been observed to vary with specific speed. Ratios of 1.1 to 2.2 have been determined. Moreover, the turbine maximum efficiencies tend to occur over a wide range of capacity. In other words, the efficiency curve for a turbine is flattish near its maximum. Consequently, relatively wider ranges of turbine operating head can be accommodated without an adverse effect upon efficiency.

However, PATs generally operate at lower efficiencies than conventional turbines, especially at partial flows. PATs can be operated most efficiently at heads of between 13 m and 75 m. 'The higher the head, the less expensive the cost per kilowatt; this is generally the case with all turbines.' (NRC, 2004).





Pump and turbine RPM = constant

Figure 2-22: Normalized performance characteristics for a pump operating in normal pump mode and in turbine mode

2.6.1.7 New technologies

Recently the use of inline turbines has increased. These turbines include spherical and ring turbines (**Figure 2-23**) 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).

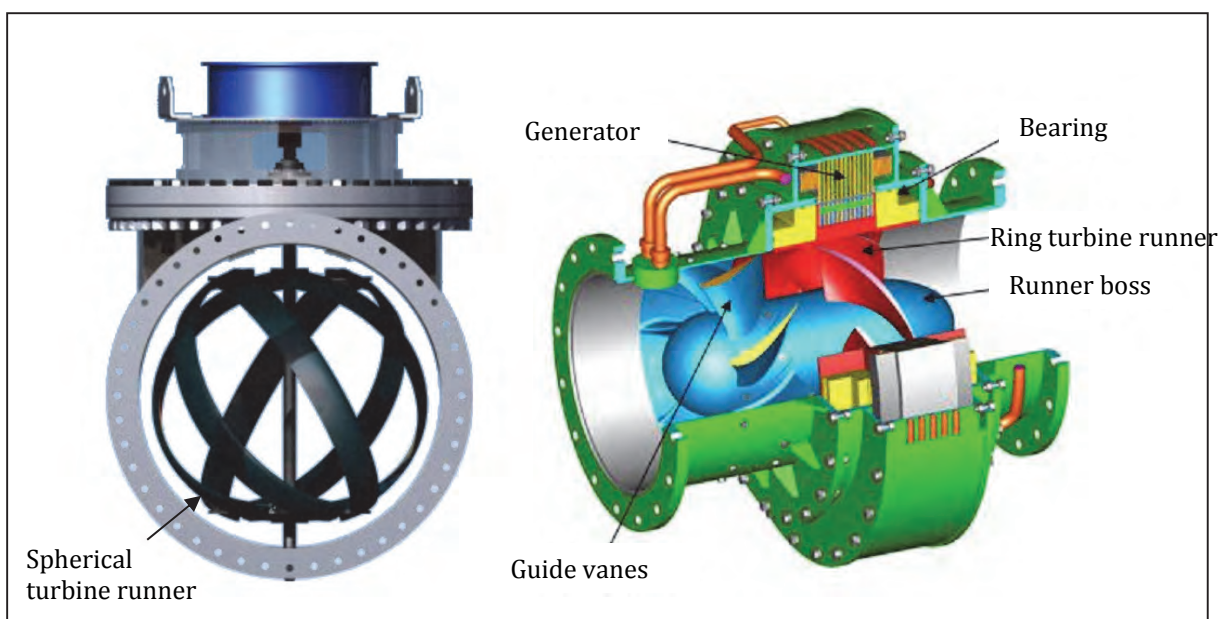


Figure 2-23: Examples of inline turbines (Kanagy, 2011; IEA, 2010)



Northwest PowerPipe

Lucid Energy Technologies, LLP (“Lucid”), in collaboration with Northwest Pipe Company (“NWP”), has developed a unique energy system to generate renewable electricity from large-diameter water and wastewater transmission pipelines Kanagy (2011).

The heart of this system is a spherical turbine designed to extract energy without significantly affecting the flow for water transmission as shown in **Figure 2-23** (Kanagy, 2011). The special turbine converts the excess head and velocity in transmission pipelines into electrical power. It will also include the process of site selection, system design, and integration of this technology, as well as the technical and regulatory challenges associated with the first installations. In 2009 Lucid began testing a NWPP prototype at the Utah Water Research Laboratory. This testing yielded dramatic results and established the system’s viability.

Lucid further developed the system by installing and testing a beta version in the Gage Pipeline in the City of Riverside, California in February 2010. It is a unique hydrokinetic technology specifically designed for deployment inside large diameter (approx. 600 mm and greater) gravity-fed water transmission pipelines. It produces significant energy by harvesting a pipeline’s excess head pressure without disrupting a water agency’s ability to deliver water as shown in the performance table, **Table 2-9**.

Table 2-9: Powerpipe™ performance table (Kanagy, 2011)

Diameter (mm)	Maximum power (kW)	Minimum flow required (m ³ /s)	Minimum flow velocity (m/s)	Pressure loss at maximum power (m)	Pressure loss – turbine stopped (m)
610	16	0.44	1.51	3.5 - 10	0.35
915	35	1.97	3.00	3.5 – 10	0.35
1067	55	2.80	3.13	3.5 – 10	0.35
1219	70	3.50	3.00	3.5 – 10	0.35
1524	105	5.48	3.00	3.5 - 10	0.35

Note: Values are per installed unit and assuming sufficient flow rates

2.7 Electro mechanical equipment

The components that make up the electro-mechanical equipment in a power house includes inlet gate or valve, turbine, speed increaser (if needed), generator, control system, condenser, switchgear, protection systems, DC emergency supply, power and current transformers etc. Turbines have been discussed in detail in the previous paragraph 2.6.



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

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

2.7.1 Generators

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

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

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

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



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

Table 2-10: Typical efficiencies of small generators (ESHA, 2004)

Rated power [kW]	Best efficiency (%)
10	91.0
50	94.0
100	95.0
250	95.5
500	96.0
1000	97.0

Modern generators are normally supplied as a packaged unit, meaning the voltage regulator, voltage adjusting rheostat, field circuit breaker, and instrumentation for volts, hertz and amperes are installed in a box on the back end of the generator as shown in **Figure 2-24**. It is possible to purchase a bare generator with separate voltage regulator and instruments for mounting in a separate switchboard.

This is often done on sizes over about 100 kW. Voltage regulators are obtainable as separate modular units to fit a wide range of generator ratings and types.

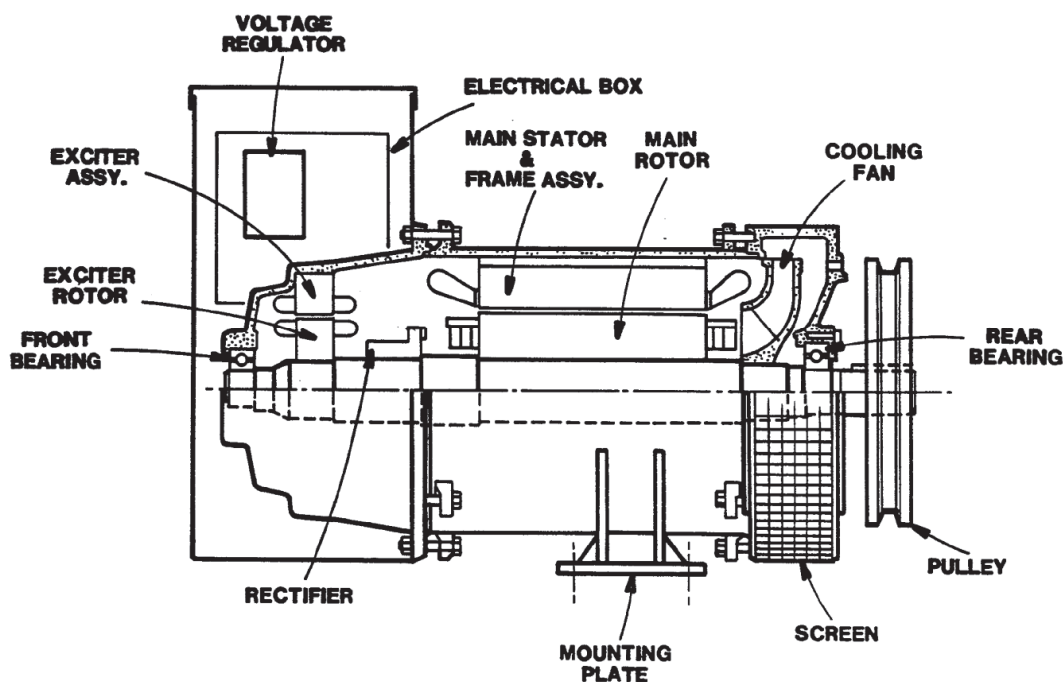


Figure 2-24: Double bearing generator (CETC, 1991)



2.7.2 Principle of Operation

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

2.7.3 Voltage regulation and synchronisation

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

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

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

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

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



2.7.3.1 Electronic voltage regulators

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

2.7.3.2 Electromechanical regulators

In electromechanical regulators, voltage regulation is easily accomplished by coiling the sensing wire to make an electromagnet. The magnetic field produced by the current attracts a moving ferrous core held back under spring tension or gravitational pull. As voltage increases, so does the current, strengthening the magnetic field produced by the coil and pulling the core towards the field. The magnet is physically connected to a mechanical power switch, which opens as the magnet moves into the field. As voltage decreases, so does the current, releasing spring tension or the weight of the core and causing it to retract. This closes the switch and allows the power to flow once more.

The regulators used for DC generators (but not alternators) also disconnect the generator when it was not producing electricity, thereby preventing the battery from discharging back into the generator and attempting to run it as a motor. The rectifier diodes in an alternator automatically perform this function so that a specific relay is not required; this appreciably simplified the regulator design.

More modern designs now use solid state technology (transistors) to perform the same function that the relays perform in electromechanical regulators.

2.7.3.3 Speed

All generators must be driven at constant speed to produce a constant 50 Hz frequency (in South Africa). The speed measured in revolutions per minute (rpm) is determined by the number of poles in the generator. The 2-pole speed of 2900 rpm is too high for practical small hydro use. 1450 rpm is most commonly used, with 760 rpm second.

The cost of generators is more or less inversely proportional to speed: the lower the speed, the larger the frame size must be for equivalent output. For this reason, speeds below 760 rpm become costly, but occasionally circumstances will justify their use. Where low speed low head turbines are involved, gear boxes are often used to raise the speed. There is a trade-off between the speed ratio, cost of the gear box, and cost of the generator.



2.7.4 Turbine controllers

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

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

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

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

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

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



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

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

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

To ensure the control of the turbine speed by regulating the water flow, certain inertia of the rotating components is required. Additional inertia can be provided by a flywheel as shown in **Figure 2-25**, on the turbine, or the generator shaft. When the main switch disconnects the generator, the power excess accelerates the flywheel; later, when the switch reconnects the load, the deceleration of this inertia flywheel supplies additional power that helps to minimise speed variation (ESHA, 2004).

2.7.5 Switchgear equipment

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

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer. The generator breaker is used to connect or disconnect the generator from the power grid. Instrument transformers, both power transformers (PTs) and current transformers (CTs) are used to transform high voltages and currents down to more manageable levels for metering. The generator control equipment is used to control the generator voltage, power factor and circuit breakers.





Figure 2-25: Flywheel (Ceres hydro power plant)

The asynchronous generator protection must include, among other devices: a reverse-power relay giving protection against motoring; differential current relays against internal faults in the generator stator winding; a ground-fault relay providing system backup as well as generator ground-fault protection, etc. The power transformer protection includes an instantaneous over-current relay and a timed over-current relay to protect the main transformer when a fault is detected in the bus system or an internal fault in the main power transformer occurs. Metering equipment must be installed at the point of supply to record measurements according to the requirements of the electric utility.

2.7.6 Controllers and electrical equipment

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

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



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

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

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

2.8 Conduit hydropower potential

2.8.1 Hydropower potential at Pressure-Reducing Valves (PRVs)

Sometimes excess energy is available in pressurised conduits (pumping or gravity), due to demand patterns and certain restrictions in the selection of component sizes in conduits. Pressure-reducing valves (PRVs) are installed to dissipate excess energy at specific points along a conduit, including just upstream of water-treatment plants and reservoirs (ESHA, 2004).

According to Giugni et al. (2009) PRVs are 'variable closure devices that reduce the conveyance capacity of the pipe by increasing the pressure losses.' This potential energy can be transformed into hydroelectricity by installing a turbine in the conduit. Therefore, by installing a turbine in parallel with the PRV, the flow and head are utilised to generate hydroelectric power (Ramos et al., 2010)



2.8.2 Examples of installed and planned conduit hydropower

During recent years the focus on conduit hydropower in distribution systems has increased and many stakeholders have installed this technology. **Table 2-11** provides a summary of some existing and planned conduit hydropower facilities.

Table 2-11: Examples of existing and planned conduit hydropower installations

Project name	Location	Capacity (kW)	Photo	Year completed	Source
La Zour	Savièse, Switzerland	465 total		2004	ESHA (2009)
Schreyerbach	Aldrans - Innsbruck, Austria	63		2006	ESHA (2009)
Mühlau	Innsbruck, Austria	5 750		1952	ESHA (2009)
Poggio Cuculo	Arezzo, Italy	44		2010	ESHA (2009)
Vienna Mauer	Vienna, Austria	500		2006	ESHA (2009)
Armory Power Plant	Aubonne, Switzerland	68		2006	ESHA (2009)

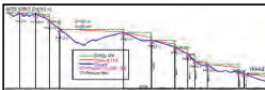
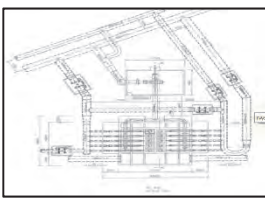


**Table 2-11: Examples of existing and planned conduit hydropower installations
(continued)**

Project name	Location	Capacity (kW)	Photo	Year completed	Source
Tordera	Blanes, Spain	2 880 total		2002	ESHA (2009)
Sangüesa	Sangüesa, Navarra, Spain	75		2006	ESHA (2009)
Lomza	Lomza, Poland	20		1997	ESHA (2009)
Rancho Peñasquitos	San Diego, USA	4 500		2007	NHA (2013)
Keene	New Hampshire, USA	55		2010	Rentricity (2010a)
Westmorland	Pennsylvania, USA	30		2010	Rentricity (2010b)



**Table 2-11: Examples of existing and planned conduit hydropower installations
(continued)**

Project name	Location	Capacity (kW)	Photo	Year completed	Source
Pierre van Ryneveld	Gauteng, South Africa	14.9		2011	Van Dijk et al. (2012b)
Faure	Cape Town, South Africa	1 475		1994	Jonker Klunne (2012b)
Blackheath	Cape Town, South Africa	700		1982	Jonker Klunne (2012c)
Tshwane	Gauteng, South Africa	4 000 total		Planning stage	Van Vuuren (2010)
Edremit	Edremit, Turkey	559 total		Planning stage	Kucukali (2011)
Ethekwini	Ethekwini, South Africa	590 total		Planning stage	Dyer (2012)
Rand Water	Gauteng, South Africa	13 000 total		Planning stage	Jonker Klunne (2013b)
Brandkop	Bloemfontein, South Africa	96		In construction	Jonker Klunne (2013c)



2.8.3 Examples of specific hydropower installations in water distribution systems

Conduit hydropower has been implemented at a number of locations in the rest of the world. Five installations in the USA are described in detail below:

2.8.3.1 *City of Logan (Utah, USA)*

The City of Logan sits near the base of the Rocky Mountains in northern Utah and draws 70% of its potable water supply from Dewitt Spring, a naturally flowing fountain of pure water located about 11km away in Logan Canyon. From the Dewitt collection basin, a pipeline runs down the canyon 8350 m to a Flow Control Vault where excess pressure is removed before the water is distributed into several concrete storage reservoirs.

The original steel pipeline was constructed in 1934, with some sections upgraded to reinforced concrete in 1949 (White, 2011). Over the years some sections started leaking and in 2008 major sections of the old 610 mm and 760 mm pipes were replaced with a 915 mm welded steel pipe. The larger diameter increased available water flow to the growing community while significantly reducing pipeline friction.

Less friction resulted in additional head pressure at the Flow Control Vault, creating both a problem and an opportunity. The existing pressure reducing valve (PRV) at the Flow Control Vault was pushed beyond its design limits under the higher pressures, causing severe cavitation and rapid deterioration of the PRV. Remedial action was required to avoid any restrictions on the municipal water supply system.

The excess head pressure, however, also created the opportunity for hydropower. A small turbine would reduce the pressure, much like a PRV, and send electrical power into the municipally-owned power system. The City of Logan decided to install a Francis turbine to replace the reducing valve, see **Figure 2-26**. The Flow Control Vault would house the selected turbine as shown in **Figure 2-27**.

Since the project involved the installation of a hydropower unit onto an existing water line, there were no environmental impacts to mitigate. The US Federal Energy Regulatory Commission (FERC) recently streamlined permitting processes for small hydro projects with low environmental impacts, and approval came quickly. Public support was also very positive because the project produced clean, renewable “green power,” simply by recovering energy that had been going to waste through the PRV.





Figure 2-26: The City of Logan, Utah installed a Francis turbine to replace a pressure reducing valve (White, 2011)



Figure 2-27: The pressure control vault houses the turbine and bypass PRV (White ,2011)

White (2011) highlighted that since implementation of this scheme community interest has been enthusiastic as the scheme provides the community with a new source of clean and reliable energy. The best part is that the new owners, the citizens of Logan, are now one step closer to securing their own energy independence for many years into the future!



2.8.3.2 San Diego County Water Authority (USA), Rancho Penasquitos Pressure Control and Hydroelectric Facility

Near San Diego, California, where a dependable water supply is a concern, the San Diego County Water Authority (CWA) sought to improve the existing pipeline delivery system and provide a more flexible method of supplying water to the San Diego region. A key component of the water delivery system, named the Rancho Penasquitos Pressure Control and Hydroelectric Facility, facilitates the transfer of water from a system of reservoirs, interconnected pipelines and pumping stations to provide more flexibility of water deliveries to the San Diego region, especially in the event of an emergency.

Consisting of a series of complex connections, interfaces and interdependencies with other storage and conveyance components, the facility is challenging in its design and operation and includes sophisticated logic software to coordinate operations. Pipe sizes at the facility range from 1050 mm to 2750 mm in diameter, and pressures can rise to nearly 17 bar. This produces tremendous thrust forces that are imposed on the structural components of the facility. The slope was used in the design of the facility to allow a large portion of it to be below grade and thus reduce the visible portion, while the above-grade portion was designed with aesthetics in mind to match the surrounding architecture, to sustainably utilize the excessive hydraulic pressure that was being dissipated by the facility; an energy recovery turbine was designed and installed.

This single hydraulic turbine, shown in **Figure 2-28**, makes use of the available hydraulic pressure to generate up to 4.5 megawatts of electricity, thus providing enough environmentally friendly power back to the system to satisfy the annual electricity demand from approximately 5 000 homes.

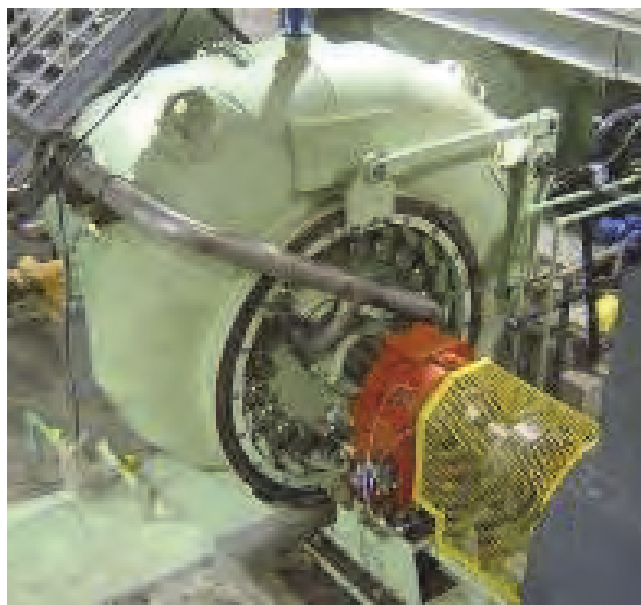


Figure 2-28: Horizontal Francis Turbine Generator, 4.5 MW (NHA, 2011)



The San Diego CWA achieved its goal of providing a reliable water supply and the hydro system offered additional benefits. The hydroelectric facility serves its function as a pressure and flow control station for the water conveyance and distribution system as well as utilising a renewable energy source.

The American Society of Civil Engineers, Region 9, has recognized the innovative project by selecting the Rancho Penasquitos Pressure Control and Hydroelectric Facility for the award of “Water Project of the Year.”

2.8.3.3 Loring Road hydroelectric, Massachusetts Water Resources Authority (MWRA) (USA)

In December 2009, the Massachusetts Water Resources Authority (MWRA) began generating more power from a segment of its vast pipeline system, which carries drinking water to 50 communities in the Boston area. The Loring Road hydroelectric project, equipped with a 200 kW horizontal Francis turbine, **Figure 2-29**, was completed in December 2009 at a water storage facility in Weston, Mass. The turbine, manufactured by The James Leffel & Co., is housed in a large underground valve chamber.



Figure 2-29: Loring road Francis turbine (200 kW)

As water is distributed via pipeline from one storage tank to another storage tank, it passes through the turbine at a rate of 880 l/s. On average, the unit will produce about 1.2 million kWh a year for on-site operations. Any excess power would be sold to the local utility.



The \$1.9 million project is expected to save MWRA about \$150,000 a year although the project received more than \$1.5 million from the American Recovery and Reinvestment Act and a \$275,000 grant from the Massachusetts Technology Collaborative. The drinking water is drawn from two reservoirs more than 48 km west of Boston. The hydro facility, officials said, will not affect the amount of water drawn from those reservoirs. MWRA already operates two other hydroelectric facilities within its 160 km system of tunnels and aqueducts. The Loring Road project was granted a conduit licensing exemption from FERC in August 2009 and was certified in July 2010 by the Low Impact Hydropower Institute.

2.8.3.4 City of Riverside, California (USA)

A PowerPipe™ was installed in the City of Riverside bulk supply system in March 2011. According to Lucid (2011) this third generation system has now over 3 500 hours of continuous operation feeding a total of 28 MWh electricity into the grid with the spherical turbine having had 32 million revolutions.



Figure 2-30: Installing the PowerPipe™





Figure 2-31: Spherical turbine (Kanagy, 2011)



Figure 2-32: Installed LucidEnergy spherical turbine (Riverside, California)



2.8.3.5 Southern Nevada Water Authority (SNWA) - Hydroelectric Projects

SNWA has developed hydropower projects at three Rate of Flow Control Stations (ROFCS) in Las Vegas and Henderson:

- 🔧 Linden ROFCS – 522 kW
- 🔧 Sloan ROFCS – 933 kW
- 🔧 Horizon Ridge ROFCS (Henderson) – 605 kW

The projects include a small turbine and induction generator at each site. As water passes through the pipeline, it turns the turbine and generates electricity. Over 2 megawatts of capacity is available from these systems.

As an example the Sloan project in the Las Vegas Valley Water District (LVVWD) consist of a generating unit with a rated capacity of 607 kilowatts replacing the pressure dissipating valve in a 1370 mm pipeline in the Rate-of-Flow Control (ROFC) station, and the other two pipelines in the station, is used as bypass facilities. The average annual energy production is 3.2 gigawatt hours. A second generating unit with a rated capacity of 600 kilowatts installed in lieu of a pressure dissipating valve in one of two pipelines in the 130-K ROFC station serving LVVWD Zone 1985 with the other Zone 1985 pipeline in the station is used as a bypass facility. The average annual energy production would be 1.95 gigawatt hours. Power produced by the stations helps to offset the energy requirements of operating the Sloan Pumping Plant.



Figure 2-33: Hydroelectric turbine at Sloan Rate of Flow Control Station (SNWA, 2010)



3. CIVIL WORKS AND MECHANICAL/ELECTRICAL/ELECTRONIC EQUIPMENT

The various aspects related to the civil, mechanical, electrical and electronic equipment is dealt with in detail in the **Conduit Hydropower Pilot Plants** report (TT596/14, Van Vuuren et.al, 2014) included on the **HydroAID** supporting DVD.

3.1 Conventional hydropower scheme components

Although the components of a conduit hydropower plant will differ, conventional hydropower was studied, as there are similarities. The similarities will be discussed in the summary at the end of the chapter. The components found in hydropower schemes can normally be grouped into two broad categories, namely civil work components and electrical and mechanical components. The following paragraphs will discuss these components in more detail.

3.1.1 Civil works

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

3.1.1.1 *Dam, barrages or weirs*

Dams, barrages or weirs are used to store and divert flow into the conveyance system and therefore to the turbine. Dams also ensure additional storage capacity and head. Dams can be constructed from a number of different materials and in a number of different forms. Site topography, environmental considerations, dam safety and budgetary constraints will be the main aspects to consider during dam design. Dams are associated with significant environmental impacts and are normally only constructed for large-scale projects, as dam construction makes small schemes economically unfeasible (ESHA, 2004).

3.1.1.2 *Intake*

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



In a run-of-river or storage controlled 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).

3.1.1.3 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).

3.1.1.4 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.

3.1.1.5 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).



3.1.1.6 Powerhouse

The purpose of the powerhouse is to support and shelter the turbines and electrical/electronic equipment, protecting these from the natural elements. 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. An example of the powerhouse for a pico/micro hydropower installation is shown in **Figure 3-1**.

3.1.1.7 Tailrace

A tailrace is used to convey the water from the turbine back to the river. 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 such as cross flow or pelton).



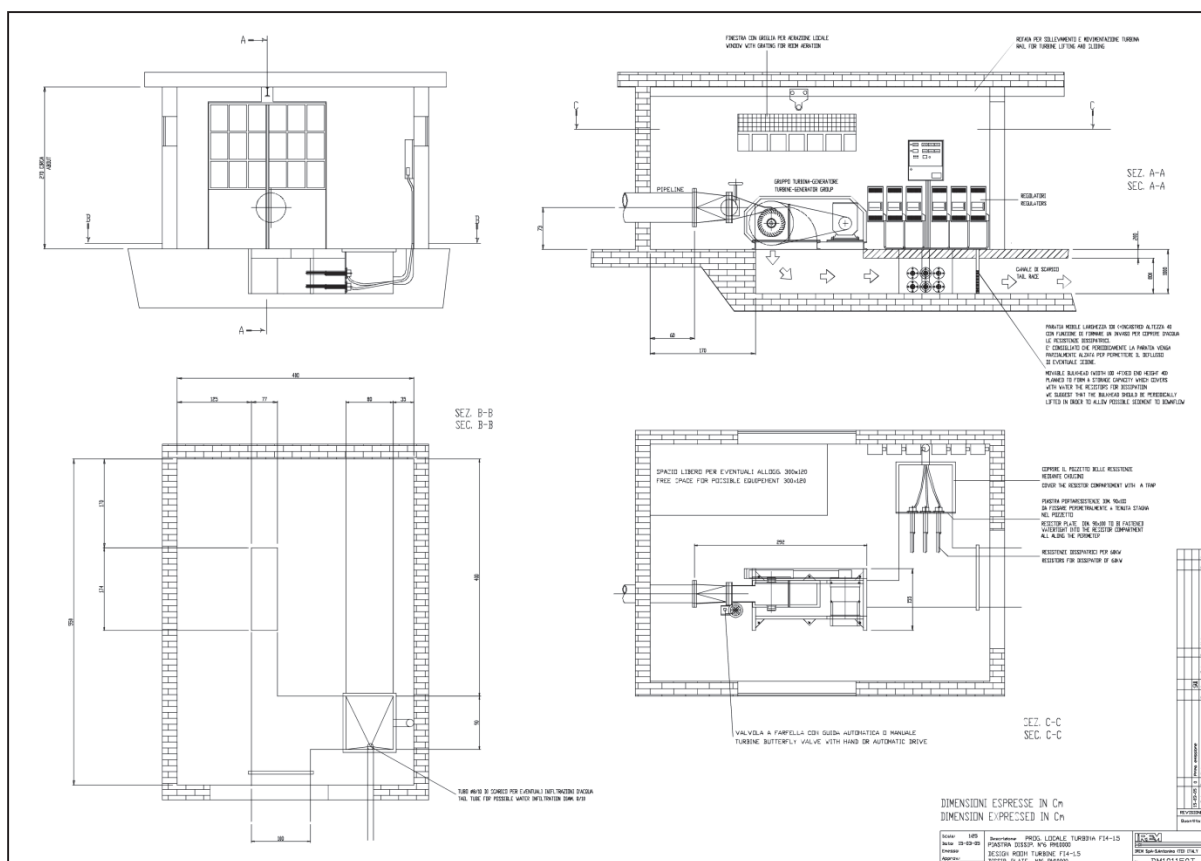


Figure 3-1: Example of powerhouse (Courtesy of IREM)

3.2 Other electrical and mechanical equipment

3.2.1 Synchronous and asynchronous generators

As illustrated in paragraph 2.7 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 (NRC, 2004). They can run isolated from the grid. Asynchronous (or induction) generators are usually applied in smaller systems, as they are more robust and less expensive than synchronous systems (NRC, 2004). However, they cannot generate high quality electricity if disconnected from the grid, as they cannot provide their own excitation current. Therefore, asynchronous generators are generally connected to the grid.

3.2.2 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 (NRC, 2004).

3.2.3 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.

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

The installed turbines can supply the electricity to either a stand-alone islanded system or connected to the grid as shown in **Figure 3-2** and **Figure 3-3**.

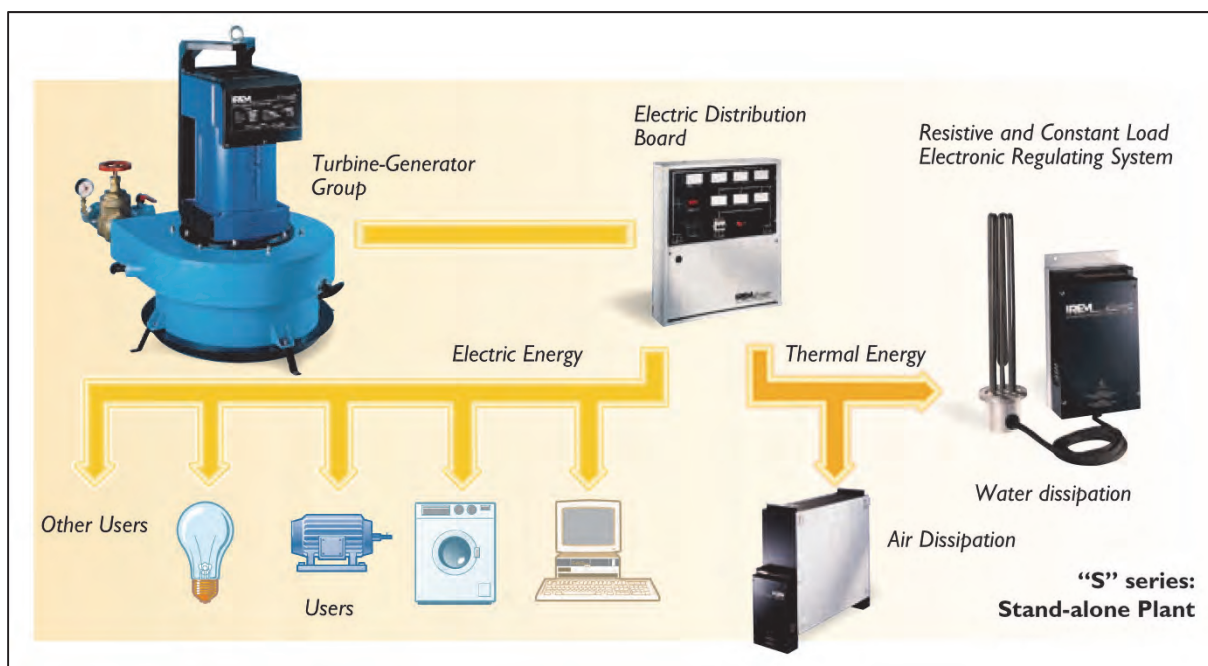


Figure 3-2: Stand-alone (islanded) plant (Courtesy of IREM)



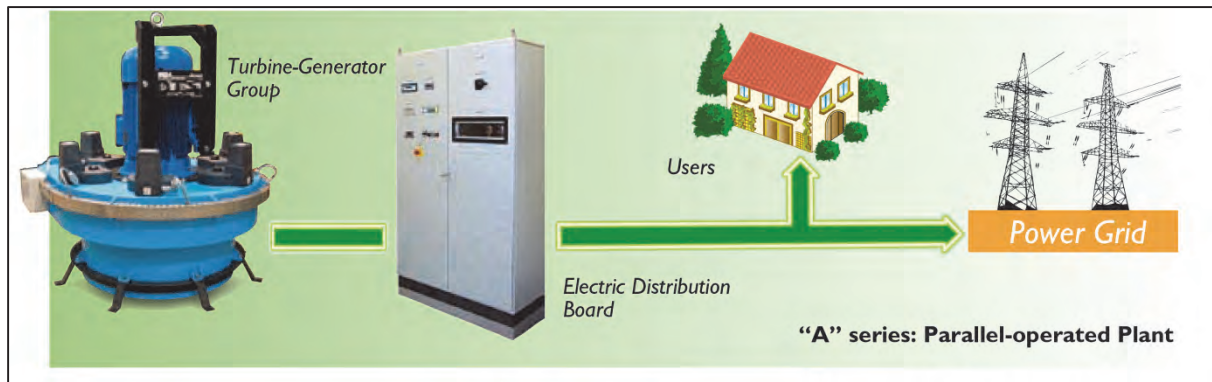


Figure 3-3: Grid connected plant (Courtesy of IREM)

3.2.4 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 (NRC, 2004).



4. POLICIES/LICENCING AND REGULATORY ASPECTS OF CONDUIT HYDROPOWER IN SOUTH AFRICA

There was initially great excitement in the market when the renewable energy feed-in tariff (Refit) was first discussed. It was however announced that the program would be replaced with a different financing system dubbed the IPP Procurement program. Initially the government indicated that it would inject R343 billion over a five year period which would target the generation 10 000 GWh of energy utilizing renewable energy projects. After a number of delays in announcing the proposed Refit by The National Energy Regulator of South Africa (NERSA) there was a significant change to the IPP Procurement Program. The Department of Energy (DoE) announced the two-part bidding process where potential investors will be evaluated on bid price as well as how certain pre-set qualification objectives are met. The Energy Ministry also allocated 3 725 MW instead of the previously determined 1025 MW that was outlined in the IRP in its first phase of renewable energy power purchase agreement, see **Table 4-1**. Preferred bidders will be required to apply for a licence from Nersa while the agency will also facilitate the conclusion of power purchase agreements (PPAs) between the state-owned utility Eskom and the renewable energy IPPs.

Table 4-1: Generation capacity allocated to each technology

Technology	Generation capacity
Onshore wind	1 850 MW
Concentrated solar thermal	200 MW
Solar photovoltaic	1 450 MW
Biomass	12.5 MW
Biogas	12.5 MW
Landfill gas	25 MW
Small hydro	75MW
Small projects	100 MW

This 3 725 MW is broadly in accordance with the capacity allocated to Renewable Energy generation in IRP 2010-2030. This IPP Procurement Programme has been designed so as to contribute towards the target of 3 725 megawatts and towards socio-economic and environmentally sustainable growth, and to start and stimulate the renewable industry in South Africa. In terms of this IPP Procurement Programme, the Bidders will be required to bid on tariff and the identified socio-economic development objectives of the Department of Energy. The tariff will be payable by the Buyer pursuant to the PPA to be entered into between the buyer and the project company of a preferred bidder (DoE, 2011).

The generation capacity allocated to each technology is in accordance with **Table 4-1** and the maximum tariff that a bidder may bid for purposes of the IPP Procurement Programme is as set out in the RFP.



Each Facility procured in terms of this IPP Procurement Programme will be required to achieve commercial operation by not later than the dates set out in the RFP.

The development and generation of hydropower as one of preferred “green technologies” must comply in South Africa with several legal and regulatory requirements before proposed development can be implemented. There are four legal/regulatory areas where it is necessary to obtain permits for implementing a hydropower scheme. The permits would be issued against relevant and detailed information about proposed hydropower installation. Besides the legal/regulatory requirements there is a need to negotiate and secure the financial funding (equity and debt) for the construction of proposed development.

4.1 Objective of the chapter

The objective of this chapter is to provide an overview of the institutional-, legislative-, regulatory-, and funding environments within which small-scale conduit hydropower installation systems will be implemented in South Africa.

This document addresses only the institutional-, legislative-, regulatory and funding aspects of **small-scale conduit hydropower installations**, mainly in the pico, micro and mini hydro-power categories (**Table 4-2**).

It does not address the institutional-, legislative-, regulatory and funding aspects relating to hydropower generated from storage schemes (dams), run-of-river schemes, irrigation canals, and pumped storage schemes. Tidal hydropower is also not addressed.

The institutional role-players and the interactions between them, the regulatory requirements as well as the funding options, differ significantly between small-scale conduit hydropower installations and the latter mentioned, larger scale schemes.

Table 4-2: Categories of small scale hydropower (Barta, 2010)

Hydropower category	Capacity in power output	Potential hydropower use
Pico	Up to 20kW	10kW network to supply a few domestic dwellings
Micro	20kW to 100kW	100kW network to supply small community with commercial/manufacturing enterprises
Mini	100kW to 1MW	Stand-alone or grid connected systems supplying significantly large communities, transformers are normally needed.
Small	1MW to 10MW	1MW to 10MW capacity installation requires that the electrical distribution to be of medium voltage ranging from 11 to 33kV and transformers are normally needed. The generation must be synchronised with the grid frequencies normally to 50 Hz.



4.2 Background statements

The following statements form the contextual background to this overview:

- i. A small-scale conduit hydropower project, similar to any other type of civil infrastructure project, progresses through various project stages.

 These stages are:

 Pre-feasibility (or Phase 1 of the decision support system);

 Feasibility (or Phase 2 of the decision support system);

 Detail design (or Phase 3 of the decision support system);

 Procurement;

 Construction;

 Operation and Maintenance and

 Decommissioning.

The institutional-, regulatory-, legal and funding aspects as considered in this document are undertaken mainly during the **feasibility stage** of a project.

- ii. The Municipal Infrastructure Investment Framework (MIIF) descriptions of infrastructure components are used. These are reflected in the table below:

Table 4-3: Description of different components of infrastructure (MIIF)

	Water Supply	Electricity
Bulk Infrastructure	Pumping systems to extract water from the resource, the water treatment works and bulk treated water storage, and pumping systems and pipelines required to transfer water to distribution reservoirs located at settlements	Power generation stations, powerlines which transfer power to settlements and associated switching stations and transformers
Connector Infrastructure	Distribution reservoirs and pipelines leading from these reservoirs to the blocks of plots	Powerlines and associated switching stations and transformers which link the bulk system to settlements
Internal Infrastructure	Pipelines located within a block of plots, including the connections to plots with meters. In rural areas the block of plots is replaced by the village and the connections may only be to public standpipes	Powerlines within the blocks which directly serve each plot or dwelling.



- iii. The small-scale conduit hydropower installation system is an “add-on” to existing connector and or bulk water supply infrastructure (as indicated by shaded selection in **Table 4-3**) in South Africa. Therefore,
-  the water services infrastructure under consideration would mainly be distribution reservoirs and distribution (or connector) pipelines, as well as bulk treated water storage reservoirs and bulk pipelines, providing for excessive gravity or pumping pressure.
 -  Entities within the South African water sector that are custodians of water services infrastructure suitable for small-scale conduit hydropower installations are:
 - o Water Boards, which are state-owned regional water services providers who provide both bulk-services to more than one Water Services Authority (WSA) area, and retail services on behalf of a WSA;
 - o Regional and Local Water Services Providers (WSPs);
 - o Municipal Water Services Entities (eg Special Purpose Vehicles);
 - o Public Water Utilities (eg Johannesburg Water)
 - o Private Water Services Companies (Section 21 companies);
 - o Water User Associations. (primarily former irrigation boards)
 -  The land on which the water infrastructure was constructed is typically situated within an entity servitude;
 -  No electricity sub-stations are typically required on the proposed site, and therefore no sub-station servitude arrangements will need to be negotiated and priced;
- iv. The electricity generated can be used for either, own use, islanded use, municipal or Eskom grid connected.
- v. The OPERATOR of the water infrastructure within which the small-scale conduit hydropower installation system is to be installed, will apply to the National Energy Regulator of South Africa (NERSA) for the electricity generation licence; and not the OWNER of the water infrastructure should these roles be allocated to separate entities but more on this later in this chapter.



4.3 Definitions

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

Where:

Generator:

"Means a person who generates electricity by any means" (South Africa, 2006).

Pico-, micro and mini conduit hydropower installations:

pico-: up to 20kW;

micro: 20kW to 100kW and

mini: 100kW to 1MW.

Conduit hydropower installation:

"In almost every water-transfer scheme and water-distribution system, excess energy can be found in conduits. Pressure reducing stations (PRSs) are installed to dissipate excess energy at specific points along a conduit, as well as upstream of water-treatment plants and reservoirs. The energy dissipated by these devices can instead be captured as hydroelectricity through the installation of turbines in the conduit." (Loots, 2013).

Water distribution network:

This would include distribution reservoirs and distribution (or connector) pipelines, as well as bulk treated water storage reservoirs and bulk pipelines, providing for excessive gravity or pumping pressure (DBSA, 2011).

Islanded use:

Electricity generated for "islanded use" is **completely independent** of municipal or Eskom distribution networks (South Africa, 2006).

Own use:

"in the context of a generation facility means a facility that generates electricity that is used only by the operator or owner of that facility and is not sold to any person and is not transmitted through a transmission power system¹ or distributed through an interconnected distribution power system."² (South Africa, 2011).

¹ Transmission power system means a network for the conveyance of electricity which operates above a nominal voltage of 132kV. (South Africa, 2011)

² Interconnected distribution power system means a distribution power system that is interconnected to a transmission power system either directly or through interconnection to a distribution power system whether the latter system is interconnected to a transmission power system. (South Africa, 2011)



Electricity distribution network:

or distribution power system “means a power system that operates at or below 132kV.” (South Africa, 2006).

4.4 Institutional role-players

4.4.1 Water Services Sector

In South Africa, the legal entities most likely to **own** water services infrastructure suitable for the implementation of pico-, micro- and mini conduit hydropower projects are **Water Services Authorities** (WSAs), **Water Boards** (WBs) and **Water User Associations** (WUAs).

4.4.1.1 Water Services Authorities (WSAs) and Water Services Providers (WSPs)

WSAs have the constitutional responsibility for ensuring access, planning and regulating provision of water services within their area of jurisdiction. They may provide water services themselves and/or contract external Water Services Providers (WSPs) to undertake the provision function on their behalf. (DWA, 2003)

WSPs are the organisations that assume operational responsibility for providing water and/or sanitation services. (DWA, 2003)

The installation of a CHP (combined heat and power) plant at Johannesburg’s Northern Works

Johannesburg Water (JW) is the WSP for the City of Johannesburg (CoJ), who is the designated WSA. JW manages, operates and maintains water and sanitation services infrastructure in the CoJ’s area of supply, and the CoJ owns the infrastructure.

In 2009, JW (as WSP) initiated a feasibility study into biogas to electrical energy generation on its Wastewater Treatment Works (WWTW). The JW appointed consulting engineers drafted design, supply, install, operate and maintain tender documents for biogas scrubbing and CHP installations. JW would retain ownership of the new installations, while the operation and maintenance functions would be outsourced to the success tenderer. (Water & Sanitation Africa, 2014)

The electricity generated is used for “own use”, reducing the demand from the Eskom distribution network, and therefore reducing the monthly electricity cost of the operations of the WWTW.



4.4.1.2 Water Boards

Water Boards in South Africa are state-owned water services providers who provide both bulk services to more than one WSA and retail services on behalf of a WSA (i.e. WSP function)

They traditionally operate some water resource infrastructure, bulk potable water supply schemes (selling to municipalities and industries), some retail water infrastructure and some wastewater systems (DWA, 2003).

There are currently 12 Water Boards in South Africa, with the potential to generate electricity from pico-, micro- and mini conduit hydropower installations.

In some instances, WSAs and WBs might own water services infrastructure with the potential to generate conduit hydropower sizable enough to generate electricity of capacity larger than 1MW. If the capacity remains under 10MW, this is classified as “small conduit hydropower.”

4.4.1.3 Water User Associations (WUAs) (former irrigation boards)

A water user association is a statutory body established by the Minister of Water and Environmental Affairs. It is a grouping of water users who wish to work together because of a common interest. The water users ‘co-operate’ in undertaking water-related activities at the local level for their mutual benefit. The main function of a WUA is to ensure fair and reliable water supply to its members, who are mostly irrigation or livestock farmers.

4.4.1.4 Department of Water Affairs (DWA)

The Department of Water Affairs is the custodian of South Africa's water resources. It is primarily responsible for the formulation and implementation of policy governing this sector. It also has oversight responsibility for water services provided by local government (DWA, 2014).

4.4.1.5 Department of Environmental Affairs (DEA)

DEA is mandated to ensure the protection of the environment and conservation of natural resources, balanced with sustainable development and the equitable distribution of the benefits derived from natural resources. In its quest for better use and management of the natural environment, the DEA is guided by its constitutional mandate, as contained in section 24 of the Constitution.

The Department of Environmental Affairs fulfils its mandate through formulating, coordinating and monitoring the implementation of national environmental policies, programmes and legislation.



4.5 Electricity Sector

4.5.1 Department of Energy (DoE)

The mandate of the Department of Energy is to:

-  ensure secure and sustainable provision of energy for socio-economic development,
-  Protect and continually enhance environmental assets and natural resources by applying cleaner energy technologies and
-  Mitigate against- and adapt to the impacts of climate change (Department of Energy, 2012).

This implies that the Department is responsible for the development of, inter alia,:

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

which govern, direct and guide the sector towards common objectives. (Department of Energy, 2012)

4.5.2 National Energy Regulator of South Africa (NERSA)

NERSA is a regulatory authority established as a juristic person in terms of Section 3 of the National Energy Regulator Act, 2004 (Act No. 40 of 2004). NERSA's mandate is to regulate the Electricity, Piped-Gas and Petroleum Pipeline industries in terms of the Electricity Regulation Act, 2006 (Act No. 4 of 2006) as amended, the Gas Act, 2001 (Act No. 48 of 2001) and the Petroleum Pipelines Act, 2003 (Act No. 60 of 2003) (NERSA, 2014).

NERSA's mandate is further derived from written government policies as well as Regulations issued by the Minister of Energy (NERSA, 2014).

NERSA regulates and controls any electricity generation-, transmission- and or distribution, and affects this through the issuing of licences or registrations. NERSA further regulates electricity tariffs that can be charged by Electricity Utilities to consumers. (NERSA, 2014)



4.5.3 Eskom

Eskom Holdings Limited is a public company, and a state owned enterprise in terms of the Public Finance Management Act, that owns and operates the National Electricity Grid³.

Eskom generates approximately 95% of the electricity used in South Africa and approximately 45% of the electricity used in Africa. Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors (Eskom, 2014).

4.5.4 Electricity Services Authority and Electricity Services Provider (Distribution Supply Authority and Electricity Distribution Utility or Electricity Distributor)

Part B of Schedule 4 of the Constitution specifies “electricity and gas reticulation” as functional areas of concurrent legislative competence. (South Africa, 1996) Chapter 7, S156(1) of the Constitution specifies that a “*municipality has executive authority in respect of, and has the right to administer the local government matters listed in Part B of Schedule 4...*” (South Africa, 1996).

The municipality therefore is the Electricity Services Authority.

In terms of the Municipal Systems Act, a municipality must decide whether to undertake this function internally within the municipality, i.e. the municipality is both ESA and ESP, or delegate this responsibility to an external ESP (South Africa, 2000).

In South Africa, electricity distributors therefore may be Eskom, or the municipal electricity service provider (SABS, 2010).

4.6 Usage Options for Electricity Generated by Pico-, Micro- And Mini Hydropower Installations, and Associated Regulatory Requirements

Electricity generated from pico-, micro-, mini- and small hydropower installations can be used for either:

-  Islanded use;
-  Own use;
-  Connecting to a Municipal distribution network.

³ The network of high-voltage power lines linking the power stations to the cities, towns, rural and residential areas where electricity is used is called the National Grid, or the interconnected grid. All electricity that Eskom generates is fed into this grid for national distribution. Eskom does not distribute electricity directly to all consumers; most municipalities buy electricity in bulk from Eskom and resell it to consumers.



Electricity generated from pico-, micro- and mini hydropower installations in water distribution systems owned by WSAs, WBs and WUAs **cannot** currently be used for connecting to the Eskom distribution network.

4.6.1 Islanded Use

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

The Department of Energy’s “Non-Grid Electrification Policy Guidelines” (DoE, 2012) guides the implementation of the latter. The main objective of the policy guidelines is to guide the provision of non-grid electrification to households as part of the **Integrated National Electrification Programme**⁴, or INEP (DoE, 2012).

Through a tendering process, the DoE procured 6 private sector “concessionaires” in 2001 to provide energy services to remote rural areas as part of the INEP. These concessionaires were allocated exclusive rights to provide off-grid electrification in particular geographic areas (DoE, 2012).

The DoE has extended the roll-out of the INEP non-grid electrification programme to other areas that fall outside of the concession areas. **This roll-out can be initiated and facilitated by Municipalities making application for non-grid electrification in their respective areas to the DoE** (DoE, 2012, DoE, 2013).

For conduit hydropower generated from water distribution systems, this option would be applicable where:

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

Case-by-case contracting⁵ and funding models⁶ would need to be developed, in order to determine the feasibility of such a project, specifically for hydropower projects operated by WBs or WSPs.

⁴ The DoE’s mandate is to ensure secure and sustainable provision of energy for socio-economic development in SA. The DoE, through the INEP has the responsibility to ensure the provision of basic access to electricity to all citizens. The set target was 92% access by 2014. (Now 100% by 2025, DoE, 2013) The INEP is implemented by both Municipalities (ESAs) and Eskom. (DoE, 2013)

⁵ The WB or WSP operating the water distribution system would initiate the process with the Municipality (ESA), who would then engage with the DoE. An ESP would need to be appointed to operate and manage the (islanded) electricity distribution network once approval from the DoE is received.

⁶ The policy specifies that consumers to non-grid systems, installed through the INEP will receive a subsidy of up to 80% of the **monthly service fee** to provide access to non-grid systems, subject to the contractual obligations between the ESP and the consumer being met (South Africa, 2003). In addition, projects implemented through the INEP receive an 80% capital subsidy.



Table 4-4 provides a summary of the regulatory requirements applicable to “islanded use”.

Table 4-4: Quick view of the regulatory requirements for Islanded Use

Description	Islanded Use	
	Completely independent from any distribution / reticulation network	
	NOT CONSIDERED AS “NEW GENERATION CAPACITY” (Electricity Regulation 2nd Amendment Bill, 2011)	
	Any type of generator (private or public)	
Electricity Generation Licence requirements February 2013 (Plant Operator to NERSA)	No Generation licence required if for non-commercial use (Electricity Regulation Act 2006, Schedule 2) Notification re this required from NERSA	Generation licence required if for commercial use (Electricity Regulation Act 2006, Schedule 2)
Local electricity utility involvement	Good Practice to inform ESA and or ESP, or Eskom	Applications to the DoE for non-grid electrification through the INEP to be done by the municipality, i.e. the ESA. Refer: non-grid electrification policy guidelines, fbe policy & INEP policy guidelines
Proof of Land Ownership/Permission to use land obtained	Good Practice to have	Required for NERSA licencing requirements
Environmental ROD (Plant operator to Provincial or National DEA)	Good Practice to have, if required	Amendment to existing EIA or BA required for Brownfields development (pers. comms. legal opinion) Record of Decision (ROD) required based on a Basic Assessment (GN544) (if 10MW<power generated <20MW, or power generated>10MW over areas>1ha) and or (if the construction of facilities or infrastructure for the distribution of electricity outside urban areas of more than 33kV but less than 275kV or inside urban areas or industrial complexes with a capacity of 275kV or more) full EIA (GN545) (if power generated>20MW) (the construction of facilities or infrastructure for the transmission and distribution of electricity of 275kV or more outside an urban area or industrial complex) (show proof of appointment of EIA consultant, indicate Public Participation Process that is being followed, DEA approval of scoping report) Includes all possible environmental aspects - waste management, air quality control etc.
Water Use Licence Requirements (WSA to DWA)	Good Practice to have, if required	Legal Opinion if none is required
Water allocation confirmation (Plant operator to WSP)	WSP must confirm that water is available and hydropower generation will not affect security of supply	

(DoE, 2012) Confirmation of whether this capital subsidy is applicable only to Solar Home Systems, or to any technology type, must be attained from the DoE.



If electricity generated will be for commercial use, a NERSA electricity generation licence⁷ will be required.

This application will include an Environmental Impact Assessment, or a notice from an Environmental Impact Assessment Practitioner that none is required, an opinion from a water sector legal expert that a water use licence from the DWA is not required for conduit hydropower installation in the water distribution system, and a notice from the WSP or WB that security of water supply will not be effected through the installation of the hydropower generation system, if applicable.

4.6.2 Own Use

Electricity generated for own use is defined as *“electricity that is used only by the operator or owner of that facility and is not sold to any person and is not transmitted through a transmission power system⁸ or distributed through an interconnected distribution power system.⁹”* (South Africa, 2011)

This option is ideal for circumstances where the capacity of the electricity generated on site, is less than the demand of the operations on site. Financial viability is achieved through incurring electricity cost savings.

The installation of a CHP (combined heat and power) plant at Johannesburg’s Northern Works

The installation of the all the gas engines at Johannesburg’s Northern WWTW will provide between 50% and 60% of the WWTW electrical power requirements. *“It is estimated that the payback period for a greenfields CHP installation generating 55% of the works needs is 5 years if the future increases in electricity cost do not exceed 8%/annum. The payback period though could be reduced to half that if the proposed Eskom tariff increase of 16% per year over the next 5 years is implemented”* (Water & Sanitation Africa, 2014)

Current legislation exempts “own use” electricity generators from requiring NERSA generation licences. The proposed Electricity Regulation second Amendment Bill though limits this exemption to 1MW.

Table 4-5 provides a summary of the regulatory requirements applicable to “own use” generation.

⁷ The NERSA electricity generation licence is included on the **HydroAID** DVD but can also be accessed from : <http://www.nersa.org.za/>

⁸ Transmission power system means a network for the conveyance of electricity which operates above a nominal voltage of 132kV. (South Africa, 2011)

⁹ Interconnected distribution power system means a distribution power system that is interconnected to a transmission power system either directly or through interconnection to a distribution power system whether the latter system is interconnected to a transmission power system. (South Africa, 2011)



Table 4-5: Quick view of the regulatory requirements for Own Use

Electricity generation usage options	Own Use
Description	Ability to generate electricity for own use in addition to receiving electricity from a network (in only)
	a facility that generates electricity that is used only by the operator or owner of that facility & is not sold to any person & is not transmitted or distributed through a relevant power systems <i>(Electricity Regulation 2nd Amendment Bill, 2011)</i>
	NOT CONSIDERED AS "NEW GENERATION CAPACITY" <i>(Electricity Regulation 2nd Amendment Bill, 2011)</i>
	Any type of generator (private or public)
	focus is on load reduction, i.e. demand management
	qualified as Eskom IDM small scale RE initiative (Standard Offer Programme) & if equipment is installed on the host side of the meter <i>(Eskom presentation)</i>
Compliance requirements (additional to the relevant grid codes)	Applicable electricity codes of best practice
Electricity Generation Licence requirements February 2013 (Plant Operator to NERSA)	No Generation licence required <i>(Electricity Regulation Act 2006, Schedule 2)</i> Notification re this required from NERSA Limit of 1MW proposed in <i>Electricity Regulation 2nd Amendment Bill, 2011, Schedule 2</i>
	<i>KSEF Guide 2012 notes that NERSA requests at least the generation application form to have been completed and submitted for NERSA info only</i>
Local electricity utility involvement	Good Practice to inform ESA and or ESP, or Eskom
Proof of Land Ownership/Permission to use land obtained	Good Practice to have
Environmental ROD (Plant operator to Provincial or National DEA)	Good Practice to have
Water Use Licence Requirements (WSA to DWA)	Good Practice to have, if required
Water allocation confirmation (Plant operator to WSP)	WSP must confirm that water is available and hydropower generation will not affect security of supply



4.7 Interconnection with the Municipal distribution network

An **Embedded Generator (EG)** is defined to be:

-  “a legal entity that operates a generating plant that is or will be connected to the Distribution Network.” (Eskom, 2008)
-  “one or more energy generation sources that includes the energy conversion device(s) the static power converter(s), if applicable, and the control and protection gear within a customer’s network that operates in synchronisation with the utility’s supply” (SABS, 2010)

Experience from eThekweni Municipality

The **eThekweni Municipality** accepts grid connection applications¹⁰ from renewable energy EGs, and is authorised to purchase electricity from EG at the Mega Flex¹¹ rate. (kzn energy, 2012) A Power Purchase Agreement (PPA)¹² is entered into between the Municipality and the EG, and it is required that all EGs comply with:

- applicable administrative issues;
- safety issues (eg EG-systems connected to the grid must be able to disconnect in the event that grid supply is interrupted, in order to protect technicians who need to repair the grid)
- security of grid;
- quality of supply;
- commercial issues and
- regulatory issues (AMEU, 2013).

Table 4-6 provides a summary of the regulatory requirements applicable to the interconnection of EGs to the municipal distribution network.

4.7.1 3.3.1 10kW<EG<100kW

EG systems installed on the host side of the meter, to the LV¹³ distribution network, are classified as small-scale EG and do not require an electricity generation licence. The EG is to be logged with the Municipality (ESA) and reported to NERSA.

NERSA’s “*Standard Conditions for small-scale embedded generation within municipal boundaries*”, as well as the SABS’ “Grid Interconnection of Embedded Generation (NRS 097-2-1:2010)” clearly define the technical, operational and licensing requirements for small-scale EGs.

¹⁰ The eThekweni grid application form is included on the **HydroAID** DVD but can also be accessed from : http://www.durban.gov.za/Resource_Centre/Current Projects and Programmes/energyoffice/Documents/Application_for_the_Connection_of_Embedded_Generation_eThekweni_Municipality_Mar_2012.doc

¹¹ The rate at which municipalities are charged to purchase electricity in bulk from Eskom. (kzn energy, 2012)

¹² The eThekweni PPA is included on the **HydroAID** DVD but can also be accessed from [http://www.durban.gov.za/Resource_Centre/Current Projects and Programmes/energyoffice/Documents/PPA_for_Embedded_Generation_eThekweni Municipality_March_2012.docx](http://www.durban.gov.za/Resource_Centre/Current Projects and Programmes/energyoffice/Documents/PPA_for_Embedded_Generation_eThekweni_Municipality_March_2012.docx)

¹³ Low Voltage <1kV (SANS 1019)



Table 4-6: Quick view of the regulatory requirements for Municipal Interconnection

Electricity generation usage options	Municipal Grid Connection		
Description	Electricity generated feeds into a municipal grid, can be used for own use also, in addition to receiving electricity from a municipal distribution network (in and out)		
	"NEW GENERATION CAPACITY" & LM Generation		
	Any type of generator (private or public)		
	Embedded Generation one or more energy generation sources... downstream of the electricity consumption meter that operate in sync with utility's supply (NRS 097-2-1:2010)	Embedded Generation (or Distributed Generation) a legal entity that operates a generating plant that is or will be connected to the Distribution Network (DST 34-1765:2008)	
	NRS 097-2-1:2010: - The max size of the EG is limited to the rating of the supply point on the premises - utility-interconnected generators do not normally regulate Voltage, they inject current - net metering or FIT metering options		
	Small-scale EG 10kW<EG<100kW	100kW<EG<1MW (KSEF 2012: 1MW limit for EG based on Eskom IDM small-scale RE programme that was accepting applications of EG in this range)	1MW<Gen<7MW (limit will depend on geographical location within distribution grid & the ability of users to absorb energy generated (urbanearth & eThekweni Presentation))
	focus is on load reduction, i.e. demand management	focus is on load reduction, i.e. demand management	Generation focus
	EGs connected to LV distribution networks (NRS 097-2-1:2010)	EGs connected to HV/MV distribution networks (NRS 097-2-1:2010)	EGs connected to HV/MV distribution networks (NRS 097-2-1:2010)
	LV <1kV (SANS 1019)	1kV<MV<44kV 44kV<HV<220kV (132kV for distribution network) (SANS 1019)	1kV<MV<44kV 44kV<HV<220kV (132kV for distribution network) (SANS 1019)
	qualified as Eskom IDM small scale RE initiative (Standard Offer Programme) & if equipment is installed on the host side of the meter (Eskom presentation)	qualified as Eskom IDM small scale RE initiative (Standard Offer Programme) & if equipment is installed on the host side of the meter (Eskom presentation)	Generation focus
Compliance requirements (additional to the relevant grid codes)	NRS 097-2-1:2010	NRS 097-1 (not yet published) DST 34-1765:2008	NRS 097-1 (not yet published) DST 34-1765:2008
Electricity Generation Licence requirements February 2013 (Plant Operator to NERSA)	No generation licence required if <100kW (Standard Conditions for small scale (<100kW) embedded generation within municipal boundaries) Notification re this required from NERSA	Generation Licence Required if >100kW PER POWER GENERATION STATION (Electricity Regulation Act 2006)	Generation Licence Required if >100kW PER POWER GENERATION STATION (Electricity Regulation Act 2006)
	Logged with NERSA via Municipality/Distribution Utility Standard Conditions for small scale (<100kW) embedded generation within municipal boundaries	Licence applications must include, inter alia, evidence of compliance with IRP (Electricity Regulation Act, 2006) or letter from Minister stating approval of generation facility to be established (ER 2nd Amendment Bill) NERSA approves licences based on Ministerial Directives which are based on IRP or at discretion of Minister	Licence applications must include, inter alia, evidence of compliance with IRP (Electricity Regulation Act, 2006) or letter from Minister stating approval of generation facility to be established (ER 2nd Amendment Bill) NERSA approves licences based on Ministerial Directives which are based on IRP or at discretion of Minister
Local electricity utility involvement		Letter from Local Municipality/electricity utility will be required as part of the application to confirm their knowledge & acceptance of the designed connection onto the network	Letter from Local Municipality/electricity utility will be required as part of the application to confirm their knowledge & acceptance of the designed connection onto the network
Proof of Land Ownership/Permission to use land obtained	Good Practice to have, if required	Required for NERSA licencing requirements	
Environmental ROD (Plant operator to Provincial or National DEA)	Good Practice to have, if required	Amendment to existing EIA or BA required for Brownfields development (pers. comms. legal opinion) Record of Decision (ROD) required based on a Basic Assessment (GN544) (if 10MW<power generated <20MW, or power generated>10MW over areas>1ha) and/or (if the construction of facilities or infrastructure for the distribution of electricity outside urban areas of more than 33kV but less than 275kV or inside urban areas or industrial complexes with a capacity of 275kV or more) Full EIA (GN545) (if power generated>20MW) (the construction of facilities or infrastructure for the transmission and distribution of electricity of 275kV or more outside an urban area or industrial complex) (show proof of appointment of EIA consultant, indicate Public Participation Process that is being followed, DEA approval of scoping report) Includes all possible environmental aspects - waste management, air quality control etc.	
Water Use Licence Requirements (WSA to DWA)	Good Practice to have, if required	Legal Opinion if none is required	
Water allocation confirmation (Plant operator to WSP)	WSP must confirm that water is available and hydropower generation will not affect security of supply		



WSAs, WBs and WUAs owned infrastructure, where the potential to generate conduit hydropower exists, are not excluded from this process. In the case of a WSA, the WSP would contract with suppliers to install the required infrastructure, and engage with the ESA regarding a Power Purchasing Agreement (PPA).

4.7.2 100kW<EG<1MW or more

The 100kW value is currently considered to be the boundary between EGs connected to LV networks and EGs connected to MV/HV networks (SABS, 2010). In addition, EGs of capacity of more than 100kW will need to apply to NERSA for an electricity generation licence.

This application will include an Environmental Impact Assessment, or a notice from an Environmental Impact Assessment Practitioner that none is required, an opinion from a water sector legal expert that a water use licence from the DWA is not required for conduit hydropower installation in the water distribution system, and a notice from the WSP or WB that security of water supply will not be effected through the installation of the hydropower generation system, if applicable.

All generation licence applications must also include evidence of compliance with the IRP (South Africa, 2006).

The Integrated Resource Plan in the South African context is not the Energy Plan - it is a **National Electricity Plan**. It is a subset of the Integrated Energy Plan. The IRP is also not a short or medium-term operational plan but a plan that directs the expansion of the electricity supply over the given period, emphasizing the objectives for the development of renewable energy technologies (DoE, 2014).

The current, unrevised IRP does not consider distribution generation (DoE, 2011). The IRP2, published for public comments in November 2013, considers embedded generation as a possible means to reduce network integration costs and minimising system losses when grouped together to form a large distributed generation network - but emphasises the photovoltaic solution option (DoE, 2013).

The principle of embedded generation is included in the IRP2, and once promulgated by the Minister of Energy, will allow WSP, WBs or WUAs who operate infrastructure where conduit hydropower generation is feasible, to submit electricity generation licence applications to NERSA.



Close interaction between the WSA, WSP and ESA and ESP will be required during the feasibility and design stages of developing such a conduit hydropower system, to ensure the endorsement and acceptance of the design and connection onto the municipal distribution network by the ESP. Confirmation of this acceptance needs to accompany the electricity generation licence application.

Compliance with applicable technical interconnection standards with regards to safety and operations is important, eg compliance with DST34-1665 (Distribution Standard for the Interconnection of EGs 100kW to 1MW) and SANS 10142-1 (the wiring of premises).

4.8 Interconnection with the Eskom distribution network

4.8.1 Legislative constraints

In South Africa, the legal entities most likely to own water services infrastructure suitable for the implementation of pico-, micro- and mini conduit hydropower projects are WSAs, WBs and WUAs; none of which qualify as **Independent Power Producers**¹⁴ (IPPs).

WSAs and WBs are therefore excluded from the Department of Energy's New Generation Capacity¹⁵ IPP procurement programmes¹⁶.

Eskom, as designated buyer of electricity from IPPs, is not mandated to purchase electricity from other Generators. Interconnection therefore of WSAs, WBs and WUAs to the Eskom distribution grid is currently not viable.

¹⁴ IPP means any person in which the Government or any organ of state does not hold a controlling ownership interest (whether direct or indirect), which undertakes, or intends to undertake the development of New Generation Capacity pursuant to a determination made by the Minister in terms of section 34(1) of the ERA. (*South Africa, 4 May 2011*)

¹⁵ New Generation Capacity is defined to be :

- a) electricity generation capacity other than the capacity of existing generation facilities,
- b) the electricity derived from the capacity referred to in (a) and
- c) ancillary services (services supplied by the National Transmission Company, Eskom, by generators which are necessary for the reliable and secure transport of electricity from generator to distributors and other customers) relating thereto individually or in any combination thereof and including an increase in the electricity generation capacity of existing generation facilities. (*South Africa, 4 May 2011*)

¹⁶ These include IPP procurement processes for renewable energy (REIPPPP), Base load, Medium Term Risk Mitigation and Open Cycle Gas Turbine Peaking Power.



Legislation and Regulations governing the procurement of Renewable Energy

New Generation Capacity

Section 34 of the Electricity Regulation Act 4 of 2006 (South Africa, 2006), as amended by the Electricity Amendment Act 28 of 2007 (South Africa, 2007), refers to “New Generation Capacity”:

“(1) The Minister may, in consultation with the Regulator-

- a) Determine that New Generation Capacity is needed to ensure the continued uninterrupted supply of electricity;*
- b) Determine the types of energy sources from which electricity must be generated and the percentages of electricity that must be generated from such sources;*
- c) Determine that electricity thus produced may only be sold to the persons or in the manner set out in such notice;*
- d) Determine that electricity thus produced must be purchased by the persons set out in such notice;*
- e) Require that New Generation Capacity must-*
 - o Be established through a tendering procedure which is fair, equitable, transparent, competitive and cost-effective;*
 - o Provide for private sector participation.”*

Section 35 of the same Act stipulates that the Regulator¹⁷ may make regulations pertaining to, inter alia:

- New Generation Capacity;
- Types of energy sources from which electricity must be generated;
- The percentages of electricity that must be generated from different energy sources and
- The participation of the private sector in new generation activities.

Electricity Regulations on New Generation Capacity came into effect on 5 August 2009 (South Africa, 2009) and stipulated, inter alia, that an Integrated Resource Plan¹⁸ (IRP) needs to be developed, and signed into effect by the Minister.

In January 2010, the Minister :

- **approved** the IRP (South Africa, 2010), which gives effect to the following primary objectives:
 - o 10 000GWh (approximately 4% of the energy mix) of renewable energy by 2013;
 - o The implementation of Energy Efficiency and Demand Side Management through a financial incentive scheme (the standard offer) and
 - o Installation of 1 million solar water heaters.
- and, as per S34 of the Electricity Regulation Act, **determined** that :
 - o New Generation Capacity was required and
 - o is to be met through projects listed in the IRP1, including an

¹⁷ Regulator means the National Energy Regulator established by section 3 of the National Energy Regulator Act. (South Africa, 2006)

¹⁸ IRP means a resource plan established by the national sphere of Government to give effect to national policy. (South Africa, 2006)



Independent Power Producer, IPP, bid programme for six listed renewable energy technologies. (The REFIT Programme¹⁹) Through the REFIT programme, electricity would be bought by an Agency housed within Eskom's Single Buyer Office, from IPPs through a procurement process facilitated by NERSA (NERSA, 2009).

The IRP1 was **promulgated** in May 2011 (South Africa, 6 May 2011).

The Electricity Regulations on New Generation Capacity of 2009 were repealed in 2011, and replaced. (South Africa, 4 May 2011). These regulations establish rules and guidelines that are applicable to the undertaking of IPP bid programmes and the procurement of IPPs for New Generation Capacity. In terms of the New Generation Regulation, the IRP1 will set out the new generation capacity per technology, taking energy efficiency and demand-side projects into account. This required, new generation capacity must be met through the technologies and projects listed in the IRP1 and all IPP procurement programmes will be executed in accordance with the specified capacities and technologies as listed in the IRP (Eskom, 2014).

In December 2012, the Minister **determined** that:

- 3 200MW of renewable energy generation capacity needs to be procured as per the IRP1;
- The renewable energy will be **procured by the Department of Energy and bought by Eskom from IPPs** (the Renewable Energy IPP Procurement Programme, or REIPPPP);
- A specified mix of renewable energy technologies is to be used with indicative capacities which can be modified by Eskom during the course of the project. (Eg. This Ministerial Determination included small hydropower projects under the REIPPPP's Small Project category for projects between 1MW and 5MW. Eskom's request for proposals though excluded small hydropower projects (Eskom, 2014).

4.8.2 Operational Opportunity

An option available to WSAs, WBs and WUAs is to **wheel** electricity through the Eskom distribution network to a municipal distribution network, to be purchased by a Municipality (Eskom, 2012).

Wheeling provides access between a non-Eskom generator and a third party to facilitate the **trading**²⁰ of energy. i.e. "wheeling of energy" is when the energy which is produced at one point, is resold at another, but transferred over a third party grid (AMEU, 2013). A condition for wheeling services provision is, inter alia, that Generators must have approved licences to generate AND to trade electricity from NERSA (Eskom, 2012).

¹⁹ REFIT (Renewable Energy Feed-in Tariff)

²⁰ Trading means the wholesale or retail buying and or selling of electricity as a commercial activity (South Africa, 2011).



In addition to this regulatory requirement, a number of administrative, contractual and financial considerations need to be addressed, which would necessitate a cost benefit study to determine the optimum generation capacity needed to justify such a cumbersome process.

4.9 Independent power producer (IPP)

According to Eskom (ESKOM, 2011b) it is crucial that the private sector plays a role in addressing the future electricity needs of the country. This will reduce the funding burden on Government, relieve the borrowing requirements of Eskom and introduce generation technologies that Eskom may not consider part of its core function which may play a vital role in the future electricity supply options, in particular off-grid, distributed generation, co-generation and small-scale renewable projects.

The introduction of private sector generation thus has multiple benefits. It will contribute greatly to the diversification of both the supply and nature of energy production, assist in the introduction of new skills and capital into the industry, and enable the benchmarking of performance and pricing.

South Africa has two acts that direct the planning and development of the country's electricity sector:

-  *The National Energy Act of 2008 (No. 34 of 2008)*
-  *The Electricity Regulation Act (ERA) of 2006 (No. 4 of 2006).*

In terms of the New Generation Regulations, the Integrated Resource Plan (IRP) will be developed by the DoE and will set out the new generation capacity requirement per technology, taking energy efficiency and the demand-side management projects into account.

This required, new generation capacity must be met through the technologies and projects listed in the IRP and all IPP procurement programmes will be executed in accordance with the specified capacities and technologies listed in the IRP.

4.9.1 Grid Access process for IPP

IPPs that wish to connect to Eskom's network will be required to apply for a connection, pay a connection charge and sign a connection and use-of-system agreement. IPPs will be provided non-discriminatory access to Eskom's network. This access is, however, subject the IPP obtaining its required approvals such as EIA's and a generating and trading licence from NERSA.

ESKOM provides details on the application process covering the following:

-  *General information*
-  *Application for connection*



-  *Cost estimate letter*
-  *Budget quote*
-  *Connection and use of system agreement*
-  *Connection works*
-  *Connection charges*
-  *Technical standards*

The application which outlines the minimum information required by Eskom to conduct an evaluation of the feasibility of connecting generators within Eskom's networks consists of two parts.

Part 1 must be filled in for Eskom to provide an (non-binding) estimate of the cost of connection.

If the required conditions are met to proceed with a budget quotation, Eskom will request Part 2 of the application form to be completed for the detailed interconnection and power system studies.

The full *Process guide for the IPP grid application* as well as the *IPP Grid Application Form - Application for a connection of a generator to the Eskom network* is included on the supporting **HydroAid** DVD.

The *Distribution Standard for the Interconnection of Embedded Generation* (DST ref 34-1765, March 2011) is a standard which sets out the minimal technical and statutory requirements for the connection of Embedded Generators to Eskom Distribution's electrical network.

The standard is included on the supporting **HydroAid** DVD

The relevant forms required to become an IPP licence is included on the supporting **HydroAid** DVD. These include:

Application for an Electricity Distribution Licence of the Electricity Regulation Act, 2006 (Act No. 4 Of 2006).

This application form requires the following details:

- o Particulars of Applicant
- o Commencement Date of Licence
- o Area of Operation to which the Application Relates
- o Details of the Distribution System
- o Maintenance Programmes
- o Customer Profile
- o Financial Information
- o Human Resources Information



- o Permission from other Government Departments or Regulatory Authorities
- o Broad-Based Black Economic Empowerment
- o Additional Information

Application for an Electricity Generation Licence in Terms of the Electricity Regulation Act, 2006 (Act No. 4 Of 2006).

This application form requires the following details:

- o Particulars of Applicant
- o Commencement Date of Licence
- o Particulars of Proposed Generation Station
- o Particulars of Long Term Arrangements with Primary Energy Suppliers
- o Maintenance Programmes and Decommissioning Costs
- o Customer Profile
- o Financial Information
- o Human Resources Information
- o Permission from other Government Departments or Regulatory Authorities
- o Broad-Based Black Economic Empowerment
- o Additional Information
- o Declaration

4.10 General legislative considerations

Before a hydropower plant can be constructed on a conduit, it is necessary that certain permissions be obtained from the relevant authorities. The following should be considered:

-  **Conduit owner permission:** Before a project can commence, it is vital to obtain permission from the owner of the conduit or infrastructure to utilise the facility for power generation.
-  **Water use license:** Permission to abstract water from a dam has to be obtained from the Department of Water Affairs (DWA). This will however not be applicable to most of the conduit hydropower facilities. In general, the generation of hydropower does not consume water or create an additional demand, in which case the only applicable costs are the water use charge. If, however, it is concluded that the plant has a negative influence on the quality of the water released, a water discharge cost will be incurred once the polluter pay principle is implemented.



 **Generation licence:** The Energy Regulation Act No.4 of 2006 gives a very clear outline of the procedures and regulations involved in the production of electricity. Under this act, the National Energy Regulator of South Africa (NERSA) is granted the sole authority to approve applications for the generation of electricity and any person who generates, distributes, transmits, imports, exports or trades electricity can only do so with a licence from NERSA (Government Gazette 2006).

 **Power purchase agreement:** Lastly, hydropower can be generated for a number of reasons and sold to an array of different people including private enterprises, local municipalities and Eskom. Whatever the case, a power purchase agreement must be signed with the authority or purchaser of the electricity under the supervision of NERSA unless produced for own use.

The following policy documentation, strategic plans and legislation, inter alia, guides the implementation of small-scale conduit hydro-power generation systems:

i. Constitution of the Republic of South Africa, 1996

The Constitution (Schedule 4) refers to 'Electricity and gas reticulation' as being a local government function. Therefore bulk electricity is not the responsibility of local government and is a national function, with Eskom being assigned primary responsibility for this.

(COGTA, Development of a strategy that informs coordinated bulk infrastructure investment and motivates for the establishment of the Bulk Infrastructure Fund)

ii. Electricity Regulation Act (Act 4 of 2006) as amended in 2007

This Act provides for **licences and registration** as the manner in which generation, transmission, distribution, trading and the import and export of electricity are regulated.

- Schedule 1 of this Act describes those activities which require an Electricity Generation licence, and
- Schedule 2 of this Act describes those activities which are exempt from the Electricity Generation Licensing requirements.

Further, the Act allows for the Minister of Energy to make determinations for the establishment of Independent Power Producers (IPP) for the purpose of greater competition in the electricity generation sector so as to increase the supply of electricity. *(DoE, Revised Strategic Plan 2011/12 – 2015/16)*

iii. Integrated Resource Plan, 2010-2030 (the National Electricity Plan)

The Integrated Resource Plan in the South African context is not the Energy Plan - it is a **National Electricity Plan**. It is a subset of the Integrated Energy Plan.



The IRP is also not a short or medium-term operational plan but a plan that directs the expansion of the electricity supply over the given period, emphasizing the objectives for the development of renewable energy technologies.

The IRP's research agenda for next IRP revision is stated to include, inter alia, distributed generation options:

"...distributed generation should be seriously considered in future iterations of the IRP with additional research into the technology options for distributed generation and the impact on networks, pricing and residual demand on centrally planned generation."

The current, unrevised IRP does not consider distribution generation.

iv. Municipal Systems Act (Act 32 of 2000)

Chapter 8 of the Municipal Systems Act describes the processes that a municipality needs to undertake to ensure efficient and sustainable municipal service provision. Part 2 in particular describes the process to be followed to determine whether municipal services (including water and electricity) should be undertaken internally, or externally. i.e. whether or not an external service provider should be appointed for the provision of specific municipal services.

It defines, inter alia, the powers and functions of "water services providers" and "electricity service providers" in relation to the municipality.

v. Municipal Finance Management Act (Act 56 of 2003) and Public Finance Management Act (1 of 1999)

Other legislation impacting on the supply chain management in a municipality is the **Municipal Finance Management Act** (56 of 2003) and the **Public Finance Management Act** (1 of 1999). The Public Finance Management Act will only be applicable in cases where a Water Board or National Government implements a water scheme. In the case where a municipality or a structure of the municipality is involved, the Municipal Finance Management Act will be applicable.

The MFMA aims to modernise budget, accounting and financial management practices by placing local government finances on a sustainable footing in order to maximise the capacity of municipalities to deliver services to communities. It also aims to put in place a sound financial governance framework by clarifying and separating the roles and responsibilities of the council, mayor and officials. *(National Treasury)*



The MFMA is required by the Constitution, which obliges all three spheres of government to be transparent about their financial affairs. It also forms an integral part of the broader reform package for local government, as outlined in the 1998 White Paper on Local Government. (*National Treasury*)

vi. National Water Act (Act 36 of 1998), as amended in 1999

The National Water Act deals with the *water resource*. (i.e. rivers, streams, dams, and ground water and governs the way that the **water resource** is protected, used, developed, conserved, managed and controlled, mainly through licensing and registration processes and procedures.

vii. Water Services Act (Act 108 of 1997) and Water Services Amendment Act (Act 30 of 2004)

This Act deals primarily with the provision of water services and the structures involved in the provision of these services.

One of the main objects of this Act is to provide for the right of access to basic water supply and the right to basic sanitation necessary to secure sufficient water and an environment not harmful to human health or well-being.

 **Water services** are defined as water supply services and sanitation services.

- o Water supply services is in turn defined as the abstraction, conveyance, treatment and distribution of potable water, water intended to be converted to potable water or water for commercial use **but not water for industrial use**.
- o Sanitation services mean the collection, removal, disposal or purification of human excreta, domestic waste-water, sewage and effluent resulting from the use of water for commercial purposes.

 Water services works means a reservoir, dam, well, pump house, borehole, pumping installation, purification work, sewage treatment plant, access road, electricity transmission line, pipeline, meter, fitting or apparatus built, installed or used by a water services institution

- o to provide water services;
- o to provide water for industrial use; or
- o to dispose of industrial effluent.

(Industrial use means the use of water for mining, manufacturing, **generating electricity**, land-based transport, construction or any related purpose.)



It is important to note that the water classification is based on its intended use and not its inherent quality. Mines often used water of a potable quality due to its proximity to a potable water system. The potable water used by the mine is, however, classified as an industrial water use in terms of the Water Services Act.

This Act also spells out the distinction between water services authorities (Local Authorities) and water services providers.

Chapter III of the Water Services Act deals with water services authorities. Section 11 describes the duty of water services authorities to provide access to water services. It clearly states in section 11(1) that *'every water services authority has a duty to **all** consumers or potential consumers in its area of jurisdiction to progressively ensure efficient, affordable, economical and sustainable access to water services'*.

Section 19(1) states that a water services authority may select a number of ways to provide these services. It may elect to perform the services itself, enter into a contract with a water services provider or form a joint venture with another water services institution.

In section 9(1) the act states that *'no person may obtain water **for industrial use** from any source other than the distribution system of a water services provider nominated by the water services authority having jurisdiction in the area in question, without the approval of the water services authority'*.

viii. The National Environmental Management Act, 1998 as amended;

The National Environment Management Act makes provisions for the Environmental Impact Assessment process.

The Government Gazette of 18 June 2010 provides three schedules of activities which define whether a full EIA-, or a Basic Assessment only, is to be undertaken. (GN544 for Basic Assessment (BA) activities, GN545 for EIA activities and GN456 for geographical activities.)

In addition to the documents listed above, the following policy documentation, strategic plans and legislation, inter alia, should be noted:

- 🔗 National Energy Regulator Act, 2004;
- 🔗 Revised Strategic Plan of the Department of Energy, 2011/12 – 2015/16;
- 🔗 The Electricity Regulation second amendment Bill;
- 🔗 National Energy Regulator Act 2004;
- 🔗 National Energy Act, 2008.
- 🔗 Strategic Framework for Water Services, 2003;



-  Public Finance Management Act, 1999;
-  Municipal Infrastructure Investment Framework, 2011.

4.11 Funding mechanisms and options

This section considers what sources of funds in South Africa could be accessed for the capital component of the project, by the entities installing small-scale conduit hydropower installations.

4.11.1 Financing Scenarios

Table 4-7 summarises the capital funding options available to the entities most likely to be involved in implementing small-scale conduit hydropower installations.

Table 4-7: Summary of funding options available

	Water Boards	Municipalities	Private Companies
Government Grants	n.a.	X	n.a.
Donor Funds	X	X	X
Own Funds	X	X	X
Loans	X	x	X

Municipalities, excluding possibly Metropolitan Municipalities, typically have limited borrowing capacity. In other words, Municipalities are typically not able to raise finance against their own balance sheets. Municipalities therefore can either make use of their own funds, donor funds or Government Grant funding to fund the capital expenditure of a small scale conduit hydro-power project. The latter of which is not available to Water Boards or any Private companies operating within the water sector.

The capital cost associated with generating 1MW through conduit hydropower technology, is estimated at approximately R18-28 million (based on 2013 values). It is therefore anticipated that the majority of municipalities and Water Boards, when implementing a single small scale conduit hydropower installation project, will make use of own funds to finance the capital expenditure component of the project.

Should a Municipality or Water Board though decide to group a number of projects together, increasing the capital cost to over approximately R150 million, that entity could decide to establish a Special Purpose Vehicle (SPV) to access non-recourse loans.

The SPV would be established so as to clearly ring-fence the specific infrastructure that would need to be funded through the non-recourse loan, thereby defining the asset that can be seized by the investor should the Municipality or Water Board default on their loan repayments.



Should a Municipality or Water Board decide not to establish a SPV for purposes of attaining a non-recourse loan, they potentially run the risk of exposing non-project related income streams to being seized in the event of them defaulting on their loan repayments.

The structuring of such a project finance deal will be expensive and time-consuming and should be undertaken by suitably qualified transaction advisors. The details of such a process are not discussed in this document.

Non-recourse loans secured by the project assets and paid from the project cash flow, are the most common form of loan for infrastructure projects in South Africa.

Other principal types of loan capital, particularly for a developing country such as South African include:

-  Aid supported loans with very low interest rates, and a long repayment span, typically offered by the World Bank;
-  Concessionary loans with moderate interest rates, and a moderate repayment span, typically offered by national financing institutions (e.g. DBSA, IDC etc);
-  Commercial loans are generally expensive with short repayment periods.

4.11.2 Grant Funding

The current version of the IRP does not make allowance for distributed (including embedded) electricity generation options, resulting in the DoE not including these options specifically into any DoE Projects or Programmes, implying therefore that no specific Government Grant funding was allocated by the DoE to cover any capital costs associated with distributed electricity generation options.

Table 4-8 below lists current Government grants that indirectly might allow for applications by Municipalities requesting funds to cover the capital costs associated with small-scale conduit hydropower installations.



Table 4-8: Description of current grants - Division of Revenue Bill, 2013

Name of allocation	Purpose	Type of allocation	Controlling department /vote
Schedule 4B: Allocations to Municipalities to Supplement the Funding of Functions Funded from Municipal Budgets			
Urban Settlements Development Grant	Supplements the capital resources of metropolitan municipalities in order to support the national human settlements development programme, focussing on poor households.		Human Settlements (Vote 31)
Schedule 5A: Specific Purpose Allocations to Provinces			
Human Settlements Development Grant	To provide funding for the creation of sustainable human settlements.	Conditional allocation	Human Settlements (Vote 31)
Schedule 5B: Specific Purpose Allocations to Municipalities			
Recurrent Grants			
Energy Efficiency and Demand Side Management Grant	To provide subsidies to municipalities to implement Energy Efficiency and Demand Side Management initiatives within municipal infrastructure in order to reduce electricity consumption and improve energy efficiency		Energy (Vote 29)
Schedule 5B: Specific Purpose Allocations to Municipalities			
Infrastructure Grants			
Municipal Infrastructure Grant	To provide specific capital finance for basic municipal infrastructure backlogs for poor households, to micro enterprises and social institutions servicing poor communities.		Cooperative Governance and Traditional Affairs (Vote 3)
Integrated National Electrification Programme (Municipal) Grant	To implement the Integrated National Electrification Programme (INEP) by providing capital subsidies to municipalities to address the electrification backlog of permanently occupied residential dwellings, the installation of bulk infrastructure and rehabilitation and refurbishment of electricity infrastructure in order to improve quality of supply.		Energy (Vote 29)
Neighbourhood Development Partnership Grant	To support and facilitate the planning and development of neighbourhood development programmes and projects that provide catalytic infrastructure to leverage third party and private sector development towards improving the quality of life of residents in targeted underserved neighbourhoods (generally townships)		
Schedule 6A: Allocation-in-kind to provinces for designated special programmes			
School Infrastructure Backlogs Grant	Eradication of entire inappropriate school infrastructure, provision of water, sanitation and electricity to schools		Basic Education (Vote 15)
Schedule 6B: Allocation-in-kind to municipalities for designated special programmes			
Neighbourhood Development Partnership Grant	To support and facilitate the planning and development of neighbourhood development programmes and projects that provide catalytic infrastructure to leverage third party and private sector development towards improving the quality of life of residents in targeted underserved neighbourhoods (generally townships)		National Treasury (Vote 10)
Integrated National Electrification Programme (Eskom) Grant	To implement the Integrated National Electrification Programme (INEP) by providing capital subsidies to Eskom to address the electrification backlog of occupied residential dwellings, the installation of bulk infrastructure and rehabilitation and refurbishment of electricity infrastructure in order to improve quality of supply.		Energy (Vote 29)
Regional Bulk Infrastructure Grant	To develop regional bulk infrastructure for water supply to supplement water treatment works at resource development and link such water resource development with the local bulk and local distribution networks on a regional basis cutting across several local municipal boundaries. In the case of sanitation, to supplement regional bulk collection as well as regional waste water treatment works.		Water Affairs (Vote 38)



4.12 Summary

In South Africa, the legal entities most likely to own water services infrastructure suitable for the implementation of pico-, micro- and mini conduit hydropower projects are WSAs, WBs and WUAs.

Where the potential for conduit hydropower has been proven feasible, these entities can consider using the capacity generated for:

-  **“own use”**, an ideal option where the capacity of the electricity generated on site is less than the demand of the operations on site. Current legislation also exempts own use generation from requiring a NERSA electricity generation licence;
-  **“Islanded use”**, if applied for commercial purposes in the context of off-grid electrification through the INEP, will require extensive compliance criteria to be met, in addition to the requirement of a NERSA electricity generation licence; and
-  interconnecting with the **Municipal distribution network**. If the capacity generated is more than 100kW, a NERSA electricity generation licence will be required. Compliance to applicable technical and safety specifications and standards is important.

WSAs, WSPs, WBs and WUAs do not qualify as IPPs, and are therefore excluded from the Department of Energy’s New Generation Capacity IPP procurement programmes. The regulatory and institutional aspects regarding connecting to a distribution network (<132kV) by Generators other than Eskom is compiled in **Table 4-9**.

In the United States of America an Act to improve the development of hydropower was recently promulgated. It is referred to as the “Hydropower Regulatory Efficiency Act of 2013”. The Act contains various sections including:

-  Promoting small hydroelectric power projects (Sec 3)
-  Promoting conduit hydropower projects (Sec 4)
-  FERC authority to extend preliminary permit periods (Sec 5)
-  Promoting hydropower development at non-powered dams and closed loop pumped storage projects (Sec 6)

The aim of the Act is to streamline the regulatory processes usually required in developing a hydropower plant. This would save time, costs and effort and would make the implementation of such developments much easier. The administrative burden on the regulators usually associated with a hydropower development is also reduced.



Table 4-9: Connection to a Distribution Power System (<132kV) by Generators other than Eskom

Electricity generation usage	Islanded Use	Own Use	Municipal Grid Connection	Eskom Grid Connection
	Completely independent from any distribution / reticulation network	Ability to generate electricity for own use in addition to receiving electricity from a network (if any)	Electricity generated feeds into a municipal grid, can be used for more use also in addition to receiving electricity from a municipal grid network (in and out)	Electricity generated feeds into the Eskom grid
	NOT CONSIDERED AS 'NEW GENERATION CAPACITY' (Electricity Regulation Act 2006, Schedule 2)	NOT CONSIDERED AS 'NEW GENERATION CAPACITY' (Electricity Regulation Act 2006, Schedule 2)	'NEW GENERATION CAPACITY' & 'LM Generation' (Electricity Regulation Act 2006, Schedule 2)	'NEW GENERATION CAPACITY' (Electricity Regulation Act 2006, Schedule 2)
Description	IPP or Organ of State/State-owned Enterprise	IPP or Organ of State/State-owned Enterprise	IPP or Organ of State/State-owned Enterprise	IPP only
	Own Generation	Own Generation	Embedded Generation (not EG)	Embedded Generation
			Small-scale EG	Small-scale EG
			Large-scale EG	Large-scale EG
Compliance requirements (additional to the relevant grid code)	Applicable electrical codes of best practice	Applicable codes of best practice	Generation licence required if >100kW	Generation licence required if >100kW
	No Generation licence required if for non-commercial use (Electricity Regulation Act 2006, Schedule 2)	No Generation licence required if for non-commercial use (Electricity Regulation Act 2006, Schedule 2)	Generation licence required if >100kW	Generation licence required if >100kW
Electricity Generation Licence (issued February 2013) (Plant Operator to NERSA)	ESF Guide 2012 notes that NERSA requires at least the generation application form to have been completed and submitted for NERSA info only	ESF Guide 2012 notes that NERSA requires at least the generation application form to have been completed and submitted for NERSA info only	ESF Guide 2012 notes that NERSA requires at least the generation application form to have been completed and submitted for NERSA info only	ESF Guide 2012 notes that NERSA requires at least the generation application form to have been completed and submitted for NERSA info only
Local electricity utility involvement	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility
Proof of Land Ownership/Permission to use land obtained	Good Practice	Good Practice	Good Practice	Good Practice
Environmental ROD (Plant operator to Provincial or National DEA)	(If the construction of facilities or infrastructure for the distribution of electricity is required, a permit must be obtained from the DEA)	(If the construction of facilities or infrastructure for the distribution of electricity is required, a permit must be obtained from the DEA)	(If the construction of facilities or infrastructure for the distribution of electricity is required, a permit must be obtained from the DEA)	(If the construction of facilities or infrastructure for the distribution of electricity is required, a permit must be obtained from the DEA)
Water Use Licence (Plant operator to NERSA)	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility
Water allocation confirmation (Plant operator to WSP)	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility	Same good practice should be applied to utility LM and or utility
Commission consent	Consent of the Civil Aviation Commission to erect a potential obstacle to aviation or confirmation from the civil aviation authority that none is required	Consent of the Civil Aviation Commission to erect a potential obstacle to aviation or confirmation from the civil aviation authority that none is required	Consent of the Civil Aviation Commission to erect a potential obstacle to aviation or confirmation from the civil aviation authority that none is required	Consent of the Civil Aviation Commission to erect a potential obstacle to aviation or confirmation from the civil aviation authority that none is required

Note: This diagram is included on the **HydroAID** supporting DVD



5. ECONOMIC FEASIBILITY STUDIES AND FINANCING

5.1 Introduction

While the accurate identification of the technical potential of a possible hydropower site is crucial, the key to its successful development is a near accurate economic analysis. This is necessary to determine whether the costs incurred for the development of a site can be recovered (ESHA, 2004).

The development of any hydropower scheme will include a number of expenses, both initial and throughout the project life, and returns distributed throughout the same period. The expenses include fixed costs (like capital cost) and variable costs (like operation and maintenance (O&M) expenses) (ESHA, 2004).

It is necessary to compare the costs and returns to determine whether a project is deemed to be economically feasible. The various methods of performing this comparison include the calculation of the net present value (NPV), benefit-cost ratio, internal rate of return (IRR), as well as determining the payback period of a project (NRC, 2004).

The principal objectives of the economic analysis can be described as follows (CETC, 1991):

-  *ensure most efficient use of resources;*
-  *compare development options in terms of scale and risk;*
-  *compare hydro power with other power generation options; and*
-  *decide whether to implement a project.*

The methodology of the economic analysis explicitly addresses efficient use of resources. It is designed to summarize the economic impacts of project development such that the results are readily interpreted to rank project alternatives and to determine whether a particular project represents a good investment.

The financial analysis and the development of the financing plan provide a means for achieving additional objectives (CETC, 1991):

-  *maximization of investor wealth;*
-  *determination of revenues and funding requirements;*
-  *identification of funding sources; and*
-  *means for explicitly addressing risk elements.*

The economic and financial considerations necessary for determining project feasibility cannot be viewed as isolated elements or a distinct step in the process. The analyst needs to be constantly mindful of the impacts that a whole range of preliminary



decisions arising from the engineering analysis will have on project economics. Depending upon the complexity of the project, it may be necessary to conduct economic assessments at various stages of the project. As more information becomes available from the technical and hydraulic investigations, the quality of the economic analysis will obviously improve and become more detailed.

It should be noted that it is appropriate to leave all considerations of economics until after all of the engineering is in hand, since the economic assessments should be used as screening and ranking tools to yield a process of elimination as project alternatives are considered. The economics of the project will be significantly influenced by the decisions of the technical design, hydraulics and power, and potential generating capacity.

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

- (i) energy and generation capacity estimates for each alternative;
- (ii) capital and operating cost estimates for each alternative;
- (iii) user demand patterns and growth projections; and
- (iv) interest rates and projected future changes in rates.

If the economic analysis is to be conducted at the conceptual or pre-feasibility stage, the detail will obviously be limited. However, significant time and cost can be wasted if the economics are not examined even at this stage.

While static methods, like the payback period, may be easier to calculate, it is valuable to consider the time value of money and therefore use dynamic methods to determine economic feasibility. The following sections investigate the parameters used in various static and dynamic analysis methods.

5.2 Static methods of economic analysis

5.2.1 Payback period

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



$$\text{Payback period} = \frac{\text{investment cost}}{\text{net annual revenue}} \quad \dots(5.1)$$

Equation 5.1 does not incorporate the time value of money and only considers the life of the project until the payback point has been reached. However, other literature suggests that inflation may be included and that the payback period would then be the time taken to equate initial capital outlay and the present value of net annual cash flow (Blank and Tarquin, 2004).

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

5.2.2 Return on investment (ROI)

This method calculates the net annual benefit (income minus costs) as a percentage of the original cost of the investment. The formula used for the calculation is:

$$\text{ROI} = \frac{\text{net annual revenue} - \text{depreciation}}{\text{investment cost}} \times 100 \quad \dots(5.2)$$

With depreciation calculated using the straight-line method:

$$\text{Depreciation} = \frac{\text{cost} - \text{salvage value}}{\text{operational life}} \quad \dots(5.3)$$

The ROI can be used as a quick estimate of a project's profitability, but, as it does not consider the time value of money or cash flow over the design life, dynamic analysis methods are preferred (ESHA, 2004).

5.3 Dynamic methods of economic analysis

Various techniques, all based on the principle of discounted cash flows, can be used for cost-benefit analysis. The four most commonly applied techniques are (SANRAL, 2013):

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

These methods are discussed in the following sections.



5.3.1 Present worth of cost (PWOC)

This technique is used to find the lowest cost alternative between various mutually exclusive projects. All costs, including the cost of provision, management, maintenance and use of each of the alternatives are discounted to their present worth. The alternative with the lowest PWOC is the most cost-effective alternative. This method can be expressed as follows (**Equation 5.4**) (SANRAL, 2013):

$$PWOC = C_A + PW(M + U) \quad \dots(7.4)$$

where:

- $PWOC$ = present worth of cost
- C_A = all costs incurred in establishing a facility (i.e. the opportunity cost of the investment)
- $PW(M + U)$ = present worth of all facility maintenance costs and user costs.'

[Note that in the case of the null alternative (i.e. the existing facility whose possible replacement or upgrading is being investigated, and against which the other mutually exclusive alternatives are measured), $PWOC = PW(M + U)$].

5.3.2 Net present value (NPV)

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

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

The net present value (NPV) of a project is determined by subtracting the present worth of investment cost from all future benefits. A positive NPV would indicate an economically feasible project, with a higher value more advantageous than a lower value. The formula used for this method is (**Equation 5.5**) (SANRAL, 2013):

$$NPV = PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A) - C_A \quad \dots(5.5)$$

where:

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



$PW(M_A + U_A)$	=	the present worth of facility maintenance costs and user costs of a proposed alternative
$PW(CS_A)$	=	consumer surplus gained through additional usage induced by the proposed alternative. This is equal to one-half of the benefit accruing to each existing journey multiplied by the number of induced trips.
C_A	=	investment (capital) cost that is required to implement the alternative A'

If the NPV > 0 then the project should be implemented, but should the NPV be < 0 the investment does not provide an acceptable return.

5.3.3 Benefit/Cost Ratio (B/C) technique

This method gives an economic viability measure using the ratio between the present worth of future benefits and costs. It is used to select the most advantageous among independent projects. Future benefits include annual savings relative to the null alternative, plus income gained through usage of the facility.

The benefit/cost ratio is calculated by dividing the sum of all income and savings by the costs. Any project with a B/C ratio greater than one is deemed feasible, with a higher value indicating a more viable project. The formula used for this method is given in **Equation 5.6** (SANRAL, 2013):

$$B/C = \frac{PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A)}{C_A} \quad \dots(5.6)$$

where:

B/C	=	benefit/cost ratio
$PW(M_0 + U_0)$	=	the present worth of facility maintenance costs and user costs of the null alternative
$PW(M_A + U_A)$	=	the present worth of facility maintenance costs and user costs of a proposed alternative
$PW(CS_A)$	=	consumer surplus gained through additional usage induced by the proposed alternative. This is equal to one-half of the benefit accruing to each existing journey multiplied by the number of induced trips.
C_A	=	investment (capital) cost that is required to implement the alternative A'



5.3.4 Internal rate of return (IRR)

This method can also be used to find the most viable between independent projects. The distinguishing feature of this method is that it shows the discount rate at which the project would break even. Future benefits and costs are calculated in the same way as for the NPV or B/C methods and discounted to the present using different rates until a rate is found where the returns and costs are equal. This rate is the internal rate of return. The higher the IRR, the more advantageous the project will be. The formula used for this method is shown in **Equation 5.7** (SANRAL, 2013):

$$IRR = r \quad \text{when} \quad PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A) = C_A \quad \dots(5.7)$$

where:

IRR	=	internal rate of return
r	=	rate at which the left-hand and right-hand sides of the equation are equal, resulting in an NPV of zero.
$PW(M_0 + U_0)$	=	the present worth of facility maintenance costs and user costs of the null alternative
$PW(M_A + U_A)$	=	the present worth of facility maintenance costs and user costs of a proposed alternative
$PW(CS_A)$	=	consumer surplus gained through additional usage induced by the proposed alternative.
C_A	=	investment (capital) cost that is required to implement the alternative'

If the prevailing real discount rate exceeds the prevailing social discount rate, the alternative is economically viable. However, when mutually exclusive projects are compared, incremental analysis should be used to identify the best alternative.

5.4 Valuation of energy

The demand for electricity is derived from users of the power and the value of the power depends on the use that will be made of it and the alternative means of obtaining it.

Electricity is desired for what it can do, not for what it is. Thus, a critical question early in the economic analysis becomes: "What is a hydro development worth?" For the purposes of the economic analysis, the value of small hydro is the stream of future benefits it can provide, or the stream of costs which can be avoided. These avoided costs are primarily associated with the alternatives to the small hydro project.



In most instances, the relevant alternatives will be diesel generation or connection to the national Eskom electric grid. Thus, the economic analysis becomes a comparison of the capital and operating costs of the small hydro development against those associated with diesel generation.

The comparison between hydro and the alternative energy sources will also be influenced by whether it will be only base load that can be supplied or will there be sufficient energy to supply the peak electrical load expected.

5.5 Alternative energy costs

For any power generation alternative, the relevant costs to be identified and quantified will be capital costs and operating and maintenance costs. Thus if you decide to generate electricity with diesel, there will be a capital cost associated with the purchase of the diesel engine and generator set, fuel tanks, electrical switchgear and wiring, etc., as well as transmission line from the generator to the end-use point. The primary operating cost will be the diesel fuel for the engine while maintenance costs will include lubricants, inspections, engine tuning and adjusting, spare parts and so on. Diesel generation is typically characterized by relatively low capital costs but high operating costs.

The other aspect of evaluating energy costs depends on the amount of energy beneficially used. Diesel generating systems are relatively flexible since the supply will, within certain bounds, react to the demand. This is not necessarily the case with hydro generation. The energy available from hydro, or from grid connection, is independent of the level of demand at any particular point in time.

For the initial examination of the economics of alternative sources of electrical energy, unit costs should be calculated. A unit cost combines capital and operating costs associated with the source and implicitly recognizes the length of time the facility will provide economic returns.

5.6 Other evaluation considerations

As noted above, the calculation of unit costs is generally the "first cut" in determining project feasibility and comparing electrical supply alternatives.

5.6.1 Back-up electrical supply

Emergency back-up would be required where there is a need to have some minimal level of power if the primary source is out of service. This situation arises where



freezers are required to preserve food, heat is required, some minimal lighting is required, medical equipment is in use, etc.

In other words, emergency power is necessary wherever the ramifications of being without power supplies are serious enough to warrant provision of back-up. In very remote areas, it is probable that some back-up will be necessary because it could take some time to repair the primary source if it is out of commission due to accidents or breakdowns. The hybrid configuration of hydro power and other RE sources may provide for a suitable emergency back-up although this would increase the cost of such a development.

Landslides, earthquakes or tornadoes can take out transmission lines, intakes could be blocked on a hydro generator, diesel systems could breakdown and so on. These circumstances make it is necessary to include the capital cost of a small back-up diesel generator in the total costs of the system being evaluated.

In order to calculate the unit costs associated with a combined supply option, you need to estimate the amount of energy which would be supplied by each. The relevant capital and operating costs for both must also be compiled.

5.6.2 Load management

Another area of consideration in the preliminary economic analysis is the managing of load to optimize the economic results. A hydroelectric development costs the same whether 50 percent of its potential power is utilized or 100 percent. Obviously, the unit price of energy under these two circumstances will be quite different, however. A similar effect is observed in the relationship between peak and average demands. Basically, if peak demands are far greater than average demands, to design capacity to meet the peaks may be quite inefficient, if by doing so, your capital costs increase significantly.

Constraints on the range of options which are feasible will be imposed by the engineering and hydraulic studies. Application of the unit costs technique or other economic evaluation techniques described later, however, will provide a useful tool for narrowing the range of alternatives.

5.6.3 Energy conservation

A final area of concern in the preliminary economic analysis involves the question of the costs of energy conservation against the costs of a new electrical generation project. Earlier, it was stated that by increasing the average load on a small hydro facility, the unit costs of the energy will decrease. In general it would always be necessary to investigate efficient use of energy first since new generation, even if it is less costly than



the present supply, will not necessarily provide greater economic efficiency if the consumption of that energy is itself wasteful and inefficient.

5.6.4 Energy use efficiency

The efficiency measures are related more to the optimization of energy usage and application of advanced technologies such as conduit hydropower. Specifically within the municipal water cycle the improvements of energy efficiency are related to pressure management and leakage reduction, off-peak pumping, load shifting as well as hydro power generation in pressurised distribution networks and low-head hydropower at for example waste water treatment plant outlets.

5.7 Detailed economic assessment

Assuming the preliminary feasibility analysis and estimation of energy unit costs provided adequate encouragement to continue, more detailed engineering, hydraulic and demand analysis tasks will have been undertaken. As a result, cost estimates will be more refined, units will have been sized and the available energy will have been calculated.

At this stage then, it is appropriate to conduct a more rigorous analysis of project economics utilizing some of the economic evaluation techniques discussed in the following paragraph.

The more detailed economic analysis is used to screen projects to insure they meet minimum economic criteria and to rank those projects which satisfy the minimum criteria so that the "best" alternative is taken. The techniques takes explicit recognition of the "time value of money" by considering that money expended or received now are more valuable than money expended or received several years in the future.

Useful life is the shorter of the expected lifetime of the major components of the hydro facility and the expected lifetime of the end-use activities. A second important timing consideration involves assigning the timing of project start-up activities. The start and length of the construction period will influence the timing of cash outflows, and will also determine the timing of when cash inflows (that is, electricity) will commence.

5.8 Defining the costs

A number of expenses are incurred throughout the project life of any hydropower scheme development. These include fixed costs (like capital cost) and variable costs (like operation and maintenance expenses) (ESHA, 2004). Barta (2011) proposes that costs be defined in the following categories: initial planning cost; capital cost; operation



and maintenance cost; and retirement/disposal costs. These categories are discussed in the following sections.

5.8.1 Initial planning cost

Initial planning costs essentially consist of the costs related to conceptual designs, basic site investigations and regulatory compliance costs. This can be summarised using the following (**Equation 5.8** and **Table 5-1**):

$$\text{Initial planning cost (IPC)} = C_{\text{investigation}} + C_{\text{environment \& social}} + C_{\text{legal \& regulatory}} \quad \dots(5.8)$$

Table 5-1: Prerequisite cost components of initial planning costs (IPC) (Barta, 2011)

Initial planning cost (IPC)		
Costs of investigation ($C_{\text{investigation}}$)	Costs of environmental and social assessment ($C_{\text{E\&S}}$)	Costs of legal and regulatory requirements ($C_{\text{L\&R}}$)
Project inception note/terms of reference (C_{TOR}) Project formulation/baseline or inception report (C_{PB}) • Desk review of previous work • Site(s) field visit(s) • Main project parameters • Conceptual design • Layout and programme of field surveys (e.g. geology, hydrology, asset status, etc.)	Environmental impacts scoping (C_{ES}) • Environmental scope • Base line data • Potential impacts • Mitigation and institutional measures Social benefits/dis-benefits evaluation (C_{SE}) Social local/regional benefits/dis-benefits • Stakeholders sentiments • Target market(s) • Risks assessment	Legal and regulatory package report (C_{LR}) • Water-use permit requirements • National Environmental Management Act (1996) • National Energy Regulator (NERSA) licence • Power Purchase Agreement (PPA) Guidelines • REIPPP costs and requirements (if applicable) Applications follow-up costs (C_{LF})

Equation 5.8 can be re-written as follows (**Equation 5.9**):

$$IPC = C_{\text{TOR}} + C_{\text{PB}} + C_{\text{ES}} + C_{\text{SE}} + C_{\text{LR}} + C_{\text{LF}} \quad \dots(5.9)$$

where:

C_{TOR} = *Terms of reference cost*: depending on the type of hydropower project and magnitude, the ToR is normally issued by national government, local government authority or parastatal entity through tenders. The private developer normally



issues an inception note to the invited consultancy. The costs incurred are carried by the issuing agency.

C_{PB} = *Project formulation baseline report costs*: the developer usually carries the costs of time and resources used by the consultant in the compilation of the baseline (inception) report.

C_{ES} = *Environmental impacts scoping*: the developer usually pays for investigation and reporting of a project's ecological effects. A specialised consultancy is normally employed for the evaluation of the scope of proposed project impacts. The environmental impacts scoping is a first step towards a full environment impacts assessment (EIA).

C_{SE} = *Social benefits/dis-benefit evaluation*: the developer usually carries the time and resource costs incurred by the consultant for investigation and reporting of the project's social impacts.

C_{LR} = *Legal and regulatory package report*: the developer typically pays all costs relevant to this aspect. The lengthy time requirements (permits) and regulations could have a significant impact on the feasibility of a project.

C_{LF} = *Applications follow-up costs*: the developer usually carries these costs.

5.8.2 Capital cost

A major aspect in any civil engineering project is the capital cost of the solution. Capital expenditure typically includes: design costs, the purchase cost of equipment, installation cost, initial training and a start-up commissioning costs. These costs occur only once. According to Barta (2011) capital expenditure in conventional hydropower projects generally consists of the following (**Equation 5.10** and **Table 5-2**):

$$\text{Capital expenditure cost (CEC)} = C_{\text{design}} + C_{\text{purchase}} + C_{\text{installation}} + C_{\text{start-up}} \quad \dots(5.10)$$

where:

C_{design} = *System design costs*: these can be significant and can include detailed design, drawings, project management programme, system operation configuration, and custom designed software. Consulting fees are normally related to the guidelines set by the Engineering Council of South Africa (ECSA).

C_{purchase} = *Purchase costs*: these include costs of materials and equipment. These costs can be obtained from local or international of turbine equipment. These costs have a high level of certainty.

$C_{\text{installation}}$ = *Installation costs*: this includes payment for casting, delivery and mounting of equipment within the civil works.

$C_{\text{start-up}}$ = *Start-up costs*: this aspect accounts mainly for the testing and commissioning of installed equipment.



Table 5-2: Prerequisite cost components of capital expenditure cost (Barta, 2011)

Capital expenditure costs (CEC)			
Costs of design (C_D)	Costs of purchase (C_P)	Costs of installation (C_I)	Costs of start-up (C_S)
Civil engineering design costs (C_{CE}) • access • intake • diversion • headrace • surge chamber • penstock • housing & crane • tailrace Mechanical & electrical design costs ($C_{M\&E}$) • turbine/generator • valves • controls • transformer • transmission • stand-by Project management costs (C_{PM}) • procurement, scheduling and controlling plans	Manufacturing costs (C_{MC}) • turbine and generator • valves • penstock • crane or hoist Quality control costs (C_{QC}) • engineering supervision • management supervision Logistic support and controls (C_{SC}) • backup and sensor systems • operational software Documentation costs (C_{DC}) • equipment O&M manuals	Construction costs (C_{CC}) • civil engineering works • mechanical/electrical works Equipment transport costs (C_{TC}) • road • railway • boat • air Mounting and connecting ($C_{M\&C}$) • mechanical/electrical equipment • SCADA controls • security lighting	Test and evaluation costs (C_{TE}) • training • testing • as-built drawings Commissioning of plant (C_{CP}) • technical • administrative

5.8.3 Operation and maintenance cost

Operation and maintenance (O&M) costs should be carefully broken down into all aspects, including spare parts, training and wages and should allow contingencies of at least 15%. If untried or newly designed and manufactured equipment is used, a full replacement cost should be incorporated. If batteries are used, they should be replaced every three years. It is important to allow for inflation in the prices of spare parts, transport and wages. Management costs should also be included (Harvey et al., 1993).

Revenue cost is related to O&M of equipment. This aspect includes the costs of power, labour, spare parts and materials used for routine maintenance. The O&M costs can be divided into two broad categories (**Figure 5-1**):



- 🔊 **fixed costs (FCs)** – these costs are independent of the output. The costs typically include: payments of loans, salaries, maintenance, etc. The FCs do not vary significantly from year to year during the time under consideration.
- 🔊 **variable costs (VCs)** – these costs are associated with the size of an installation and include charges for grid usage and sales. The VCs are costs that change as output changes. Materials like lubricants and factors like energy usage generate costs that change with varying output.

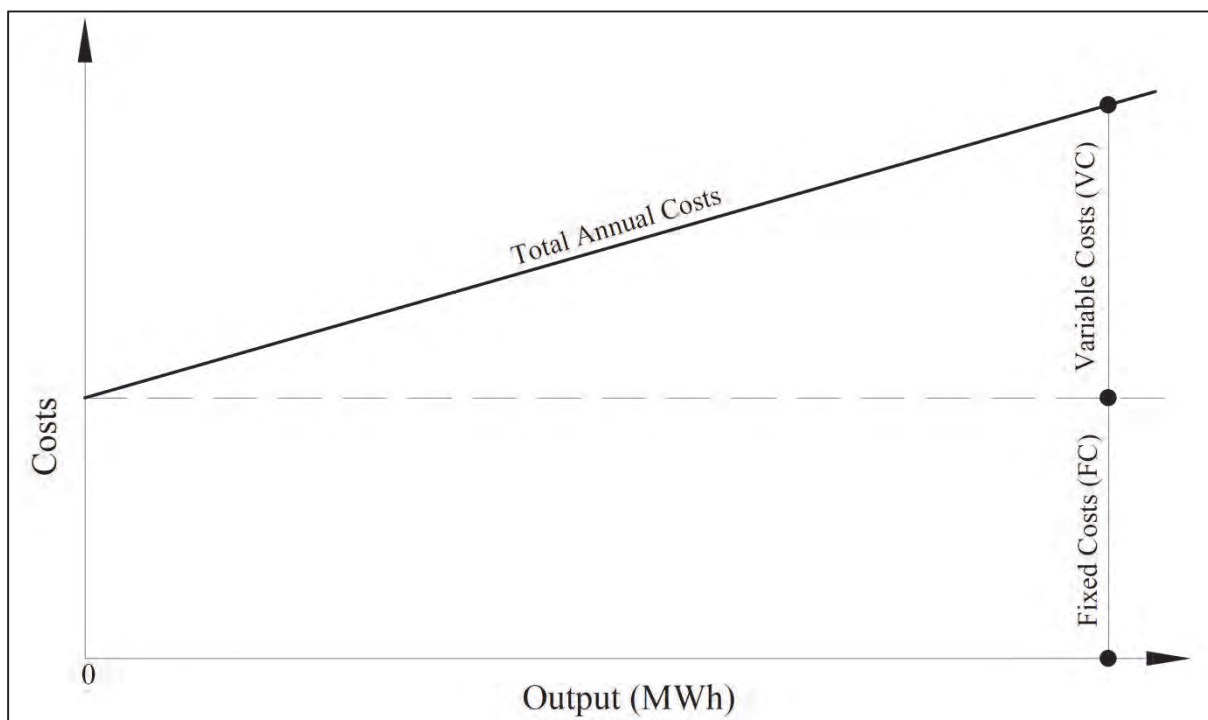


Figure 5-1: Simplified interpretation of total annual costs (Barta, 2011)

5.8.4 Refurbishment cost

These costs will be incurred when major renovations to the hydropower plant take place. The civil works will typically outlive electromechanical equipment by 20 years to 30 years. **Figure 5-2** illustrates the process of hydropower plant decline and the significance of refurbishment.



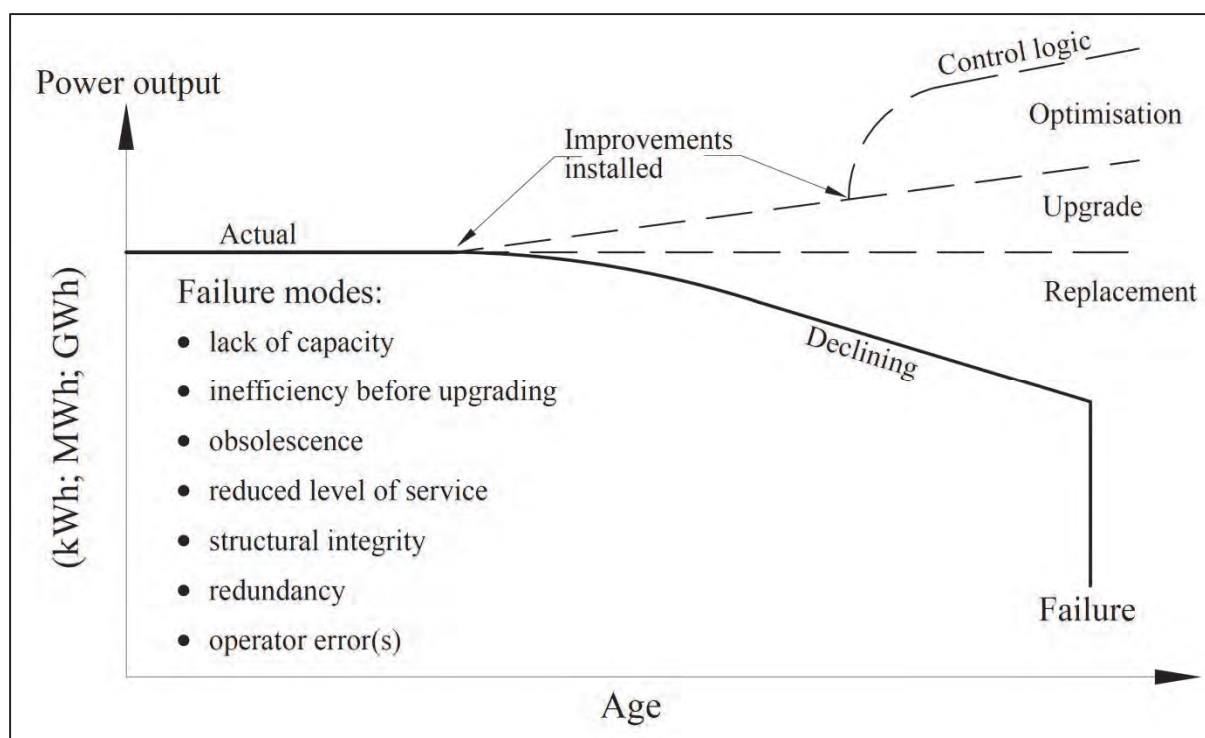


Figure 5-2: Possible status changes of a system component over its life cycle (Barta, 2011)

5.8.5 Retirement/disposal cost

These costs need to be included from planning stages to ensure that the logistics of system retirement, material recycling and, possibly, system replacement, are budgeted for. If environmental rehabilitation is required, the disposal cost will have to be increased over and above the disposal costs for structural and operational items (Barta, 2011).

5.9 Life-cycle costing

Normally engineering projects incur not only capital cost, but also various revenue costs, maintenance costs and ultimately replacement costs over their lifetimes (see **Figure 5-3**). Therefore it is important to consider the value of all the components allowing for the relationship between the value of money and time (Barta, 2011). The life-cycle cost (LCC) of a project includes all costs of constructing and operating a system over its full operating life (in present money value). The useful life of an overall hydropower facility is usually in the order of 30 years to 50 years.

However, different plant components have different expected useful life (EUL) years. **Table 5-4** shows typical useful lifetimes for different hydropower components). LCC provides valuable information that will enable the comparison of projects with different expenditure patterns.



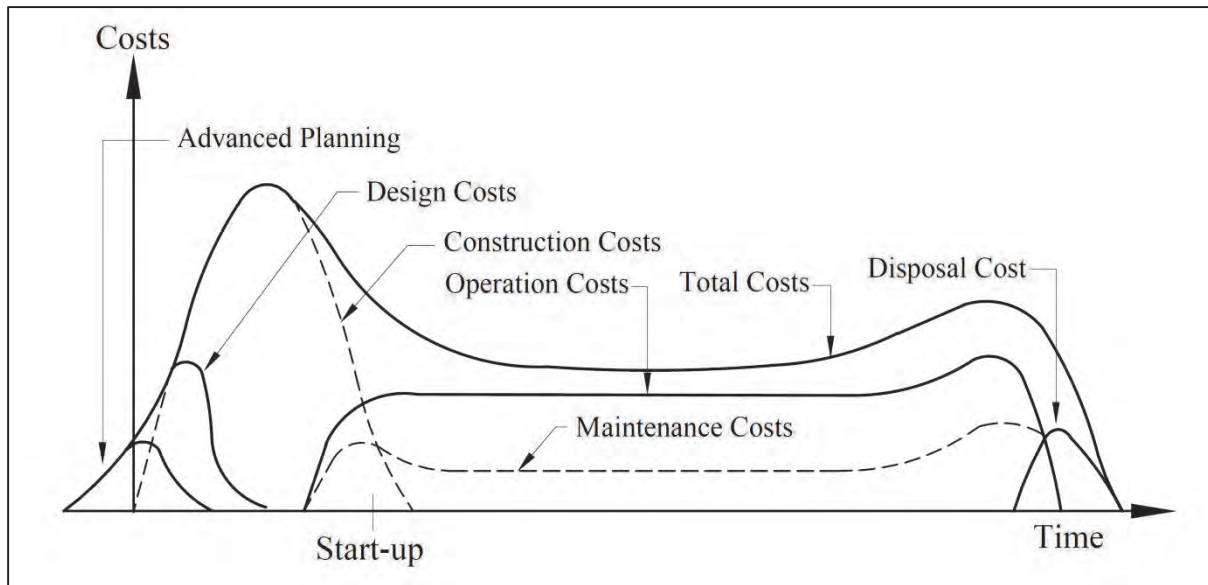


Figure 5-3: Representation of a hydroelectric system life-cycle profile (Stephenson et.al. 2001)

LCC includes all costs associated with a system (or component) as applied over the defined life cycle. It is applicable to all phases of a system design, development, production, construction, operational use and logistics support. An LCC analysis is defined as a systematic analytical process of evaluating various designs or alternative courses of action with the objective of choosing the best way to employ scarce resources (Fabrycky and Blanchard, 1996). A typical table for the determination of the LCC of a project is proposed by Barta (2011) and shown in **Table 5-3**.



Table 5-3: Example of a life-cycle costing analysis (Barta, 2011)

Capital cost of alternative:					Annual cost
Interest/opportunity cost: Capital @ annual interest (%) = C_1					
Depreciation of CC	Cost value	EUL (years)	Rand/annum		
Civil works					
Electrical Eq.					
Mechanical Eq.					
Controls					
Other					
Subtotal: C_2					
Operating costs	Quantity	Unit	Rate	Amount	
Labour		h/week			
Materials		sum			
Power/energy	12	months			
Licences, etc.		sum			
Other		sum			
Subtotal: C_3					
Maintenance costs	Percentage (%) of capital	Capital	Amount		
Civil items					
Electrical items					
Mechanical items					
Controls					
Subtotal : C_4					
Rehabilitation funded from depreciation provision C_5					
Decommissioning/demolition: Estimated cost at the end of life cycle (years): C_6					
TOTAL ANNUAL LIFE-CYCLE COST: $C_1 + C_2 + C_3 + C_4 + C_5 + C_6$					

Table 5-4: Expected useful life (EUL) of hydroelectric scheme assets (Barta, 2011)

Type of asset	Description	EUL (years)
Structures/roads	Dams/weirs/intakes/canals	50-100
	Buildings/houses	50
	Access roads (wearing surface)	20
Hydro-mechanical equipment	Turbines (small sizes)	25
	Valves and gates	45
	Penstocks (mainly steel)	50
Hydro-electrical equipment	Generators	20
	Transformers	20
	Transmission lines	30
Auxiliary equipment	Electrical controls	15
	Telemetry	15
	Security components	10
NB: Remaining useful life (RUL) is the difference in years between EUL and evaluation year		



5.9.1 Unit cost

When comparing the costs of hydropower plants of varying sizes, it is sensible to determine the unit cost of each plant and to compare these. It is recommended that the unit cost of a micro-hydropower plant be calculated using the following formula (**Equation 5.11**):

$$c_u = C_{LCC} / F_v * Dem * 365 \text{ (Rand/kWh)} \quad \dots(5.11)$$

where:

- c_u = unit cost
- $F_v = (1+d_r)^n - 1/d_r(1+d_r)^n$
- d_r = discount rate or escalation rate
- n = number of years
- Dem = system's daily demand (kWh or MWh)
- C_{LCC} = life-cycle cost

5.10 Funding of developments

Historically, funding for power-generation projects was provided by the public sector. However, privately financed and owned projects are increasing. According to IEA (2000), general financing alternatives include:

- ☒ The 'use of in-house funds', if the developer has accumulated reserves. This may be possible in very small projects, but larger projects will require a substantial initial investment.
- ☒ 'Ordinary bank loans', where a bank supplies the majority of the initial investment cost and secures the loan against assets of the developer.
- ☒ 'Co-development with a financially strong partner', where a partner is chosen either for his financial situation or for his expertise.
- ☒ 'Limited recourse project financing' in which the future cash flow of the project provides the security for the lender. This option is used when the developer does not have sufficient assets to provide as security, or when he wishes to split the risk involved in the development.
- ☒ Leasing of the hydropower plant can be used alternatively to ownership, although this is currently not often used for hydropower plants.
- ☒ In 'build-own-operate (BOO)' projects the water owner gives development rights to an independent power producer, who controls the development process and operation of the plant for a time, after which the owner resumes possession of the project.
- ☒ 'Pay-back using electricity or other goods' is an alternative method of repaying debt with electricity, rather than with cash.



-  'Supplier's credit' can be obtained from some equipment suppliers that link their purchase prices with financing terms.

In the case of small-scale conduit hydropower, municipalities and water boards will often be able to provide funds out of their own budgets. However, larger installations will require alternative funding. Funding for these projects may typically be acquired from the Development Bank of South Africa (DBSA), commercial banks or the South African National Energy Development Institute (SANEDI). (Van Dijk et al., 2012b; SANEDI, 2013). See **Chapter 4** for more detail of funding opportunities.

5.11 Returns on energy supply (tariffs)

In general terms, the energy services tariff can be defined as a set of norms and standards introduced by the authority. A tariff represents duties (or taxes) levied by the authority in order to raise revenue for energy services rendered. The national tariff norms and standards are usually provided by the government with guidelines indicating how local or specific tariffs are to be set out. The essential purpose of energy services tariffs is to serve as an important policy instrument to regulate the demand for energy services provision.

The price of energy services to the end-user is priced on the tariff structure costs of local authorities and bulk suppliers. A representative energy services tariff should be based on both fixed and variable costs of services rendered (Barta, 2011).

In March 2009 NERSA announced the South African Renewable Energy Feed-in Tariff (REFIT) Programme. The primary objective of this programme was to cover electricity generation costs with allowance for a profit potential that is sufficiently attractive to stimulate investment of small hydropower plants (NERSA, 2009).

In December 2009, the Department of Energy (DoE) with the endorsement from NERSA introduced the Integrated Resource Plan (IRP) for Electricity for South Africa 2010 – 2030. The IRP 2010 has been subjected to public scrutiny and comments and eventually the entire process resulted in a Final Policy Adjusted IRP 2010: New-Build Technology Mix (Viljoen and Wilson, 2011).

However, in August 2011 the Government abandoned the REFIT process in favour of the Renewable Energy Independent Power Producer Procurement (REIPPP) programme (originally titled REBID). This is a competitive bidding process where tariff caps are applied for specific generation technologies. If a successful tender is submitted, the DOE/NERSA guarantees to a developer a specific tariff that the produced energy will be purchased at by Eskom. To-date, only projects with a capacity of 1MW or more can qualify for REIPPP programme consideration (Barta, 2013).



Therefore, Eskom has recently launched a Rebate Programme for Small-scale Renewable Energy Generation. This programme allows renewable energy projects with a capacity of less than 1MW to apply for an incentive of R1.20 per kWh generated for an initial contract period of 3 years. However, grid-connected applications do not qualify (Eskom, 2012d).

5.12 Estimating of the CAPEX for a small scale hydropower installation

The overall cost (as per 2012 prices) of the development of a small scale hydroelectric installation of 1 MW capacity in South Africa varies between R18-R28 million depending on the type and location of hydroelectric development.

The overall cost of the hydropower installation developed as rehabilitation/upgrade, conduit hydropower from the bulk water supply and distribution systems and the hydropower added to the existing storage regulated dams is significantly lower due to either existing water storage or suitable civil infrastructure. **Table 5-5** illustrates the cost components and approach considered in estimating the capital cost of the small scale hydropower installation (all components have a full local content with an exception of the turbine equipment which has to be designed abroad and imported to SA).

Table 5-5: Illustrative development costs for small scale hydropower installations (Barta, 2012)

Primary costs	Cost item	Illustrative value (%)
Development costs (DC)	Regulatory costs	3
	Environmental & social costs	27
	Investigation and design costs	70
DC is borne typically by a developer at R1.2 million per one MW of capacity (at 2011 time basis)		100
Technical (construction) costs	Preliminary & General (P&G)	20.0
	Access to the site	0.5
	Intake structure/penstock(s)	5.0
	Power station housing & Tailrace	15.0
	Electromechanical equipment & Controls	30.0
	Transformer/transmission	10.0
	Construction supervision	4.5
Contingencies		15.0
Total		100
Note: The illustrative development cost values are based on the costing analyses of Sol Plaatje (Bethlehem) and Vaal Dam hydropower projects by Blerch (2009), Hartebeestpoort Dam by Otterman and Barta (2012) and personal communications by Barta between 2011 and 2012 with several IPPs involved in the development of small scale hydropower in South Africa.		



5.13 Typical cost functions

There is little information about hydropower development costs in South Africa, due to the small number of hydropower developments in this country during the past 30 years (Barta, 2011). Even in other countries it is difficult to accurately estimate the costs of hydropower plants during the early stages (Gunduz and Sahin, 2010).

However, various authors have developed cost functions to simplify early stage hydropower cost estimation. A study done by Aggidis et al. (2010), compared various cost functions written between 1978 and 2000 and combined the functions with obtained costs for sites in North West England. A summary of the resulting cost functions (all for British Pounds at a 2008 cost base, with P being power in kilowatts, H being available head in metres and Q being design flow in cubic metres per second) is shown in **Table 5-6**.

Table 5-6: British cost functions (Aggidis et al., 2010)

Description	Cost function (£, 2008)	Applicability
Overall project	$C_{Pr}=25\,000 \times \left(\frac{P}{H^{0.35}}\right)^{0.65}$	$2\text{ m} < H < 30\text{ m}$
	$C_{Pr}=45\,500 \times \left(\frac{P}{H^{0.3}}\right)^{0.6}$	$30\text{ m} < H < 200\text{ m}$
Electro-mechanical	$C_{EM}=12\,000 \times \left(\frac{P}{H^{0.2}}\right)^{0.56}$	
Kaplan turbine	$C_{K1}=3\,500 \times (P)^{0.68}$	$0.5\text{ m}^3/\text{s} < Q < 5\text{ m}^3/\text{s}$
	$C_{K2}=14\,000 \times (P)^{0.35}$	$5\text{ m}^3/\text{s} < Q < 30\text{ m}^3/\text{s}$
Francis turbine	$C_{F1}=122\,000 \times (P \times H^{0.5})^{0.07}$	$0.5\text{ m}^3/\text{s} < Q < 2.5\text{ m}^3/\text{s}$
	$C_{F2}=223\,000 \times \left(\frac{P}{H^{0.5}}\right)^{0.11}$	$2.5\text{ m}^3/\text{s} < Q < 10\text{ m}^3/\text{s}$
	$C_{F3}=16\,500 \times \left(\frac{P}{H^{0.5}}\right)^{0.52}$	$Q > 10\text{ m}^3/\text{s}$
Pelton turbine	$C_{PEL}=2\,600 \times (P)^{0.54}$	

Ogayar and Vidal (2009) have developed cost functions for hydropower turbines using the installed capacity and net pressure head as variables. The derived equations were compared with costs of installed plants at various locations in Spain, with resulting correlation errors of between 20% and 24%. The equations, in Euro at a 2007 cost base (with P being power in kilowatts and H being head in metres), are shown in **Table 5-7**.

Table 5-7: European cost functions (Ogayar and Vidal, 2009)

Description	Cost function (€/kW)
Pelton turbine	$C_{PEL}=17\,693 \times P^{-0.3644725} \times H^{0.281735}$
Francis turbine	$C_{F1}=25\,698 \times P^{-0.560135} \times H^{0.127243}$
Kaplan turbine	$C_{K1}=33\,236 \times P^{-0.58338} \times H^{0.113901}$
Semi-Kaplan turbine	$C_{SK}=19\,498 \times P^{-0.583385} \times H^{0.113901}$



Singal et al. (2010) conducted a study on small run-of-river hydropower projects in India, also using the installed capacity and net pressure head as variables. The derived equations were compared with costs of installed plants at various locations in India as well as installed plants in various other countries.

The derived equations correlated well with actual costs in India and Brazil. China (-32%), Columbia (-64%) and Vietnam (-27%) had significantly lower installation costs, but European costs were 112% higher and Australian costs were 79% higher than those in India. **Table 5-8** shows the resulting equations, for Indian Rupees, at a 2007 cost base (with P being power in kilowatts and H being available head in metres).

Table 5-8: Indian cost functions (Singal et al., 2010)

Description	Cost function (Rs/kW)
Turbine with governing system	$C_T = 63\,346 \times P^{0.1913} \times H^{0.2171}$
Generator with excitation system	$C_G = 78\,661 \times P^{0.1855} \times H^{0.2083}$
Electrical and mechanical auxiliary	$C_{EM} = 40\,860 \times P^{0.1892} \times H^{0.2118}$
Transformer and switchyard	$C_{ST} = 18\,739 \times P^{0.1803} \times H^{0.2075}$

RETScreen (2003) uses various cost functions for micro-hydropower project analysis (**Table 5-9**), (with P being power in megawatts, H available head in metres, Q design flow in cubic metres per second and N the number of turbines).

Table 5-9: RETScreen cost functions (RETScreen, 2003)

Description	Cost function (CAN\$)	Applicability
Kaplan turbine	$C_{K1} = 0.243N^{0.96} \times (0.482Q^{0.45})^{1.47} \times (1.17H^{0.12} + 2) \times 10^6$	$H \leq 25$ m
	$C_{K2} = 0.267N^{0.96} \times (0.482Q^{0.45})^{1.47} \times (1.17H^{0.12} + 2) \times 10^6$	$H > 25$ m
Francis turbine	$C_{F1} = 0.153N^{0.96} \times (0.482Q^{0.45})^{1.47} \times ((13 + 0.01H)^{0.12} + 3) \times 10^6$	$H \leq 25$ m
	$C_{F2} = 0.168N^{0.96} \times (0.482Q^{0.45})^{1.47} \times ((13 + 0.01H)^{0.12} + 3) \times 10^6$	$H > 25$ m
Pelton/Turgo turbine	$C_{P/T} = 3.47N^{0.96} \times \left(\frac{P}{H^{0.5}}\right)^{0.44} \times 10^6$	$\frac{P}{H^{0.5}} > 0.4$
	$C_{P/T} = 5.34N^{0.96} \times \left(\frac{P}{H^{0.5}}\right)^{0.91} \times 10^6$	$\frac{P}{H^{0.5}} \leq 0.4$
Cross-flow turbine	$C_C = 0.5 \times C_{P/T}$	
Propeller turbine	$C_{Prop} = 0.113n^{0.96} \times (0.482Q^{0.45})^{1.47} \times (1.17H^{0.12} + 4) \times 10^6$	$H \leq 25$ m
	$C_{Prop} = 0.124n^{0.96} \times (0.482Q^{0.45})^{1.47} \times (1.17H^{0.12} + 4) \times 10^6$	$H > 25$ m
Transformer	$C_{Trans} = (0.0025N^{0.95} + 0.002(N+1)) \times \left(\frac{P}{0.95}\right)^{0.9} \times V^{0.3} \times 10^6$	



The USBR (2011b) proposes various cost functions (**Table 5-10**), for US Dollars at a 2010 cost base (with P being power in megawatts, H available head in feet and L_T transmission line length in miles).

Table 5-10: United States of America cost functions (USBR, 2011b)

Description	Cost function (US\$, 2010)	Applicability
Kaplan turbine	$C_{K1}=909\,000 \times 2.718^{-0.0013 \times H} \times P^{0.72}$	$H \leq 100$ ft
	$C_{K2}=5\,240\,000 \times H^{-0.38} \times P^{0.72}$	$H > 100$ ft
Francis turbine	$C_{F1}=760\,000 \times 2.718^{-0.003 \times H} \times P^{0.71}$	$H \leq 100$ ft
	$C_{F2}=3\,930\,000 \times H^{-0.42} \times P^{0.71}$	$H > 100$ ft
Pelton turbine	$C_{PEL}=0.8 \times 3\,930\,000 \times H^{-0.42} \times P^{0.71}$	
Other turbines	$C_{OT}=760\,000 \times 2.718^{-0.003 \times H} \times P^{0.71}$	
Generator	$C_G=3\,900\,000 \times P^{0.65} \times N^{-0.38}$	
Balance of plant mechanical	$C_M=0.2 \times C_T$	
Balance of plant electrical	$C_E=0.35 \times C_G$	
Civil works	$C_{Civil}=0.4 \times (C_T + C_G)$	
Transformer	$C_{Trans}=25.403 \times \left(P \times \frac{1000}{0.9}\right) - 0.001 \times \left(P \times \frac{1000}{9}\right)^2 + 14\,866$	
Transmission line	$C_{Transmission}=L \times 160\,000$	KV < 69
	$C_{Transmission}=L \times 320\,000$	69 < KV < 115
	$C_{Transmission}=L \times 368\,000$	KV > 115
Contingency	$C_{Contingency}=0.2 \times CEC$	
Construction management	$C_{CM}=0.15 \times (CEC + C_{Contingency})$	
Licensing	$C_L=780\,000 \times P^{0.7}$	
Transmission line right of way	$C_{TransROW}=58\,180 \times L_T$	
Fixed annual O&M	$C_{FixOM}=26\,000 \times P^{0.75}$	
Variable O&M	$C_{VarOM}=26\,000 \times P^{0.8}$	

Various sources estimated component costs as percentages of investment or planning cost. These percentages are shown in **Table 5-11**.



Table 5-11: Comparison of component costs as percentages of total cost

Category	Cost Item	Percentage of total	Source
Initial planning	Regulatory	3% of IPC	Barta (2012)
	Environmental & social	27% of IPC	Barta (2012)
	Preliminary design	70% of IPC	Barta (2012)
Capital expenditure	Preliminary & general	20% of CEC	Barta (2012)
	Access to site	0.5% of CEC	Barta (2012)
	Intake structure/penstock	5% of CEC	Barta (2012)
	Power station housing & tailrace	15% of CEC	Barta (2012)
	Electro-mechanical	30% of CEC	Barta (2012)
	Electro-mechanical	34% of CEC	Aggidis et al. (2010)
	Transformer/transmission	10% of CEC	Barta (2012)
	Construction supervision	4.5% of CEC	Barta (2012)
	Contingencies	15% of CEC	Barta (2012)
Maintenance	Civil	0.25% of Civil CEC	Barta (2012)
	Civil	1% of CEC	Chutachindakate (2012)
	Mechanical	2.0% of Mech CEC	Barta (2012)
	Hydraulic equipment	2% of CEC	Chutachindakate (2012)
	Electrical	4.0% Electrical CEC	Barta (2012)
	Electro-mechanical	2.5% of CEC	Chutachindakate (2012)
	Transmission system	1% of CEC	Chutachindakate (2012)
Insurance	Civil	0.15% CEC	Barta (2012)
	Electro-mechanical	0.25% of CEC	Barta (2012)
	All	0.3% of CEC	USBR (2011b)
Overheads	All	0.5% of CEC	USBR (2011b)
Total O&M		1% of CEC	Barta (2012)

5.14 Typical cost of a small hydropower plant

The unit cost of pico to small conduit hydropower installations vary significantly, as shown in **Table 5-12**. This can be attributed to various factors, including project location, infrastructure needed and inflation (note completion year in each case).



This, combined with a shortage of available project costs, significantly complicates the development of a standardised cost function for conduit hydropower installations.

Table 5-12: Small hydropower unit cost comparison

Hydropower plant	Country	Year of completion	Capacity (kW)	Unit cost (currency/kW)	Source
Schreyerbach	Austria	2006	63	€ 6 350/kW	ESHA (2009)
Poggio Cuculo	Italy	2010	44	€ 4 550/kW	ESHA (2009)
Vienna Mauer	Austria	2006	500	€ 2 500/kW	ESHA (2009)
Armary	Switzerland	2006	68	€ 5 900/kW	ESHA (2009)
Sangüesa	Spain	2006	75	€ 4 000/kW	ESHA (2009)
Edremit	Turkey	Planning	559	€ 2 000/kW	Kucukali (2011)
Rancho Peñasquitos	USA	2007	4 500	\$ 4 700/kW	NHA (2013)
Rand Water	South Africa	Planning	13 000 (total of 4 sites)	R 28 000/kW	Mbhele (2012)
Brandkop	South Africa	Construction	96	R 28 000/kW	Van Dijk (2013)

The International Renewable Energy Agency (IRENA) based in Germany made available in June 2012 the key findings from their analysis of typical installed cost for small, large and refurbished hydropower categories as illustrated in **Table 5-13** (IRENA, 2012).

Table 5-13: Typical installed costs and LCOE of hydropower projects

Hydropower category	Installed costs (US\$/kW)	O&M costs (%/year of installed costs)	Capacity factor (%)	Levelised costs of electricity (2010 US\$/kWh) ⁽³⁾
Large hydro ⁽¹⁾	1 050 – 7 650	2 – 2.5	25 to 90	0.02 – 0.19
Small hydro ⁽²⁾	1 300 – 8 000	1 – 4	20 to 95	0.02 – 0.27
Refurbished/up grade	500 – 1 000	1 – 6	–	0.01 – 0.05

Note:

- 1) Adding additional capacity at existing hydropower schemes or existing non-powered dams can be significantly cheaper, and can cost as little as US\$ 500/kW.
- 2) Small hydropower projects don't have the same economies of scale and can have O&M costs of between 1% and 6%, or in some cases even higher.
- 3) The levelised cost of electricity calculations assume a 10% cost of capital.
- 4) Hydropower can help with grid stability, as the hydro-energy can be produced more rapidly than any other generation source.



6. A DECISION SUPPORT SYSTEM FOR CONDUIT HYDROPOWER DEVELOPMENT

6.1 Introduction

According to Shim et al. (2002), '[d]ecision support systems (DSS) are computer technology solutions that can be used to support complex decision making and problem solving.' Typical DSS tools include one or more of the following:

-  Database management capabilities;
-  Modelling functions; and
-  User-friendly interface designs allowing interactive 'queries, reporting and graphing' capability. (Shim et al., 2002)

A **Decision Support System** was developed that can be used to identify conduit hydropower potential in South Africa, as well as to provide proper guidance for the development of identified sites.

A system of flow diagrams and tools has been compiled to identify and develop conduit hydropower sites. A systematic approach must be followed when assessing hydropower potential in a distribution network to ensure that all relevant factors are considered. The procedure for determining hydropower potential is illustrated through a series of flow diagrams, whilst a tool developed in Microsoft Excel facilitates calculation of all the factors that need consideration. The DSS has been divided into three phases:

-  First Phase: Pre-Feasibility Investigation
-  Second Phase: Feasibility Study
-  Third Phase: Detailed Design

A fourth phase, dealing with operation and maintenance aspects, falls outside the scope of this document, but is also an important phase to consider when designing a conduit hydropower facility. Each phase has its own process flow diagram linked to a Conduit Hydropower Development Tool (CHD Tool). Some of the aspects of the study will be required in two or more of the phases, but will be dealt with in increasing detail as the project progresses.

6.2 Scope of works

The total scope of works for the development and operation of conduit hydropower plants in South Africa is summarised in **Figure 6-1**. This document will focus on the potential identification and design processes, shown in the first five blocks of **Figure**



6-1. The other aspects fall outside the scope of this document, but are an integral part of the complete hydropower development process.



Figure 6-1: Conduit Hydropower Development Scope of Works

6.3 Systematic approach

A systematic approach must be followed when assessing hydropower potential in a distribution network to ensure that all relevant factors are considered. The procedure



for determining hydropower potential is illustrated through a series of flow diagrams, whilst a tool developed in Microsoft Excel facilitates calculation of all the factors that need consideration.

Chapters 7 and 8 will elaborate on the items in the flow diagrams. The development procedure has been divided into the three phases as previously listed

6.4 Decision Support System (DSS)

6.4.1 First phase: pre-feasibility investigation

Phase 1 is a pre-feasibility study and comprises various first-order analyses and studies. The purpose of this phase is to rapidly determine whether more in-depth studies will be worthwhile.

Figure 6-2 and **Figure 6-3** indicate the decision flow process for this phase.



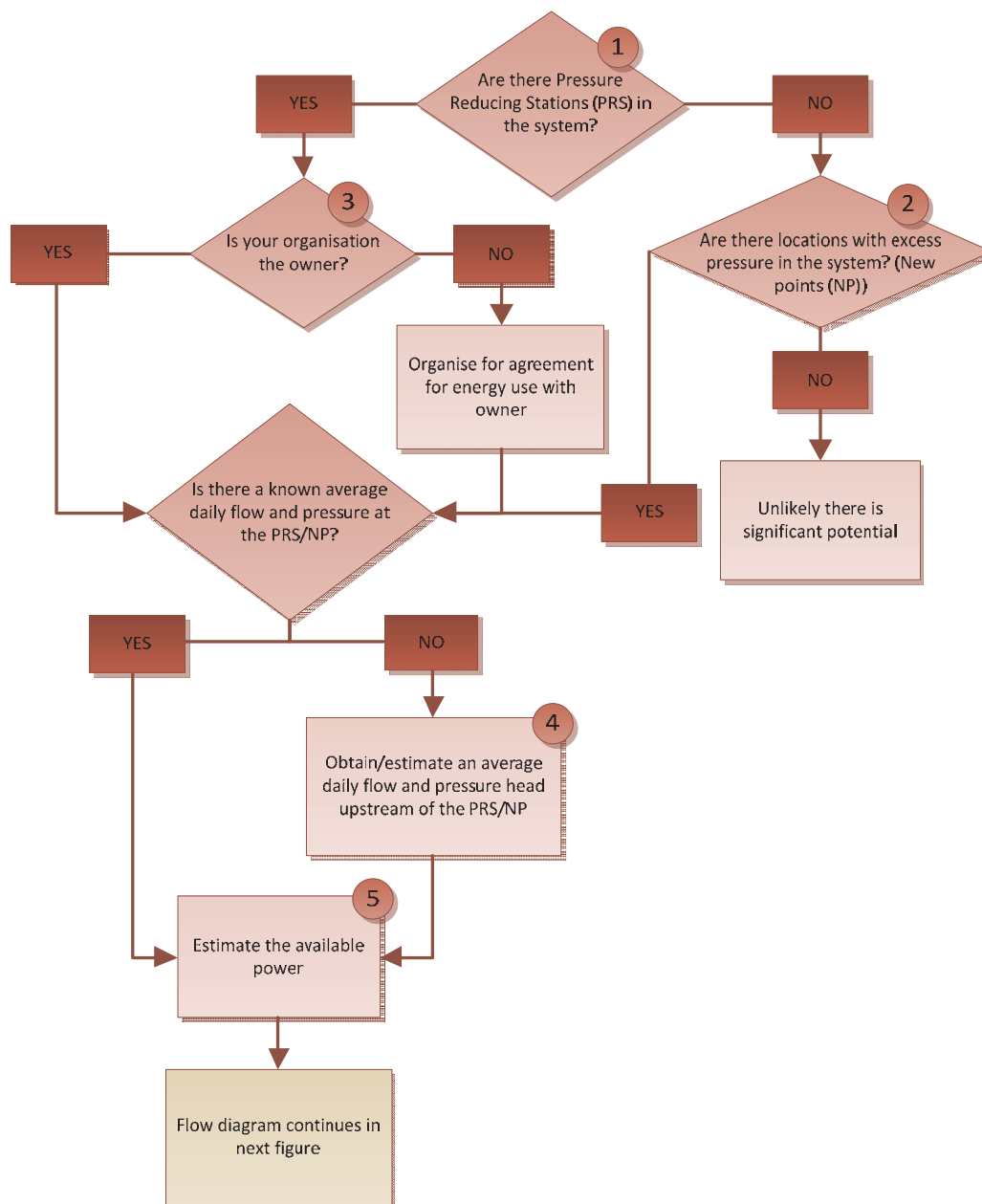


Figure 6-2: Phase 1 flow diagram Part A



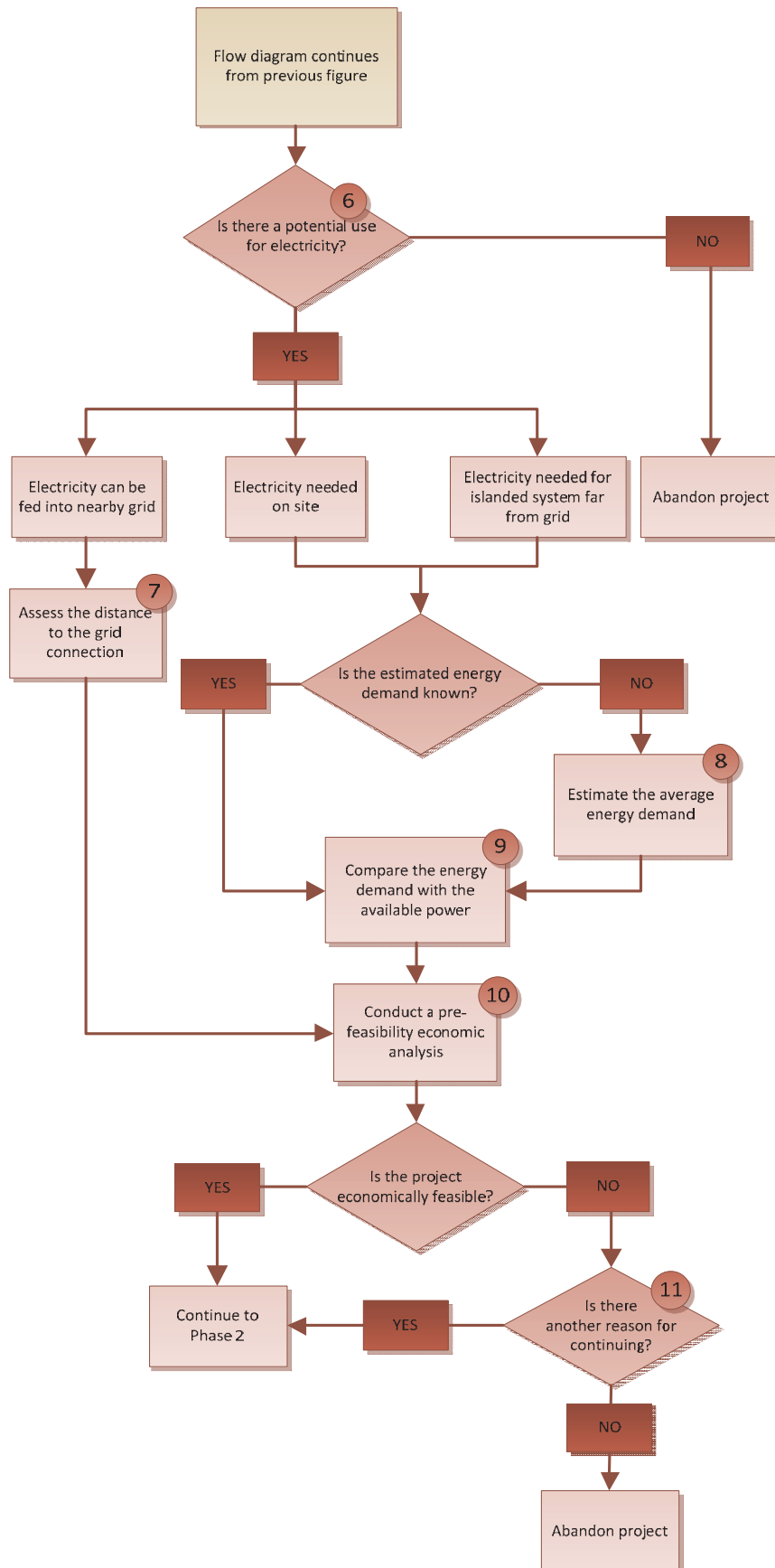


Figure 6-3: Phase 1 flow diagram Part B



6.4.2 Second phase investigation: feasibility

If Phase 1 indicates project viability, a more in-depth investigation can be done during the feasibility study of Phase 2. **Figure 6-4** and

Figure 6-5 illustrate the process to be followed during this stage.



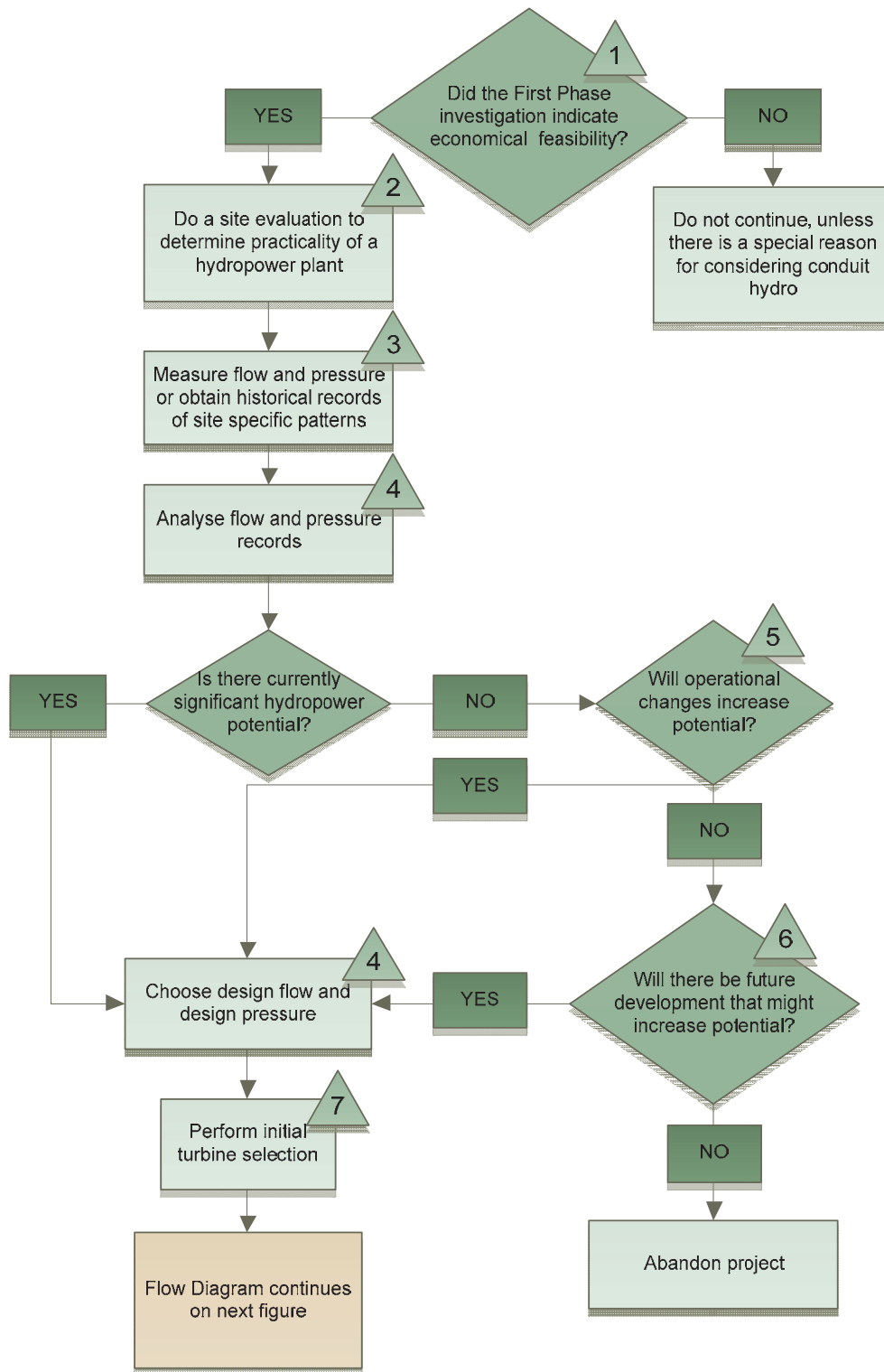


Figure 6-4: Phase 2 flow diagram Part A



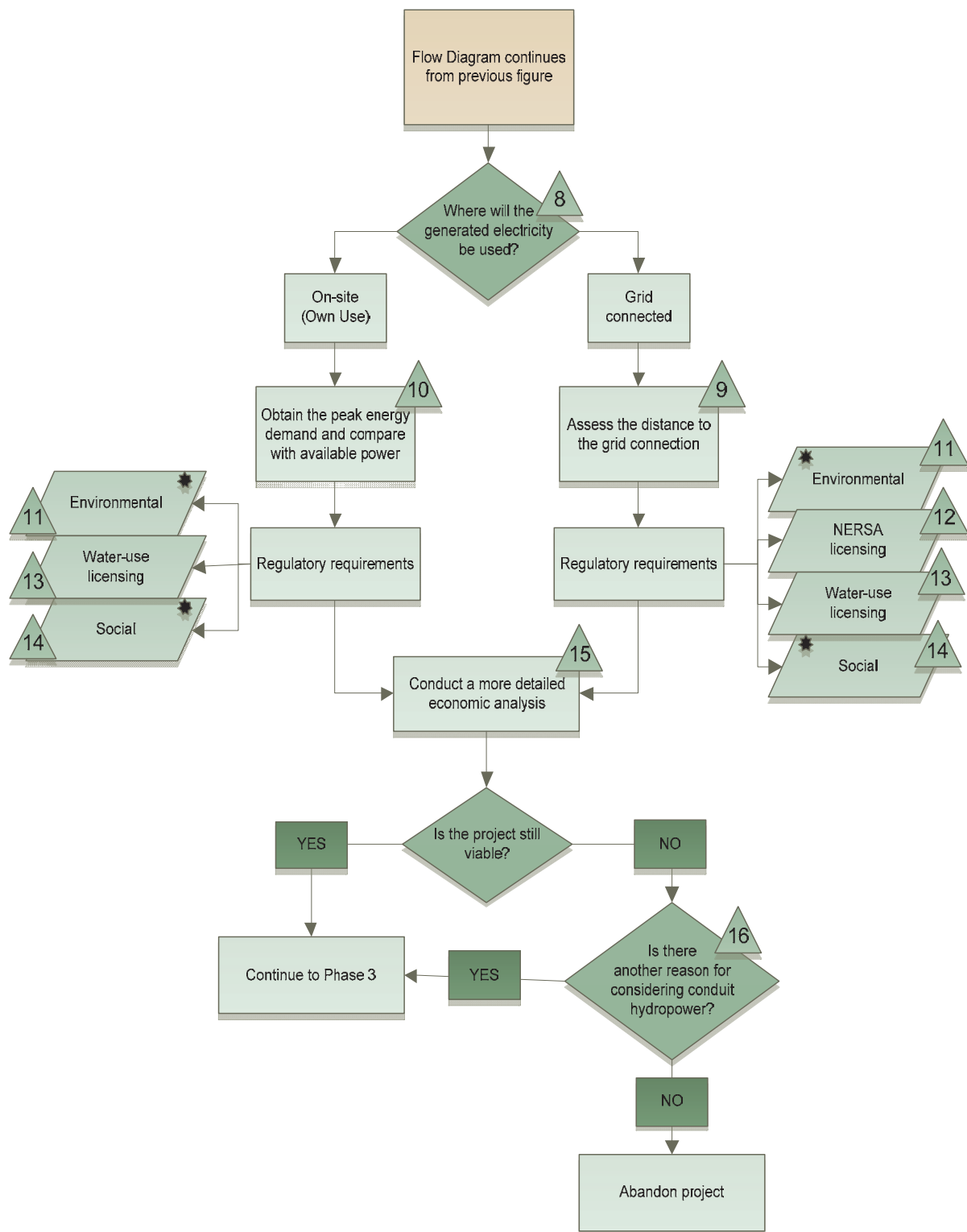


Figure 6-5: Phase 2 flow diagram Part B (* depicts specialist consultant input)



6.4.3 Third phase investigation: detailed design

If Phase 2 indicates project viability, a detailed design for the hydropower plant can be done during Phase 3. **Figure 6-6, Figure 6-7** and **Figure 6-8** depict the decision support process to be followed in developing the hydropower potential.



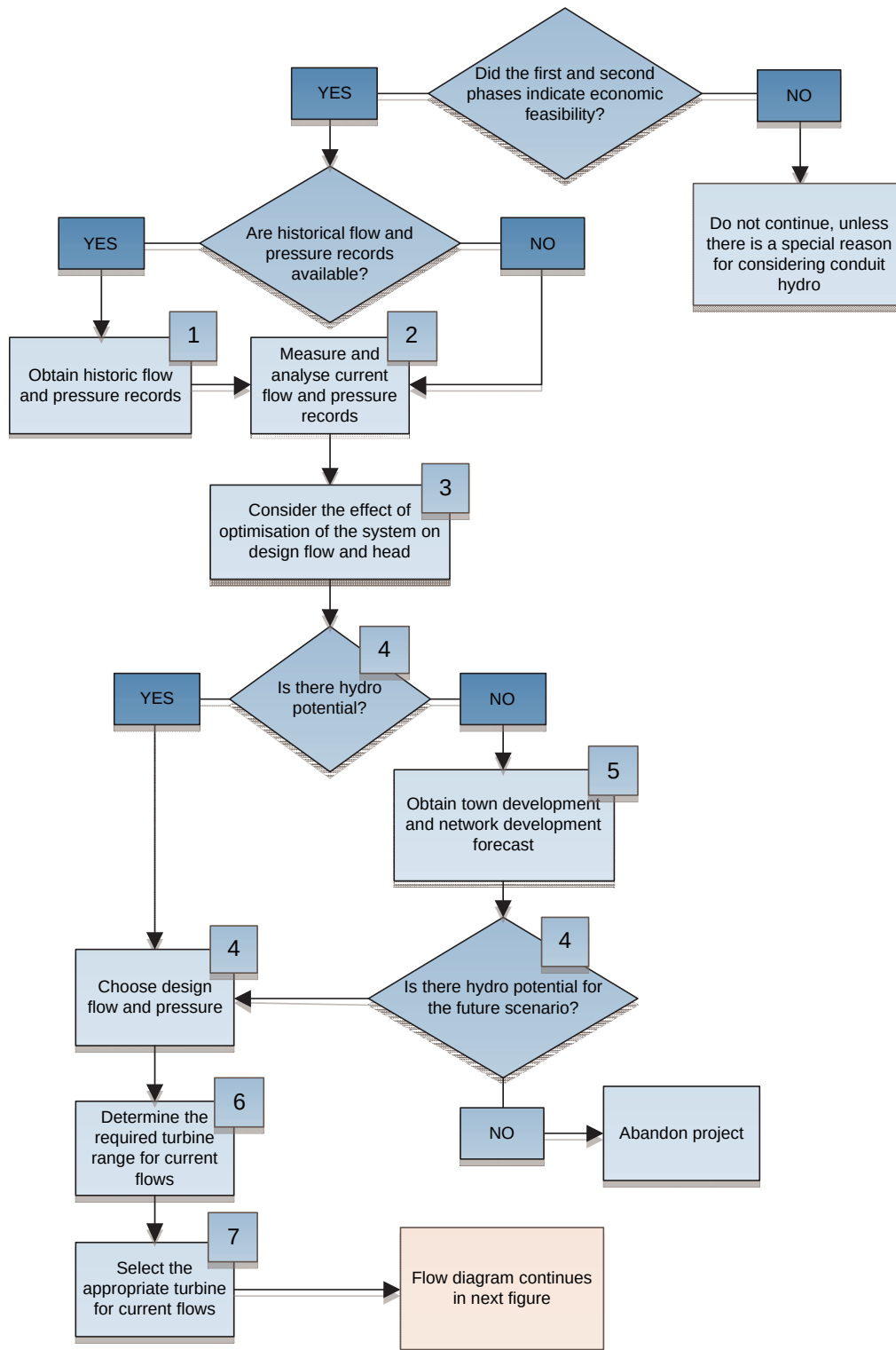


Figure 6-6: Phase 3 flow diagram Part A



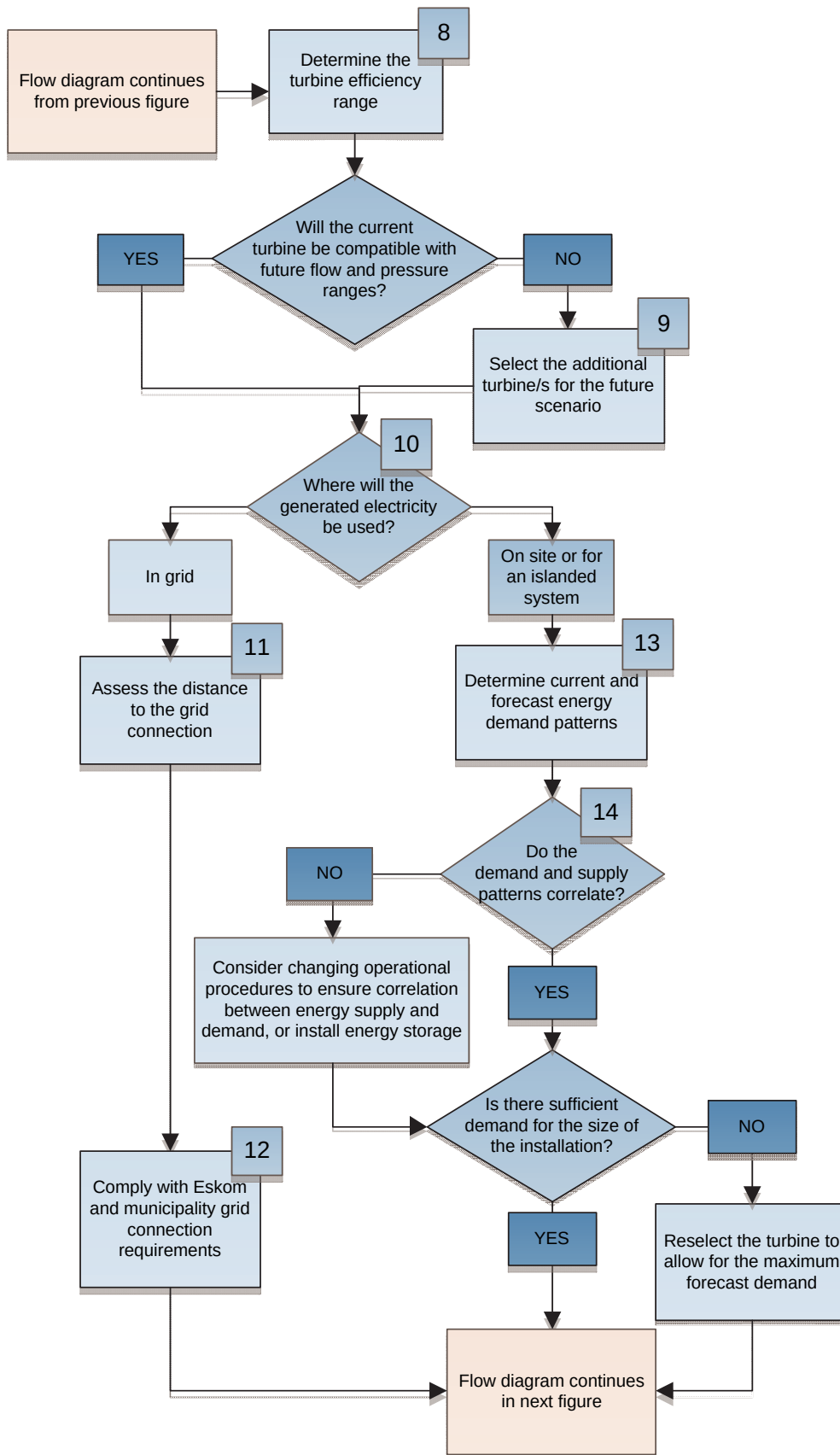


Figure 6-7: Phase 3 flow diagram Part B



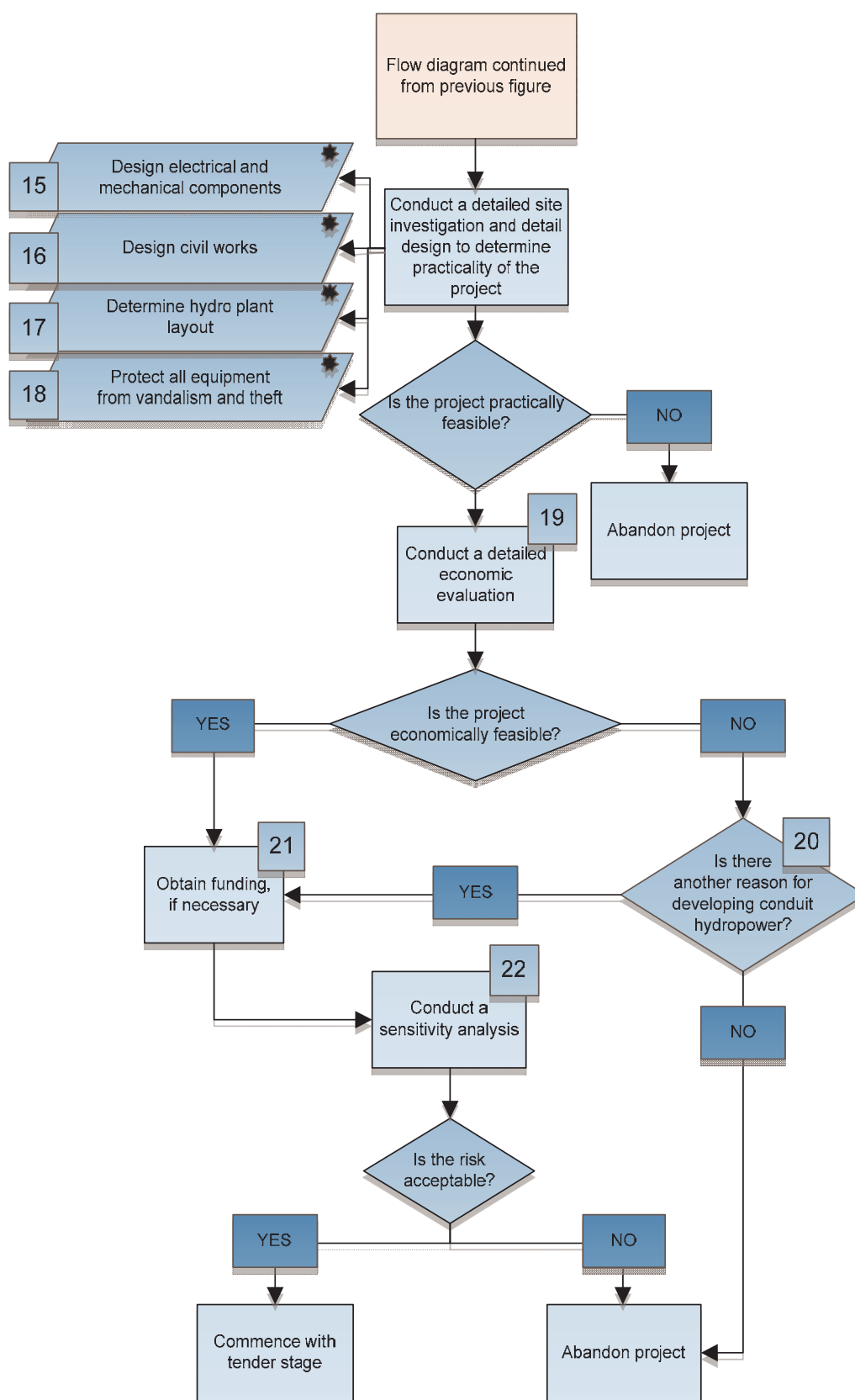


Figure 6-8: Phase 3 flow diagram Part C (* depicts specialist consultant input)



6.5 Conduit hydropower development tool (CHD Tool)

The thought process and calculations of each phase are incorporated in a Conduit Hydropower Development Tool (CHD Tool). This tool is in the form of a Microsoft Excel spreadsheet and aims to guide designers through the process (Phases 1 to 3) of conduit hydropower design by including all the calculations in a user-friendly format. The tools for all the phases have colour-coded value blocks to visually differentiate between different phases, input and output, as well as user-entered and default values. The colour-coding system is explained in **Table 6-1**. The assumptions and derivations of default values are discussed in **Appendix C**.

Table 6-1: Colour-coding system for CHD Tool

Colour coding	Description
Tan	Phase 1
Green	Phase 2
Ice blue	Phase 3
Light yellow	User must enter values
Sky blue	User may edit default values if better information is available
Light purple	Results

6.5.1 Phase 1 CHD Tool

The CHD Tool for Phase 1 is divided into three sections, namely the Hydropower Potential Section, Economic Analysis Section and the Checklist Section.

The Hydropower Potential Section is shown in **Table 6-2**. The only input required in this section is the average daily flow, the average pressure head, if available, the static energy head (if the average head is not known) and, if applicable, the distance to the grid connection and power demand. The output in this section includes the theoretically available power and the ratio of the energy demand vs. available energy, in the case of on-site or islanded systems.



Table 6-2: Phase 1 potential analysis CHD Tool

PHASE 1 POTENTIAL ANALYSIS			
Power potential:			
Site name		Garsfontein	
Date of analysis		21/01/2013	
Annual average daily demand	(AADD)	85 475	kl/d
Average daily flow	(Q)	0.989	m ³ /s
Average pressure head (if known)	(H)		
Static energy head (if average not known)	(H)	166	m
Fluid density	(ρ)	1 000	kg/m ³
Gravitational acceleration	(g)	9.81	m/s ²
Efficiency	(η)	70	%
Annual operational percentage		60	%
Percentage of peak pressure head used		60	%
Theoretical available power	(P_{av})	676.6	kW
Annual operational time		5 256	h
Potential annual power		3 556	MWh/a
Energy usage:			
Grid connected		Islanded/on-site	
Distance to grid connection		Maximum power demand	500 kW
		P_{av} /Maximum power demand	135 %
		Distance to islanded grid	

The Economic Analysis Section does not require any input, save the design life of the project, unless better information than the default values is available. The output from this section includes initial estimates of the net present value (NPV), internal rate of return (IRR) and payback period of the proposed project. It is important to note that the payback period was calculated considering inflation. **Table 6-3** provides an example of this section.



Table 6-3: Phase 1 economic analysis CHD Tool

PHASE 1 ECONOMIC ANALYSIS			
Power information			
Power rating		676.6	kW
Average daily flow	(Q)	0.989	m ³ /s
Used pressure head	(H)	100	m
Design life		15	years
Cost			
Capital		13 234 668	R
Operation & maintenance percentage		1.00	% of capital cost
Annual operation & maintenance Cost		132 347	R
Annual operational percentage		60	%
Annual operational time		5 256	h
Planning		1 350	R/kW
Disposal percentage		1.00	% of capital cost
Disposal cost (present value)		132 347	R
Income			
Value of generated electricity		0.58	R/kWh
Revenue		0.00	R/kWh
Inflation			
Annual inflation of electricity		8.00	%
Annual inflation of O&M		6.00	%
Discount rate		6.00	%
Results			
Net present value of costs		-16 265 667	R
Net present value of income		36 048 301	R
Total NPV		19 782 634	R
Internal rate of return		20	%
Payback period		7	years

The Checklist Section, **Table 6-4**, also does not require any input, but serves as a reference for the user to determine whether all the steps for the first phase have been considered.



Table 6-4: Phase 1 Checklist CHD Tool

PHASE 1 CHECKLIST 	
Are there pressure reducing stations in the system?	
Are there other locations with excess pressure in the system?	
Is there a utilization agreement with the owner?	
Have the average daily flow - and pressure records been obtained?	
Has the estimated available power been calculated?	
Has the electricity use destination been established?	
For grid tie-in: Has the distance to the grid connection been measured?	
For islanded/on-site systems: Has the energy demand been determined?	
For islanded/on-site systems: Is the energy demand less than the available power?	
Has a pre-feasibility economic analysis been conducted?	
Is the project economically feasible?	
If not, is there another reason for continuing?	

If Phase 1 indicates feasibility, the user should continue to Phase 2 of the CHD Tool.

6.5.2 Phase 2 CHD Tool

Phase 2 of the CHD Tool is divided into 15 sections. Current and Future scenarios can be included for: the Hydropower Potential; Flow-Rating Curves; Energy Delivered; Turbine Selection; Optimum Percentage Use Curves; and Flow vs. Head Curves. The final three sections (Regulatory; Economic Analysis; and Checklist Sections) are applicable to the entire project and therefore incorporate both current and future scenarios.

The Hydropower Potential Section can be seen in **Table 6-5**. The inputs required in this section are the measured values for flow and available head. The CHD Tool accepts data of up to 35 000 data points. The CHD Tool requires the data to be sorted from lowest to highest flow with corresponding pressure heads, with all data gaps removed. The number of used data points is also required.

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

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



Table 6-5: Phase 2 potential analysis CHD Tool

PHASE 2 POTENTIAL ANALYSIS							
Flow rating curve	Load factor (%)	Flow (m ³ /s)	Head available (m)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100%	0	125	8592	0.0	0.000	0
	95%	0.000	123.4	8154	0.0	0.000	0
	90%	0.001	139.5	7716	0.7	5.257	0.146331973
	85%	0.059	143.9	7278	57.9	421.481	12.58574673
	80%	0.184	142.9	6840	180.5	1234.373	51.20306327
	75%	0.310	138.0	6402	293.8	1880.647	101.8631544
	70%	0.412	131.2	5964	371.2	2213.611	142.8251233
	65%	0.553	127.4	5526	483.7	2673.165	183.6336555
	60%	0.780	113.8	5088	609.8	3102.773	261.9793884
	55%	0.959	92.6	4650	609.9	2836.029	261.9793884
	50%	0.974	94.6	4212	632.5	2664.041	261.9793884
	45%	0.981	96.6	3774	651.0	2456.741	261.9793884
	40%	0.986	99.0	3336	670.6	2237.108	261.9793884
	35%	0.992	101.0	2898	688.3	1994.790	261.9793884
	30%	0.999	103.4	2460	709.2	1744.648	261.9793884
	25%	1.009	109.8	2022	760.6	1537.894	261.9793884
	20%	1.025	120.9	1584	851.4	1348.662	261.9793884
	15%	1.105	88.0	1146	667.8	765.326	261.9793884
	10%	1.194	97.1	708	795.7	563.354	261.9793884
	5%	1.372	85.8	270	808.2	218.204	261.9793884
	0%	1.456	82.6	0	825.4	0.000	261.9793884
Optimum flow	60%	0.780	113.8	5088.0	609.8		3897.989125
Average flow		0.767	111.6	8592	588.0	5052.294	
Chosen flow		0.037	50.4	8592	12.8	110.026	
Assurance of flow		0.000	0.0	0	0.0		
Design flow	60%	0.780	113.8	5088	609.8	3898.0	
General input		Energy usage					
Fluid density (ρ)		1000	kg/m ³	Grid connected		Islanded/on-site	
Gravitational acceleration (g)		9.81	m/s ²	Distance	0.5	Max demand	
Efficiency (η)		70	%			P _{av} /Max demand	0 %
Annual maintenance days		7	days			Distance to grid	
PHASE 2 INPUT							
Site name	Carsfontein						
Data points	Load factor (%)	Date and time	Flow (m ³ /s)	Head available (m)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)
13929	100.0000%	2012/03/30 13:45	0	125	8760	0.0	0.0
13928	99.9928%	2012/03/30 14:30	0	122	8759.371096	0.0	0.0
13927	99.9856%	2012/03/30 14:45	0	123	8758.742193	0.0	0.0
13926	99.9785%	2012/03/31 16:15	0	127	8758.113289	0.0	0.0
13925	99.9713%	2012/03/31 16:30	0	127	8757.484385	0.0	0.0

This section also generates various decision support graphs. These include a flow-rating curve (**Figure 6-9**), a potential energy curve (**Figure 6-10**), an initial turbine selection curve (**Figure 6-11**), an optimum percentage use curve (**Figure 6-12**) and a flow vs. head curve (**Figure 6-14**). These curves can be viewed in the four sections subsequent to the Hydropower Potential Section.

It should be noted that in a closed system (with one inflow), there will be a specific inverse relationship between flow and pressure head, with a flow rate always associated with the same pressure head, as per **Figure 6-13**.



However, in a complex system with various independent inflow and outflow points, a specific correlation will not be found between flow rate and pressure head, as per **Figure 6-14**. It is therefore necessary to carefully choose the design pressure head in a complex system.

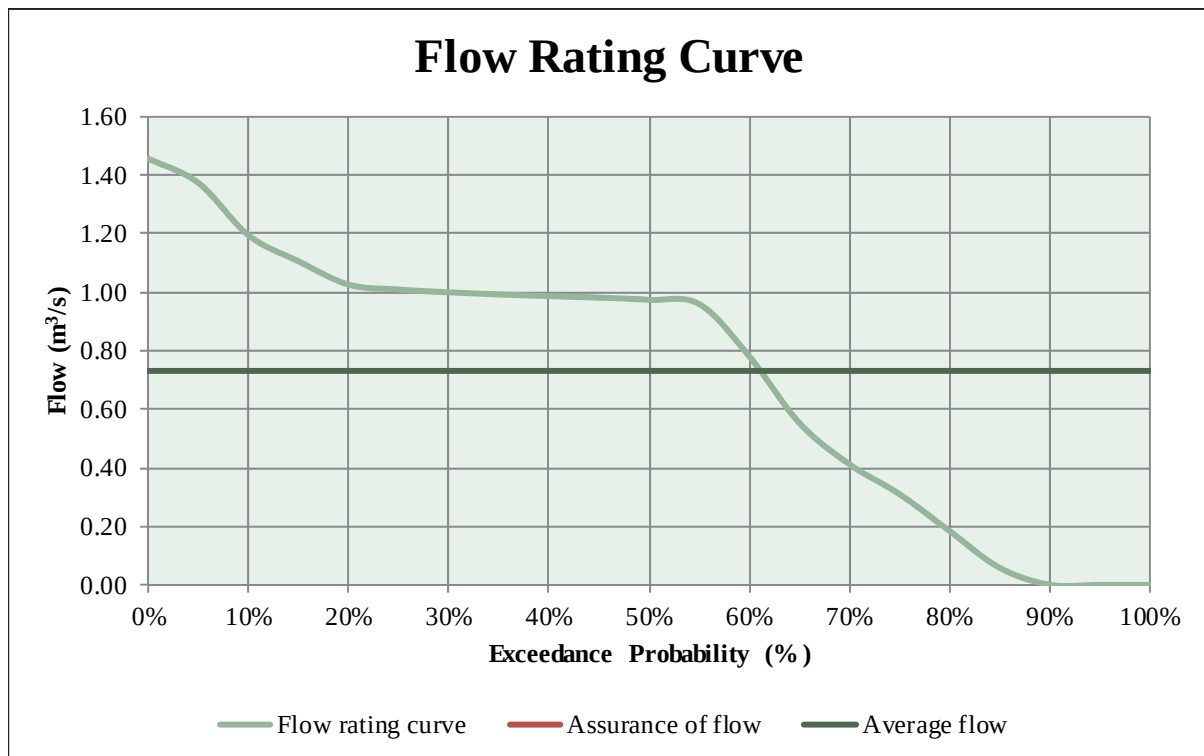


Figure 6-9: Phase 2 flow-rating curve CHD Tool

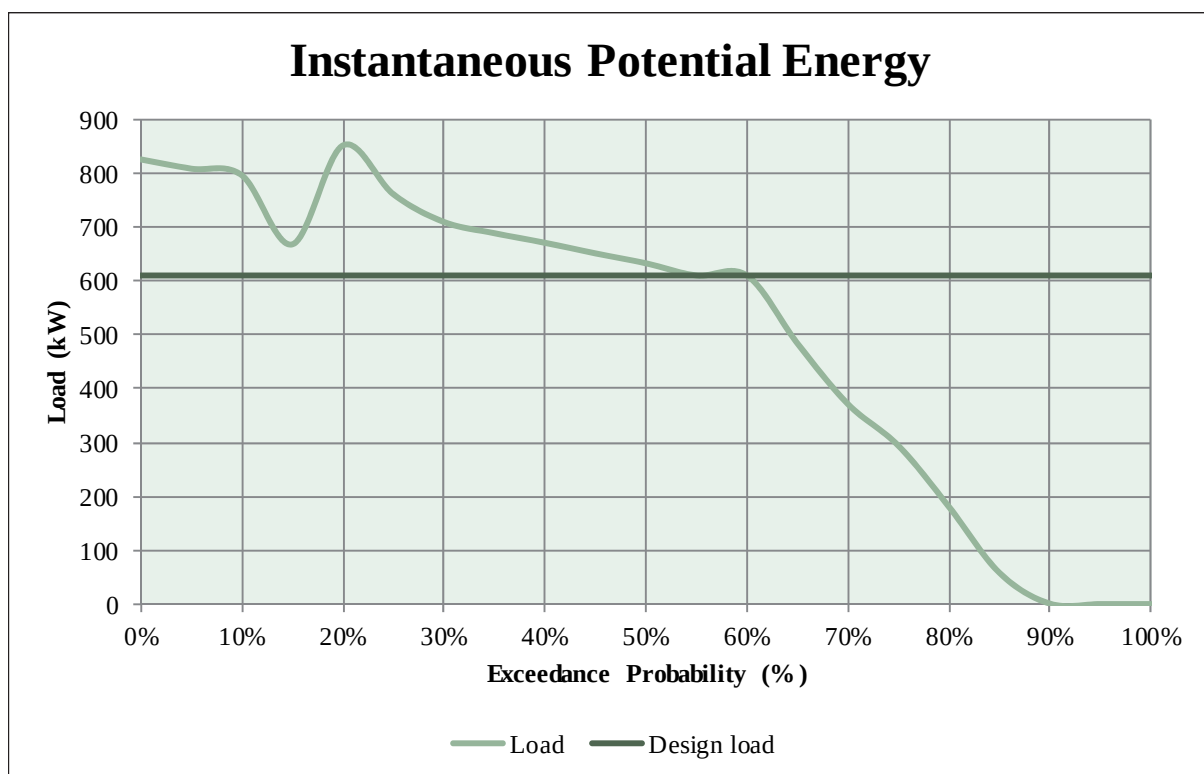


Figure 6-10: Phase 2 potential energy curve CHD Tool



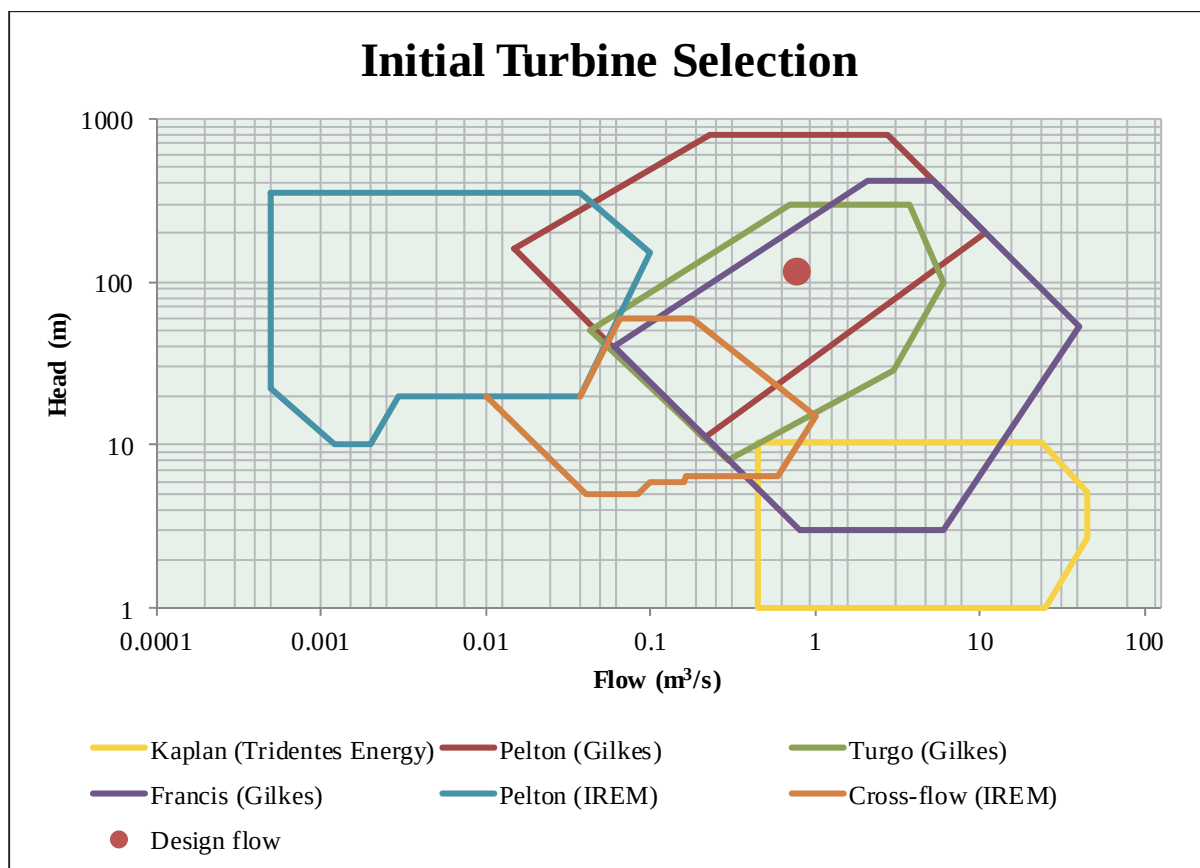


Figure 6-11: Phase 2 initial turbine selection CHD Tool

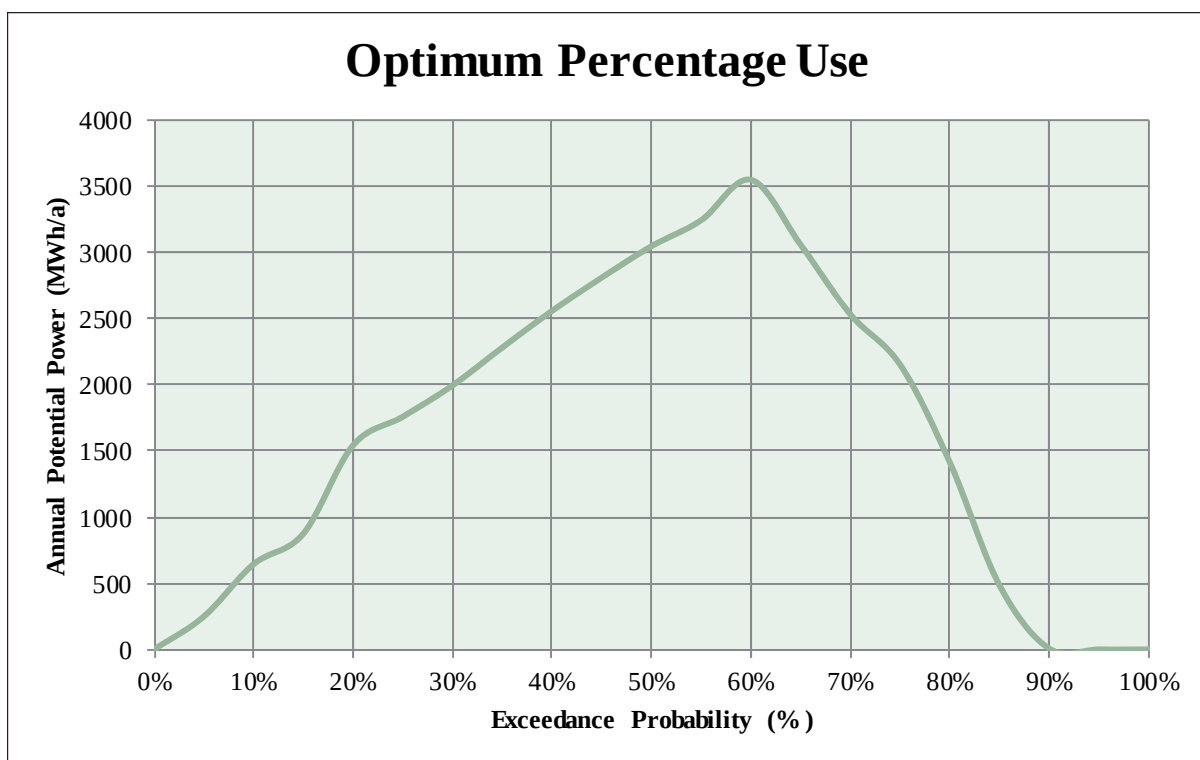


Figure 6-12: Phase 2 optimum percentage use curve CHD Tool



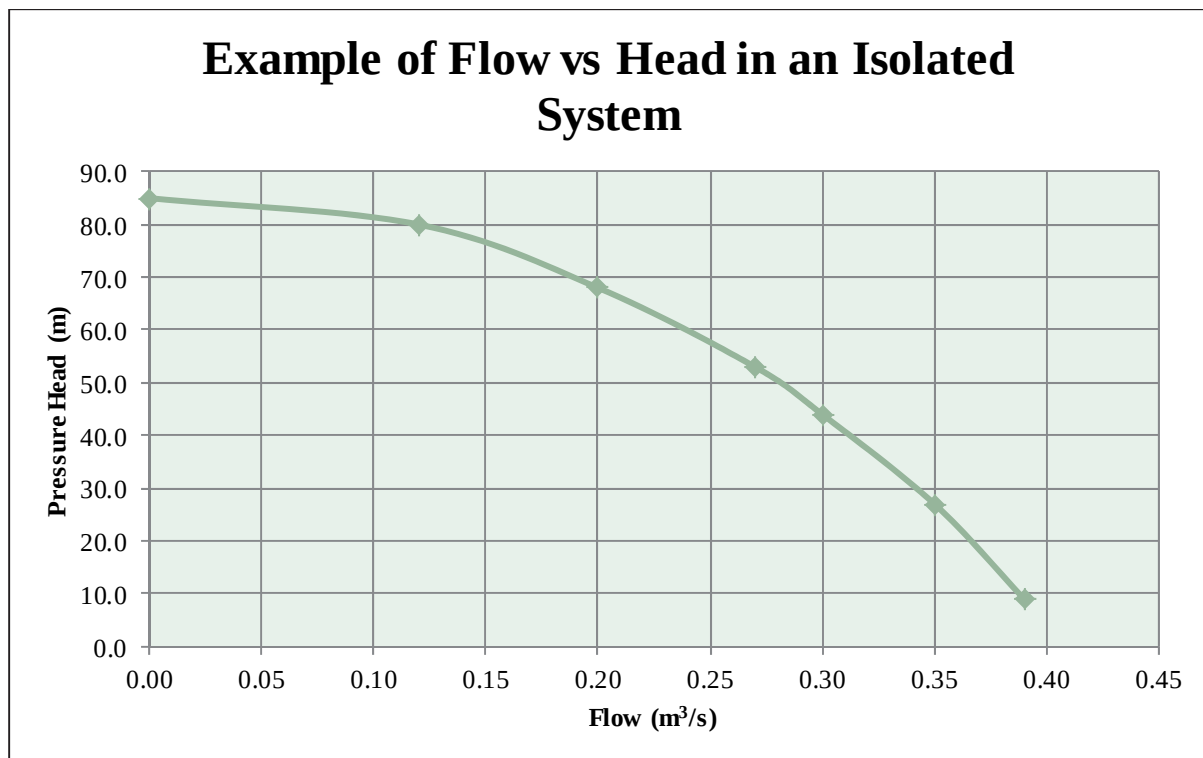


Figure 6-13: Example of flow vs. head in an isolated system

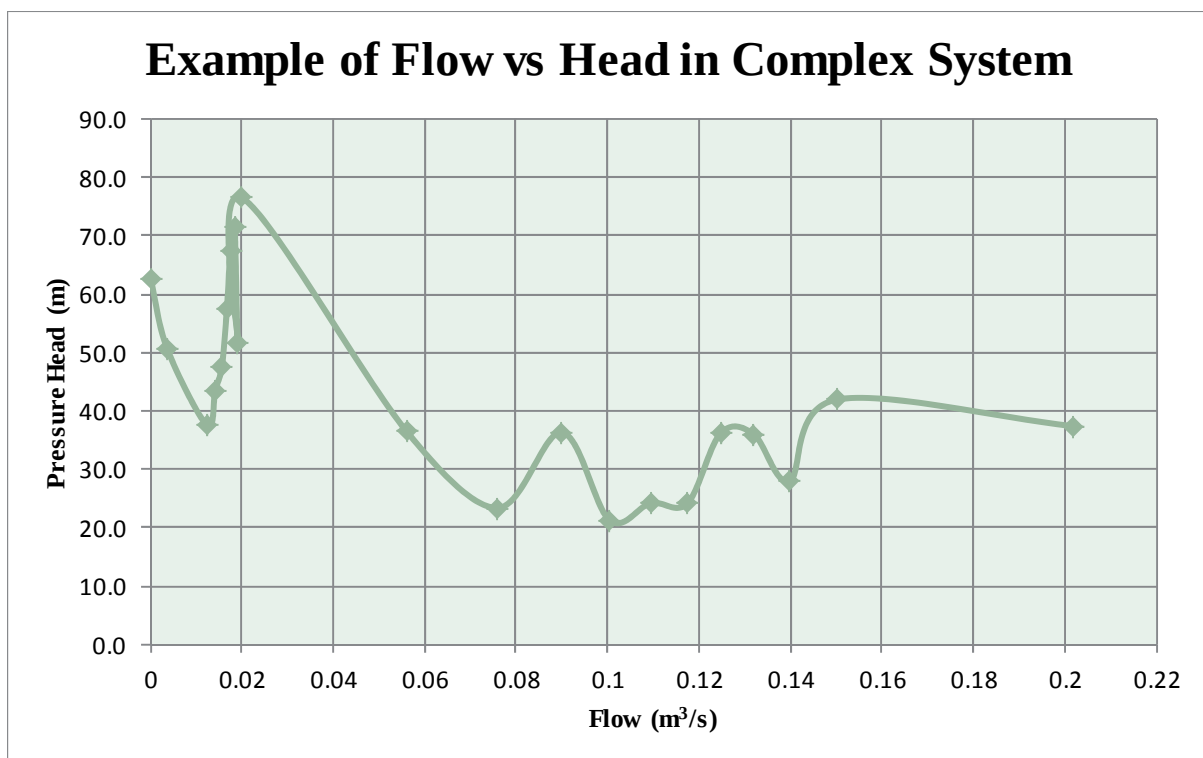


Figure 6-14: Example of flow vs. head in an open system

The Regulatory Section includes links to relevant websites, as well as applicable application forms for regulatory processes, pertaining to NERSA licensing and Eskom licensing.



The Economic Analysis Section has various default formulas (refer to **Appendix C** for derivation of formulas), but information like turbine type, updated overall costs, design life and inflation rates have to be entered into the Tool. Also, if better information than the default values is available, the values should be altered to reflect the most accurate costs. The output in this screen includes an estimated net present value (NPV), internal rate of return (IRR) and payback period of the proposed project.

Table 6-6: Phase 2 economic analysis CHD Tool

PHASE 2 ECONOMIC ANALYSIS				Inflation and maintenance factors over design life					
Power information for current scenario				Year	Annual Inflation				Maintenance factors
Power rating		609.8	kW		Electricity	Operation	Maintenance	General	
Design flow	(Q)	0.780	m ³ /s	0	8.0%	5.3%	5.3%	5.3%	0.8
Design flow corresponding head	(H)	114	m	1	8.0%	5.1%	5.1%	5.1%	0.8
Potential annual power		3 898	MWh/a	2	8.0%	6.0%	6.0%	6.0%	0.8
Turbine type		Turgo		3	8.0%	6.0%	6.0%	6.0%	0.8
Total Power information for future scenario				4	8.0%	6.0%	6.0%	6.0%	0.8
Power rating		1 220	kW	5	10.0%	6.0%	6.0%	6.0%	1
Design flow	(Q)	1.561	m ³ /s	6	10.0%	6.0%	6.0%	6.0%	1
Design flow corresponding head	(H)	114	m	7	10.0%	6.0%	6.0%	6.0%	1
Potential annual power		7 796	MWh/a	8	10.0%	6.0%	6.0%	6.0%	1
Turbine type		Turgo		9	10.0%	6.0%	6.0%	6.0%	1
				10	10.0%	6.0%	6.0%	6.0%	1
Design life		15	years	11	10.0%	6.0%	6.0%	6.0%	1
				12	10.0%	6.0%	6.0%	6.0%	1
Cost				13	10.0%	6.0%	6.0%	6.0%	1
Initial planning cost (IPC)	% of total IPC			14	10.0%	6.0%	6.0%	6.0%	1
Planning cost per MW installed (2012)		R 1 350 000		15	6.0%	6.0%	6.0%	6.0%	1.2
Planning year		2013		16	6.0%	6.0%	6.0%	6.0%	1.2
Planning cost per MW installed		R 1 350 000		17	6.0%	6.0%	6.0%	6.0%	1.2
Legal and regulatory	3.0%	R 24 698		18	6.0%	6.0%	6.0%	6.0%	1.2
Environmental and social assessment	27.0%	R 222 280		19	6.0%	6.0%	6.0%	6.0%	1.2
Investigation and preliminary design	70.0%	R 576 281		20	6.0%	6.0%	6.0%	6.0%	1.25
Subtotal	100.0%	R 823 259		21	6.0%	6.0%	6.0%	6.0%	1.25
Capital expenditure (CEC)				22	6.0%	6.0%	6.0%	6.0%	1.25
Turbine	% of total CEC			23	6.0%	6.0%	6.0%	6.0%	1.25
Capital cost per MW installed (excl turbine) (2012)		R 13 300 000		24	6.0%	6.0%	6.0%	6.0%	1.25
Construction year		2014		25	6.0%	6.0%	6.0%	6.0%	1.25
Capital cost per MW installed (excl turbine)		R 13 300 000		26	6.0%	6.0%	6.0%	6.0%	1.25
Preliminary and general	24.5%	R 1 987 104		27	6.0%	6.0%	6.0%	6.0%	1.25
Access to site	0.5%	R 40 533		28	6.0%	6.0%	6.0%	6.0%	1.25
Pipework and valves	6.5%	R 527 191		29	6.0%	6.0%	6.0%	6.0%	1.25
Power station housing and tailrace	20.0%	R 1 622 126		30	6.0%	6.0%	6.0%	6.0%	1.5
Electromechanical and controls	12.0%	R 973 275		31	6.0%	6.0%	6.0%	6.0%	1.5
Transformer/transmission	12.5%	R 1 013 829		32	6.0%	6.0%	6.0%	6.0%	1.5
Construction supervision	5.5%	R 446 085		33	6.0%	6.0%	6.0%	6.0%	1.5
Contingencies	17.5%	R 1 419 360		34	6.0%	6.0%	6.0%	6.0%	1.5
Disposal (present value (PV))	1.0%	R 81 106		35	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal	100.0%	R 14 818 821		36	6.0%	6.0%	6.0%	6.0%	1.5
Additional capital expenditure due to expansion (PV)		R 6 708 193		37	6.0%	6.0%	6.0%	6.0%	1.5
Year of expansion		2029		38	6.0%	6.0%	6.0%	6.0%	1.5
Annual operation and maintenance cost (OMC)				39	6.0%	6.0%	6.0%	6.0%	1.5
Civil items	0.25%	R 5 373		40	6.0%	6.0%	6.0%	6.0%	1.5
Electrical and mechanical items	2.00%	R 153 629		41	6.0%	6.0%	6.0%	6.0%	1.5
Transmission	0.80%	R 8 111		42	6.0%	6.0%	6.0%	6.0%	1.5
Operation	0.40%	R 59 275		43	6.0%	6.0%	6.0%	6.0%	1.5
Insurance	0.30%	R 44 456		44	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal (PV)		R 270 845		45	6.0%	6.0%	6.0%	6.0%	1.5
Income				46	6.0%	6.0%	6.0%	6.0%	1.5
Annual income for current scenario	R/kWh			47	6.0%	6.0%	6.0%	6.0%	1.5
Average value of generated electricity	0.58	R 2 260 834		48	6.0%	6.0%	6.0%	6.0%	1.5
Revenue		R 0		49	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal (PV)		R 2 260 834		50	6.0%	6.0%	6.0%	6.0%	1.5
Annual income for future scenario	R/kWh								
Average value of generated electricity	0.58	R 4 521 667							
Revenue		R 0							
Subtotal (PV)		R 4 521 667							
Results									
Net present value of costs		-R 19 266 797							
Net present value of income		R 41 090 195							
Total NPV		R 21 823 398							
Internal rate of return		19.74%							
Payback period		8 years							



The Checklist Section (**Table 6-7**) for this phase does not require any input, but serves as a reference for the user to determine whether all the steps for the second phase have been considered.

Table 6-7: Phase 2 checklist CHD Tool

PHASE 2 CHECKLIST 	
Did the first phase indicate economic feasibility?	
If not, is there another reason for considering conduit hydro?	
Did the site evaluation show feasibility?	
Were flow - and pressure records measured/obtained?	
Were all gaps discarded?	
Were the values ranked from small to large flow with corresponding pressures?	
Was a percentage assigned to each flow (100% exceedance for min flow to 0% exceedance for max flow)?	
Has the flow rating curve been populated?	
Has the hydropower potential been analysed?	
Is there currently significant potential?	
If not, will there be future development that might increase potential?	
Has a design flow and pressure been chosen?	
Has a first order turbine selection been done?	
For grid tie-in: Have all environmental aspects been considered and permission been obtained?	
For grid tie-in: Have licensing requirements been satisfied?	
For grid tie-in: Have all water use aspects been considered and permission been obtained?	
For grid tie-in: Have all social issues been addressed?	
For islanded/on-site systems: Have all environmental aspects been considered and permission been obtained?	
For islanded/on-site systems: Have all water use aspects been considered and permission been obtained?	
For islanded/on-site systems: Have all social issues been addressed?	
Has a pre-feasibility economic analysis been conducted?	
Is the project economically feasible?	
If not, is there another reason for continuing?	

6.5.3 Phase 3 CHD Tool

Phase 3 of the CHD Tool has 14 sections. Current and Future Sections are available for: the Hydropower Potential; Required Turbine Range; Potential Income (for grid-connected applications); Power Potential vs. Income Graphs (for grid-connected applications); Power Potential vs. Demand (for on-site and islanded applications); and Daily Supply-and-Demand Graphs (for on-site and islanded applications). The Economic Analysis and Checklist Sections are applicable to the entire project and therefore incorporate both current and future scenarios.

As this phase includes detailed design, site-specific information needs to be sourced and generalised information cannot be used for this phase. The CHD Tool for this phase can therefore only provide a minimum amount of default information.

The Hydropower Potential section can be seen in **Table 6-8**. The inputs required in this section are the measured values for flow and available head. The screen accepts data for up to 35 000 data points.



Table 6-8: Phase 3 potential analysis CHD Tool

PHASE 3 POTENTIAL ANALYSIS								
Flow rating curve	Load factor (%)	Flow (m ³ /s)	Head available (m)	Efficiency (%)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100	0	125	0%	8592	0.0	0.000	0.000
	95	0.000	123.4	0%	8154	0.0	0.000	0.000
	90	0.001	139.5	0%	7716	0.0	0.000	0.000
	85	0.059	143.9	22%	7278	18.2	132.465	3.976
	80	0.184	142.9	55%	6840	141.8	969.865	34.947
	75	0.310	138.0	80%	6402	335.7	2149.311	104.302
	70	0.412	131.2	83%	5964	440.1	2624.710	169.458
	65	0.553	127.4	84%	5526	577.0	3188.704	222.166
	60	0.780	113.8	84%	5088	727.4	3701.165	317.777
	55	0.959	92.6	84%	4650	727.5	3382.977	317.777
	50	0.974	94.6	84%	4212	754.5	3177.821	317.777
	45	0.981	96.6	84%	3774	776.5	2930.541	317.777
	40	0.986	99.0	84%	3336	799.9	2668.550	317.777
	35	0.992	101.0	84%	2898	821.1	2379.499	317.777
	30	0.999	103.4	84%	2460	846.0	2081.116	317.777
	25	1.009	109.8	84%	2022	907.3	1834.488	317.777
	20	1.025	120.9	84%	1584	1015.6	1608.761	317.777
	15	1.105	88.0	84%	1146	796.6	912.925	317.777
	10	1.194	97.1	84%	708	949.2	672.001	317.777
	5	1.372	85.8	84%	270	964.0	260.286	317.777
	0	1.456	82.6	84%	0	984.5	0.000	317.777
Optimum flow	60	0.780	113.8		5088	727.4	3701.165	4665.951
Average flow		0.767	111.6	84%	8592	701.4	6026.665	
Chosen flow		0.032	50.4	84%	8592	13.0	111.735	
Assurance of flow		0.000	0.0	84%	0	0.0	0.000	
Design flow	60	0.780	113.8		5088	727.4	4666.0	
Flow range								
Minimum flow	55	0.959	92.6		727.5	3382.977		
Design flow	60	0.7804	113.8		727.4	3701.165		
Maximum flow	55	0.959	92.6		727.5	3383.0		
General input								
Fluid density (ρ)		1000	kg/m ³	Energy usage				
Gravitational acceleration (g)		9.81	m/s ²	Grid connected		Islanded/on-site		
Efficiency (η)		80	%	Distance		0.5		Max demand
Annual maintenance days		7	days					Pav/Max demand
								0 %
								Distance to grid
PHASE 3 INPUT								
Site name	Carsfontein							
Data points	Load factor (%)	Date and time	Flow (m ³ /s)	Head available (m)	Time in use (h)	Potential power (MWh/a)		
13929	100.0000%	2012/03/30 13:45	0	125	8760	0.0		
13928	99.9928%	2012/03/30 14:30	0	122	8759.371096	0.0		
13927	99.9856%	2012/03/30 14:45	0	123	8758.742193	0.0		
13926	99.9785%	2012/03/31 16:15	0	127	8758.113289	0.0		
13925	99.9713%	2012/03/31 16:30	0	127	8757.484385	0.0		
13924	99.9641%	2012/04/02 06:30	0	123	8756.855481	0.0		
13923	99.9569%	2012/04/02 10:00	0	107	8756.226578	0.0		
13922	99.9497%	2012/04/02 10:15	0	117	8755.597674	0.0		
13921	99.9426%	2012/04/02 12:45	0	114	8754.96877	0.0		
13920	99.9354%	2012/04/02 15:15	0	114	8754.339866	0.0		
13919	99.9282%	2012/04/02 15:30	0	117	8753.710963	0.0		
13918	99.9210%	2012/04/02 19:30	0	130	8753.082059	0.0		
13917	99.9138%	2012/04/03 08:45	0	117	8752.453155	0.0		
13916	99.9067%	2012/04/03 09:00	0	117	8751.824252	0.0		
13915	99.8995%	2012/04/03 16:15	0	114	8751.195348	0.0		
13914	99.8923%	2012/04/03 16:30	0	115	8750.566444	0.0		



The CHD Tool requires the data to be sorted from lowest to highest flow with corresponding pressure heads, with all data gaps removed. The number of used data points is also required.

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

The first set of output values for this section includes: the design flow, design head and annual power generation. The design flow, as well as required minimum and maximum flows is entered into the Flow Range column in the section. A graph depicting the required turbine range (**Figure 6-15**) is produced from this information. This can be used when contacting turbine suppliers to obtain turbine information. It is important to note that turbines produced by different manufacturers will have different ranges of flow rate and operating heads applicable to the various turbine types and this graph is therefore only a guideline as far as turbine selection is concerned. The Required Turbine Range Section does have a column where user-defined turbine information may be entered. This is shown in **Table 6-9**.

Table 6-9: Phase 3 user turbine input CHD Tool

PHASE 3 USER TURBINE INPUT	
Manufacturer	
Flow (m ³ /s)	Corresponding head (m)



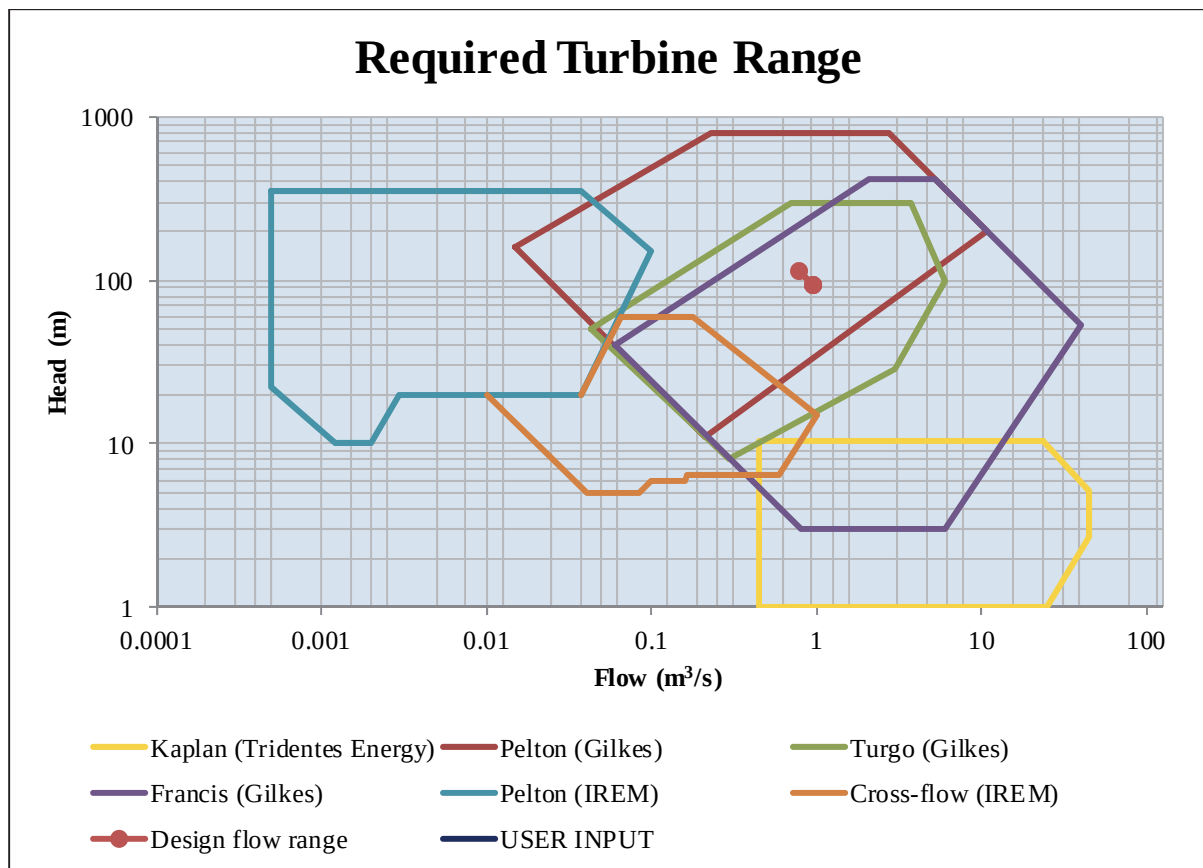


Figure 6-15: Phase 3 turbine selection CHD Tool

The next two sections are the Potential Income and Power Potential vs. Income Graph Sections and are applicable to grid-connected applications. The information entered into the Potential Income Section is depicted graphically in the Power Potential vs. Income Graphs Section.

The function of the Potential Income Section is to tabulate electricity tariffs and average hourly power potential throughout the day, for different seasons and days of the week (**Table 6-10**). This information is used to populate the Power Potential vs. Income Graphs (**Figure 6-16**), that clearly show the correlation between hours of high electricity value (peak times) and hours with high power potential. The purpose of this section is to indicate to the municipality a possible operational procedure for higher power production (to ensure a higher income), if it does not negatively affect water supply to users.



Table 6-10: Phase 3 potential income CHD Tool (for grid-connected applications)

PHASE 3: VALUE OF ELECTRICITY								PHASE 3: POTENTIAL POWER																				
Megaflex tariff 2012-2013	Time of day	Winter (c/kWh)				Summer (c/kWh)				Time of day	Average hourly power in winter																	
		Week days		Saturday	Sunday	Week days		Saturday	Sunday		Week days					Saturday					Sunday							
		Flow (m³/s)	Head (m)	Efficiency (%)	Average hourly power (kW)	Value of power (c)	Flow (m³/s)	Head (m)	Efficiency (%)		Average hourly power (kW)	Value of power (c)	Flow (m³/s)	Head (m)	Efficiency (%)	Average hourly power (kW)	Value of power (c)	Flow (m³/s)	Head (m)	Efficiency (%)	Average hourly power (kW)	Value of power (c)	Flow (m³/s)	Head (m)	Efficiency (%)	Average hourly power (kW)	Value of power (c)	
00:00	41.79	41.79	41.79	36.99	36.99	36.99		00:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
01:00	41.79	41.79	41.79	36.99	36.99	36.99		01:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
02:00	41.79	41.79	41.79	36.99	36.99	36.99		02:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
03:00	41.79	41.79	41.79	36.99	36.99	36.99		03:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
04:00	41.79	41.79	41.79	36.99	36.99	36.99		04:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
05:00	41.79	41.79	41.79	36.99	36.99	36.99		05:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
06:00	71.74	41.79	41.79	49.73	36.99	36.99		06:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
07:00	254.85	71.74	41.79	76.5	49.73	36.99		07:00	0.126	126	84.0%	130.93	33387	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
08:00	254.85	71.74	41.79	76.5	49.73	36.99		08:00	0.126	126	84.0%	130.93	33387	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
09:00	254.85	71.74	41.79	76.5	49.73	36.99		09:00	0.126	126	84.0%	130.93	33387	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
10:00	71.74	71.74	41.79	49.73	49.73	36.99		10:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
11:00	71.74	71.74	41.79	49.73	49.73	36.99		11:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
12:00	71.74	41.79	41.79	49.73	36.99	36.99		12:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
13:00	71.74	41.79	41.79	49.73	36.99	36.99		13:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
14:00	71.74	41.79	41.79	49.73	36.99	36.99		14:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
15:00	71.74	41.79	41.79	49.73	36.99	36.99		15:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
16:00	71.74	41.79	41.79	49.73	36.99	36.99		16:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
17:00	71.74	41.79	41.79	49.73	36.99	36.99		17:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
18:00	254.85	71.74	41.79	76.5	49.73	36.99		18:00	0.126	126	84.0%	130.93	33387	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
19:00	254.85	71.74	41.79	76.5	49.73	36.99		19:00	0.126	126	84.0%	130.93	33387	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471
20:00	71.74	41.79	41.79	49.73	36.99	36.99		20:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
21:00	71.74	41.79	41.79	49.73	36.99	36.99		21:00	0.126	126	84.0%	130.93	9393	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
22:00	41.79	41.79	41.79	36.99	36.99	36.99		22:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
23:00	41.79	41.79	41.79	36.99	36.99	36.99		23:00	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471	0.126	126	84.0%	130.93	5471
General input																												
Fluid density		(g)	1000 kg/m³					Total per hour		3.024	3142.28	313908			3142.28	158765			3142.28	158765			3142.28	133318				
Gravitational acceleration		(g)	9.81 m/s²					Total per year (kWh or c)		10886.4	204248.3343	204053.4474			40991.94893	2222711.55			40991.94893	2222711.55			40849.66687	1707107.578				
										8380.8	2042483343	204053.4474			4099194893	222271155			4099194893	222271155			4084966687	1707107578				

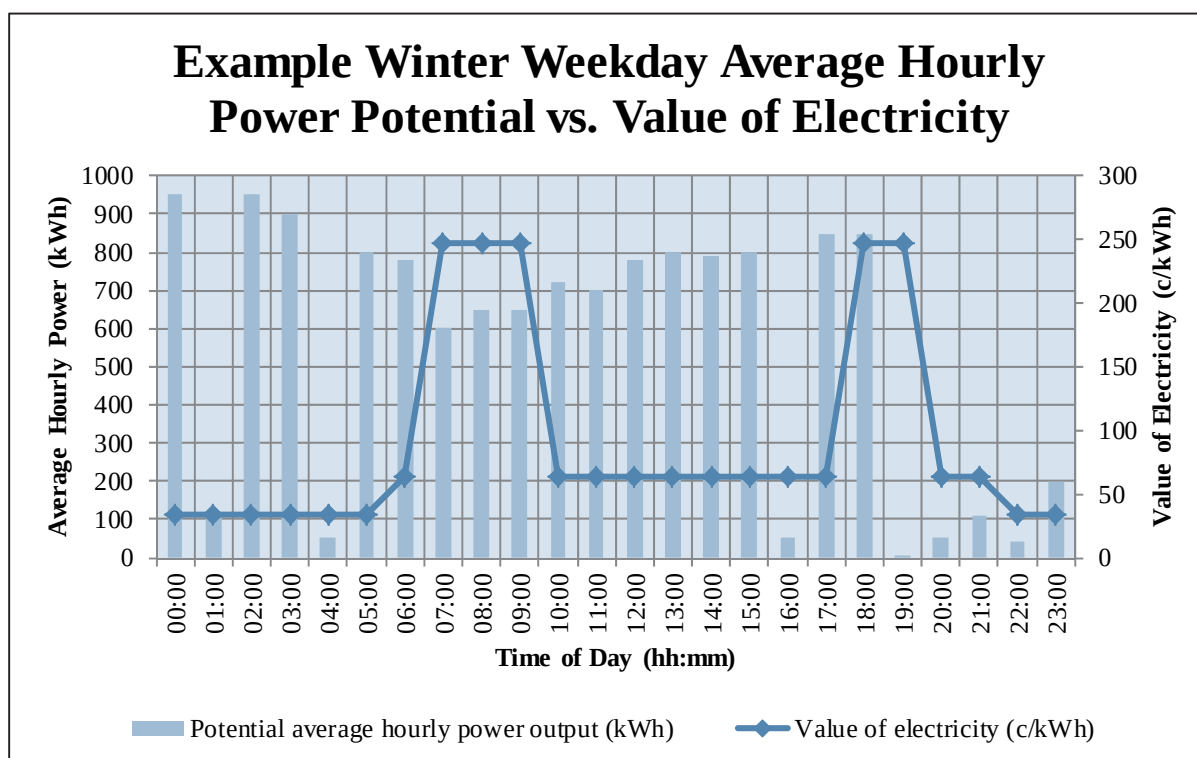


Figure 6-16: Phase 3 power potential vs. income graph (for grid-connected applications)

The next two sections are the Power Potential vs. Demand Section and the Power Potential vs. Demand Graph Section and are applicable to islanded or on-site applications. The information entered into the Power Potential vs. Demand Section is depicted graphically in the Power Potential vs. Demand Graph Section.



The function of the Power Potential vs. Demand Section is to tabulate daily and seasonal demand variation for energy usage. The table separates typical winter and summer power output, as well as winter and summer energy demands.

The available energy is then compared with demand to obtain the surplus or deficit at a number of points (typically at 15 min intervals over a 24 h period). **Table 6-11** shows a shortened version of this section. This information is summarised in the Power Potential vs. Demand Graph Section, as shown in **Figure 6-17**.

Table 6-11: Phase 3 power potential vs. demand CHD Tool (for islanded and on-site applications)

PHASE 3 POWER SUPPLY DISTRIBUTION: SUMMER						
Example daily summer power potential						
Time (hh:mm)	Flow (m ³ /s)	Head available (m)	Efficiency (η)	Potential power (kW)	Power demand (kW)	Surplus/deficiency (kW)
00:00	0.0333	50.4		13.2	12.5	0.7
00:15	0.0333	50.4		13.2	12.5	0.7
00:30	0.0333	50.4		13.2	12.5	0.7
00:45	0.0333	50.4		13.2	12.5	0.7
01:00	0.0333	50.4		13.2	12.5	0.7
01:15	0.0333	50.4		13.2	12.5	0.7
01:30	0.0333	50.4		13.2	12.5	0.7
01:45	0.0333	50.4		13.2	12.5	0.7
02:00	0.0333	50.4		13.2	12.5	0.7
02:15	0.0333	50.4		13.2	12.5	0.7
02:30	0.0333	50.4		13.2	12.5	0.7
02:45	0.0333	50.4		13.2	12.5	0.7
03:00	0.0333	50.4		13.2	12.5	0.7
03:15	0.0333	50.4		13.2	12.5	0.7
03:30	0.0333	50.4		13.2	12.5	0.7
03:45	0.0333	50.4		13.2	12.5	0.7
04:00	0.0333	50.4		13.2	12.5	0.7
04:15	0.0333	50.4		13.2	12.5	0.7
04:30	0.0333	50.4		13.2	12.5	0.7
04:45	0.0333	50.4		13.2	12.5	0.7
05:00	0.0333	50.4		13.2	12.5	0.7
05:15	0.0333	50.4		13.2	2.0	11.2
05:30	0.0333	50.4		13.2	2.0	11.2
05:45	0.0333	50.4		13.2	2.0	11.2
06:00	0.0333	50.4		13.2	2.0	11.2
06:15	0.0333	50.4		13.2	2.0	11.2
21:30	0.0333	50.4		13.2	12.5	0.7
21:45	0.0333	50.4		13.2	12.5	0.7
22:00	0.0333	50.4		13.2	12.5	0.7
22:15	0.0333	50.4		13.2	12.5	0.7
22:30	0.0333	50.4		13.2	12.5	0.7
22:45	0.0333	50.4		13.2	12.5	0.7
23:00	0.0333	50.4		13.2	12.5	0.7
23:15	0.0333	50.4		13.2	12.5	0.7
23:30	0.0333	50.4		13.2	12.5	0.7
23:45	0.0333	50.4		13.2	12.5	0.7
General input						
Fluid density (ρ)		1000	kg/m ³			
Gravitational acceleration (g)		9.81	m/s ²			
Efficiency (η)		80	%			



These sections will clearly show how the operation needs to be adjusted if power is needed throughout the day and energy storage is not available.

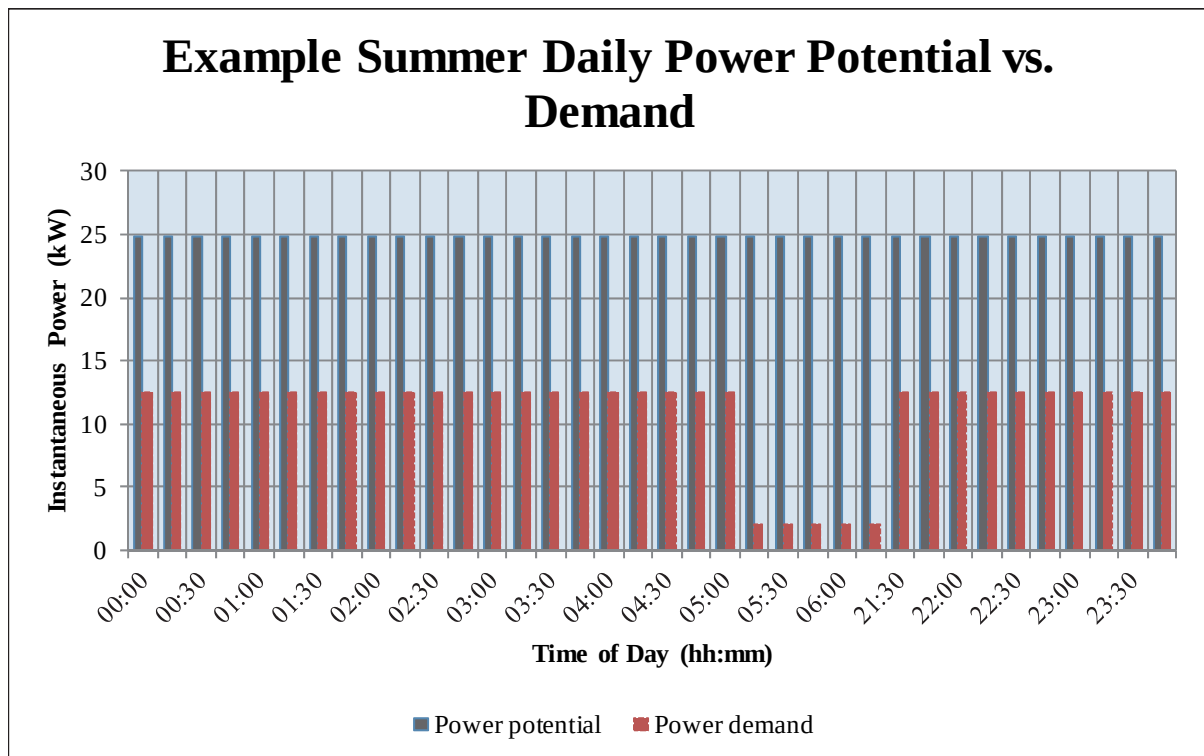


Figure 6-17: Phase 3 power potential vs. demand graph (for islanded and on-site applications)

The Economic Analysis Section is shown in **Table 6-12**. Input required for this section includes the broken down costs for initial planning and capital expenditure, as well as annual operation and maintenance expenses. It also requires the design life (maximum 50 years) of the plant, projected income and inflation rates for electricity, operation and maintenance and a general discount rate.

The output of this section includes an estimate of the net present value (NPV) and the internal rate of return (IRR) of the proposed project.



Table 6-12: Phase 3 Economic analysis CHD Tool

PHASE 3 ECONOMIC ANALYSIS					Inflation and maintenance factors over design life					
Power information for current scenario					Year	Annual Inflation				Maintenance factors
Power rating		727	kW			Electricity	Operation	Maintenance	General	
Design flow	(Q)	0.780	m ³ /s		0	8.0%	5.3%	5.3%	5.3%	0.8
Design flow corresponding head	(H)	114	m		1	8.0%	5.1%	5.1%	5.1%	0.8
Potential annual power		4 666	MWh/a		2	8.0%	6.0%	6.0%	6.0%	0.8
Turbine type		Turgo			3	8.0%	6.0%	6.0%	6.0%	0.8
Total power information for future scenario					4	8.0%	6.0%	6.0%	6.0%	0.8
Power rating		727	kW		5	10.0%	6.0%	6.0%	6.0%	1
Design flow	(Q)	1.561	m ³ /s		6	10.0%	6.0%	6.0%	6.0%	1
Design flow corresponding head	(H)	114	m		7	10.0%	6.0%	6.0%	6.0%	1
Potential annual power		9 307	MWh/a		8	10.0%	6.0%	6.0%	6.0%	1
Turbine type		Turgo			9	10.0%	6.0%	6.0%	6.0%	1
Design life					10	10.0%	6.0%	6.0%	6.0%	1
					11	10.0%	6.0%	6.0%	6.0%	1
					12	10.0%	6.0%	6.0%	6.0%	1
Cost					13	10.0%	6.0%	6.0%	6.0%	1
Initial planning cost (IPC)					14	10.0%	6.0%	6.0%	6.0%	1
Legal and regulatory		R 0			15	6.0%	6.0%	6.0%	6.0%	1.2
Environmental and social assessment		R 0			16	6.0%	6.0%	6.0%	6.0%	1.2
Investigation and preliminary design		R 1 200 000			17	6.0%	6.0%	6.0%	6.0%	1.2
Subtotal		R 1 200 000			18	6.0%	6.0%	6.0%	6.0%	1.2
Capital expenditure (CEC)					19	6.0%	6.0%	6.0%	6.0%	1.2
Construction year		2014			20	6.0%	6.0%	6.0%	6.0%	1.25
Turbine		R 7 404 665			21	6.0%	6.0%	6.0%	6.0%	1.25
Preliminary and general		R 1 300 000			22	6.0%	6.0%	6.0%	6.0%	1.25
Access to site		R 0			23	6.0%	6.0%	6.0%	6.0%	1.25
Pipework and valves		R 1 100 000			24	6.0%	6.0%	6.0%	6.0%	1.25
Power station housing and tailrace		R 1 600 000			25	6.0%	6.0%	6.0%	6.0%	1.25
Electromechanical and controls		R 1 100 000			26	6.0%	6.0%	6.0%	6.0%	1.25
Transformer/transmission		R 700 000			27	6.0%	6.0%	6.0%	6.0%	1.25
Construction supervision		R 1 000 000			28	6.0%	6.0%	6.0%	6.0%	1.25
Contingencies		R 1 300 000			29	6.0%	6.0%	6.0%	6.0%	1.25
Other (Data logging)		R 20 000			30	6.0%	6.0%	6.0%	6.0%	1.5
Disposal (Present value (PV))		R 0			31	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal		R 15 524 665			32	6.0%	6.0%	6.0%	6.0%	1.5
Additional capital expenditure due to expansion (PV)		R 0			33	6.0%	6.0%	6.0%	6.0%	1.5
Year of expansion		2029			34	6.0%	6.0%	6.0%	6.0%	1.5
Annual operation and maintenance cost (OMC) % of CEC for component					35	6.0%	6.0%	6.0%	6.0%	1.5
Civil items	0.25%	R 6 750			36	6.0%	6.0%	6.0%	6.0%	1.5
Electrical and mechanical items	2.00%	R 170 093.29			37	6.0%	6.0%	6.0%	6.0%	1.5
Transmission	0.80%	R 5 600			38	6.0%	6.0%	6.0%	6.0%	1.5
Operation	0.40%	R 62 099			39	6.0%	6.0%	6.0%	6.0%	1.5
Insurance	0.30%	R 46 574			40	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal (PV)		R 291 116			41	6.0%	6.0%	6.0%	6.0%	1.5
Income					42	6.0%	6.0%	6.0%	6.0%	1.5
Annual income for current scenario R/kWh					43	6.0%	6.0%	6.0%	6.0%	1.5
Average value of generated electricity	0.58	R 2 706 251			44	6.0%	6.0%	6.0%	6.0%	1.5
Revenue		R 0			45	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal (PV)		R 2 706 251			46	6.0%	6.0%	6.0%	6.0%	1.5
Annual income for future scenario R/kWh					47	6.0%	6.0%	6.0%	6.0%	1.5
Average value of generated electricity	0.58	R 5 398 243			48	6.0%	6.0%	6.0%	6.0%	1.5
Revenue		R 0			49	6.0%	6.0%	6.0%	6.0%	1.5
Subtotal (PV)		R 5 398 243			50	6.0%	6.0%	6.0%	6.0%	1.5
Results										
Net present value of costs		-R 20 617 844								
Net present value of income		R 49 185 573								
Total NPV		R 28 567 728								
Internal rate of return		22.14%								



As with the previous phases, the Checklist Section (**Table 6-13**) for this phase does not require any input, but serves as a reference for the user to determine whether all the steps for Phase 3 have been considered.

Table 6-13: Phase 3 checklist for CHD Tool

PHASE 3 CHECKLIST 	
Did the first two phases indicate economic feasibility?	
If not, is there another reason for considering conduit hydro?	
Has historical flow and pressure records been obtained?	
Were flow - and pressure records measured/obtained?	
Were all gaps discarded?	
Were the values ranked from small to large flow and large to small pressure?	
Was a percentage assigned to each flow (100% exceedance for min flow to 0% exceedance for max flow)?	
Has the flow rating curve been populated?	
Has the hydropower potential been analysed?	
Is there currently significant potential?	
If not, will there be future development that might increase potential?	
Has a design flow and pressure been chosen?	
Has the effect of optimization been considered?	
Has the required turbine range been determined?	
Has the appropriate turbine been selected?	
Has the turbine efficiency been determined and included in the analysis?	
Are the future flow rate scenarios compatible with the turbine range?	
If not, have additional turbines been selected for the future scenario?	
Has the electricity use destination been established?	
For grid tie-in: Has the distance to the grid been calculated?	
For grid tie-in: Does the connection comply with Eskom and Municipality requirements?	
For islanded/on-site systems: What are the current and future energy demands?	
For islanded/on-site systems: Do the demand and supply patterns correlate?	
For islanded/on-site systems: If not, can the operational procedure be changed or batteries installed to ensure reliability of supply?	
For islanded/on-site systems: Is there is sufficient demand for the size of the installation?	
For islanded/on-site systems: If not, has a smaller turbine been selected to allow for the maximum forecast demand?	
Have the electrical and mechanical components been designed?	
Have the civil works been designed?	
Has the plant setup been determined?	
Is all equipment protected from vandalism and theft?	
Is the system practically feasible?	
Has a detail design phase economic analysis been conducted?	
Is the project economically feasible?	
Has a sensitivity analysis been conducted?	
Is the risk acceptable?	
If not, is there another reason for continuing?	



7. DECISION SUPPORT SYSTEM EXPLAINED

This section serves to elaborate on the steps illustrated in the process flow diagrams in **Chapter 6**, (

Figure 6-2 to **Figure 6-8**) and to discuss the Conduit Hydropower Decision Support System (CHDSS) in greater detail.

7.1 First Phase: Pre-Feasibility Investigation

7.1.1.1 Introduction

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

7.1.1.2 Potential sites

The first task would be to determine whether there are any points in the municipality's distribution network with excess energy.

Excess energy will generally be available between points in the network with significant elevation differences. The easiest way to source this information is to obtain maps indicating the topography of the municipality and location of pressure-reducing stations (PRSs) and reservoirs in the distribution system.

Therefore three important aspects to consider at this stage include: firstly, whether there are any PRSs in the municipal distribution system; secondly whether any high pressure points exist that do not have PRSs installed; and thirdly, whether the identified reservoirs and PRSs are indeed the property of the municipality.



Pressure reducing stations ¹

In some cases the frictional and secondary losses along the length of the pipe are significantly lower than the total pressure head. To avoid unnecessary high-pressure class pipes and the increased risk of leakages in these pipes, one has to include a restriction that will dissipate the excess pressure at calculated points along the distribution line. These restrictions are particularly necessary upstream of reservoir intakes to prevent damage to the reservoir structure due to excessive pressures of piped water arriving at the reservoir.

Therefore, single or multiple PRSs are normally installed just before the inlet of a reservoir at the downstream end of a gravitational line. Pressure-reducing valves (PRVs) are commonly used.

These valves ensure sufficiently low pressures to prevent damage to the reservoir and its connections and fittings. The size and number of PRVs at a reservoir inlet are directly related to the magnitude of the pressure head to be dissipated.

PRVs or other PRSs can also be installed in strategic points along the distribution line, to reduce excess pressures and ensure more cost-effective use of pipe sizes and diameters. These PRSs therefore indicate points with excess energy along the pipeline (or at reservoirs) and can be used as a first-order indicator of hydropower potential.

High pressure points ²

It is possible that not all the high pressure points in the network have PRSs. To determine if high pressure points exist at locations that do not have PRSs, a network analysis has to be run to find high pressure points. This can typically be done in EPANET. Möderl et al. (2012) provide a description of the process with a case study.

It should be noted during the analysis that high pressure points may in some cases be necessary to maintain a balance in the system. In these cases the energy may therefore not be dissipated.

Property of the municipality ³

If the reservoirs with PRSs and PRSs along the distribution line are not the property of the municipality or water board, or do not fall within municipal boundaries, permits for use should be obtained before effort is wasted on determining hydropower potential that cannot be used by the municipality.

7.1.1.3 Hydraulic analysis

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



Flow and pressure ⁴

All available flow and pressure data should now be compiled to determine the design flow and head values, and estimates should be done where sufficient information is not readily available. At this stage, the annual average daily demand (AADD) can be used to calculate average flow and a percentage (typically 50%) of the static head may be used for a conservative pressure head, if other information is not known. More detailed studies and flow and pressure measurements during different times of the day and seasons will be done in subsequent phases, if the outcome of the First Phase is positive.

The average daily flow should be given in m³/s and the pressure head given in metres (m). These values are used for the initial calculation of the power available at the specific point in the distribution system.

Power available ⁵

In order to obtain an initial estimate of the power potential at a specific site, the following formula (**Equation 7.1**), can be used:

$$P = \rho g Q H \eta \quad \dots(7.1)$$

where:

- P = mechanical power output (W) (calculated)
- η = hydraulic efficiency of the turbine (%) (use 70% in the First Phase)
- ρ = density of water (kg/m³) (use 1 000 kg/m³)
- g = gravitational acceleration (m/s²) (use 9.81 m/s²)
- Q = flow rate through the turbine (m³/s) (use the average flow in the First Phase)
- H = effective pressure head across the turbine (m) (use average head or 60% of static head)

7.1.1.4 Energy use considerations

Use of energy ⁶

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

-  Feeding electricity into an existing grid;
-  So-called islanded systems that are far from an electricity grid; and/or
-  Own-use at reservoirs or other sites in the network that need local lighting, security and telemetry or even as base supply of a nearby small community, mine or industry.



Distance of site to energy users

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

Energy demand

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

Demand vs. energy potential

The energy potential and energy demand should be compared to determine whether the project has the potential to be feasible and whether further investigation should be undertaken.

This is especially true in the case of islanded systems or on-site usage, as insufficient hydropower potential would mean that additional sources of energy should also be utilised. It is important to consider implementation of energy-efficiency measures to reduce demand. Energy efficiency may be increased by using low-energy lights and appliances and encouraging users to switch off unused or unnecessary lights and appliances.

7.1.1.5 Pre-feasibility economic analysis

A pre-feasibility economic analysis is done using a life-cycle approach with roughly estimated values for both costs and income. It is proposed that at least the net present value (NPV) and internal rate of return (IRR) be calculated to estimate economic feasibility at this stage using the formulas as indicated in **Chapter 5**. The payback period may also be calculated, preferably considering inflation. However, it should not be used as the deciding factor in project selection. It should only be used as a tool for initial screening to supplement other methods, as it does not give sufficient information to stand alone as an evaluation tool. (ESHA, 2004; Blank and Tarquin, 2004)

7.1.1.6 Other reasons for conduit hydropower

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

-  islanded systems which are not supplied from the national electricity grid.



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

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

7.1.2 Outcome of Phase 1

This phase requires a minimal amount of input information by the user.

The main function of this phase is to obtain an initial estimate of potential power and the economic feasibility of a conduit hydropower plant at a site. The outcome of this phase is a decision on the practicability of conducting a full feasibility study.

7.2 Second Phase Investigation: Feasibility

7.2.1 First phase successful

The first step during this phase is to critically consider the answers obtained during Phase 1. If Phase 1 indicates economic feasibility, or if there is another reason for considering hydropower at the site under investigation, the Second Phase study should commence.

7.2.2 Site Evaluation

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

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

7.2.3 Hydraulic Study

Flow and pressure measurement

Flow meters (refer to **Table 2-3** for examples of typical flow meters) and pressure transducer (refer to **Table 2-5** for examples of typical pressure transducers) should be installed (or existing ones utilised) to determine the maximum and minimum flow rates and corresponding pressures at the site. At this stage, it would be unreasonable to expect long-term flow data, but longer record sets would lead to better estimation.



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

Design flow and associated power

Power estimation can be done during the Feasibility Phase, using the additional information gathered. The following formula (with values as indicated in **Equation 7.2**), can be used:

$$P = \rho g Q H \eta \quad \dots(7.2)$$

where:

- P = mechanical power output (W) (calculated)
- η = hydraulic efficiency of the turbine (%) (use 70% in Feasibility Phase)
- ρ = density of water (kg/m³)
- g = gravitational acceleration (m/s²)
- Q = flow rate through the turbine (m³/s) (use the design flow)
- H = effective pressure head across the turbine (m) (use design head)

The design flow and head can be calculated by generating a flow-rating curve (**Figure 7-1**) and calculating the available power for different combinations of flow and associated head. The design flow and head are calculated in different ways, depending on the application of the generated energy. This aspect may become quite complicated when operational procedures are incorporated in the design, but this will be dealt with in more detail in Phase 3. At this stage it should be decided whether the electricity generated by the hydropower plant should have a certain reliability of supply (for example, power should be reliable for 95% of the time), or whether the maximum possible annual amount of energy can be supplied to the grid.

If electricity should be supplied at a certain assurance level, the flow at that percentage may be used as the design flow, with its corresponding head. **Figure 7-1** shows an example of the flow for 80% reliability of supply. If the maximum potential is used, then the design flow and head will be the combination that generates the optimum potential annual power. **Table 7-1** is an example of a table used to obtain the optimum potential power and **Figure 7-2** is a graphical representation of the data.

The annual potential power for a selected turbine capacity can be calculated by multiplying the potential power with the hours per year when that potential is available. The last column in **Table 7-1** is used to calculate this and **Figure 7-3** is a visual representation.



It should be noted that in a closed system (with one inflow), there will be a specific inverse relationship between flow and pressure head, with a flow rate always associated with the same head, as per **Figure 7-4**. However, in a complex system with various independent inflow and outflow points, a specific correlation will not be found between flow rate and pressure head, as per **Figure 7-5**. It is therefore necessary to carefully select the design pressure head in a complex system.

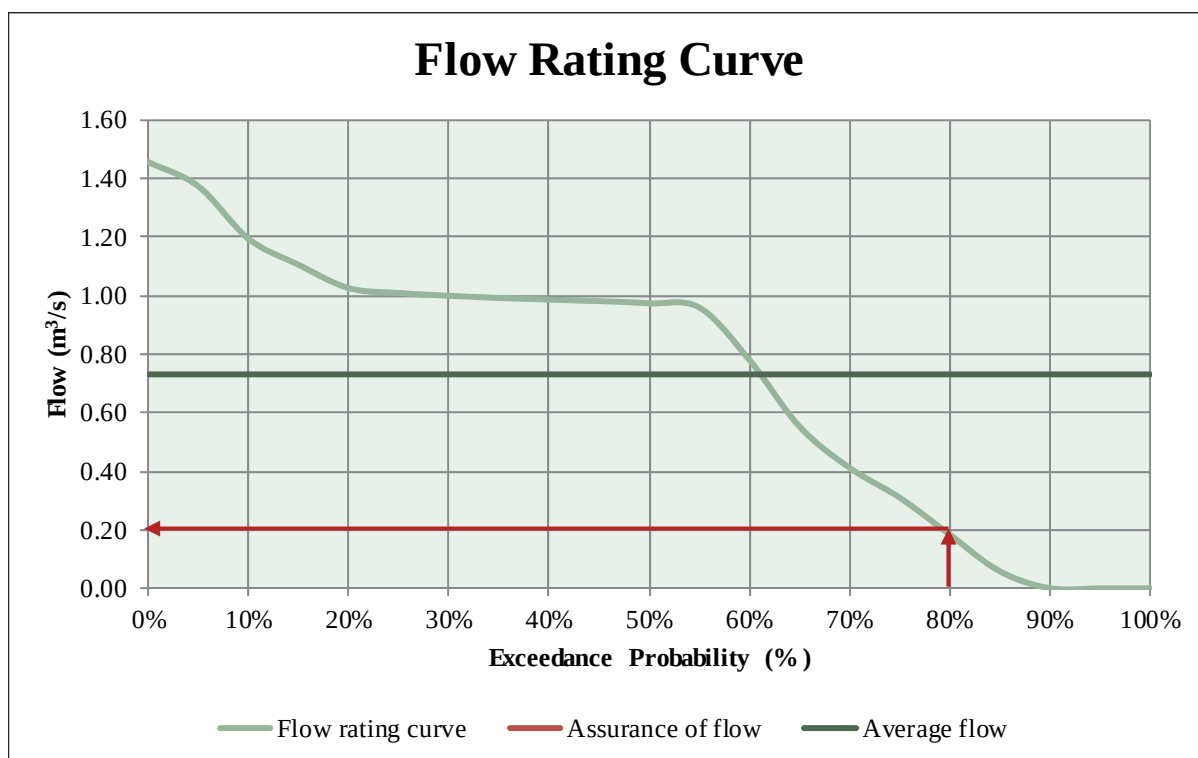


Figure 7-1: Example of a flow-rating curve with an 80% assurance of flow

Table 7-1: Example of a Phase 2 potential analysis



PHASE 2 POTENTIAL ANALYSIS



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

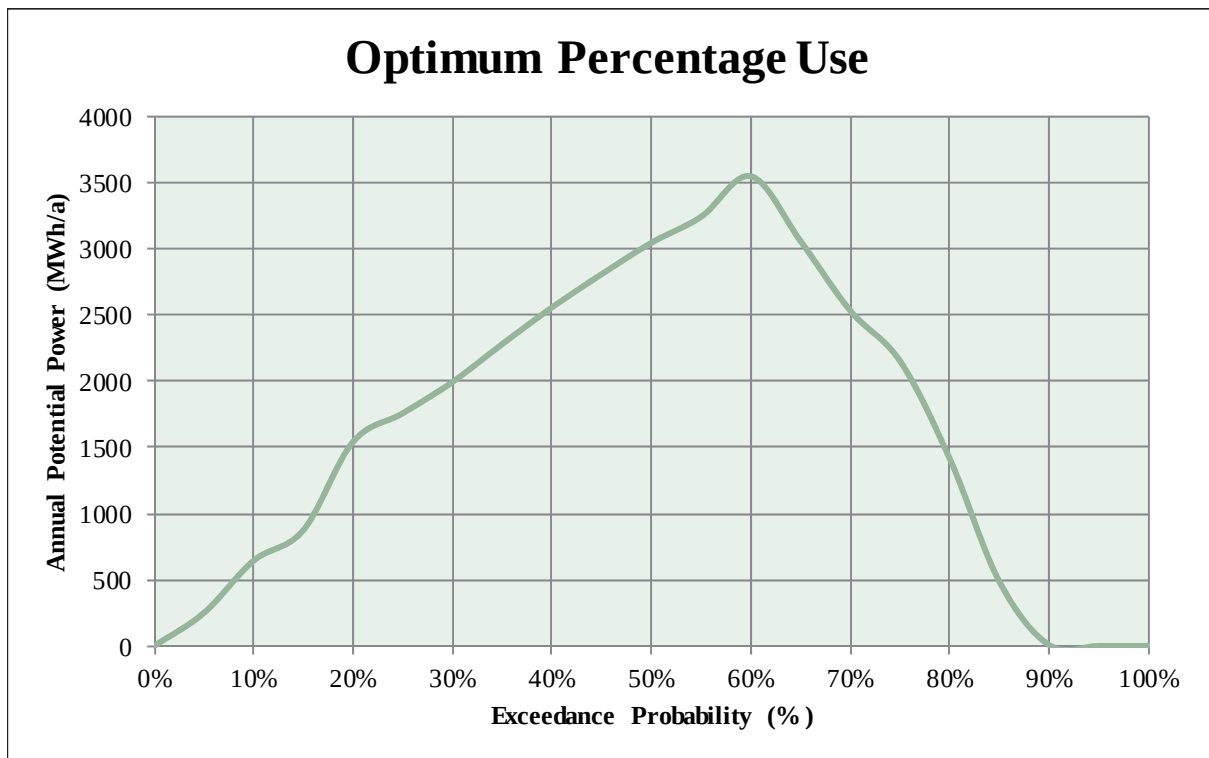


Figure 7-2: Example of an optimum percentage-use curve



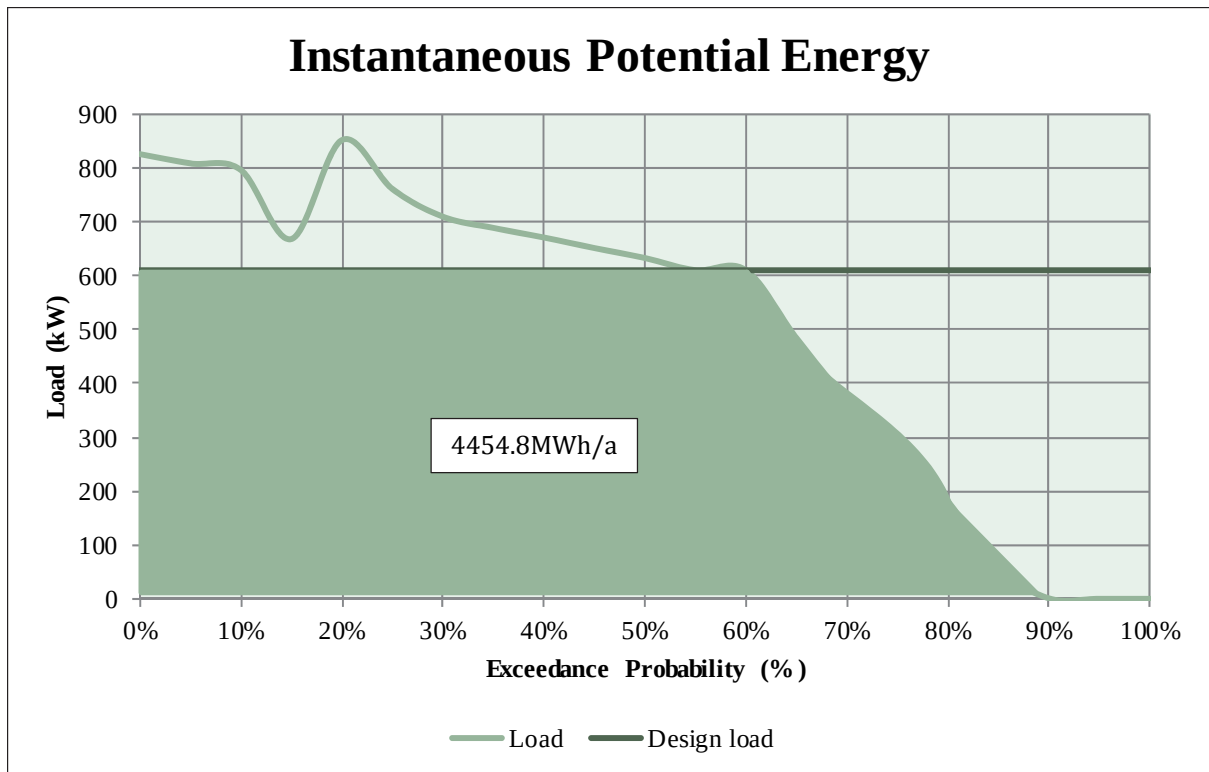


Figure 7-3: Example of an annual potential energy-calculation curve

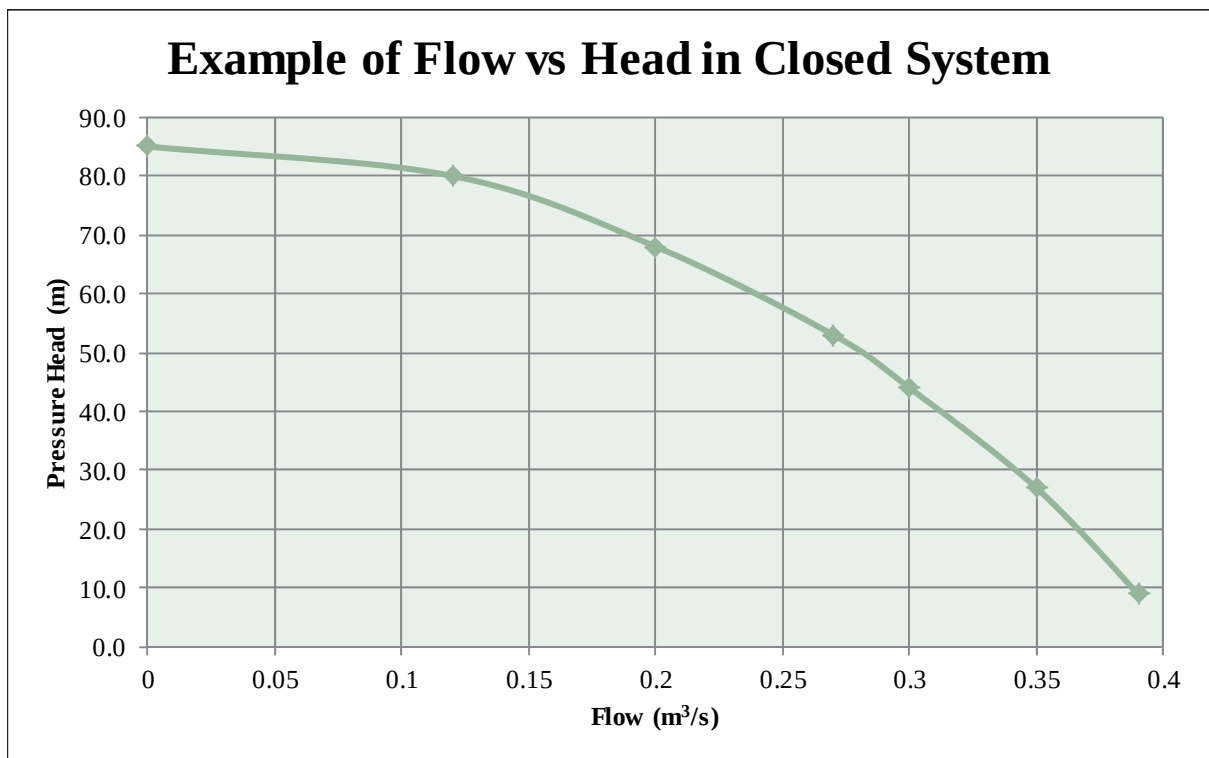


Figure 7-4: Example of a flow vs. head curve for a closed system



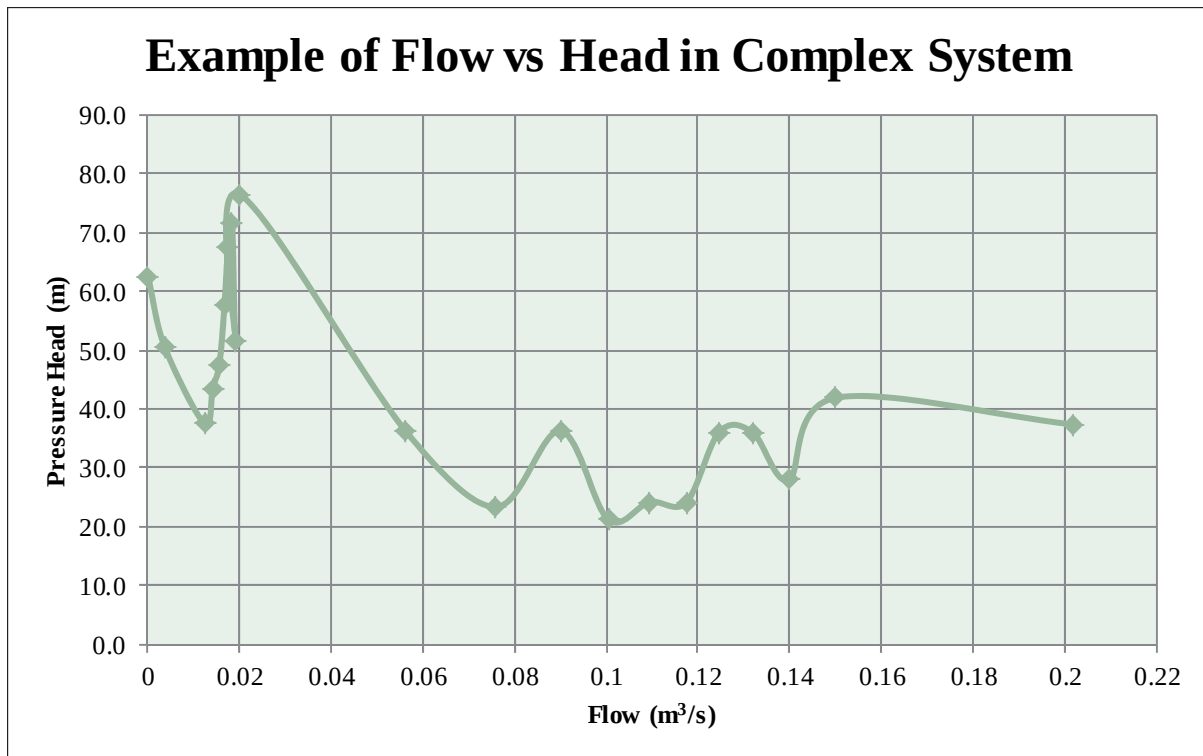


Figure 7-5: Example of a flow vs. head curve for an open system

Operation of site within system

5

The site has to be evaluated as part of the larger distribution system. The influence of a hydropower plant at the site should be investigated considering that water supply is the main function of the system and that the plant should not influence supply reliability.

The system should be optimised to allow for the maximum power generation (or generation at times with high potential income, in grid-connected projects) without negatively impacting water supply to users. This is especially the case when power should be supplied at a high assurance level, but current operational regimes include many hours of maximum flow rate. An alternative operational practice may be that supply should be provided at lower flow rates, but for longer periods at a time. Another possibility would be to ensure a constant flow and head into the reservoir for the time of day when electricity is needed.

It is important to note that no operational procedure should negatively affect water supply to users. If operational changes to the system are not possible, due to constraints and water-supply preferences, a thorough investigation should be done to determine whether the generated power could be effectively used at the times when it is able to generate power. This is especially the case when the generated electricity is not supplied to a larger grid; alternative energy sources are not available for an islanded (or



on-site) system; or power is generated to supply peak demand in the electricity network.

Future development



It may be that current flow and head will not generate a significant amount of hydropower. If this is the case, an investigation should be carried out to determine whether future development that may increase the potential is planned. If so, the future values should be used in further analyses, or phasing of hydropower development should be considered.

If future development will decrease the hydropower potential, this should be noted and the economic feasibility analysis should be done with an applicable design life for current circumstances.

Turbine selection



The design flow and head, together with the required power, can now be used for the initial selection of an appropriate turbine. The CHD Tool includes a graph (**Figure 7-6**) to facilitate this process. If necessary, turbine suppliers may be contacted for more detailed information.

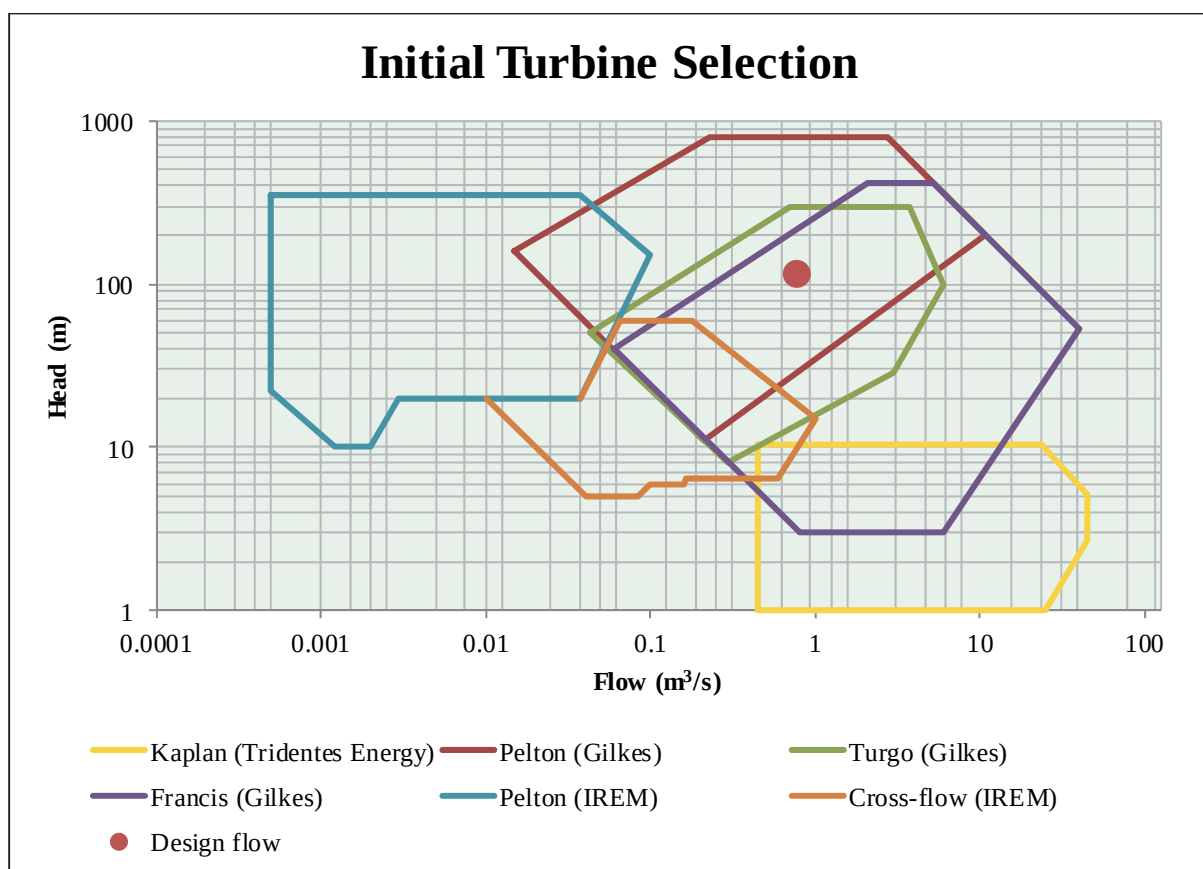


Figure 7-6: Example of an initial turbine-selection curve



7.2.4 Energy Use Considerations

Use of energy

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

-  Feeding electricity into an existing grid;
-  islanded systems that are far from an electricity grid; and/or
-  Own-use at reservoirs or other sites in the network that need local lighting, security and telemetry or even as base supply of a nearby small community, mine or industry.

Distance of site to energy users

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

Energy demand vs. energy potential

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

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

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

7.2.5 Feasibility Stage Regulatory Assessment

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

Environmental aspects



Hydropower plants installed in existing distribution systems should have minimal additional environmental impacts, as very little additional infrastructure is required. The noise from the powerhouse should account for the largest impact, but this can be mitigated by insulating the powerhouse. Other negative effects normally associated with hydropower projects, like fish migration restriction and possible flooding do not apply to conduit hydropower development. Therefore, the requirements and licences necessary for this type of scheme should be far less extensive than the requirements for conventional hydropower (Gaius-Obaseki, 2010).

Nevertheless, many regulations and protocol will still apply. Every construction project that is undertaken in South Africa is subject to environmental regulations under the National Environmental Management Act of 1998. According to this Act an environmental impact assessment (EIA) or basic assessment (BA) is needed before certain construction activities may commence. The regulations were studied and the activities possibly related to the construction of a conduit hydropower plant are listed in **Chapter 4**. It should, however, be noted that additional provincial regulations are applicable that have not been listed. It is recommended that an environmental practitioner assess the site and determine the necessity or not of an EIA or BA.

NERSA licensing

12

As described in **Chapter 4**, Section 8 of the Energy Regulation Act (Act 4 of 2006) stipulates that a licence is required for:

- a) 'operat(ion) of any generation, transmission or distribution facility;
- b) import or export (of) any electricity; or
- c) involve(ment) in trading (of electricity).'

However, Schedule II of this Act exempts some parties from holding a licence. Exemption is granted to:

1. 'Any generation plant constructed and operated for demonstration purposes only and not connected to an inter connected power supply
2. Any generation plant constructed and operated for own use
3. Non-grid connected supply of electricity except for commercial use.'

The National Energy Regulator of South Africa (NERSA) is responsible for granting energy generation licences in terms of the Energy Regulation Act (Act 4 of 2006).

The application form consists of 12 sections that include: the applicant's information; desired commencement date of the licence; details of the generation station; details of arrangements with primary energy suppliers; maintenance programmes and decommissioning costs; customer particulars; financial overview; human resource particulars; other relevant regulatory permits; information on the Broad-Based Black Economic Empowerment (BBBEE) status of the project; any additional relevant



information; and a declaration of accuracy. An example of the application form can be viewed in **Appendix B** (NERSA, 2006).

A similar application form exists for energy distribution licences in terms of the Energy Regulation Act (Act 4 of 2006). This application form consists of 11 sections that include: the applicant's information; desired commencement date of the licence; area of operation under the licence; details of the distribution system; maintenance programmes; customer particulars; financial overview; human resource particulars; other relevant regulatory permits; information on the Broad-Based Black Economic Empowerment (BBBEE) status of the project; and any additional relevant information (NERSA, 2007).

Water-use licensing



As noted in **Chapter 4** the National Water Act (Act 36 of 1998) states that water-use licensing is required in various cases. The cases that may be applicable to hydropower generation include:

- a) 'taking water from a water resource;
- b) storing water;
- c) impeding or diverting the flow of water in a watercourse;' (Section 21)
- d) 'a power generation activity which alters the flow regime of a water resource;' (Section 37) and
- e) 'disposing of waste in a manner of water which contains waste from, or which has been heated in, any industrial or power generation process.' (Section 21).

However, Section 22 states *inter alia* that water may be used without a licence 'if that water use is permissible as a continuation of an existing lawful use'. As municipalities and water boards have existing licences and conduit hydropower should not have a detrimental effect on the water quality, a water-use licence will not generally be required for conduit hydropower in water pipelines of municipalities or water boards.

Social aspects



As part of the environmental assessment phase, the interested and affected parties are identified and provided with opportunities to voice their concerns and objections with regard to the proposed project. As noted in **Chapter 4**, the general areas of consideration are:

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



It is recommended that a specialist consultant be appointed to assess the social aspects of a proposed project.

7.2.6 Feasibility Phase Economic Analysis

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

It is proposed that at least the net present value (NPV) and internal rate of return (IRR) should be determined at this stage using the formulas as indicated in **Chapter 0**. The payback period may also be calculated, preferably considering inflation. However, it should not be used as the deciding factor in project selection. It should only be used as a tool for initial screening to supplement other methods, as it does not give sufficient information to stand alone as an evaluation tool (ESHA, 2004; Blank and Tarquin, 2004).

7.2.7 Other Reasons for Conduit Hydropower

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

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

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

7.2.8 Outcome of Phase 2

The function of Phase 2 is to determine feasibility of a proposed conduit hydropower plant, with as much detail and information as is available. This phase does not contain a detailed design. It does, however, include an initial estimation of the design flow and head, using measured data. The CHD Tool also includes a graph to facilitate the initial selection of an appropriate turbine and a more detailed economic analysis than Phase 1.



7.3 Third Phase Investigation: Detailed Design

If the initial assessments of hydropower potential indicate the practicability of a hydropower plant, then a detailed engineering design and economic analysis can be done.

The complexity of the design should match the operators' level of skill and the resources available. Local economic conditions should be carefully studied before determining the financial viability of a project (Harvey et al., 1993).

This section will include generic design guidelines and necessary considerations for the different components of a hydropower plant in an existing distribution network. Discussed components will include pipe work, valves, the turbine and power distribution. However, it should be borne in mind that this phase includes a detailed design and therefore a specialist consultant should be approached to ensure that all factors are carefully considered and incorporated into the final solution.

7.3.1 Detailed Hydraulic Study

This study is done to determine the hydropower potential of the reservoir in question. The outcome will show how flow varies throughout the day and year. This information will be important when comparing the demand for electricity with the potential available power.

Historical flow and pressure records

1

It is important to know the necessary functional pressure and flow ranges of the planned turbine. In order to accurately determine the potential energy at a particular reservoir (as well as the optimum turbine), historical flow and pressure records should be obtained, if they are available. If historical data are not available, flow and pressure should be measured as described in the following paragraph before proceeding.

Measurement of flow and pressure

2

Whether historical flow and pressure measurements are available or not, current measurements should be taken. These data will be used to determine daily patterns and consequently the functional pressure and flow ranges of the planned turbine.

A flow meter (refer to **Table 2-3** for examples of typical flow meters) and pressure transducer (refer to **Table 2-5** for examples of typical pressure transducers) should be



placed on a straight section of pipe directly upstream of the location of the proposed turbine and connected to a data logger.

At this stage recorded data should preferably reflect weekly and seasonal variations in flow and pressure. Therefore a year's worth of data would be ideal. However, if this much data cannot be recorded, assumptions should be made to account for seasonal fluctuations in water demand.

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

Optimisation and operation of site within system

3

The site has to be evaluated as part of the larger distribution system. The influence of a hydropower plant at the site should be investigated considering that water supply is the main function of the system and that the plant should not influence supply reliability.

The system should be optimised to allow for the maximum power generation (or generation at times with high potential income, in grid-connected projects) without negatively impacting water supply to users. This is especially the case when power should be supplied at a high assurance level, but current operational regimes include many hours of maximum flow rate.

An alternative operational practice may be that supply should be provided at lower flow rates, but for longer periods at a time. Another possibility would be to ensure a constant flow and head into the reservoir for the time of day when electricity is needed.

In grid-connected applications, the operational regime should allow for power generation at times with high potential income (energy tariff peak times). There should be a definite correlation between hours of high electricity value (peak times) and hours with high power potential. **Figure 7-7** shows an example of an operational procedure that does not optimally exploit potential income, with high potential for power generation during the night, when tariffs are low. It is important to note that no operational procedure should negatively affect water supply to users.



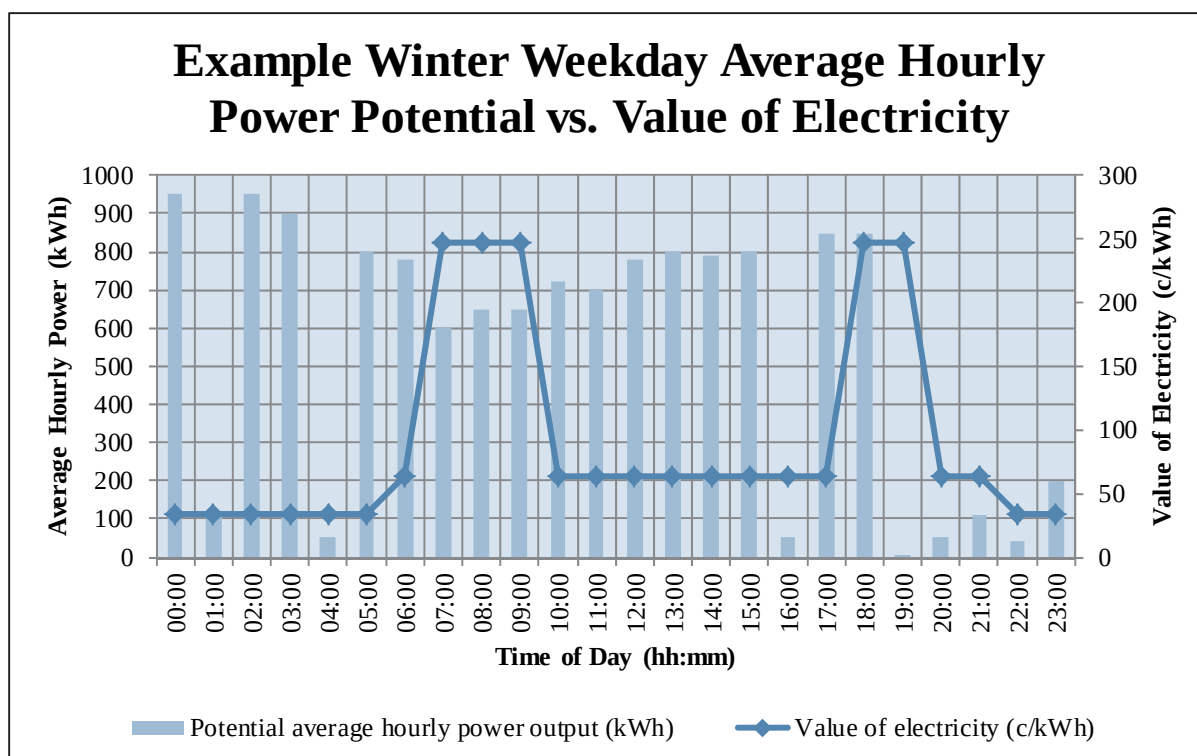


Figure 7-7: Example of a power potential vs. peak income curve (with poor correlation)

If optimisation of the system is not possible, due to operational constraints and water-supply preferences, a thorough investigation should be done to determine whether the generated power could be effectively used at the times when power generation is possible. This is especially the case when the generated electricity is not supplied to a larger grid; alternative energy sources are not available for an islanded (or on-site) system; or when power is generated to supply peak demand in the electricity network.

Design flow and associated power

4

A detailed study of available power can be done during the Third Phase, using the additional gathered information. The following formulas (with values as indicated in **Equations 7.3 to 7.5**), can be used:

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + Z_2 + h_f + h_l \quad \dots(7.3)$$

where:

- P_1 = pressure at Station 1 (N/m²)
- ρ = density of water (kg/m³)
- g = acceleration due to gravity (m/s²)



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/m²)
 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

$$h_f = \frac{\lambda L V^2}{2gD} \quad \dots(7.4)$$

$$h_L = \frac{KV^2}{2g} \quad \dots(7.5)$$

where:

h_f = friction loss (m)
 h_L = secondary losses (m)
 λ = friction coefficient of penstock or pipe (m)
 L = length of penstock (m)
 v = velocity of water flow in penstock pipe (m/s)
 g = acceleration due to gravity (m/s²)
 D = diameter of penstock or pipe (m)
 K = secondary loss coefficient (K is normally 0.5 at inlet and 1 at outlet)

The design flow and head can be calculated by generating a flow-rating curve (**Figure 7-1**) and calculating the available power for different combinations of flow and associated head. The design flow and head are calculated in different ways, depending on the application of the generated energy.

At this stage the required operational bands of the turbine should be selected and, if necessary, the operational philosophy of the pipeline should be adjusted to accommodate the required flow and pressure bands, as discussed in Step 3.

If electricity should be supplied at a certain assurance level, the flow at that percentage may be used as the design flow, with its corresponding head. If the maximum potential is used, then the design flow and head will be the combination that generates the optimum potential annual power. **Table 7-2** is an example of the table that may be used to obtain the optimum potential annual power. It is important to not only consider the design flow and head at this stage, but also the bands within which the turbine should function.

Table 7-2: Example of a Phase 3 potential analysis



PHASE 3 POTENTIAL ANALYSIS								
Flow rating curve	Load factor (%)	Flow (m ³ /s)	Head available (m)	Efficiency (%)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100	0	125	0%	8592	0.0	0.000	0.000
	95	0.000	123.4	0%	8154	0.0	0.000	0.000
	90	0.001	139.5	0%	7716	0.0	0.000	0.000
	85	0.059	143.9	22%	7278	18.2	132.465	3.976
	80	0.184	142.9	55%	6840	141.8	969.865	34.947
	75	0.310	138.0	80%	6402	335.7	2149.311	104.302
	70	0.412	131.2	83%	5964	440.1	2624.710	169.458
	65	0.553	127.4	84%	5526	577.0	3188.704	222.166
	60	0.780	113.8	84%	5088	727.4	3701.165	317.777
	55	0.959	92.6	84%	4650	727.5	3382.977	317.777
	50	0.974	94.6	84%	4212	754.5	3177.821	317.777
	45	0.981	96.6	84%	3774	776.5	2930.541	317.777
	40	0.986	99.0	84%	3336	799.9	2668.550	317.777
	35	0.992	101.0	84%	2898	821.1	2379.499	317.777
	30	0.999	103.4	84%	2460	846.0	2081.116	317.777
	25	1.009	109.8	84%	2022	907.3	1834.488	317.777
	20	1.025	120.9	84%	1584	1015.6	1608.761	317.777
	15	1.105	88.0	84%	1146	796.6	912.925	317.777
	10	1.194	97.1	84%	708	949.2	672.001	317.777
	5	1.372	85.8	84%	270	964.0	260.286	317.777
	0	1.456	82.6	84%	0	984.5	0.000	317.777
Optimum flow	60	0.780	113.8		5088	727.4	3701.165	4665.951
Average flow		0.767	111.6	84%	8592	701.4	6026.665	
Chosen flow		0.032	50.4	84%	8592	13.0	111.735	
Assurance of flow		0.000	0.0	84%	0	0.0	0.000	
Design flow	60	0.780	113.8		5088	727.4	4666.0	
Flow range								
Minimum flow	55	0.959	92.6		727.5	3382.977		
Design flow	60	0.7804	113.8		727.4	3701.165		
Maximum flow	55	0.959	92.6		727.5	3383.0		

Town development forecast

5

Anticipated future patterns are just as useful as current flow and pressure patterns. Therefore, a study should be done to determine the growth (or decline) in demand on the reservoir or pipeline in question. Daily demand patterns, as well as seasonal demand variations, should be analysed and extrapolated for any new developments or extensions planned over the design life of the hydropower plant.

It is important to indicate the appropriate timeframe for future demand, whether projections are done for every five or ten years, or just for the demand at the end of the life cycle. It is important to specify clearly which figures subsequent studies (e.g. design and financial planning) are based on and how demand growth is accommodated (Harvey et al., 1993).

If it is anticipated that future development will decrease the hydropower potential, this should be noted and the economic feasibility analysis should be done with an applicable design life for current circumstances.

Required turbine range

6



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. **Figure 7-8** shows the efficiencies of the most common turbine types.

Because different types of turbines have different efficiencies when operated at flows other than the design flow, it is important to determine not only the design flow and head, but also the required range of operation of the turbine. **Figure 7-9** provides an example of a flow and pressure range for a design flow of 55% assurance, maximum flow of 40% and minimum flow of 70% assurance.

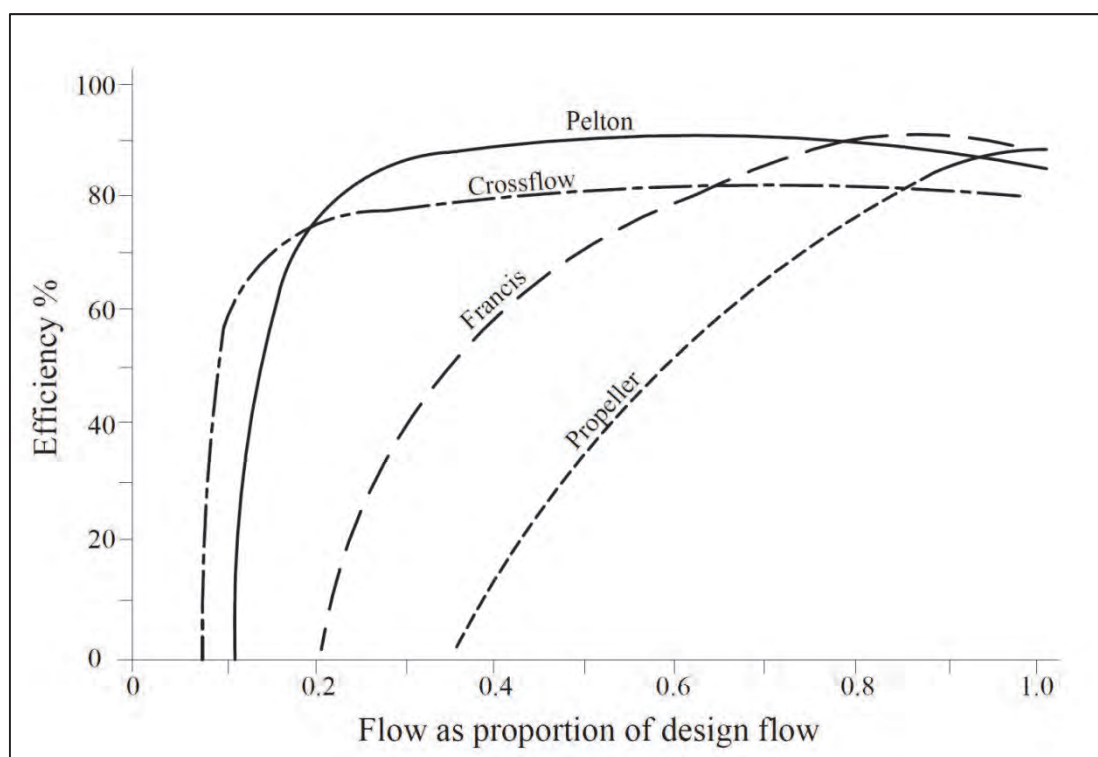


Figure 7-8: Part-flow efficiencies of different turbines (Paish, 2002)



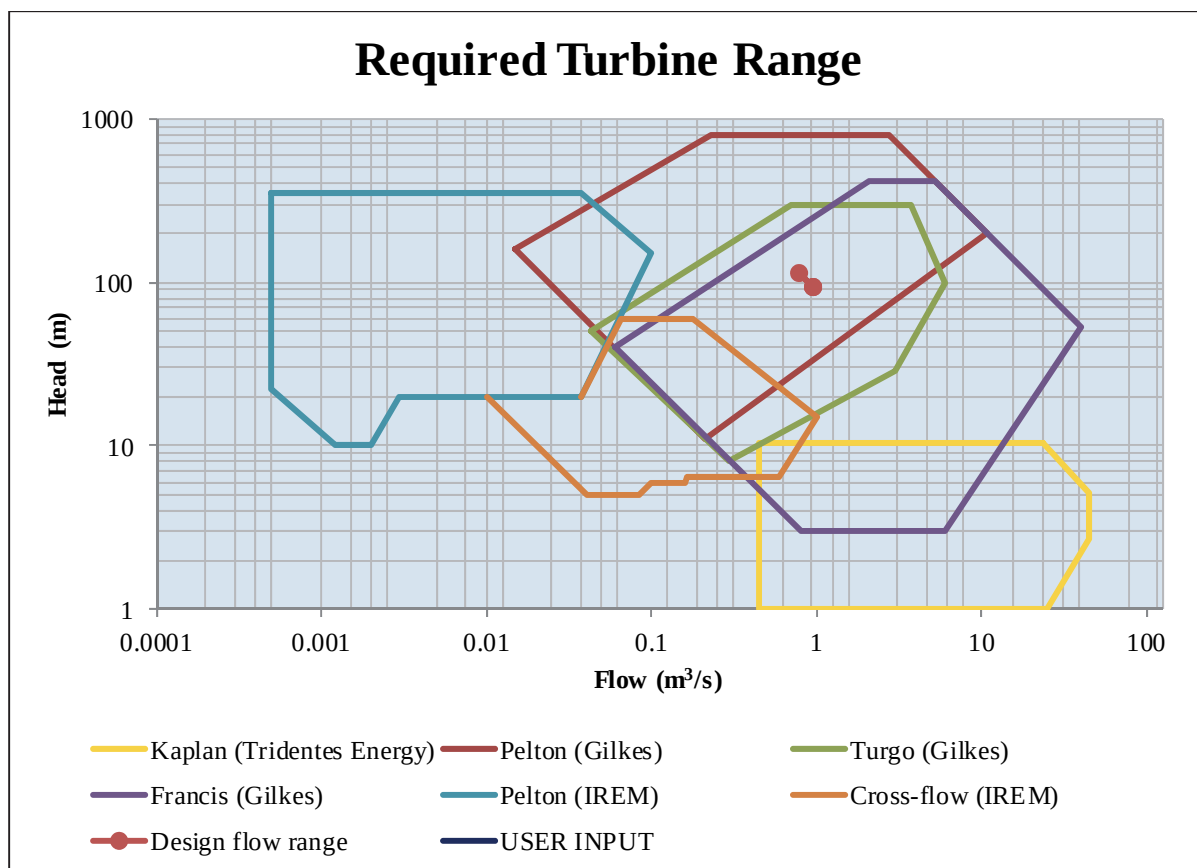


Figure 7-9: Example of a Phase 3 turbine range selection

Turbine selection for current flows

7

The next step will be to use the obtained information to select a suitable turbine. As discussed in **Chapter 2**, there are various types and sizes of turbines. It is therefore important to select the appropriate turbine for the conditions at the specific site.

The key factors to consider in turbine selection and design are the pressure head across the turbine and the manageable flow range. 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). A summary of the applicability of each type of turbine is given in **Table 7-3** and **Figure 7-10**.

In determining what turbine to use, the prevailing flow and pressure conditions need to be established. Different turbine types have different performance characteristics and each has its own advantages and disadvantages of use. The variation in future predicted flow rate also affects the choice of turbine as it may be detrimental to turbine efficiency. This CHDSS does not discuss turbine design, as it falls outside the engineer's scope of work on a hydropower project.

Table 7-3: Operational ranges of different turbines (ESHA, 2004)



Type of turbine	Head range (m)	Acceptance of flow variation	Acceptance of head variation	Maximum efficiency (%)
Kaplan/Propeller	2 - 40	High	Low	91 - 93
Francis	25 - 350	Medium	Low	94
Pelton	50 - 1 300	High	High	90
Cross-flow	2 - 200	High	Medium	86
Turgo	50 - 250	Low	Low	85

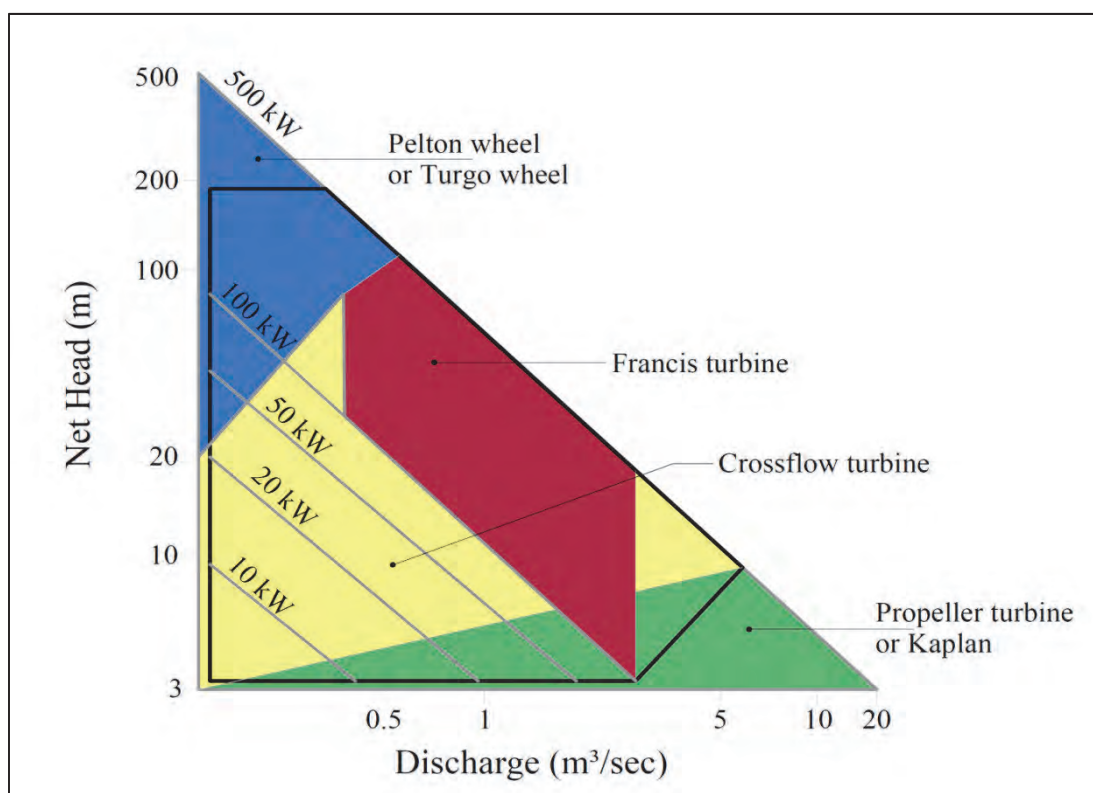


Figure 7-10: Head-flow ranges of hydro-turbines (Paish, 2002)

Efficiency

8

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 (η) can be calculated (**Equation 7.6**) by comparing the actual power output with the theoretical output at 100% efficiency, as follows:

$$\eta = \frac{P_{actual}}{P_{theoretical}} \quad \dots(7.6)$$

where:

η = turbine efficiency (%)



P_{actual} = actual power output of turbine (W)
 $P_{\text{theoretical}}$ = theoretical output at 100% efficiency (W)

The actual electrical output (**Equation 7.7**) of the turbine can be determined by multiplying the current of the electric flow by its potential difference:

$$P=IV \quad \dots(7.7)$$

where:

P = electrical power output (W)
 I = electrical current (A)
 V = potential difference (V)

Natural Resources Canada (2004) proposes efficiency ranges for different turbines (**Table 7-4**) and ESHA (2004) proposes efficiencies of small generators **Table 7-5**.

Table 7-4: Typical efficiency of turbines (Natural Resources Canada, 2004)

Prime mover	Turbine	Efficiency range
Impulse	Pelton	80-90%
	Turgo	80-95%
	Cross-flow	65-85%
Reaction	Francis	80-90%
	Pump-as-turbine	60-90%
	Propeller	80-95%
	Kaplan	80-90%

Table 7-5: Typical efficiencies of small generators (ESHA, 2004)

Rated power (kW)	Best efficiency
10	0.910
50	0.940
100	0.950
250	0.955
500	0.960
1000	0.970



At this stage, future scenarios should be compared with the turbine selection for the current flow regime. If future flow rates differ significantly from current rates, this should be incorporated in the design. This can be done in one of two ways, which will be discussed in the next paragraphs.

If future flow rates do not differ significantly from current rates, a turbine with high efficiencies at a number of flows can be selected, bearing in mind the future design flow during the sizing of the turbine.

However, in many cases, future flow rates will differ significantly from current rates and cannot be accommodated by the selected turbine.

In these cases, space should be allowed in the turbine room and pipe work for additional turbines to be added as the need arises. The economic analysis should also allow for capital expenditure at the forecast date when additional capacity will be necessary.

7.3.2 Energy Usage

10

The amount of energy needed, as well as required production patterns, will depend on the use of the generated electricity. In general, there are three potential uses for energy generated in the water-distribution network:

-  Electricity can be fed into an existing grid;
-  It can be used for islanded systems that are far from an electricity grid; and/or
-  It can be utilised at reservoirs, or other sites in the network that need local lighting, security and telemetry.

If the generated electricity is fed into an existing grid and only comprises a small portion of electricity in a stable grid, then the demand patterns are not an important aspect during design. In these cases, electricity may be fed into the grid whenever it is produced.

If the generated electricity is used to supply peak demand in an existing grid, the generation of electricity should be synchronised with peak demands in the system. Similarly, if electricity is generated to supply an islanded system or on-site needs, the generation should match the demands, considering time of day and time of year.

It is therefore necessary to determine the current and forecast energy-demand patterns for these cases.

Distance of site to energy users

11

If the generated electricity is to be connected to the grid, it is important to know how far the hydropower plant would be from the connection point.

If the plant is far away from a grid connection, it might have a significant impact on the economic feasibility of the project.



Grid-connection requirements

As noted in **Chapter 4**, permission should be granted by Eskom if the generator is to be synchronised with an Eskom grid. To obtain permission, the applicant should complete the relevant application form (Eskom, 2011b) (included on the **HydroAID** DVD) and comply with Eskom's interconnection standard (Eskom, 2008) (which is also included on the **HydroAID** DVD)

The process can be summarised as follows (the complete Eskom *Guide for IPP Grid Application Process* is available on the **HydroAID** DVD) (Eskom, 2011c):

1. Complete the application form
2. Submit the application form
3. Obtain a quotation from Eskom
4. Accept the budget quote and sign the connection and use of system agreement
5. Connect and use the system

Municipalities also have grid-connection requirements. As an example, the CoT requirements have been included on the **HydroAID** DVD (City of Tshwane Energy & Electricity, 2010).

Current and forecast demand

The daily energy demand patterns need to be obtained. This should be compared with the power supplied by the hydropower plant to determine whether the plant will be able to provide a significant portion of the required energy, or whether it will only supply a small percentage, making it possibly unfeasible.

Future scenarios of increase (or possibly decrease) in energy demand should also be drawn up. Daily demand patterns, as well as seasonal demand variations, should be analysed and extrapolated for any new developments or extensions planned over the design life of the hydropower plant.

It is important to indicate the appropriate timeframe for future demand, whether projections are done for every five or ten years, or just for the demand at the end of the life cycle. It is important to specify clearly which figures design and financial planning are based on and how demand growth is accommodated (Harvey et al., 1993).

Demand vs. energy potential



In the case of an on-site or islanded project, daily and seasonal demand variation should be obtained for both current and future energy usage. This could be illustrated using graphs that depict energy usage vs. time in a 24 h period, for both summer and winter scenarios.

After both energy demand and hydropower potential have been studied, these values should be compared. The energy demand study will be used to indicate the daily and seasonal variation in electricity demand, whereas the hydraulic study will present the variation in potential generation. This stage of the study should clearly indicate how well the supply-and-demand patterns correlate. Comparative graphs for summer and winter scenarios can be seen in **Figure 7-11** and **Figure 7-12**, respectively.

If supply-and-demand patterns do not correlate, one should either adjust the operational procedure to ensure better correlation, or supply batteries to store energy produced until it is needed. In the case of on-site or islanded system supply, it is also important to ensure that the power supplied by the turbine does not grossly outstrip current and future power needs. If the potential power is more than the usable power, a smaller turbine should be selected.

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

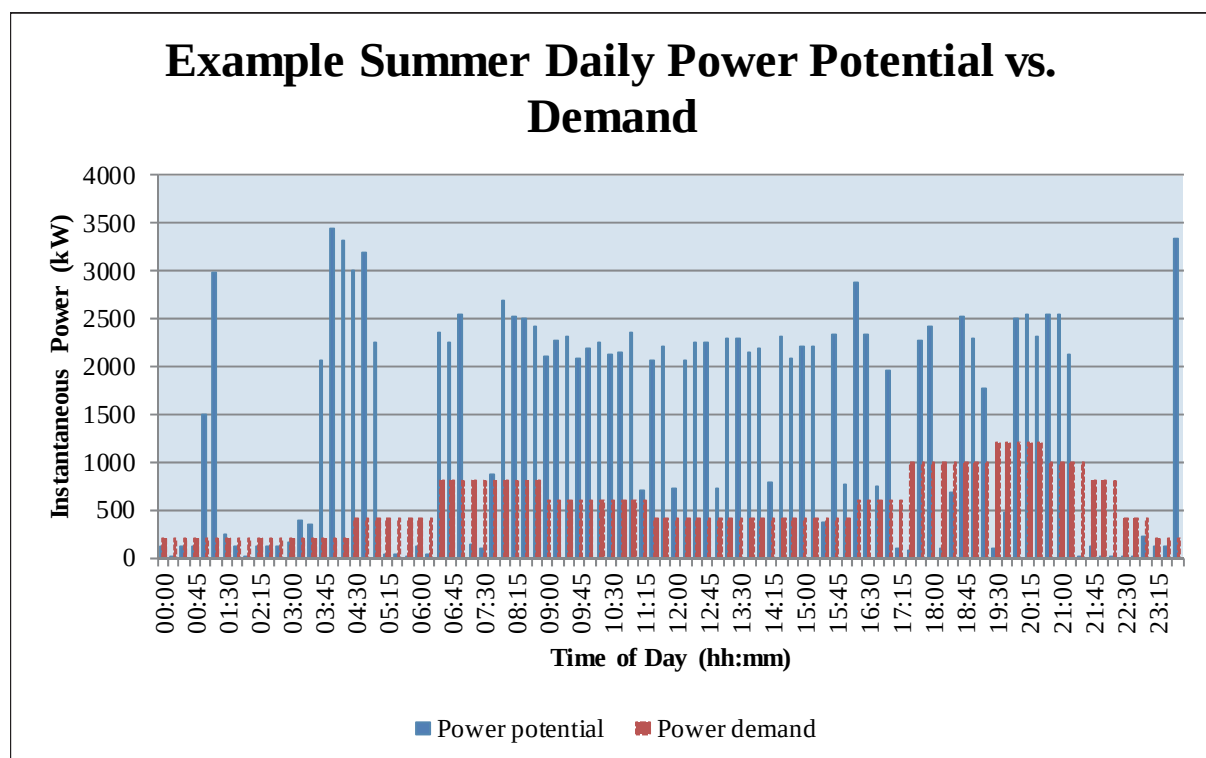


Figure 7-11: Example of summer daily power potential vs. electricity demand



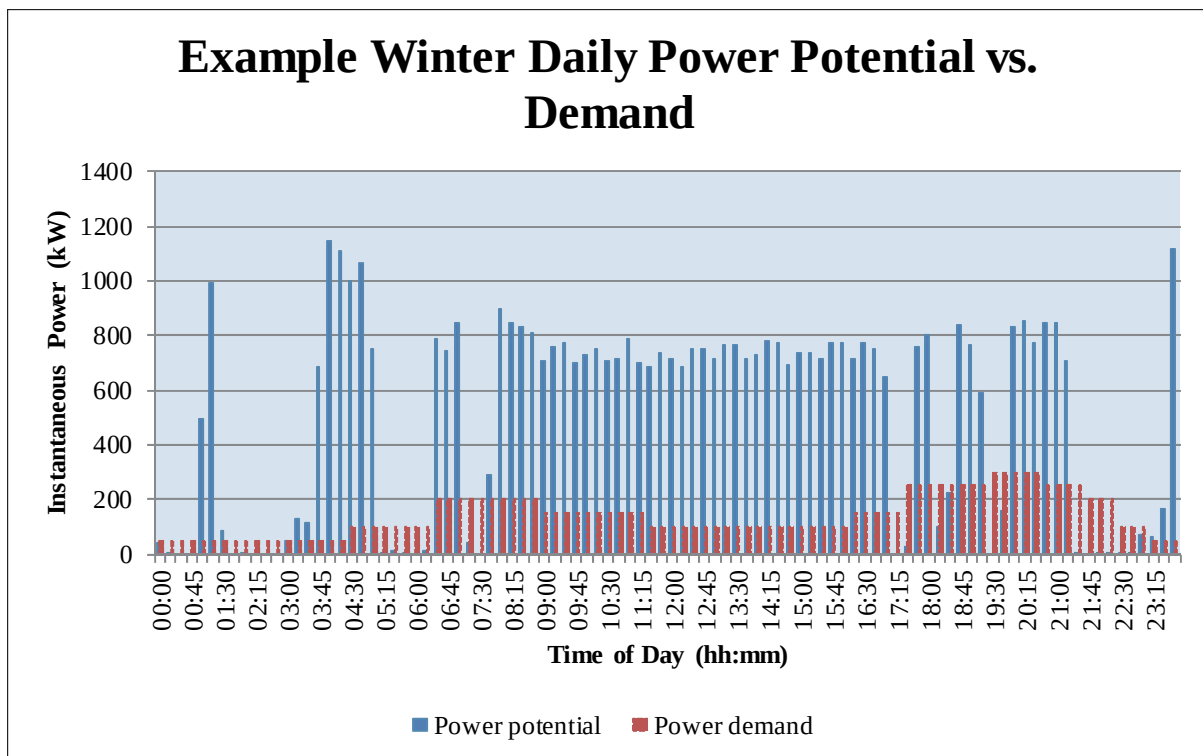


Figure 7-12: Example of winter daily power potential vs. electricity demand

7.3.3 Detailed site evaluation

The detailed site evaluation will include practical issues, including the necessary components of the plant, space restrictions, safety and the required hydropower plant set-up. The outcome of this step will indicate whether the system is practically feasible. It is important to note that the information provided here is only a guideline and it is **recommended that specialist consultant input be obtained for all detailed designs.**

Mechanical and electrical works

15

Table 7-6 was adapted from ESHA (2004) and Natural Resources Canada (2004) and provides a summary of electrical and mechanical design features. Specialist consultant input is recommended.



Table 7-6: Electrical and mechanical design considerations

Component	Discussion
Turbine	The selection of an applicable turbine has been discussed in detail in paragraph 7.3.1. The selected turbine should operate at a high efficiency for the design flow range.
Generator	The generator is used to convert mechanical energy from the turbine to electrical energy. Asynchronous generators are generally more robust and cheaper than synchronous generators. However, if the electricity will not be fed into a stable grid, a synchronous generator must be used to ensure high quality electricity.
Driver	A driver is used to keep voltage and frequency of the generated electricity stable. The driver system can be a belt, pulley, direct drive or gearbox.
Control	A control system is required to compensate for variation in flow and pressure at the turbine. Speed governors regulate the speed of the generator by controlling the flow through the turbine. Electronic load controllers manage decreased loads by switching to a pre-set resistance to maintain system frequency.
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. Eskom and Municipalities have grid-connection requirements. As an example, the Eskom requirements (Eskom, 2011c) and CoT requirements (City of Tshwane Energy & Electricity, 2010) are included on the HydroAID DVD.

Civil works

16

Table 7-7 provides a summary of civil design considerations. It is important to note that the information given here only provides a guideline and that specialist consultant input is advised.



Table 7-7: Civil design considerations

Component	Discussion
Powerhouse	The powerhouse should be designed to protect the turbine and associated equipment from the elements, animals, as well as from theft and vandalism. If the installation is done on ground level, a chamber similar to a pump house can be constructed. If the installation is done on a reservoir roof, a lightweight construction (for example a steel frame with chromadek sheeting) must be considered. Ample ventilation should be provided. It is important to provide a stable footing for the turbine. If the installation is done on ground level, an appropriately sized concrete block should be designed. If the installation is done on a reservoir roof, the turbine should rest on beams that span between reservoir columns. In this case it is also important to ensure that the reservoir columns and roof will be able to bear the weight imposed by the hydropower plant.
Pipework	Pipes with the correct diameter and pressure class should be specified. The pipework should be designed to have as few as possible sharp bends and no bends greater than 90°. A bypass should be provided to divert water away from the turbine in the case of a malfunction or maintenance. All standard design requirements for pipework are applicable.
Valves	Isolating valves should be placed at least upstream of the turbine and at the upstream end of the bypass. The bypass should also have a pressure-reducing valve of adequate size to absorb the excess pressure if water is diverted away from the hydropower turbine.
Dynamic analysis	A dynamic analysis should be performed by a specialist if water hammer in the pipeline is a possibility. If the analysis indicates potential water-hammer damage, surge tanks or other mitigation measures should be designed.

Conduit hydropower set-up

17

Next, it is important to assess whether there would be sufficient space at the reservoir to install the turbine and related equipment. To do this, the dimensions of the turbine and all necessary auxiliary equipment should be obtained. It is important to verify whether a specific distance should be present between some of the devices. It is also important to allow space for movement of both people and equipment in the turbine room (for installation, operation and maintenance purposes). The necessary information may be gathered from the respective turbine supplier.

This section will provide diagrams of several options for typical installations. As the final installation will be site-specific, this section will act as a guideline and may be adapted to suit site-specific circumstances.



The basic set-up is similar to a conventional hydroelectric power plant configuration. In this case the water-distribution pipe acts as a penstock. The net pressure head at the point where the turbine is placed will generate the power.

Various hydropower set-ups, using different turbines, may be feasible depending on the dominant flow, pressure and distribution network. A bypass option should be included to be used in case of a malfunction or maintenance of the turbine. The bypass must have a PRV or other pressure-reducing mechanism fitted, as the bypass has to be able to dissipate excess energy in the pipe.

Figure 7-13 and **Figure 7-14** show a basic plan and an elevation view, respectively, of a typical impulse turbine set-up.

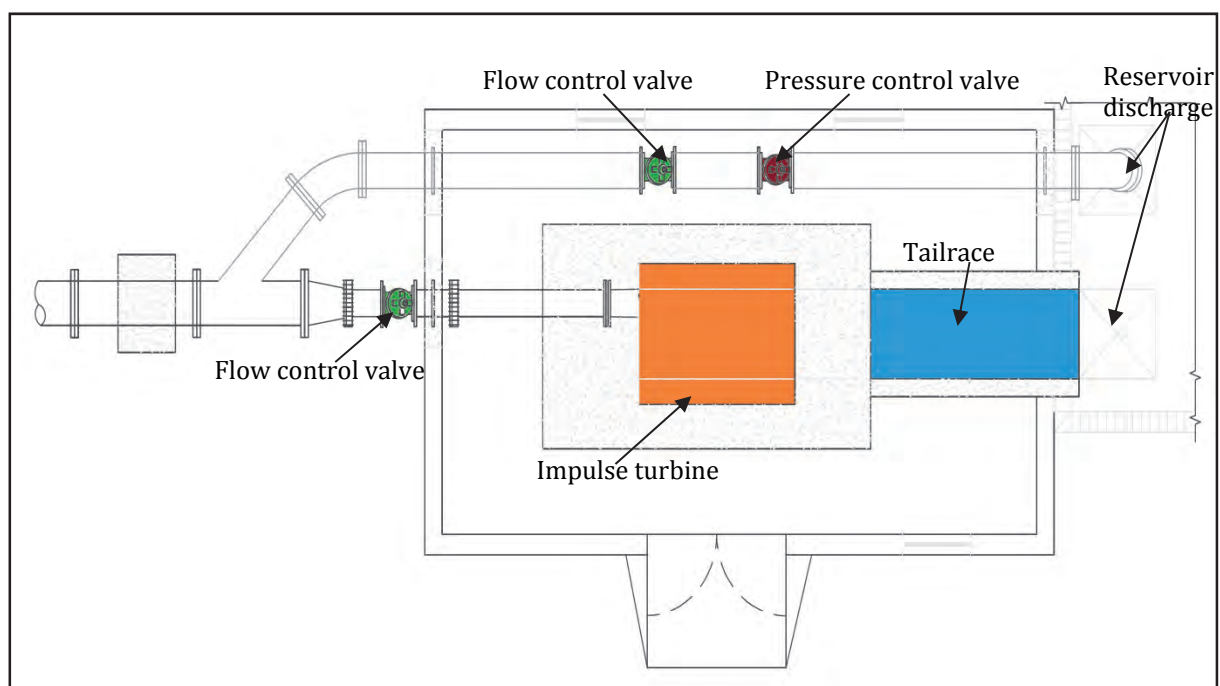


Figure 7-13: Basic plan view of a hydropower set-up using an impulse turbine



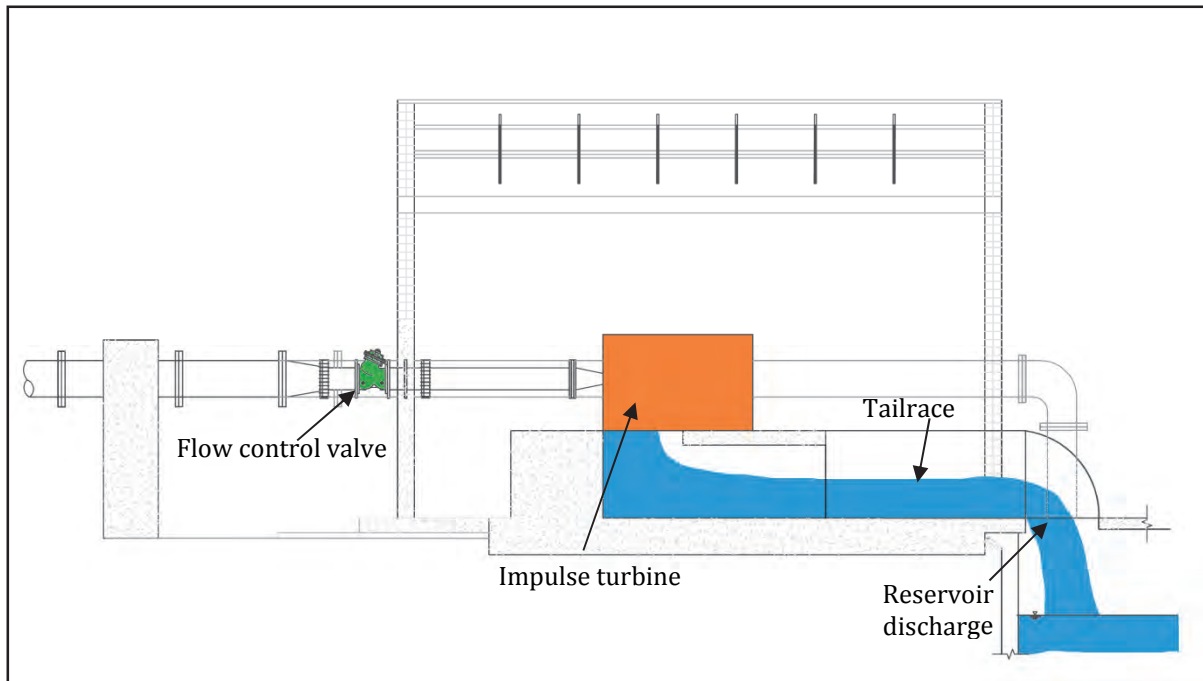


Figure 7-14: Basic elevation view of a hydropower set-up using an impulse turbine

Figure 7-15 and **Figure 7-16** show a basic plan and an elevation view, respectively, of a typical bottom-entry reservoir inflow of a hydropower plant, which will normally be served by a reaction type turbine.

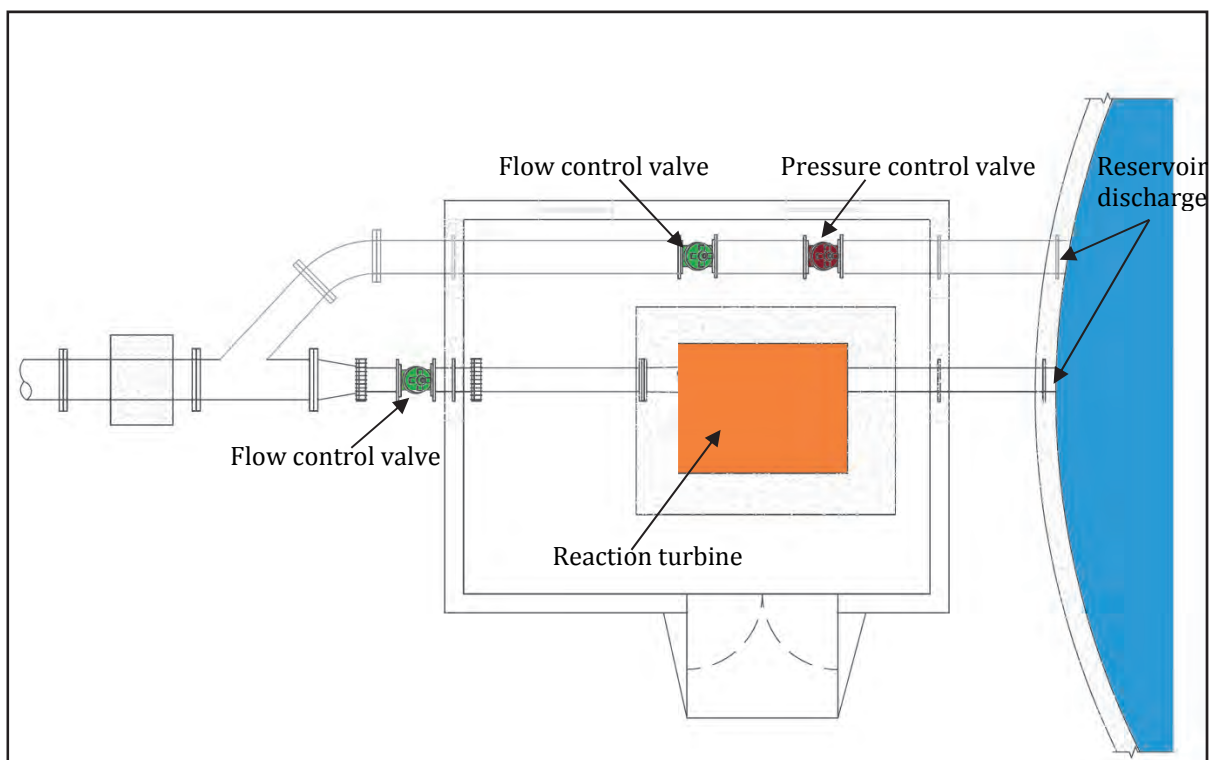


Figure 7-15: Basic plan view of a possible hydropower set-up using a reaction turbine



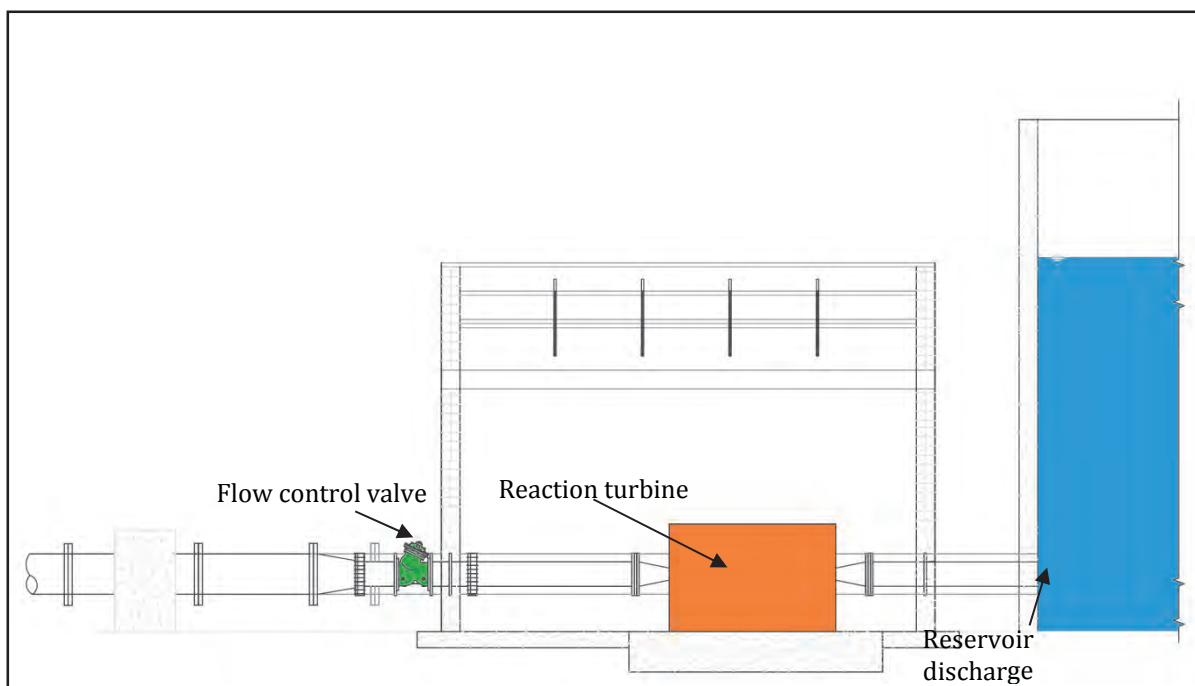


Figure 7-16: Basic elevation view of a possible hydropower set-up using a reaction turbine

Safety of equipment

18

It is imperative to ensure that equipment is kept safe from vandalism and theft and that it cannot become damaged by the elements. It is therefore necessary to ensure that there is proper security (in the form of fencing and removable ladders) and a housing structure for the turbine and related equipment.

7.3.4 Detailed Economic Evaluation

19

The detailed economic analysis should be done with the additional information gathered during this phase. A life-cycle approach should be used to determine whether the project is economically feasible. At this stage of the project, values used for both costs and income should be carefully calculated, to render the analysis as accurate as possible.

It is proposed that the net present value (NPV) and internal rate of return (IRR), with formulas as indicated in **Chapter 5**, be calculated to estimate economic feasibility of the project. The costs that need to be considered include: planning cost, design cost, capital cost, annual operating costs and annual maintenance cost. Income will include savings from not buying power and renting lines from Eskom, and/or revenue from selling electricity.



General inflation, as well as yearly inflation of electricity, operating costs and maintenance costs should be accounted for. Sensitivity analyses should be done to determine the risk if the above-mentioned inflation rates differ from the expected values. This will be discussed later.

If future development will decrease the hydropower potential, this should be noted and the economic feasibility analysis should be done with an applicable design life for current circumstances.

7.3.5 Other Reasons for Conduit Hydropower

20

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

- ☞ So-called islanded systems that have no grid connection, or are far from the national electricity grid.
- ☞ Reservoirs that need local lighting, security and telemetry.
- ☞ Areas where cable theft may be a problem.
- ☞ Areas that need additional peak-time electricity.
- ☞ Political reasons for developing greener renewable energy sources.

If another reason for considering hydropower exists, the economic feasibility should not be the deciding factor for constructing a hydropower plant at a given site.

7.3.6 Funding Of Conduit Hydropower Projects

21

Historically, funding for power-generation projects was provided by the public sector. However, privately financed and owned projects are increasing. According to IEA (2000) and Van Dijk et al. (2012b), general financing alternatives include (refer to **Chapter 4** for a discussion of each of these options):

- ☞ own funds
- ☞ commercial bank loans
- ☞ Development Bank of Southern Africa (DBSA) loans
- ☞ funding from the South African National Energy Development Institute (SANEDI)
- ☞ joint venture with a sponsor
- ☞ limited recourse project financing
- ☞ leasing
- ☞ development and operation agreement
- ☞ payment with electricity
- ☞ supplier credit

7.3.7 Sensitivity Analysis and Acceptable Risk

22

Because many factors may change unexpectedly during the design life of a hydropower plant, it is imperative that various sensitivity analyses be done.



These analyses will determine the outcome if existing information is incorrect, to establish whether the project would still be economically feasible under different circumstances.

Factors that should be tested for sensitivity are inflation of the various yearly incomes and expenses. A higher than expected and lower than expected value for each of these should be included to derive a band of possible net present values and internal rates of return.

The risk of different outcomes should be evaluated and a decision should be made on the acceptability of said risk.

7.3.8 Outcome of Phase 3

The outcome of this phase would be a conduit hydropower plant, designed, with cost analysis done, and ready for construction.

Staff training, as well as other operation and maintenance aspects, fall outside the scope of this document but are extremely important factors to consider and to include going forward with the project.



8. TESTING OF PROCEDURAL DECISION SUPPORT SYSTEM

8.1 Introduction

This chapter illustrates the application of the proposed procedural method described in the previous chapter in a municipal context. The City of Tshwane (CoT) Metropolitan Municipality Bulk Water Services division was approached as a partner in the research project. Therefore, all analyses were performed on sites within the CoT's water-distribution network.

A significant portion of Tshwane's water demand is supplied by Rand Water. The water gravitates from Rand Water (in Johannesburg) to the relatively lower lying hills in Tshwane. **Figure 8-1** shows the CoT water-distribution network, consisting of 160 reservoirs, 42 water towers, more than 10 000 km of pipe and more than 260 pressure-reducing stations. Consequently there are many sites within CoT that may have exploitable conduit hydropower potential.

The procedure described in the diagrams in **Chapter 6** will be followed step-by-step; the first two steps being a city-wide hydropower potential evaluation and the rest being applied to three selected case studies.

8.2 Hydropower potential in the City of Tshwane's WDS

A scoping study was performed by Van Vuuren (2010) to obtain a first-order estimate of conduit hydropower potential in the CoT water-distribution network, as shown in **Figure 8-1**. This study is used to illustrate the first two steps of the CHDSS.

The scoping study identified the ten larger reservoir sites in CoT. **Table 8-1** reflects the conservative assumptions used to calculate the potential annual hydropower generation from these pressurised supply pipelines. These assumptions were used to calculate the potential annual hydropower generation at reservoirs in Tshwane. The analysis can be seen as a conservative estimate of the potential hydropower capacity of the sites. **Figure 8-2** and **Table 8-2** indicate the potential hydropower generation capacity at the ten most favourable sites in the City of Tshwane water-supply area.



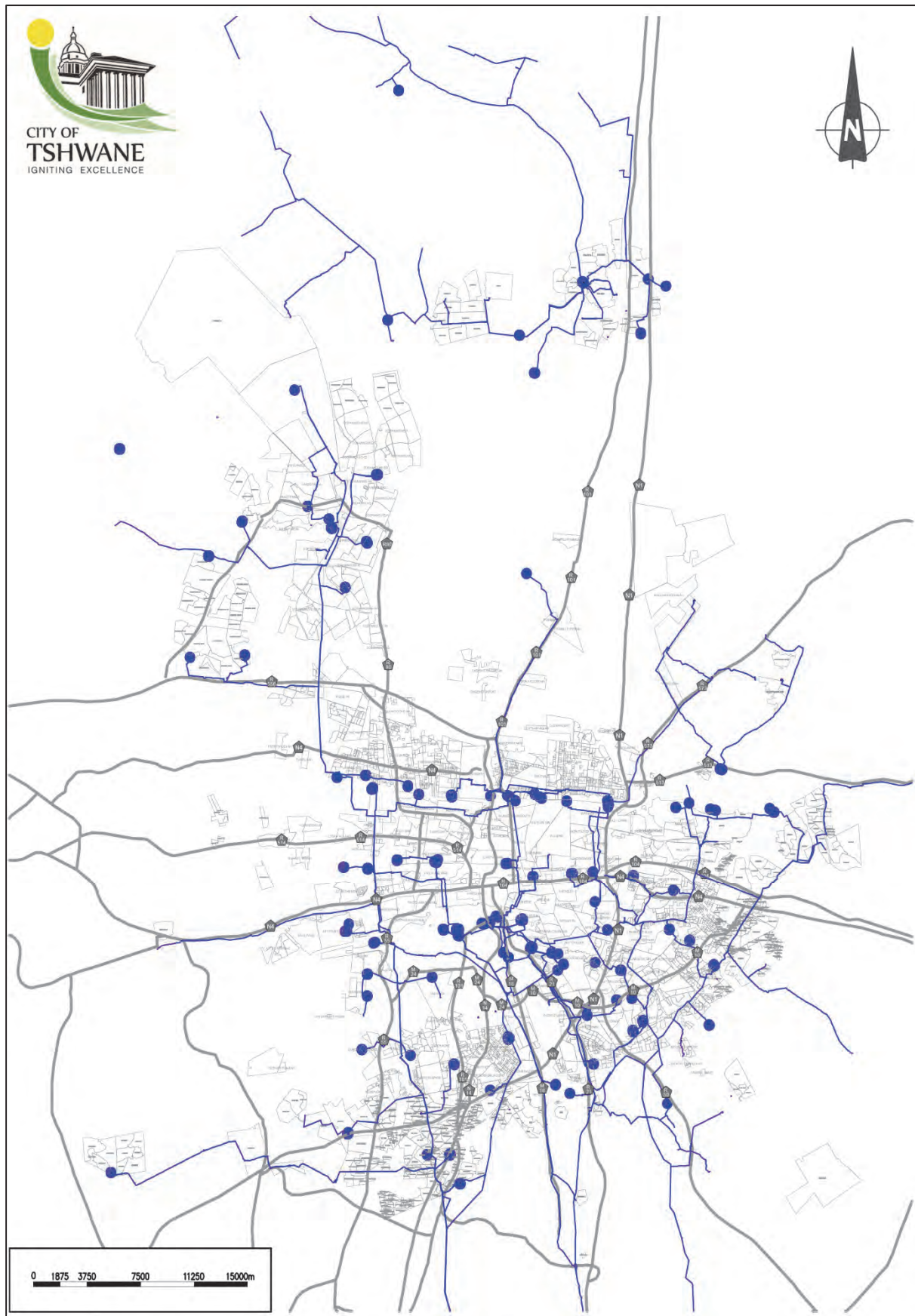


Figure 8-1: Reservoirs and bulk pipelines in the CoT WDS (Van Vuuren, 2010)



Table 8-1: Assumptions used in the determination of hydropower generation capacities in CoT reservoirs (Van Vuuren, 2010)

Variable used for the calculation of potential annual income for power generation at reservoirs in Tshwane	Value	Units
Percentage of the available static head that can be used to generate power	50	%
Hours per day when power can be generated	6	h

Table 8-2: Potential annual hydropower generation capacity at the ten most favourable reservoirs in the City of Tshwane water-distribution system (Van Vuuren, 2010)

Reservoirs	TWL (m)	Capacity (kℓ)	Pressure (m)	Flow (ℓ/s)	Annual potential power generation (kWh) #
Garsfontein	1 508.4	60 000	165	1 850	3 278 980
Wonderboom	1 351.8	22 750	256	470	1 292 471
Heights LL	1 469.6	55 050	154	510	843 673
Heights HL	1 506.9	92 000	204	340	745 062
Soshanguve DD	1 249.5	40 000	168	400	721 859
Waverley HL	1 383.2	4 550	141	505	721 483
Waverley LL	1 332.9	4 550	166	505	721 483
Akasia	1 413.8	15 000	193	340	693 930
Clifton	1506.4	27 866	196	315	663 208
Magalies	1438.0	51 700	166	350	624 107
Montana	1387.6	28 000	82	463	407 829
Total calculated annual power generation in Tshwane					±10 000 000

Note: # Refer to the assumptions listed in Table 8-1.



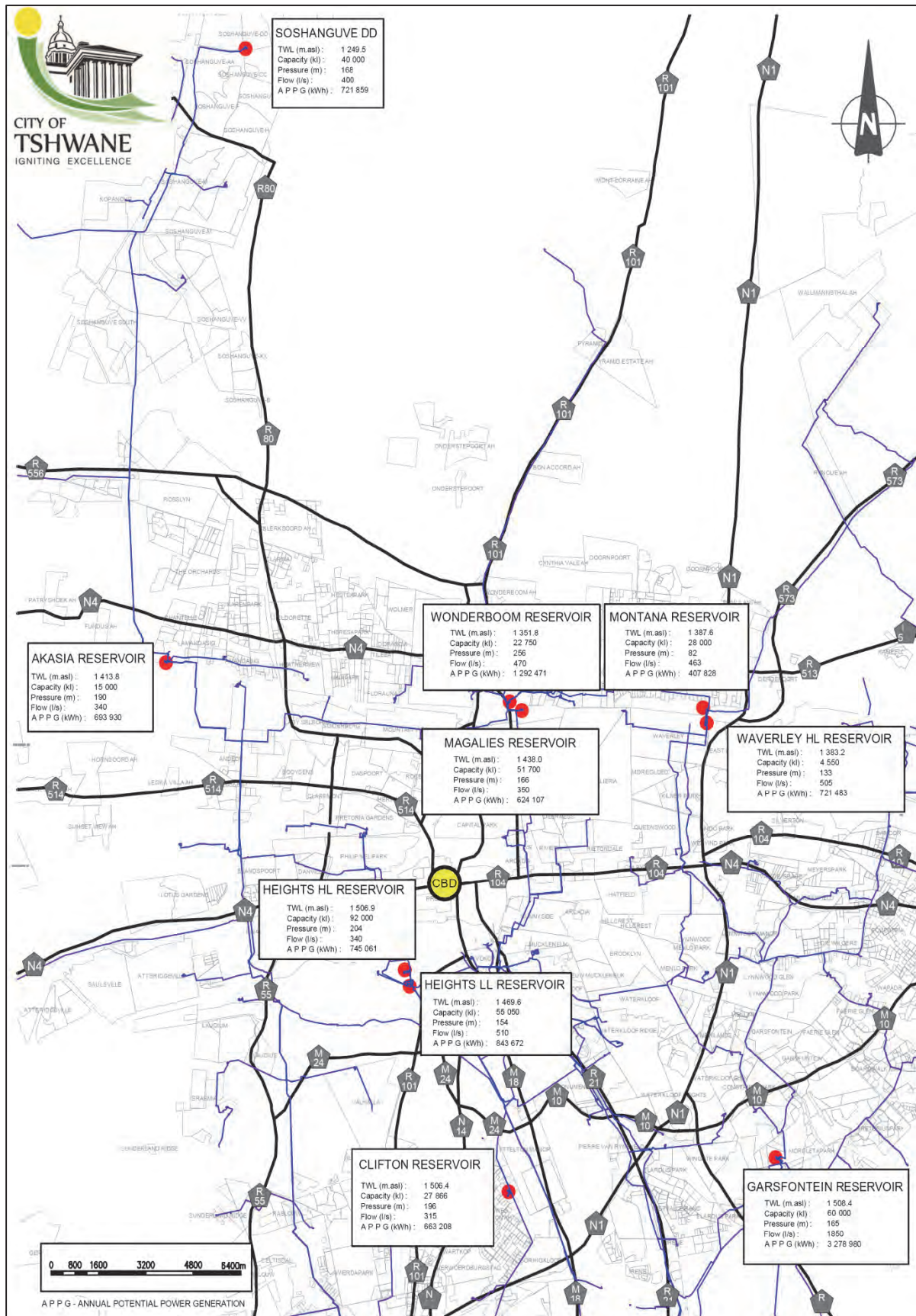


Figure 8-2: Hydropower generation capacity at different reservoirs in the CoT WDS (Van Vuuren, 2010)



8.3 Selection of case studies

Three case studies were used to test the applicability of the procedures discussed in **Chapters 6** and **7**. The three case-study sites were selected to represent a variety of circumstances that would enable comprehensive testing of the procedural method and are therefore not necessarily the three sites with the highest hydropower potential in CoT. This chapter describes the three case studies used to verify the applicability of the proposed procedural step-by-step Conduit Hydropower Decision Support System (CHDSS) and CHD Tool.

8.4 Case Study 1: Garsfontein Reservoir

8.4.1 Location

The Garsfontein Reservoir is located in Wekker Street, Moreleta Park, as can be seen in **Figure 8-3**. The GPS coordinates are 25°49'35.8"S and 28°17'33.6"E and the base of the reservoir is situated at an elevation of 1 497 m above mean sea level (amsl).



Figure 8-3: Location of Garsfontein Reservoir (Google Earth, 2012)

8.4.2 Site description

Water to the Garsfontein Reservoir is supplied from Rand Water sources and the Rietvlei Dam. The reservoir consists of three structures and is a bulk reservoir in the water-distribution network to a significant portion of the eastern parts of the Tshwane Metropolitan area, as shown in **Figure 8-4**. All three structures are cylindrical reservoirs built using post-tensioned reinforced concrete, with capacities of 30 000 m³ each.



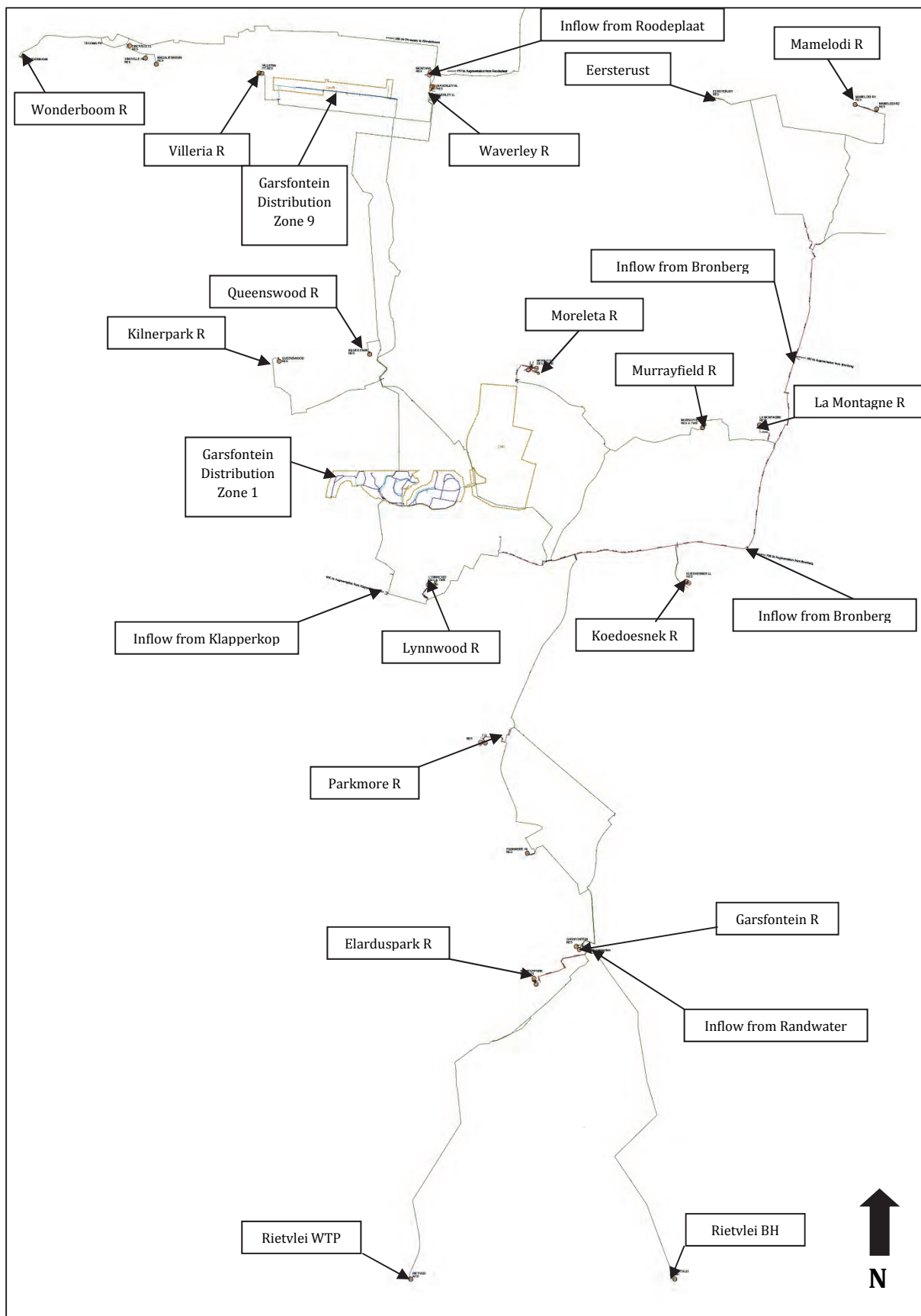


Figure 8-4: Garsfontein Reservoir water-distribution zone (IMQS)



8.4.3 Phase 1 Analysis and Results

The information used in the first phase study was obtained from The City of Tshwane Metropolitan Municipality's IMQS (Infrastructure Management Query Station) database. The relevant information can be seen in **Table 8-3**. This information was entered into the CHD Tool for Phase 1, with default values as indicated in **Appendix C** and the output is also shown in **Table 8-3**.

Table 8-3: Garsfontein Phase 1 analysis summary

DSS Step	Description	Value	Unit	Source
	Reservoir name	Garsfontein		IMQS
3	Owner of infrastructure	City of Tshwane		
4	Present average annual daily demand	85 475	kℓ/d	IMQS
	Future average annual daily demand	176 463	kℓ/d	
	Average flow	0.989	m ³ /s	CHD Tool
	Static head (pressure head used)	165.5 (100)	m	IMQS
5	Theoretically available power	676.6	kW	CHD Tool
6	Potential use	Grid connected		Decided
7	Distance to grid	0.5	km	Measured
8	On-site peak energy demand	N/A	kW	N/A
9	Average power/max demand	N/A	%	
10	Design life	15	Years	CHD Tool
	Estimated cost of plant (based on theoretically available power)	13 234 700	Rand	
	NPV of costs	16 265 700	Rand	
	NPV of income	36 048 300	Rand	
	NPV	19 782 600	Rand	
	IRR	20	%	
	Payback period	7	years	
	Economically feasible?	YES		
11	Consider next phase?	YES		

Suitable future flow rates and pressure heads for hydropower generation cannot be guaranteed at this site for future scenarios. It is assumed that parallel pipes will be installed in future, so that the final conditions at the site will be twice the current flow, but with the same corresponding pressure heads.



However, as this is only a rough estimate, future upgrades will not be allowed for in the economic analysis and a design life of only 15 years was selected to determine economic feasibility for in case future conditions do not suit hydropower. It was argued that the turbine may be moved to another location if conditions become unsuitable. If future conditions prove to be positive, an additional feasibility study for the expansion can be done in years to come. This can almost be seen as a separate project and will therefore not have an impact on the feasibility study of this project.

With an IRR of 20% and a positive NPV of more than R19 000 000, the Phase 1 analysis indicated that a full feasibility study should be undertaken.

8.4.4 Phase 2 Analysis and Results

The first phase hydropower potential analysis indicated economic feasibility and therefore a Phase 2 analysis was also performed. After determining first phase feasibility (CHDSS Step 1), it was necessary to visit the site and assess the practicability of a hydropower plant there.

Considered aspects included: space for the hydropower plant; safety of the turbine and other equipment from theft or vandalism; noise impact on the surroundings; and accessibility to the site during construction. The analysis is summarised in **Table 8-4**.

Table 8-4: Garsfontein Phase 2 site analysis summary

DSS step	Practicability aspect	Discussion	Conclusion
2	Available space	The Garsfontein Reservoir is situated on a large plot with sufficient space for a hydropower plant, as shown in Figure 8-3 and Figure 8-5 .	Sufficient space exists on site
	Safety	The site is located on CoT property in a suburban area that is fenced and locked.	Sufficient security is present
	Noise impact	As this reservoir is located within a residential area, the impact of noise may be disturbing to residents. However, various PRVs are currently installed in chambers and no complaints have been received.	Noise impact will be sufficiently low
	Accessibility of site	As shown in Figure 8-3 , the site is just off Wekker Street in Moreleta Park. Access to the site by construction vehicles may be gained through the front gate.	Easily accessible





Figure 8-5: Garsfontein Reservoir site

As the practicability of this site had been established, measuring instrumentation was installed to measure flow and pressure in the system, as recommended in the CHDSS Step 3 of Phase 2. Flow and pressure data were collected at the PRS upstream of the reservoir, as indicated in **Figure 8-3**. Data loggers were installed as shown in **Figure 8-6** (downstream pressure) and **Figure 8-7** (flow rates).



Figure 8-6: Pressure measurement at Garsfontein pressure-reducing station





Figure 8-7: Flow measurement at Garsfontein Reservoir

Figure 8-8 shows the unedited measured data for flow rates, as well as upstream and downstream pressures. A major gap in upstream pressure data was encountered between June and July. This was due to a lost connection between the pressure-gauging equipment and the pipe after maintenance was done to the pipe. Various minor gaps exist in the pressure and flow data. The reason for the gaps is possibly a communication error between the modem on site and the server where information is stored. These gaps were removed before continuing with the analysis.

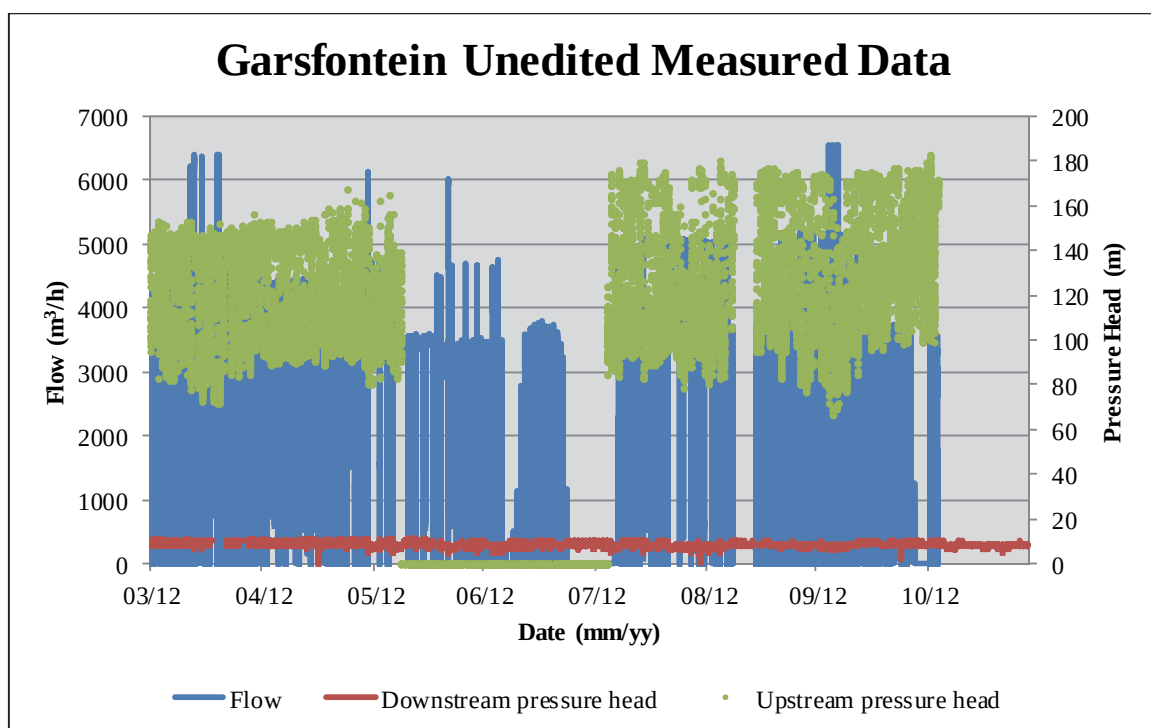


Figure 8-8: Garsfontein unedited measured data



The obtained data set was entered into Phase 2 of the CHD Tool to analyse the records (as per CHDSS Step 4 of Phase 2) and to populate **Table 8-5**. **Figure 8-9**, **Figure 8-10** and **Figure 8-11** were also generated using the CHD Tool. CHDSS Step 6 was not followed for this site, as there is already significant hydropower potential. In Phase 3 allowance will be made for future expansion of the plant for potential increases due to higher flow rates.

Table 8-5: Garsfontein Phase 2 potential analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Garsfontein		IMQS
4	Measured and calculated values	Optimum flow	0.780	m ³ /s	Measured
		Pressure head	113.8	m	
		Power rating (Figure 8-9)	609.8	kW	CHD Tool
		Annual energy (Figure 8-9)	3 898.0	MWh/a	
	Assurance of supply (% of time) (Figure 8-10)		N/A	%	N/A
	Design values	Design flow	0.780	m ³ /s	CHD Tool
		Pressure head	113.8	m	
		Power rating	609.8	kW	
		Annual energy	3 898.0	MWh/a	
5	What operational changes could be considered?		This reservoir feeds many distribution zones and other reservoirs, so operational changes are not recommended		CHD Tool
7	Selected turbine (Figure 8-11)		Turgo		
8	Electricity use		Grid-connected		
9	Distance from grid connection		0.5	km	Measured
10	On-site power demand		N/A	kW	N/A
	Power rating/max demand		N/A	%	



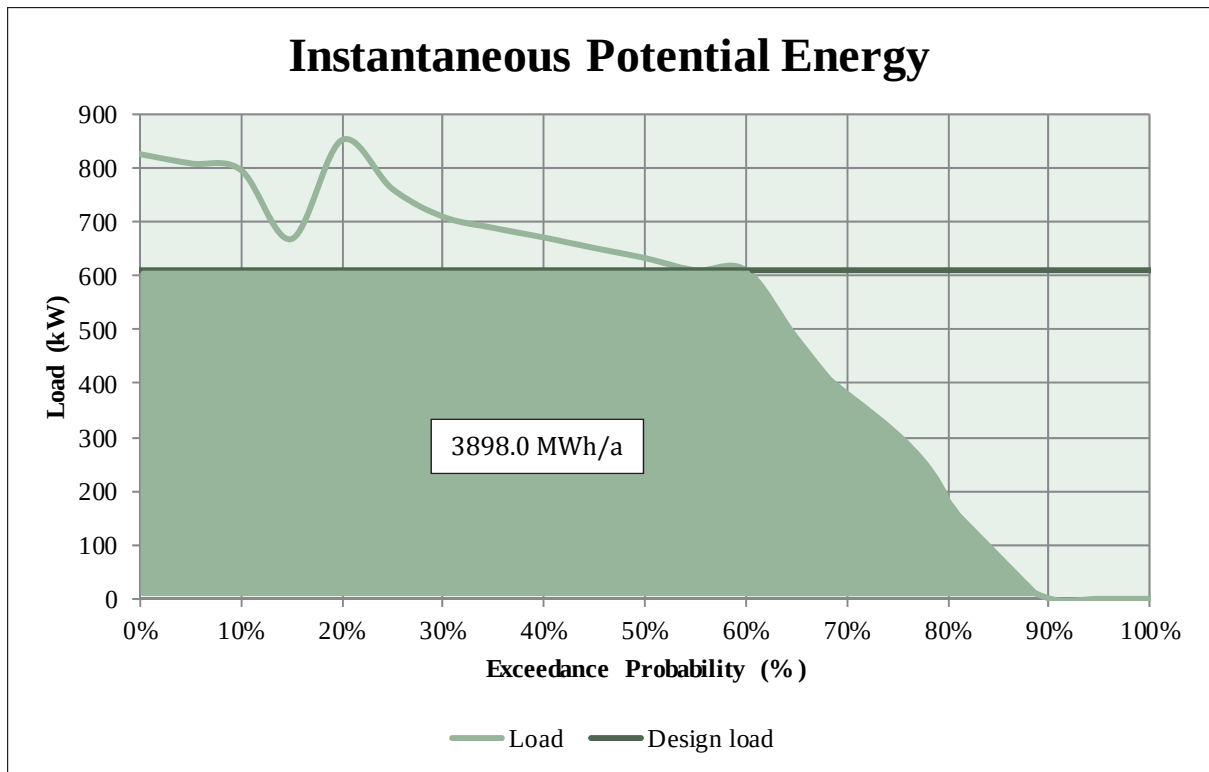


Figure 8-9: Garsfontein Phase 2 instantaneous potential energy

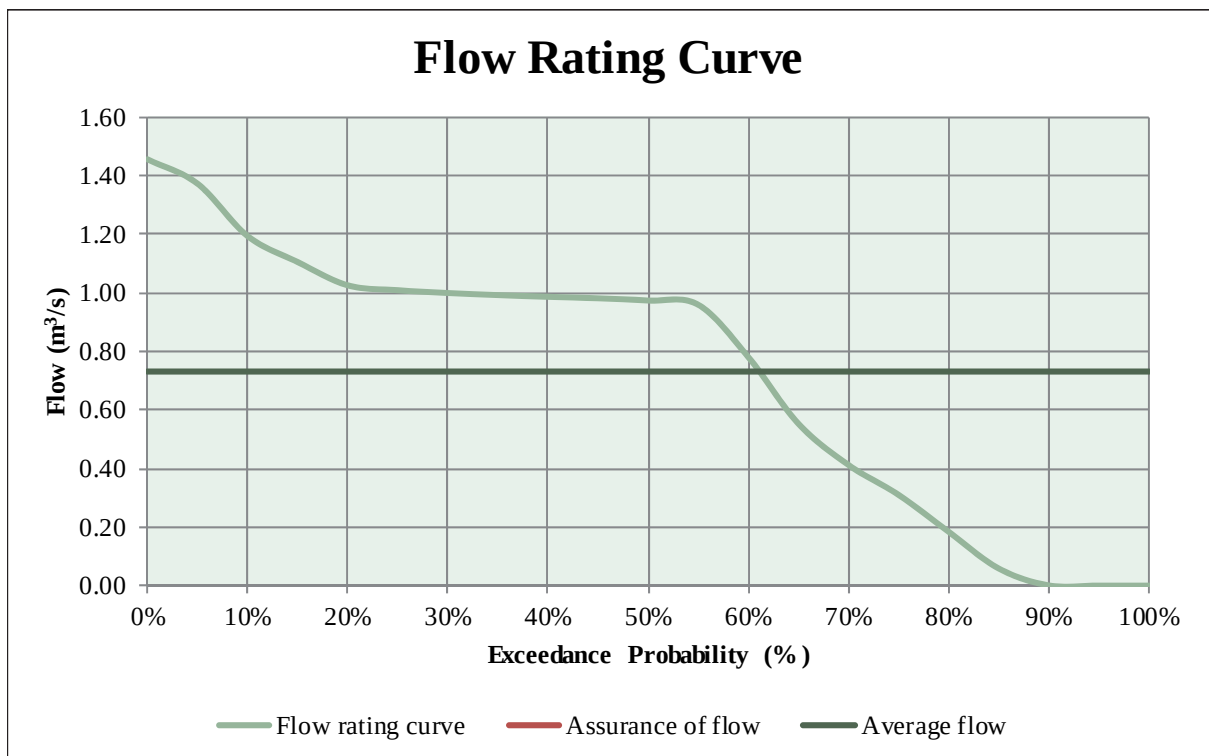


Figure 8-10: Garsfontein Phase 2 flow-rating curve

CHDSS Steps 11 to 14 deal with regulatory requirements. These steps are summarised in **Table 8-6**.



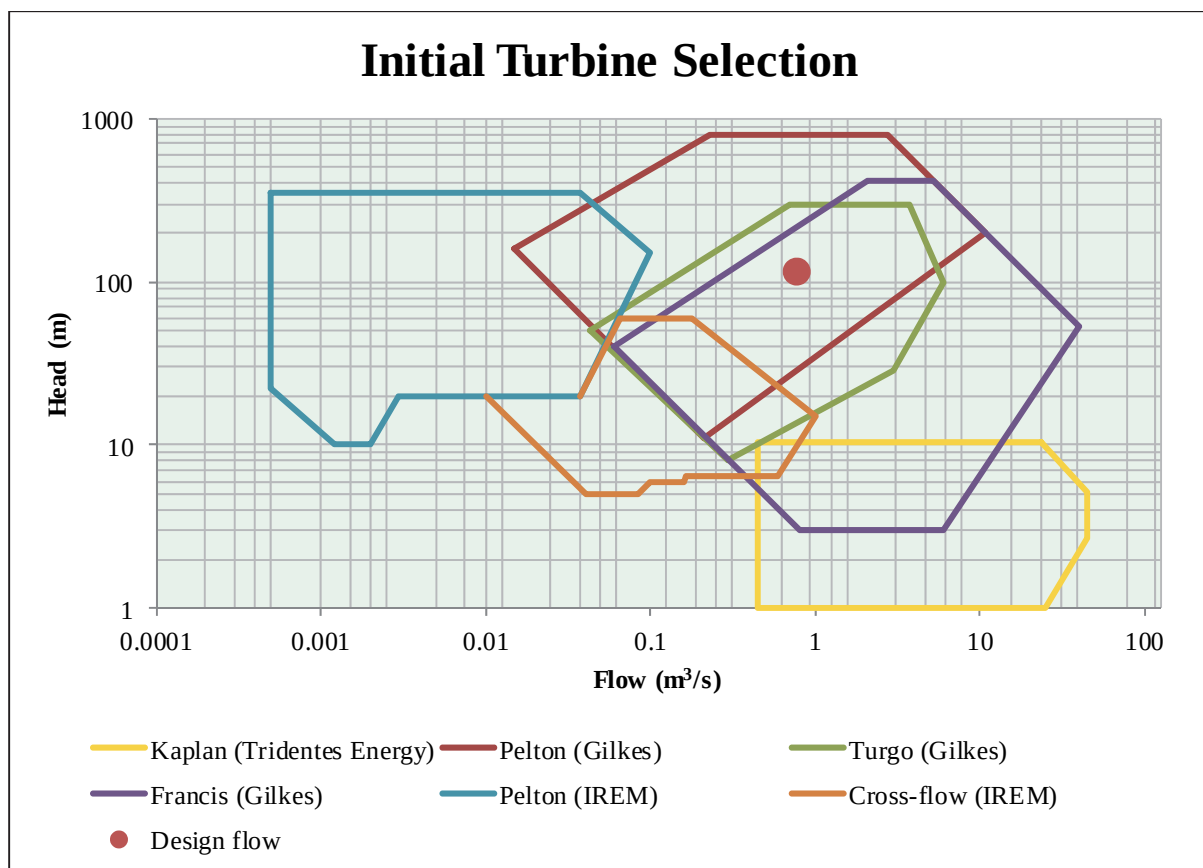


Figure 8-11: Garsfontein Phase 2 initial turbine-selection curve

Table 8-6: Garsfontein Phase 2 regulatory analysis

DSS step	Regulatory aspect	Discussion	Conclusion
11	Environmental studies	All power plant and construction areas are smaller than the minimum sizes for which environmental studies are required, according to the National Environmental Management Act (Act 107 of 1998)	Neither BA nor EIA required
12	NERSA licence	As the generated electricity would be fed into the municipal grid and sold commercially, NERSA licensing would be required. Example of a generation application form is attached in Appendix B .	Generation licence required
13	Water-use licence	Water-use licensing would not have to be obtained, as this project can be seen as a continuation of an existing lawful use under Tshwane's water-use licence.	Not required
14	Social requirements	A public participation process (PPP) would have to be followed wherein a notice board, meeting the requirements set in Government Notice 543 of 18 June 2010, is displayed on boundary fence. If complaints are received, public hearings should be held.	PPP required

The next step was to perform an economic evaluation for Phase 2. The CHD Tool was used, with default values and cost functions as discussed in **Appendix C**. **Table 8-7** was populated with the input and calculated values.



Table 8-7: Garsfontein Phase 2 economic analysis

DSS Step	Description		Value	Unit	Source
	Reservoir name		Garsfontein		IMQS
4	Design values	Design flow	0.780	m ³ /s	Measured
		Pressure head	114	m	
		Power rating	610	kW	CHD Tool
		Annual energy potential	3 898.0	MWh/a	
7	Selected turbine		Turgo		
15	Planning cost per MW		1 350 000	R	Industry average
	Planning cost for this site		823 300	R	CHD Tool
	Turbine cost		6 708 200		
	Capital cost per MW (excluding turbine)		13 300 000	R	Industry average
	Total capital cost for this site (including turbine)		14 818 800	R	CHD Tool
	Annual operation and maintenance cost (for year 1)		270 800	R	
	Annual income (for year 1)		2 260 800	R	
	Design life		15	years	Decided
	NPV of costs		19 266 800	R	CHD Tool
	NPV of income		41 090 200	R	
	Total NPV		21 823 400	R	
	Internal rate of return		19.74	%	
	Payback period		8	years	

With an NPV of almost R22 000 000 and an IRR of 19.74%, without considering Eskom SOP tariffs, the Phase 2 economic analysis indicated that a detailed design was warranted.

8.4.5 Phase 3 Analysis and Results



The Phase 2 economic analysis indicated financial feasibility. Therefore the Phase 3 analysis and detailed design was completed. The first step in this phase was to obtain historical flow and pressure records. Longer historical records (of a year or more) would be useful, as they would improve accuracy. However, as longer records were not available for this site, the same measured flow and pressure records were used as in Phase 2, for Step 2 of Phase 3.

The third step of this phase was to consider the effect of system optimisation. **Figure 8-12** shows the flow rates and corresponding pressures during a representative week in September 2012. From this figure it is clear that flow in the pipe is normally controlled at either about 3 600 m³/h or 5 100 m³/h until the reservoir is full, at which stage the flow in the pipe becomes almost zero. **Figure 8-13** shows that hours with high power potential do not typically correlate well with hours of high electricity value (peak times). Therefore operational changes to ensure better correlation would produce higher income.

However, as the Garsfontein Reservoir serves various distribution zones and other reservoirs in Tshwane (as shown in **Figure 8-4**), it is not advisable to adjust the operational philosophy of this reservoir significantly to obtain a more constant flow, as this might have a detrimental effect on water supply downstream. The potential analysis was therefore done with unchanged operational philosophy for current flows, as shown in **Table 8-8**.

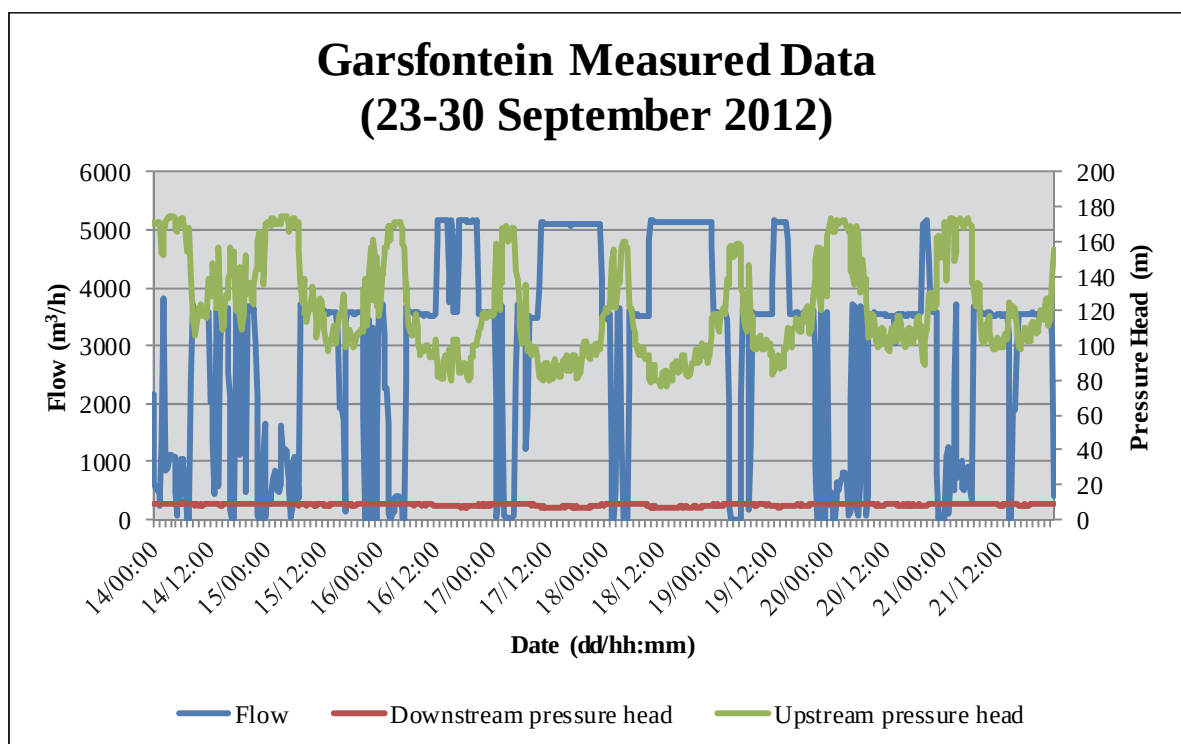


Figure 8-12: Garsfontein measured data for a typical week



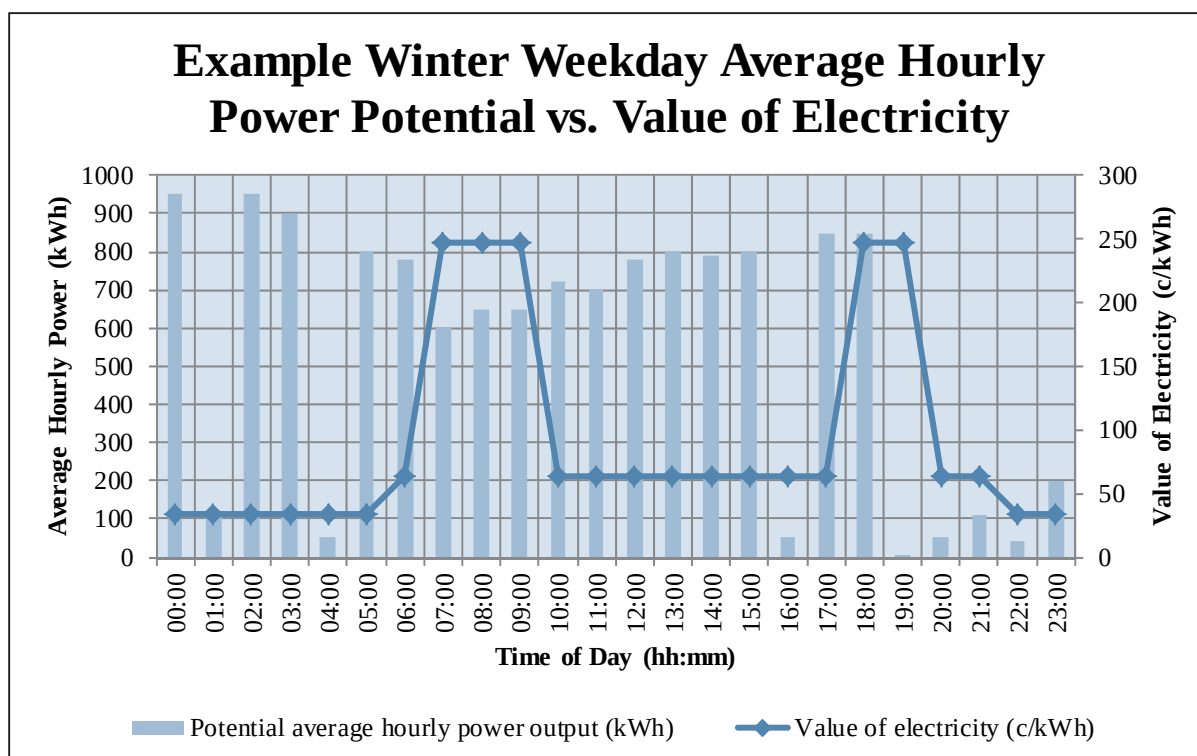


Figure 8-13: Garsfontein typical correlation between power potential and electricity tariffs

According to IMQS, the maximum future AADD at Garsfontein Reservoir will be approximately 176 000 kℓ/d, which is double the current AADD of 85 000 kℓ/day. For this analysis it was assumed that parallel pipes would be installed in future, so that the final conditions at the site would meet the future AADD, but with the same corresponding pressure heads. As this is only a rough estimate, future upgrades will not be allowed for in the economic analysis, but space will be provided in the turbine room for future expansion. If future conditions prove to be positive, an additional feasibility study for the expansion can be done in years to come. This can almost be seen as a separate project and will therefore not have an impact on the feasibility study of this project. Future conditions were also analysed and are presented in **Table 8-8**.



Table 8-8: Garsfontein Phase 3 potential analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Garsfontein		IMQS
3	Measured and calculated values	Current design flow	0.780	m ³ /s	CHD Tool
		Pressure head	113.8	m	
4		Power rating	727	kW	
		Annual energy potential	4 666.0	MWh/a	
5 (4)	Estimated future values	Estimated future design flow	1.561	m ³ /s	Described
		Pressure head	113.8	m	(Conservative)
		Power rating	1 455	kW	CHD Tool
		Annual energy potential	9 307.3	MWh/a	
6	Required turbine range for current flow		700-730	kW	CHD Tool
7	Selected turbine for current flow (Figure 8-14)		Gilkes Turgo		Product catalogue
8	Turbine efficiency for current flow		83.5	%	Product catalogue
6	Required turbine range for future flow		1 390-1 400	kW	CHD Tool
9	Additional turbines for future flow		1 x Gilkes Turgo		Product catalogue
8	Turbine efficiency for future flow		83.5	%	Product catalogue
10	Electricity use		Grid		
11	Distance from grid connection		0.5	km	Measured
12	Grid-connection requirements		HydroAID DVD		
14	Do supply-and-demand patterns correlate?		N/A		N/A
	Is there sufficient demand?		N/A		



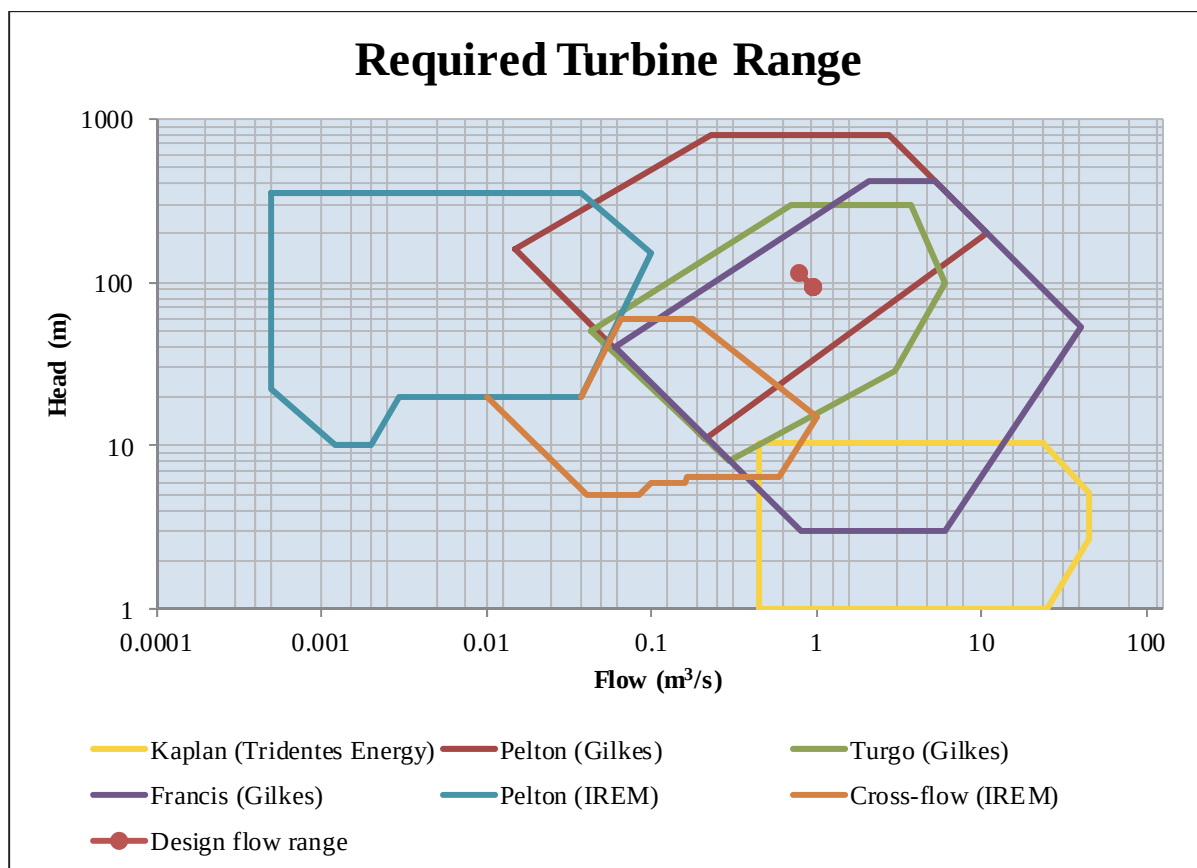


Figure 8-14: Garsfontein Phase 3 turbine selection

The next set of steps involved the detailed design of all the components of the conduit hydropower plant. Due to time constraints, a detailed design was not done for the Garsfontein development. However, a detailed design was done for the Pierre van Ryneveld development and is given in paragraph 8.5.5.

A detailed economic evaluation was conducted with obtained costs, where applicable. The results can be seen in **Table 8-9**. A sensitivity analysis was also conducted to determine the sensitivity of project feasibility when considering alternative inflation rates. The results of this analysis are summarised and presented in **Table 8-10**.

Step 21 of the CHDSS concerns funding of the project. This project has a projected capital expenditure of just over R16 700 000. At the time of writing, the municipality was considering paying for the project out of own funds, as renewable energy is currently a focus point in both the city and the country. It should be noted that CoT is a major city with a large budget. Smaller municipalities may have trouble financing a project of this magnitude out of own funds and will have to explore alternative funding options, as discussed in **Chapter 7.3.6**.



Table 8-9: Garsfontein Phase 3 economic analysis

DSS Step	Description		Value	Unit	Source
	Reservoir name		Garsfontein		IMQS
4	Design values	Design flow	0.780	m ³ /s	CHD Tool
		Pressure head	114	m	
		Power rating	727	kW	
		Annual energy potential	4 666	MWh/a	
6	Selected turbine		Gilkes Turgo		
19	Costs	Planning and design	1 200 000	R	Industry average
		Preliminary and general	1 300 000	R	
		Turbine	7 404 700	R	
		Other electrical and mechanical	1 100 000	R	
		Civil and construction	1 000 000	R	
		Transformer	400 000	R	
		Transmission	300 000	R	
		Contingencies	1 300 000	R	
		Disposal (present value)	0	R	
		Annual O&M (for year 1)	291 100	R	
		Annual income (for year 1)	2 706 300	R	
	Design life		15	years	Decided
	Total initial cost (planning and capital)		16 724 700	R	CHD Tool
	NPV of costs		20 617 800	R	
	NPV of income		49 185 600	R	
	Total NPV		28 567 800	R	
	Internal rate of return		22.14	%	

A sensitivity analysis was done to determine the impact of different future inflation rates. The results are shown in **Figure 8-15**, **Figure 8-16** and **Table 8-10**. It is clear that the current uncertainty about future changes in the value of electricity is likely to cause a more significant impact on the net present value (NPV) of the project than operation and maintenance inflation, with an NPV of between R33 700 000 for high average electricity tariff inflation (12% after 2017) and R20 400 000 for low average electricity tariff inflation (6% after 2017). The expected NPV is R28 600 000, as determined in the economic analysis. The internal rate of return (IRR) of the project was found to have a range of between 19.53% (for low electricity inflation) and 23.47% (for high electricity inflation).



It can therefore be assumed that this project should be feasible even if inflation rates are not as expected.

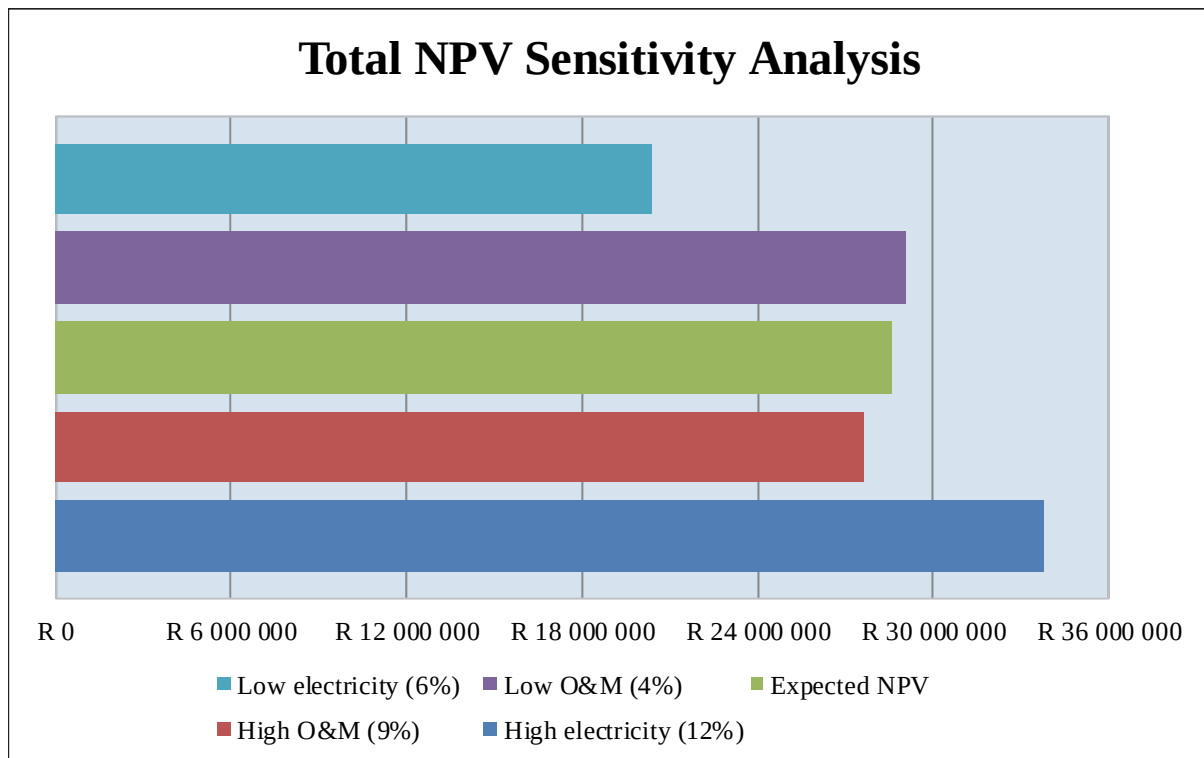


Figure 8-15: Garsfontein Phase 3 NPV sensitivity analysis

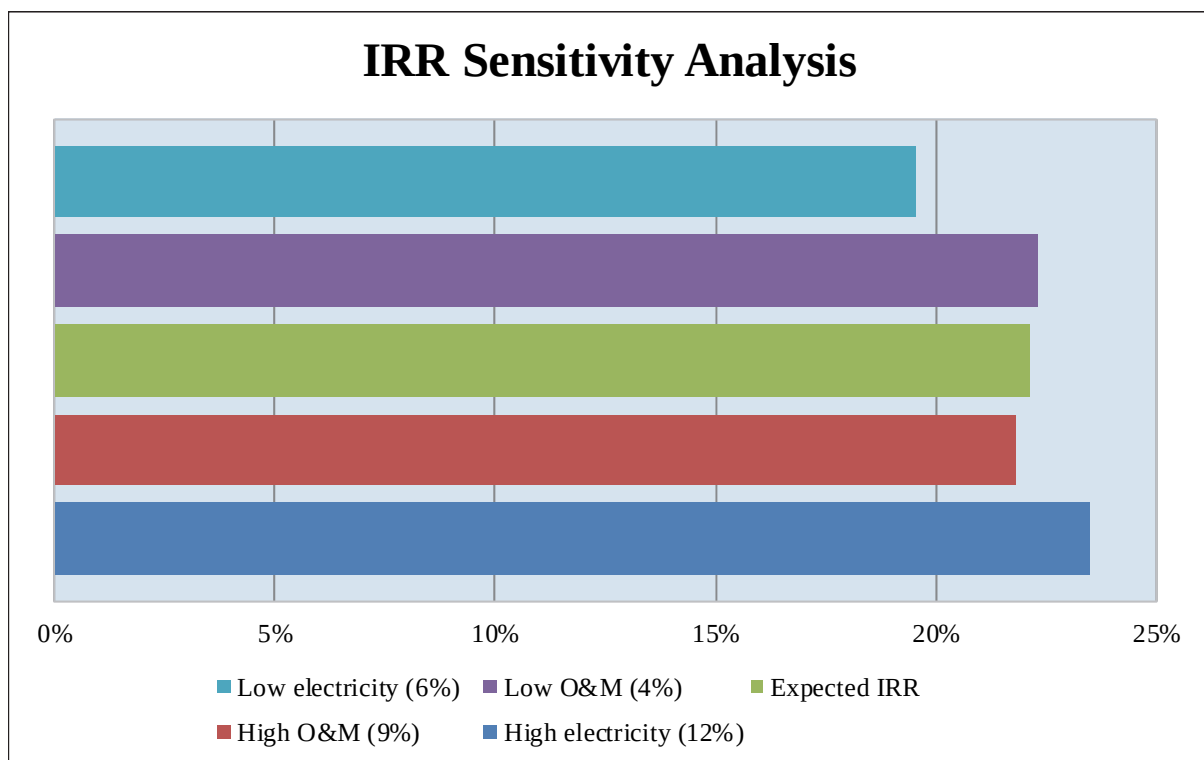


Figure 8-16: Garsfontein Phase 3 IRR sensitivity analysis



Table 8-10: Garsfontein Phase 3 sensitivity analysis summary

DSS Step		Operation & maintenance			Value of generated electricity		
		High	Expected	Low	High	Expected	Low
22	Inflation	9%	6% avg	4%	12% from 2017	8% avg	6% from 2017
	Total NPV	27 600 000	28 600 000	29 100 000	33 700 000	28 600 000	20 400 000
	IRR	21.81%	22.14%	22.32%	23.47%	22.14%	19.53%

8.4.6 Discussion of results

The analysis of hydropower at the Garsfontein Reservoir showed that there is economically exploitable potential at this site, with an expected NPV of R44 000 000 and an IRR of 28%. It is proposed that a 730 kW grid-connected Gilkes Turgo turbine (**Figure 8-17**) be installed for current use, with space allowed for future extension.

This is a bulk reservoir in the water-distribution network to a significant portion of the eastern parts of the City of Tshwane. Therefore, operational changes to increase hydropower were not made, as water-supply reliability is the primary concern. Another option that may be considered is to use a pump-as-turbine installation, as this installation would not have to be positioned on the reservoir roof and would therefore require a smaller capital investment. Another advantage of a pump-as-turbine would be that maintenance staff would be more familiar with the equipment.

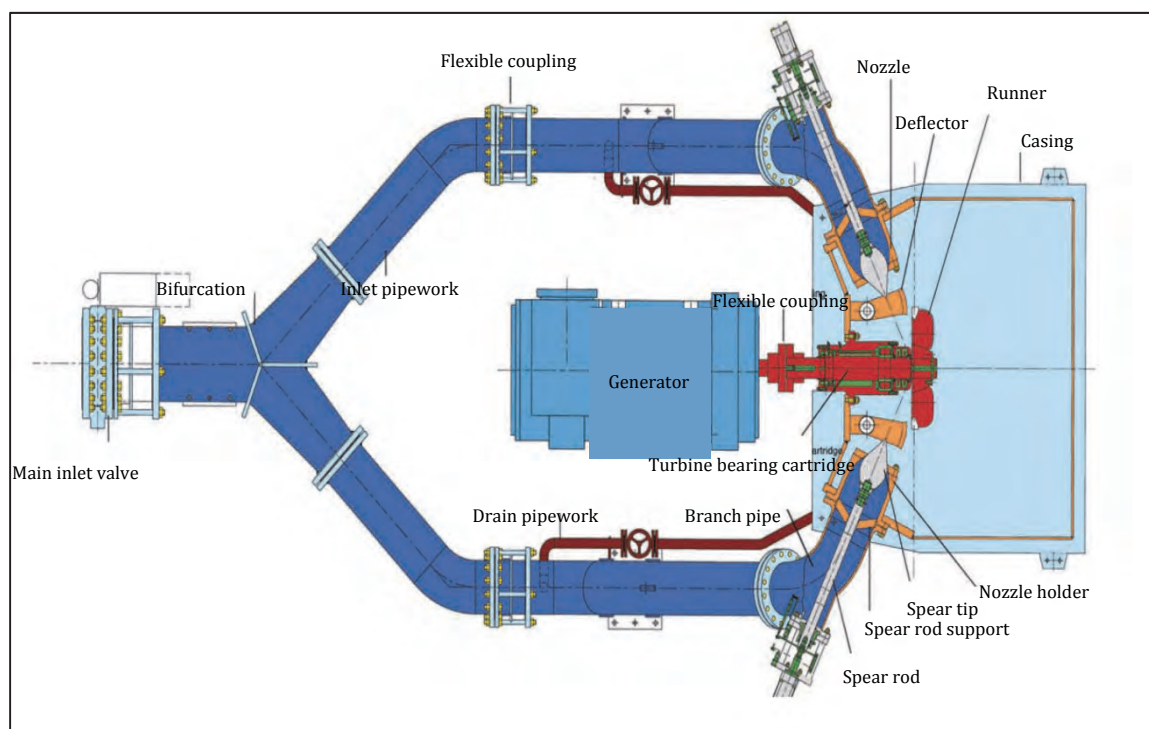


Figure 8-17: Typical Gilkes Turgo layout (Gilkes, 2012)



8.5 Case Study 2: Pierre Van Ryneveld Reservoir

8.5.1 Location

The Pierre van Ryneveld Reservoir consists of two structures that are located in the Country Lane Estate in Rietvalleirand, City of Tshwane, as can be seen in **Figure 8-18**. The GPS coordinates are 25°51'8.50"S and 28°15'26.09"E and the base of the reservoir is situated at an elevation of 1 559 m amsl.

There is a booster pump station on the western side of the R21 that is used occasionally during summer when demand is exceptionally high (this pump station will become redundant when new pipelines are completed and the pressure of the off-take from the Rand Water pipeline increases). This site also houses a series of PRVs that are used under normal flow conditions.



Figure 8-18: Location of Pierre van Ryneveld Reservoir (Google Earth, 2012)

8.5.2 Site description

As is the case in much of the City of Tshwane, water to the Pierre van Ryneveld Reservoir is supplied by Rand Water. It gravitates from a higher altitude in Johannesburg to a lower elevation in Tshwane. The reservoir supplies potable water to the Pierre van Ryneveld suburb in Centurion. **Figure 8-19** shows the reservoir's water-distribution zone.



The site currently consists of two structures; both were built using post-tensioned reinforced concrete. The older structure has a capacity of 7 600 m³ and the newer structure has a capacity of 15 000 m³. The flow meter and pressure gauges were installed at the PRSs located at the pump station site west of the R21, **Figure 8-18**.

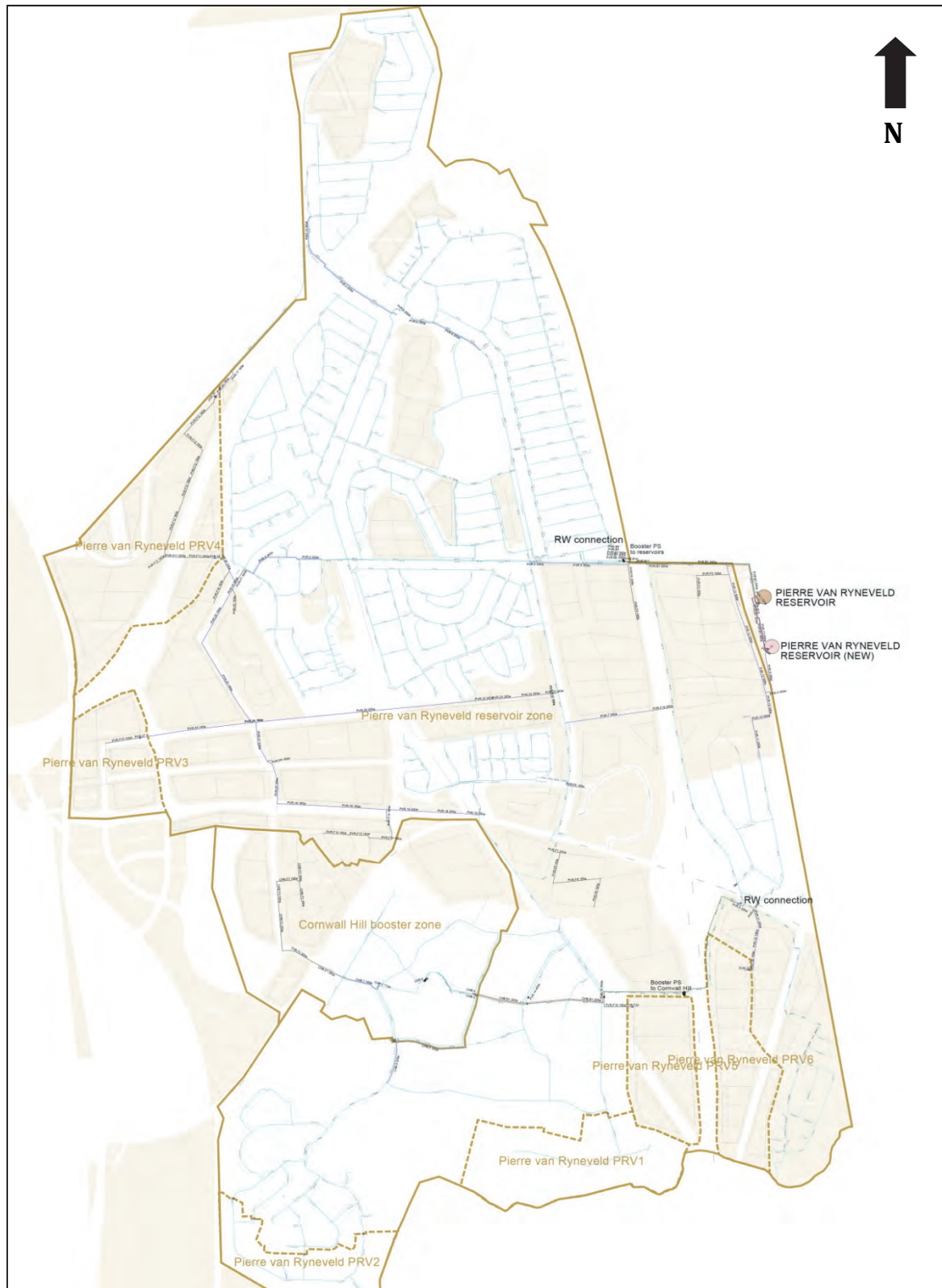


Figure 8-19: Pierre van Ryneveld Reservoir water-distribution zone (IMQS)



8.5.3 Phase 1 Analysis and Results

The information used in the Phase 1 study was obtained from The City of Tshwane Metropolitan Municipality's IMQS (Infrastructure Management Query Station) database. The relevant information can be seen in **Table 8-11**. This information was entered into the CHD Tool for Phase 1, with default values as indicated in **Appendix C** and the output is also shown in **Table 8-11**.

Suitable future flow rates and pressure heads for hydropower generation cannot be guaranteed at this site for future scenarios. Therefore a short design life of 15 years was selected, to determine economic feasibility if future conditions do not suit hydropower. It was argued that the turbine may be moved to another location if conditions become unsuitable.

With an IRR of 1% and a negative NPV, the Phase 1 analysis indicated that a full feasibility study should not be undertaken, unless another reason exists for considering conduit hydropower (CHDSS Step 11). The City of Tshwane is currently committed to developing more renewable energy sources and political reasons can therefore be given for continuing with subsequent phases. It may also be that operational changes can have a positive impact on the economic feasibility of a project. As this might be the case at Pierre van Ryneveld, a Phase 2 analysis was done.

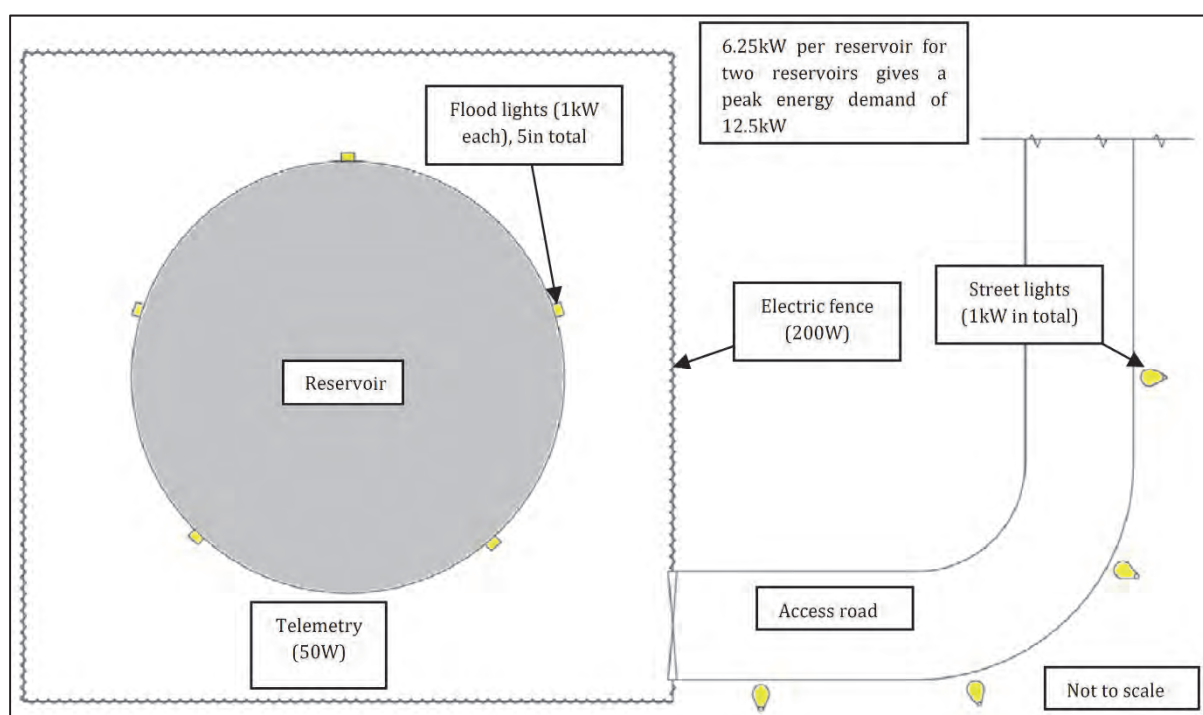


Figure 8-20: Schematic layout of on-site electricity use at Pierre van Ryneveld Reservoir



Table 8-11: Pierre van Ryneveld Phase 1 analysis summary

	Description	Value	Unit	Source
	Reservoir name	Pierre van Ryneveld		IMQS
3	Owner of infrastructure	City of Tshwane		
4	Present average annual daily demand	7 123	kℓ/d	IMQS
	Future average annual daily demand	25 961	kℓ/d	
	Average flow	0.082	m ³ /s	CHD Tool
	Static head (used head)	40 (24)	m	IMQS
5	Theoretically available power	13.6	kW	CHD Tool
6	Potential use	On-site		Decided
7	Distance to grid	N/A	km	
8	On-site peak energy demand	12.5	kW	Figure 8-20
9	Average power/max demand	109	%	
10	Design life	15	Years	CHD Tool
	Estimated cost of plant (based on on-site peak energy demand)	856 900	Rand	
	NPV of costs	848 500	Rand	
	NPV of income	723 900	Rand	
	NPV	-124 600	Rand	
	IRR	4	%	
	Payback period	16	years	
	Economically feasible?	NO		
11	Consider next phase?	YES		Other reasons

Although this phase did not indicate economic feasibility, operational changes to the system may have a positive impact on the viability of the project (CHDSS Step 11).

8.5.4 Phase 2 Analysis and Results

The first phase hydropower potential analysis did not indicate economic feasibility. However, a Phase 2 analysis was performed, because operational changes may have a positive impact on the power potential and economic feasibility of the project (CHDSS Step 1). (A conduit hydropower plant has already been installed here as a pilot project (**Figure 8-21**), because CoT was in the process of constructing a second reservoir on the site and therefore had a construction team to build a valve chamber and install the necessary pipework.)



To complete the CHDSS Step 2, it was necessary to visit the site and assess the practicability of a hydropower plant there. Considered aspects included: space for the hydropower plant; safety of the turbine and other equipment from theft or vandalism; noise impact on the surroundings; and accessibility to the site during construction.



Figure 8-21: Existing Pierre van Ryneveld Reservoir hydropower installation

Table 8-12: Pierre van Ryneveld Phase 2 site analysis summary

DSS step	Practicability aspect	Discussion	Conclusion
2	Available space	This site already has a pico unit installed on the reservoir roof, as shown in Figure 8-21 , therefore it has already been confirmed that enough space exists at this site.	Sufficient space exists on site
	Safety	The site is located within the boundaries of the Country Lane Estate, which has electric fencing and 24 hour security.	Sufficient security is present
	Noise impact	As this reservoir is located within the boundaries of a residential estate, the impact of noise may be disturbing if a large turbine is installed. However, due to the anticipated size of the turbine, noise should be minimal	Noise impact will be sufficiently low
	Accessibility of site	As shown in Figure 8-18 , the site is located close to the R21 Nellmapius off-ramp. Access to the site by construction vehicles may be achieved by using the service gate to the south of the reservoir.	Easy accessibility



As the practicability of this site had been established, measuring instrumentation was installed to measure flow and pressure in the system, as recommended in CHDSS Step 3 of Phase 2. Flow and pressure data were collected at the PRS next to the booster pump station to the west of the R21, as indicated in **Figure 8-18**. Data loggers were installed as shown in **Figure 8-22** and **Figure 8-23**.



Figure 8-22: Pressure measurement at Pierre van Ryneveld pressure-reducing station

Gaps in measured data occurred at various times. **Figure 8-24** shows the unedited measured data for flow rates, as well as upstream and downstream pressures. A major gap in flow data was experienced between June and September 2012. This was due to the installation of new pipes and the construction of a new valve chamber on site. Various minor gaps exist in the pressure data. The reason for the gaps is possibly a communication error between the modem on site and the server where information is stored. These gaps were removed before continuing with the analysis.





Figure 8-23: Flow measurement at Pierre van Ryneveld Reservoir

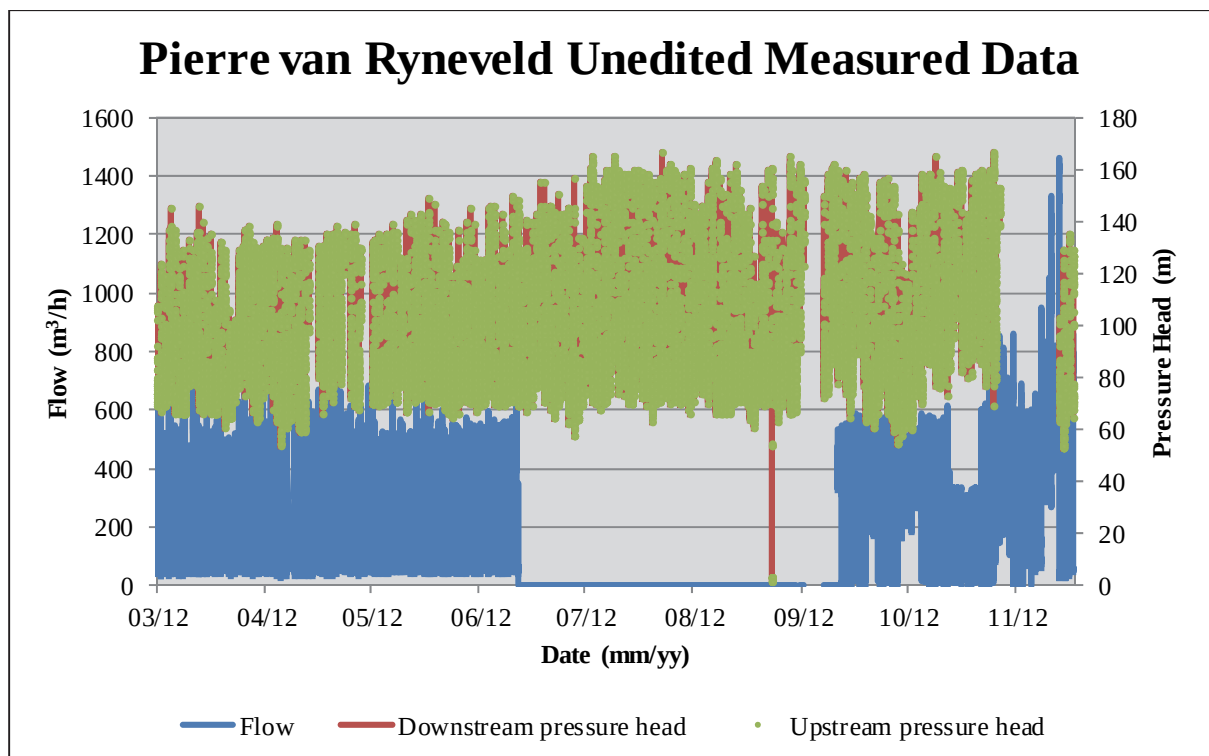


Figure 8-24: Pierre van Ryneveld unedited measured data



The obtained data set was entered into Phase 2 of the CHD Tool to analyse the records (as per CHDSS Step 4 of Phase 2) and to populate **Table 8-13**. **Figure 8-25** and **Figure 8-26** were also generated using the CHD Tool.

Table 8-13: Pierre van Ryneveld Phase 2 potential analysis (original)

DSS step	Description		Value	Unit	Source	
	Reservoir name		Pierre van Ryneveld		IMQS	
4	Measured and calculated values	Optimum flow	0.082	m³/s	Measured	
		Pressure head	41.9	m		
		Power rating	23.7	kW	CHD Tool	
		Annual energy	123.1	MWh/a		
	Assurance of supply (% of time) (Figure 8-25)		95	%	Decided	
	Initial Design values	Design flow	0.003	m³/s	CHD Tool	
		Pressure head	79.8	m		
		Power rating	1.5	kW		
		Annual energy	12.5	MWh/a		
5	What operational changes could be considered?		The reservoir feeds one distribution zone, so consider constant flow			CHD Tool
4	Design values after operational change	Design flow	0.067	m³/s		
		Pressure head	50.4	m		
		Power rating	23.1	kW		
		Annual energy	198.3	MWh/a		
7	Selected turbine (Figure 8-26)		Cross-flow			
8	Electricity use		On-site		Decided	
9	Distance from grid connection		N/A	km	Decided	
10	On-site power demand		12.5	kW	Figure 8-20	
	Power rating/max demand		185	%		



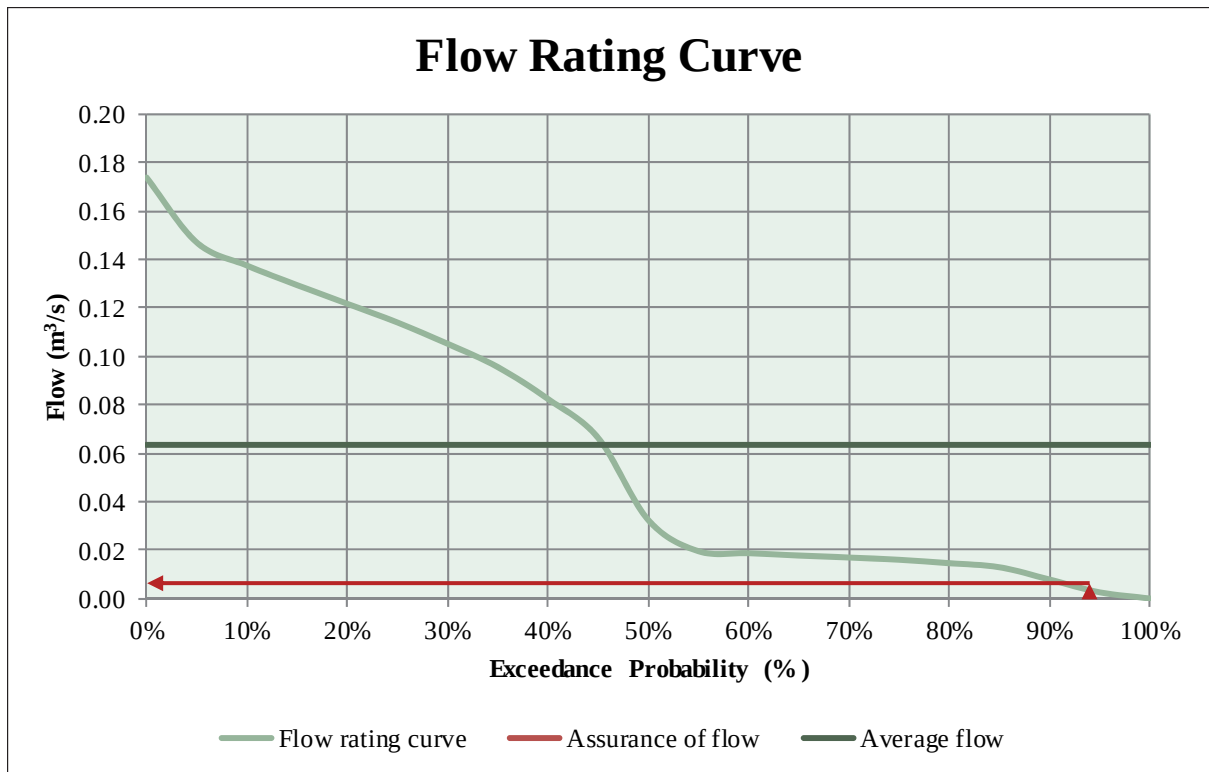


Figure 8-25: Pierre van Ryneveld Phase 2 flow-rating curve

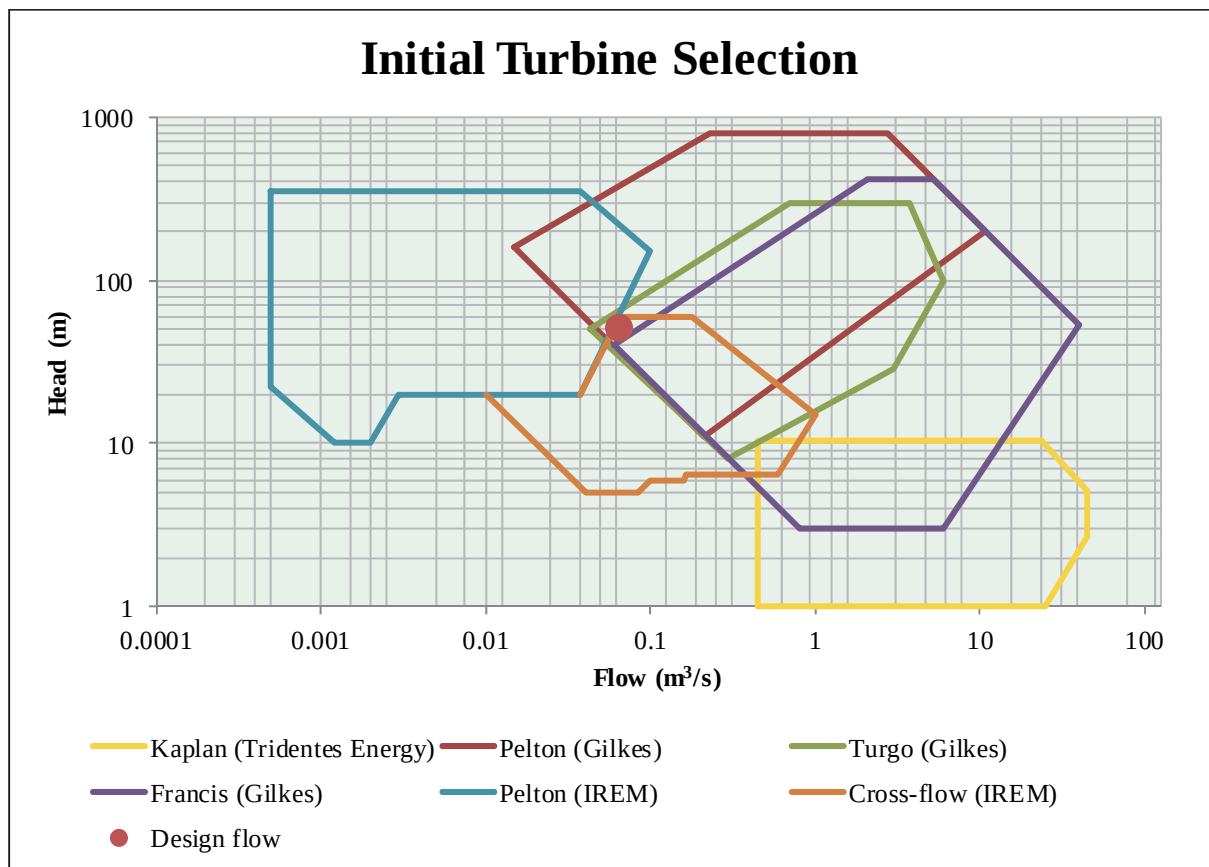


Figure 8-26: Pierre van Ryneveld Phase 2 initial turbine-selection curve (original)



From **Table 8-13**, it is clear that the power potential exceeds the energy requirements if operational changes are made to the system to allow a more constant flow rate into the reservoir. Therefore, the future development of the reservoir distribution zone was not considered in detail, as per CHDSS Step 6. It should be noted, however, that future conditions at the reservoir are uncertain. Future total flow rates will increase as development increases, but it is not clear whether parallel pipes will be installed or not to ensure a similar pressure head. Therefore a design life of 15 years was used for the site, assuming constant flow and pressure. If the project is economically feasible for the short design life and conditions remain favourable, the project will only become more profitable. If conditions change significantly, the turbine can be moved to another location after decommissioning.

The use of a smaller turbine was, however, considered, as the power potential exceeds the energy requirements if operational changes are made to the system to allow a more constant flow rate into the reservoir (**Table 8-13**). A lower flow rate was used to populate **Table 8-14**, **Figure 8-27** and **Figure 8-28**.

Table 8-14: Pierre van Ryneveld Phase 2 potential analysis (final)

DSS step	Description		Value	Unit	Source
	Reservoir name		Pierre van Ryneveld		IMQS
	Assurance of supply (% of time)		95	%	Decided
	Final design values	Design flow	0.037	m ³ /s	CHD Tool
		Pressure head	50.4	m	
		Power rating (Figure 8-27)	12.8	kW	
		Annual energy (Figure 8-27)	110.0	MWh/a	
7		Selected turbine (Figure 8-28)	Pelton		
8		Electricity use	On-site		
9		Distance from grid connection	N/A	km	Decided
10		On-site power demand	12.5	kW	Figure 8-20
		Power rating/ max demand	102	%	CHD Tool



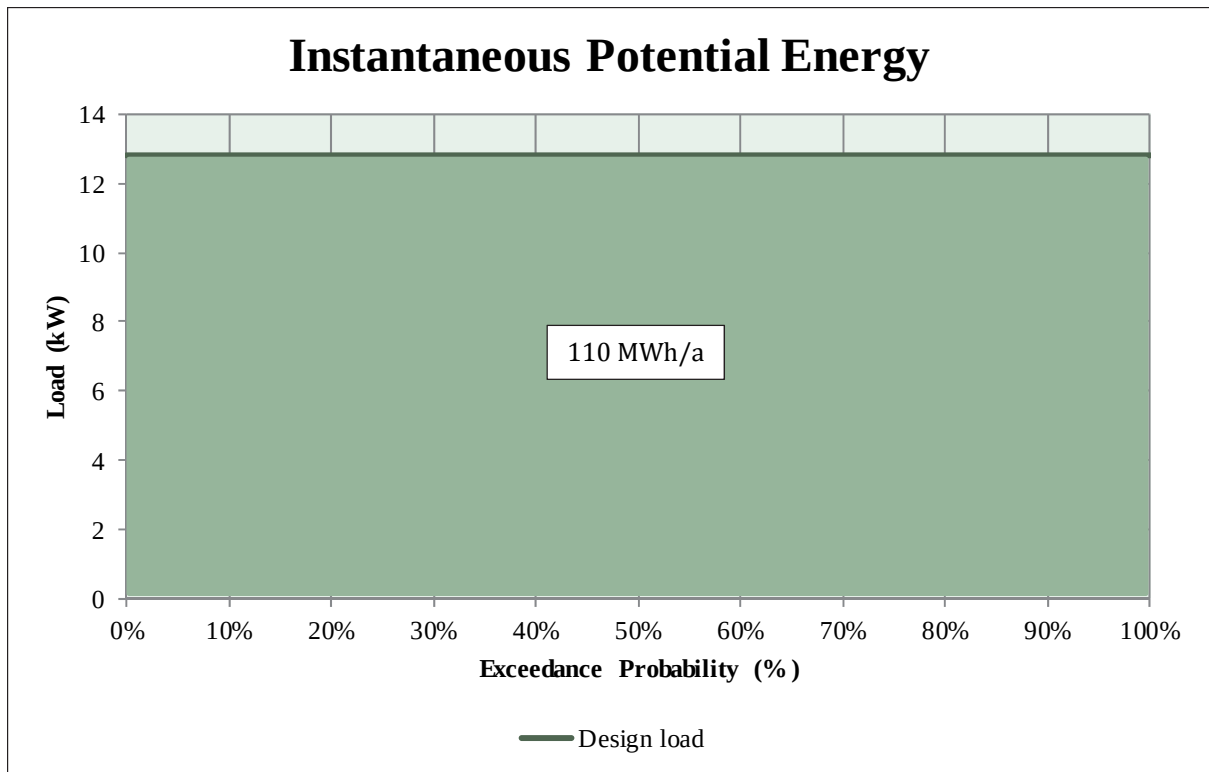


Figure 8-27: Pierre van Ryneveld Phase 2 instantaneous potential energy

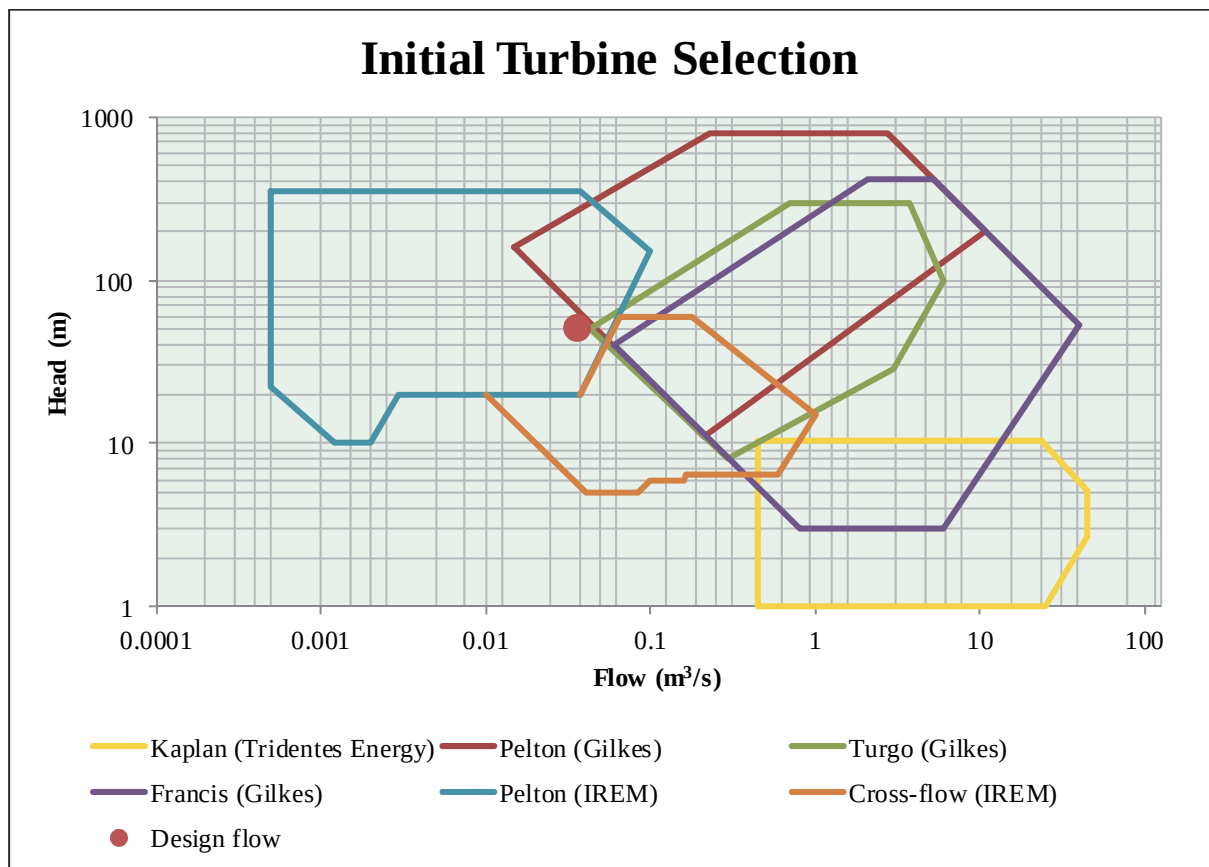


Figure 8-28: Pierre van Ryneveld Phase 2 initial turbine-selection curve (final)



CHDSS Steps 11-14 deal with regulatory requirements. These steps are summarised in **Table 8-15**.

Table 8-15: Pierre van Ryneveld Phase 2 regulatory analysis

DSS step	Regulatory aspect	Discussion	Conclusion
11	Environmental studies	All power plant and construction areas are smaller than the minimum sizes for which environmental studies are required, according to the National Environmental Management Act (Act 107 of 1998)	Neither BA nor EIA required
12	NERSA licence	As the generated electricity will be used for lighting and electric fencing on site, this can be classified as 'own use' and is therefore exempt from NERSA licensing (Energy Regulation Act (Act 4 of 2006))	Generation licence not required
13	Water-use licence	Water-use licensing is not needed, as this project can be seen as a continuation of an existing lawful use under Tshwane's water-use licence (National Water Act (Act 36 of 1998)).	Not required
14	Social requirements	A public participation process (PPP) would have to be followed wherein a notice board, meeting the requirements set in Government Notice 543 of 18 June 2010, is displayed on the boundary fence. If complaints are received, public hearings should be held.	PPP required

The next step was to perform an economic evaluation for Phase 2. The CHD Tool was used, with default values and cost functions as discussed in **Appendix C**.

Table 8-16 was populated with the input and calculated values.



Table 8-16: Pierre van Ryneveld Phase 2 economic analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Pierre van Ryneveld		IMQS
4	Design values	Design flow	0.037	m ³ /s	Measured
		Pressure head	50.4	m	
		Power rating	12.8	kW	CHD Tool
		Annual energy potential	110	MWh/a	
7	Selected turbine		Pelton		
15	Planning cost per MW		1 350 000	R	Industry average
	Planning cost for this site		17 300	R	CHD Tool
	Turbine cost		389 200		
	Capital cost per MW (excluding turbine)		13 300 000	R	Industry average
	Total capital cost for this site (including turbine)		559 500	R	CHD Tool
	Annual operation and maintenance cost (for year 1)		12 400	R	
	Annual income (for year 1)		63 800	R	
	Design life		15	years	Decided
	NPV of costs		741 900	R	CHD Tool
	NPV of income		1 159 800	R	
	Total NPV		418 000	R	
	Internal rate of return		13.92	%	

With operational changes (as discussed in **Table 8-13**) and the use of a correctly sized turbine (as discussed in **Table 8-14**), a positive NPV and an IRR of around 14% was calculated, which made the project economically feasible. The major contributing factor in the IRR and NPV increases between Phase 1 and Phase 2 is the fact that operational changes will produce a better load factor on the plant. So, instead of generating 60 MWh/a (with a load factor of 60% in Phase 1), 110 MWh/a (with a load factor of 95% in Phase 2) is now possible. A Phase 3 detailed design analysis was therefore performed.



8.5.5 Phase 3 Analysis and Results

The Phase 2 economic analysis indicated financial feasibility. Therefore the Phase 3 analysis and detailed design was completed. The first step in this phase was to obtain historical flow and pressure records. Longer historical records (of a year or more) would be useful, as they would improve accuracy. However, as longer records were not available for this site, the same measured flow and pressure records were used as in Phase 2, for Step 2 of Phase 3.

The third step of this phase was to consider the effect of system optimisation. **Figure 8-29** shows the flow rates and corresponding pressures during a representative week in October 2012. From this figure it is clear that flow in the pipe is normally open until the reservoir is full, at which stage the flow in the pipe becomes almost zero. As the Pierre van Ryneveld Reservoir serves only a single water-distribution zone (as shown in **Figure 8-19**), the operational philosophy of this reservoir can be adjusted easily to obtain a more constant flow. This will in turn provide the opportunity for more constant energy generation, as determined in **Table 8-17**. It should be noted that CHDSS Step 9 was not followed at this site, as the future circumstances at the reservoir are not certain. This site is therefore only evaluated for a 15-year design life, with no increase in flow or pressure.

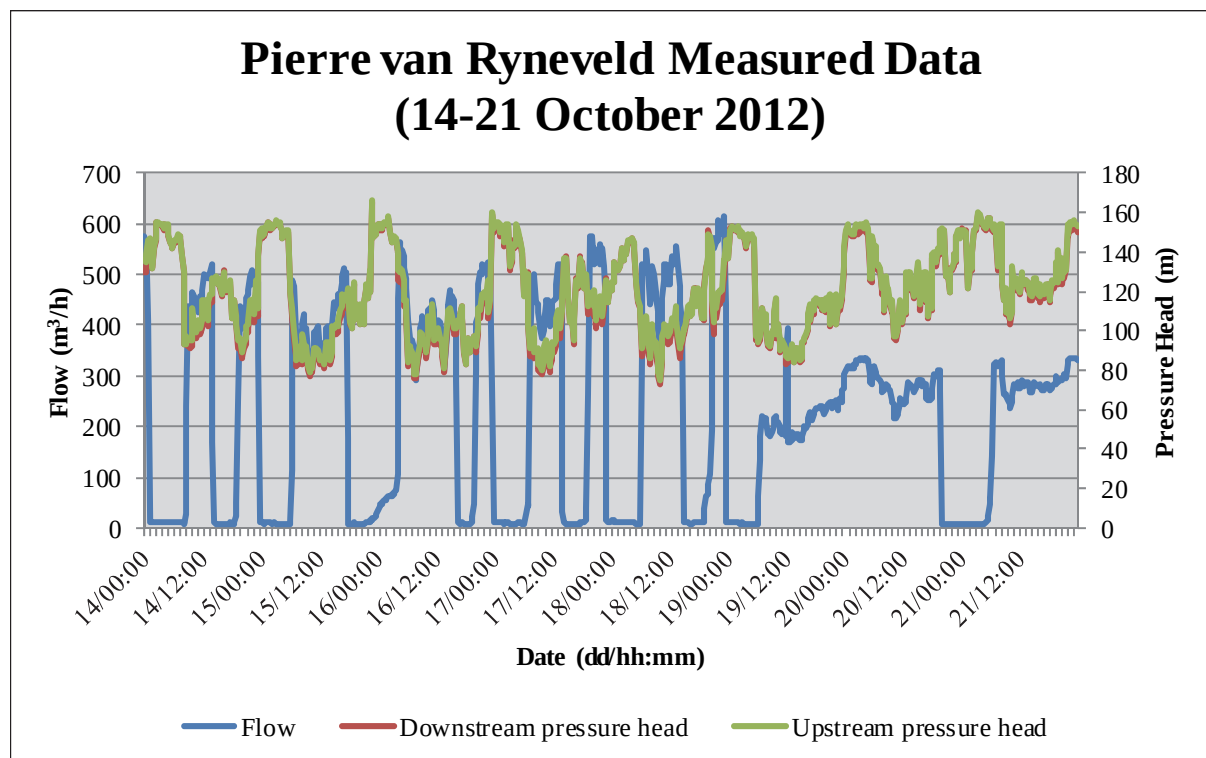


Figure 8-29: Pierre van Ryneveld measured data for a typical week



Table 8-17: Pierre van Ryneveld Phase 3 potential analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Pierre van Ryneveld		IMQS
3	Measured and calculated values	Average current flow	0.067	m ³ /s	CHD Tool
		Pressure head	50.4	m	
		Power rating	26.4	kW	
4		Annual energy potential	226.7	MWh/a	
	Assurance of supply (% of time)		98	%	Decided
6	Required turbine range for current flow		21-27	kW	CHD Tool
7	Selected turbine for current flow		IREM Pelton		Product catalogue
8	Turbine efficiency for current flow		78%		Product catalogue
10	Electricity use		On-site		
11	Distance from grid connection		N/A	km	Decided
13	Demand patterns		Figure 8-30	kW	CHD Tool
14	Do supply-and-demand patterns correlate?		Supply is higher than peak demand		CHD Tool
	Is there sufficient demand for the installation size?		No		
6	Required turbine size for demand?		12.5	kW	Figure 8-30
4	Final design	Flow	0.041	m ³ /s	CHD Tool
		Pressure head	50.4	m	
7	Selected turbine (Figure 8-31)		BHG Cross-flow		Easily obtainable
8	Turbine efficiency		75%		Supplier information



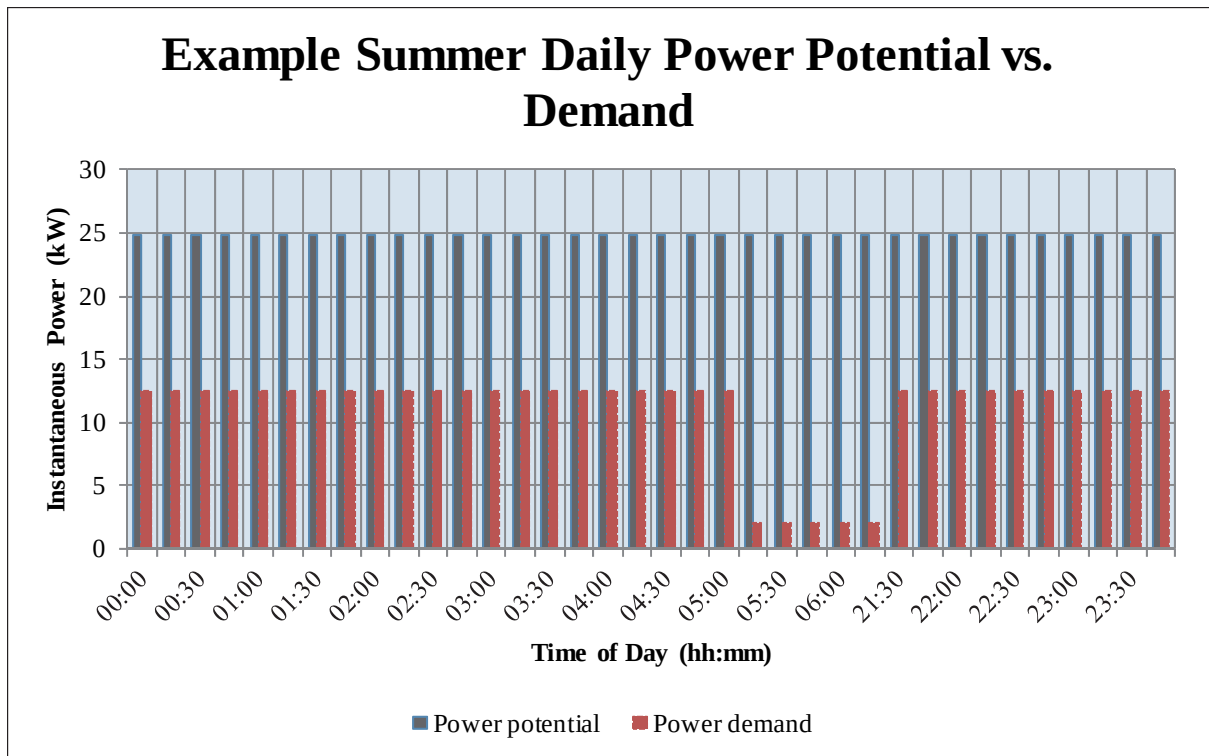


Figure 8-30: Pierre van Ryneveld Phase 3 example power potential vs. power demand

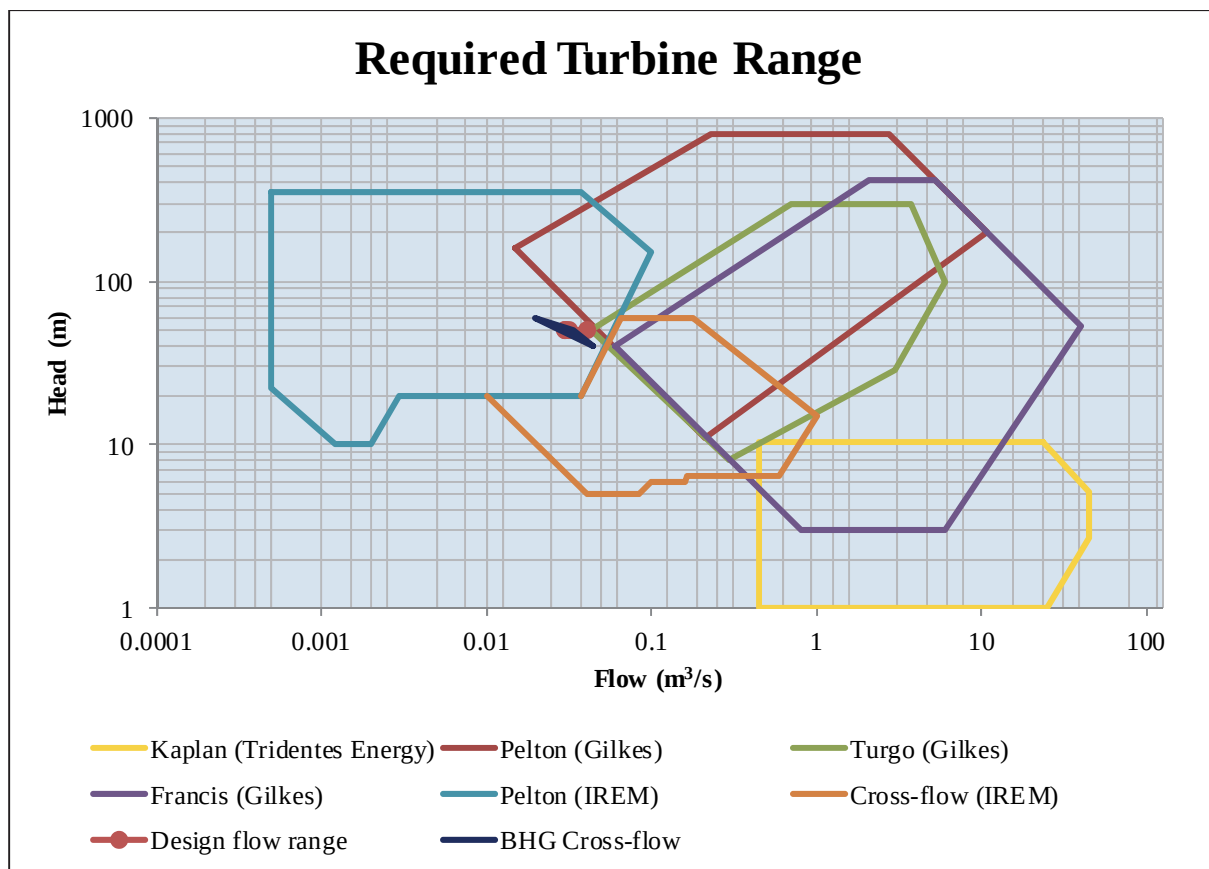


Figure 8-31: Pierre van Ryneveld Phase 3 turbine selection



The next set of steps involved the detailed design of all the components of the conduit hydropower plant. **Table 8-18** to **Table 8-22** provide a summary of the procedure, with references to drawings, photos and other relevant information.

Table 8-18: Pierre van Ryneveld Phase 3 electrical and mechanical design summary

DSS step	Design component	Discussion
15	Electrical and mechanical	A cross-flow turbine (Figure 8-32) was selected as it is a low-speed impulse turbine that works best with lower head and higher flow. These turbines have the advantage that water passes through the runner twice, thereby keeping the runner clean from debris. It also has a simple construction and easy maintenance, with only two bearings and three rotating elements. A summary of the technical details is provided in Table 8-19. A synchronous generator was selected, since the electricity will be used on-site and not fed into the grid. A summary of the technical details is provided in Table 8-19. The belt drive between the turbine and generator is a flat belt of polyamide synthetic material with a leather coating. A load control governor was not used for this turbine. Instead a ballast tank with heating elements to consume excess energy was designed. An emergency bypass (using a pinch valve upstream of the turbine) was also designed to divert flow and pressure away from the turbine in case of a power failure (Figure 8-38).

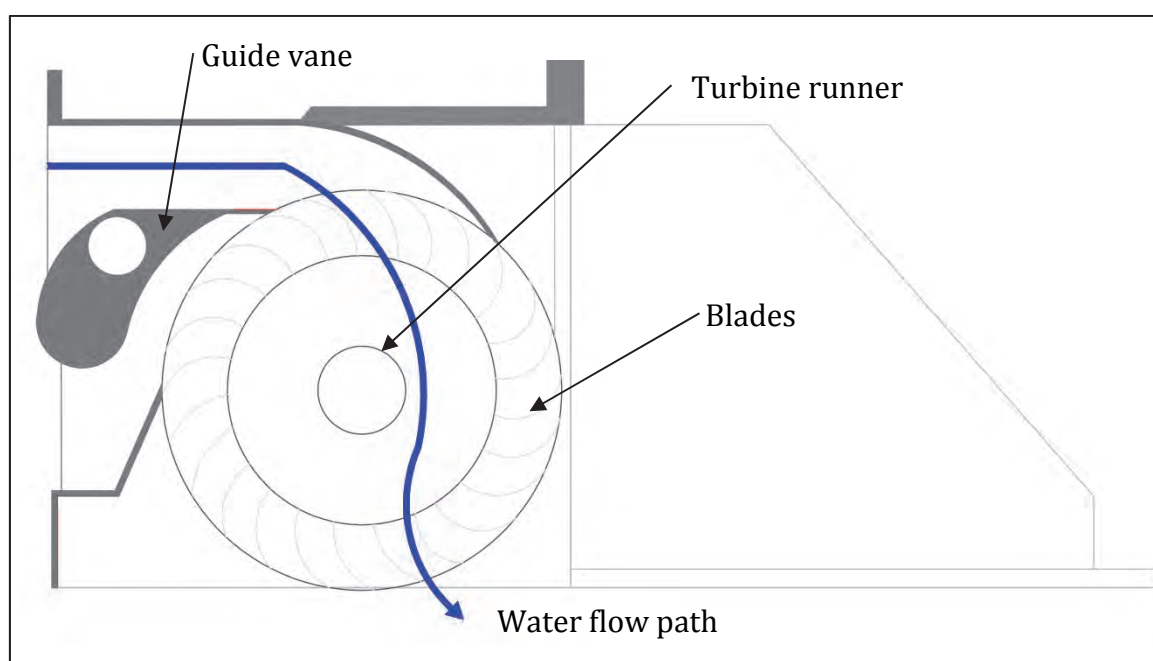


Figure 8-32: Cross-flow turbine



Table 8-19: Pierre van Ryneveld turbine technical details

Description	Normal condition
Rotor diameter	241.9 mm
Rotor length	170 mm
Net operating head	16.7 m
Turbine speed	642 r/min
Generator power	14.9 kW

Table 8-20: Pierre van Ryneveld generator technical details

Description	Normal condition
Generator type	Synchronous
Phasing	3-phase
Frequency	50 Hertz
Generator speed	1 500 r/min
Generator rating	17 kVA, 380/220 Volt

Table 8-21: Pierre van Ryneveld Phase 3 civil design summary

DSS step	Design component	Discussion
16	Civil works	An off-take pipe and connections, as shown in Figure 8-33, were designed. The off-take was placed upstream of the existing reservoir PRV and the design of the pipe leading to the turbine on top of the reservoir allowed for fastening to the reservoir wall (Figure 8-34 shows the pipework under construction). The off-take was enclosed in a valve chamber (Figure 8-35 shows the completed off-take with control valve and flow meter). To prevent damage to the reservoir roof, steel beams spanning between reservoir columns were designed as an anchor for the turbine (Figure 8-36). A steel frame with chromadek cladding was used for the turbine enclosure (Figure 8-37).



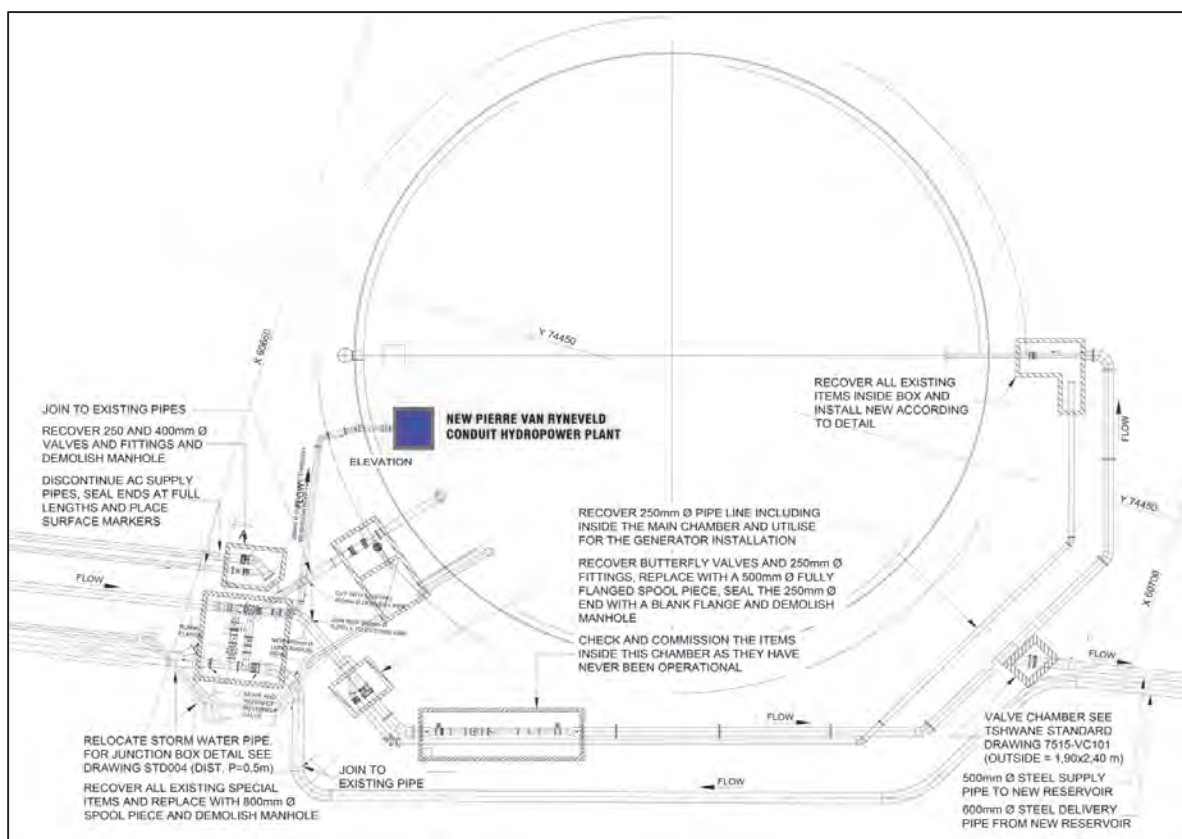


Figure 8-33: Pierre van Ryneveld pipework design



Figure 8-34: Pierre van Ryneveld off-take pipework under construction





Figure 8-35: Completed off-take pipework



Figure 8-36: Completed turbine on steel-beam supports





Figure 8-37: Pierre van Ryneveld turbine enclosure

Table 8-22: Pierre van Ryneveld Phase 3 plant set-up and safety design summary

DSS step	Design component	Discussion
17	Plant set-up	A cross-flow turbine was selected. It is a type of impulse turbine and therefore has to discharge to atmosphere. A set-up with the turbine on the reservoir roof was therefore chosen. Figure 8-38 shows the turbine set-up on the reservoir roof.
18	Equipment safety	Equipment safety is not a major concern at this site, as the reservoir is located inside a security estate with electric fencing (that will be powered by the hydropower plant) and 24 hour security guard presence.



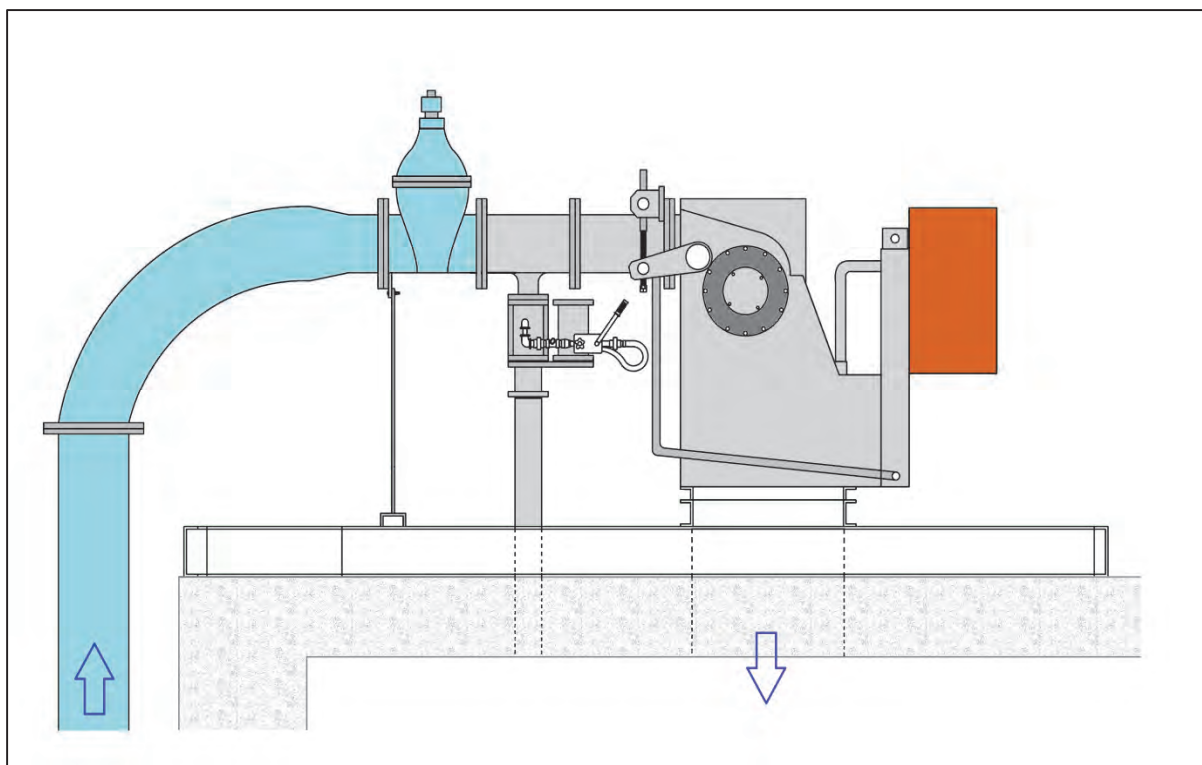


Figure 8-38: Pierre van Ryneveld cross-flow set-up

Next, a detailed economic evaluation was conducted with obtained costs, where applicable. The results can be seen in **Table 8-23**. A sensitivity analysis was also conducted to determine the sensitivity of project feasibility when considering alternative inflation rates. The results of this analysis are summarised in **Table 8-24**.



Table 8-23: Pierre van Ryneveld Phase 3 economic analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Pierre van Ryneveld		IMQS
4	Design values	Design flow	0.041	m ³ /s	CHD Tool
		Pressure head	50.4	m	
		Power rating	14.9	kW	
		Annual energy potential	120	MWh/a	
6	Selected turbine		BHG cross-flow		
19	Costs	Planning and design	74 000	R	Industry average
		Preliminary and general	15 000	R	
		Turbine	170 000	R	
		Other electrical and mechanical	102 000	R	
		Civil and construction	150 000	R	
		Data logging and communication	49 000	R	
		Disposal (present value)	0	R	
		Annual O&M (for year 1)	10 300	R	
	Annual income (for year 1)		74 800	R	CHD Tool
	Design life		15	years	
	Total initial capital expenditure		685 000	R	
	NPV of costs		857 000	R	
	NPV of income		1 360 200	R	
	Total NPV		537 300	R	
	Internal rate of return		14.38	%	

Step 21 of the CHDSS concerns funding of the project. Since this project has a projected capital expenditure of less than R700 000, no external funding is required and the municipality can source funds from their own CAPEX budget.

A sensitivity analysis was done to determine the impact of different future inflation rates. The results are shown in **Figure 8-39**, **Figure 8-40** and **Table 8-24**. It is clear that the current uncertainty about future changes in the value of electricity is likely to cause a more significant impact on the net present value (NPV) of the project than operation and maintenance inflation, with an NPV of between R681 000 for high average electricity tariff inflation (12% after 2017) and R311 000 for low average electricity tariff inflation (6% after 2017). The expected NPV is R537 000, as determined in the economic analysis.



The internal rate of return (IRR) of the project was found to have a range between 11.65% (for low electricity inflation) and 15.78% (for high electricity inflation).

It can therefore be assumed that this project should be feasible even if inflation rates are not as expected.

Table 8-24: Pierre van Ryneveld Phase 3 sensitivity analysis summary

DSS step		Operation & maintenance			Value of generated electricity		
		High	Expected	Low	High	Expected	Low
21	Inflation	9%	6% avg	4%	12% from 2017	8% avg	6% from 2017
	Total NPV	R503 200	R537 300	R555 800	R680 600	R537 300	R311 400
	IRR	13.99%	14.38%	14.60%	15.78%	14.38%	11.65%

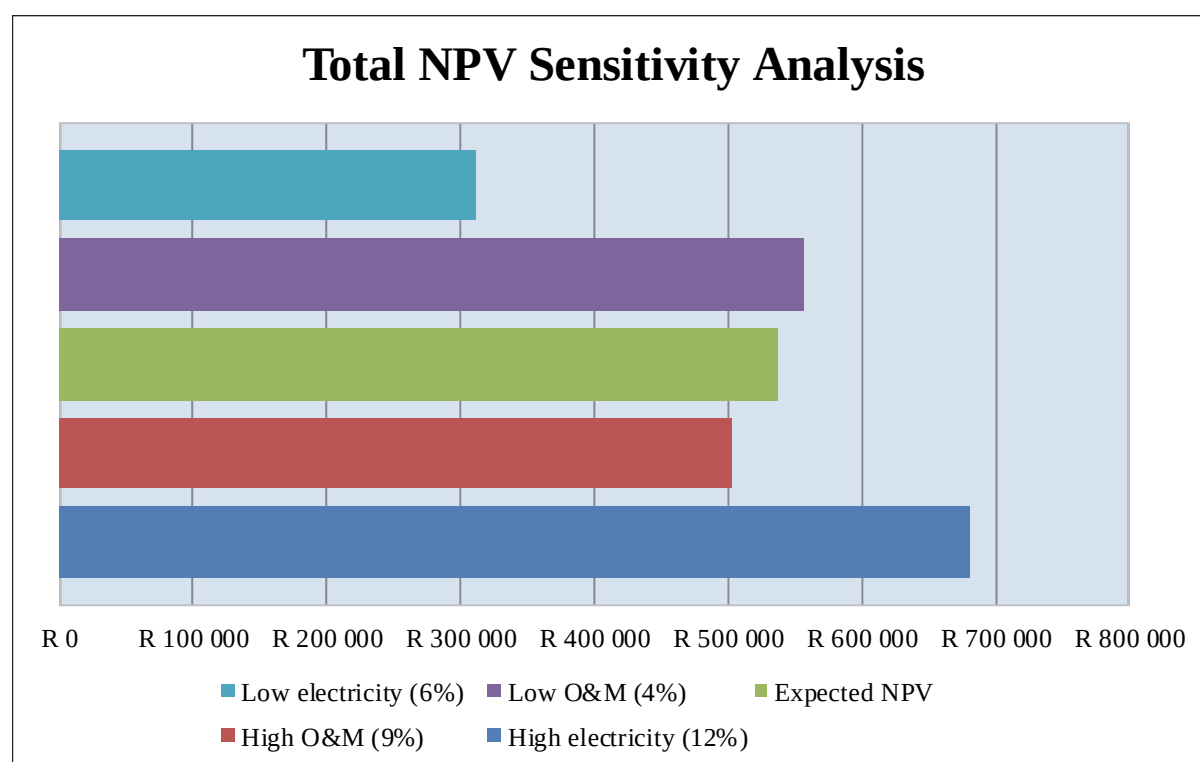


Figure 8-39: Pierre van Ryneveld Phase 3 NPV sensitivity analysis



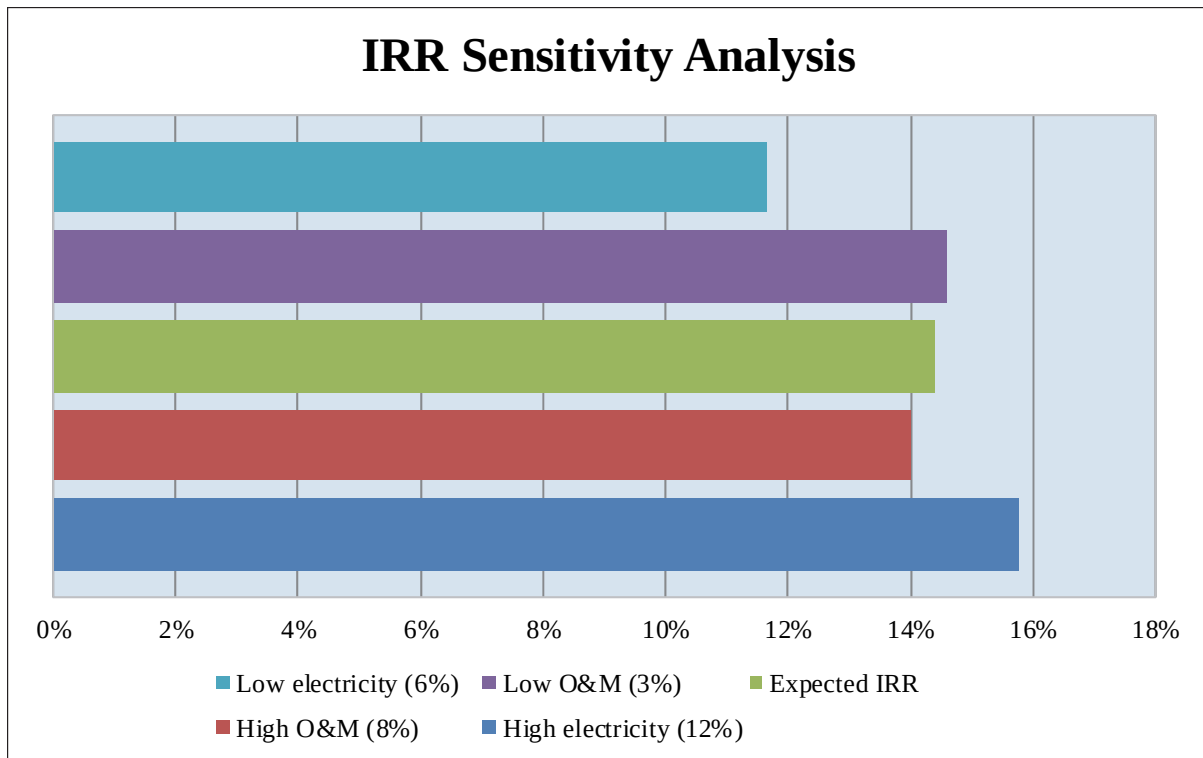


Figure 8-40: Pierre van Ryneveld Phase 3 IRR sensitivity analysis

8.5.6 Discussion of Results

The analysis of hydropower at the Pierre van Ryneveld Reservoir showed that operational changes to the system may make a pico hydropower plant viable for on-site usage **Table 8-17**.

Since future circumstances at the reservoir and its distribution zone are not certain, a design life of only 15 years was selected. The project will be economically feasible even for this short design life, as shown in **Table 8-23**. A BHG cross-flow turbine with a capacity of 15 kW was selected (**Figure 8-41**), as it was available and applicable to the flow range on site.



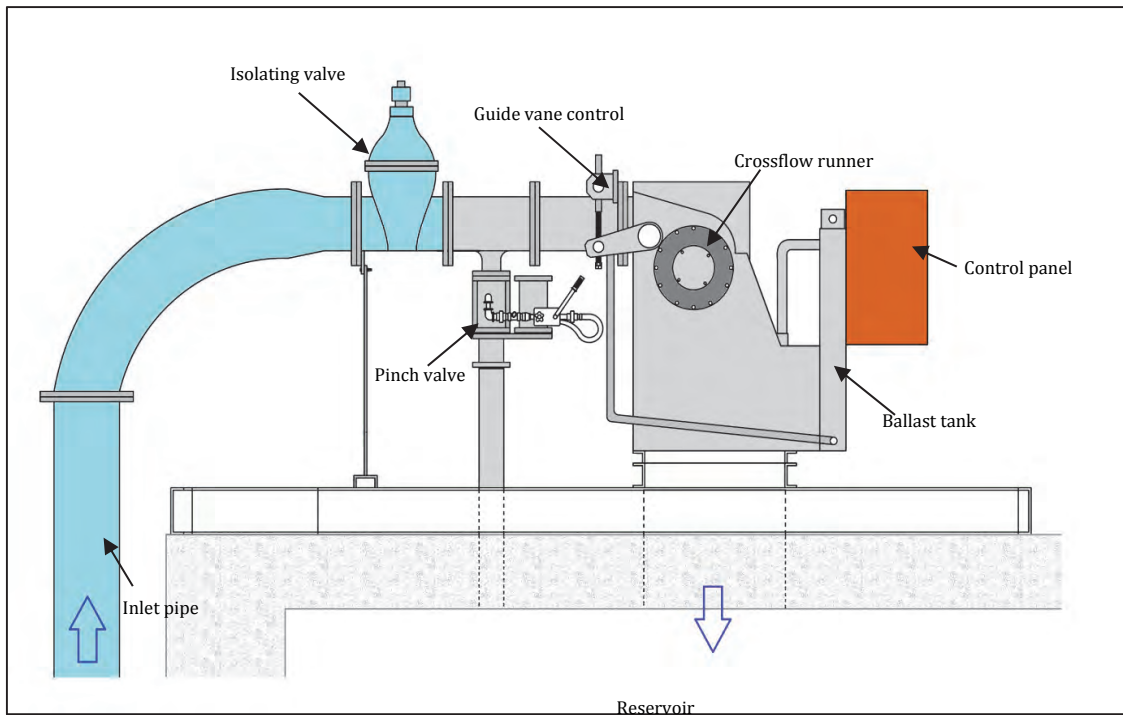


Figure 8-41: BHG cross-flow turbine set-up at Pierre van Ryneveld Reservoir

8.6 Case Study 3: Waterkloof Reservoir

8.6.1 Location

The Waterkloof Reservoir is located in Argo Place, Waterkloof, City of Tshwane, as can be seen in **Figure 8-42**. The GPS coordinates are 25°47'5.3"S and 28°13'44.9"E and the base of the reservoir is situated at an elevation of 1 465 m amsl.

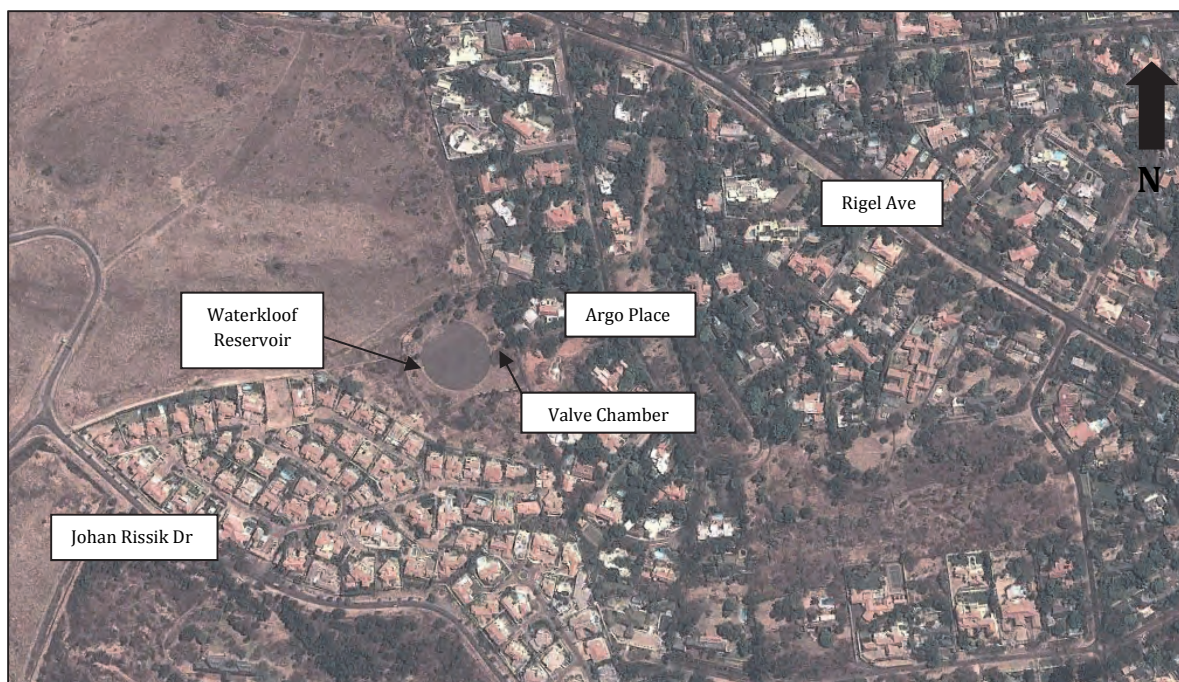


Figure 8-42: Location of Waterkloof Reservoir (Google Earth, 2012)



8.6.2 Site Description

As is the case in much of the City of Tshwane, water to the Waterkloof Reservoir is supplied by Rand Water. It gravitates from a higher altitude in Johannesburg to a lower elevation in Tshwane. The reservoir supplies potable water to the Waterkloof suburb in Pretoria. **Figure 8-43** shows the reservoir's water-distribution zone. The site consists of one structure with a capacity of 22 750 m³ and built using post-tensioned reinforced concrete.

The flow meter and pressure gauge were installed at the PRS located in the valve chamber upstream of the reservoir, as indicated in **Figure 8-42**.



Figure 8-43: Waterkloof Reservoir water-distribution zone (IMQS)

8.6.3 Phase 1 Analysis and Results

The information used in the first phase study was obtained from The City of Tshwane Metropolitan Municipality's IMQS (Infrastructure Management Query Station) database. The relevant information can be seen in **Table 8-25**. This information was entered into the CHD Tool for Phase 1, with default values as indicated in **Appendix C** and the output is also shown in **Table 8-25**.



This reservoir supplies water to a developed residential area and little change in future scenarios is expected, as shown in **Table 8-25** by the small increase between current annual average daily demand (AADD) and maximum future possible AADD. Therefore a design life of 30 years was selected.

Table 8-25: Waterkloof Phase 1 analysis summary

DSS step	Description	Value	Unit	Source
	Reservoir name	Waterkloof		IMQS
3	Owner of infrastructure	City of Tshwane		
4	Present average annual daily demand	8 783	kℓ/d	IMQS
	Future average annual daily demand	11 575	kℓ/d	
	Average flow	0.102	m ³ /s	CHD Tool
	Static head (pressure head used)	186 (112)	m	IMQS
5	Theoretically available power	77.9	kW	CHD Tool
6	Potential use	Grid connected		Decided
7	Distance to grid	0.08	km	Measured
8	On-site peak energy demand	N/A	kW	N/A
9	Average power/max demand	N/A	%	
10	Design life	30	Years	CHD Tool
	Estimated cost of plant (based on theoretically available power)	3 544 400	Rand	
	NPV of costs	4 748 300	Rand	
	NPV of income	9 644 100	Rand	
	NPV	4 895 700	Rand	
	IRR	12	%	
	Payback period	16	years	
	Economically feasible?	YES		
11	Consider next phase?	YES		

With an IRR of 12% and a positive NPV, the Phase 1 analysis indicated that a full feasibility study may be undertaken, even though the payback period seems long. Operational changes may also have a positive impact on the economic feasibility of the project.

8.6.4 Phase 2 Analysis and Results

The first phase hydropower potential analysis indicated economic feasibility and therefore a Phase 2 analysis was also performed.



After determining first phase feasibility (CHDSS Step 1), it was necessary to visit the site and assess the practicability of a hydropower plant there.

Considered aspects included: space for the hydropower plant; safety of the turbine and other equipment from theft or vandalism; noise impact on the surroundings; and accessibility to the site by construction equipment. The analysis is summarised in **Table 8-26**.

Table 8-26: Waterkloof Phase 2 site analysis summary

DSS step	Practicability aspect	Discussion	Conclusion
2	Available space	The Waterkloof Reservoir is situated on a small, steep plot on a hill, but sufficient space for a hydropower plant is available on or next to the reservoir roof as shown in Figure 8-42 and Figure 8-44 .	Sufficient space exists on site
	Safety	The site is located on locked CoT property within the boundaries of a residential estate, which has 24 hour security.	Sufficient security is present
	Noise impact	As this reservoir is located within a residential area, the impact of noise may be disturbing to residents. However, a PRV is currently installed and no complaints have been received.	Noise impact will be sufficiently low
	Accessibility of site	As shown in Figure 8-42 , the site is just off Argo Place in Waterkloof. Access to the site by construction vehicles may be gained through the front gate.	Easy accessibility

As the practicability of this site had been established, measuring instrumentation was installed to measure flow and pressure in the system, as recommended in CHDSS Step 3 of Phase 2. Flow and pressure data were collected at the PRV in the valve chamber upstream of the reservoir, as indicated in **Figure 8-42**. Data loggers were installed as shown in **Figure 8-45**.





Figure 8-44: Waterkloof Reservoir roof



Figure 8-45: Pressure and flow measurement at Waterkloof Reservoir pressure-reducing station



Figure 8-46 shows the unedited measured data for flow rates and upstream pressures. No major gaps were experienced. However, some minor gaps exist in the pressure and flow data. The reason for the gaps is possibly a communication error between the modem on site and the server where information is stored. These gaps were removed before proceeding with the analysis.

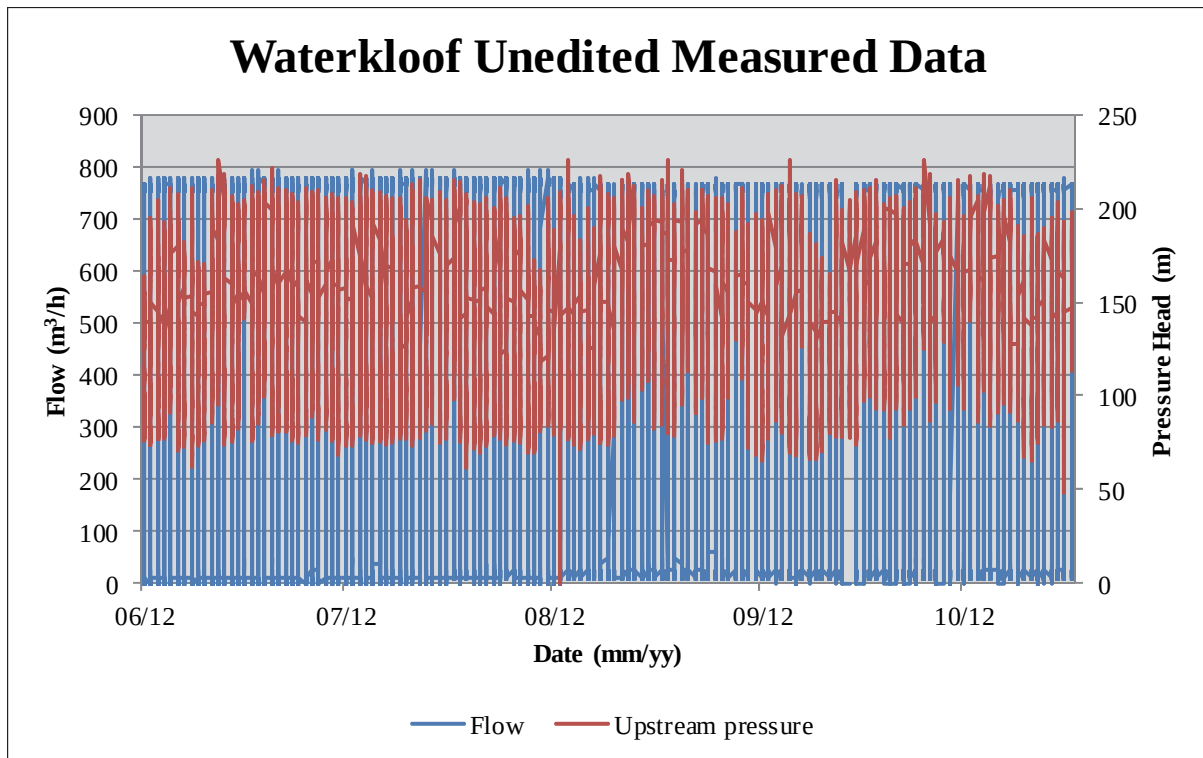


Figure 8-46: Waterkloof unedited measured data

The obtained data set was entered into Phase 2 of the CHD Tool to analyse the records (as per CHDSS Step 4 of Phase 2) and to populate **Table 8-27**. **Figure 8-47**, **Figure 8-48** and **Figure 8-49** were also generated using the CHD Tool.

CHDSS Step 5 was followed, as it was noticed that changing the operational procedure to maintain the average flow rate would generate almost twice as much power on an annual basis, even though a smaller turbine is required. CHDSS Step 6 was not followed for this site, as there is already significant hydropower potential. In Phase 3 allowance will be made for future operation of the plant as the potential increases due to higher flow rates.



Table 8-27: Waterkloof Phase 2 potential analysis

DSS step	Description		Value	Unit	Source	
	Reservoir name		Waterkloof		IMQS	
4	Measured and calculated values	Optimum flow	0.192	m³/s	Measured	
		Pressure head	95.2	m		
		Power rating	125.5	kW	CHD Tool	
		Annual energy	506.1	MWh/a		
	Assurance of supply (% of time) (Figure 8-47)		N/A	%	N/A	
	Initial Design values	Design flow	0.192	m³/s	CHD Tool	
		Pressure head	95.2	m		
		Power rating	125.5	kW		
		Annual energy	506.1	MWh/a		
5	What operational changes could be considered?		The reservoir feeds one distribution zone, so consider constant flow			CHD Tool
4	Design values after operational change	Design flow	0.097	m³/s		
		Pressure head	126.1	m		
		Power rating (Figure 8-48)	83.8	kW		
		Annual energy (Figure 8-48)	720.3	MWh/a		
7	Selected turbine (Figure 8-49)		Pelton			
8	Electricity use		Grid-connected		Decided	
9	Distance from grid connection		0.08	km	Measured	
10	On-site power demand		N/A	kW	N/A	
	Power rating/max demand		N/A	%		



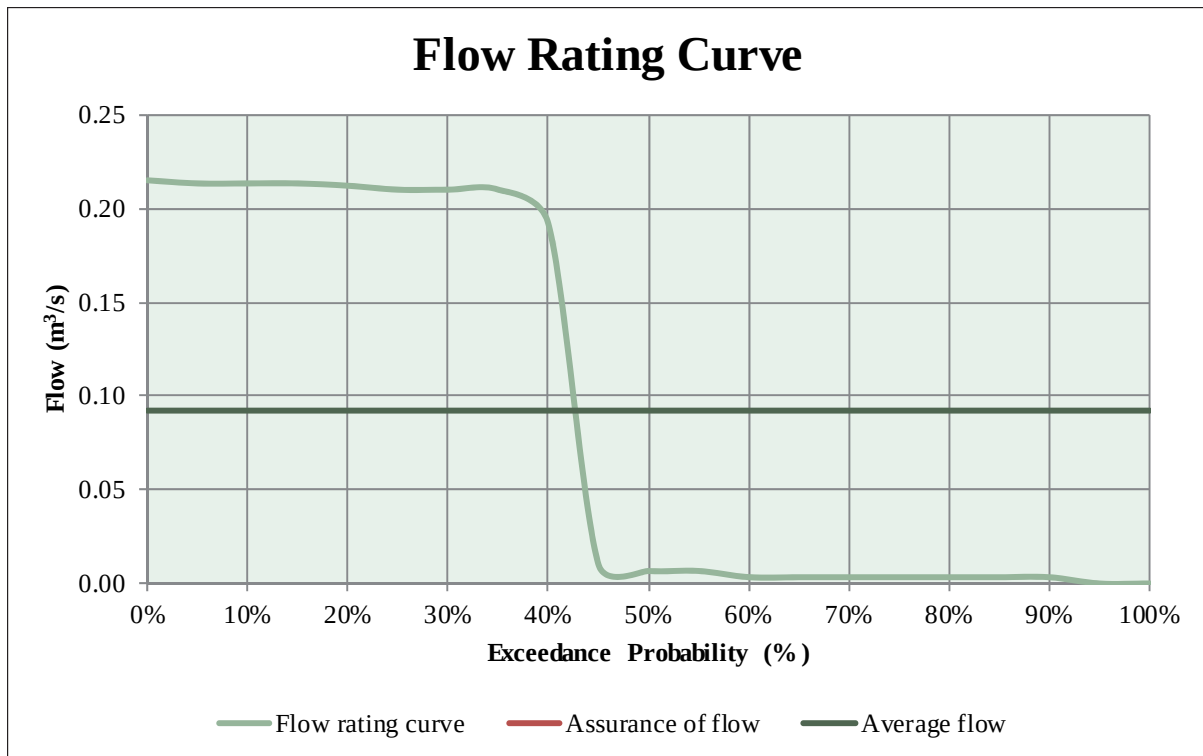


Figure 8-47: Waterkloof Phase 2 flow-rating curve

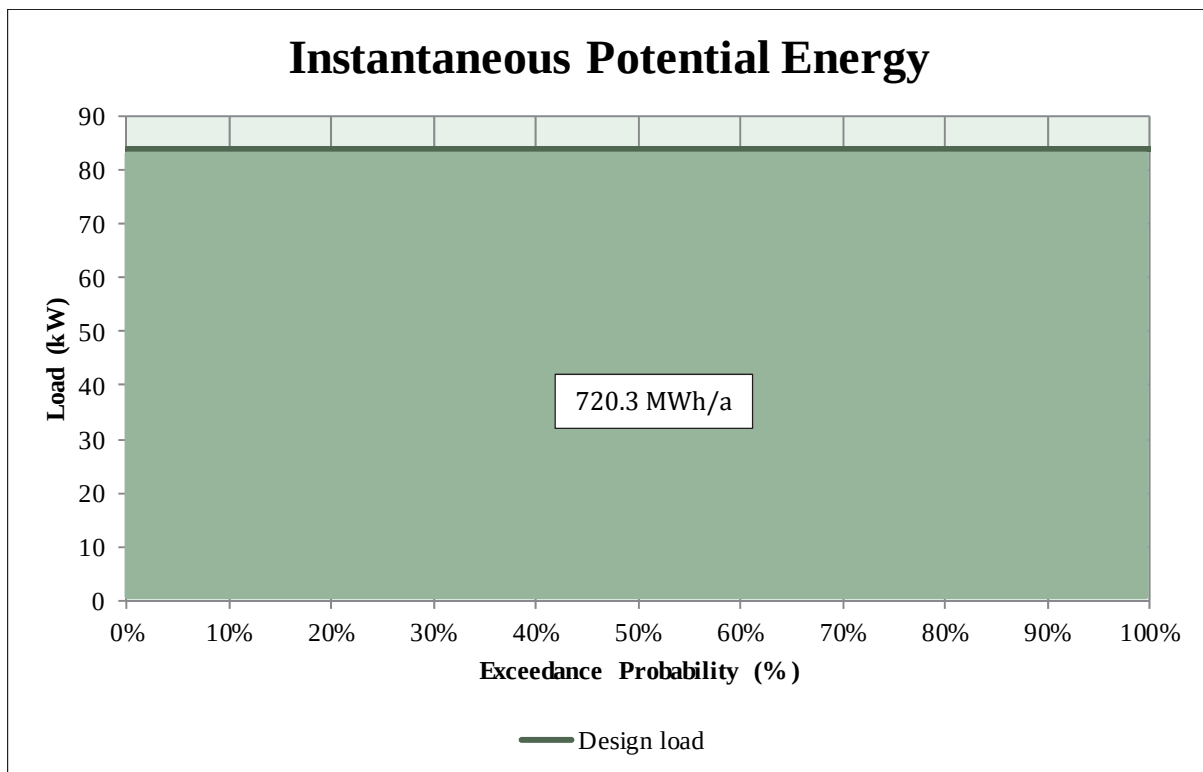


Figure 8-48: Waterkloof Phase 2 instantaneous potential energy

CHDSS Steps 11-14 deal with regulatory requirements. These steps are summarised in **Table 8-28**.



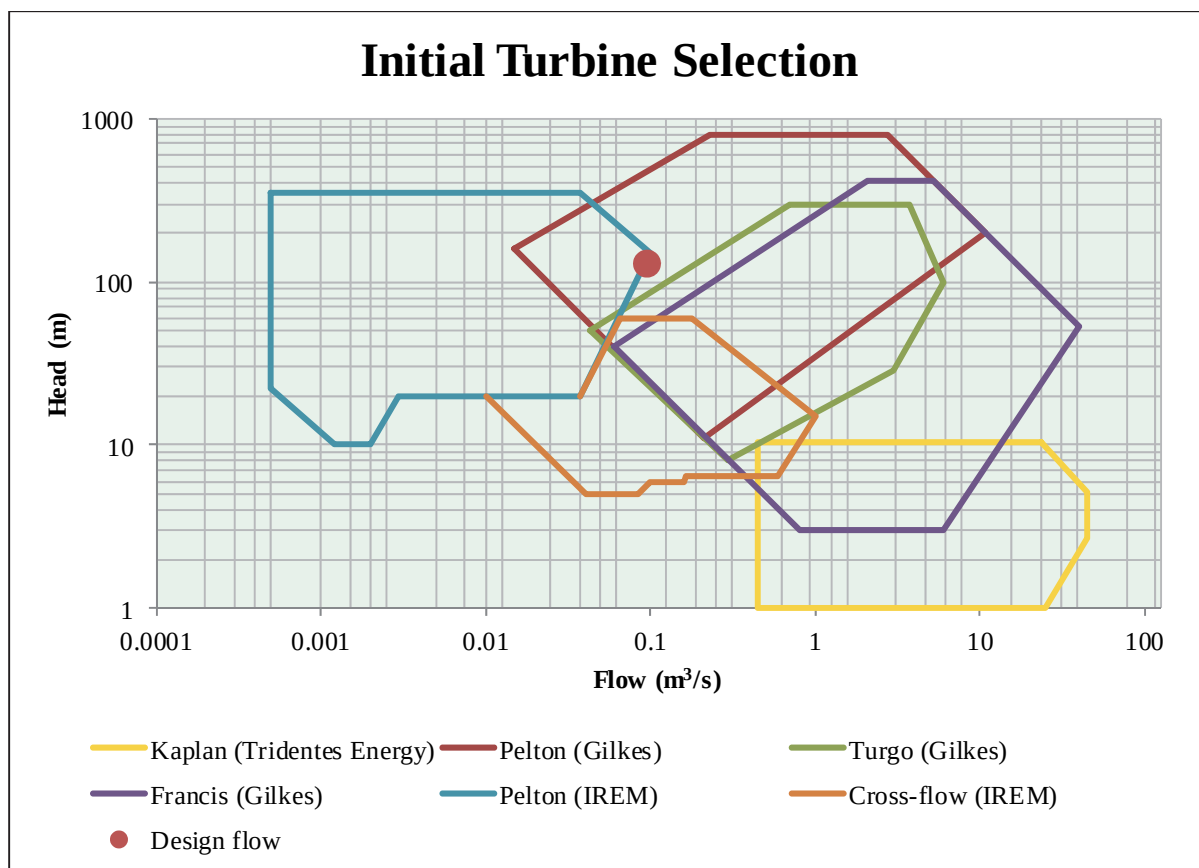


Figure 8-49: Waterkloof Phase 2 initial turbine-selection curve

Table 8-28: Waterkloof Phase 2 regulatory analysis

DSS step	Regulatory aspect	Discussion	Conclusion
11	Environmental studies	All power plant and construction areas are smaller than the minimum sizes for which environmental studies are required, according to the National Environmental Management Act (Act 107 of 1998)	Neither BA nor EIA required
12	NERSA licence	As the generated electricity would be used fed into the municipal grid and sold commercially, NERSA licensing would be required. An example of a generation application form included in Appendix B .	Generation licence required
13	Water-use licence	Water-use licensing would not have to be obtained, as this project can be seen as a continuation of an existing lawful use under Tshwane's water-use licence.	Not required
14	Social requirements	A public participation process (PPP) would have to be followed wherein a notice board, meeting the requirements set in Government Notice 543 of 18 June 2010, is displayed on the boundary fence. If complaints are received, public hearings should be held.	PPP required



The next step was to perform an economic evaluation for Phase 2. The CHD Tool was used, with default values and cost functions as discussed in **Appendix C. Table 8-29** was populated with the input and calculated values.

Table 8-29: Waterkloof Phase 2 economic analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Waterkloof		IMQS
4	Design values	Design flow	0.097	m ³ /s	Measured
		Pressure head	126	m	
		Power rating	83.8	kW	CHD Tool
		Annual energy potential	720	MWh/a	
7	Selected turbine		Pelton		
15	Planning cost per MW		1 350 000	R	Industry average
	Planning cost for this site		113 200	R	CHD Tool
	Turbine cost		992 100		
	Capital cost per MW (excluding turbine)		13 300 000	R	Industry average
	Total capital cost for this site (including turbine)		2 107 100	R	CHD Tool
	Annual operation and maintenance cost		39 100	R	
	Annual income		417 800	R	
	Design life		30	years	Decided
	NPV of costs		3 409 700	R	CHD Tool
	NPV of income		17 457 500	R	
	Total NPV		14 047 900	R	
	Internal rate of return		27.96	%	
	Payback period		7	years	

With an NPV of almost R15 000 000 and an IRR of 28%, without considering Eskom SOP tariffs, the Phase 2 economic analysis indicated that a detailed design was warranted. It should be noted that this phase indicated a significantly shorter payback period (6 years) compared to the value calculated in Phase 1 (14 years). The main reason for this is because operational changes to the system resulted in a better load factor (approximately 98% of time), allowing more electricity to be generated annually.



8.6.5 Phase 3 Analysis and Results

The Phase 2 economic analysis indicated financial feasibility. Therefore the Phase 3 analysis and detailed design was completed. The first step in this phase was to obtain historical flow and pressure records. Longer historical records (of a year or more) would be useful, as they would improve accuracy. However, as longer records were not available for this site, the same measured flow and pressure records were used as in Phase 2, for Step 2 of Phase 3.

The third step of this phase was to consider the effect of system optimisation. **Figure 8-50** shows the flow rates and corresponding pressures during a representative week in August 2012. From this figure it is clear that flow in the pipe is normally controlled at around 780 m³/h until the reservoir is full, at which stage the flow in the pipe becomes almost zero. **Figure 8-51** shows that hours with high power potential do not typically correlate well with hours of high electricity value (peak times). Therefore operational changes to ensure better correlation would produce higher income.

As the Waterkloof Reservoir serves only one distribution zone (as shown in **Figure 8-43**), the operational philosophy can be adjusted to obtain a more constant flow, with higher flow values at electricity peak times, all the while ensuring that the reservoir does not run dry. The potential analysis was therefore done for constant flow rates, as shown in **Table 8-30**.

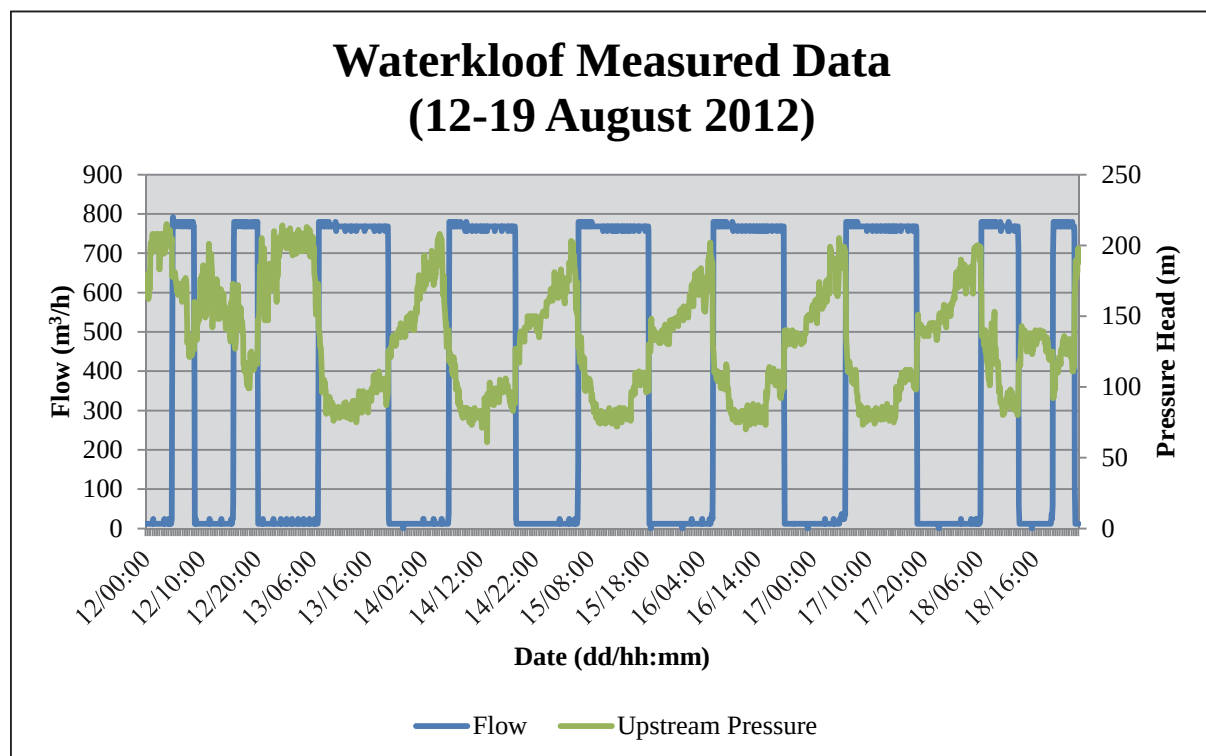


Figure 8-50: Waterkloof measured data for a typical week



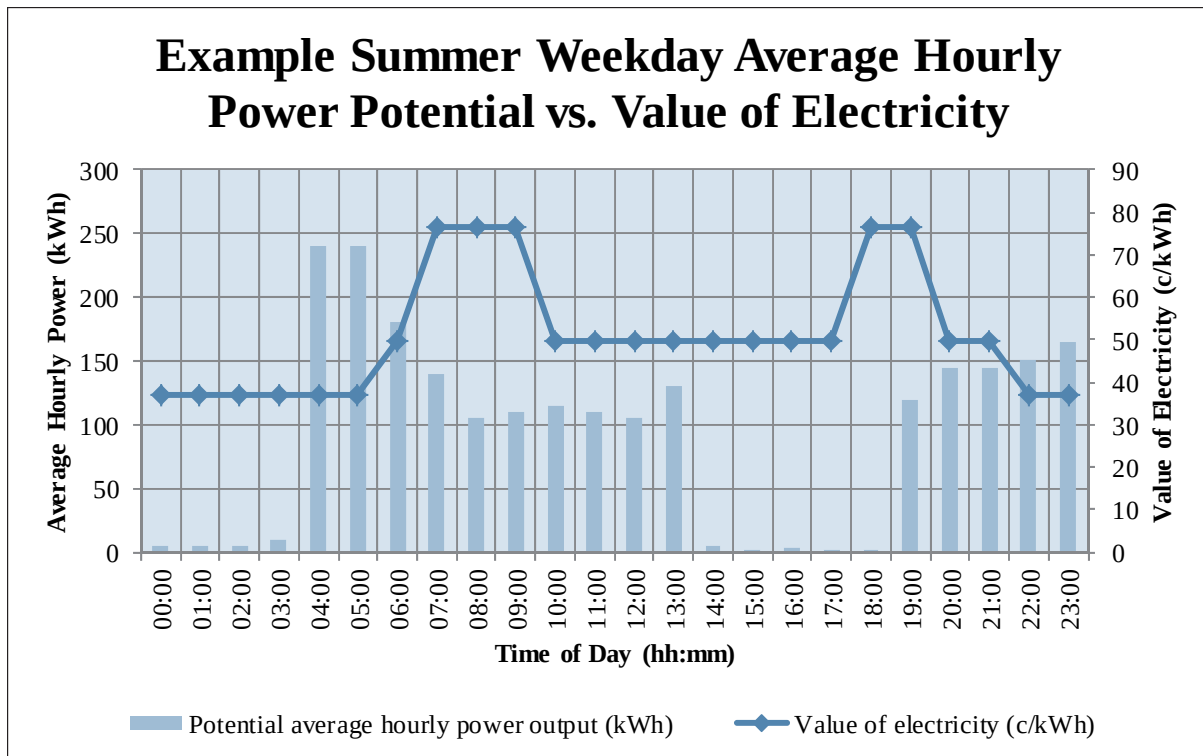


Figure 8-51: Waterkloof typical correlation between power potential and electricity tariffs

Based on information in the IMQS, the maximum future AADD at Waterkloof Reservoir will be approximately 12 000 kℓ/d, which is roughly 30% more than the current AADD of 9 000 kℓ/d. For this analysis it was assumed that operation with the current flow could be manipulated so that an above-average current flow (equal to the future average flow) could be maintained during peak energy tariff hours, with a slightly below-average flow in off-peak times (**Figure 8-52**). In this way a turbine with a capacity to match future flow rates can be installed now and future expansion would not be necessary. A flow range including the current and future average flows was therefore used, as seen in **Table 8-30** and **Figure 8-53**.



Table 8-30: Waterkloof Phase 3 potential analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Waterkloof		IMQS
3	Measured and calculated values	Current design flow	0.097	m ³ /s	Average of measured values
		Pressure head	126	m	
4		Power rating	98.2	kW	CHD Tool
		Annual energy potential	843.8	MWh/a	
5 (4)	Estimated future values	Estimated future design flow	0.126	m ³ /s	Described
		Pressure head	126	m	(Conservative)
		Power rating	130.9	kW	CHD Tool
		Annual energy potential	1124.9	MWh/a	
6	Required turbine range for current flow (Figure 8-52)		95-135	kW	CHD Tool
7	Selected turbine for current flow (Figure 8-53)		Gilkes Pelton		Product catalogue
8	Turbine efficiency for current flow		82	%	Product catalogue
6	Required turbine range for future flow		95-135	kW	CHD Tool
9	Additional turbines for future flow		None		Product catalogue
8	Turbine efficiency for future flow		84	%	Product catalogue
10	Electricity use		Grid-connected		
11	Distance from grid connection		0.08	km	Measured
12	Grid-connection requirements		HydroAID DVD		
14	Do supply-and-demand patterns correlate?		N/A		N/A
	Is there sufficient demand for the installation size?		N/A		



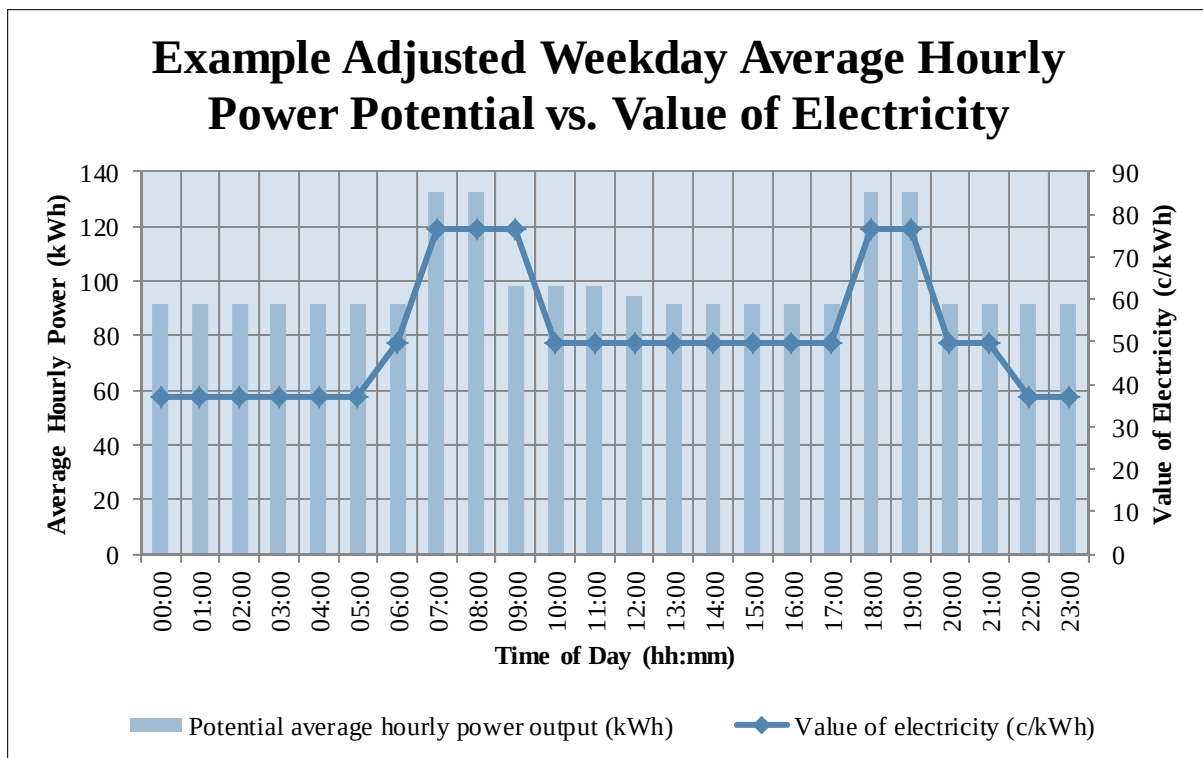


Figure 8-52: Waterkloof Phase 3 adjusted operation

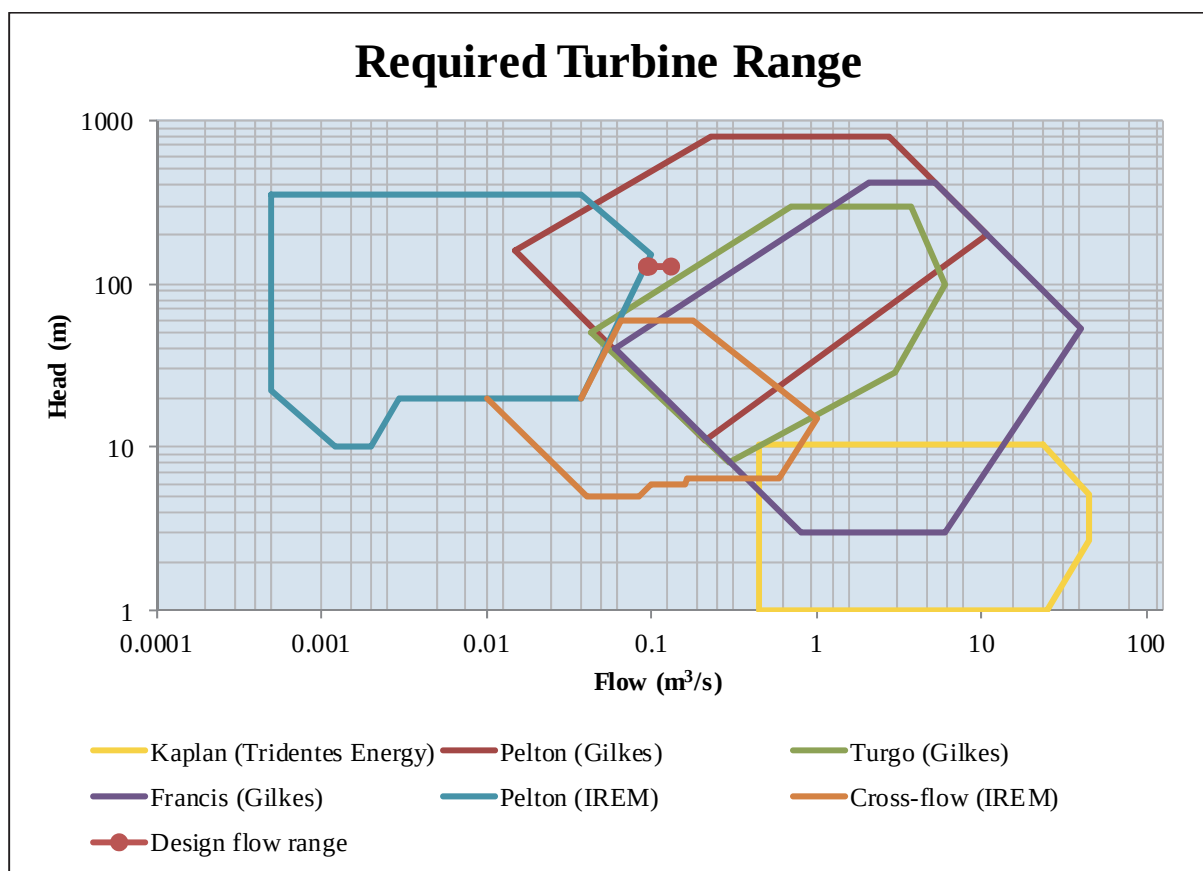


Figure 8-53: Waterkloof Phase 3 turbine selection



The next set of steps involved the detailed design of all the components of the conduit hydropower plant. Due to time constraints, a detailed design was not done for the Waterkloof development. However, a detailed design was done for the Pierre van Ryneveld Reservoir and can be seen in **Chapter 8.5.5**. A detailed economic evaluation was conducted with obtained costs, where applicable. The results can be seen in **Table 8-31**. The future flow scenario was applied from 2029 (15 years from project commencement). A sensitivity analysis was also conducted to determine the sensitivity of project feasibility when considering alternative inflation rates. The results of this analysis are summarised in **Table 8-32**.

Table 8-31: Waterkloof Phase 3 economic analysis

DSS step	Description		Value	Unit	Source
	Reservoir name		Waterkloof		IMQS
4	Design values	Design flow	0.09-0.126	m ³ /s	CHD Tool
		Pressure head	126	m	
		Power rating	91-133	kW	
		Current annual energy potential (future)	869 (1 147)	MWh/a	
6	Selected turbine		Gilkes Pelton		
19	Costs	Planning and design	235 000	R	Industry average
		Preliminary and general	80 000	R	
		Turbine	1 317 000	R	
		Other electrical and mechanical	300 000	R	
		Civil and construction	200 000	R	
		Transformer	352 000	R	
		Transmission	48 000	R	
		Contingencies	100 000	R	
		Disposal (present value)	0	R	
		Annual O&M (for year 1)	58 800	R	
	Annual income (for year 1)		520 800	R	Decided
	Annual income (for year 15, PV in year 1)		652 200	R	
	Design life		30	years	
	Total initial cost (planning and capital)		3 292 100	R	CHD Tool
	NPV of costs		5 080 200	R	
	NPV of income		24 451 000	R	
	Total NPV		19 370 700	R	
	Internal rate of return		24.81	%	



Step 21 of the CHDSS concerns funding of the project. Since this project has a projected capital expenditure of just over R3 000 000, no external funding is required and the municipality can source funds from their own internal budget.

A sensitivity analysis was done to determine the impact of different future inflation rates. The results are shown in **Table 8-32**, **Figure 8-54** and **Figure 8-55**. It is clear that the current uncertainty about future changes in the value of electricity is likely to cause a more significant impact on the net present value (NPV) of the project than operation and maintenance inflation, with an NPV of between R23 719 000 for high average electricity tariff inflation (12% from 2017 to 2027) and R13 160 000 for low average electricity tariff inflation (6% from 2017). The expected NPV is R19 371 000, as determined in the economic analysis. The internal rate of return (IRR) of the project was found to have a range of between 22.25% (for low electricity inflation) and 26.24% (for high electricity inflation).

It can therefore be assumed that this project should be feasible even if inflation rates are not as expected.

Table 8-32: Waterkloof Phase 3 sensitivity analysis summary

DSS step		Operation & maintenance			Value of generated electricity		
		High	Expected	Low	High	Expected	Low
22	Inflation	9%	6% avg	4%	12% from 2017 to 2027	8% avg	6% from 2017
	Total NPV	R18 307 200	R19 370 700	R19 818 500	R23 718 900	R19 370 700	R13 159 700
	IRR	24.46%	24.81%	24.99%	26.24%	24.81%	22.25%



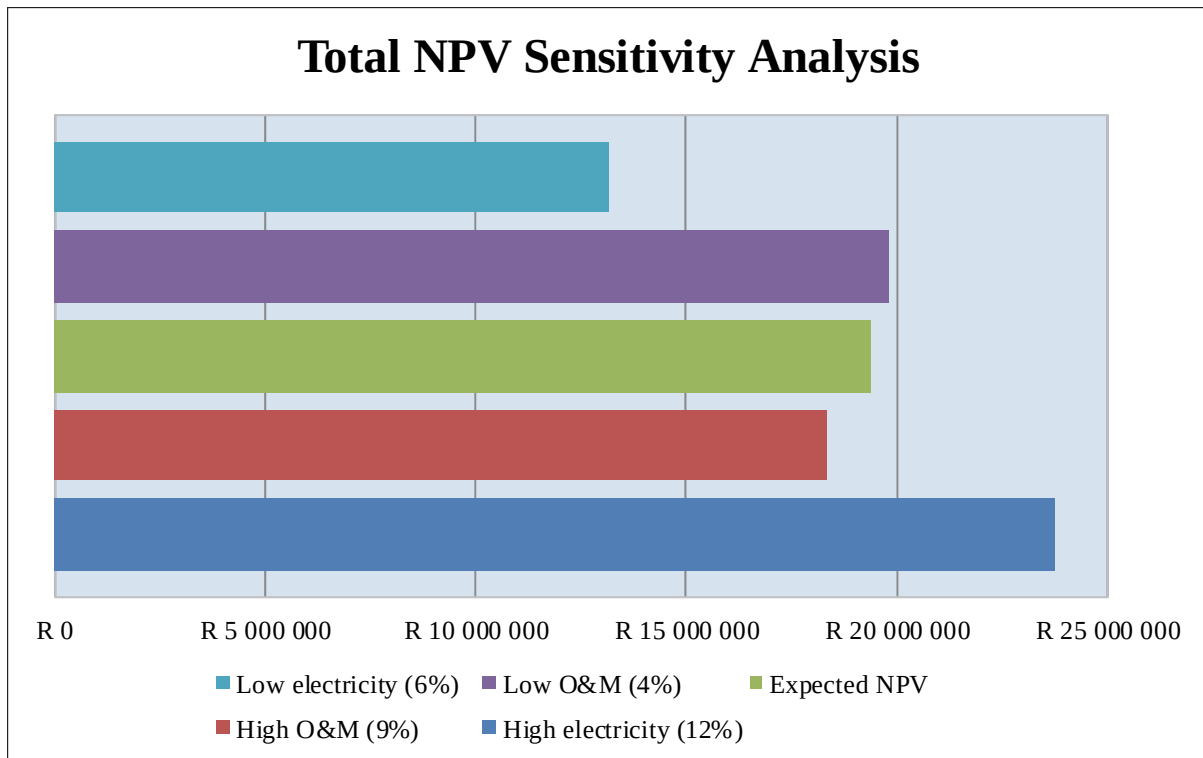


Figure 8-54: Waterkloof Phase 3 NPV sensitivity analysis

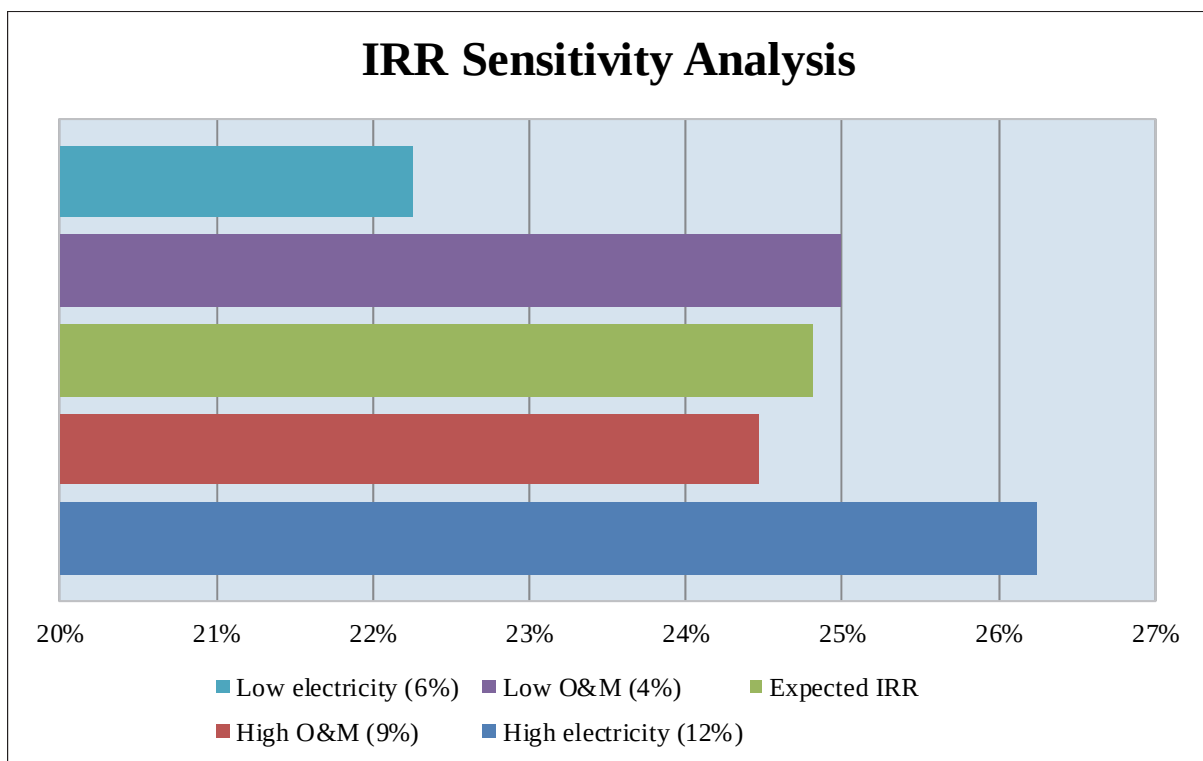


Figure 8-55: Waterkloof Phase 3 IRR sensitivity analysis



8.6.6 Discussion of Results

The analysis of hydropower at the Waterkloof Reservoir showed that there is economically exploitable potential at this site, especially if operational changes are made, as shown in **Figure 8-52**. It is proposed that a 135 kW grid-connected Gilkes Pelton (Figure 8-56) turbine be installed for current use, with operational changes made to accommodate average flow for future use.

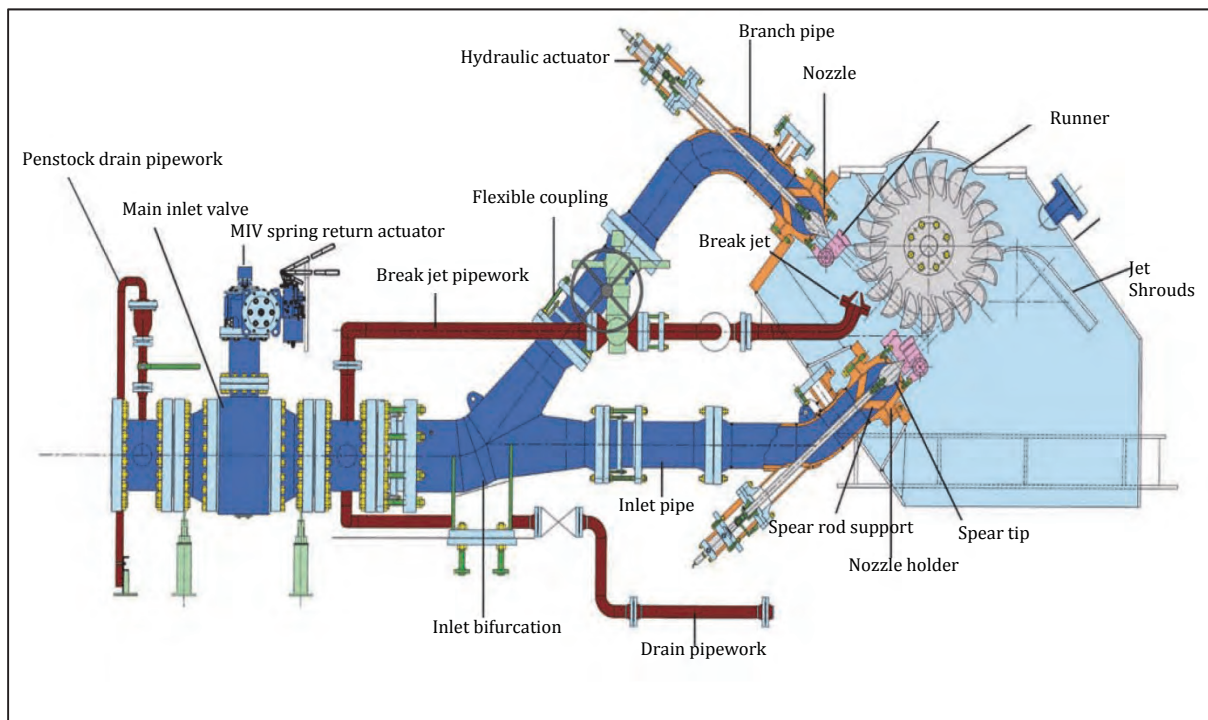


Figure 8-56: Typical Gilkes Pelton layout (Gilkes, 2012)

As an alternative a pelton turbine (TPA082) from IREM can be selected, see **Figure 8-57** using the selection chart as indicated in **Figure 8-58**.



Figure 8-57: Pelton turbine (IrREM, TPA082)



9. HYDRAULIC ANALYSES TO DETERMINE CONDUIT HYDROPOWER GENERATION POTENTIAL

9.1 Introduction

One of the main differences between conventional hydropower development and conduit hydropower development is in the hydraulic/hydrological analyses. Conventional hydropower development such as adding hydropower generating capacity to a dam or a run-off-river scheme requires an analysis of the hydrological aspects to determine the yield from the dam or the runoff in the river system. There is a hydraulic analysis component which focuses on the penstock. This is however in most cases a relatively short conduit dedicated to supplying the turbine.

In conduit hydropower development the focus is not on the hydrological analysis but rather on the hydraulic and dynamic analysis. The penstock could be much longer in length than what would typically be the case in conventional hydropower systems. The conduit could also have multiple off-takes or even be from different sources. This complicates the determination of the two most important parameters at the planned hydropower location i.e. available pressure head and flow rate. The variations/changes in these two parameters also occur much quicker which needs to be accommodated in the hydropower plant design.

It must also be remembered that the main aim is to supply water for domestic, industrial or agricultural use and that the energy generation opportunity is a secondary benefit which can be harnessed from the system.

The potential energy at the specific site must thus be meticulously calculated and if possible verified by means of actual pressure and flow measurements over a period of time.

9.2 Basic conduit flow theory

A conduit transports a fluid (in these cases water) from one point to another. In order to transport the fluid effectively, sufficient energy is required to maintain the flow. Furthermore, the pipeline system requires valves, bends, couplings etc. for system integrity and to regulate the flow. In a conduit system, the total head loss is a summation of the following loss components:

- ☺ The friction loss in the pipe itself (h_f);
- ☺ the entrance loss (h_{Le});
- ☺ the loss in bends (h_{Lb});
- ☺ the loss at discontinuities (h_{Ld});
- ☺ the loss at couplings (h_{Lc});



-  the loss due to biofilm growth (h_{fBio});
-  the loss associated with transitions where the diameter changes (h_{Lt});
-  the loss across valves (h_{Lv}), and
-  the exit loss (h_{Lx}).

The well-known friction factor and friction loss equation such as Colebrook White and Darcy-Weisbach makes provision to quantify the energy loss due to surface roughness and viscosity. The other losses in the system are defined as local or secondary losses and are caused by disruption in the boundary of the pipeline leading to eddy losses at these positions and is described with reference to the kinetic energy.

The contribution of the losses related to the growth of biofilm (h_{fBio}) has not been fully quantified and is currently not assessed in the design of pipelines. There are however examples where biofilm growth in penstocks has severely affected the hydropower generating capacity (Barton et al. 2008).

9.2.1 Friction losses in conduit flow systems

It was establish that the two main contributing factors to energy losses are:

-  Inherent resistance against flow exerted by the fluid (viscosity); and
-  The friction losses and secondary losses resulting from the inter-phase (shear) between the fluid and the stationary conduit boundary.

The distinction between **Laminar** and **Turbulent** flow is based on the value of the Reynolds Number which is a dimensionless parameter and is defined by:

$$Re = \frac{DV}{\nu} \quad \dots(9.1)$$

where:

- Re = Reynolds' number (dimensionless)
- D = Diameter (m)
- V = Velocity (m/s)
- ν = Kinematic viscosity ($1.14 \times 10^{-6} \text{ m}^2/\text{s}$ for water at 20°C)

For Re less than $\pm 2\,000$ the flow is **always laminar**, and for Re **greater than $\pm 4\,000$** **the flow is almost always fully turbulent**. The transition between $2\,000$ and $4\,000$ is either laminar or turbulent flow.

For turbulent flow in pipes which is the flow regime normally prevailing in pipelines, several relationships for the determination of the energy losses, h_f , could be used. For



conduit flow, the well-known **Darcy-Weisbach equation** (Equation 10.2) is commonly used to determine the energy loss.

$$h_f = \frac{\lambda LV^2}{2gD} \quad \dots(9.2)$$

where:

- h_f = Friction head loss in conduit (m)
- λ = Pipe friction factor (dimensionless)
- L = Length of conduit (m)
- V = Flow velocity of fluid inside conduit (m/s)
- g = Gravitational acceleration (m/s²)
- D = Internal diameter of conduit (m)

There is a change in the friction factor, (λ), as the Reynolds number varies. Equations relating lambda (λ) to both the Reynolds' number and the pipe roughness were developed (see **Table 9-1**).

Table 9-1: Friction formulae

	Name	Equation	Equation nr
1	Karman & Prandtl	$\frac{1}{\sqrt{\lambda}} = 2\log\left(\frac{Re\sqrt{\lambda}}{2.51}\right)$ for smooth pipes $\frac{1}{\sqrt{\lambda}} = 2\log\left(\frac{3.7D}{k_s}\right)$ for rough pipes	...(9.3)
2	Colebrook-White transition	$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{k_s}{3.7D} + \frac{2.51}{Re\sqrt{\lambda}}\right)$	...(9.4)
3	Barr	$\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{k_s}{3.7D} + \frac{2.51}{Re\sqrt{\lambda}}\right)$	...(9.5)
4	Moody	$\lambda = 0.0055 \left[1 + \left(\frac{200k_s}{D} + \frac{10^6}{Re} \right)^{1/3} \right]$	...(9.6)
5	Swamee, Jain	$\lambda = \left[-2\log\left(\frac{k_s}{3.7D} + \frac{5.74}{Re^{0.9}}\right) \right]^{-2}$	...(9.7)
6	Brkic	$\lambda = \left[-2\log\left(\frac{2.18\beta}{Re} + \frac{k_s}{3.71}\right) \right]^{-2}$ $\beta = \ln \left[\frac{Re}{1.816 \ln \left(\frac{1.1Re}{\ln(1 + 1.1Re)} \right)} \right]$	...(9.8)



Where:

- k_s = Absolute pipe roughness (m)
- L = Length of conduit (m)
- V = Flow velocity of fluid inside conduit (m/s)
- g = Gravitational acceleration (m/s²)
- D = Internal diameter of conduit (m)
- Re = Reynolds' number (dimensionless)
- λ = Pipe friction factor (dimensionless)

There are a number of factors which will influence the roughness of the pipe such as pipe material, age, water quality, operational performance etc.

9.2.2 Secondary/Local head losses in closed conduit flow

Energy losses, according to Chadwick et al. (2004), are always encountered at junctions, valves; pipe bends etc. in addition to those due to friction. Eddy formation generated in the fluid at the fitting causes these local head losses. The local losses may be insignificant in the case of long pipelines (e.g. several kilometres), but may be greater than the frictional losses in short pipelines. The local head losses can be determined with the formulae listed in **Table 9-2**.

Table 9-2: Secondary/local losses

	Description	Equation	Equation nr
1	Entrance losses	$h_{Le} = \frac{k_e V^2}{2g}$	...(9.9)
2	Wherever there is a bend in a pipeline, an increase in head loss will occur due to the additional turbulence.	$h_{Lb} = \frac{k_b V^2}{2g}$	...(9.10)
3	The head loss in a valve depends on the type of valve, while the manufacturer generally provides the head loss coefficient	$h_{Lv} = \frac{k_v V^2}{2g}$	...(9.11)
4	The head loss at a discontinuity such as an air valve, T-piece or scour valve off-take.	$h_{Ld} = \frac{k_d V^2}{2g}$	...(9.12)
5	The head loss at couplings , for example PVC pipes with spigot and socket connections.	$h_{Lc} = \frac{k_c V^2}{2g}$	...(9.13)
6	The head loss associated with transitions (change in diameter)	$h_{Lt} = \frac{k_t V^2}{2g}$	...(9.14)
7	Exit losses	$h_{Lx} = \frac{k_x V^2}{2g}$	...(9.15)



Where:

- h_{Le} = The local head loss at the entrance to the conduit (m)
- h_{Lb} = The local head loss at the bend (m)
- h_{Lv} = The local head loss at the valve (m)
- h_{Ld} = The local head loss at a discontinuity (m)
- h_{Lc} = The local head loss due to couplings (m)
- h_{Lt} = The local head loss at transitions (m)
- h_{Lx} = The local head loss at the exit (m)
- k_e = Coefficient of entrance loss which is a function of the shape of the entrance to the conduit
- k_b = A function of deviation at the bend
- k_v = Dependent on the valve type and obstruction caused
- k_d = Dependent on the size of the discontinuity
- k_c = Dependent on the pipe lengths and type of coupling
- k_t = Dependent on the area ratio change and length of transition
- k_x = Coefficient of 1.0 for a pipe discharging water from the system
- V = Velocity (m/s)
- g = Gravitational acceleration (m/s^2)

The total secondary loss in a pipe system is calculated by the summation of all these local head losses due to bends, valves etc. as shown in **Equation 9.16**.

$$h_L = \sum \frac{k_i V_i^2}{2g} \quad \dots(9.16)$$

Where:

- h_L = The total local head loss (m)
- k_i = Secondary loss coefficient at position i
- V_i = Velocity at position i (m/s)
- g = Gravitational acceleration (m/s^2)

9.3 Hydraulic analyses to determine hydropower generation potential

As indicated determining of the pressure head flow relationship at a specific location could be intricate. For this reason it is recommended that hydraulic modelling with software programs such as EPANET be performed. This will allow extended period simulation of the hydraulic behaviour within a pressurized pipe network which is typically where there might be conduit hydropower potential. EPANET which is a freeware software program has been used by various researchers in the field of



hydropower assessment. Möderl, et al. (2012) used it to identify hydropower potential in water distribution systems in the Alpine regions.

A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

Running under Windows, EPANET, as shown in **Figure 9-1**, provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. These include colour-coded network maps, data tables, time series graphs, and contour plots.

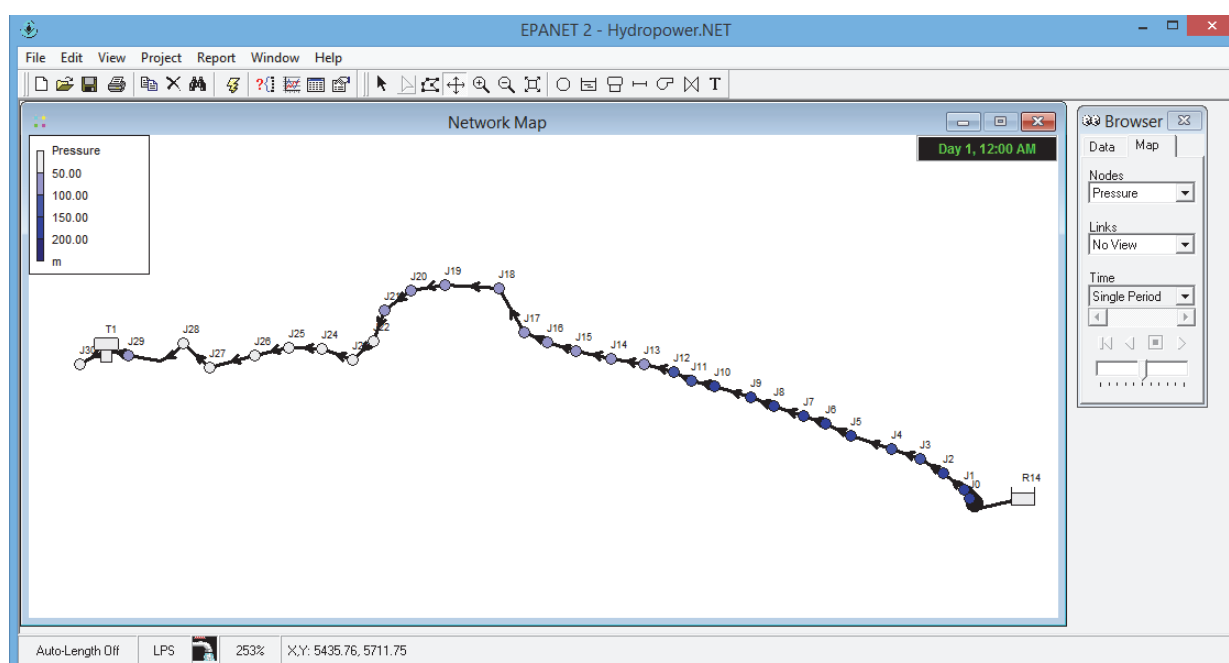


Figure 9-1: EPANET used water supply modelling

One typically carries out the following steps when using EPANET to model a water supply system with hydropower potential:

1. Draw a network representation of the distribution system
2. Edit the properties of the objects that make up the system
3. Describe how the system is operated (curves, time patterns and controls)
4. Describe the hydropower facility (head loss curve)
5. Select a set of analysis options
6. Run a hydraulic analysis
7. View the results of the analysis



This is a very handy tool to assist in the assessment of the conduit hydropower potential in the water distribution network.

9.4 Examples of EPANET and hydropower generation modelling

Trashlieva and Puleva (2010), used the EPANET software for the optimal control for daily scheduling of combined turbo and hydro power generation.

Giugni, Fontana and Portolano (2009) used EPANET for modelling an Energy saving policy in water distribution networks. The opportunity to combine water saving with current renewable energy policies, pointed out the chance of replacing (in part or at all) PRVs with turbines or pumps as turbines (PATs).

Turbine fitting in water networks is an unusual application requiring preliminary analysis to guarantee: optimal choice of the turbine; sufficient network pressure; suitable sanitary conditions; protection against potential pipes damage due to water hammer effects. In particular, water hammer effects should be evaluated in normal operating conditions and in specific states as starting and electric shedding, in order to protect distribution system with adequate devices.

Vieira and Ramos (2008) modelled the optimization of operational planning for wind/hydro hybrid water supply systems using EPANET as one of the modelling tools. Their research presented a model for optimization of the energy efficiency in a water supply system. The system is equipped with a pump station and presents excess of available energy in the gravity branch. First, a water turbine is introduced in the system in order to use this excess of hydraulic available energy. Then, an optimization method to define the pump operation planning along the 24 h of simulation, as well as the analysis of the economic benefits resulting from the profit of wind energy to supply the water pumping, while satisfying the system constraints and population demands, is implemented, in order to minimize the global operational costs. The rules obtained as output of the optimization procedures are subsequently introduced in a hydraulic simulator (e.g. EPANET), in order to verify the system behaviour along the simulation period. The results indicated that the insertion of the water turbine generates significant economical benefits for the water supply system.

The optimization of operations energy consumer or production systems has been investigated for some decades. The interest in this area is not only related to the complexity of the problem but mainly by the environmental, economical and social benefits by adopting this type of solution. The implementation of energy production components in water supply systems is a solution that intends to increase the energy efficiency by using local available renewable resources. With this kind of systems the external energy dependence and their costs can be reduced. The adaptation of water



supply systems to produce energy is an advantageous solution because most of the system components already exist (e.g. reservoirs, pipe system, valves) and there is a guaranteed discharge continuous flow along each day (Ramos, 2012).

An example of a discretized optimization model for the determination of operational planning in a wind pumped-hydro system is described by Ramos (2012). It is a real WDS, the “Multi-purposes Socorridos system” located in Madeira Island, Portugal, **Figure 9-2**. This system was designed to supply water to Funchal, Câmara de Lobos and Santa Quitéria, as well as to regularize the irrigation flows and produce electric energy.

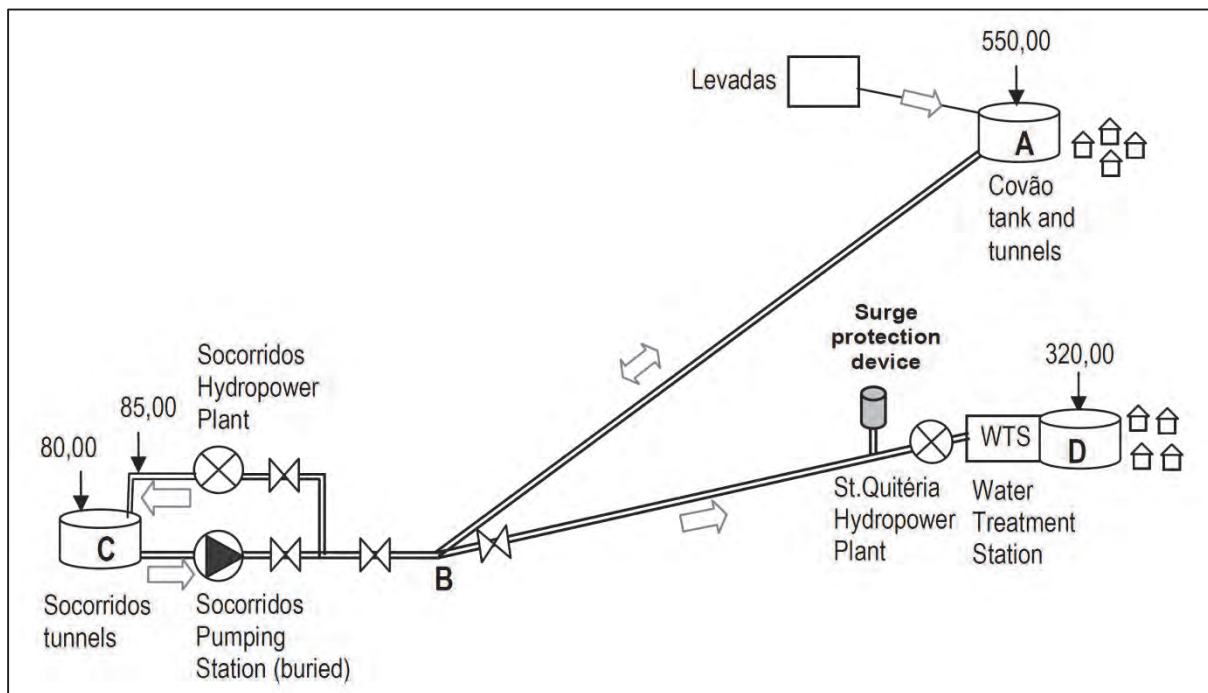


Figure 9-2: Example water supply and hydropower generation system (Ramos, 2012)

This pumping station was designed to pump 40000 m³ of water stored in Socorridos reservoir during 6 h, for the electricity low peak hours (from 0 to 6 am). In the remaining hours of the day, the water is discharged from Covão reservoir to Socorridos hydropower station, in reverse flow direction, in order to produce energy. By the end of the day, the total volume of water in the system is in Socorridos reservoir. Ramos(2012) developed an integrated software tool for determining the optimum pump and turbine schedules and reservoirs water levels, that minimize pumping costs (i.e., maximize off-peak electrical energy consumption) and maximize energy production. This tool incorporates a ‘hydraulic simulator’ that describes the hydraulic behaviour of the system during 24 hour simulation (EPANET), and an ‘optimization solver’ based on Linear and Non-linear programming to determine the optimal solution without violating system constraints (e.g., minimum and maximum allowable water levels in the storage reservoirs) and ensuring that downstream demands are satisfied.



9.5 Optimization of Hydropower Generation Potential in Conduits

An optimization methodology have been developed for maximizing the hydropower generation potential from a WDS containing multiple hydropower generation locations.

9.5.1 Problem Formulation

The difficulty of optimising water distribution systems is mainly due to the discrete nature of the variables and the size of the solution space. A major problem for water supply authorities is to select those components in a network that should be changed, increased or replaced to ensure a sustainable service to the consumers at the lowest cost. Water supply authorities are also faced with problems other than that of network design such as network calibration, operation and reliability. For each type of optimisation, the main objective function, possible variables and the main constraints are summarised in **Table 9-3**.

Table 9-3: Types of optimisation for water supply/distribution systems (Adapted from Van Dijk et al., 2008)

Optimisation type	Objective	Possible variables	Main constraints
Design	Minimise cost	Pipe layout; Pipe diameters; Pipe rehabilitation	Min level of service; Available diameters; Rehabilitation options; Available budget; LCC
Operation	Minimise operational cost	Pump controls; Reservoir levels; Sources and capacity	Min level of service; Number of pump switches; Source capacity; Pump capacity.
Calibration	Minimise difference between model and observed values	Pipe roughness; Pipe diameter; Valve settings; Leakage; Demands	System layout; Available data.
Level-of-service	Maximise level of service, e.g. pressure, water quality or reliability	All above	System configuration; Budget.
Monitoring system design	Minimise cost of monitoring system	Number and position of monitoring points	System configuration; Budget.
Utilization of excess head for hydropower generation	Maximize energy generation potential	Turbine selection; Reservoir levels; Sources and capacity	Acceptable operating risk levels; Hydraulic operating range; Source capacity; Turbine capacity; LCC



A water supply distribution system consists of a complex network of interconnected pipes, service reservoirs and pumps that deliver water from the treatment plant to a consumer. The distribution of water through the supply system is governed by complex, non-linear, non-convex and discontinuous hydraulic equations (Keedwell and Khu, 2005). Adding to this complex network, the hydropower plant from which the maximum benefit needs to be extracted requires a systematic procedure to evaluate the interrelationship between: storage volumes, supply/demand patterns, turbine selection, operational flexibility and reliability of supply. The procedure is a multi-objective genetic algorithm, maximizing electricity generation and hence revenue and minimizing the risk of non-supply.

9.5.2 Formulation of optimization algorithm

The objective function of the optimization model is to maximize the net annual income from the hydropower generation system whilst still operating the water supply system within acceptable reliability regimes. Numerous new optimization algorithms have been described in power engineering literature. Most of these heuristic approaches rely on innovative search techniques, drawn from biological and physical processes (Harpman, 2012). In the formulation of the optimization algorithm natural or logical constraints need to be identified. The identification of these constraints is site specific and in some cases requires the assessment of:

- 🔍 Dynamic analysis to determine safe operating conditions (maximum velocity, pressure ranges)
- 🔍 Hydraulic assessment (physical pressure and flow measurements are required to back calculate pipe roughness)
- 🔍 Quantification of acceptable reservoir levels (could be based on proposed location of hydropower plant in relation to other storage facilities)
- 🔍 Analyses of the source to determine historical supply characteristics and constraints

One approach to characterize constraints in a constrained mathematical optimization problem is to penalize solution results which violate a constraint. For example too high velocities could increase the potential impact of surges in the pipeline and thus affect the pipe integrity. The heuristic optimization approach that was followed applies rules and logic which results in a reduction in search space and allows for the solution of difficult optimization problems. The proposed genetic algorithm used here falls in the evolutionary algorithm class.

GAs have been applied as search techniques for various engineering problems such as structural design optimization, water distribution network evaluation, network calibration, pump scheduling, hydrological runoff predictions and resource utilization.



According to Michalewicz (1994), GAs can basically be described as artificial evolution search methods based on the theories of natural selection and mechanisms of population genetics. GAs emulate nature's optimization technique of evolution, based on:

- 🔍 survival and reproduction of the fittest members of the population;
- 🔍 the maintenance of a population with diverse members;
- 🔍 the inheritance of genetic information from parents; and
- 🔍 the occasional mutation of genes.

A GA evolves optimal solutions by sampling from the total solution space. The best of these solutions are then combined, using the genetic operators of crossover and mutation, to form new solutions. The identification of these best solutions is done based on a set of objective functions. This process continues until some termination condition is fulfilled. A flow diagram of the basic GA process is given in **Figure 9-3**.

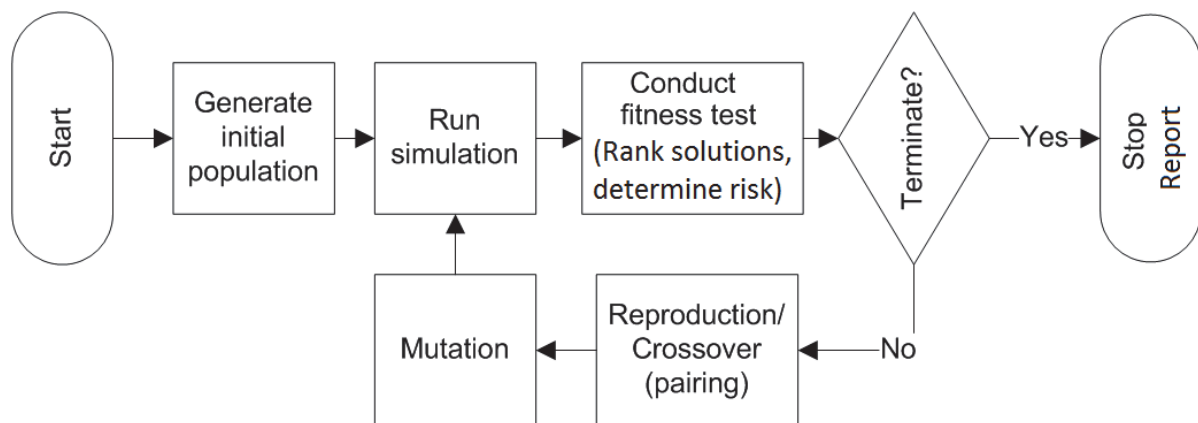


Figure 9-3: Basic genetic algorithm process

Recruitment is the process of determining which individuals from the population will survive into the next generation. Although there are numerous approaches the simplest approach was followed whereby the population was ranked based on their fitness values (generated electricity, including penalty constraints) and the elitist status i.e. the higher the fitness values the higher the probability of being selected for reproduction. Harpman (2012) describes that the tournament selection approach is preferred in identifying the parents in the reproduction process of Real Coded Genetic Algorithms (RCGA). In the tournament selection approach two individuals are chosen at random from the population. The one with the greatest fitness is selected as a parent and a “partner” is selected in a similar way. There is however little evidence for selecting a particular scheme for the crossover and mutation approaches (Harpman, 2012). In this research the reproduction scheme was selected where two parents produced two offspring and parental traits are conveyed to the offspring via the crossover procedure, inter-mingling their genes. A small probability of mutation was selected to ensure the diversity of the solutions.



One objective is to maximize generation output from the CHP over an operating period according to typical historical supply and demand patterns, graphically depicted in **Figure 9-4**, similar to system scheduling proposed by Cheng (2008). The objective function to be maximized can be written as (Equation 9.17):

$$F_j = \max \sum_{t=1}^T (\rho g H_{t,j} Q_{t,j} \eta_{t,j} C_{t,j}) \quad \dots(9.17)$$

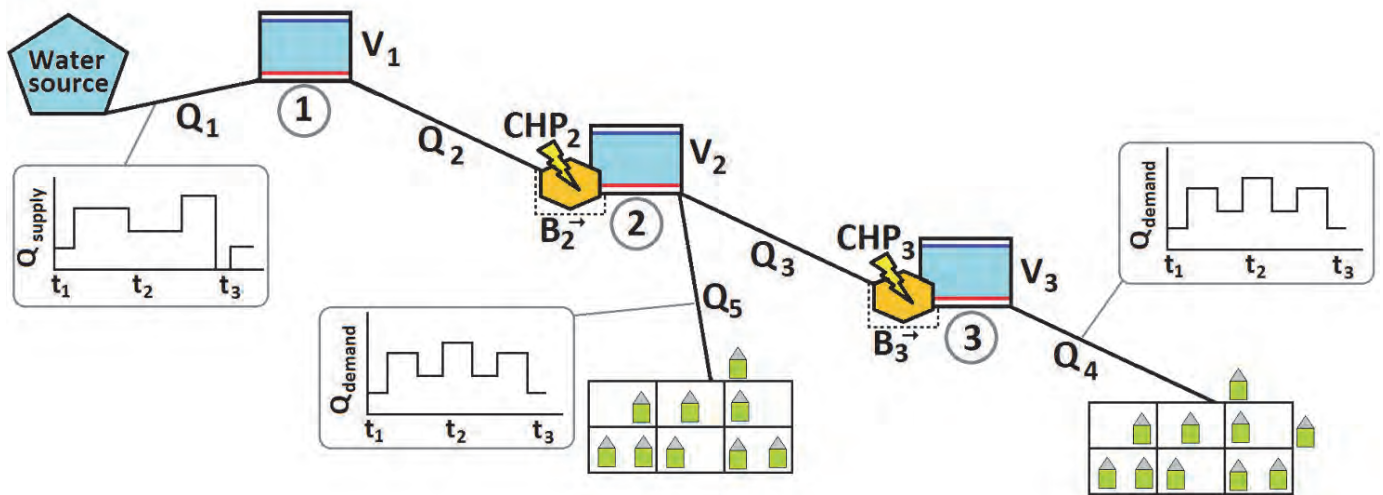


Figure 9-4: Layout of CHP series connected system

Subject to the following constraints (Equations 9.18 to 9.22)

Reservoir storage limits

$$V_{t,j,min} \leq V_{t,j} \leq V_{t,j,max} \quad \dots(9.18)$$

Pipe system discharge limits

$$Q_{t,j,min} \leq Q_{t,j} \leq Q_{t,j,max} \quad \dots(9.19)$$

Hydropower station power generation limits

$$N_{j,min} \leq \rho g H_{t,j} Q_{h,t,j} \eta_{t,j} \leq N_{j,max} \quad \dots(9.20)$$

Hydropower station discharge limits

$$Q_{h,t,j,min} + Q_{b,t,j,min} \leq Q_{t,j} \leq Q_{h,t,j,max} + Q_{b,t,j,max} \quad \dots(9.21)$$



Water balance equation

$$V_{t+1,j} = V_{t,j} + (Q_{h,t,j} + Q_{b,t,j})\Delta t \quad \dots(9.22)$$

Where

F	= objective function (cost unit)
T	= total period count within a week, T = 672 (every 15 minutes)
Q_t	= average water discharge in pipe system (m^3/s)
Q_h	= average water discharge through turbine (m^3/s)
Q_b	= average water discharge through bypass (m^3/s)
H_t	= average head at time period t (m)
ρ	= density of water (kg/m^3)
g	= gravitational acceleration (m/s^2)
Δt	= time step (s)
η_t	= hydropower plant efficiency at time period t (%)
V_t	= volume of reservoir storage at the beginning of period t (m^3)
C_t	= energy tariff at time period t (unit cost/kW)
$Q_{t,\max}$	= maximum water discharge capacity of pipe system (m^3/s)
$Q_{t,\min}$	= minimum water discharge capacity of pipe system (m^3/s)
$Q_{h,t,\max}$	= maximum water discharge capacity of hydropower plant (m^3/s)
$Q_{h,t,\min}$	= minimum water discharge capacity of hydropower plant (m^3/s)
$Q_{b,t,\max}$	= maximum water discharge capacity of bypass (m^3/s)
$Q_{b,t,\min}$	= minimum water discharge capacity of bypass (m^3/s)
$V_{t,\max}$	= maximum volume of reservoir storage (m^3)
$V_{t,\min}$	= minimum volume of reservoir storage (m^3)
$N_{\max}$	= maximum installed plant capacity (kW)
$N_{\min}$	= hydro power minimum power generation constraint (kW)

The subscript “j” refers to each hydropower plant in the interconnected system.

The multi-objective problem has the objective of maximizing energy generation and maximizes the reliability of supply.

To solve a multi-objective optimization problem, one option is to convert the problem into a single objective optimization problem, by using adjustments, such as a weighted sum of objectives, or an ϵ -constraint method. The weighted sum approach gives a certain weight to the different objectives, and then factors in all these weights to form a single objective function that can be solved by single objective optimization. This method has its limitations because it is almost impossible to qualify the weights.

Another approach is termed the constraint method in which one chooses the objective function as the single objective, and the other objective functions are treated as constraints with a limited range for their values. The optimal solution depends on the selection of the pre-defined constraint limits.



The multi-objective optimization problem described in this paper involves computing the trade-off between the generated income and potential impact on reliability of the system. A set of solutions can be determined varying certain parameters i.e. a sensitivity analysis. There is however no single optimal solution that will satisfy the global optimality of both objectives. As both objectives are to some extent contradictory, it is not possible to improve one objective without sacrificing the other. This optimization problem can best be adjudicated by setting up a Pareto-optimal trade-off curve between the potential generated income and reliability of the bulk supply system, and choosing the best combination.

The second objective function is to minimize the risk of non-supply i.e. the associated risk when reservoir levels are low, or operating scenarios which could compromise the integrity of the supply system. This can also be described as maximizing the reliability of the supply system.

In general bulk water supply systems are designed based on deterministic guidelines. Many systems have some redundancy since the system design capacity was set to supply the ultimate demand at the end of the design life. The uncertainties during the design phase of the pipe roughness decay parameter and future demands, leads to the adoption of a conservative design. Due to this conservative design approach a number of bulk supply systems have excess capacity or excess storage available. This allows for optimizing of the energy generating potential at a site but will influence the reliability. According to Chang and Van Zyl (2012) various authors have analysed the reliability of bulk water supply systems using frequency durations, Markov chains and Monte Carlo approaches. Hokstad et.al (2009) indicated that the main steps to complete a risk analysis are:

- 🔍 Scope/analysis objective;
- 🔍 System description;
- 🔍 Identification of hazards and hazardous events; and
- 🔍 Estimation of risk (probabilities and consequences).

A Coarse Risk Analysis (CRA) is proposed presented as a risk matrix. This is a simple analysis method which should be able to be carried out by most water utilities. In the risk analysis the impact of the incorporation of the hydropower plants in the water supply system is defined. This is done by estimating the frequency of hazardous events and the various consequences of these events.

The risk evaluation is where the risk acceptance criterion is defined and in some cases how certain risks above acceptance criteria should be treated (Hokstad et.al, 2009). A risk matrix identifying the hazardous events (in this case operational activities) which could result in non-delivery of water is set-up (**Table 9-4**).



Table 9-4: Example of risk matrix (Hokstad, et.al, 2009)

Likelihood	Severity of consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	5	6	7	8	9
Likely	4	5	6	7	8
Moderately likely	3	4	5	6	7
Unlikely	2	3	4	5	6
Rare	1	2	3	4	5

The definitions of likelihood (probability) and severity (consequence) categories is defined which allows risk scoring of hazardous events. Using average unavailability of supply may not always be sufficient and thus both the frequency and durations of an interruption is considered. Some examples of risk quantification extents are:

- ☒ Probability (fraction of time) that supply cannot be met due to low reservoir level.
- ☒ Frequency of events resulting in failure to supply water due to, for instance, pipe bursts.
- ☒ Volume of water shortage due to demand exceeding supply and low reservoir levels.
- ☒ Time required re-filling pipeline after reservoir “run-dry”.
- ☒ Potential dynamic pressures when operating above design capacity.

Each risk should be assessed as well as the probability of the risk occurring against the impact it has on the water utilities main responsibility i.e. supplying water. A major problem in performing of risk analyses is the lack of relevant data for example the pipe burst frequency. Ideally water utilities should design their own database and record undesired events with causes and consequences in order to estimate failure probabilities.

Each probability and consequence is given a numeric value (scoring). The Probability (P) multiplied by its qualified Consequence or impact value (I) will result in a Risk Value (R).

The following Equation 10.23 details this analysis:

$$R_i = \sum_{i=1}^T (\alpha_{t,i} \beta_{t,i} P_{t,i} I_{t,i}) \quad \dots(9.23)$$

Where the risk evaluation (acceptance criterion) is defined and for some components how certain risks above the adopted acceptance criteria should be treated (Equations 9.24 and 9.25):



Reservoir operating risk evaluation

$$\alpha_{t,i} = f(P_{t,i}I_{t,i}) \text{ range 0 to 1} \quad \dots(9.24)$$

The consequence of operating reservoir at a certain water level is not static and is dependent on time of day/demand pattern.

Pipeline operating risk evaluation

$$\beta_{t,i} = f(P_{t,i}I_{t,i}) \text{ range 0 to 1} \quad \dots(9.25)$$

The consequence of operating pipeline in a specific manner is not inert.

Where

- T = total period count for a week, T = 672 (every 15 minutes)
- R_i = risk value for each component in pipeline system which could have impact on reliability and needs to be assessed
- I_i = impact factor (consequence)
- P_i = probability (%)
- α = coefficient to incorporate variation in operating risk at reservoirs (risk quantification, default is 0)
- β = coefficient to incorporate variation in operating risk for pipe system (risk quantification, default is 0)

9.5.2.1 Model input parameters

The model parameters required to adequately optimize the operational functioning of the CHP, meeting the objective functions is provided in **Table 9-5**.



Table 9-5: Model input parameters

Input parameter		Value
Supply	Historical flows (ranges)	Maximum, minimum and average
	Supply patterns	15 minute intervals (linked to AADD)
Demand	Historical demands (ranges)	Maximum, minimum and average
	Demand patterns	15 minute intervals (linked to AADD)
Pipeline supply characteristics	Diameter	Diameter of pipe sections
	Pipe roughness	Absolute roughness of pipe sections (assessed)
	Pipeline decay function	Estimated (or historical information)
	Valves	Required for secondary loss calculations
	Bends – secondary loss coefficient	Required for secondary loss calculations
	Age of infrastructure	Age in years
	Design life	Design life in years
Reservoir details	Volume	Total volume of storage facility in Ml
	Area depth relationship	Relationship of reservoir depth versus surface area
Pressure control/reducing station	Layout	Setup of PRS
	Pressure reducing valves	Size, type, number of
	PRV settings	Current settings
	Bypass flow	Range of flows bypassing turbine
Turbine selection	Capacity	Flow and head
	Operating range (Q,H)	Operating range of turbine/generator unit
	Efficiency	Efficiency curve
Energy tariff structure	Hourly energy tariffs	Hourly tariffs for specified time periods (see Figure 9-5 , ESKOM defined time periods used in South Africa)
	Demand period	High (Jun to Aug) or low demand season.
Risk quantification	Reservoir operating levels	Penalty structure for each level (percentage of volume) based on risk matrix
	Pipe supply integrity	Penalty structure for operational conditions (percentage of design capacity and pressure ranges) based on risk matrix
Sensitivity analysis	Range of parameters used in sensitivity analysis	Modify of parameters to test sensitivity e.g. roughness parameter

Note: AADD = Average Annual Daily Demand



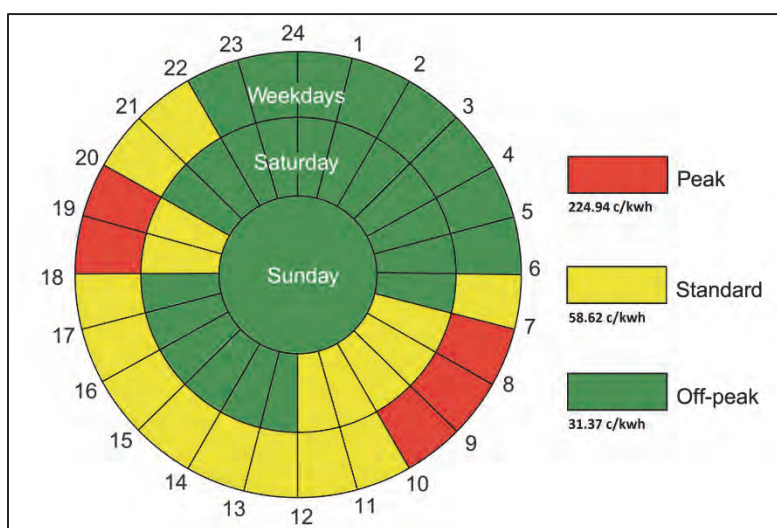


Figure 9-5: ESKOM defined time periods (Megaflex, WEPS, Miniflex and Ruraflex) for high demand season

EPANET which performs extended period simulation of hydraulic behaviour within pressurized pipe networks (Rossman, 2000) was utilized as the hydraulic engine. The Conduit Hydropower Optimizing Tool (CHOT) was developed which incorporates a Genetic Algorithm and reliability evaluation and links to the EPANET hydraulic engine. The model parameters required to adequately optimize the operational functioning are provided in **Table 9-5**. This multi-objective algorithm procedure was tested on the Caledon-Bloemfontein Pipeline, an existing bulk water supply line which contains two locations where conduit hydropower generation is considered.

9.5.2.2 Application of procedure

The Bloem Water Board situated in Bloemfontein in South Africa is considering conduit hydropower installations at their Uitkijk and Brandkop reservoirs on the Caledon-Bloemfontein Pipeline. The water is abstracted from the Welbedacht Dam situated in the Caledon River, purified at the Welbedacht Dam WTW and pumped 6.7 km to the De Hoek Reservoir (22.7 Ml). From here it gravitates via a 50 year old, 1 170 mm Ø pre-stressed concrete gravity mains 47 km to the Uitkijk break water reservoir (9.1 Ml) and a further 58,8 km to the Brandkop Reservoir (136 Ml) as shown in **Figure 9-6**.



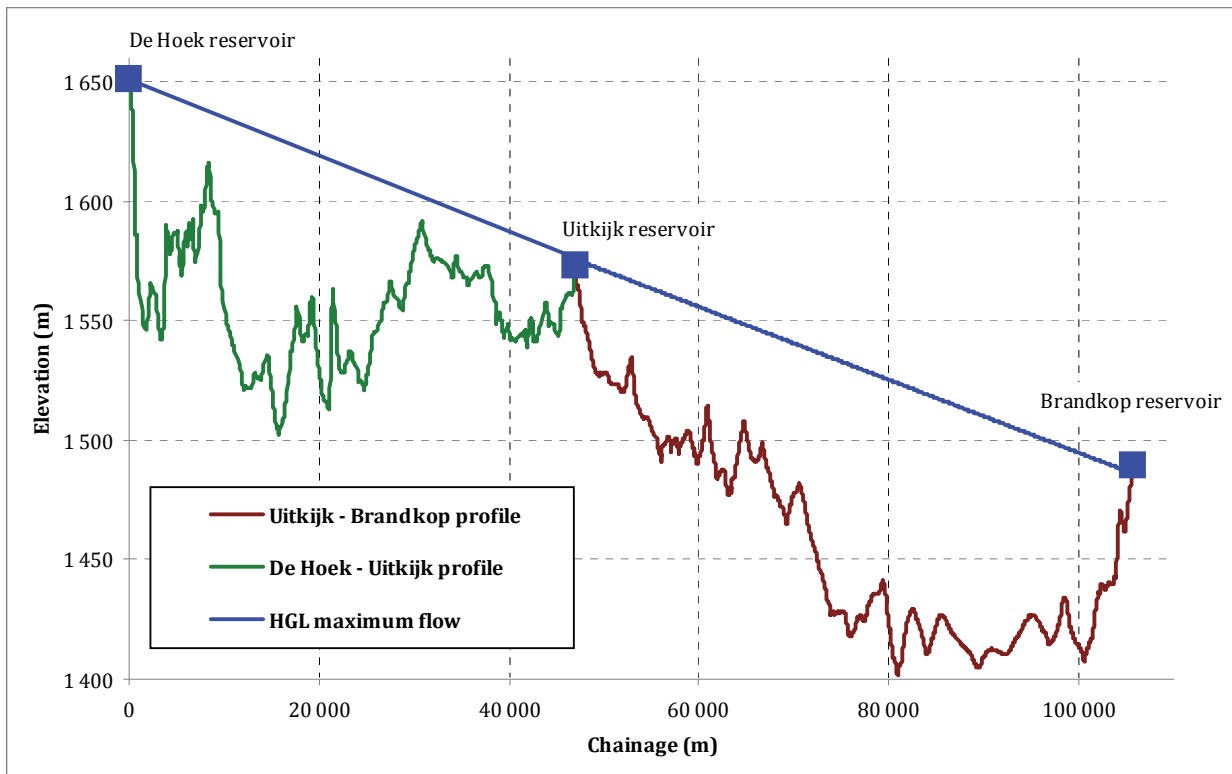


Figure 9-6: Longitudinal profile of the Caledon-Bloemfontein Pipeline

The two segments of the Caledon-Bloemfontein gravity pipeline are controlled on the downstream ends, at the Uitkijk- and Brandkop Reservoirs. **Figure 9-7** and **Figure 9-8** respectively provide details of the pressure control valves at Uitkijk and Brandkop reservoirs.

In order to determine the energy potential at the inlets into the two reservoirs (Uitkijk and Brandkop) the pipelines were hydraulically assessed. This required field measurements to determine the friction factors as well as a surge analysis to determine the impact of the planned installation of hydro turbines on the integrity of the pipeline system.

Turgo turbines were selected at both these sites, seeing that these have flat performance curves which were ideal for how the system could potentially be operated over wide flow and load variations. A risk matrix was set-up for each of the pipeline components as well as defining the acceptance criterion and how certain risks above the adopted acceptance criteria should be treated.





Figure 9-7: The six control valves on the 3 branches feeding into the Uitkijk Reservoir



Figure 9-8: Control valves on the 5 branch pipes leading into Brandkop Reservoir



The Pareto-optimal trade-off curve was set-up for potential generated income for the week analysed (**Figure 9-9**) for this interconnected supply system. The peak rates for electricity are significantly higher than standard and off-peak rates (**Figure 9-5**) and therefore the maximum income in this case is not generated when the total maximum power is generated for the week but rather generating maximum power during peak periods.

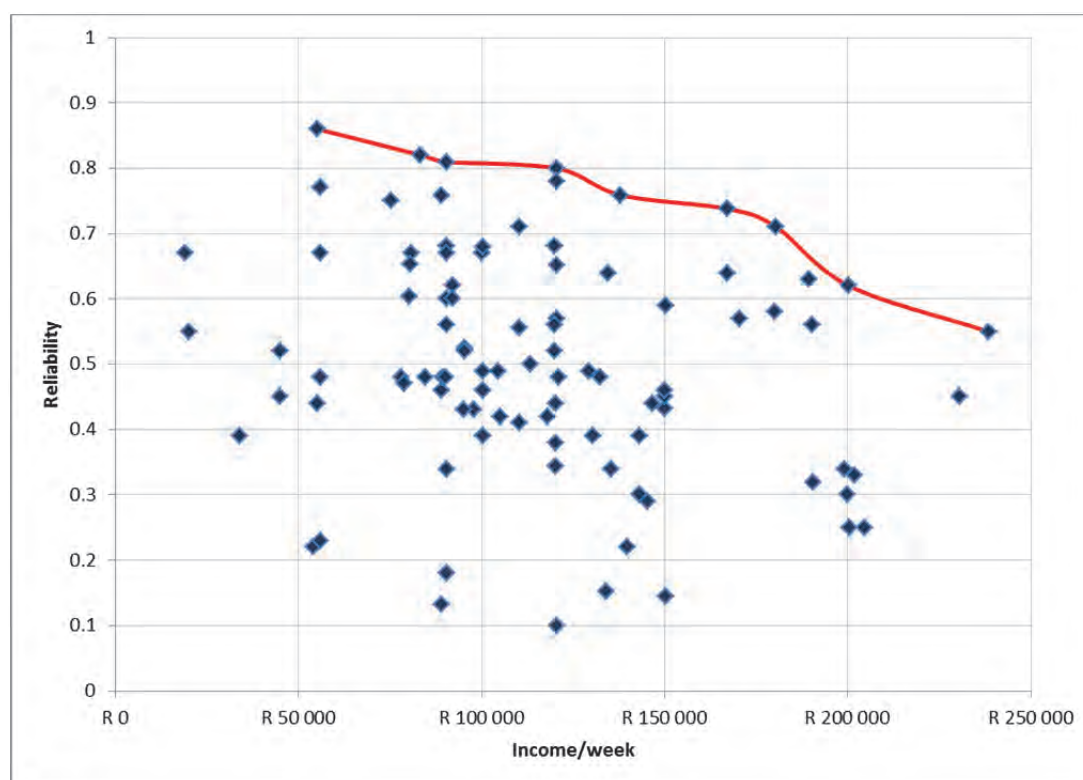


Figure 9-9: Pareto-optimal trade-off curve showing potential generated income/week vs. reliability

9.5.2.3 Summary and Conclusions

Globally countries have been working intensively to improve energy efficiency in all sectors whilst at the same time increasing the use of renewable energies. This can be a key issue to solve environmental, self-sufficiency and cost problems and adequately provide for increasing energy demand. These will contribute to (Vieira and Ramos, 2009):

- 🔍 promoting the development of energy production from clean and renewable resources;
- 🔍 minimizing environmental impacts resulting from energy production and consumption;
- 🔍 reducing the external dependence of the national power system;
- 🔍 promoting the diversification of energy supply sources;
- 🔍 ensuring energy supply under efficient and safe conditions; and
- 🔍 reducing oil dependency.



10. CONDUIT HYDROPOWER PILOT PLANTS

One of the objectives of this research project was to demonstrate the technologies (turbines, controls etc.) by means of full scale pilot plants. Three pilot plants, listed in **Table 10-1**, were constructed showcasing several of the intricacies in the development process and demonstrate the working of a conduit hydropower plant.

Table 10-1: Conduit Hydropower Pilot Plants

Nr	Name	Owner	Turbine	Installed capacity (kW)	Use	Payback period (months)
1	Pierre van Ryneveld	City of Tshwane Metropolitan Municipality	Crossflow	14.9	Islanded – On site only	96 months
2	Brandkop	Bloemwater	Crossflow	96	Islanded – Supplying the Bloemwater head office	72 months
3	Newlands 2	Ethekwini Municipality	Pelton	1 x 2	Islanded and grid connected	n.a.

The planning, design, construction and testing of these pilot plants are described in detail in Van Vuuren, et.al (2014). The following paragraphs provide a summary and visual overview of the three pilot plants that were constructed by the collaborating organisations.

10.1 Pierre van Ryneveld Pilot Plant – City of Tshwane

A conduit hydropower pilot plant was developed at the Pierre van Ryneveld Reservoir in the City of Tshwane water distribution network. The Pierre van Ryneveld Reservoir is located south of Pretoria in the Country Lane Estate East of the R21 National Road. The generated power is utilized on site for lighting, alarm, communication etc. The home owners association of the Country Lane Estate have also indicated that they would like to utilize the power for street lighting.

The pilot plant utilizes a cross-flow turbine and a synchronous generator. The maximum capacity is ± 14.9 kW of renewable, zero-emissions, electricity but depends on the flow and head pressure conditions at any given time.

Visual details of the progress on the construction of this hydropower pilot plant are shown in **Figure 10-1** to **Figure 10-15**.





Figure 10-1: Providing an offtake from the main supply line



Figure 10-2: Plan view of off take pipework



Figure 10-3: Constructing the off-take chamber



Figure 10-4: Nearly complete off take chamber (Pierre van Ryneveld Reservoir)



Figure 10-5: Completed turbine supply line on to top of reservoir



Figure 10-6: Completed off-take chamber pipework





Figure 10-7: Completed off take chamber



Figure 10-8: Crossflow turbine hoisted onto the reservoir roof



Figure 10-9: Crossflow turbine installation (connecting to supply line)



Figure 10-10: Emergency pinch valve (discharging into reservoir)

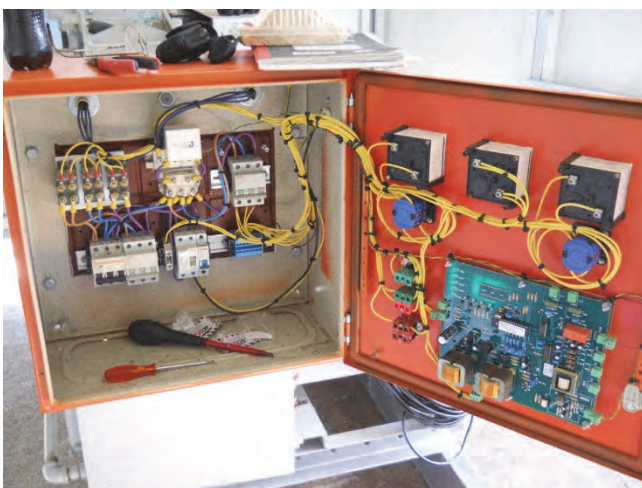


Figure 10-11: Generator control panel



Figure 10-12: Completed installation of turbine, generator and electrical controls





Figure 10-13: Electrical switch over (grid power or hydropower)



Figure 10-14: Enclosure framework



Figure 10-15: Pilot plant enclosure

10.2 Brandkop Reservoir Pilot Plant - Bloemwater

The Caledon–Bloemfontein pipeline supplies potable water from the Welbedacht Dam in the Caledon River to Bloemfontein. The treated water is pumped with a high lift pump station, 6.7 km to the De Hoek reservoir (22.7 Ml). From here it gravitates through a 1 170 mm Ø pre-stressed concrete gravity mains 47 km to the Uitkijk break water reservoir (9.1 Ml) and a further 58.8 km to the Brandkop Reservoir (136 Ml).

In order to determine the energy potential at the inlets into the two reservoirs (Uitkijk and Brandkop) the pipelines were hydraulically assessed. This assessment indicated that there is approximately 350 to 400 kW available at each of these sites. Bloemwater decided to initially develop a hydropower plant with sufficient capacity to meet the electricity demand of their head office which is situated at the Brandkop Reservoir.



Pressure, flow and electricity consumption data was recorded for a number of months at the site which is situated at the south-west corner of the reservoir (see **Figure 10-16**). This resulted in the selection of a 96 kW crossflow turbine.



Figure 10-16: Hydropower plant location

Visual details of the progress on the construction of this hydropower pilot plant are shown in **Figure 10-17** to **Figure 10-24**.



Figure 10-17: Connection point



Figure 10-18: Recording electricity consumption of the Bloemwater head office





Figure 10-19: Turbine room foundation



Figure 10-20: Turbine room almost complete



Figure 10-21: Outlet canal into reservoir



Figure 10-22: Crossflow turbine (belt driven)



Figure 10-23: Control panel and regulator



Figure 10-24: Turbine and generator in position



Based on the pressure head at Brandkop Reservoir during higher flow rates it was decided to select a crossflow (Banki) turbine as shown in **Figure 10-24**. The turbine selected was the IREM ECOWATT Micro hydroelectric power plant type TBS 4-0.5 with synchronous generator. Electronic Regulators are connected to provide the dissipating capability (9 x RMP 12000/B i.e. with total capacity of 108 kW). The regulator keeps the voltage and frequency stable, as the absorption of the energy produced by the turbine-generator group remains constant.

10.3 Newlands 2 Reservoir Pilot Plant – Ethekwin Municipality

It was decided to construct a turbine room with two pico pelton turbines at the Newlands 2 Reservoir site in Durban, see **Figure 10-25**.

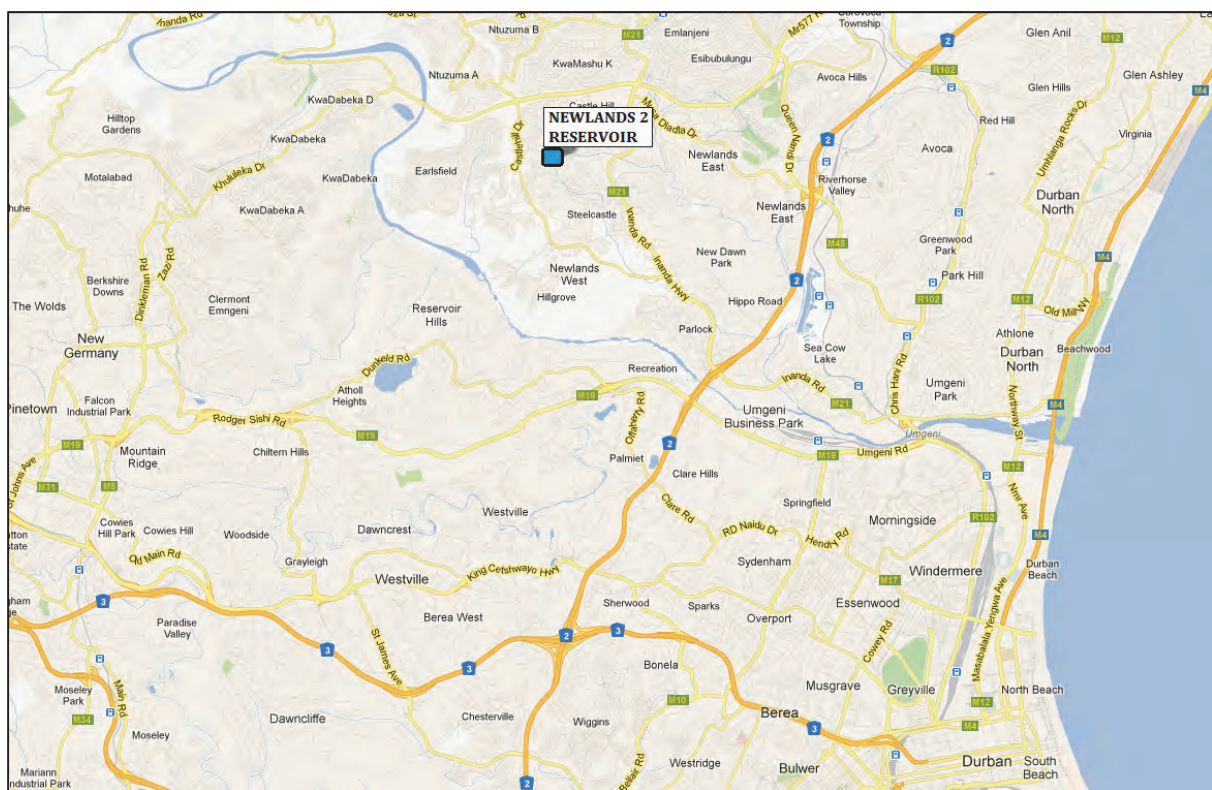


Figure 10-25: Location of site

The following is a summary of the hydro power plant:

- 🔧 The turbines and equipment is housed in a steel, lockable container.
- 🔧 There are two turbines installed
 - A Powerspout BE Micro Hydro Pelton System connecting to an islanded grid (1 kW).
 - A Powerspout GE Micro Hydro Pelton System connecting to the Municipal grid (1 kW).
- 🔧 Connection to the grid is via a VSX/GVSX Inverter.
- 🔧 The islanded grid is fed through a Deltec Lead Crystal Battery bank (4 x 12v200ah) and controlled with an Outback charge controller – FM60.



- ⓘ A bypass line is installed from the pressure reducing valve chamber up to the turbine room (container).

One unit, a PowerSpout GE, is connected to the municipal grid in a setup similar to that depicted in **Figure 10-26**.

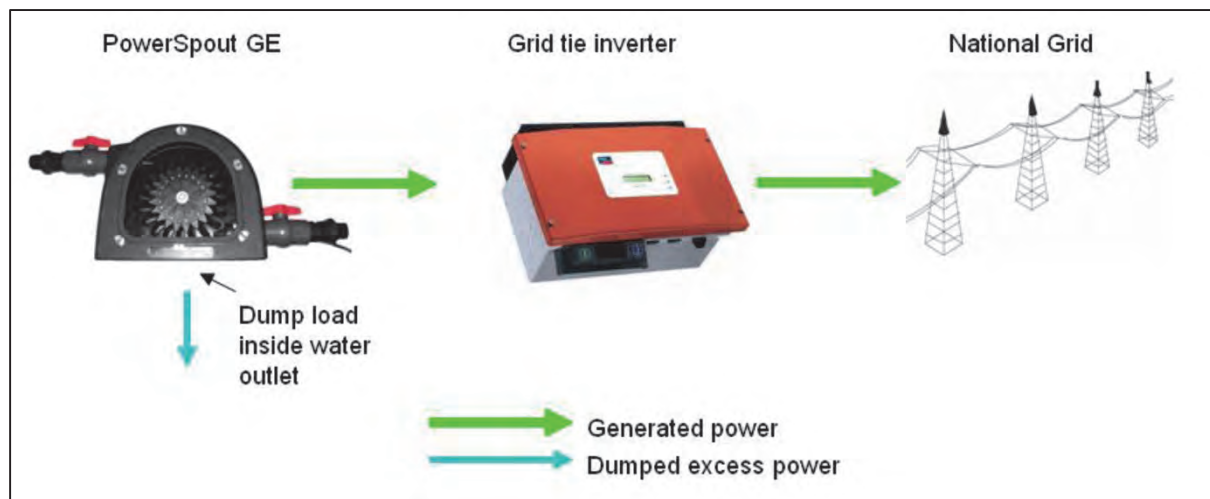


Figure 10-26: PowerSpout GE system setup

The second, a PowerSpout BE, connects to an islanded system for the site's energy needs, see setup in **Figure 10-27**. It connects directly to a battery bank with a diversion load controller for system regulation.

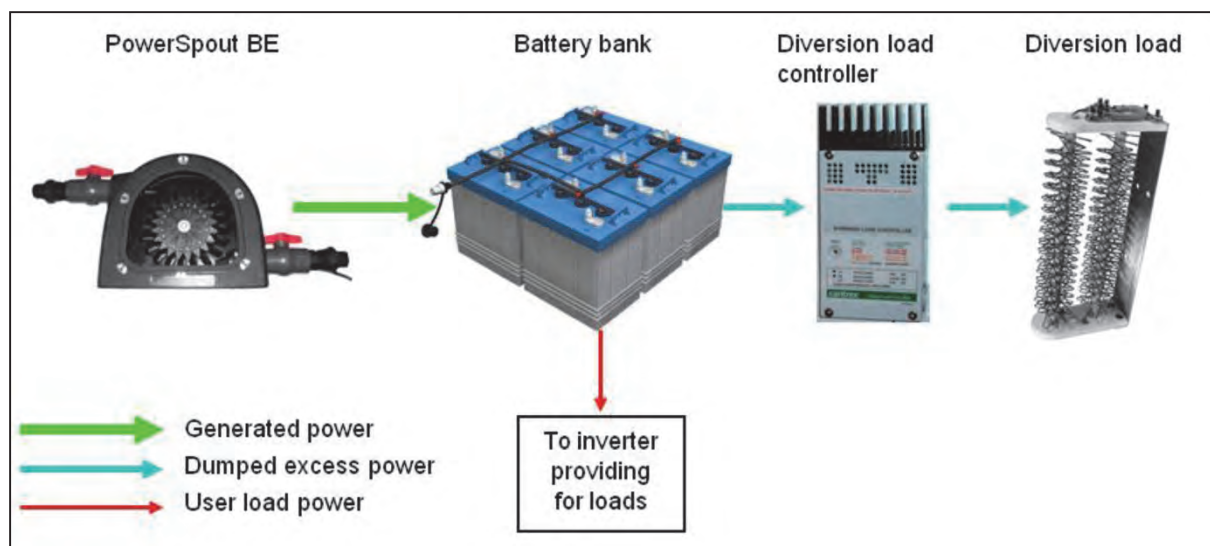


Figure 10-27: PowerSpout BE system setup

Visual details of the progress on the construction of this hydropower pilot plant are shown in **Figure 10-28** to **Figure 10-32**.





Figure 10-28: Connection point (off take from main supply)



Figure 10-29: Turbine room foundation and connection point into reservoir



Figure 10-30: View from PRS to position on top of reservoir



Figure 10-31: Turbine room (steel container) and connection point



Figure 10-32: Two Powerspout pelton turbines



11. OTHER WATER UTILITIES WITH CONDUIT HYDROPOWER OPPORTUNITIES

There are a number of water utilities and other entities whom are investigating conduit hydropower opportunities at the moment:

- ☒ Rand Water Board (4 sites total 15 MW);
- ☒ Bloem Water (2 x 350 kW);
- ☒ Umgeni Water (various);
- ☒ Lepelle Northern Water (3 sites total 370 kW);
- ☒ City of Tshwane (5 sites total 1.6 MW);
- ☒ Ethekewini Municipality (various);
- ☒ George Municipality (various);
- ☒ ESKOM at the Orange-Fish Tunnel outlet at Teebus (5.4-7MW); and
- ☒ City of Cape Town (upgrading existing installations at WTW)

11.1 Deep level mines – hydro-energy recovery high pressure cold water

11.1.1 General background

South Africa has widely expanded mining industry consuming up to 18 percent of the country's total electricity supply. Due to the serious constraints with the electricity generation and often interrupted supply from the national grid, mining sector is seeking alternatives allowing for the reduced energy consumption and improving energy efficiency of existing installations without reducing mining outputs.

Most of energy consumption (i.e. fuels and electricity) on the particularly deep-levels mines is due to primarily pumping and circulation of the hot and cold water between the working levels and the surface where are situated the refrigeration plants. The refrigerated water is circulated from the surface down to the bottom of a mine (in some cases more than 3 000 m below surface) through the system of conduits of varying flow capacities. The extensive pressures generated in the water conduits at the bottom of a mine have to be reduced by means of the PRVs down to acceptable working pressures between 1 and 2 MPa. The circulated water quantities at the deep-level mines are fluctuating typically between 15 and 40 Ml per day (le Roux, 2012).

11.1.2 Hydropower applications at deep-level mines

Le Roux (2012) recorded that some 60 Pelton turbines were installed on the SA's deep-level mines since late 1970. It is estimated that about 20 Pelton turbine installations are



still in working condition. These installations are now obsolete, having rather low efficiencies and in a need of refurbishment and modernization. However, other energy recovery technologies have been in recent years installed at several deep-level mines. Two favoured systems of hydraulic energy recovery on the deep-level mines in South Africa are described by Le Roux (2012 and 2014).

3CPS energy recovery system - this system is providing for the chilled water to displace outgoing hot water, see **Figure 11-1**. A small booster pump is installed to overcome friction in the U-tube conduit system. Typically the hydrostatic head in the U-tube system is greater than 1000 m. At present six 3CPS systems of total potential generation capacity of 30 MW are installed at the deep-level mines, mainly around Gauteng Province. The 3CPS system can recover some 80 percent of energy from available high hydrostatic head.

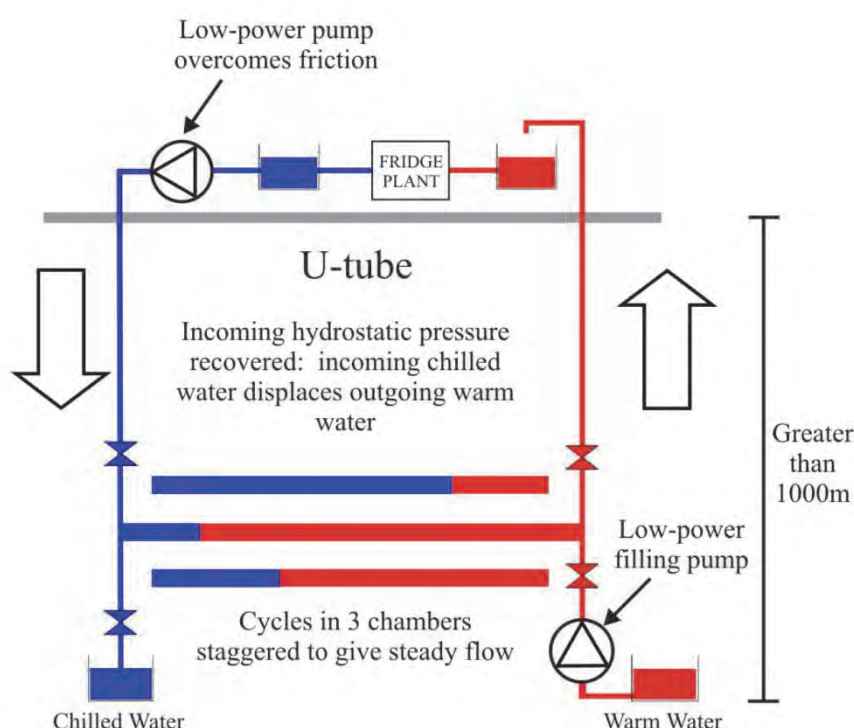


Figure 11-1: The 3 Chamber Pump System (Le Roux, 2012)

The valves as shown in **Figure 11-1**, are only shown for one of the three chambers. There are a total of 12 valves.

Pumps-as-turbines (PaTs) – the principle and characteristics of the PaTs are described in the paragraph 2.6.1.6. As a PaT installation can provide a back pressure it is suitable to be used at the production levels of the deep-level mines. The incoming pressure of cold water can reach as much as 20 MPa and flows can vary between 30 and 130 l/sec. The PaT system can be designed to deliver the same back pressure as the existing PRV (Le Roux, 2012).



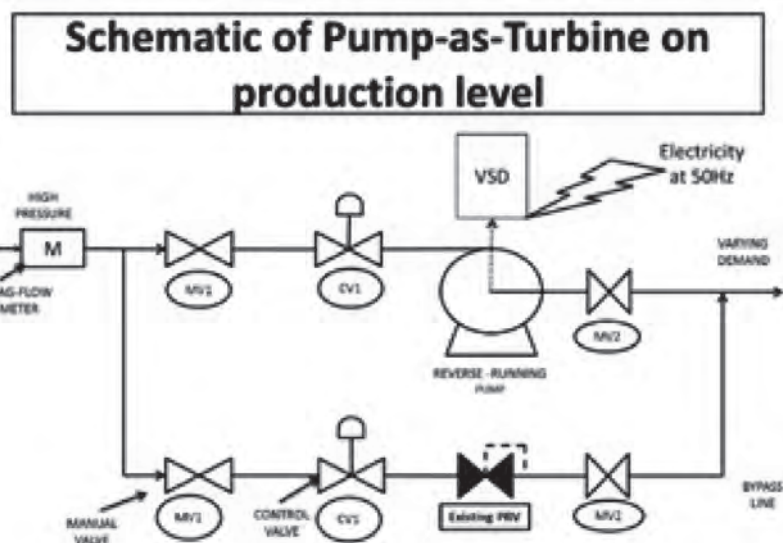


Figure 11-2: Schematic of PaT installed in parallel with existing PRV (Le Roux, 2012)

11.1.3 Tshepong Gold Mine 3CPS installation

Hydro Power Equipment (HPE) company is behind installations of the 3CPS systems on the SA's deep-level mines. The foremost installation is located at the Anglo American Corporation of SA Ltd Tshepong Gold mine (formerly Freddie's No. 1 Shaft) Tshepong Gold Mine a part of Harmony Gold already since 1994 (Van Rensburg, 2004).

From the period of two decades running the 3CPS installations it is determined that the energy savings are in order of 2.1 GWh per month, manifesting in the cost savings of some R6-million per annum.

11.1.4 Prospects for hydropower in deep-level mining energy recovery

The hydropower technology, although being applied on the deep-level mines for several decades didn't use, until recently, its full potential in reducing energy consumption and also in electricity generation (i.e. ultimately lowering industry's carbon footprint) reducing thus mining industry's dependence on the national grid. It is envisaged that certain mines can be eventually supplying their electricity surplus to the local or national grid. The ways in reducing reliance on the electricity supplies from ESKOM could be as follows.

- ④ refurbishment/upgrading and modernization of existing hydropower installations on the deep-level mines,



-  cutting inefficiencies in the deep-level mines as for example by installing the Peterstow Aquapower drills instead standard pneumatic drills, which can reduce energy consumption by unbelievable 95 percent in comparison to the standard installations, and
-  installing combine systems comprising the 3CPS (or Pelton turbines) together with the PaTs in parallel with existing PRVs at the production levels, resulting thus in energy efficiency and also electricity generation at production levels.

The hydropower applications described above will enable, at particularly deep-level mines, the prolonged mining of the strategic minerals as are mainly gold, platinum and chrome.

11.2 Hydropower opportunities

South Africa is 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 and again in 2013 made all citizens aware of the fact that demand for electricity is grossly outstripping supply.

This project identified that there are a number of hydropower opportunities in the water supply and distribution infrastructure that could be harnessed. A recently completed study by Van Vuuren et.al (2013) illustrated that there are other untapped sources of hydropower which should be developed. These include unused potential in run-of-river generation; impoundments, wastewater treatment plants and irrigation schemes.

This projected reflects that the retrofitting of hydropower to infrastructure has many advantages.



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APPENDIX A

TURBINE SUPPLIERS

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 surrounded by air while reaction turbines are submerged in water (Paish, 2002). **Table A1** provides a summary of the classification of turbines.

Table A1: Groups of water turbines (Natural Resources Canada, 2004)

Turbine runner	High head	Medium head	Low head	Ultra-low head
	> 100 m	20 m - 100 m	5 m - 20 m	< 5m
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

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

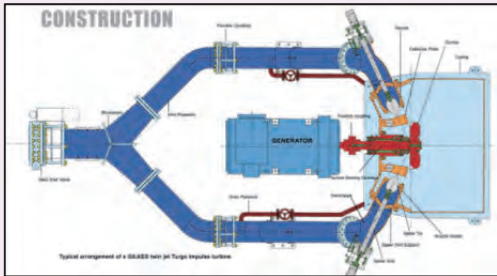
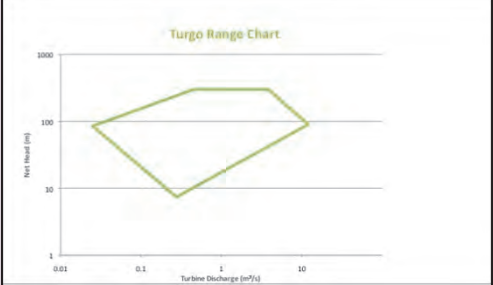


Table A2: Layout of Appendix A

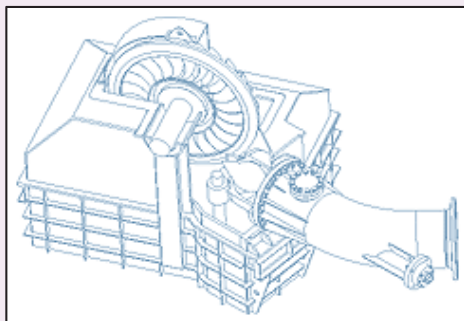
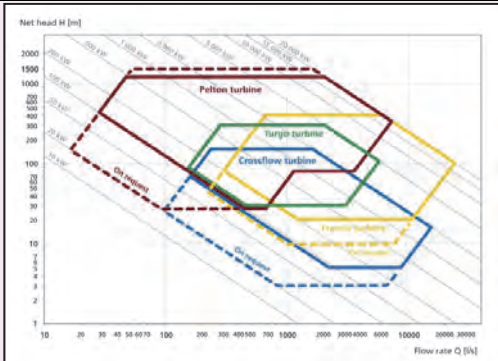
Impulse	Turgo	Gilkes
		Wasserkraft Volk
	Pelton	Gilkes
		IREM
		Powerspout
		Mavel
		Voith
		Wasserkraft Volk
	Crossflow	IREM
		Ossberger
		Wasserkraft Volk
	Hydrodynamic Screw	Andritz
Reaction	Kaplan	Ossberger
		Mavel
		Voith
	Bulb	Voith
	Francis	Wasserkraft Volk
		Gilkes
		Mavel
		Voith
	Pump-as-turbine	Voith
		Andritz
	Syphon-turbine	Mavel
	Inline Turbines	Kawasaki Ring
		Lucidpipe Spherical



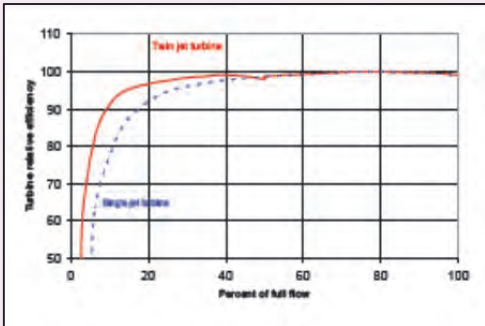
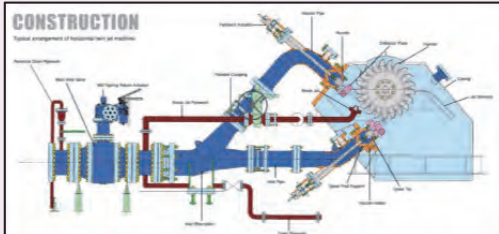
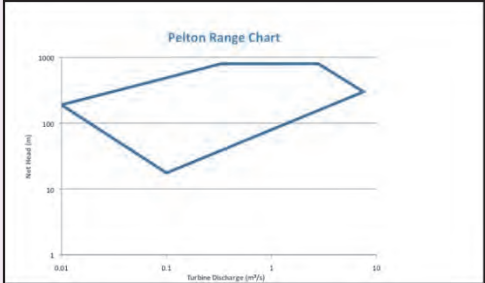
IMPULSE TYPE TURBINES

Turbine Name:	TURGO TURBINE		
Company name:	Gilbert Gilkes & Gordon Ltd		
Company Address:	Canal Head North Kendal Cumbria UK		
Company Tel:	+44 (0) 1539 720028		
Company E-mail:	enquiries@gilkes.com		
Website:	www.gilkes.com		
Turbine Description:	The Gilkes Turgo is a simple machine with high specific speed, where water is directed at an angle onto the runner. It can handle dirty water.		
Pressure Head Range	Up to 300 m		
Flow Range	0.04 m ³ /s to 6 m ³ /s		
Power Range	Up to 10 000 kW		
Illustrations, Photos and Applicable Graphs:	 <i>Turgo runner</i>		
	 <i>Turgo turbine installation</i>		
	 <i>Typical layout</i>		
	 <i>Turbine range</i>		

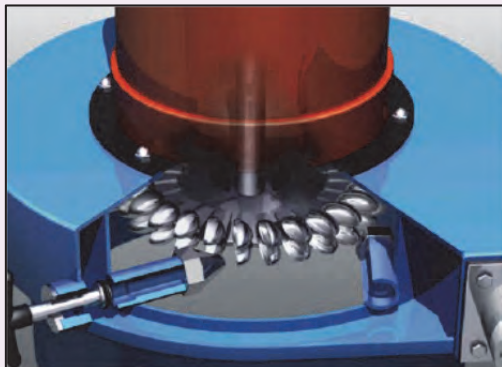
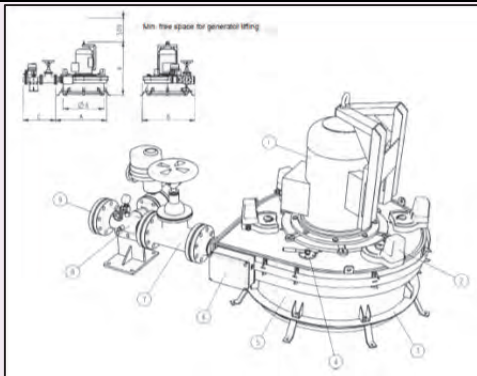
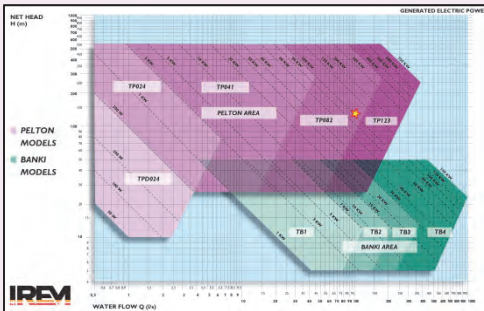


Turbine Name:	TURGO TURBINE	
Company name:	Wasserkraft Volk AG	
Company Address:	Am Stollen 13 D-79261 Gutach GERMANY	
Company Tel:	+49 7685-9106-0	
Company E-mail:	mail@wkv-ag.com	
Website:	www.wkv-ag.com	
Turbine Description:	Wasserkraft Volk Turgo turbines have low equipment cost due to high specific speed, maintenance-free shaft-seal design, with bearings rated for more than 100 000 operating hours.	
Pressure Head Range	30 m to 300 m	
Flow Range	Not given	
Power Range	Up to 5 000 kW	
Illustrations and Applicable Graphs:	 <i>Turgo turbine room</i>	 <i>Turgo turbine wheel</i>
	 <i>Typical turbine drawing</i>	 <i>Wasserkraft Volk turbine ranges</i>

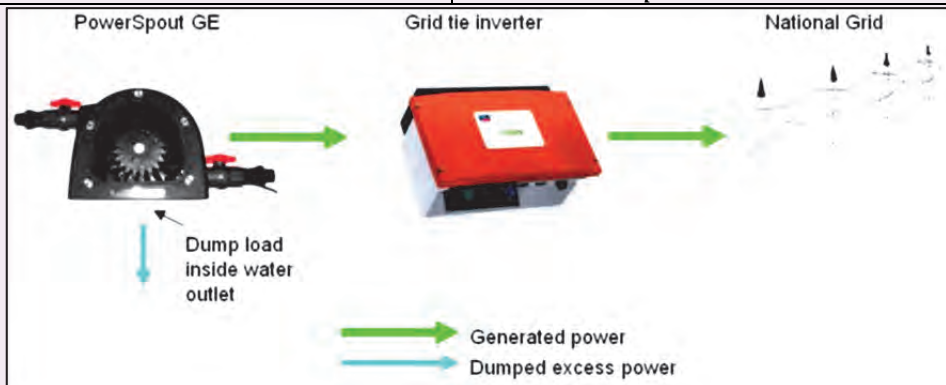


Turbine Name:	PELTON TURBINE	
Company name:	Gilbert Gilkes & Gordon Ltd	
Company Address:	Canal Head North Kendal Cumbria UK	
Company Tel:	+44 (0) 1539 720028	
Company E-mail:	enquiries@gilkes.com	
Website:	www.gilkes.com	
Turbine Description:	Gilkes Pelton turbines can be supplied as horizontal (single or twin jet) units or vertical (three, four or six jet) units and high efficiencies over a wide range.	
Pressure Head Range	Up to 1 000 m	
Flow Range	0.01 m ³ /s to 10 m ³ /s	
Power Range	Up to 20 000 kW	
Illustrations, Photos and Applicable Graphs:	 <i>Pelton runner</i>	 <i>Pelton turbine efficiency</i>
	 <i>Typical layout</i>	 <i>Turbine range</i>

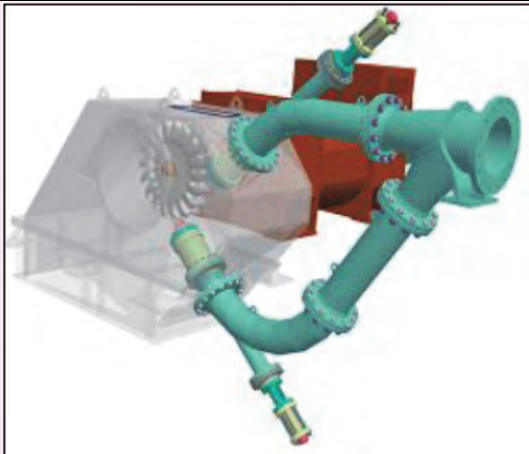
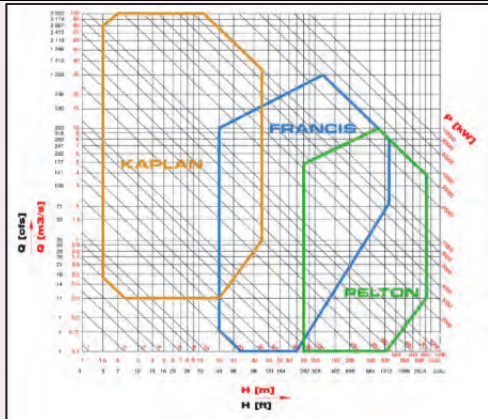


Turbine Name:	PELTON TURBINE	
Company name:	IREM SpA a Socio Unico	
Company Address:	Via Abegg 75 Borgone Susa ITALY	
Company Tel:	+39 011 9648211	
Company E-mail:	irem@irem.it	
Website:	www.irem.it	
Turbine Description:	IREM Pelton turbines have six nozzles and are splined directly onto a synchronous or asynchronous generator shaft, depending on the electricity use.	
Pressure Head Range	20 m to 350 m	
Flow Range	0.0005 m³/s to 0.1 m³/s	
Power Range	Up to 100 kW	
Illustrations, Photos and Applicable Graphs:		
	<i>Pelton runner</i>	<i>Pelton turbine</i>
		
	<i>Turbine components</i>	<i>IREM turbine range</i>

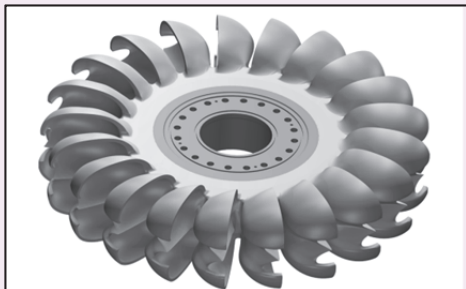
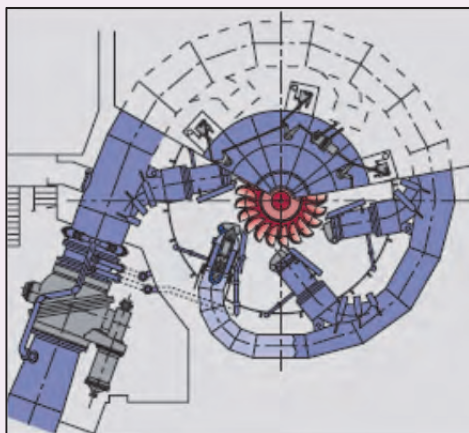
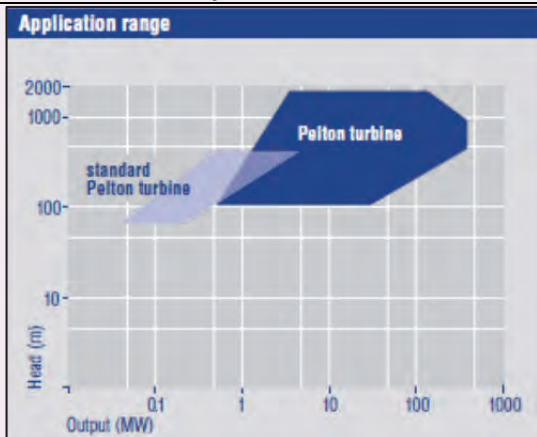


Turbine Name:	POWERSPOUT PELTON TURBINE	
Company name:	POWERSPOUT (Papersmith and Son (PTY) Ltd. (South African Distribution))	
Company Address:	PO BOX 72548 Parkview GT 2122 SOUTH AFRICA	
Company Tel:	+27 011 2406900	
Company E-mail:	jo@papersmith.co.za	
Website:	www.powerspout.com	
Turbine Description:	Powerspout Pelton turbines are made from more than 60% recycled material. This pico turbine can be installed in parallel to generate up to 16kW.	
Pressure Head Range	3 m to 100 m	
Flow Range	0.008 m³/s to 0.01 m³/s	
Power Range	Up to 1.6 kW per turbine	
Illustrations, Photos and Applicable Graphs:		
	<i>Pelton runner</i>	<i>Powerspout turbine room</i>
		
	<i>Turbine set-up</i>	

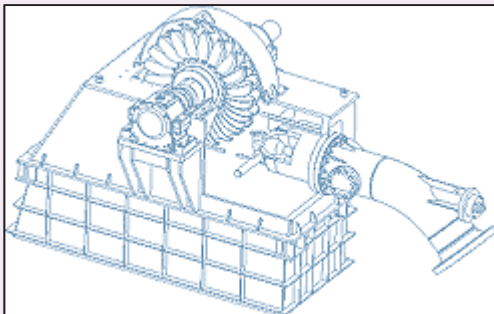
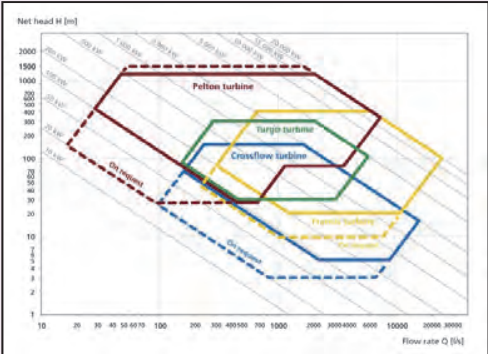


Turbine Name:	PELTON TURBINE	
Company name:	Mavel Hydro Turbines (Scion Technologies (South African Distribution))	
Company Address:	Northbank 3 rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA	
Company Tel:	+27 21 552 9993	
Company E-mail:	karenr@sciontechnologies.co.za	
Website:	www.mavel.cz	
Turbine Description:	Mavel Pelton runners are customized and can be configured either vertically or horizontally.	
Pressure Head Range	80 m to 1000 m	
Flow Range	0.1 m ³ /s to 10 m ³ /s	
Power Range	70 kW to 30 MW	
Illustrations and Applicable Graphs:		
	<i>Pelton turbine runner</i>	<i>Pelton turbine layout</i>
		
	<i>Installed vertical Pelton turbines</i>	<i>Turbine range</i>

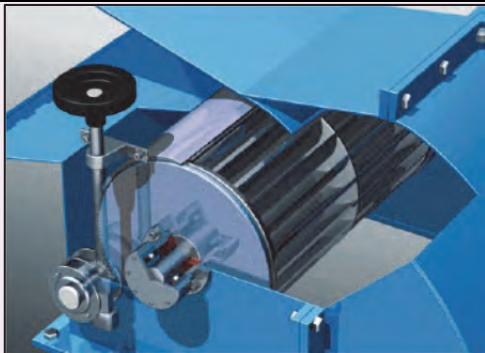
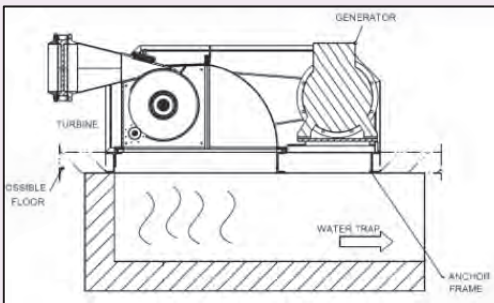
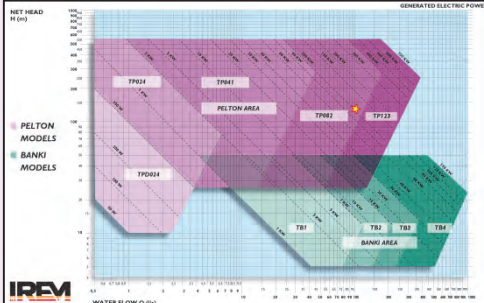


Turbine Name:	PELTON TURBINE	
Company name:	Voith Hydro Holding GmbH & Co. KG	
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY	
Company Tel:	+49 7321 37 0	
Company E-mail:	info.voithhydro@voith.com	
Website:	www.voithhydro.com	
Turbine Description:	A full range, from large custom-built machines, to standard small hydro turbines, is available from Voith.	
Pressure Head Range	95 m to 1 500 m	
Flow Range	Not given	
Power Range	10k W to 400 MW	
Illustrations and Applicable Graphs:		
	<i>Pelton turbine runner</i>	<i>5-jet turbine</i>
		
	<i>Drawing of 6-jet turbine</i>	<i>Turbine range</i>

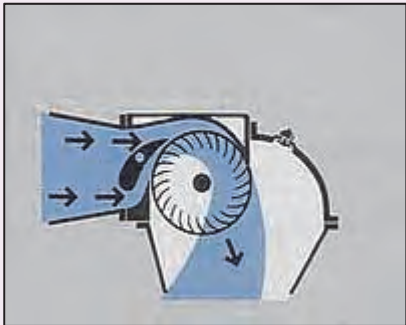
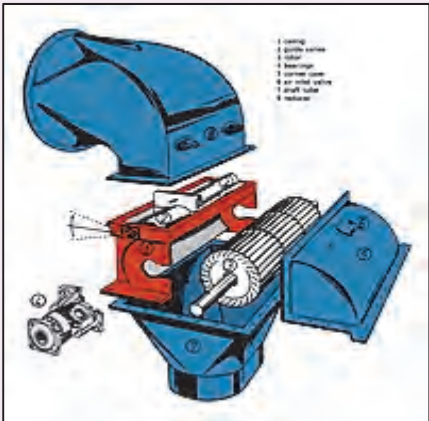
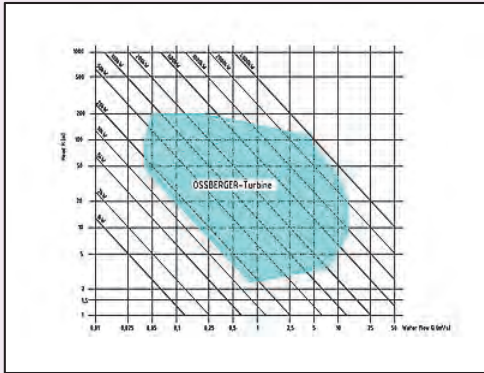


Turbine Name:	PELTON TURBINE		
Company name:	Wasserkraft Volk AG		
Company Address:	Am Stollen 13 D-79261 Gutach GERMANY		
Company Tel:	+49 7685-9106-0		
Company E-mail:	mail@wkv-ag.com		
Website:	www.wkv-ag.com		
Turbine Description:	Wasserkraft Volk Pelton turbines can have up to six jets. These machines have high efficiency with fluctuating flow and can handle debris.		
Pressure Head Range	30 m to 1 00 0m		
Flow Range	0.04 m ³ /s to 13 m ³ /s		
Power Range	Up to 20 000 kW		
Illustrations and Applicable Graphs:	 <i>5 WKV twin-jet Pelton turbines, total power about 40 MW</i>		 <i>Pelton wheel</i>
	 <i>Typical turbine drawing</i>	 <i>Wasserkraft Volk turbine ranges</i>	

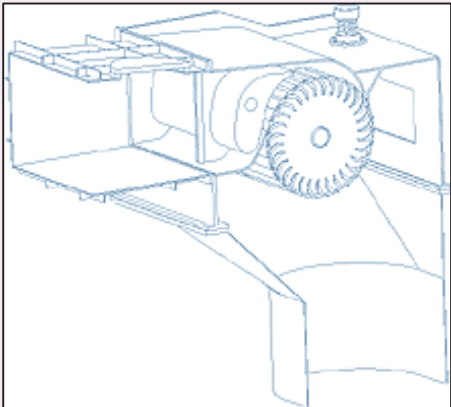
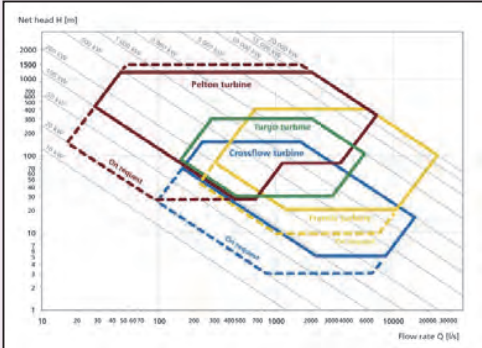


Turbine Name:	BANKI (CROSS-FLOW) TURBINE	
Company name:	IREM SpA a Socio Unico	
Company Address:	Via Abegg 75 Borgone Susa ITALY	
Company Tel:	+39 011 9648211	
Company E-mail:	irem@irem.it	
Website:	www.irem.it	
Turbine Description:	The IREM Banki turbine is connected to a belt driven synchronous or 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:	 <i>Banki runner</i>	 <i>Banki turbine</i>
	 <i>Turbine set-up</i>	 <i>IREM turbine range</i>

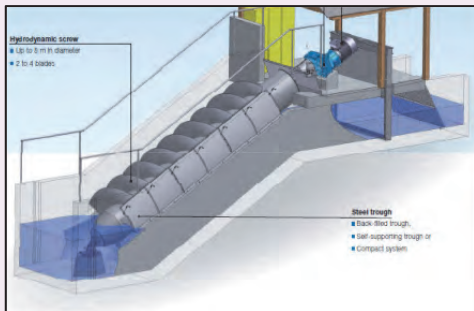
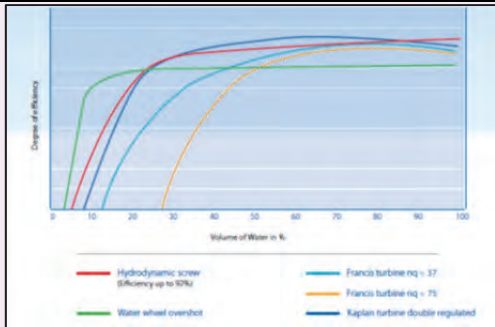


Turbine Name:	OSSBERGER-TURBINE		
Company name:	OSSBERGER GmbH + Co		
Company Address:	Otto-Rieder-Str. 7 91781 Weissenburg / Bavaria GERMANY		
Company Tel:	+49 (0)9141/977-0		
Company E-mail:	info@ossberger.de		
Website:	www.ossberger.de/cms/pt/hydro/contact/		
Turbine Description:	Ossberger turbines 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:	 <i>Inflow horizontal</i>		
	 <i>Inflow vertical</i>		
	 <i>Two-cell Ossberger turbine</i>		
	 <i>Turbine range</i>		

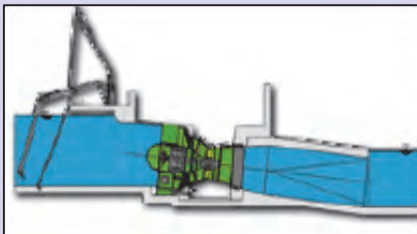
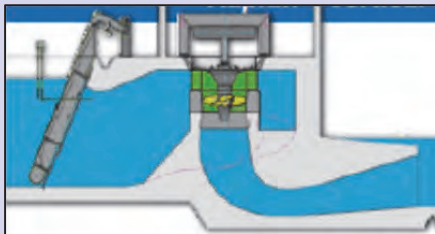
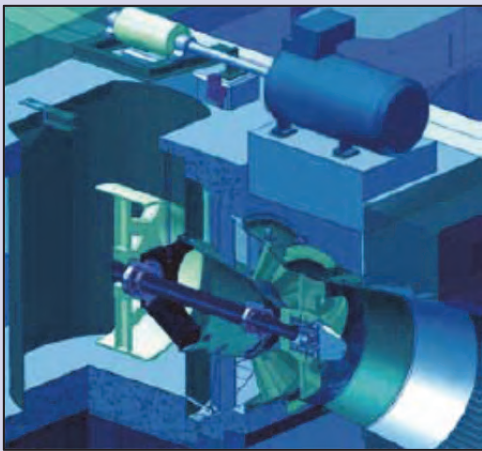
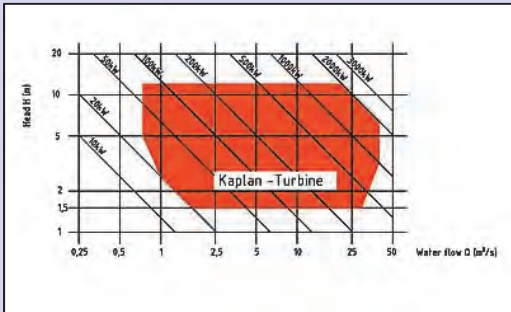


Turbine Name:	CROSS-FLOW TURBINE		
Company name:	Wasserkraft Volk AG		
Company Address:	Am Stollen 13 D-79261 Gutach GERMANY		
Company Tel:	+49 7685-9106-0		
Company E-mail:	mail@wkv-ag.com		
Website:	www.wkv-ag.com		
Turbine Description:	These turbines have high efficiencies down to 17% of design flow. 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:	 <i>Crossflow turbine room</i>		
	 <i>Crossflow turbine wheel</i>		
	 <i>Typical turbine drawing</i>		
	 <i>Wasserkraft Volk turbine ranges</i>		

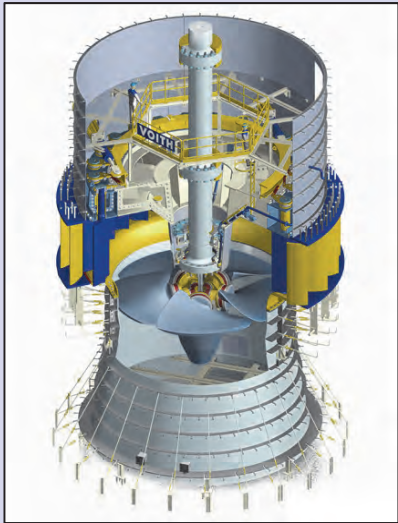
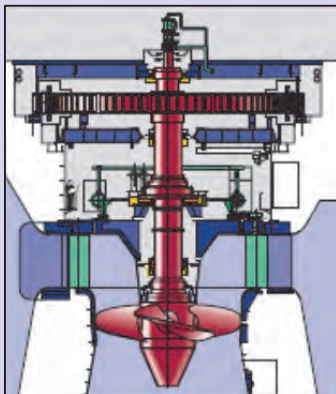
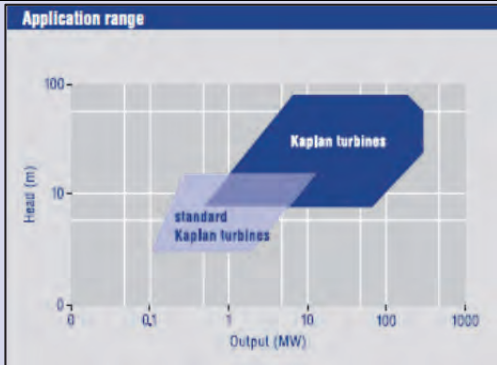


Turbine Name:	HYDRODYNAMIC SCREW	
Company name:	ANDRITZ Atro	
Company Address:	Penzinger Strasse 76 Vienna AUSTRIA	
Company Tel:	+43 (1)891 00 0	
Company E-mail:	hydro@andritz.com	
Website:	www.andritz.com	
Turbine Description:	This turbine is based on the Archimedean screw and is applicable to very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

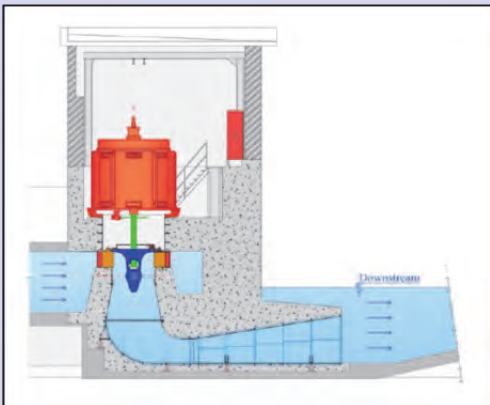
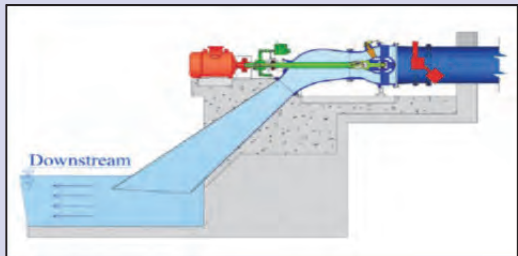
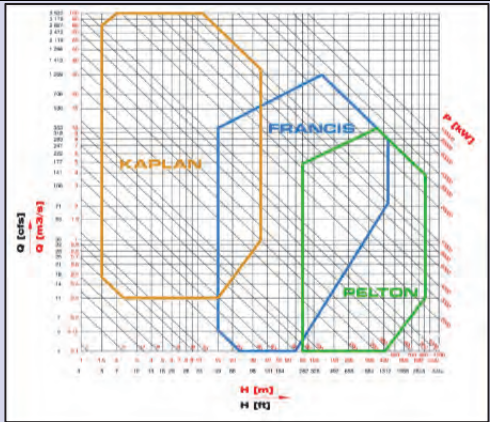


Turbine Name:	KAPLAN TURBINE	
Company name:	OSSBERGER GmbH + Co	
Company Address:	Otto-Rieder-Str. 7 91781 Weissenburg / Bavaria GERMANY	
Company Tel:	+49 (0)9141/977-0	
Company E-mail:	info@ossberger.de	
Website:	www.ossberger.de/cms/pt/hydro/contact/	
Turbine Description:	The Ossberger Kaplan turbine 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:		
	<i>Inflow horizontal</i>	<i>Inflow vertical</i>
		
	<i>Computer generated view of Kaplan</i>	<i>Turbine range</i>

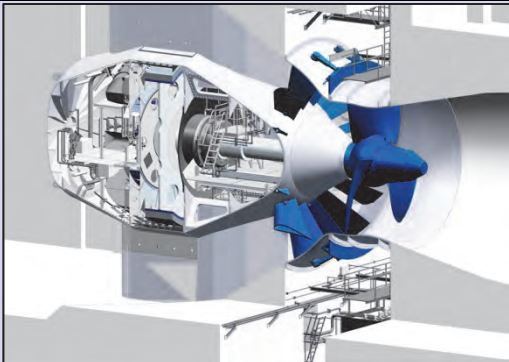
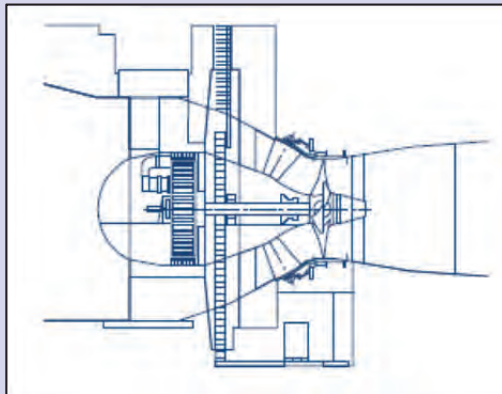
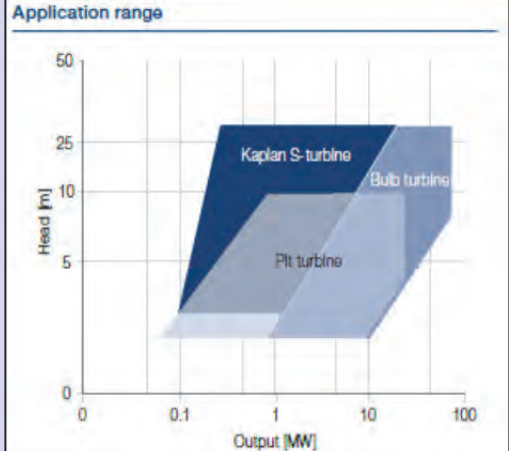


Turbine Name:	KAPLAN TURBINE	
Company name:	Voith Hydro Holding GmbH & Co. KG	
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY	
Company Tel:	+49 7321 37 0	
Company E-mail:	info.voithhydro@voith.com	
Website:	www.voithhydro.com	
Turbine Description:	Voith Kaplan turbines are designed to 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:		
	<i>Kaplan turbine runner</i>	<i>Turbine layout</i>
		
	<i>Cross section of a Kaplan runner</i>	<i>Turbine range</i>

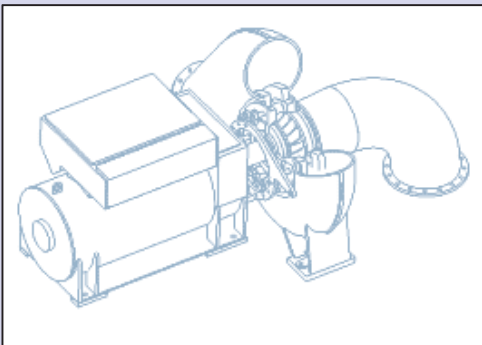
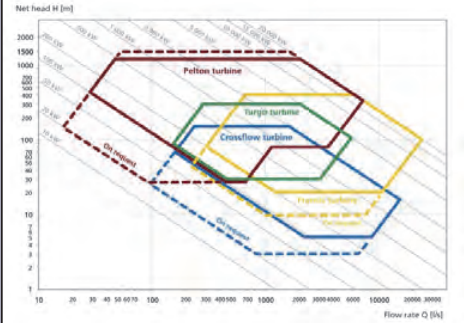


Turbine Name:	KAPLAN TURBINE	
Company name:	Mavel Hydro Turbines (Scion Technologies (South African Distribution))	
Company Address:	Northbank 3 rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA	
Company Tel:	+27 21 552 9993	
Company E-mail:	karenr@sciontechnologies.co.za	
Website:	www.mavel.cz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

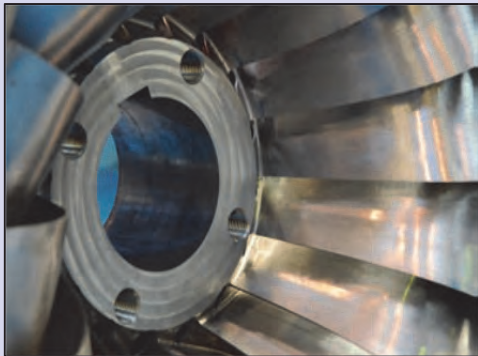
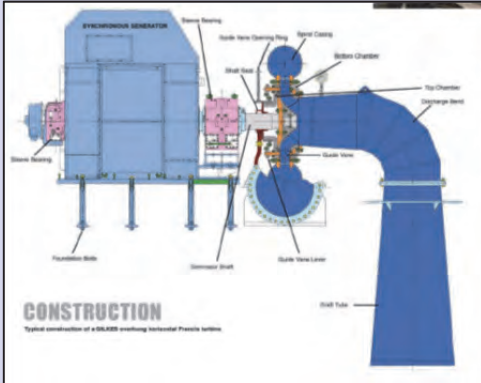
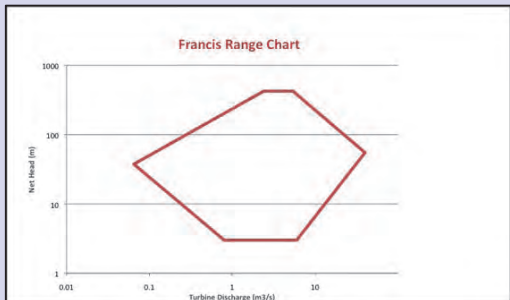


Turbine Name:	BULB TURBINE	
Company name:	Voith Hydro Holding GmbH & Co. KG	
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY	
Company Tel:	+49 7321 37 0	
Company E-mail:	info.voithhydro@voith.com	
Website:	www.voithhydro.com	
Turbine Description:	Voith bulb turbines are used primarily for 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:		
	<i>Bulb turbine</i>	<i>Bulb turbine computer illustration</i>
		Application range 
	<i>Cross section of a bulb turbine</i>	<i>Turbine range</i>

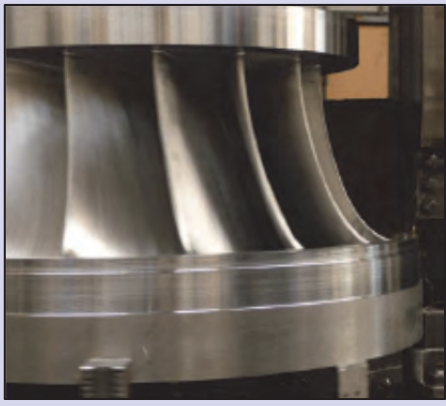
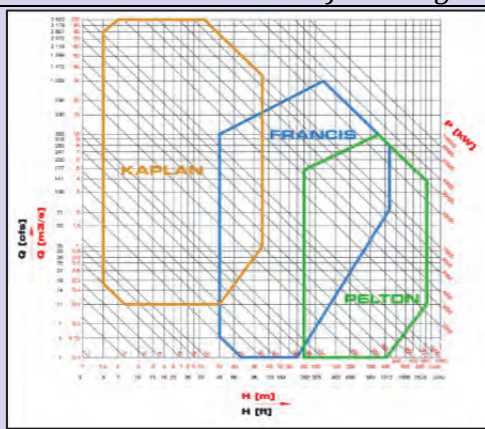


Turbine Name:	FRANCIS TURBINE	
Company name:	Wasserkraft Volk AG	
Company Address:	Am Stollen 13 D-79261 Gutach GERMANY	
Company Tel:	+49 7685-9106-0	
Company E-mail:	mail@wkv-ag.com	
Website:	www.wkv-ag.com	
Turbine Description:	This turbine has a high peak capacity, compact design and low maintenance, 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:	 <i>Francis turbine room</i>	 <i>Francis turbines manufacturing</i>
	 <i>Typical turbine drawing</i>	 <i>Wasserkraft Volk turbine ranges</i>

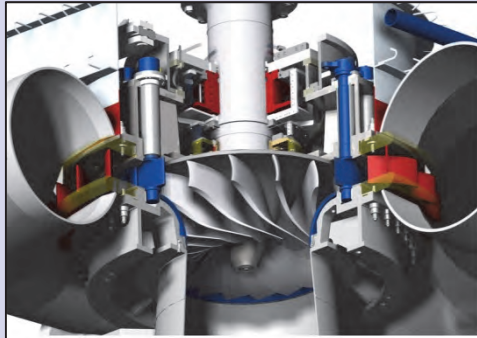
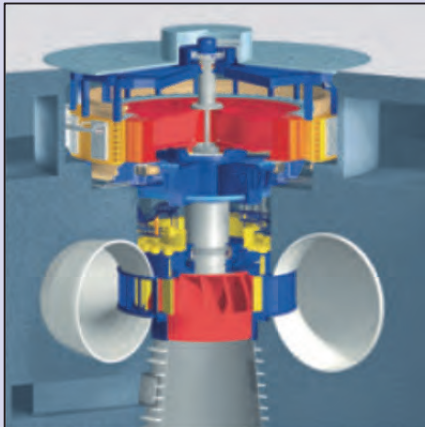
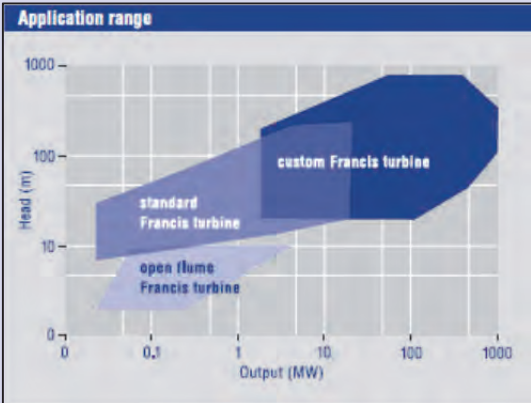


Turbine Name:	FRANCIS TURBINE	
Company name:	Gilbert Gilkes & Gordon Ltd	
Company Address:	Canal Head North Kendal Cumbria UK	
Company Tel:	+44 (0) 1539 720028	
Company E-mail:	enquiries@gilkes.com	
Website:	www.gilkes.com	
Turbine Description:	This turbine can be supplied as a horizontal or vertical 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 m³/s to 40 m³/s	
Power Range	Up to 20 000 kW	
Illustrations, Photos and Applicable Graphs:	 <i>Francis runner</i>	 <i>Francis turbine</i>
	 <i>Typical layout</i>	 <i>Turbine range</i>

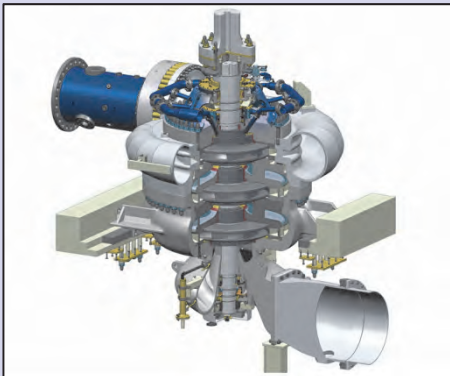
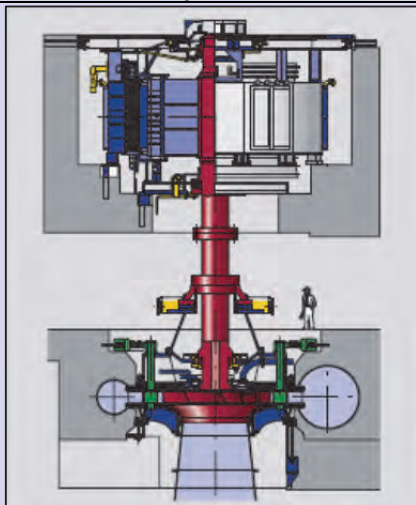
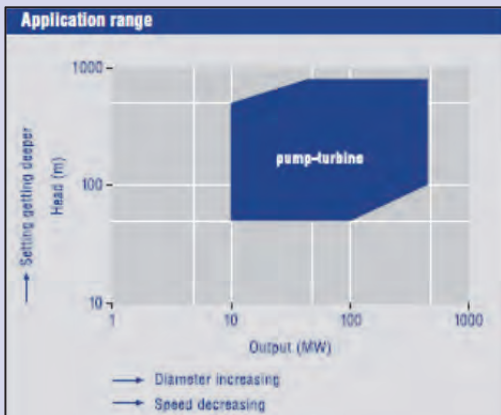


Turbine Name:	FRANCIS TURBINE
Company name:	Mavel Hydro Turbines (Scion Technologies (South African Distribution))
Company Address:	Northbank 3 rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel:	+27 21 552 9993
Company E-mail:	karenr@sciontechnologies.co.za
Website:	www.mavel.cz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

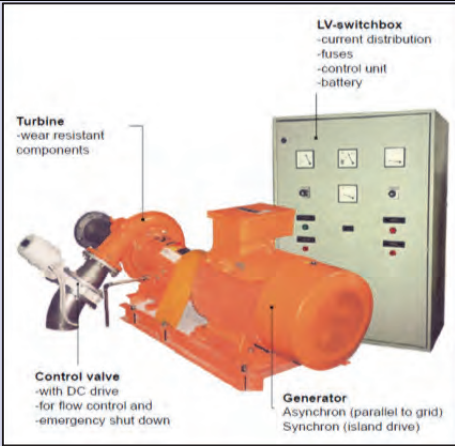
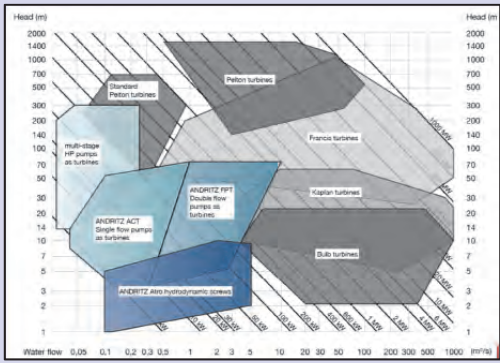
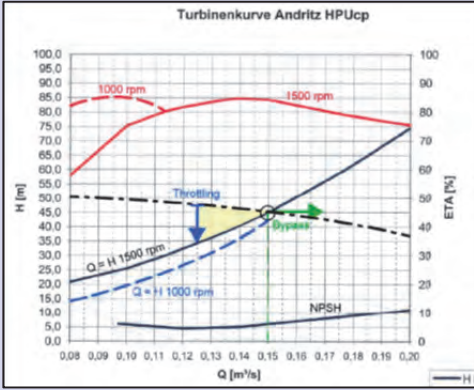


Turbine Name:	FRANCIS TURBINE	
Company name:	Voith Hydro Holding GmbH & Co. KG	
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY	
Company Tel:	+49 7321 37 0	
Company E-mail:	info.voithhydro@voith.com	
Website:	www.voithhydro.com	
Turbine Description:	The Voith Francis turbines are used primarily 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:	 <i>Francis turbine runner</i>	 <i>Turbine layout</i>
	 <i>Cross section of a Francis turbine</i>	 <i>Turbine range</i>

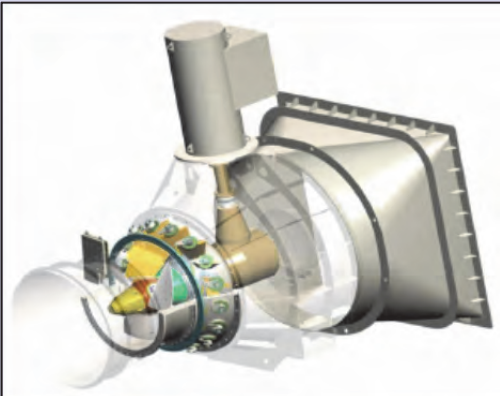
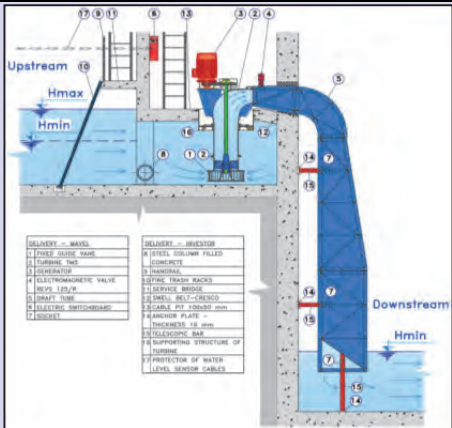
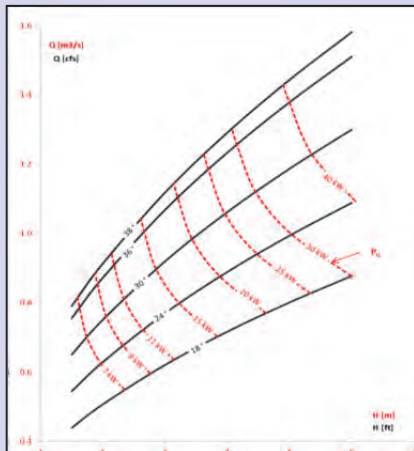


Turbine Name:	PUMP-AS-TURBINE	
Company name:	Voith Hydro Holding GmbH & Co. KG	
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY	
Company Tel:	+49 7321 37 0	
Company E-mail:	info.voithhydro@voith.com	
Website:	www.voithhydro.com	
Turbine Description:	These machines can function both as turbines and, in reverse direction, as pumps. They are generally used in pumped storage schemes.	
Pressure Head Range	50 m to 900 m	
Flow Range	Not given	
Power Range	10 MW to 500 MW	
Illustrations and Applicable Graphs:	 <i>Turbine runner for Palmiet, South Africa</i>	 <i>Turbine layout</i>
	 <i>Cross of a variable speed pump-turbine runner</i>	 <i>Turbine range</i>

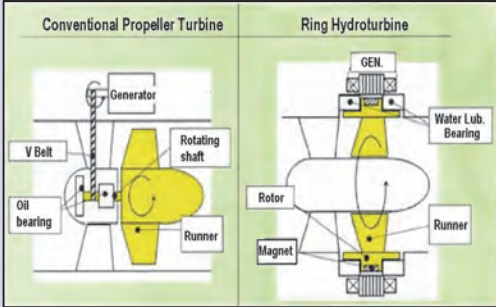
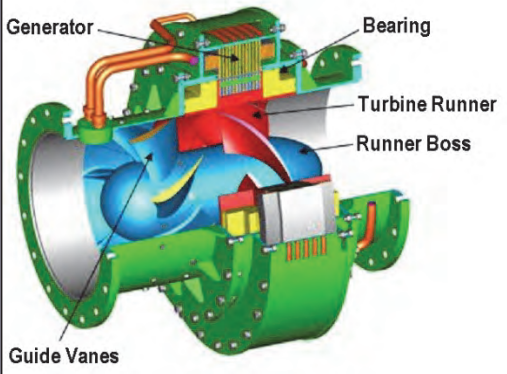
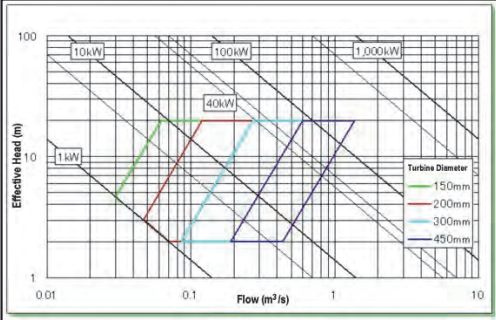


Turbine Name:	PUMP-AS-TURBINE	
Company name:	Andritz	
Company Address:	Penzinger Strasse 76 Vienna AUSTRIA 1141	
Company Tel:	+43 (1)891 00 0	
Company E-mail:	hydro@andritz.com	
Website:	www.andritz.com	
Turbine Description:	This turbine utilizes a centrifugal pump in reverse to generate electricity 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 m³/s to 6 m³/s	
Power Range	30 kW to 10 000 kW	
Illustrations and Applicable Graphs:	 <i>Installed turbines</i>	 <i>Turbine components</i>
	 <i>Turbine range</i>	 <i>Turbine curve</i>

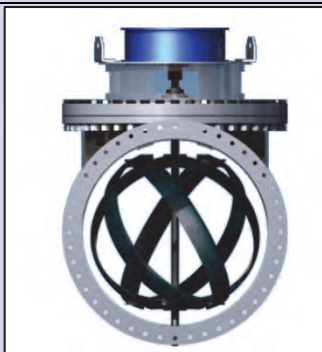
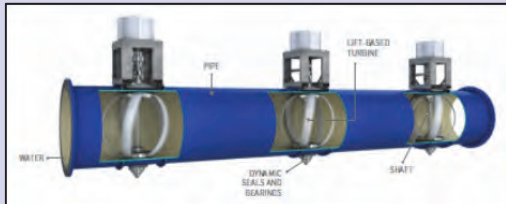
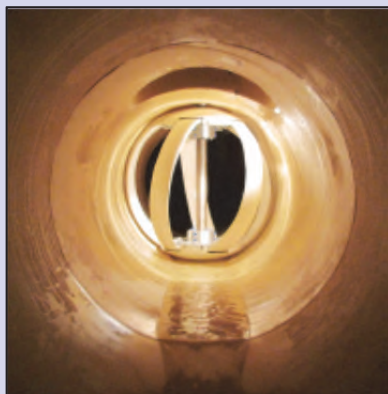


Turbine Name:	SYPHON-TYPE TURBINE		
Company name:	Mavel Hydro Turbines (Scion Technologies (South African Distribution))		
Company Address:	Northbank 3 rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA		
Company Tel:	+27 21 552 9993		
Company E-mail:	karenr@sciontechnologies.co.za		
Website:	www.mavel.cz		
Turbine Description:	Mavel Micro turbines are designed to function with low head and work on the principle of syphoning water over a weir. Turbines can be placed in parallel or series.		
Pressure Head Range	1.5 m to 6 m		
Flow Range	0.15 m ³ /s to 4.5 m ³ /s (per turbine)		
Power Range	1 kW to 180 kW		
Illustrations and Applicable Graphs:	 <i>Three micro turbines in parallel</i>		 <i>Turbine layout</i>
	 <i>Construction drawing of a syphon turbine</i>		 <i>Turbine range (MT5)</i>



Turbine Name:	RING HYDROTURBINE		
Company name:	Kawasaki Plant Systems Ltd.		
Company Address:	1-14-5, Kaigan, Minato-ku Toyo JAPAN		
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 requires little maintenance.		
Pressure Head Range	3 m to 30 m		
Flow Range	0.14 m ³ /s to 2.8 m ³ /s		
Power Range	20 to 500 kW		
Illustrations and Applicable Graphs:	 <i>Ring hydroturbine</i>		 <i>Ring and propeller comparison</i>
	 <i>Turbine layout</i>		 <i>Turbine ranges</i>



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:		 <i>Three Lucidpipe turbines in series</i>
	 <i>Turbine in pipe</i>	 <i>Installed turbine</i>







APPLICATION FOR AN ELECTRICITY GENERATION
LICENCE IN TERMS OF THE ELECTRICITY REGULATION
ACT, 2006 (ACT NO. 4 OF 2006).

Please return completed form to:

HOD: Electricity Licensing and Compliance
National Energy Regulator of South Africa
Kulawula House, 526 Vermeulen Street
Arcadia, 0083
Pretoria

Or:

HOD: Electricity Licensing and Compliance
National Energy Regulator of South Africa
P.O. Box 40343
Arcadia
0007

Tel (012) 401 - 4600
Fax (012) 401 - 4700

SECTION A PARTICULARS OF APPLICANT

A1 Full name of applicant (business name) and business registration number

A2 Address of applicant, or in the case of a body corporate, the registered head office

Physical address

Postal address

A3 Telephone number of applicant

() _____

A4 Fax number of applicant

() _____

A5 Email address of applicant

A6 Contact person

First name _____

Surname _____

Telephone No _____

Mobile No _____

Fax No. _____

Email address _____

A7 Legal form of applicant

Note to Section A

- 1) State whether the applicant is a local government body, a juristic person established in terms of an act of parliament, a department of state, a company or other legal body.
- 2) If the applicant is a local government body, attach a copy of the proclamation establishing such body. Where the applicant is a company, the full names of the current directors and the company registration number are required.

SECTION B COMMENCEMENT DATE OF LICENCE

B1 Desired date from which the licence (if granted) is to take effect

Note to Section B

- 3) The normal processing time for a licence application is 120 days once all relevant information has been provided and there are no objections received.
- 4) If the applicant intends operating more than one generation station under the proposed licence, please complete separate application forms for each generation station.

SECTION C PARTICULARS OF PROPOSED GENERATION STATION

C1 Name of generation station

C2 Geographical location of generation station (please attach maps)

C3 Address of generation station

C4 Contact person at generation station
First name and Surname _____
Telephone No _____
Mobile No _____
Fax No _____
Email address _____

C5 Type of generation station (thermal, nuclear, hydro, pumped storage, gas turbine, diesel generator or other)

C6 Expected commissioning date for a proposed generation station or at which the station was commissioned (if an existing station).

C7 The installed capacity (existing and/or planned) of each unit within the generation station (MW)

Existing Capacity

Planned Capacity

- C8 Maximum generation capacity (MW) expected to be available from the generation station and energy to be produced (MWh) over the next 5years of operation. These estimates should be based on modelling of how the power station will fit into the demand profile of its customers, taking into account the least cost energy purchase consideration and demand management options of customers.

YEAR	Max MW	Total MWh	Own use MWh	Export (Sales) MWh

- C9 Estimate of the energy conversion efficiency of the generation station.

- C10 Expected future life of the generation station.

**SECTION D PARTICULARS OF LONG TERM ARRANGEMENTS
WITH PRIMARY ENERGY SUPPLIERS**

D1 Name of primary energy supplier/s (mining house, colliery or other fuel supplier)

D2 Particulars of the contractual arrangements with primary energy supplier

Notes to Section D

- 5) Please provide brief particulars of any long term agreements entered into with fuel suppliers and copies of such contracts (Signed Fuel Supply Agreements).

**SECTION E MAINTENANCE PROGRAMMES AND
DECOMMISSIONING COSTS**

- E1 Details of any proposed major maintenance programmes, including the expected cost and duration thereof, covering the next six years. Project proposals to state the expected availability, planned outage rate and forced outage rate of the plant over the first five years of operation.

- E2 Details of any major decommissioning costs expected during the life span of the power station and provided for in the project feasibility study.

- E3 Details of major generation station expansion and modifications planned for in the feasibility study (Dates, Costs in Rands (state year) and description)

SECTION F CUSTOMER PROFILE

- F1 Particulars of the person or persons to whom the applicant is providing or intends to provide electricity from the generation station

- F2 Network connection details (connection points, voltages, wheeling arrangement, single line diagram)

- F3 Provide summary details of Power Purchase Agreements with customer including purchasing price etc. (Please attach Power Purchase Agreements).

Notes to Section F

- 6) For example, supply to ESKOM or supply to local government distribution system. Please include the details of power purchase agreements entered into and the price structure of the contract.

SECTION G FINANCIAL INFORMATION

- G1 Submit projections of and current statements of the accounts in respect of the undertaking carried on by the applicant, showing the financial state of affairs of the most recent period, together with copies of the latest audited annual accounts where such have been prepared.
- G2 Submit annual forecasts for the next five years of costs, sales and revenues generated by the project, stating the assumptions underlying the figures.
- G3 Estimates of net annual cash flows for subsequent periods (5 years; 10 years; 15 years) sufficient to demonstrate the financial security and feasibility of operating the generation station.
- G4 Project financing: Who will finance the project, how is funding split between debt and equity, and what is the terms and conditions of the funding agreements.

Notes to Section G

- 7) The financial projections should be based on a production plan for the generation station and the revenue generated by participating in the electricity market and by bilateral contracts (Power Purchase Agreements) with customers. Reference to the latest version of National Integrated Resource Plan (IRP) is required to demonstrate that the proposed power purchase agreement is the least cost solution available to the electricity purchaser.

SECTION H HUMAN RESOURCES INFORMATION

- H1 Submit details of the number of staff and employees and their categories in the service of the applicant at the generation station and in any support services separate from the generation station. Also provide information regarding relevant qualifications and experience in critical areas e.g. Professional registration (Engineering Council of South Africa i ECSA), Government Certificate of Competency.

**SECTION I PERMISSION FROM OTHER GOVERNMENT
DEPARTMENTS OR REGULATORY AUTHORITIES**

- I1 What progress has been made to obtain the required permits and approvals for the generation project? Please provide copies of permits issued by the relevant environmental and safety agencies in respect of the operation of the generation station.

SECTION J**BROAD-BASED BLACK ECONOMIC EMPOWERMENT**

J1 Please provide information in terms of the following categories:

COMPONENTS	POINTS	0.5	0.75	1
Direct Empowerment	Black Ownership	10% to <20%	20% to 50%	>50%
	Black Management	20% to <35%	35% to 50%	>50%
	Black Female Management	1% to <5%	5% to 10%	>10%
Human Resource Development	Black Skilled Personnel as % of payroll	20% to <35%	35% to 50%	>50%
	Skills Development Programs as % of payroll	1% to <5%	5% to 10%	>10%
	Employment Equity i.e. Women Representation	20% to <35%	35% to 50%	>50%
Indirect Empowerment	Procurement from Black/BEE Suppliers	20% to <35%	35% to 50%	>50%
	Enterprise Development i.e. Monetary Investment or quantifiable non-monetary support in SMME with BEE contributions as % of Net Asset Value/ EBITDA/Total Procurement	10% to <20%	20% to 25%	>25 %
	Industry specific initiatives to facilitate the inclusion of black people in the sector as % of net profit	1% to <5%	5% to 10%	>10%
NERSA's Discretionary Points	Based on skills transfer and fulfilment or acceleration of other national objectives e.g. employment of disabled personnel robust implementation of mechanisms to verify the BEE status of suppliers reported under preferential procurement and utilization of DTI approved accreditation agencies and so on.	1% to <5%	5% to 10%	>10%

SECTION K ADDITIONAL INFORMATION

Provide any other relevant information related to this application

This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slight shadow on the right side, suggesting it's resting on a surface.

SECTION L DECLARATION

On behalf of the applicant, I hereby declare that:

- (a) the applicant shall at all times comply in every respect with the conditions attached to any licence that may be granted to the applicant;
- (b) the applicant shall at all times comply with lawful directions of the National Energy Regulator of South Africa;
- (c) the information provided by me on behalf of the applicant is accurate and complete in all respects; and
- (d) I am authorised to make this declaration on behalf of the applicant.

Signed:

--

Full name(s) of Signator(y/ies):

--	--

Position held (if the applicant is a company, co-operative, partnership, unincorporated association or any other body corporate):

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Date:

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APPENDIX C

CHD TOOL - DEFAULT VALUES AND FUNCTIONS

1. INTRODUCTION

This appendix discusses the derivations and assumptions relevant to all default values and functions in the CHD Tool. It is important that users understand the origin of default values and functions, so that they may be altered if different circumstances are prevalent for a certain project.

2. DEFAULT VALUES

Table C-1 shows all the default values used in the CHD Tool that are not related to project economics, with motivation for each of the default values.

Table C-1: Default values not related to economic analyses

Component	Abbreviation	Applicable phase	Default value	Unit	Motivation
Fluid density	(ρ)	1, 2, 3	1 000	kg/m ³	Industry-accepted value (Chadwick et al., 2004)
Gravitational acceleration	(g)	1, 2, 3	9.81	m/s ²	Industry-accepted value (Chadwick et al., 2004)
Efficiency	(η)	1, 2, 3	70	%	BHA (2005) considers this typical system efficiency for micro-hydropower systems.
Annual operational percentage		1	60	%	Conservative value
Percentage of peak pressure head used		1	60	%	Based on comparative values between Phase 1 and Phase 2 potential power for the three case studies.
Annual maintenance days		2, 3	7	days	Conservative assumption

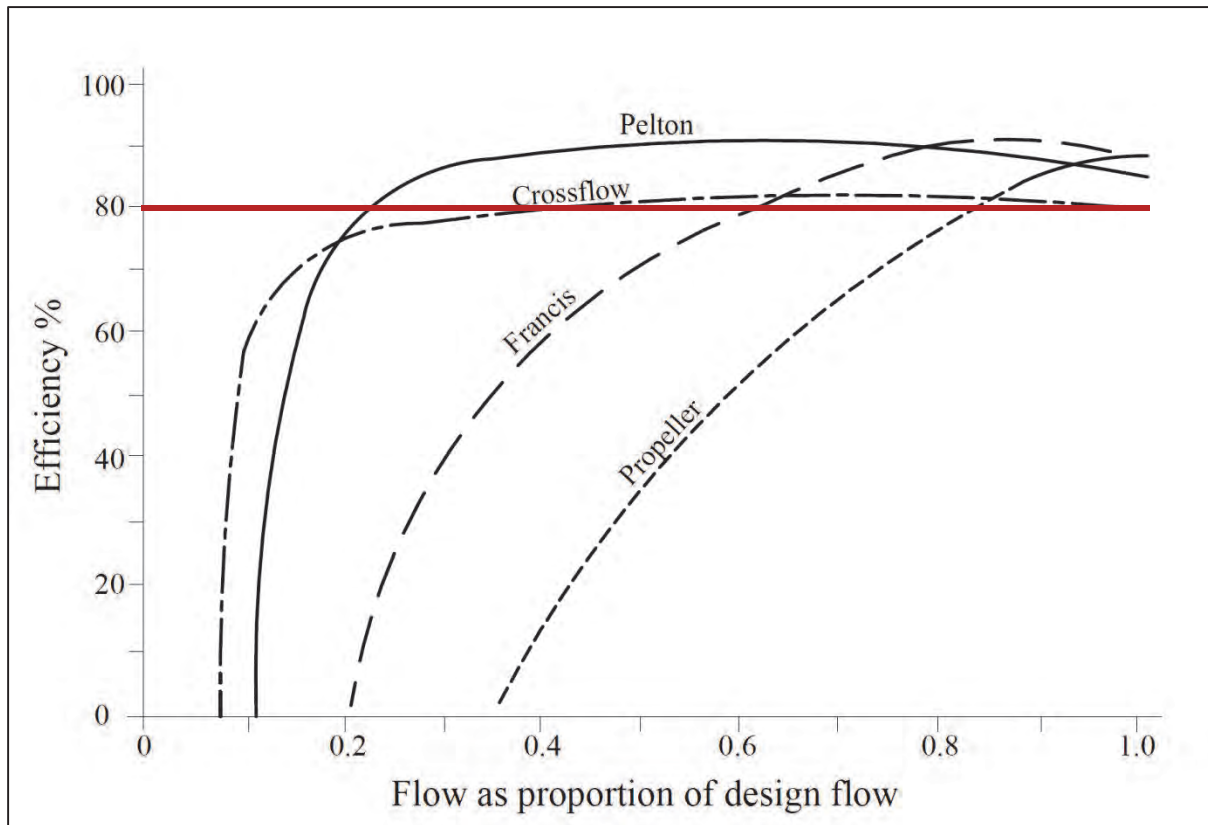


Figure C-1: Typical turbine part-flow efficiencies (Paish, 2002)

3. FUNCTIONS USED FOR ECONOMIC ANALYSES

The following sections will discuss the default values and functions applicable to the economic analyses for each of the three phases.

3.1 Cost Functions and Default Cost Values

Various sources were studied in an attempt to include realistic cost functions in the CHD Tool. These cost functions were compared using a turbine with a capacity of 1 MW and an available pressure head of 85 m, which can be seen as a typical head for a high pressure conduit hydropower installation. As indicated in **Table C-2** there are major discrepancies between the values obtained using cost functions from different sources. The turbine cost functions used in the CHD Tool were chosen from functions used in articles in peer reviewed journals and adapted using applicable inflation and exchange rates to suit South African circumstances. The applicable information is shown in **Tables C-3 to C-8**.

Tables C-9 to C-11 was populated using information gathered by Barta (2012), considering South African hydropower installations.

Table C-2: Typical turbine cost comparison

Typical turbine cost comparison (R/MW)				
Turbine	Source			
	Aggidis et al. (2010)	Ogayar and Vidal (2009)	Singal et al. (2010)	USBR (2011b)
Pelton	R 1 787 000	R 5 359 900		R 2 767 000
Kaplan (low head)	R 6 327 800	R 4 677 400		R 5 925 600
Kaplan (high head)	R 2 589 500			R 5 776 700
Francis (low head)	R 3 111 500			
Francis (medium head)	R 6 154 900	R 4 002 100		R 3 084 000
Francis (high head)	R 2 791 600			R 3 458 800
Other turbines			R 1 573 500	R 3 084 000

Table C-3: Overall project cost function for capacities above 20 kW

Component	Overall cost
Original cost function (£)	$C_{Pr}=45\,500\times\left(\frac{P}{H^{0.3}}\right)^{0.6}$
Source	Aggidis et al. (2010)
Cost function base year	2008
Base currency	Pound Sterling (£)
Average inflation rate	3.20%
Exchange rate (12 January 2013)	R 14.08/£
Modified cost function (R)	$C_{Pr}=600\,000\times\left(\frac{P}{H^{0.3}}\right)^{0.6}$
Motivation	Adapted for inflation and exchange rate from a conservative cost function in a peer reviewed journal, bearing in mind that conventional hydropower has a larger civil construction component than conduit hydropower (40% vs. 20%) (Ogayar and Vidal, 2009 and Barta, 2012)

Table C-4: Initial overall project cost function for pico installations (capacity < 20 kW)

Component	Overall cost
Original cost function (£)	$C_{Pr}=25\,000\times\left(\frac{P}{H^{0.35}}\right)^{0.65}$
Source	Aggidis et al. (2010)
Cost function base year	2008
Base currency	Pound Sterling (£)
Average inflation rate	3.20%
Exchange rate (12 January 2013)	R 14.08/£
Modified cost function (R)	$C_{Pr}=333\,500\times\left(\frac{P}{H^{0.35}}\right)^{0.65}$
Motivation	Adapted for inflation and exchange rate from a conservative cost function (for applications with pressure head between two and 30m) in a peer reviewed journal, bearing in mind that conventional hydropower has a larger civil construction component than conduit hydropower (40% vs. 20%) (Ogayar and Vidal, 2009 and Barta, 2012)

However, from the Pierre van Ryneveld case study, where actual capital expenditure was only R 546 000 (excluding design and construction related cost, that would amount to approximately R 140 000), the function was therefore adjusted as shown in **Table C-5**, to offer a slightly less conservative capital expenditure value of R 704 600 for the Pierre van Ryneveld case study.

Table C-5: Final overall project cost function for pico installations (capacity < 20 kW)

Component	Overall cost
Original cost function (£)	$C_{Pr}=333\,500\times\left(\frac{P}{H^{0.35}}\right)^{0.65}$
Source	Derived in Table C-4
Pierre van Ryneveld case study value	R 891 000
Modified cost function (R)	$C_{Pr}=265\,000\times\left(\frac{P}{H^{0.3}}\right)^{0.6}$
Pierre van Ryneveld case study value	R 718 200
Motivation	Adapted for inflation and exchange rate from a conservative cost function (for applications with pressure head between two and 30 m) in a peer reviewed journal, bearing in mind that conventional hydropower has a larger civil construction component than conduit hydropower (40% vs. 20%) (Ogayar and Vidal, 2009 and Barta, 2012) and then adjusted to suit the actual project cost at the Pierre van Ryneveld plant.

Using the adapted function (C_{Pr}) for a typical 1 MW installation, will lead to a total project cost of R 17 000 000. Subtracting a typical turbine cost of R 3 700 000 (derived using the average of used cost functions, for a typical 1 MW installation), will give a total project cost (excluding turbine) of R 13 300 000. This value was used as the default value for “Capital cost per MW installed (excl. turbine cost)” used in the Phase 2 analysis.

Table C-6: Pelton turbine cost function

Component	Pelton turbine
Original cost function (€/kW)	$C_{PEL}=17\,693\times P^{-0.3644725}\times H^{-0.281735}$
Source	Ogayar and Vidal (2009)
Cost function base year	2007
Base currency	Euro (€)
Average inflation rate	2.01%
Exchange rate (12 January 2013)	R 11.65/€
Modified cost function (R)	$C_{PEL}=232\,300\times P^{0.6355275}\times H^{-0.281735}$
Motivation	Adapted for inflation and exchange rate from a conservative cost function in a peer reviewed journal

Table C-7: Small Kaplan turbine cost function

Component	Kaplan turbine (small)
Original cost function (€/kW)	$C_{K1}=3\,500 \times (P)^{0.68}$
Applicability	Flow rates 0.5 m ³ /s to 5 m ³ /s
Source	Aggidis et al. (2010)
Cost function base year	2008
Base currency	Pound Sterling (£)
Average inflation rate	3.20%
Exchange rate (12 January 2013)	R 14.08/£
Modified cost function (R)	$C_{K1}=57\,700 \times (P)^{0.68}$
Motivation	Adapted for inflation and exchange rate from a conservative cost function in a peer reviewed journal

Table C-8: Large Kaplan turbine cost function

Component	Kaplan turbine (large)
Original cost function (£)	$C_{K2}=14\,000 \times (P)^{0.35}$
Applicability	Flow rates 5 m ³ /s to 30 m ³ /s
Source	Aggidis et al. (2010)
Cost function base year	2008
Base currency	Pound Sterling (£)
Average inflation rate	3.20%
Exchange rate (12 January 2013)	R 14.08/£
Modified cost function (R)	$C_{K2}=230\,700 \times (P)^{0.35}$
Motivation	Adapted for inflation and exchange rate from a conservative cost function in a peer reviewed journal

Table C-9: Francis turbine cost function

Component	Francis turbine
Original cost function (€/kW)	$C_F=25\,698 \times P^{-0.560135} \times H^{-0.127243}$
Source	Ogayar and Vidal (2009)
Cost function base year	2007
Base currency	Euro (€)
Average inflation rate	2.01%
Exchange rate (12 January 2013)	R 11.65/€
Modified cost function (R)	$C_F=337\,400 \times P^{0.560135} \times H^{-0.127243}$
Motivation	Adapted for inflation and exchange rate from a conservative cost function in a peer reviewed journal

Table C-10: Other turbines cost function

Component	Other turbines
Original cost function (€/kW)	$C_{OT}=25\,698 \times P^{-0.560135} \times H^{-0.127243}$
Source	Ogayar and Vidal (2009)
Cost function base year	2007
Base currency	Euro (€)
Average inflation rate	2.01%
Exchange rate (12 January 2013)	R 11.65/€
Modified cost function (R)	$C_{OT}=337\,350 \times P^{-0.560135} \times H^{-0.127243}$
Motivation	The USBR (2011b) proposes a similar cost function for Francis turbines and other turbines (excluding Kaplan and Pelton). Therefore, the chosen function for Francis turbines was applied for other turbines. It was a conservative cost function in a peer reviewed journal.

Table C-11: Initial planning cost functions

Initial planning cost (IPC) (Total IPC in 2010 was R 1 200 000 per MW (Barta, 2012))			
Component	Percentage of IPC for component	Source	Motivation
Legal and regulatory	3%	Barta (2012)	Although the source is unpublished, the information has been derived from a continuing study on SA hydropower installations and percentages correlate well with those in Chutachindakate (2012), and USBR (2011b)
Environmental and social assessment	27%		
Investigation and preliminary design	70%		

Table C-12: Capital expenditure cost functions

Capital expenditure cost (CEC)				
Component	Percentage of CEC		Source	Motivation
	(Incl. turbine)	(Excl. turbine)		
Preliminary and general	20.0%	24.5%	Barta (2012)	Although the source is unpublished, the information has been derived from a continuing study on South African hydropower installations and percentages correlate well with those in Chutachindakate (2012), Aggidis (2009) and USBR (2011b)
Access to site	0.5%	0.5%		
Pipework and valves	5.0%	6.5%		
Power station housing	15.0%	20.0%		
Electrical and mechanical	30.0%	12.0%		
Transformer/ transmission	10.0%	12.5%		
Construction management	4.5%	5.5%		
Contingency	14.0%	17.0%		
Disposal	1.0%	1.5%		

Table C-13: Annual operation and maintenance cost functions

Annual operation and maintenance cost (OMC)			
Component	Percentage of CEC for component	Source	Motivation
Civil	0.25%	Barta (2012)	Although the source is unpublished, the information has been derived from a continuing study on South African hydropower installations and percentages correlate well with those in Chutachindakate (2012), and USBR (2011b)
Electrical and mechanical	2.00%		
Transmission	0.80%		
Operation	0.40%		
Insurance	0.30%		
Overall	1.0%		

3.2 Electricity Tariffs

Table C-14 shows the calculations that were performed to obtain an average rate (in c/kWh) for Megaflex tariffs in 2012-2013. Megaflex tariffs were used; as this is the tariff structure paid by metropolitan municipalities, like the City of Tshwane, to Eskom. This rate does not include reactive energy charges, distribution network charges or service and administration charges, but the entire tariff structure can be seen in **Table C-15** with the peak and off-peak periods depicted in **Figure C-2** (Eskom, 2012c).

Table C-14: Average value of generated electricity for Megaflex tariffs

[illegible]

Table C-15: Megaflex local authority rates 2012-2013 (Eskom, 2012c)

		Active energy charge [c/kWh]												Transmission network charges [R/kVA/m]	
Transmission zone	Voltage	High demand season [Jun - Aug]						Low demand season [Sep - May]							
		Peak	Standard	Off Peak	Peak	Standard	Off Peak	Peak	Standard	Off Peak	Peak	Standard	Off Peak		
		VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl	VAT incl
≤ 300km	< 500V	216.99	247.37	56.37	64.26	30.10	34.31	60.54	69.02	37.06	42.25	25.89	29.51	R 5.40	R 6.16
	≥ 500V & < 66kV	210.06	239.47	54.61	62.26	29.16	33.24	58.65	66.86	35.95	40.98	25.13	28.65	R 4.94	R 5.63
	≥ 66kV & ≤ 132kV	202.47	230.82	52.68	60.06	28.18	32.13	56.58	64.50	34.70	39.56	24.28	27.68	R 4.81	R 5.48
	> 132kV	195.39	222.74	50.91	58.04	27.28	31.10	54.65	62.30	33.55	38.25	23.53	26.82	R 6.09	R 6.94
> 300km and ≤ 600km	< 500V	219.14	249.82	56.90	64.87	30.37	34.62	61.13	69.69	37.39	42.62	26.15	29.81	R 5.46	R 6.22
	≥ 500V & < 66kV	212.11	241.81	55.12	62.84	29.43	33.55	59.22	67.51	36.26	41.34	25.36	28.91	R 4.98	R 5.68
	≥ 66kV & ≤ 132kV	204.44	233.06	53.18	60.63	28.47	32.46	57.13	65.13	35.01	39.91	24.51	27.94	R 4.84	R 5.52
	> 132kV	197.32	224.94	51.42	58.62	27.52	31.37	55.19	62.92	33.86	38.60	23.69	27.01	R 6.15	R 7.01
> 600km and ≤ 900km	< 500V	221.28	252.26	57.44	65.48	30.61	34.90	61.70	70.34	37.75	43.04	26.37	30.03	R 5.52	R 6.29
	≥ 500V & < 66kV	214.23	244.22	55.64	63.43	29.71	33.87	59.77	68.14	36.59	41.71	25.58	29.16	R 5.04	R 5.75
	≥ 66kV & ≤ 132kV	206.47	235.38	53.69	61.21	28.71	32.73	57.65	65.72	35.32	40.26	24.73	28.19	R 4.89	R 5.57
	> 132kV	199.30	227.20	51.86	59.12	27.79	31.68	55.74	63.54	34.17	38.95	23.92	27.27	R 6.23	R 7.10
> 900km	< 500V	223.48	254.77	58.00	66.12	30.92	35.25	62.29	71.01	38.08	43.41	26.63	30.36	R 5.54	R 6.32
	≥ 500V & < 66kV	216.33	246.62	56.18	64.05	29.98	34.18	60.35	68.80	36.92	42.09	25.84	29.46	R 5.09	R 5.80
	≥ 66kV & ≤ 132kV	208.53	237.72	54.19	61.78	28.97	33.03	58.21	66.36	35.68	40.68	24.95	28.44	R 4.91	R 5.60
	> 132kV	201.26	229.44	52.37	59.70	28.01	31.93	56.22	64.09	34.49	39.32	24.15	27.53	R 6.27	R 7.15

Electrification and rural subsidy [c/kWh]		Environmental levy charge [c/kWh]				Reactive energy charge [c/kvarh]			
All seasons		Apr 2012 to Jun 2012		Jul 2012 to Mar 2013		High season		Low season	
VAT incl		VAT incl		VAT incl		VAT incl		VAT incl	
4.56	5.20	2.00	2.28	3.50	3.99	8.72	9.94	0.00	0.00

Distribution network charges				
Voltage	Network access charge [R/kVA/m]		Network demand charge [R/kVA/m]	
	VAT incl		VAT incl	
< 500V	R 10.80	R 12.31	R 20.49	R 23.36
≥ 500V & < 66kV	R 9.90	R 11.29	R 18.78	R 21.41
≥ 66kV & ≤ 132kV	R 9.59	R 10.93	R 18.20	R 20.75
> 132kV	R 0.00	R 0.00	R 16.41	R 18.71

Monthly utilised capacity	Service charge [R/Account/day]		Administration charge [R/POD/day]	
	VAT incl		VAT incl	
> 1 MVA	R 123.36	R 140.63	R 55.59	R 63.37
Key customers	R 2 417.62	R 2 756.09	R 77.20	R 88.01

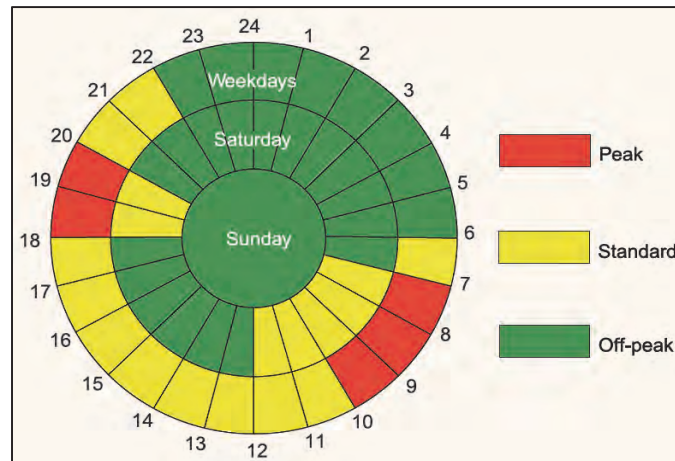


Figure C-2: Eskom's defined time periods for Megaflex (Eskom 2012c)

3.3 Inflation rates

Figure C-3 shows the general inflation rate in South Africa between 1997 and 2012, with estimated inflation rates for 2013 and 2014 (National Treasury, 2012). The average inflation rate in the country for the last ten years (2003 to 2013) is approximately 5.9%.

For many years, the average inflation in electricity tariffs in the country was below general inflation. However, this situation changed in 2003, as indicated in **Figure C-3** (Eskom, 2007). Since April 2008, electricity tariff increases have been significantly above inflation every year. NERSA has recently approved an average annual electricity hike of 8% for the next five years until April 2017. This will cause an average electricity tariff increase of more than 220% between 1997 and 2017 (Eskom, 2012b; Eskom 2012e; Eskom 2013b), as shown in **Figure C-4**.

The main reason for the significant hike in electricity prices is because electricity generation has been subsidized for many years. It has therefore been supplied at below cost to consumers. However, this practice is not sustainable and electricity prices need to become cost-reflective to support a sustainable industry in future. (Eskom, 2012b) Therefore, as the approved annual increase of 8% was significantly below the 16% applied for, it is expected that higher-than-inflation electricity tariff increases will continue for a number of years until electricity prices are more cost-reflective.

As it is difficult to accurately estimate inflation even for 5 or 10 years, the average general inflation in the country was used as a default value for general, operation, and maintenance inflation. However, electricity inflation was estimated higher, especially after 2017, as Eskom will probably continue to strive to become cost-reflective. The higher rates were estimated for the next 15 years, until 2027, from where general inflation was assumed for electricity tariffs.

Maintenance factors were populated assuming that little maintenance will be necessary in the first few years of operation, but increasing as the equipment ages.

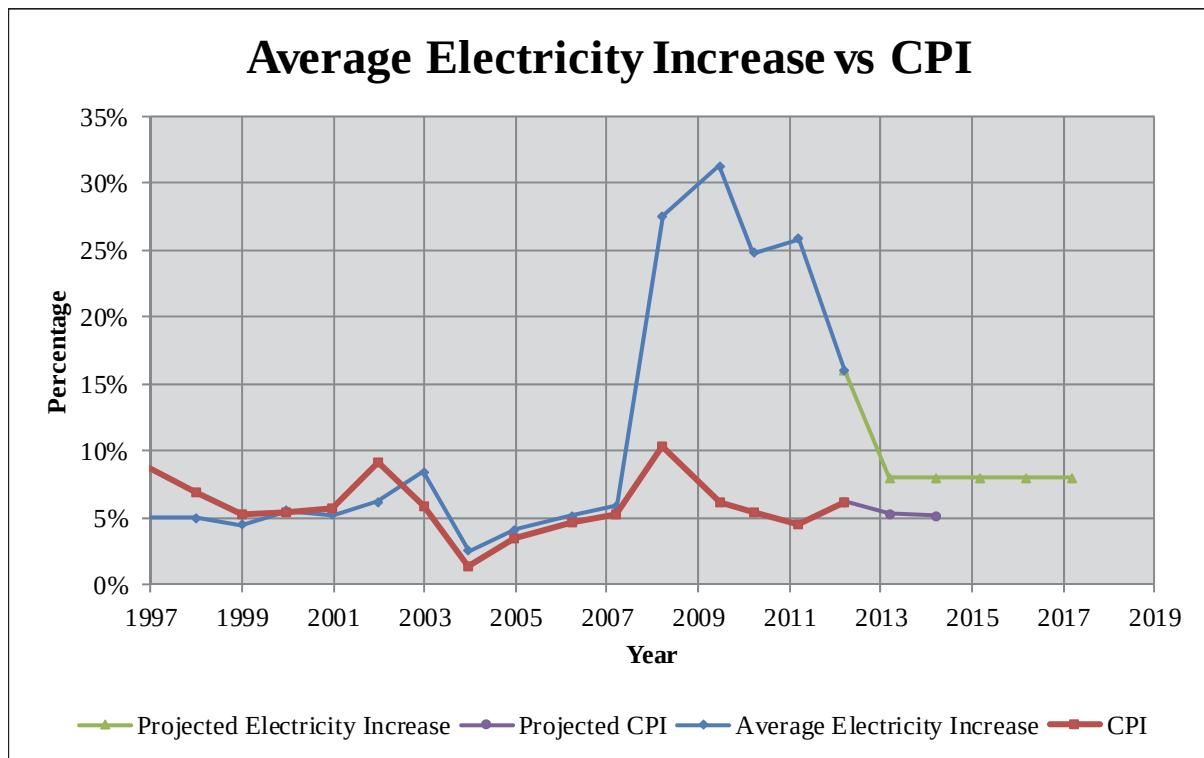


Figure C-3: Average energy increases vs. CPI (Eskom, 2007; 2012b; Eskom 2012e; National Treasury, 2012; Eskom 2013b)

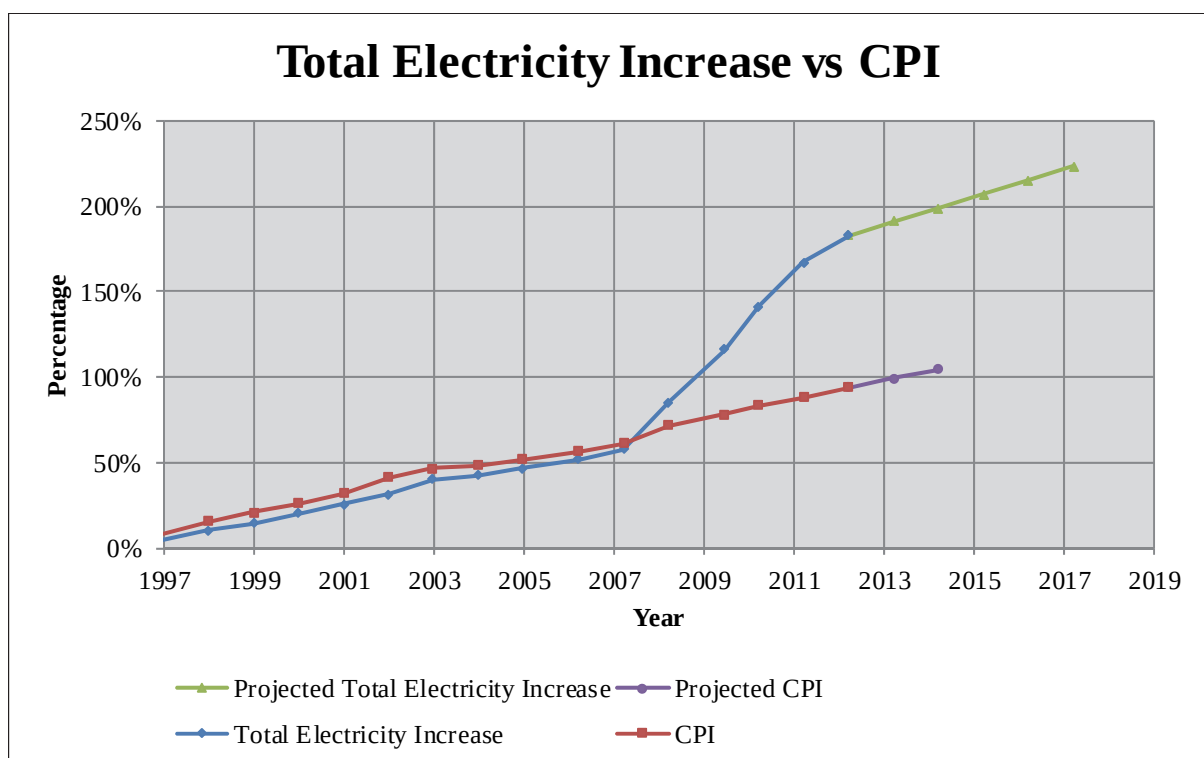


Figure C-4: Total energy increases vs. CPI (Eskom, 2007; 2012b; Eskom 2012e; National Treasury, 2012; Eskom 2013b)

Table C-16: Default inflation rates in CHD Tool

Inflation and maintenance factors over design life					
Year	Annual inflation				Maintenance factor
	Electricity	Operation	Maintenance	General	
2013	8.0%	5.3%	5.3%	5.3%	0.8
2014	8.0%	5.1%	5.1%	5.1%	0.8
2015	8.0%	6.0%	6.0%	6.0%	0.8
2016	8.0%	6.0%	6.0%	6.0%	0.8
2017	8.0%	6.0%	6.0%	6.0%	0.8
2018	10.0%	6.0%	6.0%	6.0%	1
2019	10.0%	6.0%	6.0%	6.0%	1
2020	10.0%	6.0%	6.0%	6.0%	1
2021	10.0%	6.0%	6.0%	6.0%	1
2022	10.0%	6.0%	6.0%	6.0%	1
2023	10.0%	6.0%	6.0%	6.0%	1
2024	10.0%	6.0%	6.0%	6.0%	1
2025	10.0%	6.0%	6.0%	6.0%	1
2026	10.0%	6.0%	6.0%	6.0%	1
2027	10.0%	6.0%	6.0%	6.0%	1
2028	6.0%	6.0%	6.0%	6.0%	1.2
2029	6.0%	6.0%	6.0%	6.0%	1.2
2030	6.0%	6.0%	6.0%	6.0%	1.2
2031	6.0%	6.0%	6.0%	6.0%	1.2
2032	6.0%	6.0%	6.0%	6.0%	1.2
2033	6.0%	6.0%	6.0%	6.0%	1.25
2034	6.0%	6.0%	6.0%	6.0%	1.25
2035	6.0%	6.0%	6.0%	6.0%	1.25
2036	6.0%	6.0%	6.0%	6.0%	1.25
2037	6.0%	6.0%	6.0%	6.0%	1.25
2038	6.0%	6.0%	6.0%	6.0%	1.25

	eThekweni Electricity MV/LV Operations	APPLICATION FOR THE CONNECTION OF EMBEDDED GENERATION		
		Page 1		

Return Completed Forms To:	Roy Wienand Deputy Head MV/LV Operations eThekweni Electricity P O Box 147 Durban 4000	Telephone : (031) 311 9006 Facsimile : (031) 306 3196
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Applicant Contact Details	Name Telephone Number Cell Number Facsimile Number E-Mail Address Address	
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Electricity Account Holder and Number (Only if embedded generation is to be connected within an eThekweni Electricity consumer's network)	
--	--

Address of Embedded Generator Installation	
---	--

Mode of Embedded Generation: (Tick appropriate box)	Energy from Embedded Generation to be used solely within a consumer's electricity network Energy from Embedded Generation to be used within a consumer's electricity network and excess to be exported to eThekweni Electricity's distribution network Energy from Embedded Generation to be used solely for exporting to eThekweni Electricity's distribution network Energy from Embedded Generation to be used solely for wheeling to third party through eThekweni Electricity's distribution network	
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Energy/Fuel Source for Embedded Generation: Eg: Coal, Gas, Bagasse, Hydro, Wind, Photo-Voltaic, etc	
Expected Life of Embedded Generation Project	years

Type of Energy Conversion: Eg: Synchronous Generator, Asynchronous/Induction Generator, Inverter, Fuel Cells, etc	
---	--

Total Capacity of Embedded Generation (kVA) and PF Attach schedule for each unit if more than one generation unit		kVA		PowerFactor
---	--	-----	--	-------------

Total Export Generation Capacity ((kVA) and PF) (Maximum power intended for export into eThekweni Electricity's distribution network)		kVA		PowerFactor
---	--	-----	--	-------------

Proposed Project Start Date	
------------------------------------	--



Proposed Project Completion Date

Electrical Parameters of Embedded Generation:	Positive Sequence Impedance	Negative Sequence Impedance	Zero Sequence Impedance
(All units in parallel, to be use for fault-level studies) Attach all generator and transformer data sheets for modeling analysis.			
Three phase symmetrical fault level contribution from the embedded generators			MVA

Generator Transformer Parameters (if generator transformer is used to step up the voltage level prior to export)

Rating in kVA	
Voltage Ratio(s) (kV/kV)	400V/11kV
Transformer Impedance	4,5 %
Tap Change range +/- in percentage	-5 % and 5 %
Tap Change step size in percentage	2,5 %
Tap Changer type, eg on-load, off load	Off load
Tap Changer location (HV or LV side)	HV
Winding Vector Group	Dyn11
Method of HV Winding earthing	None
Method of LV winding earthing	None
NER/NEC/NECR size	None

Point of Common Coupling:

(Isolation point to be used to connect/disconnect embedded generation from the Distribution Network, attach single-line diagram showing arrangement including consumer network)

Network Connection Point:

(In the case of applicant not being an existing consumer only, attach single-line diagram showing arrangement)

Protection Details: (Attach data sheets)

Method of synchronizing: (Auto/Manual, make and type of relay etc)	
Method of anti-islanding: (Details of scheme, relays to be used etc)	
Method of generator control: (AVR, speed, power, PF etc , relays to be used)	
Other protection to be Applied: (O/C,E/F, over/under voltage, over/under frequency, reverse power etc)	

Intended Recipient of Embedded Generation Output:

(Own use, eThekweni Electricity Consumer, eThekweni Electricity)

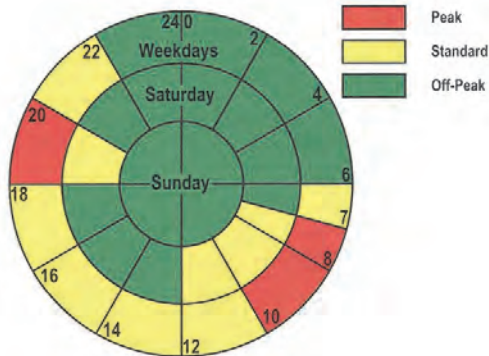
eThekweni Municipality



Has a Power Purchase Agreement been entered into with a Recipient:
(If Yes, supply details)

Under negotiation

Proposed Generation Power Output Levels:



	TOTAL GENERATION		EXPORT	
Peak Period		kWh		kWh
Standard Period		kWh		kWh
Off-Peak Period		kWh		kWh
TOTAL		kWh		kWh

Proposed Total Monthly Energy Generation:

(Attach schedule if monthly generation is not consistent, eg linked to availability of prime energy source)

Any projects in existence similar to the proposed embedded generation project:

Has Incentive Capital Funding been obtained for this Installation:

(State source(s) and amount)

Has a subsidy been granted for production of energy from this installation:

(State source(s) and amount)

List of Regulatory Approvals:

National Electricity Regulator in Terms of Electrical Act for >5GWh/annum or >500 kW

Department of Environmental Affairs & Tourism in terms of Environment Conservation Act etc

I agree to the terms in the Annexure

YES

NO

Application Completed

By:

Designation :

Date:

Signature:

ADDITIONAL COMMENTS



FOR OFFICE USE

Date Application Received:					Application Reference No:	
Further Information Required:	YES		NO		Date Received:	
Load Flow Analysis Required:	YES		NO		Date Complete:	
Fault Level / Protection Grading Study Required:	YES		NO		Date Complete:	
Approved in Principle:	YES		NO		Date Applicant Advised:	

ANNEXURE A

Responsibilities of Embedded Generators to eThekweni Electricity (Distributor)	
1	The Embedded Generator shall enter into a connection agreement with eThekweni Electricity (Distributor) before connecting onto the Distribution System.
2	The Embedded Generators shall ensure that the reliability and Quality of Supply complies with the terms of the connection agreement.
3	The Embedded Generator shall comply with the Distributor's protection requirement as well as protection of own plant against abnormalities, which could arise on the Distribution System.
4	The Embedded Generator shall be responsible for any dedicated connection costs incurred on the Transmission System or Distribution System as a result of connection of the Embedded Generation facility to the Distribution System.
5	The Embedded Generator shall be responsible for synchronizing the generating facility to the Distribution System within pre-agreed settings.
Connection Point Technical Requirements	
1	The Embedded Generator shall be responsible for the design, construction, maintenance and operation of the equipment on the generation side of the connection point.
2	The Embedded Generator shall be responsible for the provision of the site required for the installation of the Distributor's equipment required for connecting the generating facility.
3	The technical specifications of the connection shall be agreed upon by the participants based on the Distribution System Impact Assessment Studies.
4	A circuit breaker and visible isolation shall be installed at the connection point to provide the means of electrically isolating the Distribution System from the generating facility.
5	The Embedded Generator shall be responsible for the circuit breaker to connect and disconnect the generator plant.
6	The location of the circuit breaker and visible isolation shall be decided upon by the participants.

	eThekweni Electricity MV/LV Operations	APPLICATION FOR THE CONNECTION OF EMBEDDED GENERATION Page 5
Protection Requirement for Embedded Generators		
General Protection Requirements		
1	The Embedded Generator’s protection shall comply with the requirements of eThekweni Electricity.	
2	Additional features including inter-tripping and generator plant status to be agreed upon by the participants.	
3	The protection schemes used by the Embedded Generator shall incorporate adequate facilities for testing and maintenance.	
4	The protection scheme shall be submitted by the Embedded Generator for approval by eThekweni Electricity.	
Specific Protection Requirements		
1	Phase and Earth Fault Protection (a) The protection system of the Embedded Generator shall fully coordinate with the protective relays of the Distribution System. (b) The Embedded Generator shall be responsible for the installation and maintenance of all protection relays at the connection point.	
2	Over/under Voltage and over/under Frequency Protection (a) The Embedded Generator shall install over/under voltage and over/under frequency protection to disconnect the generating facility under abnormal network conditions as agreed between the Distributor and the Embedded Generator.	
3	Faults on the Distribution System (a) The Embedded Generator shall be responsible for protecting its generation facility in the event of faults and other disturbances arising on the Distribution System.	
4	Islanding (b) The Embedded Generation facility shall be equipped with loss of mains detection protection system to prevent the generator from being connected to a de-energised Distribution System. The Distributor shall take reasonable steps to prevent closing circuit breakers onto an islanded network. (c) For unintentional network islanding, the Embedded Generator and the Distributor shall agree on methodology for disconnecting and connecting the Embedded Generator.	
Quality of Supply Requirements		
1	Frequency Variations The Embedded Generation facility shall remain synchronized to the Distribution System while the network frequency remains within the agreed frequency limitations at all time.	
2	Power Factor (a) The power factor at the connection point shall be maintained within the limits agreed upon by eThekweni Electricity.	
3	Fault Levels (a) The Embedded Generator shall ensure that the contractually agreed fault level contribution from the generation facility shall not be exceeded at any time.	
Telemetry		
1	The Embedded Generator shall have the means to remotely report any status change of any critical function that may negatively impact on the Quality of Supply of the Distribution System.	
Operational Responsibilities of Embedded Generators		
1	The Embedded Generator shall ensure that its generating units are operated within the capabilities defined in the Connection Agreement entered into with the Distributor.	
2	The Embedded Generator shall reasonably cooperate with the Distributor in executing all the operational activities during an emergency generation condition.	
3	The Embedded Generator shall assist the Distributors in correcting Quality of Supply problems caused by its equipment connected to the Distribution System.	
4	All customers must declare any co-generating plant (whether licensed or not) and specify the interlocking mechanism to prevent inadvertent parallel operation with the Distributor’s network.	
5	Embedded Generators shall have the required protection to trip in the event of a momentary supply loss causing an island condition to prevent paralleling out of synchronism due to auto-reclose functionality on the Distributor’s Network.	
Fault Reporting and Analysis/Incident Investigation		
1	The Embedded Generators shall report the loss of generation (as agreed by the participants) to the Distributor within 15 minutes	



of the event occurring. Notice of the intention to reconnect such shall be given with at least 15 minutes advance notice to enable the Distributor to take any necessary action required.

Outage Scheduling and co-ordination

- 1 Embedded Generators with the maximum capacity greater than 1MW shall furnish the Distributor with information on planned outages in order for the Distributor to properly plan, and coordinate its control, maintenance and operation activities.

Standards to abide by

- 1 NRS 097 :GRID INTERCONNECTION FOR EMBEDDED GENERATION
- 2 NRS 048 :ELECTRICITY SUPPLY: QUALITY OF SUPPLY

Additional Requirements

- 1 Where the 11 kV side of the generator transformer is Star, an NER must be fitted.
- 2 Where the 11 kV side of the generator transformer is Delta, an NECR must be fitted.



water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

Application for a License or Registration of a Water Use

**A guide to completing registration
or license application forms for
waste discharge related water uses
under the National Water Act (Act
36 of 1998)**

A Guide to the Registration of Water Use

Under the National Water Act (Act 36 of 1998)

Published by

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PURPOSE AND STRUCTURE OF THIS REGISTRATION GUIDE

This *Registration Guide* explains how water users must register their water use with the Department of Water Affairs and Forestry.

It starts with a section that explains how to use this *Guide*, and includes a useful "road map" to the *Guide*, followed by-

- an overview of water use registration - why water users should register their water use with the Department, which users should and should not register, and when they must register
- some important definitions that will assist users to complete their forms
- practical information on the water use registration forms and how to complete them.

Lastly, the *Guide* provides a list of registration help lines and contact details of the Department's various offices around the country where users can obtain the forms and assistance to complete the forms.

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SECTION 1

HOW TO USE THIS GUIDE

Use the road map below to familiarise yourself with what this Guide contains.

Section 1	How to use this guide	
Section 2	Registration of water use	The process of registration: Why, who, how and when.
Section 3	Definitions	Some useful definitions, as well as more technical definitions required to complete Part 2 Forms
Section 4	Permissible water use ▪ Schedule 1 use of water ▪ Existing lawful use ▪ General authorisations to use water ▪ Licences	You will need to understand these to complete some of the forms.
Section 5	Overview of registration forms	Structure and approach of the forms.
Section 6	Part 1 forms - user particulars	Part 1 forms for different types of users.
Section 7	Part 2 forms - water use	Part 2 forms for different types of water use.
Section 8	Registration help lines	Where to obtain the forms and assistance to complete them.

SECTION 2

REGISTRATION OF WATER USE

WHY REGISTER?

Registration of water use is required in terms of section 26 (1)(c) and 34(2) of the National Water Act (Act 36 of 1998). There are several reasons why water users are required to register their water use with the Department. Most important are:

- to manage and control water resources for planning and development
- to protect water resources against over-use, damage and impacts
- to ensure fair allocation of water among users.

Registration is also the first step in recovering the true and actual costs of water use in a fair and systematic manner. These funds in turn will be used to achieve the above goals.

Registration is to the benefit of the country as a whole, and not only to water users.

South Africa is one of the most water-scarce countries in the world. We are on the threshold of being what is internationally defined as a country "under water stress." Estimates are that all freshwater resources will be fully allocated in about 20-30 years from now, depending on economic growth scenarios.

Impacts on freshwater resources from waste discharges can limit the value of water for other use. Contamination can also lead to health problems and can damage the aquatic environment.

Good water resource management and long-term planning are thus essential for South Africa. In order to do this, it is important to understand how much water we have, who is using it and where.

WHAT IS REGISTRATION?

Registration is the process of officially notifying the Department of a water use.

Registration is required in terms of a Notice issued under the Registration Regulations, or under a General Authorisation published in the Government Gazette.

Water use is registered by completing the official forms obtainable from the Department.

WHO DOES NOT HAVE TO REGISTER?

The following water use need NOT be registered:

- if the water use is listed in Schedule 1 of the Act (see Section 4).
- if the water use is excluded from the requirement to register in terms of a Notice issued under the Registration Regulations.
- if the water use is part of the services offered by a Water Services Provider, such as a Local Authority (municipality) or a Water Board. An example of this is water and sanitation provided to households by a municipality. Each household is not required to be registered. However, the municipality must register its use.

WHO MUST REGISTER THEIR WATER USE?

- Individuals – such as farmers, small-holders, land-owners or lessees
- Communities – such as communal enterprises, traditional farmers groups
- National or Provincial Government
- Companies and businesses – including partnerships, public companies, private companies, companies not for gain, guarantee companies, foreign companies, incorporated private companies, closed corporations etc.
- Water User Associations.
- Water Services Providers, including Water Boards and Local Government.

WHEN MUST USERS REGISTER?

From 8 October 1999, all NEW water use must be registered as set out in the **Registration Regulations**.

Those users engaging in a waste discharge related water use identified in Section 21 (e), (f), (g), (h) and (j) will be required to register their water use by 31 August 2009 as specified in Government Gazette 32209, dated 6 May 2009.

HOW WILL USERS BE REGISTERED?

Forms to register are obtainable from any office of the Department (see Section 8). To register your water use, submit completed registration forms to the Department.

Registration cannot be turned down or denied, if it is for a legitimate water use.

Incomplete forms may be returned to the water user, and registration suspended until complete information is provided.

A Registration Certificate will be issued bearing the Register Number as soon as the forms have been processed.

WHAT DOES IT COST TO REGISTER?

Registration is free of charge if you submit your application to register within the time period stated in the Notice. If you delay unnecessarily, you may have to pay for the processing of your registration forms.

Registration certificates are issued free of charge for the first certificate, and for valid amendments to registration details.

Reprints of lost registration certificates can be obtained for a replacement fee from the Departmental office of issue.

REGISTRATION NO ENTITLEMENT

Registration is not an entitlement to use water. Issuing of registration certificate is not a license to use water. A water use license authorizes you to use water. Registration can be seen as the first step in establishing yourself as a water user with the Department.

WASTE DISCHARGE CHARGE SYSTEM	The information provided by the user in the registration forms will be used to calculate charges under the Waste Discharge Charge System (WDCS). The WDCS defines 2 charges – an Incentive Charge and a Mitigation Charge. The Incentive Charge will be calculated based on actual discharge, while the Mitigation Charge will be calculated on registered information.
Water Resource Management Charge	WRM charge defined under the Pricing Strategy will be charged to users, either abstraction related or discharge related, based on registered information.

SECTION 3

DEFINITIONS USED IN REGISTRATION

General definitions of key terms in the registration process are provided here to aid the water user in completing registration forms. Technical definitions for certain fields on the Part 2 forms are also included.

BIODEGRADABLE INDUSTRIAL WASTEWATER

- Biodegradable industrial wastewater is wastewater that contains a high concentration of organic waste arising from industrial activities and premises.
- Biodegradable industrial wastewater does not contain any substances that may accumulate in the environment such as heavy metals and persistent organic compounds.
- Biodegradable industrial wastewater is generated by activities such as:
 - Milk processing
 - Manufacture of fruit and vegetable products
 - Sugar mills
 - Manufacturing and bottling of soft drinks and water bottling
 - Production of alcoholic beverages in breweries, wineries and malt houses
 - Manufacturing of animal feed from plant or animal products
 - Manufacturing of gelatine and of glue from hides, skin and bones
 - Abattoirs
 - Fish processing and feedlots.

CATEGORIES OF MINES

- Mines are classified into 3 categories, according to the potential impacts that may occur on water resources due to the mining activity: Category A, B and C.

Category A mines

- All gold and coal mines, irrespective of size;
- Any mine with any kind of extractive metallurgical process, including heap leaching. This includes most other precious and base metal mines; and
- Any mine where pyrites occur in the mineral deposit.

Category B mines

- Mines with potentially significant and/or permanent impact only on non-water quality aspects of the water environment, such as yield or availability of water, dynamics of the river, riparian use etc.

Category C mines

- All other mines, including big mines with no significant impact on the water environment, and small- or low-impact mines and prospecting operations.

**DOMESTIC
WASTEWATER**

- Domestic wastewater consists of 90% or more wastewater by volume that arises from domestic and commercial activities and premises, and may contain sewage.
- Domestic wastewater includes household waste from washing, bathing, toilets.

*Management
Practice
Classification*

- Applicable to all non-point source (NPS) related water use in respect of section 21e/g
 - Management practice classification will distinguish between best, standard and poor practice:
 - Best Practice
 - Standard
 - Poor
-

POLLUTION

Pollution is the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it-

- a) less fit for any beneficial purpose for which it may reasonably be expected to be used; or
- b) harmful or potentially harmful-
 - to the welfare, health or safety of human beings;
 - to any aquatic or non-aquatic organisms;
 - to the resource quality; or
 - to property.

NON-POINT SOURCE DISCHARGE

Discharge to a land-based facility where impact to a water resource, either ground or surface water is indirect. NPS sources include waste disposal sites, tailing dams and agricultural activities

POINT SOURCE DISCHARGE

Discharge directly to a water resource through a conduit such as a canal, pipe, outfall. The point of discharge to the water resource is easily identifiable and measurable.

WASTE

Waste includes any material that is dissolved, suspended or transported in water and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted

WASTE MANAGEMENT FACILITY

Disposing of waste in a manner which may impact on water resources is a water use, described in 21(g) under the definition for Water Uses below. Disposal of waste is also regulated in terms of section 20 of the Environment Conservation Act, 1989 (Act No. 73 of 1989).

Waste management facilities refer to disposal of waste or discharge of wastewater to a land-based facility. This includes evaporation ponds, tailings dams, landfills, sewage treatment works etc.

WASTEWATER

Wastewater is water containing waste, or water that has been in contact with waste material. Also referred to as effluent.

- Wastewater includes
 - domestic wastewater
 - biodegradable industrial wastewater
 - industrial wastewater.

Domestic Wastewater

- Domestic wastewater consists of 90% or more wastewater by volume that arises from domestic and commercial activities and premises, and may contain sewage.
- Domestic wastewater includes household waste from washing, bathing, toilets.
- In urban areas domestic wastewater from households is usually collected through a sewer system, and treated at a sewage treatment plant.
- In rural areas domestic wastewater is often disposed of into on-site facilities, such as into pit latrines and septic tanks.
- Individual households are not required to register disposal of domestic wastewater.

WATER RESOURCE

A water resource is:

- a river or a spring;
- a natural channel in which water flows regularly or intermittently;
- a wetland, lake or dam into which, or from which, water flows;
- any collection of water which the Minister may declare to be a watercourse; and
- surface water, estuaries and aquifers (underground water).

All waterbodies in the hydrological cycle, including underground water, are regarded as water resources

WASTE DISCHARGE RELATED WATER USES

These water uses are defined in Section 21 (e), (f), (g), (h), and (j) of the National Water Act, 36 (Act 36 of 1998). They are briefly outlined below.

S21(e) of Act Engaging in a controlled activity identified as such in section 37(1) or declared in section 36

- Currently, the following are controlled activities:
 - irrigating with waste water;
 - modification of atmospheric precipitation (cloud seeding);
 - power generation which alters the flow regime of a water resource;
 - and
 - intentional recharge of underground water with waste water.
- A common controlled activity is irrigation with wastewater, typically from a water treatment works.
- This can be a productive use of water if a crop is grown with the wastewater.

S21(f) of Act Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit

- This water use entails the discharge of waste or wastewater **directly** into a water resource.
- Common examples of this water use are waste released into a river or dam at a discharge point such as waste water from factories, or partially treated wastewater from treatment plants.
- Waste discharged into a municipal sewer is NOT included in this water use. However, the waste discharged by the municipal treatment works into a water resource IS an example of this water use.

*S21(g) of Act
Disposing of waste in a
manner which may
detrimentally impact on
a water resource*

- This is typically disposal that takes place into on-site facilities such as french drains, conservancy tanks, pit latrines and soak-aways.
- Another example of this water use is disposal into wastewater treatment systems, such as oxidation ponds that do not have an outlet into a water resource. If the oxidation pond has an outflow into a river or dam, it is defined as water use 21(f) above for discharging waste water into a water resource.
- Evaporation dams are a further common example of this water use.

*S21(h) of Act
Disposing in any manner
of water which contains
waste from, or which
has been heated in, any
industrial or power
generation process*

- This water use refers specifically to the **temperature** of the wastewater which may have a significant effect on the environment.
- This water use also refers to discharges to the marine environment (sea, surf-zone)

*21 (J) of Act Removing,
Discharging or
disposing of water
found underground if it
is necessary for the
efficient continuation
of an activity or for
the safety of people*

- This water use applies when water must be removed for efficiency or safety reasons.
- An example of this use is to ensure safety in underground mining.
- Many construction sites also require underground water to be removed.
- This water use does NOT apply to the taking of water referred to in 21(a) above
- This water use is indirectly related to waste discharge

WATER SERVICES PROVIDER

- A water Services Provider is defined in Water Services Act (Act No. 108 of 1997) as a municipality, district or rural council, a water board or institution that provides water services.
- Water Services are defined as water supply and sanitation

WATER USER ASSOCIATION

- A Water User Association is an association of individual water users who undertake water related activities for their mutual benefit.
- A Water User Association is formally established by the Minister, through publication of a Notice in the Government Gazette after approval of its constitution.
- Water User Associations will be transformed from existing irrigation boards, subterranean water control boards, water boards established for stock watering, settlement boards and water conservation boards.
- Individuals members of a Water User Association do NOT have to register their use as individuals for water obtained from a distribution system controlled by the Association. The Association as a whole must register.
- Individual members who have other types of water use must register these uses as individuals.
- A common example is a farmer who takes water from the canal of a government water scheme, and also from a borehole on his property. Taking of water from the scheme need not be registered, but it may be necessary to register taking of water from the borehole.

SECTION 4

PERMISSIBLE WATER USE

USE OF WATER	Permissible water use is described in section 22 of the Act as: ▪ Schedule 1 use ▪ Continuation of an existing lawful use ▪ Use authorised under a General Authorisation ▪ Licensed use. An overview of these mechanisms for regulating water use is provided below.
SCHEDULE 1 USE OF WATER	"Schedule 1" refers to Schedule 1 of the Act which lists a range of permissible water use. Schedule 1 water use is NOT required to be either registered or licensed.
<i>Schedule 1 in detail</i>	The following water use detailed in Schedule 1 need NOT be registered: ▪ Taking water directly from any water resource to which a person has lawful access, for: - Reasonable domestic use in a person's household; - small gardening (but not for commercial purposes); and - the watering of animals (but not for commercial purposes, thus excluding feedlots), provided that the use is not excessive in relation to the capacity of the water resource and the needs of other users. ▪ Storing and using run-off water from a roof. ▪ In emergency situations, taking water from any water resource for human needs or firefighting. ▪ Recreation, if a person has lawful access to that water resource. ▪ Discharge of waste or water containing waste or run-off water (including stormwater) into a canal, sea outfall or other conduit, provided these are controlled by persons that have been authorised to purify, treat or dispose of this wastewater.
EXISTING LAWFUL USE OF WATER	▪ Existing Lawful Use means any lawful use of water authorised by or under any law which took place at any time during the period from 1 October 1996 to 30 September 1998, i.e. the two years before the National Water Act came into effect. ▪ Stream flow reduction activities and controlled activities also fall under the requirements of existing lawful use (see Section 3 21(d) and (e) above for definitions). ▪ Existing Lawful Users will be required to register their use in terms of a Notice issued under the Registration Regulations.
GENERAL AUTHORISATIONS TO USE WATER	A General Authorisation is an authorization to use water without a license, provided that the water use is within the limits and conditions set out in the General Authorisation. General authorizations are reviewed every 5 years .

General Authorisations apply only to NEW water use that took place after 1 October 1999 when the Act was fully promulgated. This means that General Authorisations are not retro-active or "back-dated".

Schedule 1 water uses are not included under the General Authorisations, as they are already permissible in terms of the Act and do not require further authorisation.

REGISTRATION AND THE GENERAL AUTHORISATIONS

The General Authorisations describe the conditions under which a water use must be registered. Water users must acquaint themselves with the terms and conditions of the General Authorisations, as there are specific conditions applicable to certain water use.

For new water use that started after 8 October 1999 and does NOT fall within the areas or limits set out in the General Authorisation, the user must approach the Department for a license.

The requirements for registration are outlined in the General Authorisations that were published in Government Gazette No. 399 and 26187, dated 26 March 2004. The current General Authorisations are available on the following links:

<http://www.dwaf.gov.za/Documents/Notices/GA%2026%20March%20sec%2021-a%20and%20b.doc>

[http://www.dwaf.gov.za/Documents/Notices/GA%2021\(C\)%20\(1\)%20\(J\).doc](http://www.dwaf.gov.za/Documents/Notices/GA%2021(C)%20(1)%20(J).doc)

LICENCES AND THE GENERAL AUTHORISATIONS

Any new water user who does not comply with the terms and conditions of the General Authorisations must approach the Department for a license.

SECTION 5

OVERVIEW OF REGISTRATION FORMS

REGISTRATION FORM	Registration forms consist of Part 1 and Part 2 as well Supplementary forms. ▪ Part 1 forms - information on the water user and the property where the water use takes place. ▪ Part 2 forms - information about the water use. ▪ Supplementary forms - additional information that may be needed. One Part 1 form and one or more Part 2 forms must be completed to register a water use.
AMENDMENTS TO WATER USE DETAILS	Details about a registered water use may be amended on any registration form: ▪ quote the Register Number allocated when the water use was first registered and complete a Part 1 form ▪ amend the registered water use details on a new Part 2 form.
ADD A NEW WATER USE	A registered water user may register additional water uses: ▪ quote the Register Number and complete a Part 1 form ▪ give the new water use details on a new Part 2 form.
SURRENDER OF A REGISTERED WATER USE	Once registered, a water use may be surrendered if the activity ceases to take place. Surrendering a water use cancels the water use registration: ▪ quote the Register Number and indicate which water use/s are to be surrendered on the Surrender of Water Use form.

REGISTRATION FORM NUMBERS	The numbers of the various kinds of registration forms are provided below	
REGISTRATION PART 1 FORMS	DW 756	Individual
	DW 757	Water Service Provider
	DW 758	Company, Business or Partnership; National or Provincial Government
	DW 759	Water User Association
REGISTRATION PART 2 FORMS	DW 760	Taking water from a water resource
	DW 761	Storing water
	DW 762	Storing water - Dam Safety Registration
	DW 763	Impeding or diverting the flow of water in a watercourse
	DW 764	Engaging in a Stream Flow Reduction Activity
	DW 765	Engaging in a controlled activity: Irrigation of any land with waste or water containing waste generated through any industrial activity or by a waterwork
	DW 766	Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit
	DW 767	Disposing of waste in a manner which may detrimentally impact on a water resource
	DW 780	Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
	DW 768	Altering the bed, banks, course or characteristics of a watercourse
	DW 805	Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people
	DW 806	Using water for recreational purposes
SUPPLEMENTARY FORM NUMBERS	DW 901	Property where water use occurs
	DW 902	Details of property owner
	DW 903	Compliance management information: Actual/Monitored Waste Discharge Details applicable for sections 21 (f) and (h)
	DW 904	Compliance management information: Actual/Monitored Waste Discharge Details applicable for sections 21 (e) and (g)
	DW 905	Supporting technical information for waste disposal facilities (21g water uses
IMPORTANT NOTES WHEN COMPLETING YOUR FORMS	▪ Make sure you have the correct Part 1 form and all the Part 2 forms you need. • Some fields and blocks are marked with a dot, like this: ●. The information required in these fields and blocks is compulsory and must be filled in. ▪ Please write clearly in black ink ▪ Use capital letters ▪ Use one letter or digit per square ▪ Return completed forms to the nearest office of the Department ▪ A Registration Certificate cannot be issued unless the information is complete. The Department may return any incomplete forms received.	

SECTION 6

HOW TO COMPLETE REGISTRATION PART 1 FORMS

PART 1 FORMS	Part 1 forms consist of: ▪ DW756 for Individuals ▪ DW757 for Water Services Providers (see definition in Section 3) ▪ DW758 for Companies and National or Provincial Government Departments ▪ DW759 for Water User Associations (see definition in Section 3)
PARTICULARS OF THE APPLICANT	This section of the forms is for general information such as name, title, address and telephone number.
<i>DW756 Individual applicant</i>	▪ A South African ID number or temporary ID number is sufficient for identification. ▪ Individuals who do not have a South African ID number may use a passport number for identification purposes. ▪ Foreign ID numbers not acceptable. In the case of foreign nationals, supply the passport number, passport date of issue and country of issue.
<i>DW757 Water Services Provider</i>	▪ Each Water Services Provider must submit a Management Plan to the Department in terms of the Water Services Act.
<i>DW758 Company or Business; National or Provincial Government</i>	▪ Company, Business or Partnership means registered companies, close corporations, sole proprietors, partnerships, public companies, private companies, companies not for gain, guarantee companies, foreign companies, incorporated private companies, closed corporations etc. ▪ Registered businesses must give the RCCC number issued when the business registers in terms of the Trade and Industries Act. ▪ In cases where property is owned by a number of shareholders that have not been registered as a company, the principal shareholder must complete form DW756 - Individual. ▪ "Country where established" means a foreign company's country of origin. ▪ For National Government, supply the Department name in full (not just an abbreviation). ▪ For Provincial Government Departments, please also give the name of the Province.
<i>DW759 Water User Association</i>	▪ A Water User Association is formally established through publication by the Minister of a Notice in the Government Gazette. ▪ The total area of operation of the Association includes the properties of all its members at the date of registration, either in hectares or square kilometers(Km). ▪ Previous Irrigation Boards, Settlement Boards and Water Conservation Boards should attach a certified copy of the Register of Properties form that was submitted with the proposal to establish your Water User Association.

For more assistance on completing Part 1 Forms: Water User Information, go to **REGISTRATION GUIDE: WATER USER REGISTRATION** (available on <http://www.dwaf.gov.za/Projects/WARMS/registration.asp>)

SECTION 7

HOW TO COMPLETE REGISTRATION PART 2 FORMS

PART 2 FORMS	Part 2 forms require information on: ▪ the <i>water resource</i> (see definition in Section 3) ▪ <i>water use</i> and related activities (see definition in Section 3) ▪ <i>existing authorisations or permits</i> (see Existing Lawful Use of water in Section 4) More than one Part 2 form may need to be completed. For example a municipality operating a sewage treatment works, discharges a portion of the final effluent into a water resource and irrigates a golf course with the remainder of the effluent must complete the following: - a DW765 form for irrigating with wastewater; - a DW766 form for discharging wastewater into a water resource and - a DW767 form for the sewage treatment works which is defined as disposing of waste in a manner which may detrimentally impact on a water resource.
AMENDMENTS	Part 2 forms allow existing registered use to be amended. Quote the Register Number and complete the applicable Part 2 forms with the amended details.
EXISTING AUTHORISATIONS	Existing authorisations may be- - Existing Lawful Use (defined in Section 4) or - General Authorisations (defined in Section 4). Where applicable please supply the number of each permit or other authorisation in respect of each water use. Where no permit or authorisation was obtained ignore this section.

Registration Part 2E: Engaging in a Controlled Activity: irrigation of any land with waste or water containing waste generated through any industrial activity or by a waterworks

- This form is intended for the **Controlled Activity of Irrigating with Wastewater**.
- Irrigating with wastewater is NOT the same as irrigation with water taken from a water resource.
- Irrigating with wastewater can be seen as an extended form of wastewater treatment, whereby a water user may be unable to treat the wastewater to an acceptable quality and return it to a resource. In irrigating this wastewater instead of discharging it, the possible impacts on the resource are minimised.
- Irrigation with wastewater should be carried out in such a manner that a crop is produced through the irrigation process. This is an indication that the irrigation is sustainable, and is not causing deterioration to the soil.
- Irrigation of lawns and pasture with wastewater is also acceptable. However, irrigation of undeveloped veld without growing a crop is not considered to be a productive water use activity.
- Irrigation with wastewater must comply with any Health Regulations and zoning by-laws.

SECTIONS ON FORM	EXPLANATIONS
1. GENERAL INFORMATION	Mark the applicable options with an X and/or complete details where applicable.
1.1. Indicate the nature of this application	▪ Indicate if the application is an application for a water use license in terms of the National Water Act, 36 of 1998 or whether the application is only to register the water use. An application for a license will automatically be registered by the Department. Registration of the water use is NOT an authorization and the application will not be processed for a license.
1.2 Have you already registered a water use with the Department of Water Affairs and Forestry?	▪ If the water use has been registered with the Department, and/or a license issued, provide the registration number and/or water use number provided on the registration certificate.
1.3. Indicate if Section 21 (j) is applicable to this water use application	▪ Indicate if the wastewater being irrigated comprises of water obtained through dewatering of water found underground. If so, ensure that a DW805 form is completed.
1.4 Do you have a license, permit or exemption for this waste discharge?	▪ The purpose of this section is to determine whether the water use is considered an Existing Lawful Use. If you have been issued with license, permit or exemption in terms of any of the environmental legislations as mentioned please provide the reference number that is provided on the relevant authorization.
Declaration by Applicant	▪ Individual applicants must sign and date the form themselves. ▪ In the case of a power of attorney a certified copy of the appointment must be attached to the application form. ▪ Use of a thumbprint in the space provided will be acceptable in some cases as an alternative to an applicant's signature
2. DESCRIPTION OF WASTE GENERATED	The purpose of this section is to obtain information on how the wastewater is generated and the nature and composition of the wastewater.

SECTIONS ON FORM	EXPLANATIONS
2.1 Select the sector that generates the waste or wastewater which this application refers to	▪ Select one of the broad waste generating sectors (Agriculture, Domestic, Industry and Mining) from which the waste is generated ▪ Feedlots as well as piggeries, dairies, poultry etc should be regarded as "Intensive Animal Husbandry" ▪ If more than one sector is applicable complete a separate form for each sub-sector together with all the other forms
2.2 Describe the nature of the wastewater	▪ See definition of wastewater in Section 3 of this Guide ▪ This section describes the flow and quality characteristics of the wastewater ▪ Select an option/s best describing the nature of the wastewater ▪ If the nature of the wastewater is best described by means of a combination of the descriptions both options could be selected
2.3 Describe the composition of the wastewater	▪ Select an option/s that best describes the composition of the wastewater ▪ This section describes the organic and inorganic solid matter composed in wastewater and this matter will be in the form of dissolved and suspended solids ▪ This option is for any combination of domestic and biodegradable industrial wastewater. ▪ The percentage by volume is the proportion of the total wastewater that is made up of industrial wastewater.
2.4 Describe the activity that generates wastewater	▪ Please provide a clear description of the activity on how the waste/wastewater is generated.
2.5 DETAILS OF WATER USE	This section describes the volume and concentration of the wastewater as well as details of the crop/s being irrigated.
2.5.1 Water use start & end date	▪ Include start date of water use and end date (Where applicable)
2.5.2 Portion of property/Land under irrigation	▪ Give the total area in hectares that is irrigated with wastewater, at any given time.
2.5.3 Crops under wastewater irrigation	▪ List the crop types to be irrigated with wastewater ▪ Each crop grown on the field should be entered on a separate line. If the same field is used to cultivate seasonal crops, a separate entry for each crop must be made
2.5.4 Volume of wastewater irrigated	▪ The total volume of wastewater irrigated is the wastewater applied to the land area specified in 2.5.2. This volume should not include any rainwater or stormwater runoff. ▪ Many wastewater irrigation activities take place only at certain times of the year. Indicate the volume irrigated per month, or alternatively give the percentage of the total amount as an estimate.
2.5.5 Monthly irrigation pattern	▪ Indicate the volume irrigated per month, or alternatively give the percentage of the total amount as an estimate.
2.5.6 Origin of irrigated wastewater	The purpose of this section is to obtain information on the source of wastewater being irrigated. The source water could be: ▪ Water removed from underground (21j water use); ▪ Wastewater from a waste management facility such as a sewage treatment works (21g water use);

SECTIONS ON FORM	EXPLANATIONS
2.5.7 Registered waste discharge information	- Requires the quality and quantity of wastewater irrigated. - The average volume of wastewater irrigated per month or year must preferable be stated in cubic meters (m³). Wastewater quality and quantity are crucial to calculate waste load per variable that may be subjected to the Waste Discharge Charge System.
2.5.8 Description of management measures	- Tick each option applicable to the management practice associated with the particular irrigation with wastewater. - Note: the management practice will be classified as either best, standard or poor practice based on the options identified in this section; - The calculation of waste load contribution will be based on a % proportion as a result of the management practice
3. RECEIVING ENVIRONMENT/ RECEPTOR	This section will address the resource that needs to be protected and the applicable catchment where the water use is occurring.
3.1 Description of nearby water resources	Requires information on the nearby water resource which is likely to be affected by discharged or irrigated wastewater
3.1.1 Description of surface water resources	A surface water resource is associated with the following: - a river or a stream as a natural channel in which water flows regularly or intermittently - a wetland, lake or dam into which, or from which, water flows; - any collection of water which the Minister may declare to be a watercourse such as GWS; and - estuaries and marine Select only one option with X - If "other" is selected provide a clear description - Provide the name of the nearest surface water resource e.g. Rietvlei or orange River - Provide the distance in meters to the nearest surface water resource e.g. 1500m
3.1.2 Description of groundwater resources	A ground water resource is associated with the following: - An aquifer in which underground water is obtained through a spring or eye, borehole, ground water Government Water Scheme (GWS) or boreholes and windmills on Government land Select one option with a X for the type of groundwater resource nearest to the location where the discharge is taking place - If "other" is selected provide a concise description - If an indicated type of selection had been made provide the name or description of the nearest ground water resource - Provide the distance in meters to the nearest ground water resource e.g. 1000m
3.2 Location of area irrigated with waste or water containing waste	Complete the geographical location information of the area irrigated with wastewater
3.2.1 Geographical location for each of the external corner points of the area	- Enter the geographic location in degrees (°), minutes (') and seconds (''), or in decimal degrees or in degrees (°) and decimal minutes (') of each of the external corner points of the area - At least three external corner points must be provided - Co-ordinates are required per irrigated field - Indicate the <i>Datum Type</i> used by means of X
3.2.2 Drainage region details	Indicate the drainage region or quaternary catchment where the wastewater irrigation activity is taking place

SECTIONS ON FORM	EXPLANATIONS
3.2.3 Property relationship details (Note: Supplementary forms DW901 and DW902 must be completed)	If property is unsurveyed: ▪ Water use on unsurveyed property may be registered on behalf of the village or community who owns or occupies the land. ▪ Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands. ▪ Supply the magisterial district or local authority. ▪ Supply the surname and initials of village leader, community or tribal authority If property is surveyed: ▪ All the necessary information for surveyed properties is available in the office of the Surveyor-General and must be correctly supplied.
4 List of supporting technical information	Mark with an X, the technical information that supports this application ▪ Indicate which applicable DW forms accompanying this DW765 form ▪ Note: It is optional to provide additional technical information for registering this water use, unless required by the Department

Registration Part 2F: Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit

- This form is for discharge of wastewater directly into a surface water resource, usually through a pipe or canal.
- This water use is considered to be a point source discharge.
- Commonly, water containing domestic or industrial waste is discharged to a water resource.

SECTIONS ON FORM	EXPLANATIONS
3. GENERAL INFORMATION	Mark the applicable options with an X and/or complete details where applicable.
1.1. Indicate the nature of this application	▪ Indicate if the application is an application for a water use license in terms of the National Water Act, 36 of 1998 or whether the application is only to register the water use. An application for a license will automatically be registered by the Department. Registration of the water use is NOT an authorization and the application will not be processed for a license.
1.2 Have you already registered a water use with the Department of Water Affairs and Forestry?	▪ If the water use has been registered with the Department, and/or a license issued, provide the registration number and/or water use number provided on the registration certificate.
1.3. Indicate if Section 21 (j) is applicable to this water use application	▪ Indicate if the wastewater being discharged to a water resource comprises of water obtained through dewatering of water found underground. If so, ensure that a DW805 form is completed.
1.4 Do you have a license, permit or exemption for this waste discharge?	▪ The purpose of this section is to determine whether the water use is considered an Existing Lawful Use. If you have been issued with license, permit or exemption in terms of any of the environmental legislations as mentioned please provide the reference number that is provided on the relevant authorization.
Declaration by Applicant	▪ Individual applicants must sign and date the form themselves. ▪ In the case of a power of attorney a certified copy of the appointment must be attached to the application form. ▪ Use of a thumbprint in the space provided will be acceptable in some cases as an alternative to an applicant's signature
2. DESCRIPTION OF WASTE GENERATED	The purpose of this section is to obtain information on how the wastewater is generated and the nature and composition of the wastewater.
2.1 Select the sector that generates the waste or wastewater which this application refers to	▪ Select one of the broad waste generating sectors (Agriculture, Domestic, Industry and Mining) from which the waste is generated ▪ Feedlots as well as piggeries, dairies, poultry etc should be regarded as "Intensive Animal Husbandry" ▪ If more than one sector is applicable complete a separate form for each sub-sector together with all the other forms
2.2 Describe the nature of the wastewater	▪ See definition of wastewater in Section 3 of this Guide ▪ This section describes the flow and quality characteristics of the wastewater ▪ Select an option/s best describe the nature of the wastewater ▪ If the nature of the wastewater is best described by means of a combination of the descriptions both options could be selected

SECTIONS ON FORM	EXPLANATIONS
2.3 Describe the composition of the wastewater	▪ Select an option/s that best describe the composition of the wastewater ▪ This section describes the organic and inorganic solid matter composed in wastewater and this matter will be in the form of dissolved and suspended solids ▪ This option is for any combination of domestic and biodegradable industrial wastewater. ▪ The percentage by volume is the proportion of the total wastewater that is made up of industrial wastewater.
2.4 Describe activity that generates wastewater	▪ Please provide a clear description of the activity on how the waste/wastewater is generated.
2.5 DISCHARGE TO A WATER RESOURCE	▪ This section describes volumes and concentrations of the wastewater.
2.5.1 Water use start & end date	▪ Include start date of water use and end date (Where applicable)
2.5.2 Total volume of waste/ wastewater discharged per year	▪ Discharge may occur at different rates during the year. Indicate the exact volume discharged per year and the maximum discharged on any given day. ▪ The total volume of waste water discharged per year must preferably be stated in cubic metres (c³m) ▪ The total volume of waste discharged per year should be based on the average volume
2.5.3 Maximum volume of waste/ wastewater discharged on any given day	▪ Requires maximum volume of waste/ wastewater discharge into a water resource in cubic meters (m³) on any given day.
2.5.4 Monthly discharge pattern	▪ Select with a "X" in the appropriate box the option in which the monthly discharge pattern is expressed ▪ If a unit of measure other than cubic meters or percentage is selected specify the unit in the space provided ▪ Specify the annual waste discharge pattern by stating the minimum, maximum and average volume for each calendar month ▪ The summation of the monthly average volume of waste discharged should correlate with the annual total of waste discharged
2.5.5 Intake Water	▪ Intake water is defined as water that is used in the waste generating activity that results in wastewater generated ▪ DWAF requires intake water details for the calculation of waste discharge loads ▪ Indicate the source of intake water which could be either obtained from a water services provider or water user association; or obtained through one or more of the following sources: • Abstraction from a water resource • Wastewater from a holding facility; or ▪ Water obtained through a dewatering process

SECTIONS ON FORM	EXPLANATIONS
2.5.6 Registered waste discharge information	- Indicates the quality and quantity of wastewater discharged into a water resource. - The total volume of wastewater discharged per year must preferable be stated in cubic meters (m³). - Refer to section 9 for assistance with conversion of units; - The total volume of wastewater discharged per year should be based on the average volume - Indicate the concentration of each of the applicable quality variables specified in this section - Intake water volumes and quality is required for calculation of waste loads discharged into a water resource - Wastewater quality and quantity are crucial to calculate waste load per variable that may be subjected WDCCS. - Load calculations will be completed by the Department
3. RECEIVING ENVIRONMENT/ RECEPTOR	This section will address the resource that needs to be protected and the applicable catchment where the water use is occurring.
3.1 Description of nearby water resources	Requires information on the nearby water resource which is likely to be affected by discharged or irrigated wastewater
3.1.1 Description of surface water resources	A surface water resource is associated with the following: - a river or a stream as a natural channel in which water flows regularly or intermittently - a wetland, lake or dam into which, or from which, water flows; any collection of water which the Minister may declare to be a watercourse such as GWS; estuaries and marine Select only one option with X - If "other" is selected provide a clear description - Provide the name of the nearest surface water resource e.g. Rietvlei or Orange River - Provide the distance in meters to the nearest surface water resource e.g. 1500m
3.1.2 Description of groundwater resources	A ground water resource is associated with the following: - An aquifer in which underground water is obtained through a spring or eye, borehole, ground water Government Water Scheme (GWS) or boreholes and windmills on Government land Select one option with a X for the type of groundwater resource nearest to the location where the discharge is taking place - If "other" is selected provide a concise description - If an indicated type of selection had been made provide the name or description of the nearest ground water resource - Provide the distance in meters to the nearest ground water resource e.g. 1000m
3.2 Water resource (receiving the wastewater discharge) information	- See definition of water resource in section 3. - This section requires the details of the water resource that the wastewater is discharged into.
3.2.1 Name of the water resource receiving the wastewater discharge	If the water resources does not have a specific name, enter "no name"
3.2.2 Type of the water resource receiving the waste/ wastewater discharge	The type of water resources refers to surface water bodies only. Note that only one type of resource should be selected. For registration of more than one discharge point, complete a separate DW 766 form.

SECTIONS ON FORM	EXPLANATIONS
3.2.3 Geographical location of the discharge point	Enter the geographic location either in degrees(°), minutes(') and seconds(''), or in decimal degrees. The geographic location can be read from a 1:50 000 topographic map available from the Government Printers at a nominal charge, or at the nearest office of the Department, or by using a Global Positioning System (GPS) instrument.
3.2.4 Reliability of water resources receiving waste/ wastewater	Indicate the reliability of the water resources by selecting one option only.
3.2.5 Drainage region details	- Indicate the drainage region or quaternary catchment where receiving wastewater body found - For more information on the drainage region details contact your nearest DWAF office (See Section 10 of this Guide)
3.2.6 Property relationship details (Note: Supplementary forms DW901 and DW902 must be completed)	If property is unsurveyed: - Water use on unsurveyed property may be registered on behalf of the village or community who owns or occupies the land. - Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands. - Supply the magisterial district or local authority. - Supply the surname and initials of village leader, community or tribal authority If property is surveyed: - All the necessary information for surveyed properties is available in the office of the Surveyor-General and must be correctly supplied.
4 List of supporting technical information	Mark with an X, the technical information that supports this application - Indicate which applicable DW forms accompanying this DW766 form - Note: It is optional to provide additional technical information for registering this water use, unless required by the Department

Registration Part 2G: Disposing of waste in a manner which may detrimentally impact on a water resource

- This form is applicable to disposing of wastewater into land-based facilities such as evaporation dams, oxidation ponds or a wastewater pond system. It also applies to disposal of industrial ash and mine residue, which may consist primarily of solid waste materials.
- On-site disposal systems must be also registered on this form, for:
 - Industrial wastewater;
 - Domestic wastewater into communal septic tanks serving more than 50 households.
- This form must be accompanied by the completion of a DW905 supplementary form. Submission of a DW767 without a DW905 form would be considered as an incomplete registration.

SECTIONS ON FORM	EXPLANATIONS
1. GENERAL INFORMATION	Mark the applicable options with an X and/or complete details where applicable.
1.1. Indicate the nature of this application	▪ Indicate if the application is an application for a water use license in terms of the National Water Act, 36 of 1998 or whether the application is only to register the water use. An application for a license will automatically be registered by the Department. Registration of the water use is NOT an authorization and the application will not be processed for a license.
1.2 Have you already registered a water use with the Department of Water Affairs and Forestry?	▪ If the water use has been registered with the Department, and/or a license issued, provide the registration number and/or water use number provided on the registration certificate.
1.3. Indicate if Section 21 (j) is applicable to this water use application	▪ Indicate if the wastewater discharged to a land-based wastewater facility comprises of water obtained through dewatering of water found underground. If so, ensure that a DW805 form is completed.
1.4 Do you have a license, permit or exemption for this waste discharge?	▪ The purpose of this section is to determine whether the water use is considered an Existing Lawful Use. If you have been issued with license, permit or exemption in terms of any of the environmental legislations as mentioned please provide the reference number that is provided on the relevant authorization.
Declaration by Applicant	▪ Individual applicants must sign and date the form themselves. ▪ In the case of a power of attorney a certified copy of the appointment must be attached to the application form. ▪ Use of a thumbprint in the space provided will be acceptable in some cases as an alternative to an applicant's signature
2. DESCRIPTION OF WASTE GENERATED	Describes the nature and composition of the waste or wastewater generated.
2.1 Select the sector that generates the waste or wastewater which this application refers to	▪ Select one of the broad waste generating sectors (Agriculture, Domestic, Industry and Mining) from which the waste is generated ▪ Feedlots as well as piggeries, dairies, poultry etc should be regarded as "Intensive Animal Husbandry" ▪ If more than one sector is applicable complete a separate form for each sub-sector together with all the other forms.

SECTIONS ON FORM	EXPLANATIONS
2.2 Describe the nature of the wastewater	- See definition of wastewater in Section 3 - Select an option/s best describe the nature of the wastewater - If the nature of the wastewater is best described by means of a combination of the descriptions both options could be selected
2.3 Describe the composition of the wastewater	- Select an option/s that best describe the composition of the wastewater - This option is for any combination of domestic and biodegradable industrial wastewater. - The percentage by volume is the proportion of the total wastewater that is made up of industrial wastewater.
2.4 Describe activity that generates wastewater	Please provide a clear description of the activity on how the waste/wastewater is generated.
2.5 DISCHARGE TO A LAND BASED FACILITY	This section requires information on the volumes and concentration of wastewater discharged to a land-based facility.
2.5.1 Water use start & end date	Include start date of water use and end date (Where applicable)
2.5.2 Total volume of waste/ wastewater discharged per year	- Discharge may occur at different rates during the year. Indicate the exact volume discharged per year and the maximum discharged on any given day. - The total volume of waste water discharged per year must preferably be stated in cubic metres (c³m) - The total volume of waste discharged per year should be based on the average volume
2.5.3 Maximum volume of waste/ wastewater discharged on any given day	Requires the maximum volume of waste/ wastewater discharge into a land-based facility in cubic meters (m³) per in any given day.
2.5.4 Monthly discharge pattern	- Select with a "X" in the appropriate box the option in which the monthly discharge pattern is expressed - If a unit of measure other than cubic meters or percentage is selected specify the unit in the space provided - Specify the annual waste discharge pattern by stating the minimum, maximum and average volume for each calendar month - The summation of the monthly average volume of waste discharged should correlate with the annual total of waste discharged
2.5.5 Intake Water	- Intake water is defined as water that used in the waste generating activity that results in wastewater generated - Indicate the source of intake water which could be either obtained from a water services provider or water user association; or obtained through one or more of the following sources: - Abstraction from a water resource - Wastewater from a holding facility; or - Water obtained through a dewatering process

SECTIONS ON FORM	EXPLANATIONS
2.5.6 Registered waste discharge information	- Indicates the quality and quantity of wastewater discharged into a water resource. - The total volume of wastewater discharged per year must preferably be stated in cubic meters (m³). - The total volume of wastewater discharged per year should be based on the average volume - Indicate the concentration of each of the applicable quality variables specified in this section - Wastewater quality and quantity are crucial to calculate waste load per variable that may be subjected waste discharge charges. - Load calculations will be completed by the Department
3. RECEIVING ENVIRONMENT/ RECEPTOR	This section will address the resource that needs to be protected and the applicable catchment where the water use is occurring.
3.1 Description of nearby water resources	Requires information on the nearby water resource which is likely to be impacted by the waste facility
3.1.1 Description of surface water resources	A surface water resource is associated with the following: - a river or a stream as a natural channel in which water flows regularly or intermittently - a wetland, lake or dam into which, or from which, water flows; - any collection of water which the Minister may declare to be a watercourse such as GWS; estuaries and marine - Select only one option with X - If "other" is selected provide a clear description - Provide the name of the nearest surface water resource e.g. Rietvlei or Orange River - Provide the distance in meters to the nearest surface water resource e.g. 1500m
3.1.2 Description of groundwater resources	A ground water resource is associated with the following: - An aquifer in which underground water is obtained through a spring or eye, borehole, ground water Government Water Scheme (GWS) or boreholes and windmills on Government land Select one option with a X for the type of groundwater resource nearest to the location where the discharge is taking place - If "other" is selected provide a concise description - If an indicated type of selection had been made provide the name or description of the nearest ground water resource - Provide the distance in meters to the nearest ground water resource e.g. 1000m
3.2 Drainage Region Details	Indicate the drainage region or quaternary catchment where the waste disposal activity is taking place

SECTIONS ON FORM	EXPLANATIONS
3.3 Property relationship details (Note: Supplementary forms DW901 and DW902 must be completed)	If property is unsurveyed: - Water use on unsurveyed property may be registered on behalf of the village or community who owns or occupies the land. - Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands. - Supply the magisterial district or local authority. - Supply the surname and initials of village leader, community or tribal authority If property is surveyed: - All the necessary information for surveyed properties is available in the office of the Surveyor-General and must be correctly supplied.
4. Disposal of Waste	The purpose of this section is to obtain information on the type of waste disposed as well as the waste management facility details.
4.1.1 Description of the type of waste to be disposed	- Indicate the type of waste (to be) disposed on the land-based facility. - If more than one type of waste is disposed on the land-based facility, ensure that a separate DW767 form is completed per waste type. - Every DW767 form MUST be supported by a DW905 Supplementary form.
4.1.2 Approximate maximum volume/tonnage per site per day	Indicate the maximum volume of wastewater or maximum tonnage of waste discharged per waste management facility per day.
4.1.3 Approximate total tonnage per site per annum	Indicate the total tonnage of waste disposed per annum
4.2 Type of waste management facility	The purpose of this section is to obtain information on the type of waste management facility and its geographical location
4.2.1 Name of waste site or facility	Indicate the name of the waste site or facility. Ensure that the name of the site corresponds to the name on the DW905 supplementary form accompanying this registration.
4.2.2 Type of waste disposal site	- Select the applicable waste management facility. - Mark only one option. - If waste is disposed on more than one waste management facility, each waste management facility must be registered with an accompanying DW905 supplementary form. - Indicate, in hectares, the size of the site; - Indicate when disposal to the particular site started and where applicable when the disposal ceased.
5. List of supporting technical information	Mark with an X, the technical information that supports this application - Indicate which applicable DW forms accompanying this DW767 form - It is compulsory to include a DW905 form with this DW767 form Note: It is optional to provide additional technical information for registering this water use, unless required by the Department

Registration Part 2H: Disposing in any manner of water which contains waste, or which has been heated in, any industrial or power generation process

- This water use refers specifically to the temperature of the wastewater which may have a significant effect on the water resources;
- The discharge of heated wastewater to a water resource is defined as a 21(h) water use;
- Discharges to the marine environment, i.e. land-derived wastewater discharged to the sea, commonly through a sea outfall is included under section 21(h).

SECTIONS ON FORM	EXPLANATIONS
1. GENERAL INFORMATION	Mark the applicable options with an X and/or complete details where applicable.
1.1. Indicate the nature of this application	▪ Indicate if the application is an application for a water use license in terms of the National Water Act, 36 of 1998 or whether the application is only to register the water use. An application for a license will automatically be registered by the Department. Registration of the water use is NOT an authorization and the application will not be processed for a license.
1.2 Have you already registered a water use with the Department of Water Affairs and Forestry?	▪ If the water use has been registered with the Department, and/or a license issued, provide the registration number and/or water use number provided on the registration certificate.
1.3. Indicate if Section 21 (j) is applicable to this water use application	▪ Indicate if the wastewater being discharged to a water resource comprises of water obtained through dewatering of water found underground. If so, ensure that a DW805 form is completed.
1.4 Do you have a license, permit or exemption for this waste discharge?	▪ The purpose of this section is to determine whether the water use is considered an Existing Lawful Use. If you have been issued with a license, permit or exemption in terms of any of the environmental legislations as mentioned please provide the reference number that is provided on the relevant authorization.
Declaration by Applicant	▪ Individual applicants must sign and date the form themselves. ▪ In the case of a power of attorney a certified copy of the appointment must be attached to the application form. ▪ Use of a thumbprint in the space provided will be acceptable in some cases as an alternative to an applicant's signature
2. DESCRIPTION OF THE WASTE GENERATED	Describes the nature and composition of the waste or wastewater generated.
2.1 Select the sector that generates the waste or wastewater which this application refers to	▪ Select one of the broad waste generating sectors (Agriculture, Domestic, Industry and Mining) from which the waste is generated ▪ Feedlots as well as piggeries, dairies, poultry etc should be regarded as "Intensive Animal Husbandry" ▪ If more than one sector is applicable complete a separate form for each sub-sector together with all the other forms.

SECTIONS ON FORM	EXPLANATIONS
2.2 Describe the nature of the wastewater	- See definition of wastewater in Section 3 - This section describes the flow and quality characteristics of the wastewater - Select an option/s best describes the nature of the wastewater - If the nature of the wastewater is best described by means of a combination of the descriptions, more than one option could be selected
2.3 Describe the composition of the wastewater	- This section describes the organic and inorganic solid matter composed in wastewater and this matter will be in the form of dissolved and suspended solids. - Select an option/s that best describes the composition of the wastewater - This option is for any combination of domestic and biodegradable industrial wastewater. - The percentage by volume is the proportion of the total wastewater that is made up of industrial wastewater.
2.4 Describe the activity that generates the wastewater	Please provide a clear description of the activity on how the waste/wastewater is generated.
2.5 DISCHARGE TO A WATER RESOURCE	This section describes volumes and concentrations of the wastewater.
2.5.1 Water use start & end date	Include start date of water use and end date (where applicable)
2.5.2 Total volume of waste/ wastewater discharged per year	- Discharge may occur at different rates during the year. Indicate the exact volume discharged per year and the maximum discharged on any given day. - The total volume of waste water discharged per year must preferably be stated in cubic metres (c³m) - The total volume of waste discharged per year should be based on the average volume
2.5.3 Maximum volume of waste/ wastewater discharged on any given day	Requires highest volume of waste/ wastewater discharge into a water resource in cubic meters (m³) per in any given day.
2.5.4 Monthly discharge pattern	- Select with a "X" in the appropriate box the option in which the monthly discharge pattern is expressed - If a unit of measure other than cubic meters or percentage is selected specify the unit in the space provided - Specify the annual waste discharge pattern by stating the minimum, maximum and average volume for each calendar month - The summation of the monthly average volume of waste discharged should correlate with the annual total of waste discharged
2.5.5 Intake Water	- Intake water is defined as water that used in the waste generating activity that results in wastewater generated - Indicate the source of intake water which could be either obtained from a water services provider or water user association; or obtained through one or more of the following sources: - Abstraction from a water resource - Wastewater from a holding facility; or - Water obtained through a dewatering process

SECTIONS ON FORM	EXPLANATIONS
2.5.6 Registered waste discharge information	- Indicates the quality and quantity of wastewater discharged into a water resource. - The total volume of wastewater discharged per year must preferably be stated in cubic meters (m³). - The total volume of wastewater discharged per year should be based on the average volume - Indicate the concentration of each of the applicable quality variables specified in this section - Wastewater quality and quantity are crucial to calculate waste load per variable that may be subjected waste discharge charges. - Load calculations will be completed by the Department
3. RECEIVING ENVIRONMENT/ RECEPTOR	This section will address the resource that needs to be protected and the applicable catchment where the water use is occurring.
3.1 Description of nearby water resources	Requires information on the nearby water resource which is likely to be affected by discharged or irrigated wastewater
3.1.1 Description of surface water resources	A surface water resource is associated with the following: - a river or a stream as a natural channel in which water flows regularly or intermittently - a wetland, lake or dam into which, or from which, water flows; - any collection of water which the Minister may declare to be a watercourse such as GWS; estuaries and marine Select only one option with X - If "other" is selected provide a clear description - Provide the name of the nearest surface water resource e.g. Rietvlei or Orange River - Provide the distance in meters to the nearest surface water resource e.g. 1500m
3.1.2 Description of groundwater resources	A ground water resource is associated with the following: - An aquifer in which underground water is obtained through a spring or eye, borehole, ground water Government Water Scheme (GWS) or boreholes and windmills on Government land Select one option with a X for the type of groundwater resource nearest to the location where the discharge is taking place - If "other" is selected provide a concise description - If an indicated type of selection had been made provide the name or description of the nearest ground water resource - Provide the distance in meters to the nearest ground water resource e.g. 1000m
3.2 Water resource (receiving the wastewater discharge) information	See definition of water resource in section 3.
3.2.1 Name of the water resource receiving the wastewater discharge	Requires the name of that particular water resources receiving wastewater discharge. If the water resources does not have a specific name, enter "no name"
3.2.2 Type of the water resource receiving the waste/ wastewater discharge	- Indicate the appropriate water resources receiving waste/ wastewater - The type of water resources refers to surface water bodies only. Note that only one type of resource should be selected. For registration of more than one discharge point, complete a separate DW 766 form

SECTIONS ON FORM	EXPLANATIONS
3.2.3 Geographical location of the discharge point	Enter the geographic location either in degrees(°), minutes(') and seconds(''), or in decimal degrees. The geographic location can be read from a 1:50 000 topographic map available from the Government Printers at a nominal charge, or at the nearest office of the Department, or by using a Global Positioning System (GPS) instrument.
3.2.4 Reliability of water resources receiving waste/ wastewater	Indicate the reliability of the water resources by selecting one option only.
3.2.5 Drainage region details	Indicate the drainage region or quaternary catchment where the water use occurs
3.2.6 Property relationship details (Note: Supplementary forms DW901 and DW902 must be completed)	If property is unsurveyed: - Water use on unsurveyed property may be registered on behalf of the village or community who owns or occupies the land. - Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands. - Supply the magisterial district or local authority. - Supply the surname and initials of village leader, community or tribal authority If property is surveyed: - All the necessary information for surveyed properties is available in the office of the Surveyor-General and must be correctly supplied.
4 List of supporting technical information	Mark with an X, the technical information that supports this application - Indicate which applicable DW forms accompanying this DW780 form - Note: It is optional to provide additional technical information for registering this water use, unless required by the Department

Registration Part 2J: Removing, Discharging or Disposing of Water found Underground if it is necessary for the Efficient Continuation of an Activity or for the Safety of People

- This form is for registration of removing underground water such as water that seeps into mine works or construction sites.
- It does **NOT** refer to the taking of groundwater for another purpose such as for drinking water, irrigation or industrial activities. For taking of groundwater, complete form DW760.
- Common examples of this water use include:
 - dewatering of mines,
 - removing underground water from construction sites to allow construction activities, or
 - removing water from under buildings that experience groundwater seepage into their foundations.
- Mine dewatering and the subsequent use of the water must comply with the Mining Regulations.

SECTIONS ON FORM	EXPLANATIONS
1. GENERAL INFORMATION	Mark the applicable options with an X and/or complete details where applicable.
1.1. Indicate the nature of this application	▪ Indicate if the application is an application for a water use license in terms of the National Water Act, 36 of 1998 or whether the application is only to register the water use. An application for a license will automatically be registered by the Department. Registration of the water use is NOT an authorization to use water.
1.2 Have you already registered a water use with the Department of Water Affairs and	▪ If the water use has been registered with the Department, and/or a license issued, provide the registration number and/or water use number provided on the registration certificate.
2. WATER RESOURCE INFORMATION	
2.1	▪ If the site where removal of underground water does not have a specific name, enter "no name".
2.2	▪ Indicate the type of water resource receiving the discharged water
2.3	▪ Enter the geographic location either in degrees(°), minutes(') and seconds(''), or in decimal degrees. The geographic location can be read from a 1:50 000 topographic map available from the Government Printers at a nominal charge, or at the nearest office of the Department, or by using a Global Positioning System (GPS) instrument.
2.4	▪ Indicate the drainage region or quaternary catchment where the water use occurs

3. DETAILS OF THE WATER USE 3.1 (a) 3.1 (b) 3.2	▪ This is the total amount of water removed over a period of one year. The removal may take place continuously throughout the year, or at certain times of the year. ▪ The maximum amount removed per day is the greatest volume that has ever been removed on any given day. ▪ After removing the water, the discharge or disposal must be registered on the relevant forms DW766 and DW767. ▪ If the water is stored after removal from underground, also complete form DW761.
4. Property relationship details (Note: Supplementary forms DW901 and DW902 must be completed)	If property is unsurveyed: ▪ Water use on unsurveyed property may be registered on behalf of the village or community who owns or occupies the land. ▪ Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands. ▪ Supply the magisterial district or local authority. ▪ Supply the surname and initials of village leader, community or tribal authority If property is surveyed: ▪ All the necessary information for surveyed properties is available in the office of the Surveyor-General and must be correctly supplied.
5. Authorisation details 5.1 5.2 5.3	Indicate if the water use falls under the <i>General Authorisations</i> Indicate if the water use is authorised under another legislation. Specify the regulation or legislation If the water use has been licensed in terms of the National Water Act, 36 of 1998 specify the license number.
6. Supporting Technical Information	Mark with an X, the technical information that supports this application ▪ Indicate which applicable DW forms accompanying this DW805 form ▪ Note: It is optional to provide additional technical information for registering this water use, unless required by the Department

SECTION 8

SUPPLEMENTARY FORMS

DW 901

Supplementary Form: Property Where Water Use Occurs

- The completion of this form is **COMPULSORY**
- The purpose of this form is to obtain information on the Property on which the water use occurs
- Registration of a water use will be considered incomplete if a DW901 does not accompany the Part 1 and 2 registration forms

SECTIONS ON FORM	EXPLANATIONS
1. PROPERTY WHERE WATER USE(S) OCCURS	▪ The property where water use occurs is not necessarily the same as the residence of the person applying for registration of a water use ▪ The property must be describe as follow: ▪ ZAAIHOEK_123_JS_0 where Zaaihoek is the original farm name, 123 is the property number, JS is the district and the last number the specific portion. ▪ NB - Only one property per registration is allowed!
1.1. Property where water use takes place	▪ Unsurveyed property may be registered on behalf of the village or community who owns or occupies the land. ▪ Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands.
1.2 Property type	Property is classified as being agricultural holding, farm, township, unsurveyed etc.
1.3. Unsurveyed property type	▪ Property type with no deeds information ▪ Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands.
1.4 Property type not equal to unsurveyed	▪ All the necessary information for a surveyed property which is available from the office of the Surveyor-General. The Deeds Office, Registration Division, Property Number, Portion of Property and Title Deed Number and Cadastral Code Number must be correctly supplied.
1.5 Property Area Size	• Size or Measurement of property to be provided in hectares, square meters or acres.
1.6 Ownership of the Property	▪ Indicates the percentage of shareholder value for the owner of the property. ▪ Property may be registered on behalf of the village or community who owns or occupies the land. ▪ Unsurveyed property includes communal lands, tribal lands and some of the lands in the former homelands.
2. PROPERTY OWNER RELATIONSHIP	▪ Details the link between the property and the property owner from the date he/she becomes the owner and his/her shareholder value on the property. The property owner document ID number, Title Deeds Number and Register number must be supplied.
3. DECLARATION BY APPLICANT	▪ Individual applicants must sign and date the form themselves. ▪ In the case of a power of attorney a certified copy of the appointment must be attached to the application form.

Supplementary Form: Details of Property Owner

- The completion of this form is **COMPULSORY**
- The purpose of this form is to obtain information on the Property Owner/s of the property which the water use occurs
- Registration of a water use will be considered incomplete if a DW902 does not accompany the Part 1 and 2 registration forms

SECTIONS ON FORM	EXPLANATIONS
1. DETAILS OF PROPERTY OWNER	▪ Allows for details of property owner to be provided and/or specified.
1.1. Nature of property owner	▪ Allows for the property owner to be defined as either as an Individual, Water Services Provider, Water User Association, Provincial Department, Company, Business Partnership or Community Etc
1.2 Individual Property owner	▪ South African Property owners must supply his/her SA ID records. Non SA applicant must supply their passport records. Date and country of issue. Foreign ID are not acceptable
1.3 Cooperative property owner (e.g. Company, Business, Partnership or Community)	▪ Allows for the details of the cooperative property owner to be supplied. Indicate whether the it's a company, partnership or community and whether it's a public company, parastatal, external company, close cooperation etc.
1.4 Property owner (If a national Department)	▪ Indicate if the property owner is the national department. List the name of the National Department. That is Department of Water Affairs and Forestry, Department of Environment Affairs and Tourism
1.5 Property owner (If a Provincial Department)	▪ Indicate if the property owner is a provincial department. List the name of the Provincial Department such as Gauteng Department of Agriculture, Conservation and Environment.
1.6 Property owner (If a Water Services Provider)	▪ Indicate if the property owner is the Water Service Provider
1.6.1 Name of Water Services Provider	▪ List the name of the service provider under application
1.7 Property owner (If a Water User association)	▪ Specify if the applicant is a water user association
1.7.1 Name of Water User Association	▪ Indicate the name of the water Use services provider
1.8 Postal Address	▪ Specify the postal details of the Property Owner
1.9 Street Address	▪ Specify the residential address for the Property Owner
1.10 Contact Telephone Number During Office Hours	▪ Indicate the applicant cell number/home telephone number
2. DECLARATION BY PROPERTY OWNER	▪ Applicants or property representative must sign and date the form themselves. ▪ In the case of a power of attorney a certified copy of the appointment must be attached to the application form.
2.1 Property owner or delegated person	▪ Designated signatories must indicate if they are the owner of the property or representative.

SECTIONS ON FORM	EXPLANATIONS
2.2 Property owner passport (If not holder of South African I.D)	Property owner who is not the SA citizen must indicate their passport details i.e. date and country of issue
2.3 Position or official status	Occupation of the property owner must be provided
2.4 Declaration	Property owner or property representative with power of attorney must sign the application
3. LIST OF ATTACHED DOCUMENTS	
3.1 Certified copy of identity document or passport	Applicant must attach copies of their identity document in their application form
3.2 Certified copy of property owner document	Property owner must attach copies of their attached as detailed in the application form
3.3 Certified copy of lease agreement	Applicant must attach copies of the property leasing agreement
3.4 Certified copy of the "power of attorney" or appropriate supporting documentation	Person signing on behalf of the applicant must attach his/her relationship document with the applicant.

**Supplementary Form: Actual/ Monitored Waste Discharge Details Section
21f/h water uses (Point Source Discharges)**

- This supplementary form provides a structured manner of reporting actual discharge information by a waste discharger;
- This form is applicable to section 21(f) and (h) discharges directly to a water resource - point source discharges;
- This form communicates to DWAF the monitored discharge information as well as compliance management information;
- Waste discharge charges may be applied to the discharge information provided.

SECTIONS ON FORM	EXPLANATIONS
1. REGISTERED WATER USE	▪ If the water use has been registered, the registration number can be obtained from the registration certificate; ▪ The water use number can be obtained either on the registration certificate or the water use license; ▪ These numbers are unique reference numbers for a specific water use registered or authorized by DWAF; ▪ Contact the appropriate DWAF office for assistance if you are unable to locate these numbers.
2. ACTUAL/ MONITORED WASTE DISCHARGE DETAILS	▪ This section specifies: ▪ the period of reporting and includes a start & end date; ▪ intake (or source water) volume; ▪ volume of discharge (output); ▪ water quality variable concentrations ▪ Indicate the time interval per required;
3. LIST OF ATTACHED DOCUMENTS	A certificate of analysis from an accredited laboratory is required with the submission of a DW903.

**Supplementary Form: Actual/ Monitored Waste Discharge Details Section
21e/g water uses (Non-Point Source Discharges)**

- This supplementary form provides a structured manner of reporting actual discharge information by a waste discharger;
- This form is applicable to section 21(e) and (g) water users - non-point source discharges;
- This form communicates to DWAF the monitored discharge information as well as compliance management information;
- Waste discharge charges may be applied to the discharge information provided.

SECTIONS ON FORM	EXPLANATIONS
1. REGISTERED WATER USE	▪ If the water use has been registered, the registration number can be obtained from the registration certificate; ▪ The water use number can be obtained either on the registration certificate or the water use license; ▪ These numbers are unique reference numbers for a specific water use registered or authorized by DWAF; ▪ Contact the appropriate DWAF office for assistance if you are unable to locate these numbers.
2. ACTUAL/ MONITORED WASTE DISCHARGE FOR NWA SECTION 21e/g WATER USES	Indicate the following information in the space provided: ▪ The period (start and end date) for which this compliance report is submitted; ▪ The volume (in cubic metres) of waste applied to the land-based facility; ▪ Average concentration values of the waste or wastewater; Please note that DWAF will calculate the average load applied to the facility.
2. LIST OF ATTACHED DOCUMENTS	A certificate of analysis from an accredited laboratory is required with the submission of a DW904.
4. MANAGEMENT CLASSIFICATION DETAILS	The purpose of this section is to obtain information on the state of management practices at the waste management facility. Indicate if the management practices of a particular waste management facility has changed since the facility has been registered with DWAF. Specify what management measures have been put in place.

Supplementary Forms: Details of waste management facility

- This supplementary form accompanies a DW767 registration
- A registration of a waste disposal site or waste management facility will be considered as incomplete without the completion of a DW767 **AND** a DW905
- The purpose of this form is to provide information on the details of the waste management facility registered as a 21(g) water use on a DW767 form

SECTIONS ON FORM	EXPLANATIONS
1. WASTE MANAGEMENT FACILITY DETAILS	This section provides information on the method of disposal, details on the lining of the site, the potential to generate leachate and leachate management measures.
1.1 Name of waste management facility	▪ If a name was given to a particular waste management facility, supply the name. If no name please enter in the space provided "no name". Ensure that the name provided in this section corresponds to the name provided in the accompanying DW767 form
1.2 Fatal flaw indicators	▪ These criteria are non negotiable aspects that apply to a waste management facility. If relaxed for a waste management facility specific water management approaches need to be incorporated to minimise the potential impacts ▪ Select from the list and mark with X all the indicators that apply to the site or the proposed site in respect of non conformation
1.3 Method of Disposal	▪ Select the most appropriate method of disposal and mark with X ▪ If "other" is selected please provide a clear description on the method of disposal
1.4 Distance from nearest borehole used for drinking water or stock water	▪ Provide the distance in meters to the nearest borehole used for domestic and stock watering purposes, not boreholes used for routine monitoring purposes
1.5 Distance from the edge of nearest downstream surface water resource	▪ Refer to surface water resource as described in segment B1 ▪ Edge is seen as the outer limit of a natural channel in which water flows regularly or intermittently in the case of a river or stream or the full level supply line in the case of a dam or lake
1.6 Lining of the site	▪ Lining is the barrier that had been implemented to prevent the migration of the pollutants through to the resource ▪ The type of lining indicate the efficiency of the barrier to prevent migration of pollutants and are assessed in respect of management practice classification ▪ Indicate whether the site will be lined or not ▪ Select the type of lining with X
1.7 Total area of 'property' on which waste is disposed	▪ What is the total size of the property in hectares on which waste is disposed?
1.8 Area of actual waste body ("footprint area")	▪ The footprint area is the area on which the waste is disposed and encompasses the actual waste body ▪ Provide the size of the footprint area in hectares
1.9 Dimensions of waste site	▪ Provide dimensions in terms height, length and breadth in meters; ▪ Air space typically refers to available space in a landfill.
1.10 Buffer Zone	▪ Distance to the boundary of the closest residential and industrial area

SECTIONS ON FORM	EXPLANATIONS
1.11.1 Geographical location	Enter the geographic location either in degrees(°), minutes(') and seconds(''), or in decimal degrees. The geographic location can be read from a 1:50 000 topographic map available from the Government Printers at a nominal charge, or at the nearest office of the Department, or by using a Global Positioning System (GPS) instrument.
1.11.2 Drainage Region Details	Indicate the quaternary drainage region where the water use occurs.
1.12 Climatic water balance	- Waste sites are classified in terms of their potential to generate leachate. The potential to generate leachate is calculated using rainfall and evaporation. Where rainfall, exceeds evaporation, the potential for leachate generation increases. - Rainfall data can be sourced from the closest gauging station or the South African Weather Services
1.13 Details of the person in control of the site	- Supply surname as follow: Masike; de Jonge - Supply initials without spaces or punctuation: AB - Use the following: Mr, Me, Ms, Dr - Supply the whole number. SA ID number or temporary ID number is sufficient for identification purposes. Individuals who do not have a SA ID number must use their passport number for identification purposes - Supply the contact numbers where (i) area is the 3 digits dialling code and (ii) the number is the telephone/fax number without spaces. Ext. is only for extensions where necessary. International codes like +27 must not be used for domestic numbers - If available the complete e-mail address must be provided - Select the highest educational qualification
2. OPERATION OF THE WASTE MANAGEMENT FACILITY	The purpose of this section is to obtain information on the management practices employed at the waste management facility. The management practices will enable DWAF to determine the management classification of the site which could be best, standard or poor.
2.1 Type of operation	- Indicate the type of operation of the facility; - In the case of "Other", specify the appropriate type of operation.
2.2 Length of time of the operation	Indicate the start date of the disposal and the end date (optional).
2.3 Is sufficient cover material on site	Indicate the applicable option.
2.4 Covering and burning of waste	Mark the applicable options
2.5 Is a leachate management system present	Indicate if the site has a leachate management system in place
2.6 Storm water management	Indicate the stormwater management practice on site

SECTIONS ON FORM	EXPLANATIONS
3. MANAGEMENT PRACTICES OF THE WASTE MANAGEMENT FACILITY	▪ Tick the options that describe the management practices per waste management facility. ▪ Ensure that a separate DW767 and DW905 form is completed for each waste management facility. ▪ This section will enable DWAF to classify the management practices at the waste facility. ▪ The management practice enables DWAF to calculate the waste load that has the potential of polluting a water resource. ▪ Tick the appropriate option that describes the management practice. ▪ Describe any other practice on site.

SECTION 9

Conversion Table

VOLUME (m ³) cubic meters	
Milliliter (ml)	0.000001 m ³
Liter (l)	0.001 m ³
Kiloliter (kl)	1 m ³
Cubic centimeter (cm ³)	0.000001m ³

WEIGHT (kg) kilograms	
Milligram (mg)	0.000001 kg
Gram (g)	0.001 kg
Tonnage (ton)	1000 kg

AREA (ha) hectares	
Square centimeter (cm ²)	0.00000001 hectares
Square meter (m ²)	0.0001 hectares

LENGTH (m) meters	
Millimeter (mm)	0.001 m
Centimeter (cm)	0.01 m
Kilometer (km)	1000 m

CONCENTRATION (mg/l) milligrams per liter	
Milligram per milliliter (mg/ml)	1000 mg/l
Microgram per litre (ug/l) = 1 parts per billion	0.001 mg/l
Milligram per cubic centimeter (mg/cm ³)	1000 mg/l
Gram per Cubic meter (g/m ³)	1 mg/l
Gram per Kiloliter (g/kl)	1 mg/l
Milligram per cubic meter (mg/m ³)	0.001 mg/l
Milligram per Kiloliter (mg/kl)	0.001 mg/l
1 milligram per litre	1 parts per million

SECTION 10

REGISTRATION HELPLINES AND CONTACTS IN THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY

The various offices of the Department of Water Affairs and Forestry around the country are standing by to provide you with the correct forms to fill in, and to assist you to fill in the forms.

Forms can also be obtained from the Departmental web-site: <http://www-dwaf.gov.za> or call the toll-free line on 0800 200 200

Ask for the Registration Help Desk at the Regional Office that serves your area.

Head office and regional offices

Head Office

Department of Water Affairs and Forestry
Private Bag X313
PRETORIA
0001
Tel: 012-336 7500
Fax: 012-326 1488

Free State

Department of Water Affairs and Forestry
P O Box 528
BLOEMFONTEIN
9300
Tel: 051- 4303134
Fax: 051-4308146

Northern Cape

Department of Water Affairs and Forestry
Private Bag X6101
KIMBERLEY
8300
Tel: 053-830 8800
Fax: 053-831 5682

Eastern Cape

Department of Water Affairs and Forestry
Private Bag X7485
KING WILLIAM'S TOWN
5600
Tel: 043-643 4352
Fax: 043-642 1136

KwaZulu/Natal

Department of Water Affairs and Forestry
P O Box 1018
DURBAN
4000
Tel: 031-3362700
Fax: 031-3049546

Gauteng

Department of Water Affairs and Forestry
Private Bag X335
PRETORIA
0001
Tel: 012-392 2880

Limpopo

Department of Water Affairs and Forestry
Private Bag X9506
POLOKWANE
0700
Tel: 015-2959410/1/2/3/4/5
Fax: 015-2953215

Western Cape

Department of Water Affairs and Forestry
Private Bag X16
SANLAMHOF
7532
Tel: 021-950 7100
Fax: 021-946 3664

Mpumalanga

Department of Water Affairs and Forestry
Private Bag X11259
NELSPRUIT
1200
Tel: 013-752 4183/4
Fax: 013- 7551678

North West

Department of Water Affairs and Forestry
Private Bag X5
MMABATHO
2735
Tel: 018-387-9500
Fax: 018-384-2059

