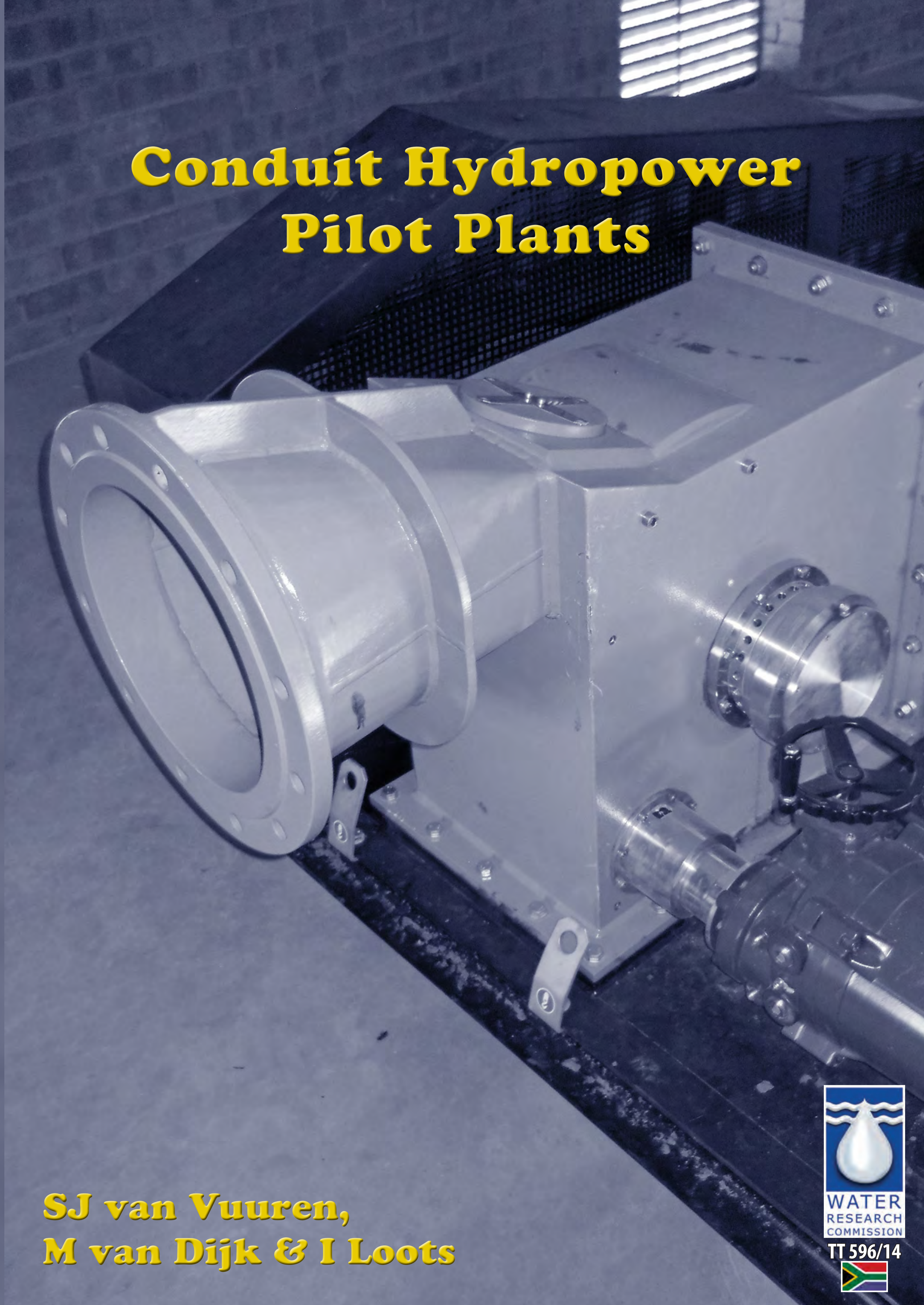

Conduit Hydropower Pilot Plants

SJ van Vuuren,
M van Dijk & I Loots

WATER RESEARCH COMMISSION
TT 596/14

Conduit Hydropower Pilot Plants

Report to the
Water Research Commission by

SJ van Vuuren, M van Dijk and I Loots
University of Pretoria

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Private Bag X03
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orders@wrc.org.za or download from www.wrc.org.za

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

The outputs emanating from this study include:

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

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 beneficiation, 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 CO_2 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 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, 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.

Pilot plants

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	1 x 2	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 project 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"

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 (this report)
- TT597/14 - Conduit Hydropower Development Guide
- 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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The members of the Reference Group and Project Team were:

Mr JN Bhagwan	:	Water Research Commission – Chairman
Ms C Khanyile	:	Water Research Commission – Project co-ordinator
Mr T Velen	:	ESKOM
Mr N Govender	:	ESKOM
Mr S Moodliar	:	eThekwini Water and Sanitation
Mr F Stevens	:	eThekwini Water and Sanitation
Mr R Dyer	:	eThekwini Water and Sanitation
Mr GFJ Van Rensburg	:	MBB Consulting Engineers (Nelspruit)
Dr J Ndiritu	:	University of the Witwatersrand
Prof JE van Zyl	:	University of Cape Town
Mr N Trebicki	:	Rand Water
Dr M Shand	:	Aurecon
Dr M Bipath	:	South African National Energy Research Institute
Mr WE Jonker Klunne	:	CSIR
Mr DM Kgwale	:	Bloemwater
Mr A Kurtz	:	City of Tshwane Metropolitan Municipality
Prof SJ van Vuuren	:	University of Pretoria (Project leader)
Mr M van Dijk	:	University of Pretoria
Ms I Loots	:	University of Pretoria
Mr B Barta	:	Energy and Water Resources Development
Mrs BG Scharfetter	:	Specialist hydropower consultant

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CONDUIT HYDROPOWER GENERATION DEVELOPMENT GUIDE

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LIST OF SYMBOLS AND ABBREVIATIONS

AADD	average annual daily demand
BA	basic assessment
B/C	benefit/cost ratio
CHD Tool	Conduit Hydropower Development Tool
CHDSS	Conduit Hydropower Decision Support System
CO_2	carbon dioxide
CoT	City of Tshwane
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
DSS	decision support system
EIA	environmental impact assessment
ESHA	European Small Hydropower Association
g	gravitational acceleration (m/s^2) (typically 9.81 m/s^2)
H	effective pressure head (m)
h_f	friction loss (m)
h_l	secondary losses (m)
I	electrical current (A)
IHA	International Hydropower Association
IMQS	Infrastructure Management Query Station
IPP	independent power producer
IRR	internal rate of return
K	secondary loss coefficient
L	length of penstock (m)
LCC	life cycle cost
n	number of years
NERSA	National Energy Regulator of South Africa
NPV	net present value of benefits
O&M	operation and maintenance
P	mechanical power output (W)
P_{actual}	actual power output of turbine (W)
$P_{theoretical}$	theoretical output at 100% efficiency (W)
PRS	pressure-reducing station
PRV	pressure-reducing valve
PW	present worth
Q	flow rate through the turbine (m^3/s)
REBID	Renewable Energy Bidding (now REIPPPP)
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROI	return on investment
SABS	South African Bureau of Standards
SANEDI	South African National Energy Development Institute

USBR	United States Bureau of Reclamation
V	potential difference (V)
v	velocity of water in penstock or pipe (m/s)
η	hydraulic efficiency of the turbine (%)
λ	friction coefficient of penstock or pipe (m)
ρ	hydraulic efficiency of the turbine (%)

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

Overspeed	:	A speed higher than the normal operating speed. A turbine/generator in overspeed will produce harmful power surges (unless the main breaker acts to put the generator off line) and prolonged operation at overspeed can result in bearing failure and destruction of rotating parts.
Penstock	:	A closed conduit or pipe for conducting water to the powerhouse.
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

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 there could be a potential to generate energy in the water supply and distribution system, 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.

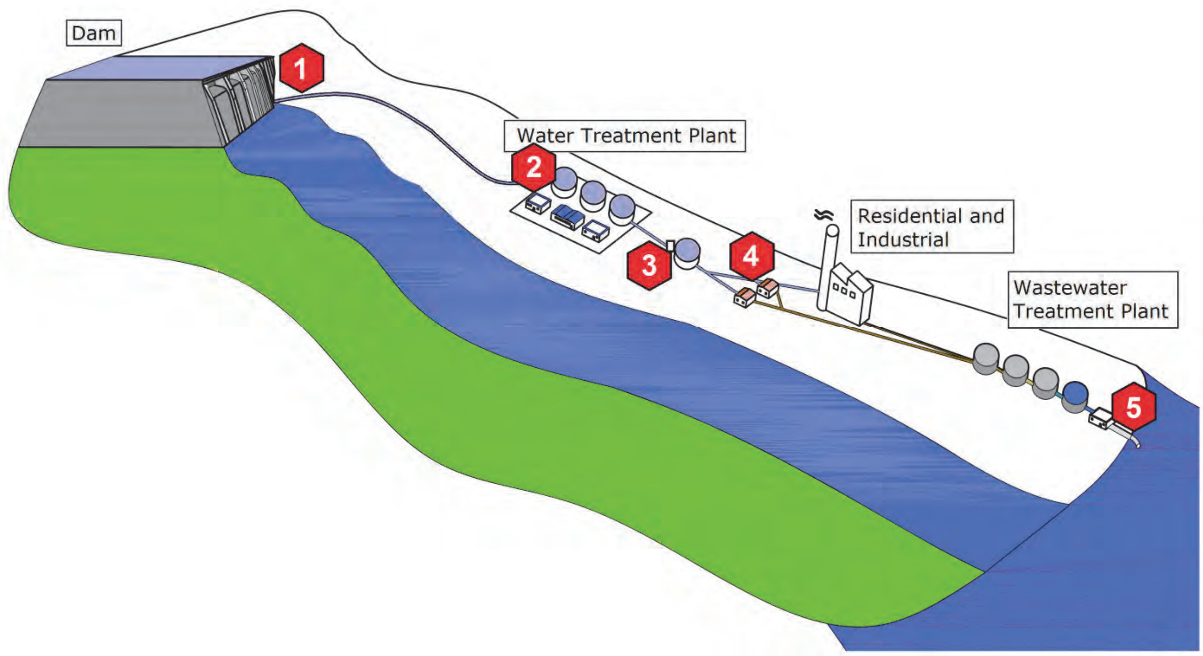


Figure 1-1: Location of energy generation potential (Van Dijk et al. 2012)

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

There are numerous benefits provided by hydropower over other energy sources (USBR, 2011):

- 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.
- <u>Conduit hydropower</u> uses the available water distribution infrastructure and thus as long as there is a demand, hydroelectric energy can be generated.
- <u>Conduit hydropower</u> "piggy backs" onto existing water infrastructure resulting in a minimal environmental impact.

A broad overview of the development potential based on the different types of hydropower categories are presented in **Table 1-1**.

To introduce conduit hydropower into the South African market the WRC with assistance from the collaborating organisations (City of Tshwane, Bloemwater and Ethekwini Municipality) have developed a number of full scale pilot hydropower plants in their water supply and distribution infrastructure. The objective of this was to demonstrate the technologies (turbines, controls etc.) by means of full scale pilot plants. Three pilot plants, listed in, **Table 1-2**, were constructed showcasing several of the intricacies in the development process and demonstrate the working of a conduit hydropower plant.

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, water utilities 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.	Several dam reservoirs and numerous bulk water supply systems – Water Transfer Systems

Table 1-2: 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 by the collaborating organisations are described in detail in the following paragraphs.

2. A DECISION SUPPORT SYSTEM FOR CONDUIT HYDROPOWER DEVELOPMENT

2.1 Introduction

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

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.

2.2 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. The ***Conduit Hydropower Development Guide*** elaborates on the items in the flow diagrams.

Each phase has its own process flow diagram linked to the 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.

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.

2.3 Decision Support System (DSS)

2.3.1 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 2-1** and **Figure 2-2** indicate the decision flow process for this phase.

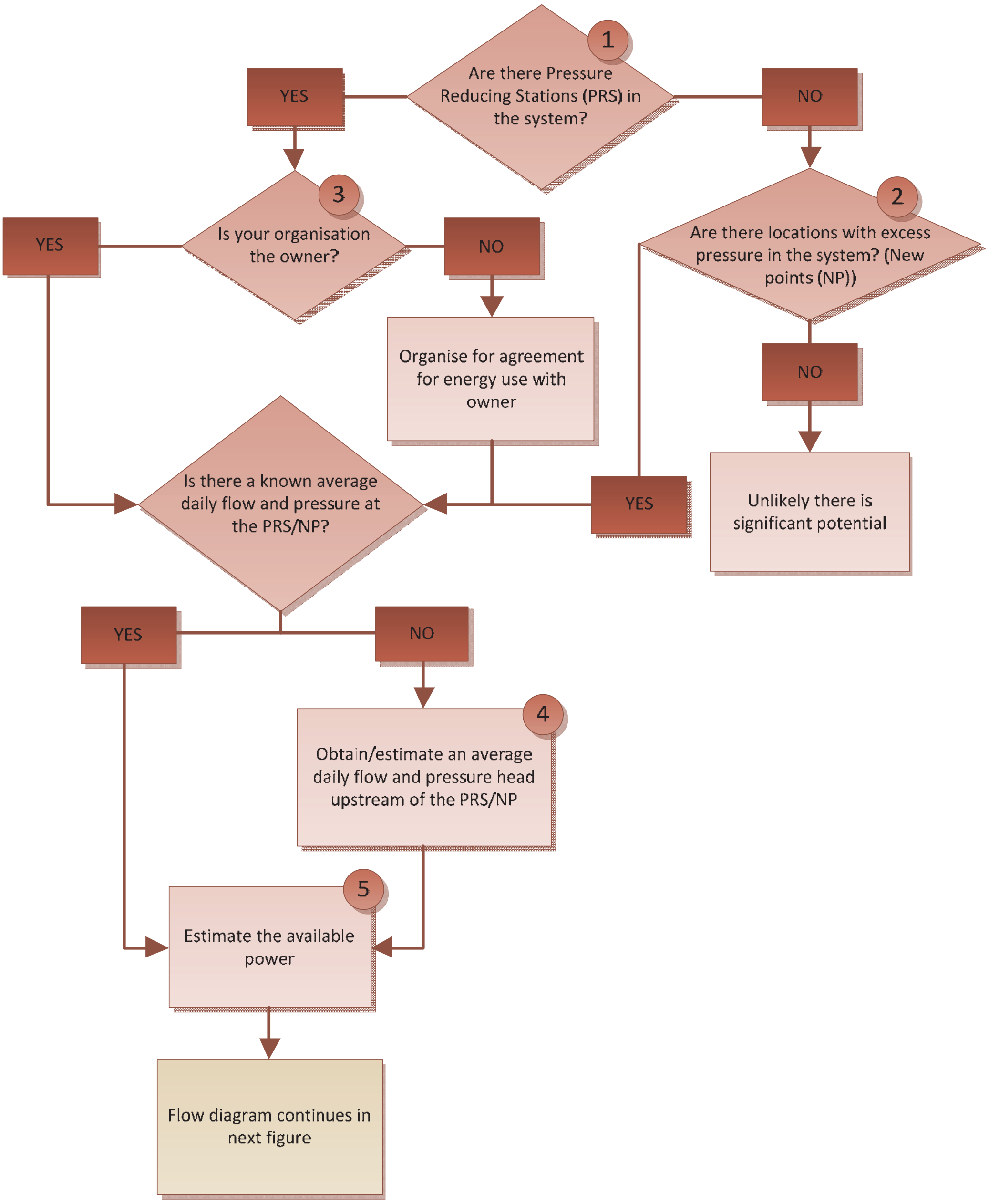


Figure 2-1: Phase 1 flow diagram Part A

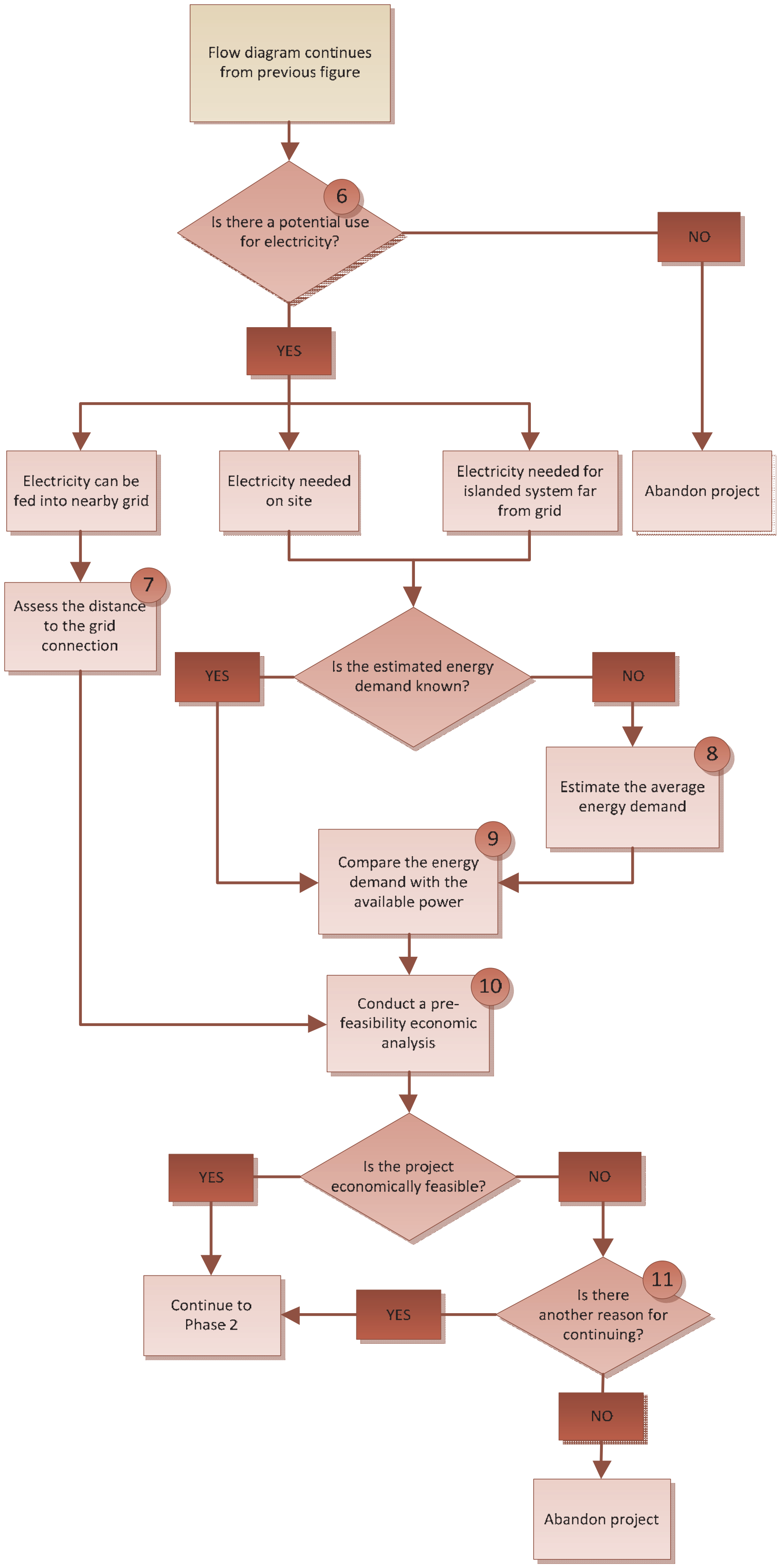


Figure 2-2: Phase 1 flow diagram Part B

2.3.2 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 2-3** and **Figure 2-4** illustrate the process to be followed during this stage.

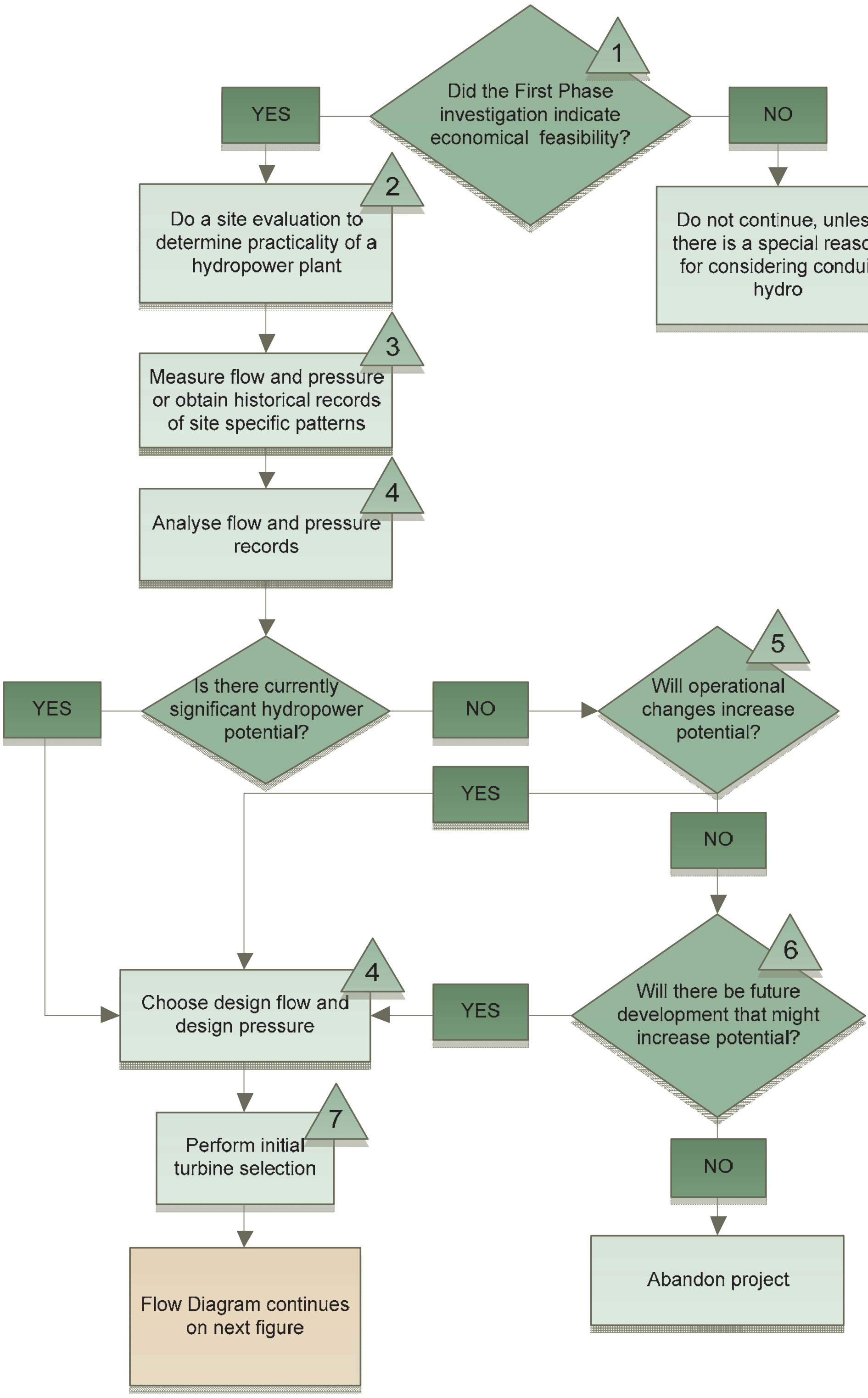


Figure 2-3: Phase 2 flow diagram Part A

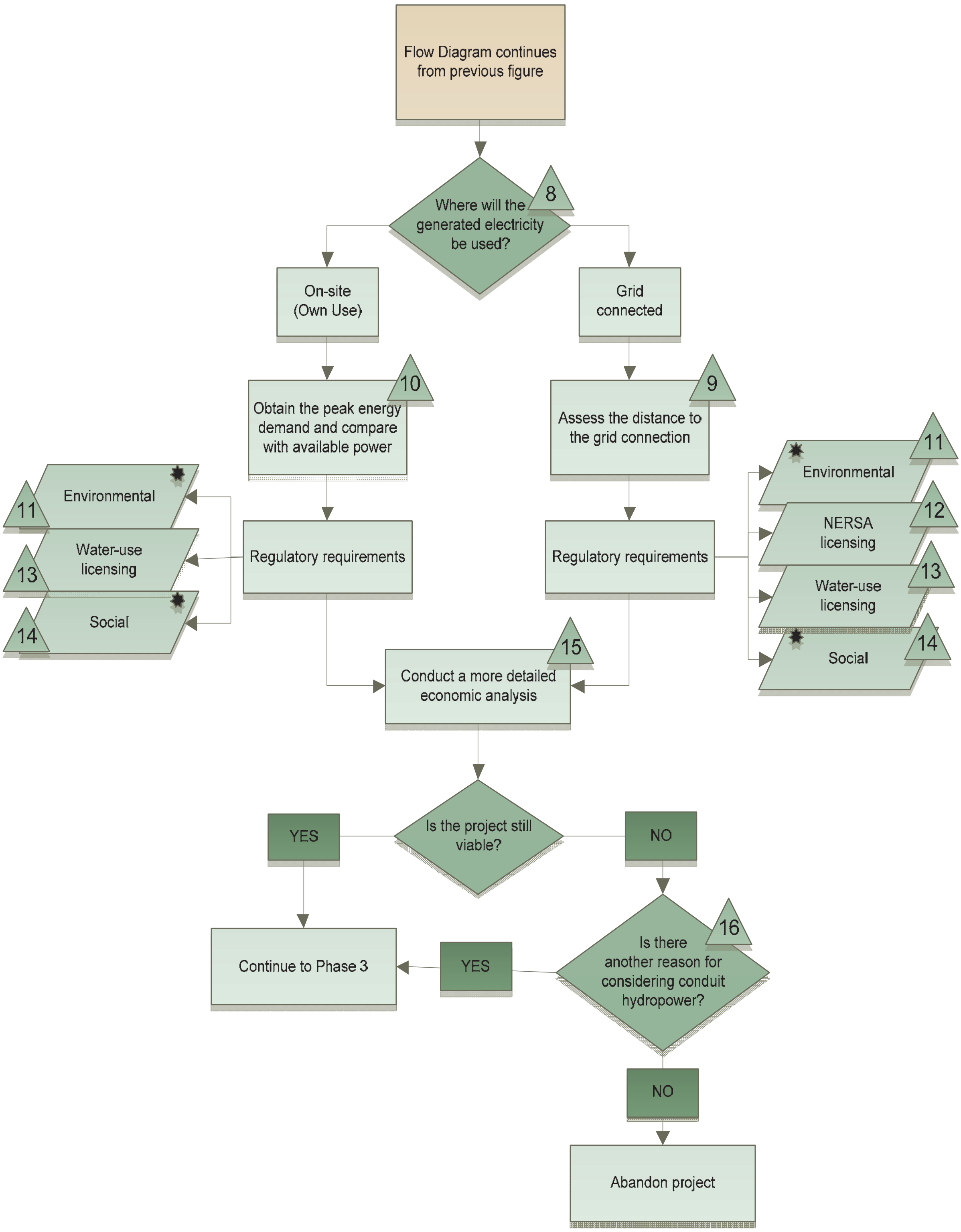


Figure 2-4: Phase 2 flow diagram Part B (✸ depicts specialist consultant input)

2.3.3 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 2-5**, **Figure 2-6** and **Figure 2-7** depict the decision support process to be followed in developing the hydropower potential.

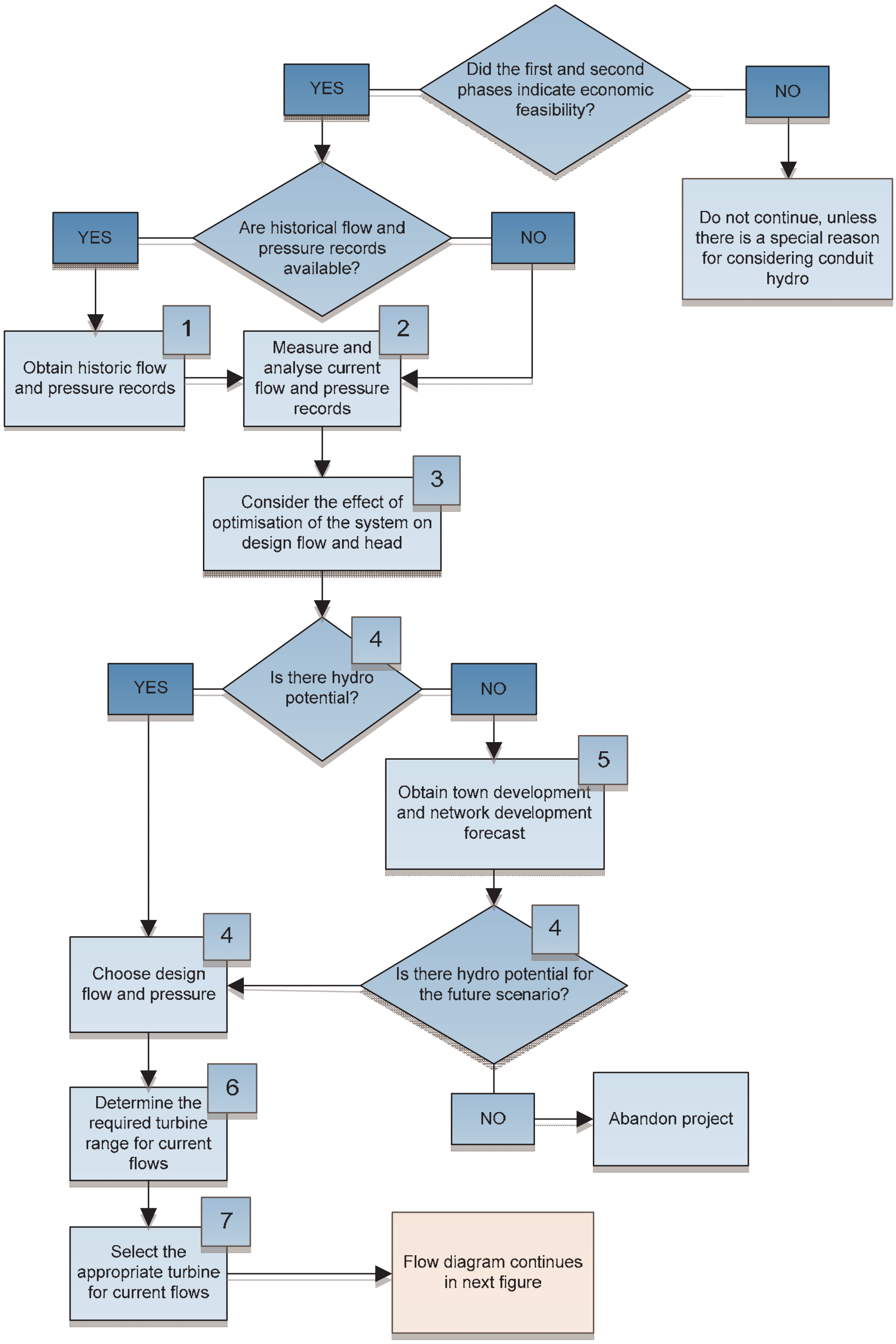


Figure 2-5: Phase 3 flow diagram Part A

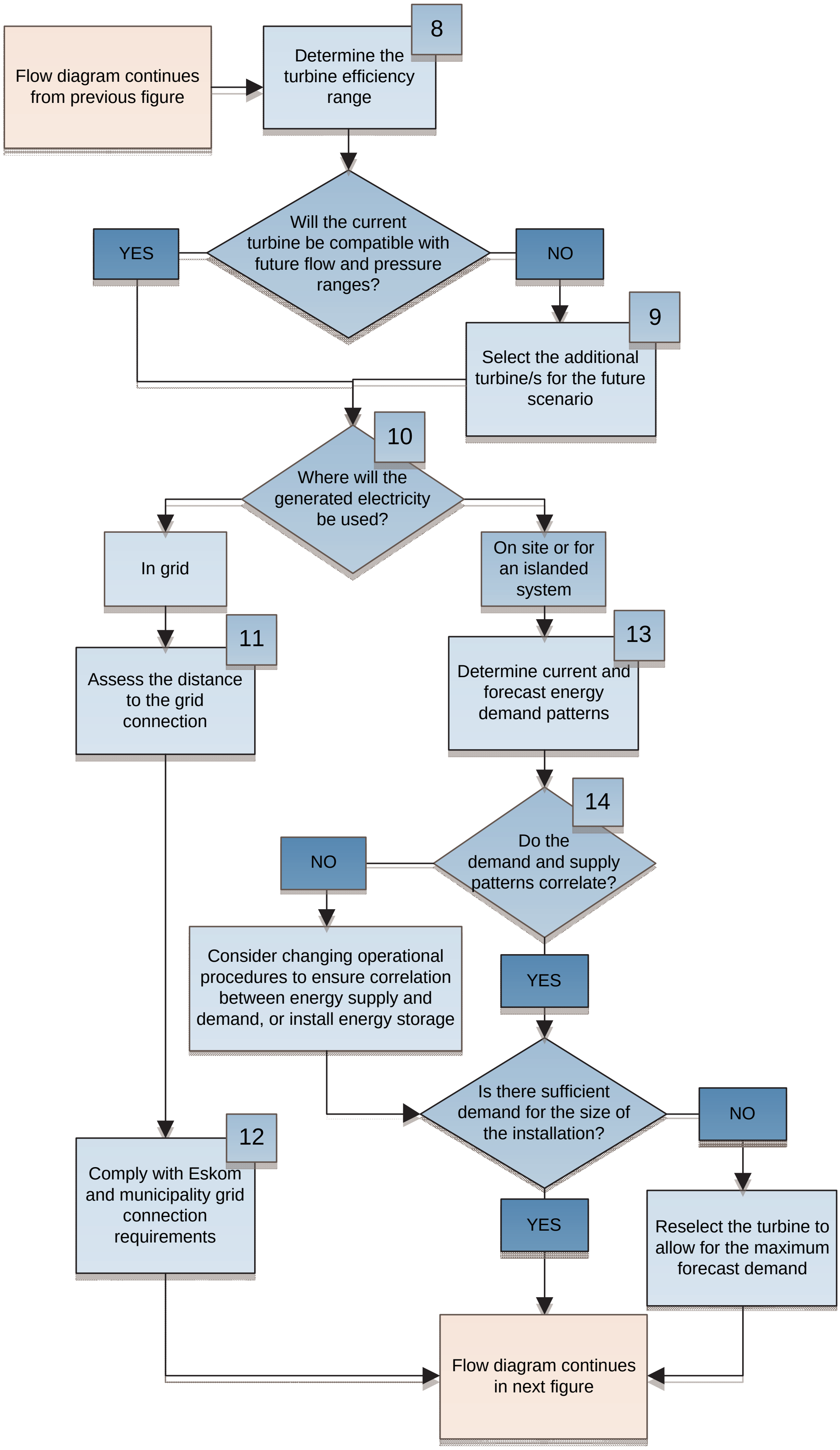


Figure 2-6: Phase 3 flow diagram Part B

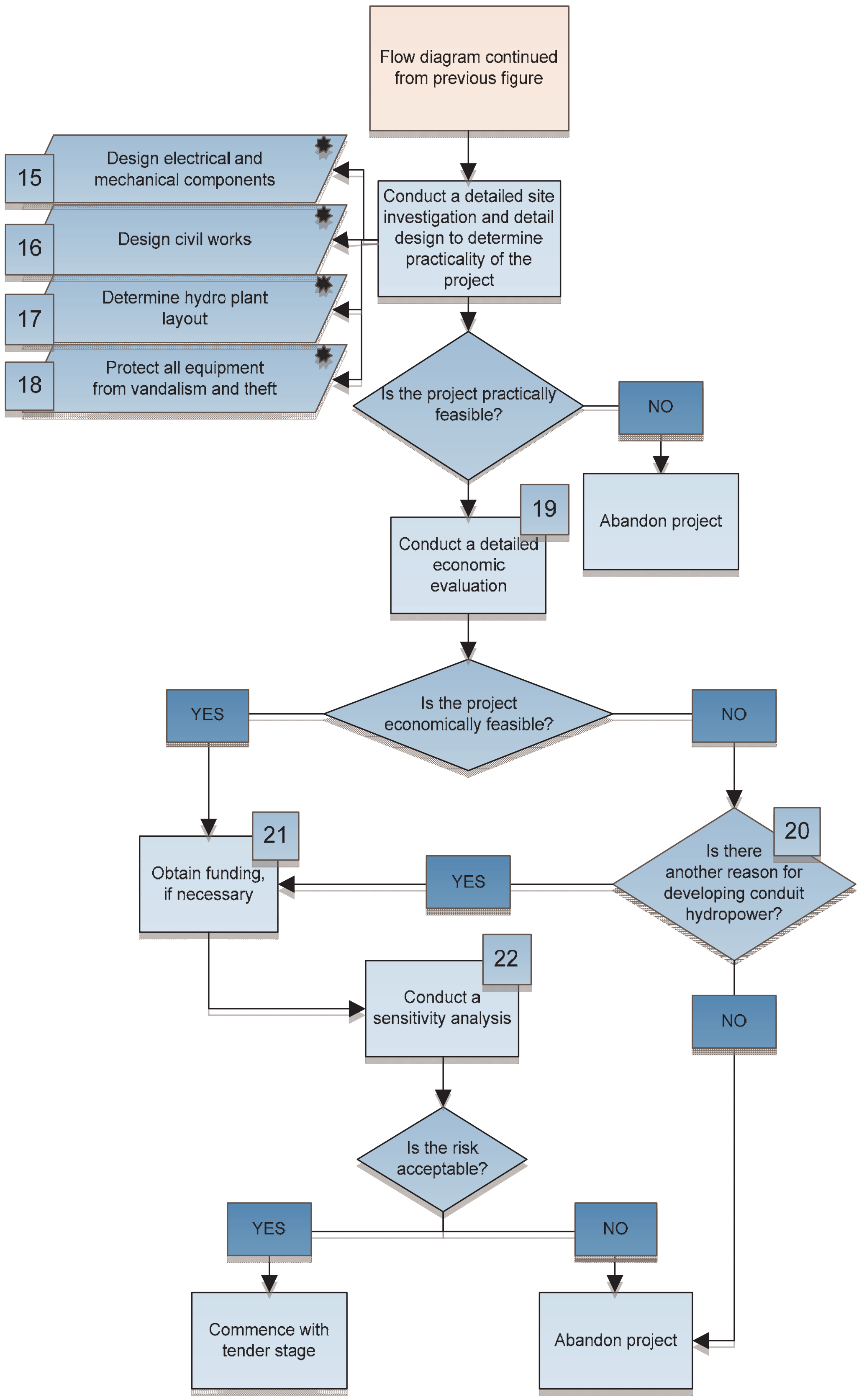


Figure 2-7: Phase 3 flow diagram Part C (* depicts specialist consultant input)

2.4 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, see the ***Conduit Hydropower Development Guide*** for more details.

2.5 Scope of works

The total scope of works for the development and operation of conduit hydropower plants in South Africa is summarised in **Figure 2-8**.

Figure 2-8: Conduit Hydropower Development Scope of Works

The planning, design, construction and testing of these pilot plants by the collaborating organisations are described in detail in the following paragraphs.

3. PIERRE VAN RYNEVELD PILOT PLANT (CITY OF TSHWANE)

3.1 Introduction

The Pierre van Ryneveld Reservoir is located south of Pretoria as shown in **Figure 3-1**. Although the site was not one of the top ten favourites in the City of Tshwane WDS the site was selected due to the construction of a new 15 ML reservoir near the existing reservoir. This provided the opportunity to construct the first closed conduit hydropower pilot plant in South Africa on the existing reservoir situated in the Country Lane Estate.

Figure 3-1: Location of Pierre van Ryneveld Reservoir

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.

3.2 Description of pilot plant site

The two reservoirs are currently operational, supplying water to the Pierre van Ryneveld suburb, near Centurion. The old reservoir is a medium sized, round and built from post-tensioned reinforced concrete with a concrete slab roof.
The old reservoir has a diameter of 32 m and a height of 10 m with a total capacity of 7.6 Ml. The source of the water is from Rand Water, via a bulk pipeline.

The new reservoir constructed in 2011 was constructed, to meet growing demand due to new developments in the area. The new reservoir has a capacity of 15 Ml receiving its water from the same source

The Pierre van Ryneveld reservoir has all the components of a typical water reticulation storage reservoir. There is an inlet pipe, outlet pipe, various control valves, flow meters, strainers and telemetry as shown in **Figure 3-2**.

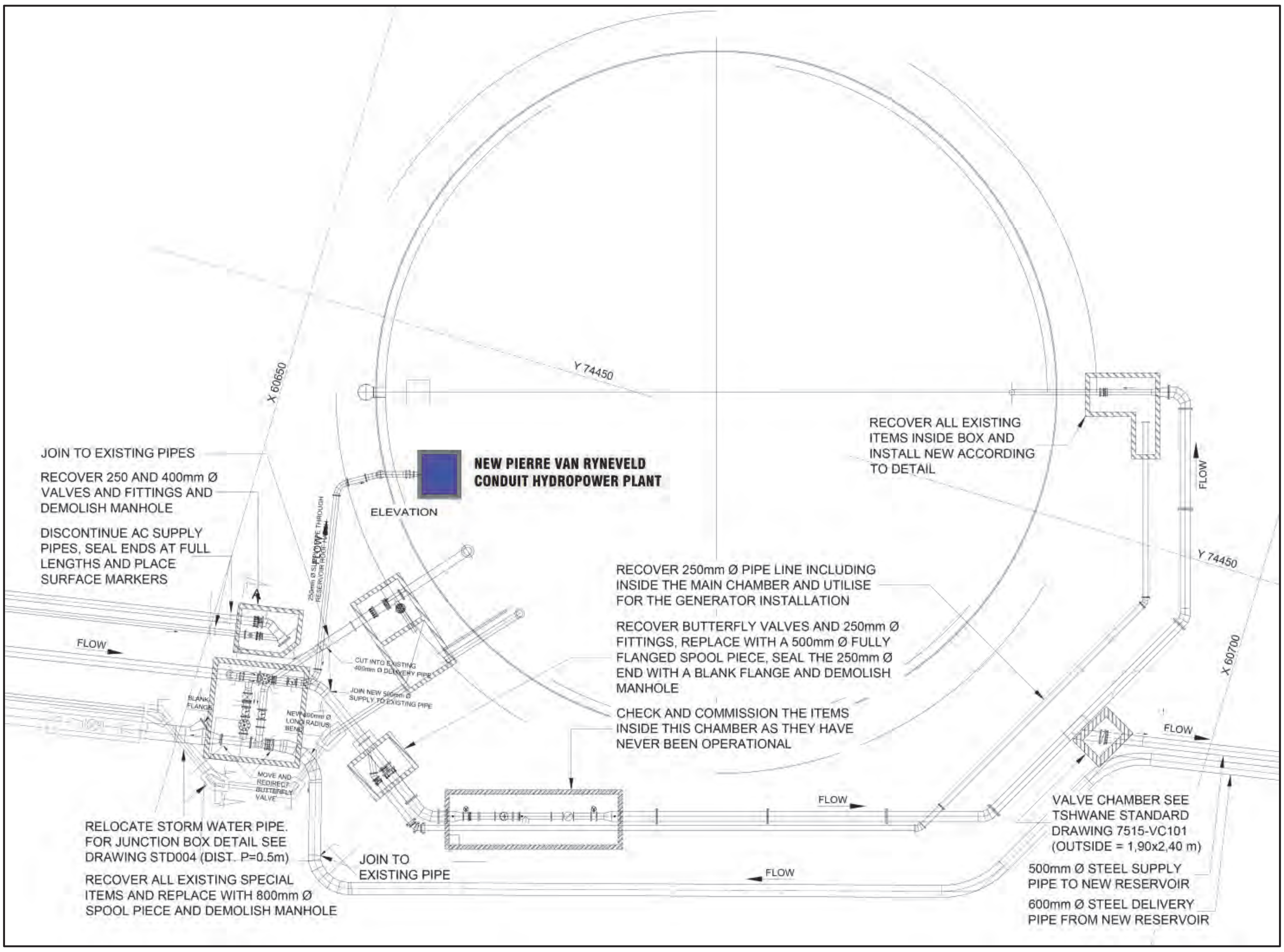


Figure 3-2: Layout of pipe system at the old reservoir

Water flows into the reservoir via an inlet pipe. As indicated in **Figure 3-2** water flow into the reservoir is governed by control valves. PRV's, flow control valves (FCV) and level control valves are vital in operating the system.

Table 3-1 lists the control valves utilized in operational control of the flow into the reservoir. The PRV's reduce the pressure head down to acceptable levels. FCV's manage the rate of inflow into the reservoir whilst level control valves close and open the flow according to the changing reservoir water levels.

Table 3-1: Types and functions of control valves

Type of control valve	Function
Pressure reducing valve	Dissipate excess pressures
Flow control valve	Control the rate of flow into reservoir
Level control valve	Manage flow according to reservoir level

The current set-up of the pipe network that supplies the old Pierre van Ryneveld reservoir is shown in **Figure 3-3**. This image is taken from the Infrastructure Management Query Structure (IMQS) software used by Tshwane Municipality to manage its infrastructure. The pipe represented in blue is the bulk pipe connecting the reservoir inlet to the Rand Water pipeline near the booster pump-house. This pump-house is positioned directly alongside the R21 road. Water flows from the Rand Water pipeline connection along this pipe into the Pierre van Ryneveld reservoir.

Figure 3-3: Plan view of bulk water pipe connecting reservoir to Rand Water (IMQS, 2011)

3.3 Preliminary site evaluation

In order to identify the generation potential at this site some basic data needed to be captured. The variation in flow rate and available head at the site needed to be recorded. The basic set-up was to measure and record pressure heads at relevant points along the supply line to the reservoir. **Figure 3-4** is a basic plan view schematic of the bulk supply line at the bottom of the hill near the connection to Rand Water. The sketch serves to illustrate the locations where testing instrumentation was placed. The booster pumps, are only used occasionally during summer months if demand for water is extremely high. Under usual flow conditions water flows in the direction as indicated in **Figure 3-4** along the bulk pipe up the hill and into the reservoir. Under these flow conditions PRV 2 dissipates excess pressure heads as shown in **Figure 3-4**.

In order to determine what kind of normal operating pressures can be expected to occur, a pressure transducer with a logger was placed both upstream and downstream of PRV 2. The location of pressure loggers are represented in **Figure 3-4** by a red uppercase letter *P*. The loggers were programmed to record readings at a frequency of a reading every second. The loggers were set to run for a 24 hour period. The reason for taking readings at this high frequency was to ensure that any possible pressure surges due to opening and closing of valves would also be detected.

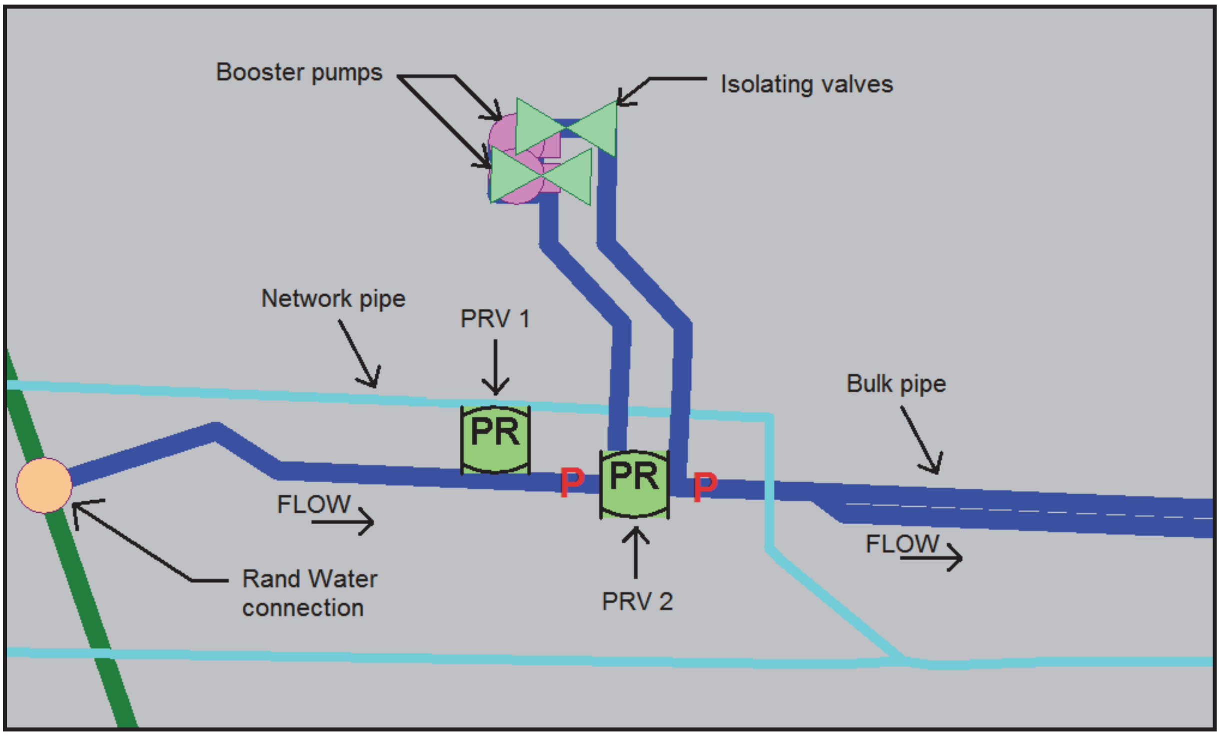


Figure 3-4: Schematic of pipe network and location of pressure transducers on bulk water pipe

The location of testing instrumentation which was placed nearer to the reservoir itself is depicted in **Figure 3-5**. An ultra-sonic flow meter is used to determine the flow rate in the pipe and is represented in the drawing with a green uppercase *F*. Flow rate was measured at one second intervals to allow the flow measurements to be aligned with the pressure readings recorded at the PRVs.

Pressure measurements were also taken near the reservoir. The locations of pressure transducers are symbolized again by a red uppercase *P* in **Figure 3-5**. As is indicated in **Figure 3-5** a transducer is placed just upstream of the FCV. This FCV has the dual function of acting as a flow control valve and level control valve of the reservoir. Readings taken from here will show the pressure in the supply line just upstream of the FCV. This pressure can be used to determine the friction loss (h_f) and secondary losses (h_L) experienced along the pipe from the location of the pressure transducer placed downstream of the PRV, to this transducer.

Another pressure transducer was placed on a tapping on the wall of the reservoir to give readings of the change in water level of the reservoir over time. This was required to indicate the correlation of the flow rate into the reservoir with regards to the varying reservoir water levels.

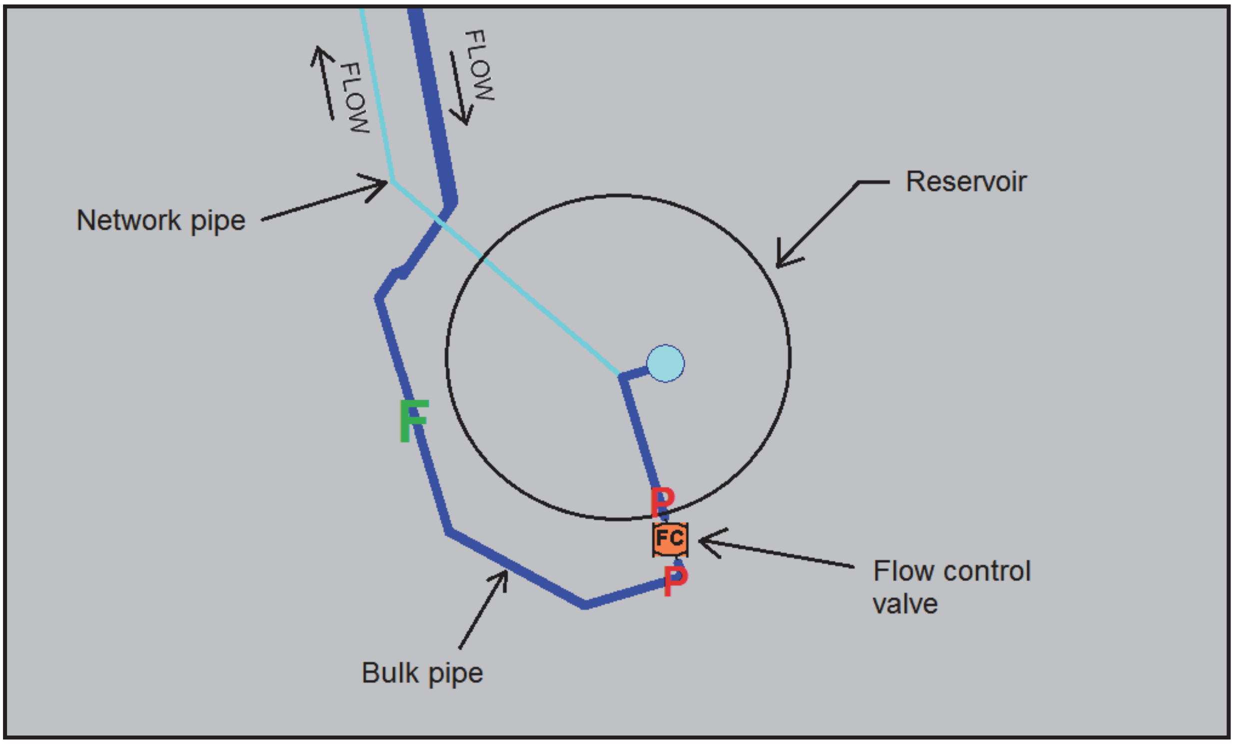


Figure 3-5: Testing locations at reservoir

The two key testing instruments utilized are the pressure transducer and the ultrasonic flow meter. Both these instruments work in tandem with loggers that record all readings. The readings are then downloaded from the loggers onto a personal computer and analyzed with the specific software.

The flow meter used is a Portaflow X transit time ultrasonic flow meter, manufactured by Fuji Electric. The device consists of a sensor rack with two receive and transmit ultrasonic sensors, BNC electric cable connection and a computational device that calculates and logs flow rate readings. A simple sketch diagram of the device can be viewed in **Figure 3-6**.

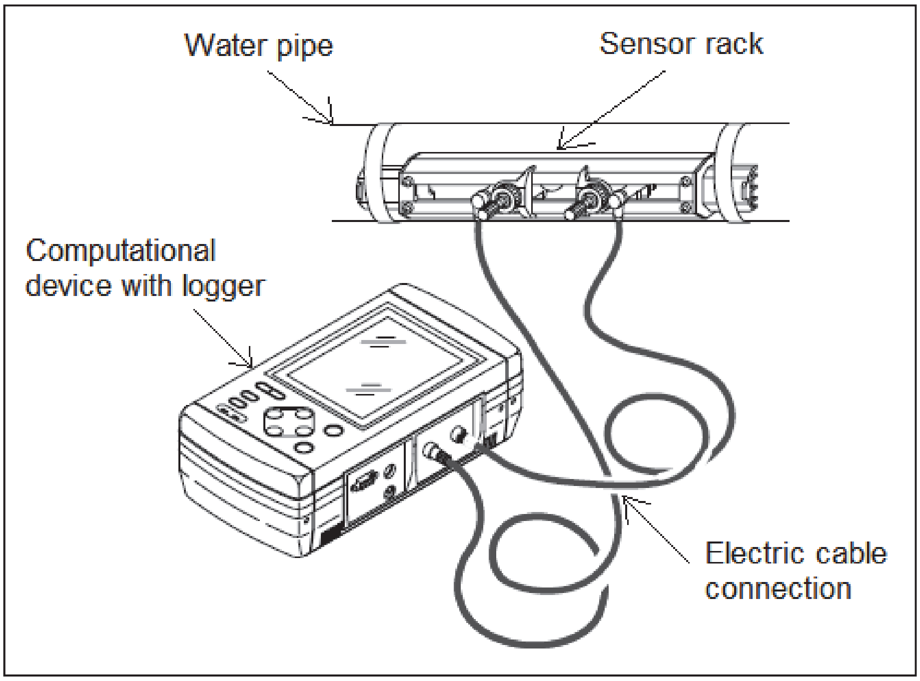


Figure 3-6: Portaflow X transit time ultrasonic flow meter (Instrusmart, 2011)

When setting up the flow meter the microprocessor device first needs to be configured. The characteristics of the pipe and flow need to be entered into the device. The key parameters of the pipe include:

- Outer pipe diameter.
- Pipe wall thickness.
- Pipe material type.
- Pipe lining.
- Fluid type.

It is important to ensure that the flow meter is placed in the middle of a straight section of pipe with a length of at least ten times the outside diameter of the pipe. This straight section should be clear of any bends, T-pieces, flow meters, valves or any other connection or fitting that could cause local turbulence of flow lines. For best accuracy the flow meter should operate where flow lines move in straight lines.

The pressure transducers used for carrying out tests are specifically designed for measuring pressure heads on pipelines. The type of pressure transducer used is more specifically known as a strain gauge based transducer.

The pressure transducers have small pipe fittings on the bottom to allow for a direct connection to a pressure tapping installed on large pipes. On the top is a female BNC cable connection. The set of pressure transducers that were used for site tests are shown in **Figure 3-7.** The pressure transducers are manufactured by Gems sensors and controls. These pressure transducers are commonly available in a range of different maximum pressure measurement capacities.

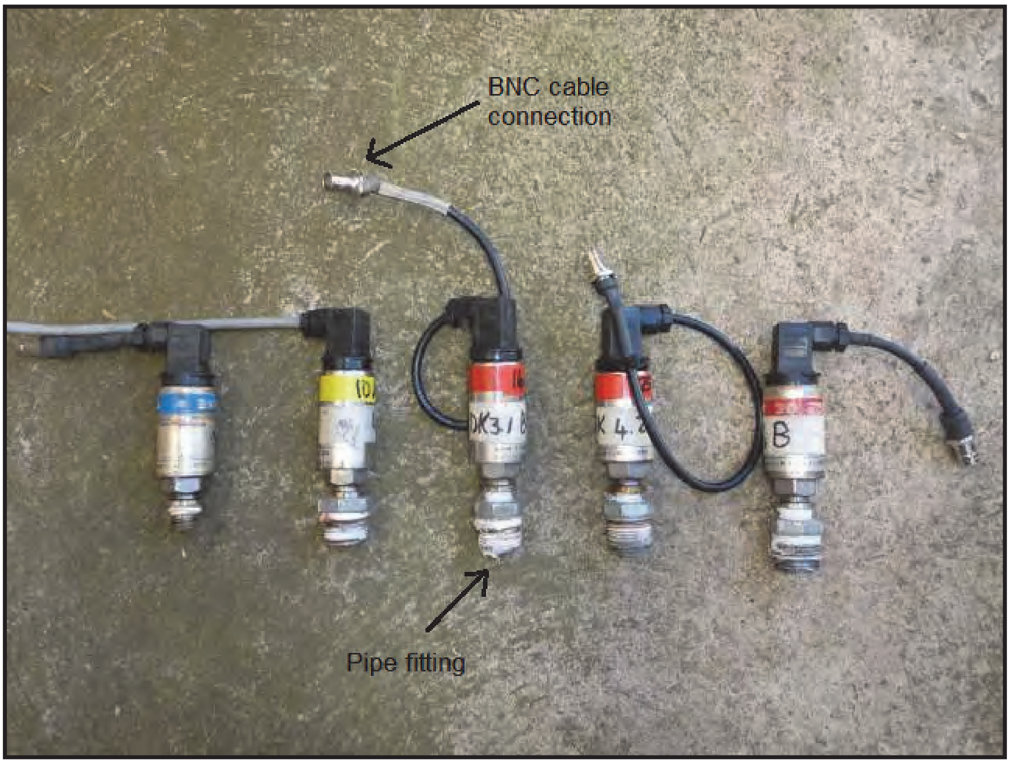


Figure 3-7: Pressure transducers used for static pressure head measurements

A pressure transducer converts pressure into an analog electrical signal. The analog electrical signal can then be read and logged by a logging device. To set up a pressure transducer a pressure tapping is required to be attached onto the pipe, at the point where pressure readings are to be recorded. A typical ball valve pressure tapping found on pipelines is portrayed in **Figure 3-8**.

The pressure transducers were connected via a BNC cable to a HOBO U12 Outdoor Industrial 4 channel logger manufactured by Onset. Configuration of the logger was done by connecting the logger to a notebook personal computer with appropriate software and entering the required parameters (frequency, period etc.).

Figure 3-8: Pressure tapping welded onto bulk pipe

The pipe fitting of the pressure transducer was then attached on the pressure tapping. This may require the addition of size conversion fittings if necessary to connect different size fittings. In addition to this a T-piece with additional ball valve, as shown in **Figure 3-9**, was connected to make it possible to purge any possible air pockets that may be caught in the tapping.

Figure 3-9: Pressure transducer with T-piece connector to expel air

After fitting the transducer to the pressure tapping, the logger connected to it was placed in a plastic bag to protect it from moisture as seen in **Figure 3-10**.

Figure 3-10: HOBO logger placed in plastic packet for protection from moisture in chamber

As is the case with the Portaflow X flow meter logger, the HOBO loggers have a limited amount of internal memory and required regular downloads of data especially when measurements were taken at high frequency or over a long period of time.

Readings recorded by these specific loggers were recorded as values of electric current (mA). The range for readings is 4-20 mA. This means that a zero pressure reading should be recorded at about 4 mA whilst a maximum pressure reading should indicate 20 mA. The mA was converted to pressure (bar) or flow (l/s) readings.

Measurements had to be retaken a number of times due to unforeseen problems. These included shut-downs for maintenance purposes of the Rand Water supply line, locked chambers where measurements wanted to be taken and a full reservoir resulting is no flow.

3.3.1 First preliminary test

As stated previously in the experimental set-up, the objective of the field test was to measure flow rate and pressure heads of the supply line to the reservoir for a 24 hour period. The plan was to place four pressure transducers with loggers at four key positions, **Figure 3-4** and **Figure 3-5**.

These positions were considered to provide the most vital information regarding the range of pressure heads that can be typically expected in the inlet pipe. The four loggers would take pressure readings for a 24 hour period. In addition to this the flow rate in the pipe would also be measured over this 24 hour period.

The first preliminary test started at 19:00 on 13 May 2011. Upon arrival at site, and entering the valve chamber housing of the PRV, it was discovered that there were no pressure tappings available either upstream or downstream of the PRV.

Due to the amount of effort required to organise such a 24 hour field test it was decided to continue with the test regardless of this problem. The test would now only consist of taking pressure head measurements at the other two key locations, and measuring the flow rate of the inlet pipe.

The limited results from such testing did not provide a complete set of data. Nevertheless the procedure at least allowed for a learning process to determine other problems that could occur and allow for the development of familiarity with testing conditions and equipment.

Pressure readings were now only to be taken upstream of the flow control valve of the reservoir and on the threaded pipe tapping of the reservoir. In addition the flow rate would still be measured. The flow rate was measured at the inlet pipe on a section of pipe with an inner diameter of 300 mm, depicted in **Figure 3-11**.

Figure 3-11: Set-up of flow meter

The results of the 24 hour flow rate test at one second intervals are graphically illustrated in **Figure 3-12.** The graphic clearly shows how the flow rate into the reservoir varies during the course of the 24 hour day. High demands for water supplying a residential network tend to occur in the morning from 05:00 – 08:00, when the majority of residents make use of water at the start of their day for bathing and preparing breakfast, and 17:00 – 20:00 when these residents make use of water at the end of their day again for bathing and preparing dinner.

The graphic does provide evidence of a local flow rate spike occurring at 06:00 carrying through to 08:00 and also between 18:00 and 20:30. The local spikes measured on the inflow may not correlate directly with the increases in water demand.. This is caused by the fact that the reservoir acts as a buffer between the inflow of the reservoir and the outflow of it.

The most important evidence provided from the flow rate time series in **Figure 3-12**, is that although the flow rate varies during the course of the day, there is almost always an inflow into the reservoir. The graph indicates that flow ran into the reservoir for the entire day except over a short period of thirty minutes from 08:30 – 09:00, where it stopped. **Managing of the water level in the reservoir will thus be crucial to provide a constant inflow and subsequent energy generation.**

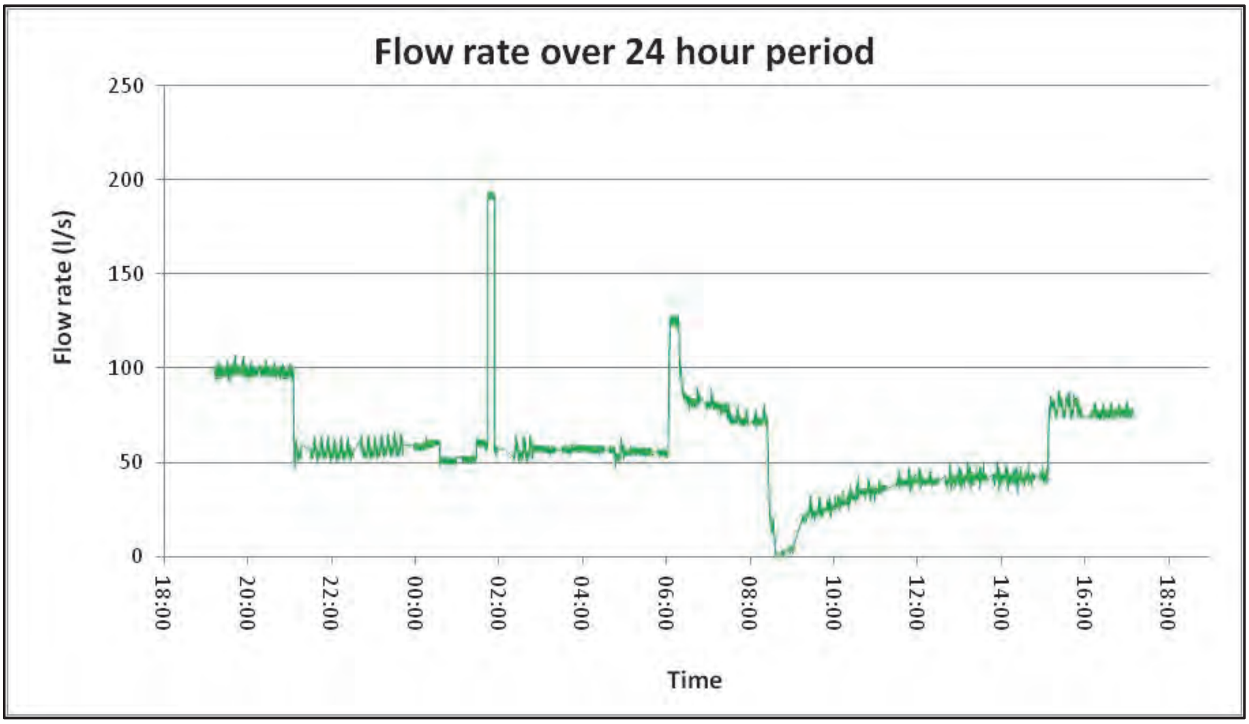


Figure 3-12: Graphic representation of flow rate over a 24 hour period at inlet pipe

Pressure of the flow was measured upstream of the flow control valve and at the reservoir water level tapping. A 10 bar gauge pressure transducer was fitted onto a tapping upstream of the flow control valve. An abridged extract from the pressure loggings data captured in Microsoft Excel is given in **Table 3-2**. The data was exported to Excel using the Onset Greenline software program.

Table 3-2: Extract of pressure loggings recorded

Date and time	Current (mA)
2011/05/13 19:00:00	7.45
2011/05/13 19:00:01	7.46
2011/05/13 19:00:02	7.49
2011/05/13 19:00:03	7.45
2011/05/13 19:00:04	7.43
2011/05/13 19:00:05	7.52
2011/05/13 19:00:06	7.50
2011/05/13 19:00:07	7.48
2011/05/13 19:00:08	7.49
2011/05/13 19:00:09	7.47
......	......

Figure 3-13 provides a graphic representation of the data series recorded by the logger over the 24 hour testing period. The pressure transducer measures analogue electrical signals in units of milliamps. The signal is representative of the pressure experienced by the transducer.

The analogue electrical signals recorded by the HOBO logger were converted to a pressure head. **Figure 3-14** gives a graphic illustration of the pressure head time series formulated from the analogue electrical signal time series in **Figure 3-13**. The pressure remains above 10 m throughout. An exception occurs between 06:00 and 10:30. Due to limited internal memory capacity of the loggers, data is periodically downloaded and the logger then reconnected. The first download and reconnection took place at around 05:00 after which the logger was erroneously placed on the thrust block directly next to the pipe.

The spike in the pressure just after 06:00 seems to have caused a large vibration in the pipe. The large vibration caused a cyclical connection and disconnection between the BNC cable connectors. The mistake was made of placing the logger on top of the thrust block and very near to the inflow pipe, at an elbow bend in the pipe.

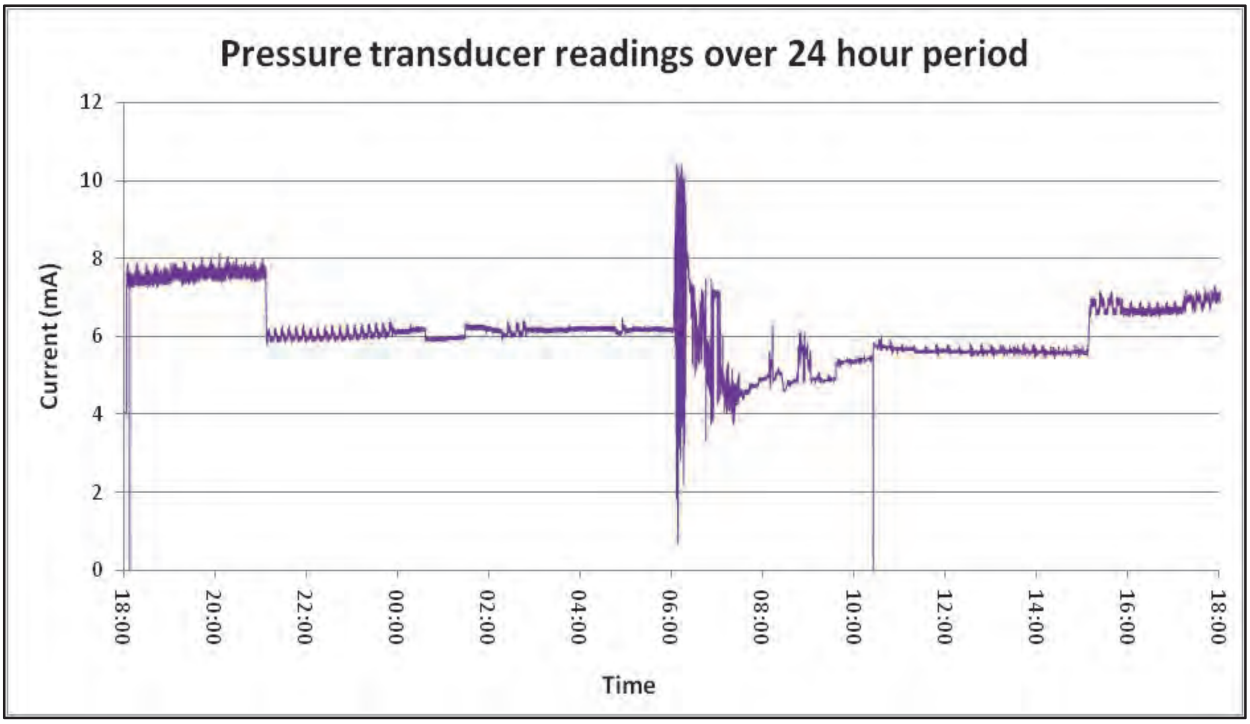


Figure 3-13: 24-hour time series of pressure transducer readings

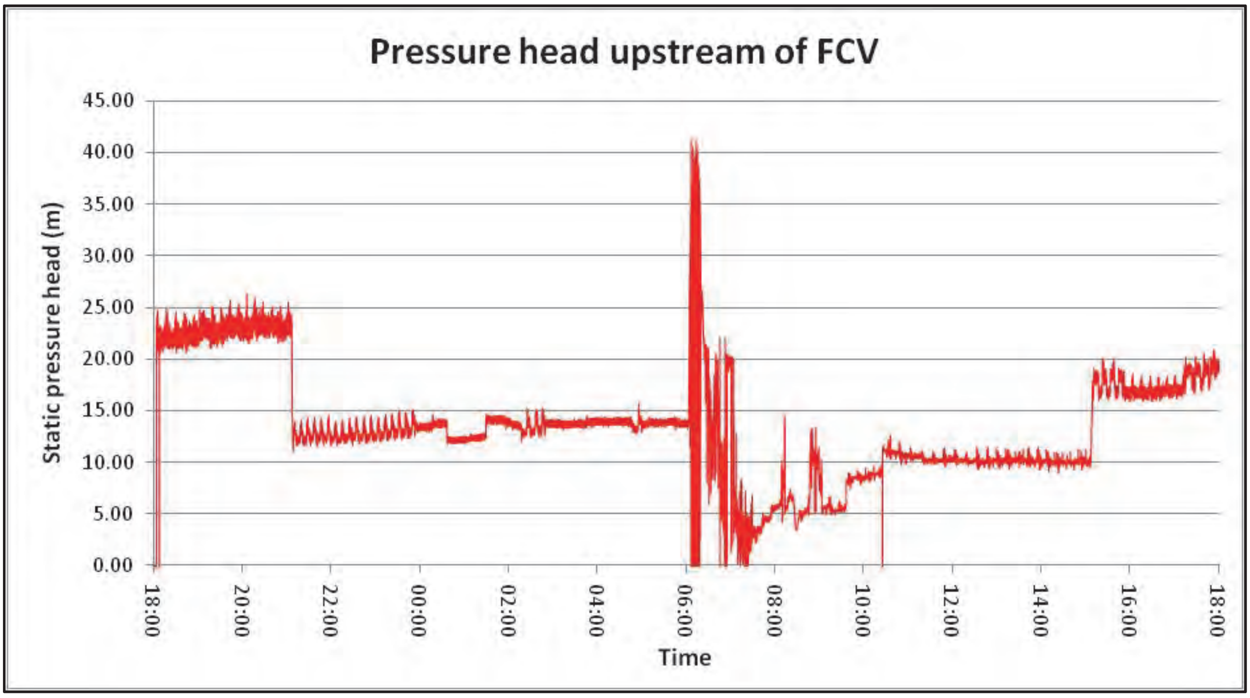


Figure 3-14: Time series of pressure head over 24 hours

The pressure heads upstream of the FCV are rather low. It was later discovered that the PRV's controlling the pressure, were set to only allow enough pressure downstream for the water to ascend up the hill to reach the reservoir. An adjustment to the PRV could allow for greater pressures to exist upstream of the reservoir. Therefore the pressure graph (**Figure 3-14**) is not a true indication of how much pressure is available upstream of the reservoir for hydropower purposes.

In order to determine the relationship between inflows into the reservoir, the pressure head at the reservoir and its water level, **Figure 3-15** was produced. There is a definite relationship between the flow rate into the reservoir and the pressure upstream of the FCV. The relationship indicates that any increase in pressure upstream of the FCV results in an increase in the flow rate. The FCV not only controls the level of the reservoir but also allows a larger flow to enter the reservoir when higher pressures are experienced.

As mentioned the first test had major shortcomings in that no pressures were measured upstream and downstream of the PRV. These are the most important pressure heads needed to be determined in order to verify if enough pressure exists for a pico hydropower scheme to be technically feasible. Further testing was required to enable determination these pressures.

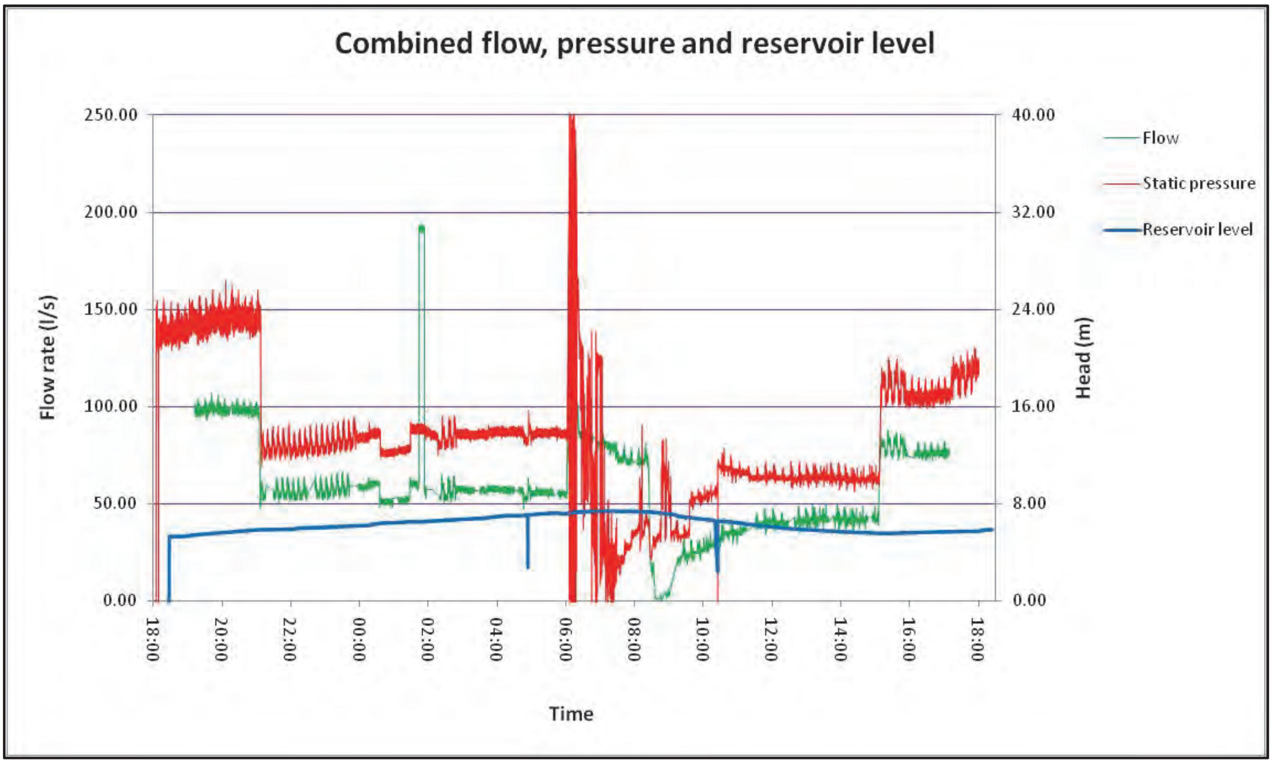


Figure 3-15: Combined time series of flow, static pressure and reservoir level

3.3.2 Second preliminary test

The second test followed the same experimental design set-up as described in paragraph 3.3.1. The second tests were necessary due to major setbacks experienced in the first test. The major shortcoming was the absence of any pressure head measurements taken upstream of the PRV and downstream of the PRV.

It was ensured that pressure tappings were subsequently installed onto the bulk pipe upstream and downstream of the PRV before carrying out the second preliminary test.

This test again required a 24 hour measurement period. Whilst measuring flow for the 24 hour period pressure head readings were measured at the reservoir level tapping, upstream of the FCV, downstream of the PRV and upstream of the PRV (**Figure 3-4** and **Figure 3-5**).

Figure 3-16 indicates the newly installed pressure tappings upstream and downstream of the PRV with a 25 bar gauge pressure transducer fitted to each of these tappings.

Figure 3-16: Pressure transducers fitted either side of the PRV

The second preliminary test was initiated at 06:00 on 5 July 2011. Once again major setbacks were encountered. The source of the water supply, Rand Water happened to be experiencing problems with their pipelines. This resulted in only short periods of random stop-start flow between large time periods of zero flow.

At the time of testing it was not known that Rand Water had been experiencing problems with their pipeline. Flow did eventually start just after 17:00 and continued to run until just before 19:00. The testing was abandoned just after 01:00 when it was realized that there would be no more flow into the reservoir.

The flow rate recorded from 17:00 – 19:00 is graphically depicted in **Figure 3-17**. It can be clearly seen that two local high flow rates occurred, ±180 l/s and ±160 l/s. The flow then dropped and evens out at ±80 l/s. The pressure head measurements taken upstream of the FCV can be seen in **Figure 3-18**. Local high points and low points in recorded head exist between 17:00 and 17:30. The pressure head readings then smooth out and remain constant from 17:45 – 18:30 with a constant head of ±60 m.

Although this data is clearly unstable and unreliable a calculation could be made to determine what kind of electrical power output may be experienced, if these flow and pressure measurements were indeed correct

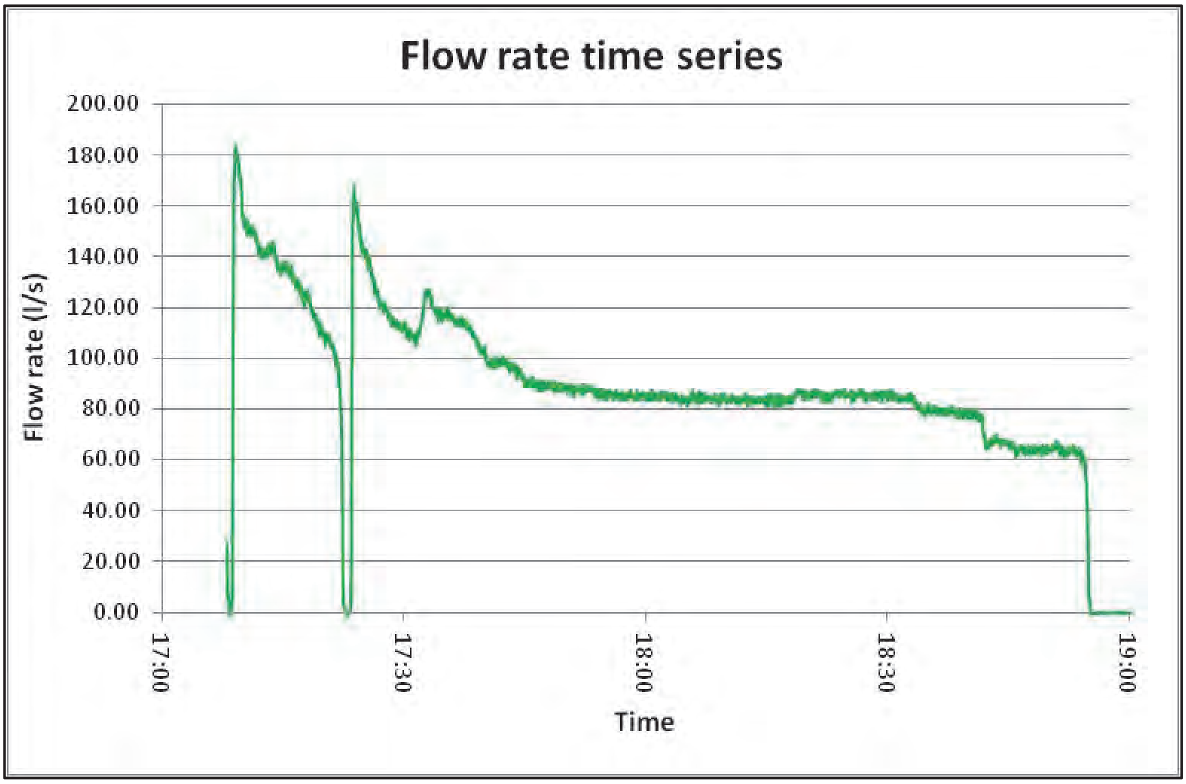


Figure 3-17: Flow rate recorded

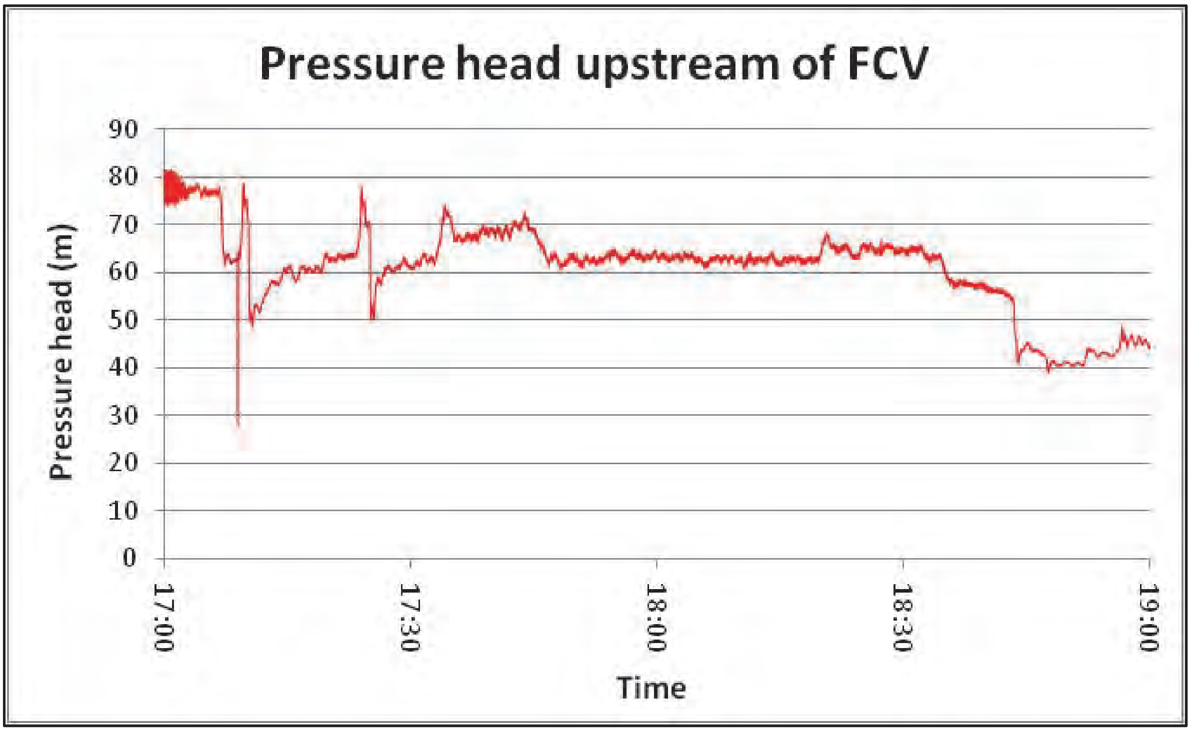


Figure 3-18: Pressure head readings upstream of FCV

The residual pressure and flow values indicate that a hydro-turbine placed at the point just upstream of the flow control valve could produce 23.5 kW of electrical power. This is a preliminary indication of what electric power could be generated but as mentioned the data series is unstable and unreliable and a third test was carried out.

Results of pressure measurements taken upstream of the PRV are graphically shown in **Figure 3-19**.

As a means of determining the magnitude of friction and secondary losses occurring in the pipe, between the PRV and the FCV, **Figure 3-20** is drawn. The graphic shows pressure heads downstream of the PRV in comparison to values experienced upstream of the FCV.

The average difference is about 46 m. This is very close to the difference in elevation levels of 47 m between the PRV placed at the bottom of the hill and the FCV at the base of the reservoir. The slight difference may be due to a slight accuracy problem in the topography map used or due to the slight difference in the level of pipes below ground level, at the different points.

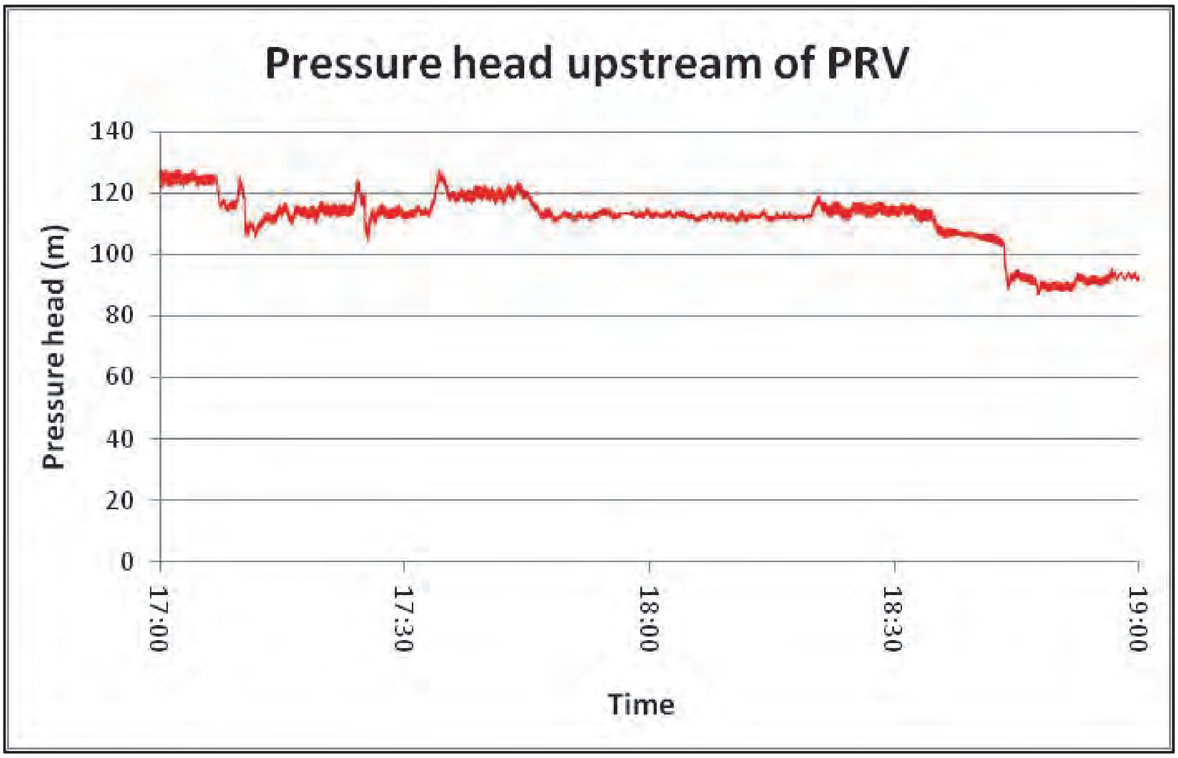


Figure 3-19: Pressure head measurements upstream of PRV

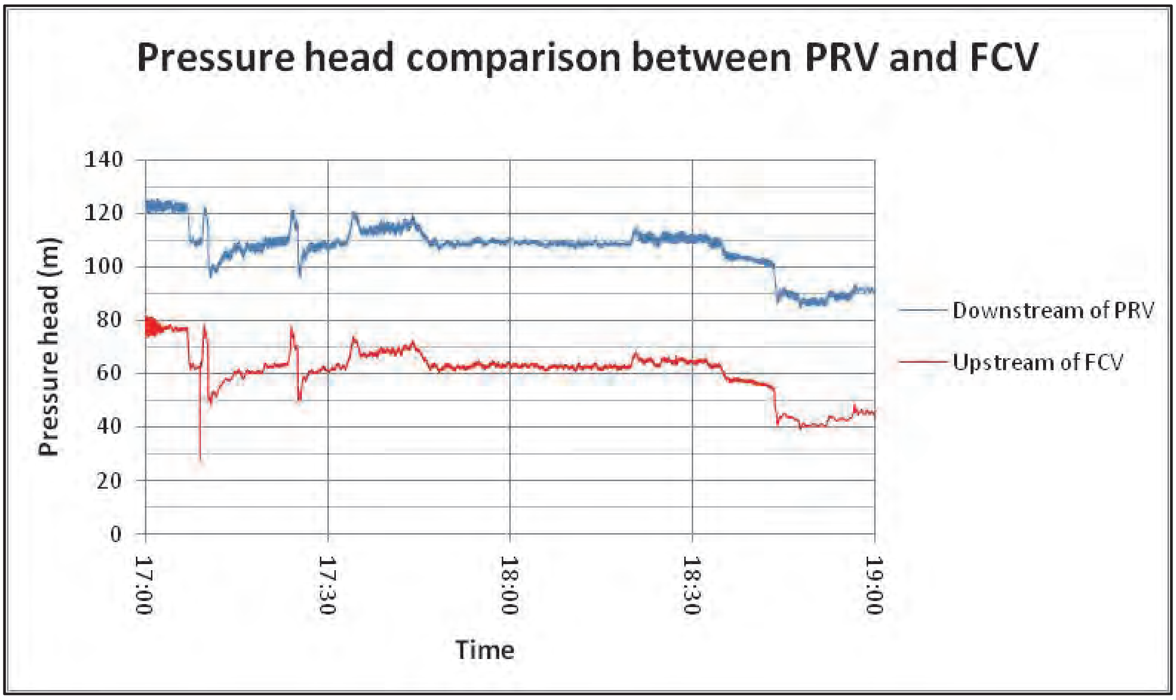


Figure 3-20: Comparison of static pressure head downstream of PRV and upstream of FCV

Apart from the fact that major shortcomings were experienced, some useful data was retrieved from this test in the form of the pressure surges experienced on the opening and closing of the FCV. A hydro-turbine installed at the inlet of the reservoir may also cause such pressure surges on starting up or shutting down due to intermittent flow.

3.3.3 **Third preliminary tests**

In preliminary test one and two the ultrasonic flow meter, as described in the setting up of experimental instrumentation, was used to measure flow. This device has a small internal memory and requires regular downloads when measuring flow at one second intervals. In addition the device needs a constant external power supply.

At the time of the third preliminary field test winter had set in and the cold weather would make it very difficult to man another 24 hour test in the outdoors. This would require the use of a flow rate measurement device that could be operated for extended periods without the constant presence of the author. As a result a Global System for Mobile Communications (GSM) wireless data logger, manufactured by Cello, was used in the third preliminary test. This device was configured and installed with the help of WRP Consulting Engineers.

A picture of the GSM wireless data logger is given in **Figure 3-21**. The device has an internal memory to store data, as well as the capability of sending data packages via SMS to a remote server using the GSM cellular telephone network.

The device has a robust internal battery with a life of five years. Flow rate loggings can be downloaded directly from the device or from the server and analysed or further exported using PMAC Lite software.

Figure 3-21: Cello GSM wireless data logger

The device is only a logger and not a flow meter instrument. It makes use of flow meters already installed on water pipe networks. The instrument is compatible with Sensus WP or WP-Dynamic flow meters. These flow meters are commonly found at the inlet and outlet of most reservoirs, and at various other relevant locations on bulk water pipes. Such flow meters make use of a meter device that is turned when water flows through its vanes.

The GSM wireless logger is connected to the Sensus flow meter with electric cables. A pin on the end of the cable is inserted into a slot on the side of the Sensus flow meter as demonstrated in **Figure 3-22**. The logger picks up mechanical pulses given off by the Sensus flow meter to measure flow rate. The logger needs to be specifically configured according to the size of the flow meter.

Fortunately the HOBO pressure loggers have enough internal memory to take pressure readings at one second intervals for up to 12 hours. No substitute for these was required to carry out an unmanned 24 hour field test.

At the time of performing the third preliminary field test the bulk pipe set-up near the reservoir had been altered. This change in set-up was done to provide for the installation of the hydro-turbine, on the inlet of the reservoir. Provision had been made for the hydropower set-up but the turbine had not yet been installed. In addition the new reservoir under construction would also require an inflow pipe. This would stem from the same bulk pipe supplying the current reservoir.

Figure 3-22: Connection of GSM wireless logger to flow meter

As part of the new reservoir inflow set-up the FCV was moved a further distance upstream of the reservoir inlet. The FCV was placed inside a newly constructed valve chamber. This valve chamber is the new access point to a newly installed flow meter, two butterfly valves, a T-piece and the FCV. These can be seen in **Figure 3-23**. The FCV here acts as a level control valve and is preset to maintain the water level in the reservoir at an acceptable height.

An aerial photograph of the new location of the FCV and valve chamber can be seen in **Figure 3-24**, and **Figure 3-25** depicts the positions on the inlet pipe where pressure readings will be taken on the new set-up. The PRV's remain in the same location as described in site selection and description and are not shown again here.

The field experimental design set-up for the third test consisted of taking measurements over a 24 hour period of the:

- Flow rate of water into the reservoir;
- Pressure head upstream of the PR;,
- Pressure head downstream of the PRV;
- Pressure head upstream of the FCV; and
- Reservoir water level.

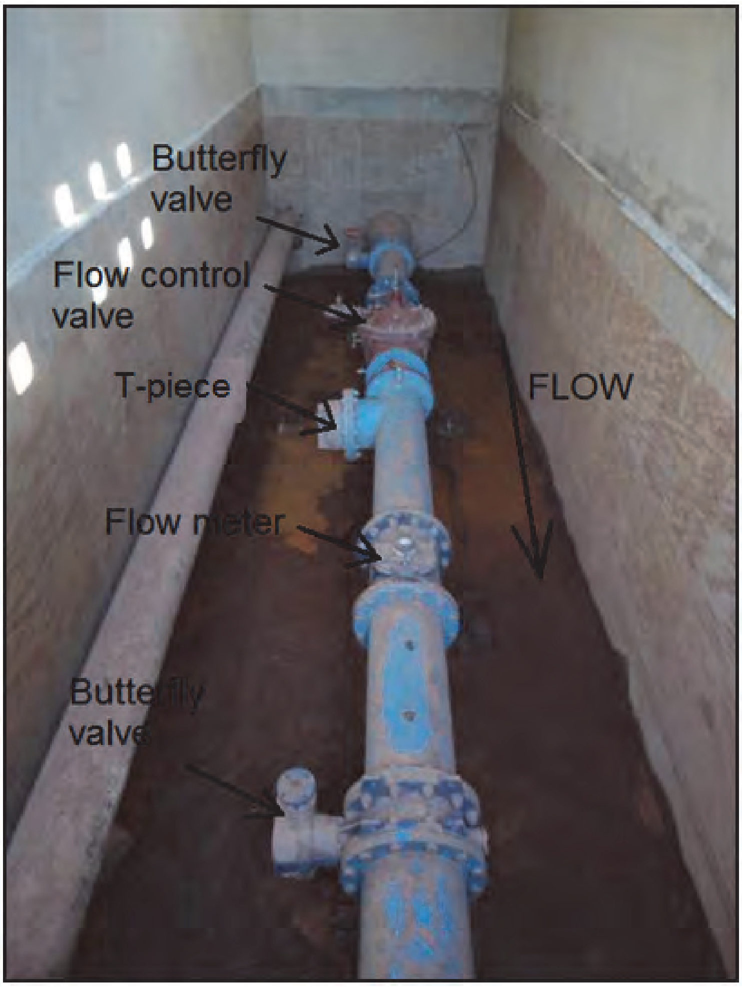


Figure 3-23: New valve chamber set-up

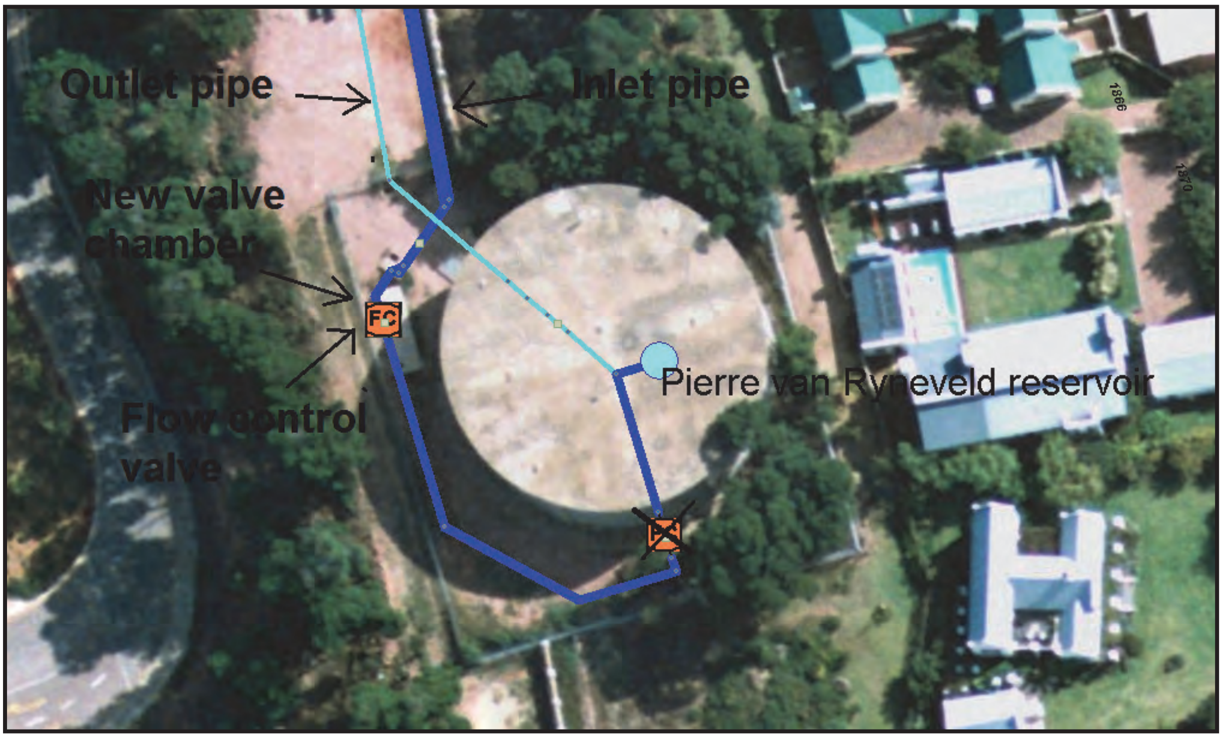


Figure 3-24: New location of FCV and valve chamber

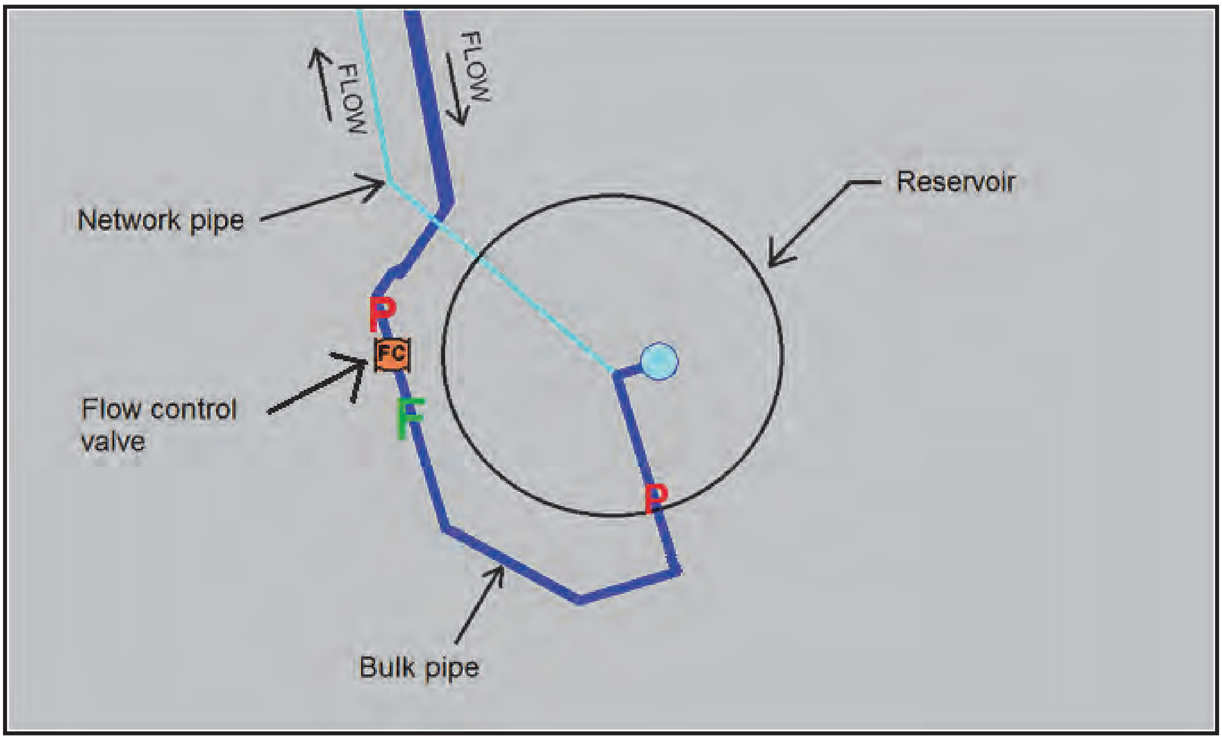


Figure 3-25: New locations where pressure was measured

The third preliminary test started at 15:00 on 11 July 2011. The GSM wireless logger was set-up and connected to the bulk water meter on the inflow pipe of the reservoir as seen in **Figure 3-26**. Another older logger can also be seen in the picture. Two loggers were used simultaneously to ensure flow data would be obtained in case any problems were experienced by one of them.

The older logger malfunctioned and no data was retrieved from it. The GSM wireless logger worked and flow rate measurements were captured.

The results of the 24 hour flow rate test are illustrated graphically in **Figure 3-27**. As can be seen the flow rate never drops below ±50 l/s. The highest flow rate reached during the 24 hour period is ±80 l/s. This high flow rate occurs late at night or very early in the morning, when pressures in the water network are high due to low usage of water.

The pressure head received from Rand Water, at the point of connection to Rand Water, can be determined from the pressure head measurements taken upstream of the PRV. A 25 bar gauge pressure transducer was fitted to the tapping upstream of the PRV. After fitting the transducer and opening the pressure tapping, the ball valve tapping is momentarily opened as demonstrated in **Figure 3-28**. This allows air to be purged out of the tapping. Unfortunately there was a connection fault and no data could be recorded upstream of the PRV.

Figure 3-26: GSM wireless logger connected to flow meter

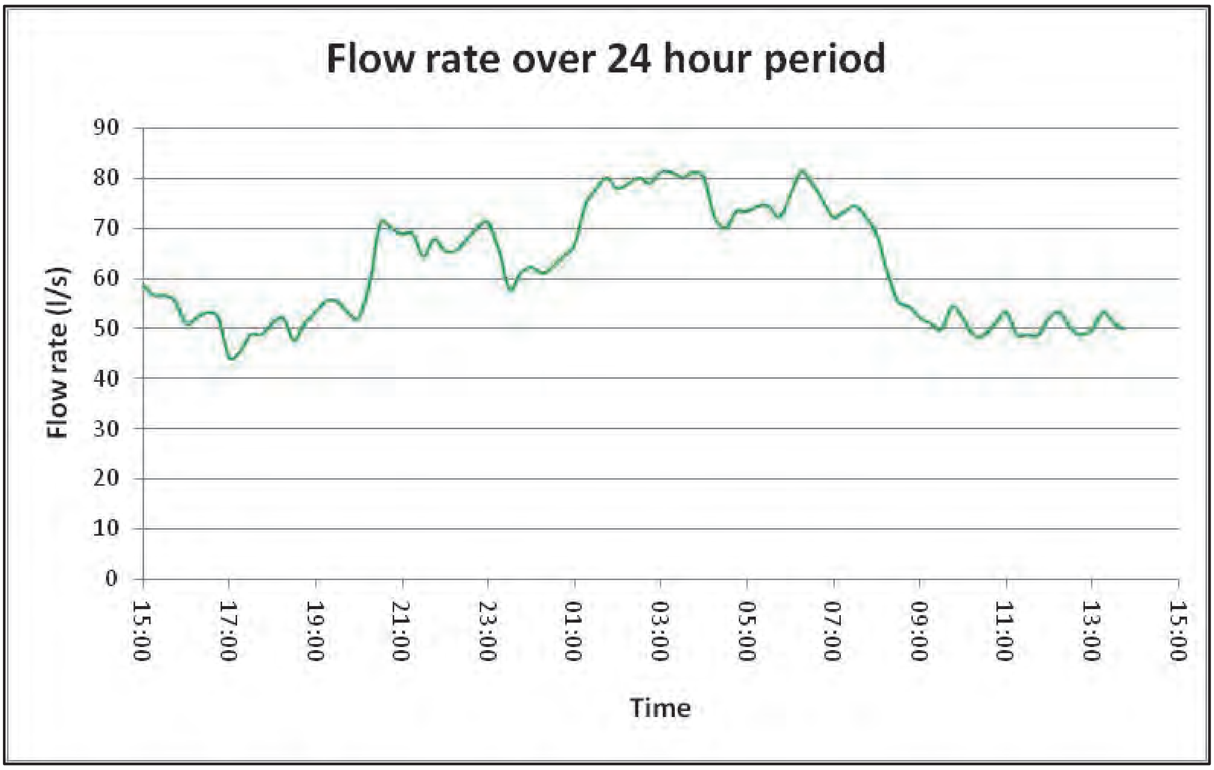


Figure 3-27: Graphic representation of flow rate time series over a 24 hour period

Figure 3-28: Purging of possible air pockets in pressure tapping

Pressure head measurements taken downstream of the PRV are plotted on the graph in **Figure 3-29**. The graphic clearly shows that higher pressures exist in the bulk water pipe between 21:00 and 08:00. This is as a result of a lower demand for water experienced during this period. Throughout the course of the day the pressure never drops below a value of approximately 80 m. Very low friction and secondary losses between the point downstream of the PRV and a point at the inlet of the reservoir can be assumed. This is due to the short length of pipe of approximately 850 m between these two points. An estimated pressure head of 30 m may exist at the reservoir inlet if only the difference in elevation of approximately 50 m is considered. The accuracy of this preliminary calculation was verified from pressure measurements taken upstream of the FCV.

The local vertical downward spike seen at 01:15 in **Figure 3-29** is not a negative pressure surge. It is plainly an electrical disturbance picked up when disconnecting the data logger to carry out a data download.

The most important pressure measurements taken are those upstream of the FCV. This is the location where a hydro-turbine was placed. Pressure readings taken upstream of the FCV can be paired with corresponding flow rates. This will determine the quantity of electrical power output that can be expected from a hydro-turbine, installed on the inlet of the reservoir.

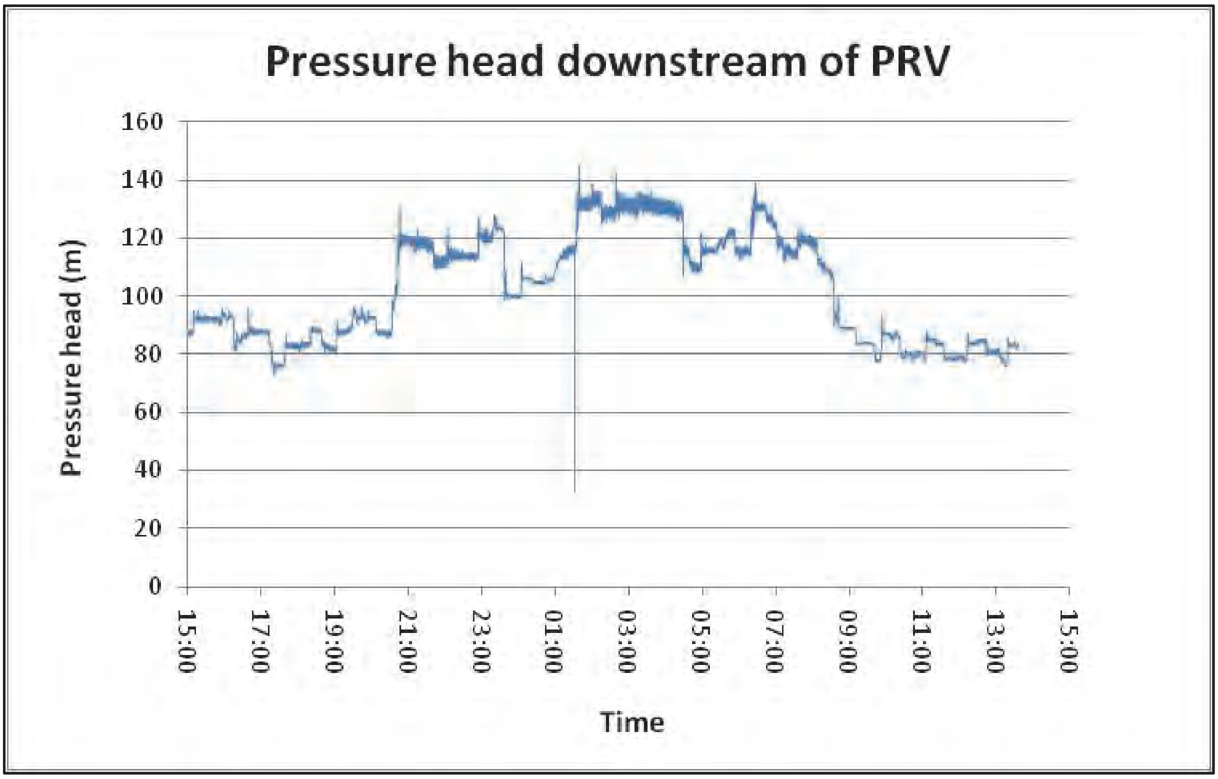


Figure 3-29: Pressure head readings downstream of PRV

Pressure readings taken upstream of the FCV are graphically shown in **Figure 3-30**. **Figure 3-31** indicates the pressure head downstream of the FCV. The low pressures on the downstream side of the FCV indicate that the reservoir level control function may be incorrectly set at a value too low. This would result in the water reservoir not filling up. Vertical spikes on the graph in **Figure 3-31** are not pressure surges. Instead these again are caused by electrical disturbances at disconnection of logger for data downloading.

The friction and secondary losses in the 850 m length of pipe leading from the PRV up to the reservoir are very small compared to the static head difference along the line. The friction and secondary losses in this pipeline for a flow rate of ±80 l/s is approximately 0.25 m.

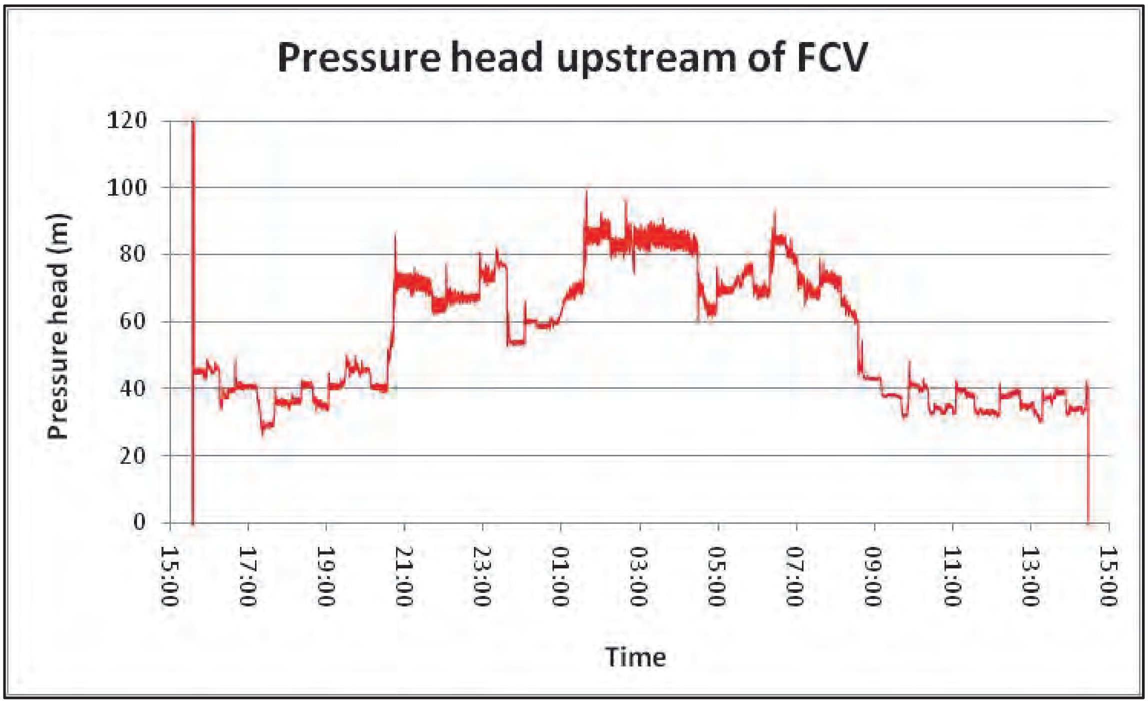


Figure 3-30: Pressure head readings upstream of FCV

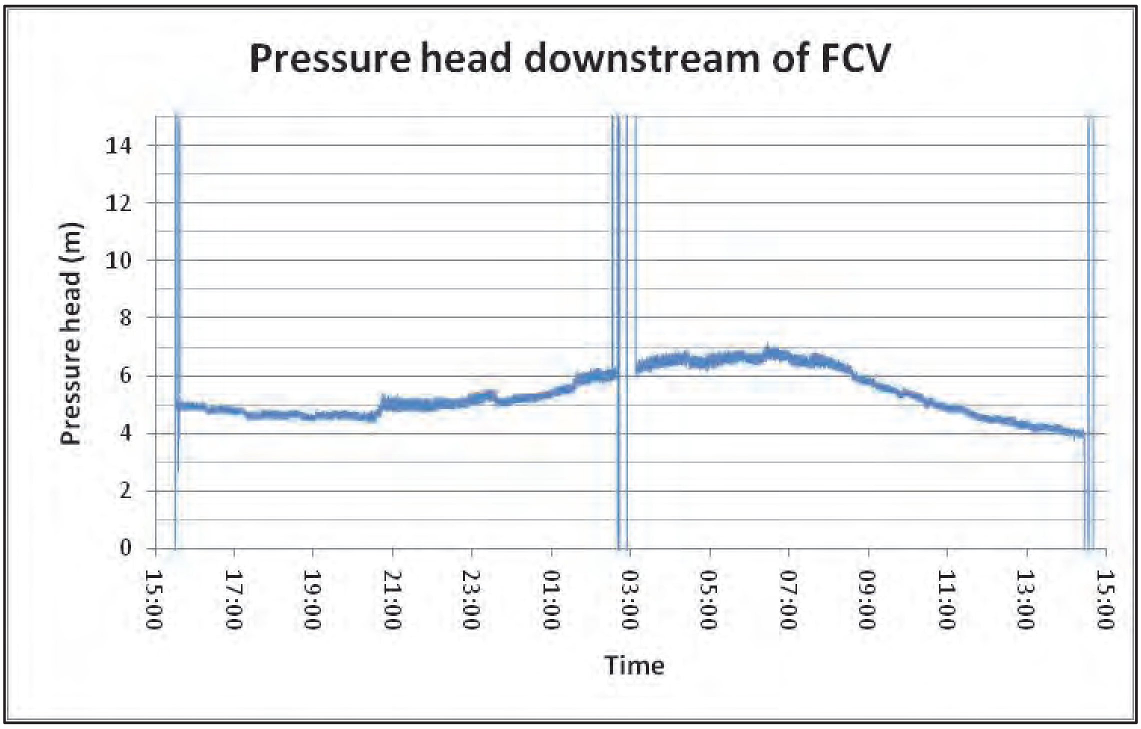


Figure 3-31: Pressure head readings downstream of the FCV

Figure 3-32 serves to show what range of flow rates and pressure heads can be expected to occur during the course of a 24 hour day. These values could be used to calculate the amount of electrical power that could potentially be generated by a hydro-turbine placed at the inlet of the reservoir. The graph shows how the flow and pressures are related. Higher pressures in the network result in a higher inflow rate into the reservoir.

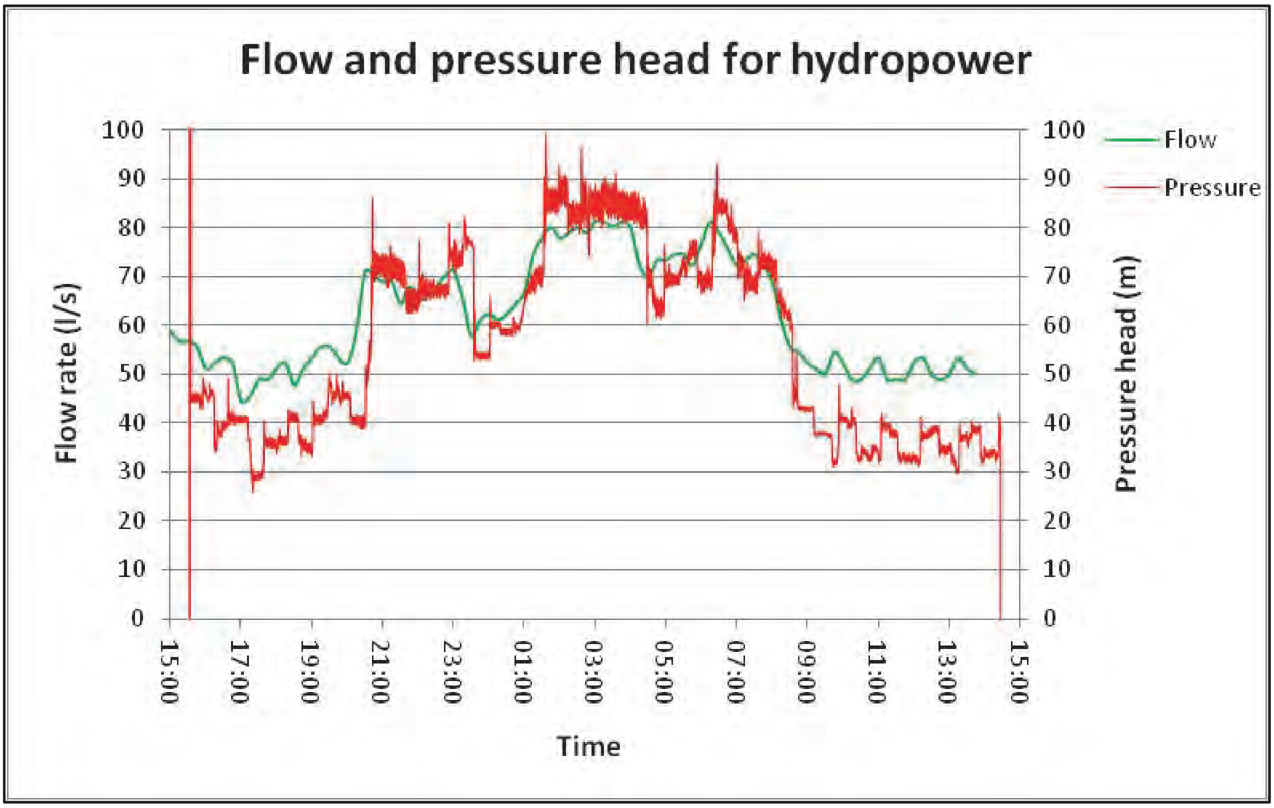


Figure 3-32: Graphic representation of flow against pressure head

An indication of the range of electrical power output that can be expected to be generated is shown in **Table 3-3**. These values are calculated using the pressure heads and flows evident in **Figure 3-32**. It needs to be taken into account that the pressure at the base of the reservoir will be approximately 11 m higher than at the turbine which was placed on top of the reservoir. This means that a value of ±11 m should be subtracted from the pressure head values given in **Figure 3-32** to get the available head. An efficiency of 70% was assumed and used to calculate the power outputs. The efficiency value will vary based on the final turbine choice. Testing after installation of the turbine will better indicate the actual efficiency obtained with the turbine.

Table 3-3: Range of electrical power potential

	Flow (l/s)	Head (m)	Available head (m)	Electrical power output (kW)
Minimum	50	35	24	8.2
Maximum	80	80	69	37.9
Average	60	60	49	20.2

An average electrical power output of 20.2 kW over a 24 hour day would result in the production of 177MWh/annum.

3.3.4 Preliminary test results

The outcome of the three extensive field experiments provided enough evidence, that there is sufficient flow and pressure at the inflow to the Pierre van Ryneveld reservoir, to generate electric power on a pico scale. The results of testing also indicated that pressure surges do occur in the system and this was used as a benchmark to ensure that the hydropower plant does not result in an increase in risk for the pipe system.

3.4 Turbine and generator selection and pilot plant design using DSS

This section illustrates the application of the procedural method described in the **Conduit Hydropower Design Guide** in a municipal context. The City of Tshwane (CoT) Metropolitan Municipality Bulk Water Services division was approached as a partner in the research project.

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 6-20** 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 **paragraph** 2 was followed.

3.4.1 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 3-33** 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 m^3 and the newer structure has a capacity of 15 000 m^3. The flow meter and pressure gauges were installed at the PRSs located at the pump station site west of the R21, Figure 3-1.

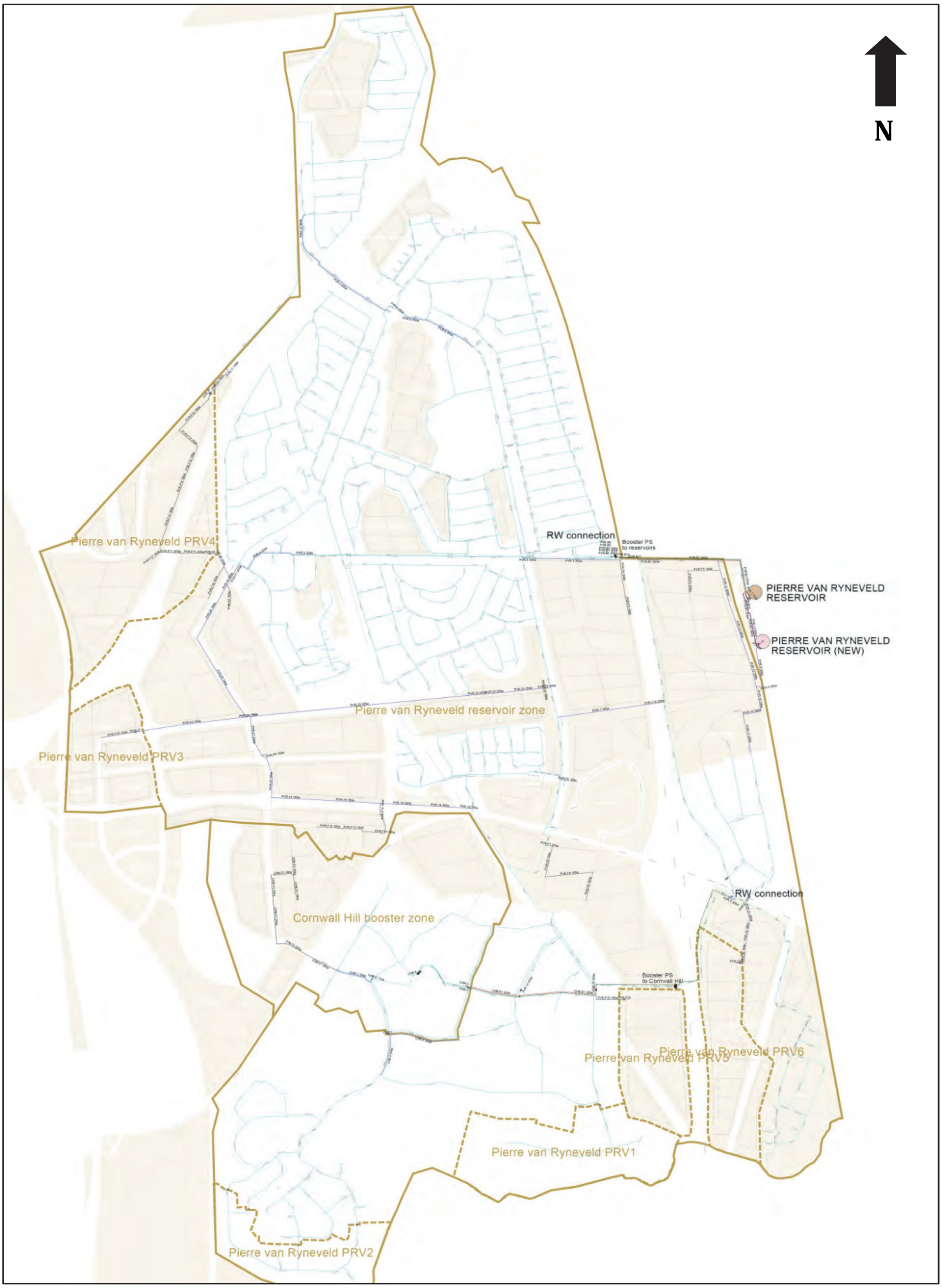


Figure 3-33: Pierre van Ryneveld Reservoir water-distribution zone (IMQS)

3.4.2 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 3-4**. This information was entered into the CHD Tool for Phase 1, with certain default values as prescribed in the CHD Tool and the output is also shown in **Table 3-4**.

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.

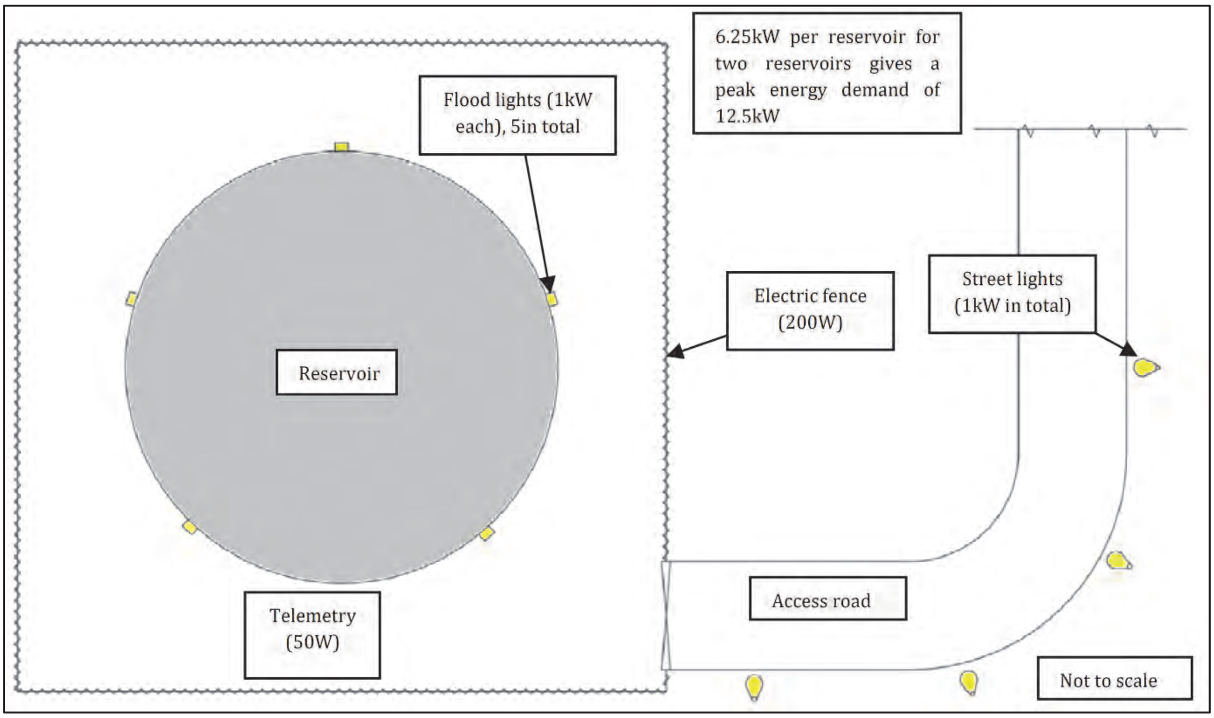


Figure 3-34: Schematic layout of on-site electricity use at Pierre van Ryneveld Reservoir

Table 3-4: 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 3-34**
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).

3.4.3 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). 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.

Table 3-5: Pierre van Ryneveld Phase 2 site analysis summary

DSS step	Practicability aspect	Discussion	Conclusion
2	Available space	This site already has space available on the reservoir roof if impulse turbine is selected.	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 3-1**, 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 3-4**. Data loggers were installed as shown in **Figure 3-35** and **Figure 3-36**.

Gaps in measured data occurred at various times. **Figure 3-37** 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 3-35: Pressure measurement at Pierre van Ryneveld pressure-reducing station

Figure 3-36: Flow measurement at Pierre van Ryneveld Reservoir

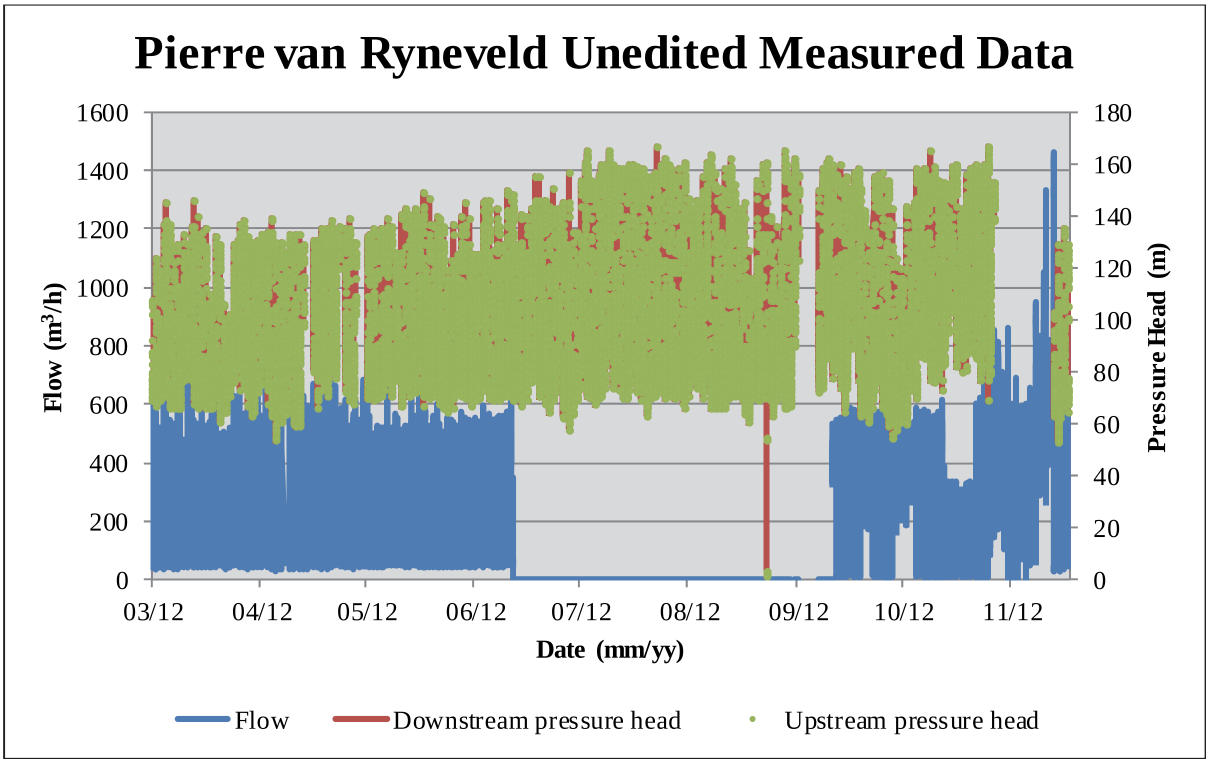


Figure 3-37: Pierre van Ryneveld unedited measured data

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 3-6**. **Figure 3-38** and **Figure 3-39** were also generated using the CHD Tool.

Table 3-6: 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	m^3/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 3-38**)		95	%	Decided
	Initial Design values	Design flow	0.003	m^3/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		
4	Design values after operational change	Design flow	0.067	m^3/s	
		Pressure head	50.4	m	
		Power rating	23.1	kW	
		Annual energy	198.3	MWh/a	
7	Selected turbine (**Figure 3-39**)		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 3-34**
	Power rating/max demand		185	%	

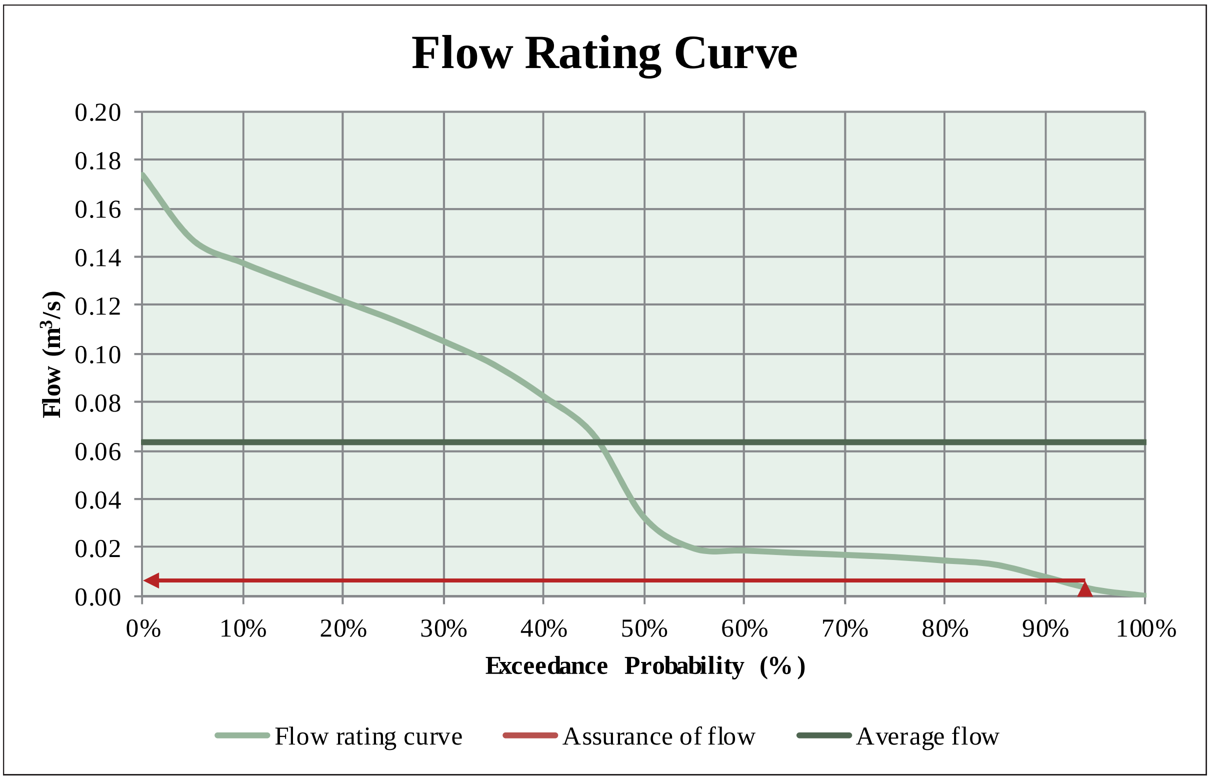


Figure 3-38: Pierre van Ryneveld Phase 2 flow-rating curve

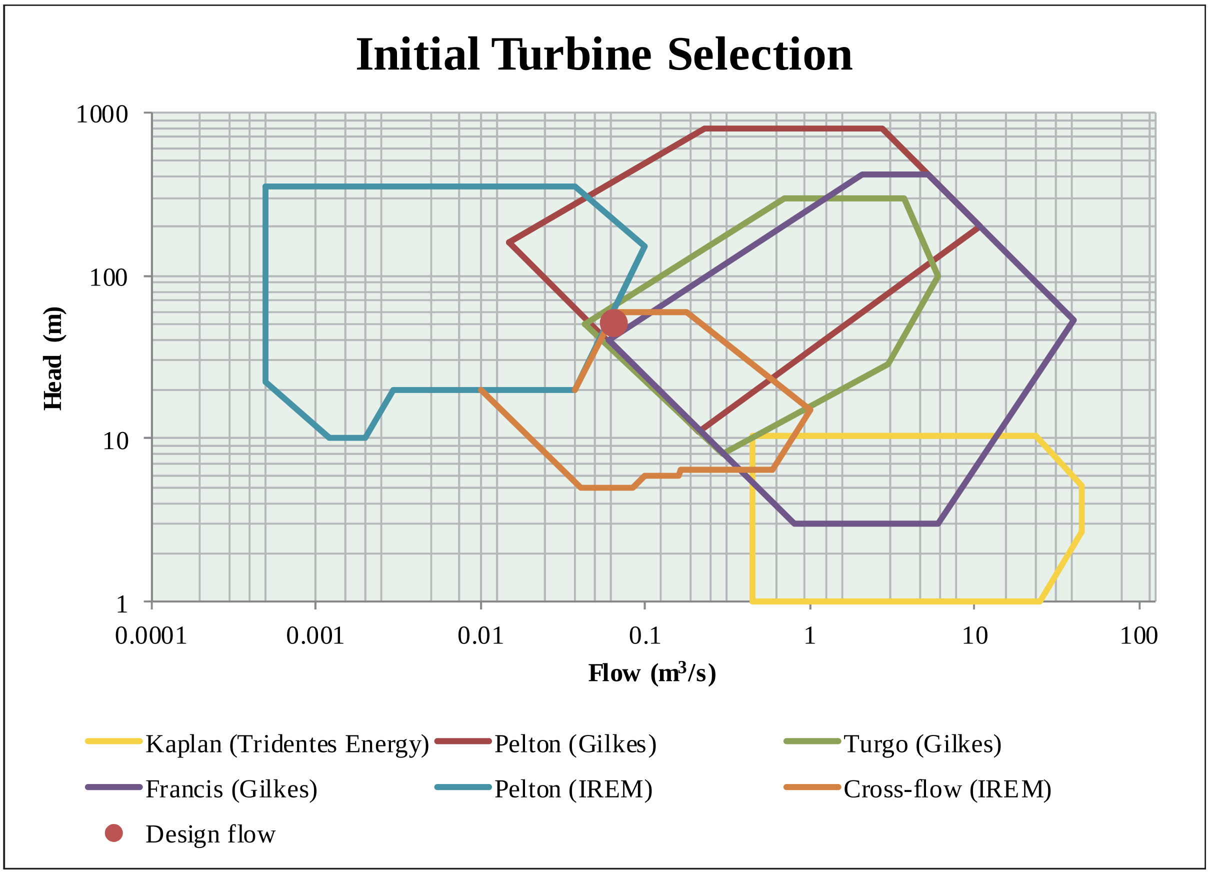


Figure 3-39: Pierre van Ryneveld Phase 2 initial turbine-selection curve (original)

From **Table 3-6**, 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 3-6**). A lower flow rate was used to populate **Table 3-7**, **Figure 3-40** and **Figure 3-41**.

Table 3-7: 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
	Final design values	Pressure head	50.4	m	CHD Tool
	Final design values	Power rating (**Figure 3-40**)	12.8	kW	CHD Tool
	Final design values	Annual energy (**Figure 3-40**)	110.0	MWh/a	CHD Tool
7		Selected turbine (**Figure 3-41**)	Pelton		CHD Tool
8		Electricity use	On-site		
9		Distance from grid connection	N/A	km	Decided
10		On-site power demand	12.5	kW	**Figure 3-34**
10		Power rating/ max demand	102	%	CHD Tool

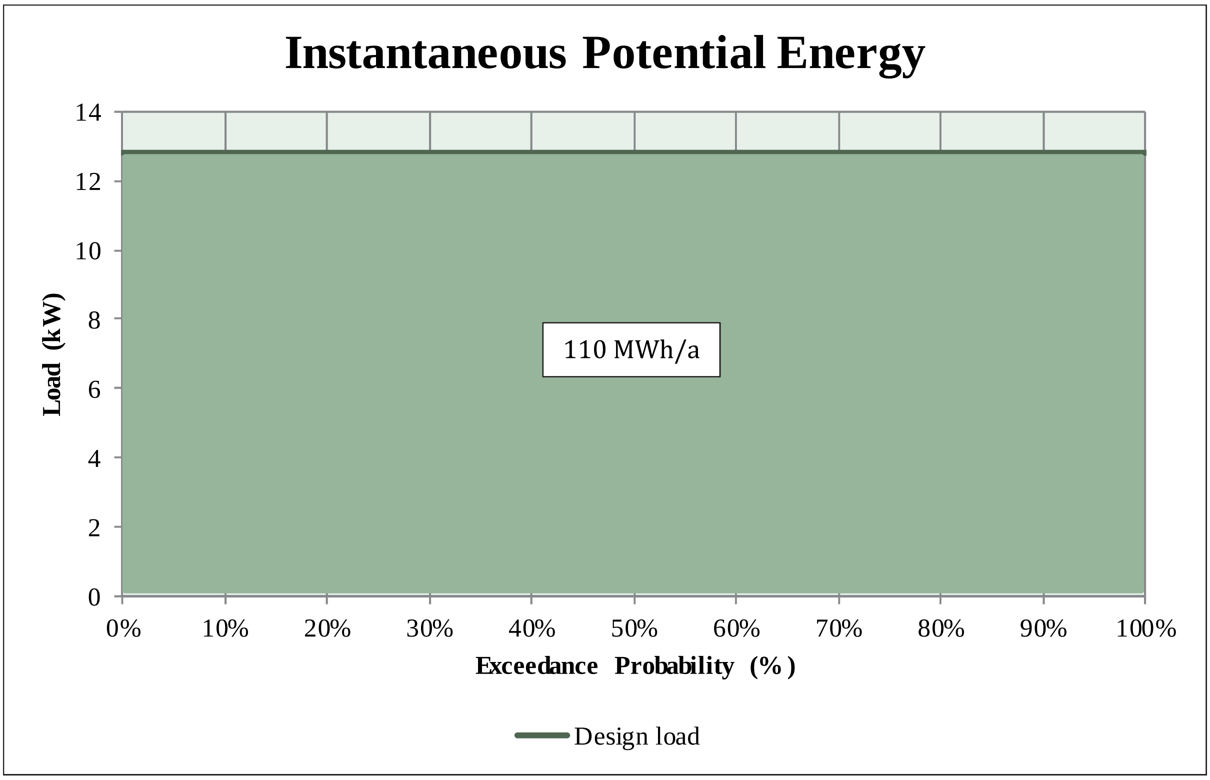


Figure 3-40: Pierre van Ryneveld Phase 2 instantaneous potential energy

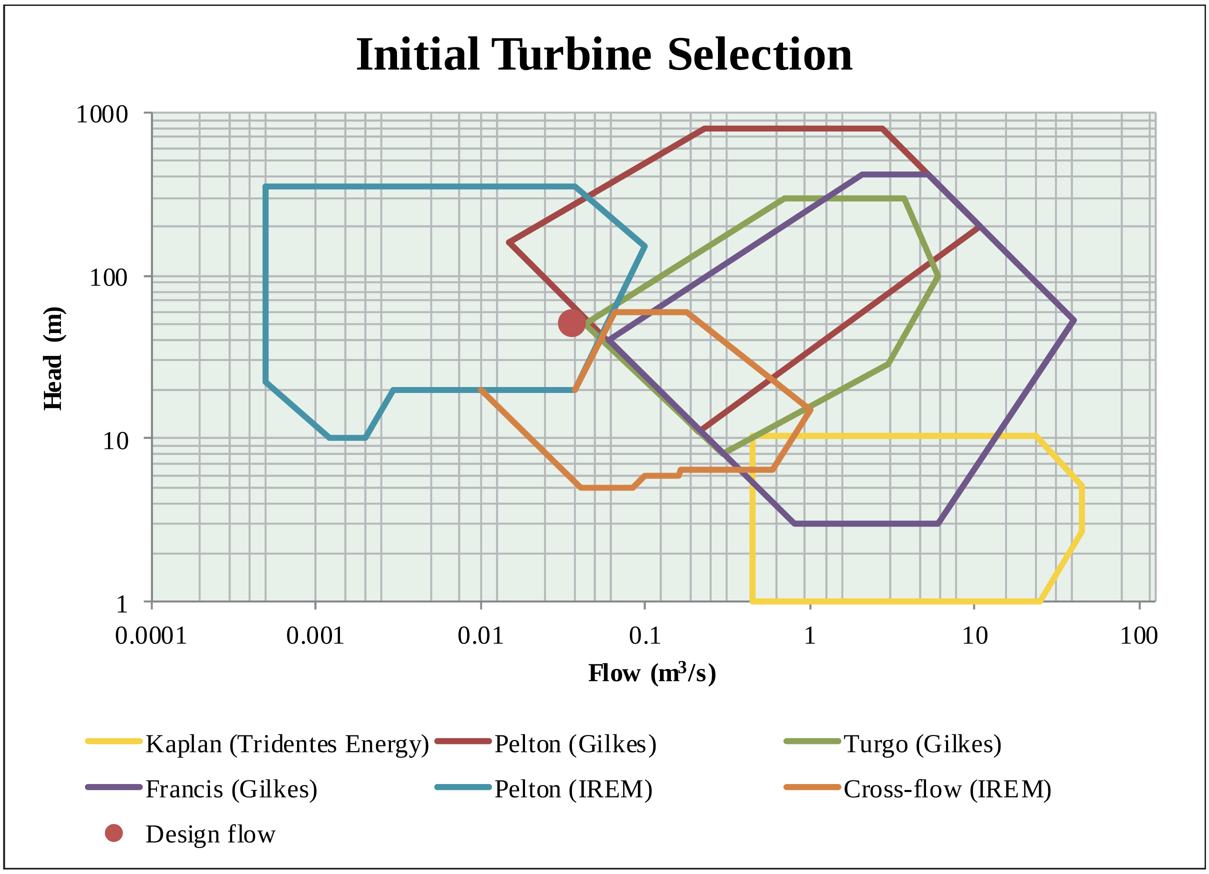


Figure 3-41: Pierre van Ryneveld Phase 2 initial turbine-selection curve (final)

CHDSS Steps 11-14 deal with regulatory requirements. These steps are summarised in **Table 3-8**.

Table 3-8: 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 certain default values and cost functions as prescribed in the **Conduit Hydropower Design Guide**. **Table 3-9** was populated with the input and calculated values.

Table 3-9: 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 3-6**) and the use of a correctly sized turbine (as discussed in **Table 3-7**), 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.

3.4.4 **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 3-42** 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 3-33**), 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 3-10**. 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.

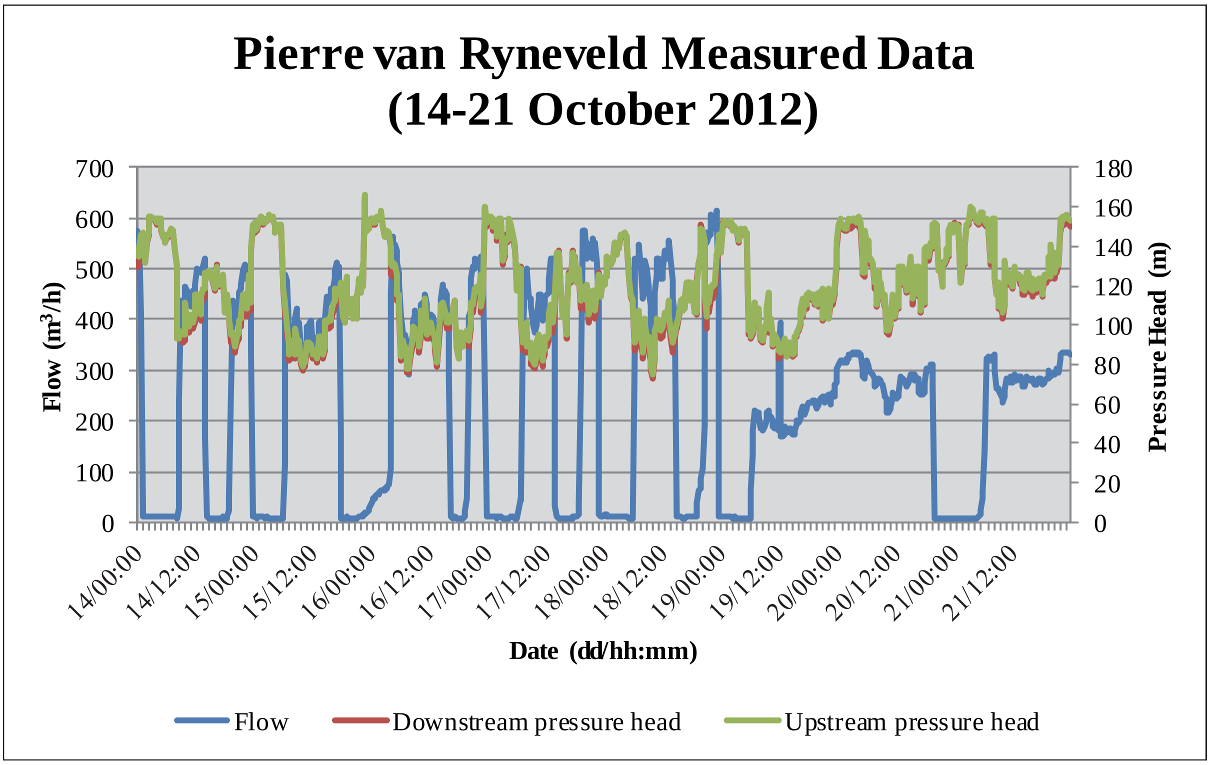


Figure 3-42: Pierre van Ryneveld measured data for a typical week

Table 3-10: 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
3	Measured and calculated values	Pressure head	50.4	m	CHD Tool
4	Measured and calculated values	Power rating	26.4	kW	CHD Tool
4	Measured and calculated values	Annual energy potential	226.7	MWh/a	CHD Tool
4	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 3-43**	kW	CHD Tool
14	Do supply-and-demand patterns correlate?		Supply is higher than peak demand		CHD Tool
14	Is there sufficient demand for the installation size?		No		
6	Required turbine size for demand?		12.5	kW	**Figure 3-43**
4	Final design	Flow	0.041	m^3/s	CHD Tool
4	Final design	Pressure head	50.4	m	
7	Selected turbine (**Figure 3-44**)		BHG Cross-flow		Easily obtainable
8	Turbine efficiency		75%		Supplier information

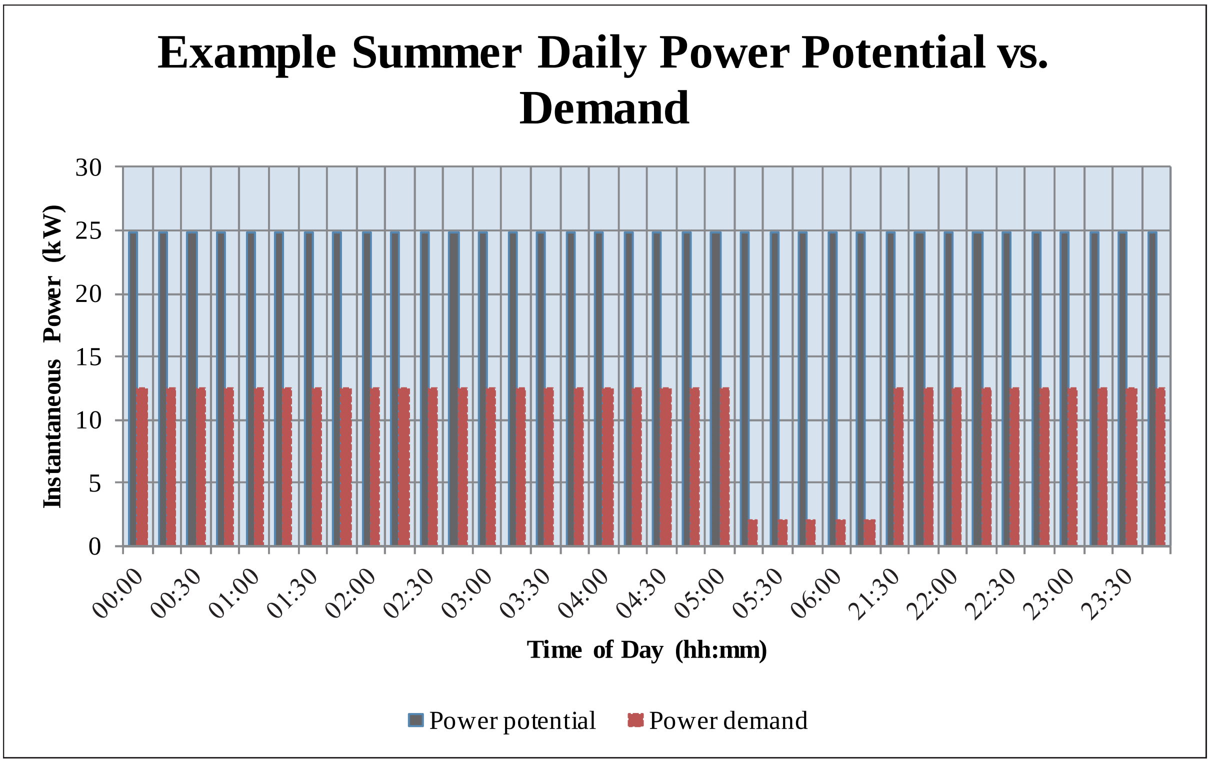


Figure 3-43: Pierre van Ryneveld Phase 3 example power potential vs. power demand

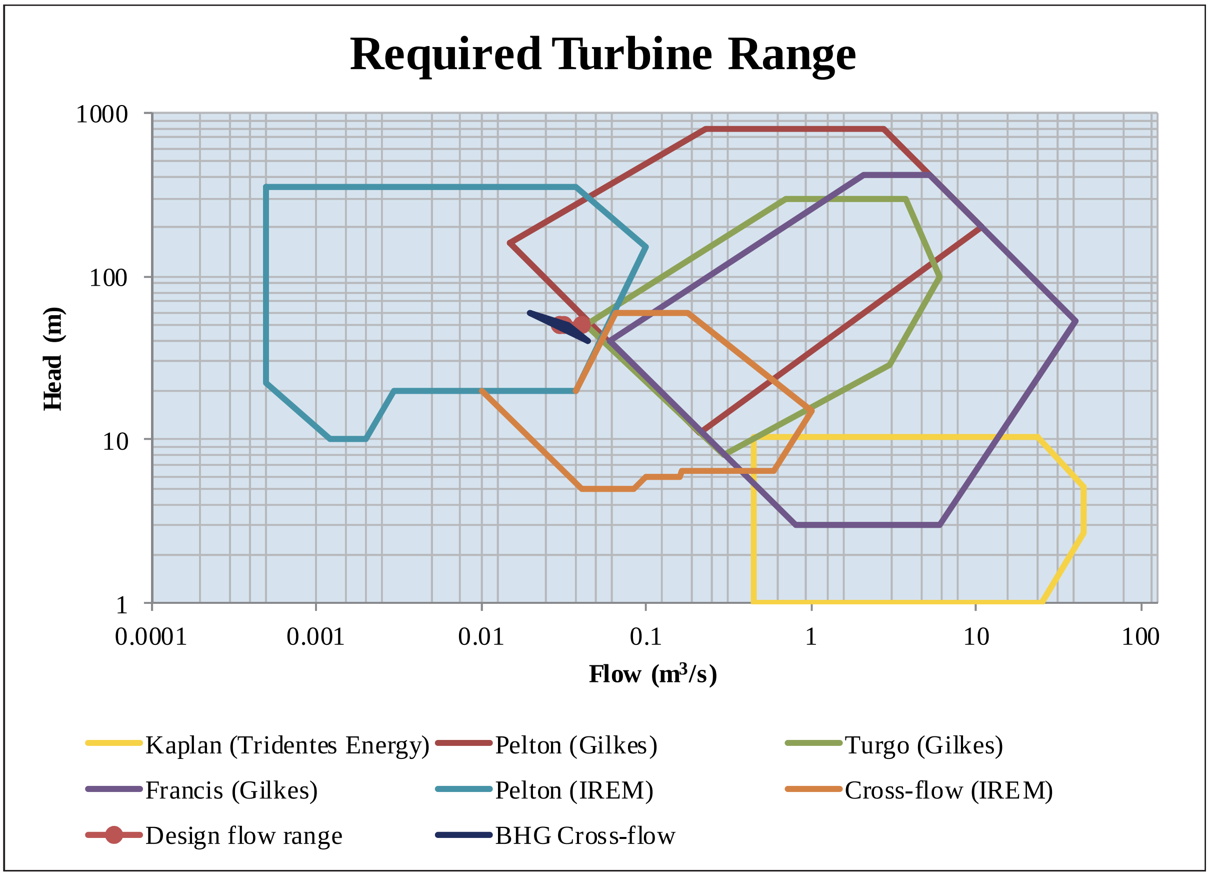


Figure 3-44: Pierre van Ryneveld Phase 3 turbine selection

The next set of steps involved the detailed design of all the components of the conduit hydropower plant. **Table 3-11** to **Table 3-15** provide a summary of the procedure, with references to drawings, photos and other relevant information.

Table 3-11: Pierre van Ryneveld Phase 3 electrical and mechanical design summary

DSS step	Design component	Discussion
15	Electrical and mechanical	A cross-flow turbine (**Figure 3-45**) 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 3-12.** 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 3-12.** 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.

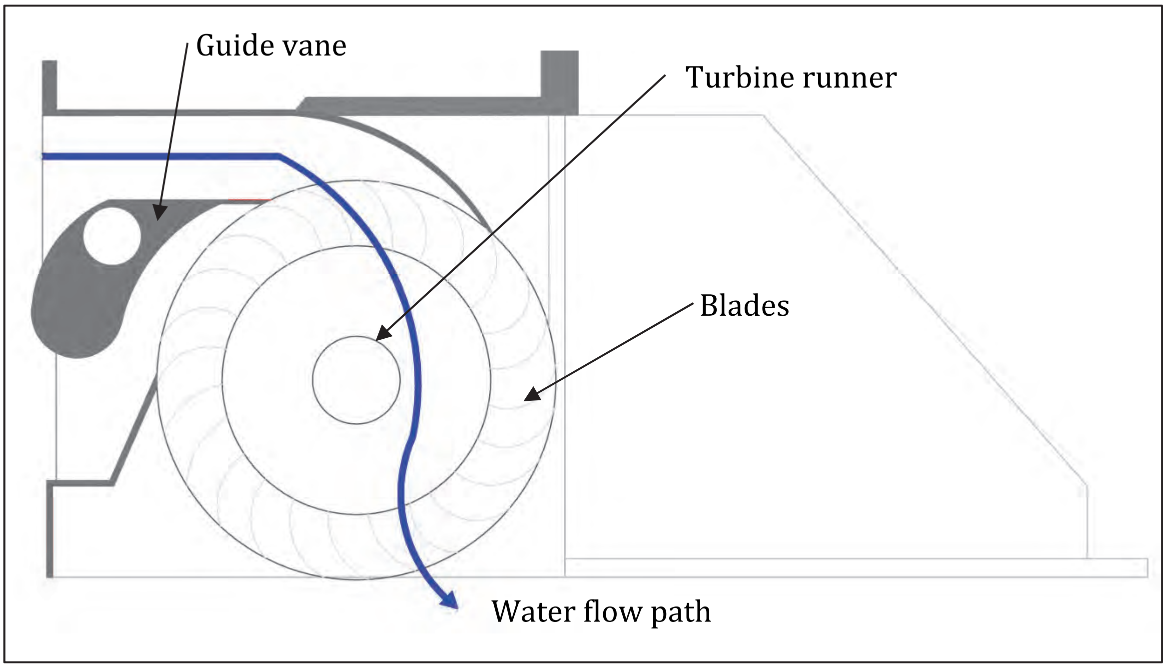


Figure 3-45: Cross-flow turbine

Table 3-12: 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 3-13: 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 3-14: 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 3-46**, 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. The off-take was enclosed in a valve chamber (**Figure 3-47** 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 3-48)**. A steel frame with chromadek cladding was used for the turbine enclosure (**Figure 3-49**).

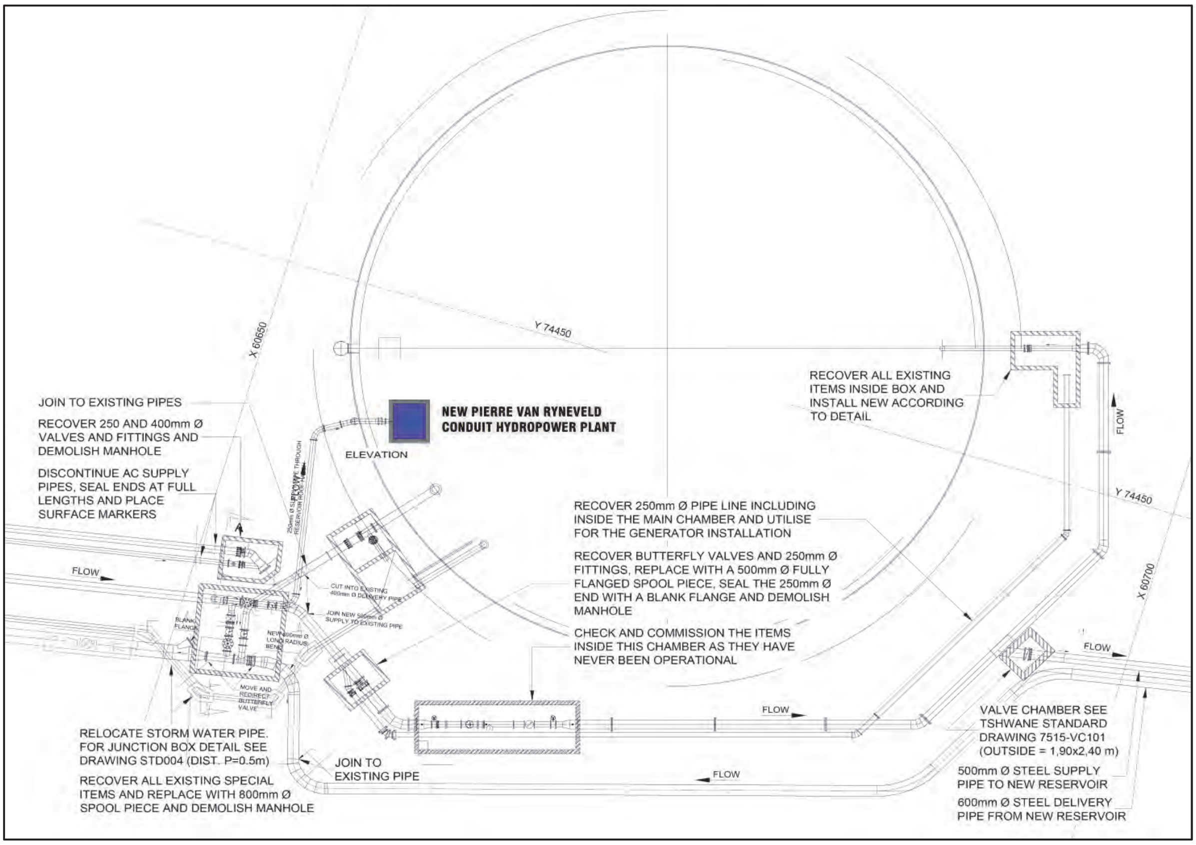


Figure 3-46: Pierre van Ryneveld pipework design

Figure 3-47: Completed off-take pipework

Figure 3-48: Completed turbine on steel-beam supports

Figure 3-49: Pierre van Ryneveld turbine enclosure

Table 3-15: 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 3-50** 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.

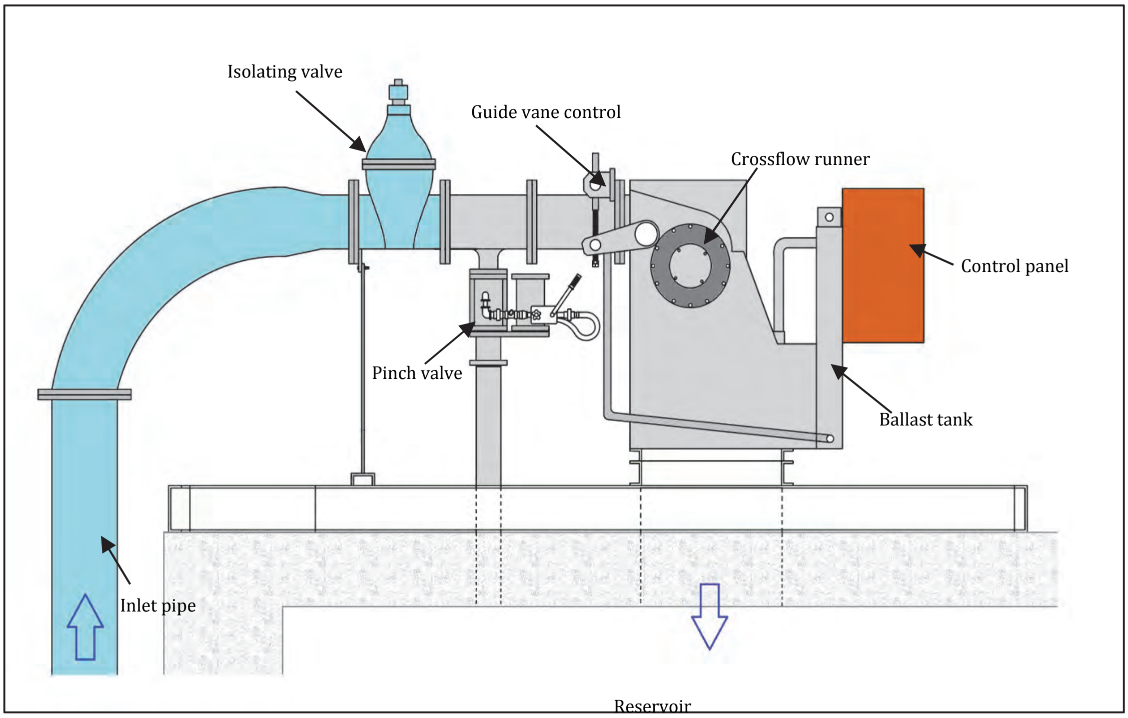


Figure 3-50: BHG cross-flow turbine set-up at Pierre van Ryneveld Reservoir

Next, a detailed economic evaluation was conducted with obtained costs, where applicable. The results can be seen in **Table 3-16**. 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 3-17**.

Table 3-16: 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	
		Design life	15	years	Decided
		Total initial capital expenditure	685 000	R	CHD Tool
		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 3-51**, **Figure 3-52** and **Table 3-17**. 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 3-17: 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%

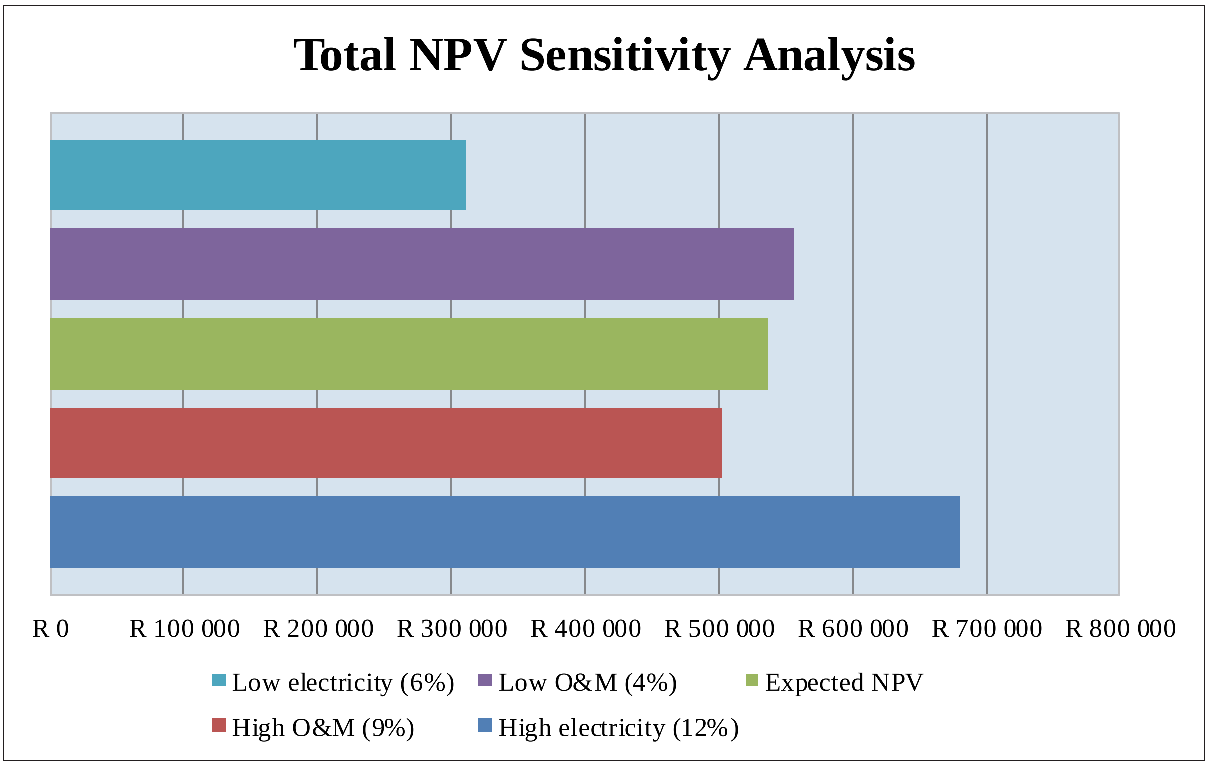


Figure 3-51: Pierre van Ryneveld Phase 3 NPV sensitivity analysis

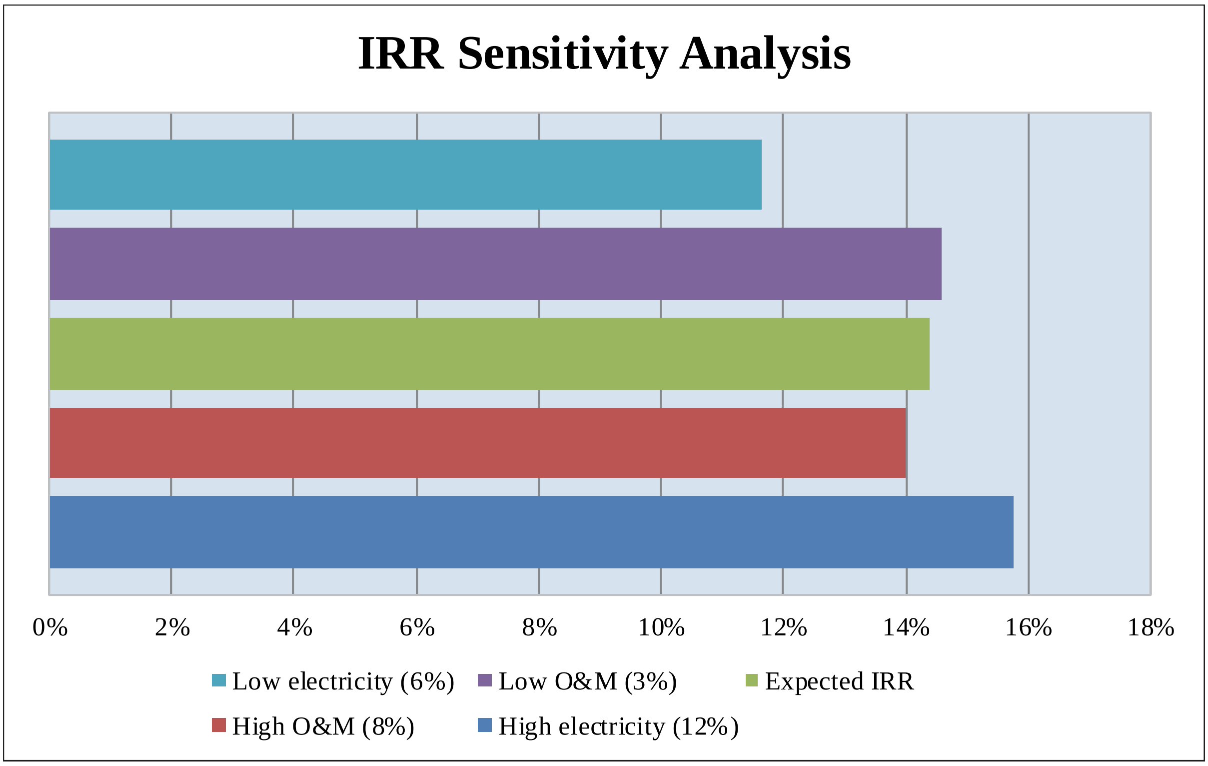


Figure 3-52: Pierre van Ryneveld Phase 3 IRR sensitivity analysis

3.4.5 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 3-10**.

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 3-16**. A BHG cross-flow turbine with a capacity of 15 kW was selected, as it was available and applicable to the flow range on site. Annually ±131000 kWh could be generated with this unit, enough to supply 10 households.

3.4.5.1 Turbine

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 3-53** 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 cross-flow and pelton turbines will maintain a good efficiency even at very low flow rates.

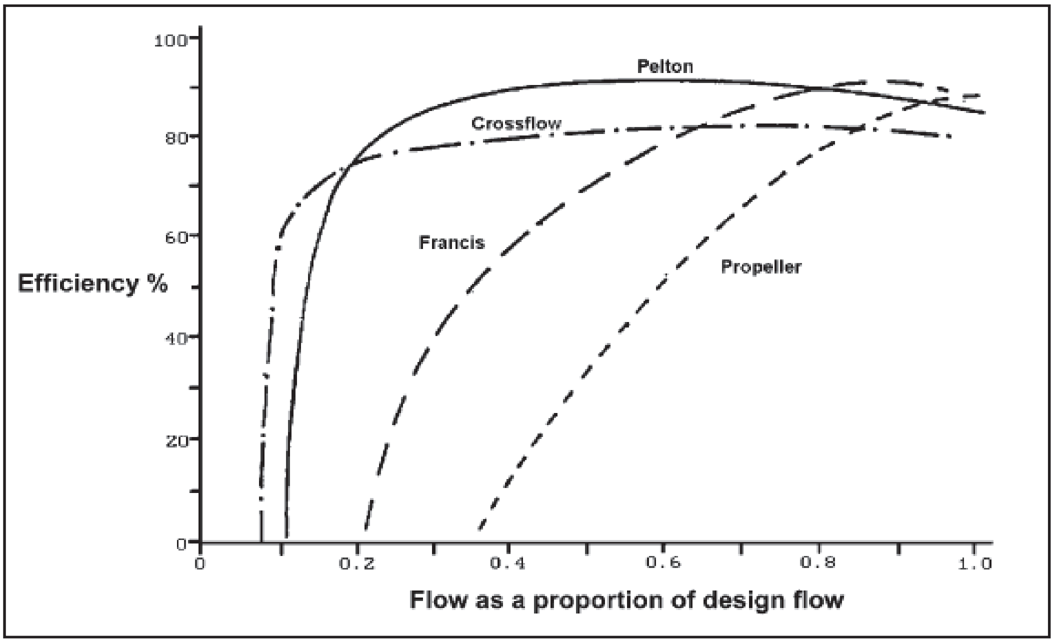


Figure 3-53: Part-flow efficiencies of different turbines (Paish, 2002)

A cross-flow turbine (Banki-Michell turbine or Ossberger turbine) is a water turbine where the water passes through the turbine transversely, or across the turbine blades, unlike most water turbines which have axial or radial flows.

As with a water wheel, the water is admitted at the turbine's edge. After passing the runner, it leaves on the opposite side. Going through the runner twice provides additional efficiency. When the water leaves the runner, it also helps clean the runner of small debris and pollution. The cross-flow turbine is a low-speed machine that is well suited for locations with a low head but high flow. The subdivided regulating unit, the guide vane system in the turbine's upstream section, provides flexible operation. Low operating costs are obtained with the turbine's relatively simple construction.

The main advantages of utilizing a cross-flow turbine are:

- The peak efficiency of a cross-flow turbine is somewhat less than a Kaplan, Francis or Pelton turbine. However, the cross-flow turbine has a flat efficiency curve under varying load. With a split runner and turbine chamber, the turbine maintains its efficiency while the flow and load vary from 15% to 100%.
- Since it has a low price, and good regulation, cross-flow turbines are mostly used in mini and micro hydropower units of less than 2 MW and with heads less than 200 m.

- It’s simple construction makes it easier to maintain than other turbine types; only two bearings must be maintained, and there are only three rotating elements. The mechanical system is simple, so repairs can be performed by local mechanics.
- Another advantage is that it can often clean itself. As the water leaves the runner, leaves, grass etc. (not present in the potable water supply of CoT) will not remain in the runner, preventing losses.

The selected hydro turbine is of the cross flow type of standard design. The water passages including the runner blades and side discs are nickel-plated, and the turbine housing is hot-dipped galvanized to ensure long life against erosion.

The turbine is equipped with a guide vane to regulate the water consumption. The guide vane is manually operated by a screw, turned by a removable lever. The turbine operates at constant water consumption, which means constant power, normally full load.

A roller type bearing is used on the drive side [pulley] and a ball bearing type at the non-drive end. The latter was selected to obtain an acceptable radial load, which would be too small for a roller type bearing.

3.4.5.2 Generator

It was decided to utilize a synchronous generator. The synchronous electric motor is an AC motor distinguished by a rotor spinning with coils passing magnets at the same rate as the power supply frequency and resulting rotating magnetic field which drives it.

The generator is of the synchronous 3-phase, 50 Hertz, brushless type, with the main field being supplied through a rotating diode bridge from a built-in exciter. The enclosure type is IP23, drip proof with internal fan cooling. The generator is a special hydro design, being capable to withstand a short term 80 % over speed, in case the power is suddenly lost, as for example during a lightning strike, and the plant accelerates to runaway speed. The generator is rated 17 kVA, 380 / 220 Volts, rotating at 1500 rpm.

3.4.5.3 Belt Drive

The generator is belt driven from the turbine, with a pulley ratio to rotate the turbine at maximum efficiency [642 rpm] with reference to the synchronous speed of the generator [1500 rpm]. The belt is of the flat type of polyamide synthetic material with a leather coated running surface.

3.4.5.4 Speed / Load Control

Speed / load control by a governor is not possible in this specific setup and thus the turbine is operated at constant load, normally full load, consuming a constant rate of water consumption. A ballast tank with water-cooled heating elements is provided which can accommodate full load power. Thus, any difference between generated power and power consumed is regulated in the ballast tank.

During normal operation, stability of the power supply without hunting is ensured as described above. However, in an emergency when power is suddenly lost, a by-pass is provided ahead of the turbine inlet, which automatically opens and diverts the flow and pressure away from the turbine. The solution adopted is the use of a "Pinch valve", using the water pressure to open the pinch valve in an emergency.

3.4.5.5 Turbine room

A steel frame with Cromadeck cladding was used to provide an enclosure for the turbine, generator, electrical and monitoring equipment.

3.4.6 **Construction of the hydropower plant**

Visual details of the progress on the construction of this hydropower pilot plant are shown in **Figure 3-54** to **Figure 3-70**.

Figure 3-54: Providing a offtake from the main supply line

Figure 3-55: Plan view of off take pipework

Figure 3-56: Pipework for hydropower installation

Figure 3-57: Constructing the off-take chamber

Figure 3-58: Nearly complete off take chamber (Pierre van Ryneveld Reservoir)

Figure 3-59: Completed turbine supply line on to top of reservoir

Figure 3-60: Completed off-take chamber pipework

Figure 3-61: Completed off take chamber

Figure 3-62: Crossflow turbine hoisted onto the reservoir roof

Figure 3-63: Crossflow turbine installation (connecting to supply line)

Figure 3-64: Emegency pinch valve (discharging into reservoir)

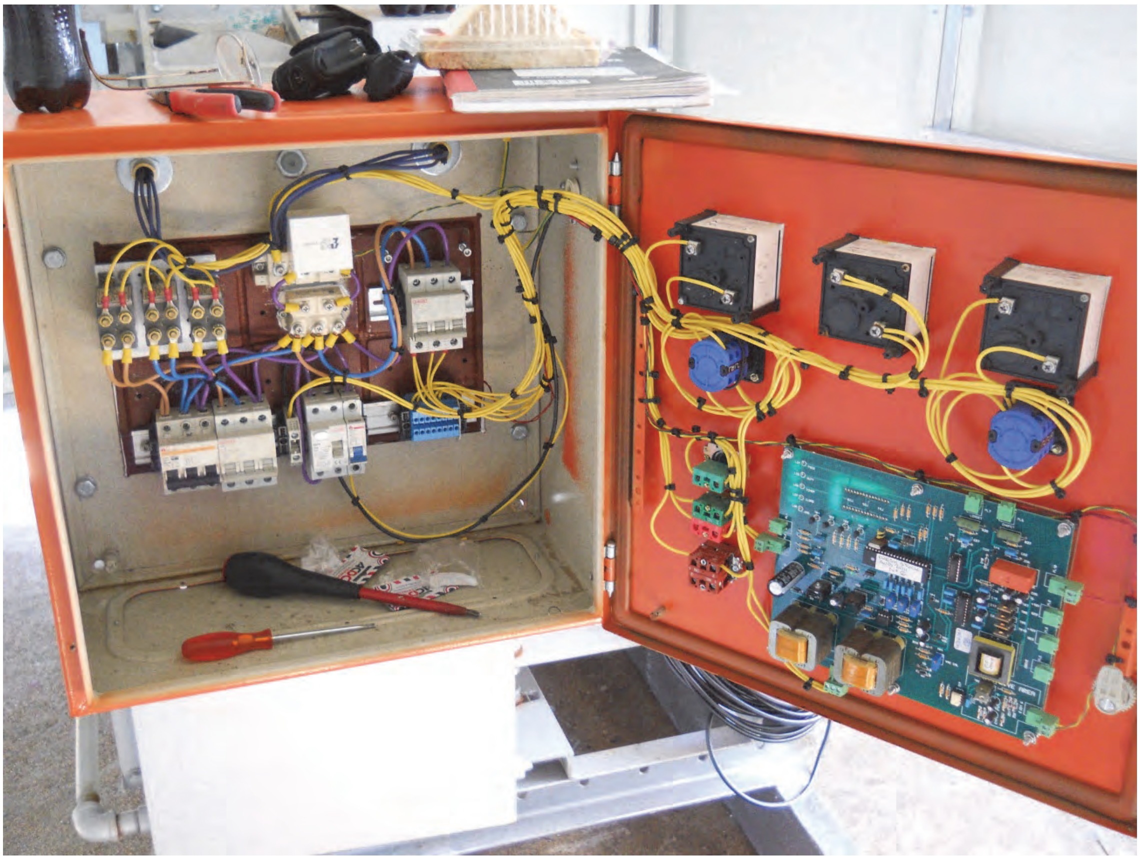


Figure 3-65: Generator control panel

Figure 3-66: Completed installation of turbine, generator and electrical controls

Figure 3-67: Electrical switch over (grid power or hydropower)

Figure 3-68: Enclosure framework

Figure 3-69: Pilot plant enclosure

Figure 3-70: Commissioning of hydropower plant

3.4.7 Monitoring and evaluation of plant performance

The monitoring of the plant performance is done providing the following data outputs:

1. Gross power output from generator. One 4-20mA output.
2. Net power to the external load. One 4-20mA output.
3. System voltage, three 4-20mA signals, one for each phase.
4. Gross system current, three 4-20mA signals, one for each phase.
5. Net system current, three 4-20mA signals, one for each phase.
6. Status of all shutdown functions - indicated by potential-free contacts
7. System frequency. One 4-20mA signal.
8. Turbine speed. Indicated by one 4-20mA signal.
9. Turbine guide vane position. Indicated by one 4-20mA output

All of the listed transducers are housed in a steel cabinet mounted on the side of the existing control cabinet. An instrumentation power supply is provided in a wall mounted cabinet. This provides 12v DC power supply and will have a battery capacity of 45Ah. Provision was made for continuous battery charging.

The above listed data outputs are captured with a dataTaker DT85M data logger, connected via a modem in order for the data to be captured remotely.

The dataTaker DT85M, **Figure 3-71**, is a robust, stand alone, ultra-low power data logger with an integrated 3G modem that allows it to be used across a wide variety of remote applications.

Figure 3-71: dataTaker DT85M data logger

The data loggers automatic data delivery features allows the user to schedule data to be automatically emailed to your inbox every day, week, month or other time interval. Alarm conditions can also trigger data delivery or alarm messages to multiple email addresses or mobile phones.

An example of the operational data recorded for an evening in January 2014 is shown in **Table 3-18**.

Table 3-18: Operational data recorded

Time	Flow (l/s)	Pressure (m)	Voltage (V)	Frequency (Hz)	Velocity (m/s)	Generated power (kW)
08:00 PM	81.74	17	230	50.1	1.503	8.86
08:15 PM	82.27	17	229	49.9	1.518	8.92
08:30 PM	81.57	17	229	50.0	1.503	8.84
08:45 PM	81.80	17	229	50.0	1.504	8.87
09:00 PM	82.19	18	229	49.9	1.512	9.43
09:15 PM	81.96	18	229	49.0	1.512	9.41
09:30 PM	81.35	18	229	49.1	1.506	9.34
09:45 PM	81.53	18	229	50.1	1.500	9.36
10:00 PM	81.75	18	229	50.0	1.508	9.38
10:15 PM	81.76	18	229	50.0	1.468	9.38
10:30 PM	82.03	18	229	49.9	1.504	9.42
10:45 PM	82.07	18	230	49.6	1.512	9.42
11:00 PM	81.47	18	229	49.5	1.507	9.35
11:15 PM	81.51	18	229	50.1	1.500	9.36
11:30 PM	81.53	18	229	50.0	1.504	9.36
11:45 PM	81.86	18	229	50.0	1.516	9.40
12:00 AM	82.02	18	229	49.9	1.506	9.41
12:15 AM	81.45	18	229	50.1	1.509	9.35
12:30 AM						0.00
12:45 AM						0.00
01:00 AM						0.00
01:15 AM						0.00
01:30 AM						0.00
01:45 AM						0.00
02:00 AM						0.00
02:15 AM	81.92	18	229	49.9	1.507	9.40
02:30 AM	82.13	18	229	49.7	1.503	9.43
02:45 AM	81.05	18	229	50.1	1.497	9.30
03:00 AM	81.73	18	229	50.0	1.504	9.38
03:15 AM	81.72	18	229	49.7	1.504	9.38
03:30 AM	81.74	18	229	50.0	1.504	9.38
03:45 AM	81.66	18	230	50.0	1.503	9.37
04:00 AM	81.51	18	229	49.3	1.500	9.36
04:15 AM	81.93	18	230	50.1	1.509	9.40
04:30 AM	81.47	18	299	49.8	1.499	9.35
04:45 AM	81.96	18	229	50.0	1.503	9.41
05:00 AM	82.62	18	229	49.4	1.520	9.48

As indicated the electricity is used on site for lighting, telemetry etc.

3.5 Cost estimate

The best estimate of the final total cost was determined and is summarized in **Table 3-19**.

Table 3-19: Estimated cost of Pierre van Ryneveld Conduit Hydropower Plant

Item	Description	Cost
Cross-flow turbine	Manufacture and supply of cross-flow turbine with bottom outlet, synchronous 3-phase generator, ballast tank and control panel.	R170 000
Electrical	Site lighting, cabling and kiosk	R50 000
Pipework	Supply and installation of bypass pipeline including valves connecting main supply line and turbine	R115 000
Valve chamber	Construction of bypass valve chamber	R50 000
Enclosure/plant housing	The turbine, generator, control panel, monitoring equipment and electrical switchgear is housed in a Cromadek structure with safety fencing, lighting etc.	R60 000
Monitoring system	Measurement of power output from generator, net power to the external load, system voltage, gross and net system current, status of all shutdown functions, system frequency, and turbine speed, and turbine guide vane position. An instrumentation power supply with wall mounted cabinet. All of the above installed on site and commissioned.	R52 000
Data logging and communication system	DataTaker DT85M logger with internal 3G modem in order for the data to be captured remotely.	R49 000
Total (incl VAT)		**R546 000**

This total in **Table 3-19** excludes the manpower hours spend by the City of Tshwane and University of Pretoria staff in designing and erecting this hydropower plant.

3.6 Commissioning of the pilot plant

On 29 November 2011 the *Pierre van Ryneveld Conduit Hydropower Plant* was launched jointly by the City of Tshwane, the Water Research Commission and the University of Pretoria. After a number of speeches by dignitaries Mr Mduduzi Shabangu of the City of Tshwane Metropolitan Municipality switched all the site lighting from the conventional municipal grid over onto the hydropower generated on site.

Figure 3-72: Switching to conduit hydropower

Cameras were placed on top of the reservoir connected to big screen televisions for the attendees' to view this historic moment.

Figure 3-73: Research project team

4. BRANDKOP RESERVOIR PILOT PLANT (BLOEMWATER)

4.1 Introduction

The Caledon–Bloemfontein potable water supply system was commissioned in the late 1960's, operated and owned by the DWAF. The Caledon–Bloemfontein supply system consists of:

- An abstraction point at the Welbedacht Dam wall;
- Raw water pump station;
- Water Treatment Plant at the Welbedacht Dam with a capacity of 145 Ml/day;
- High Lift Pump Station;
- 6.7km 1 200mm Ø Steel rising main;
- 105.7km 1 170mm Ø Pre-stressed Concrete gravity mains; and
- Reservoirs with the following particulars:
  - De Hoek Reservoir – 22.7 Ml
  - Uitkijk Reservoir – 9.1 Ml
  - Brandkop Reservoir – 136 Ml

The supply system has a design capacity of 141 Ml/day (1.632 m^3/s) (Bloemwater, 2009). With the exception of the Welbedacht Dam the assets were transferred to Bloemwater in 1991. Bloemwater had operated the infrastructure ever since. The system layout is graphically illustrated in **Figure 4-1**.

Bloemwater augmented the supply capacity with the construction of a 700mm Ø steel and GRP combined pipeline, 33.6 km in length, between the Lieuwkop take off and the Brandkop Reservoir. The construction of the Lieuwkop – Bloemfontein pipeline in 1999, henceforth the LB pipeline, allowed water supply from either the Welbedacht- or from the Rustfontein Dams. This infrastructure addition yields a supplementary capacity of 33 Ml/day via the Rustfontein – Bloemfontein supply system and is restricted by the capacity of the ±25 km 648 mm ID Steel pipeline between Rustfontein Dam and the Lieuwkop take off.

Potable water is supplied via the Caledon/Bloemfontein Pipeline from the Welbedacht Dam in the Caledon River to Bloemfontein (see **Figure 4-1**). The treated water is pumped with a high lift pump station, 6.7 km to the De Hoek reservoir. From this reservoir it flows under gravity through a 105.7 km long, 1 170 mm Ø Pre-stressed concrete gravity mains as shown in **Figure 4-2**, via Uitkijk Reservoir to Brandkop Reservoir.

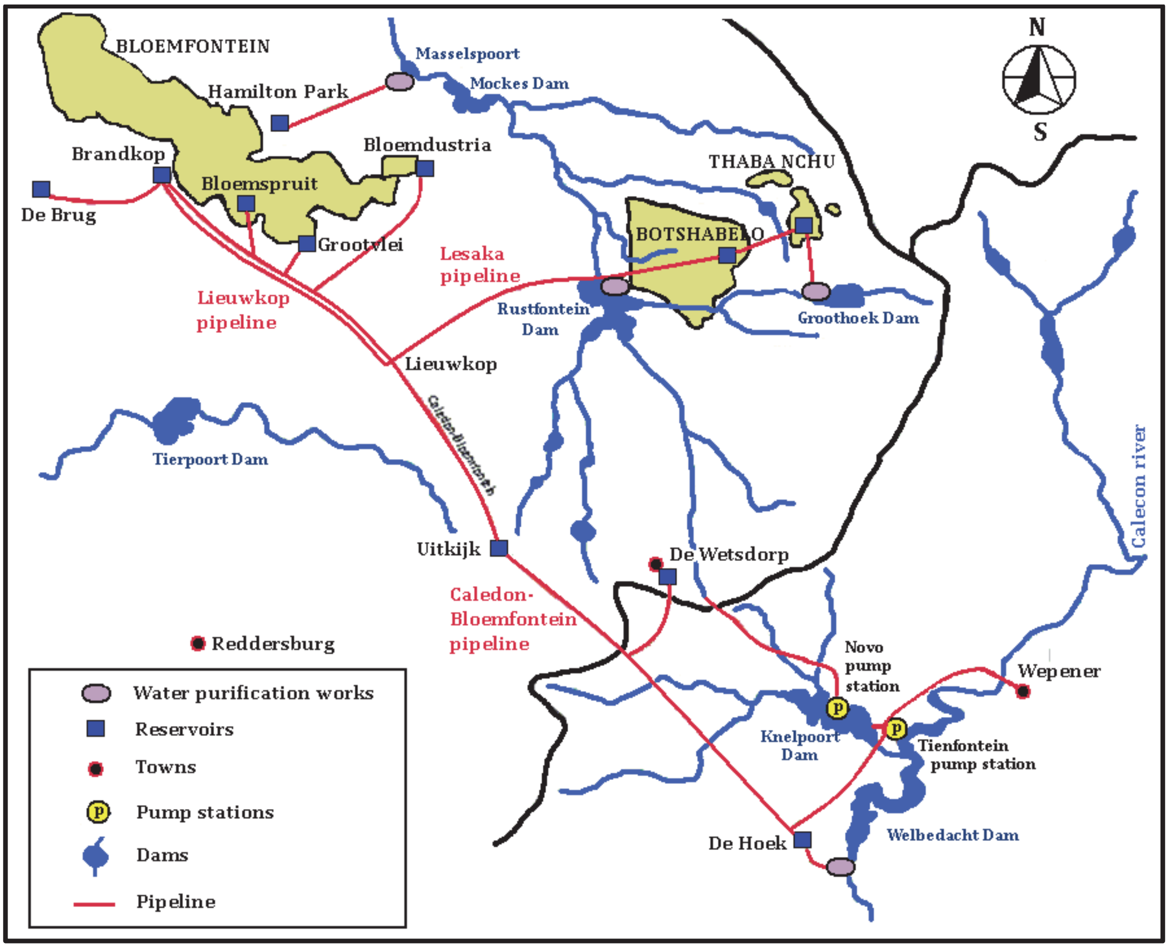


Figure 4-1: Schematic layout of the Caledon-Bloemfontein Gravity Pipeline

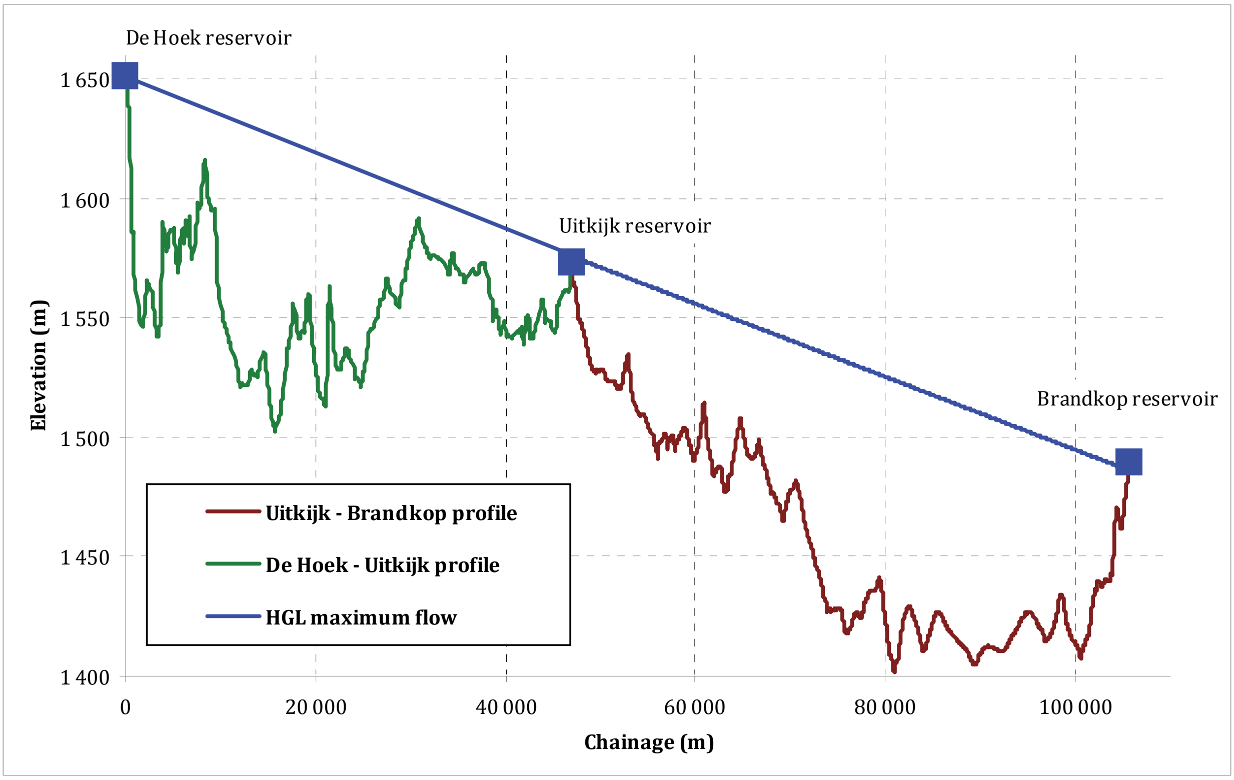


Figure 4-2: Longitudinal profile of the Caledon-Bloemfontein Pipeline

4.2 Description of the prospective conduit hydropower sites on the Caledon-Bloemfontein Pipeline

The two segments of the Caledon-Bloemfontein gravity pipeline are controlled on the downstream end, at the Uitkijk- and Brandkop Reservoirs, respectively.

4.2.1 Description of the Uitkijk Reservoir hydropower site

The De Hoek to Uitkijk pipeline system is downstream controlled by means of a series of level control valves at Uitkijk Reservoir. The control station at Uitkijk Reservoir consists of 3 sets of control valve branches in parallel supplied via an inlet manifold (see **Figure 4-3**). A schematic drawing of the system shown in **Figure 4-4,** reflects the 3 parallel control branches each with two legs. Branches 2 and 3 (legs 3 to 6) consists of sets of single Bermad control valve whilst branch 1 (leg 1 and 2) consist of a set of two Bermad control valves placed in series. Branch 1 and 2 consists of 300 mm Bermad control valves and branch 3 consists of 400 mm diameter Bermad control valves as shown in **Figure 4-5**.

Figure 4-3: Inlet manifold at Uitkijk Reservoir

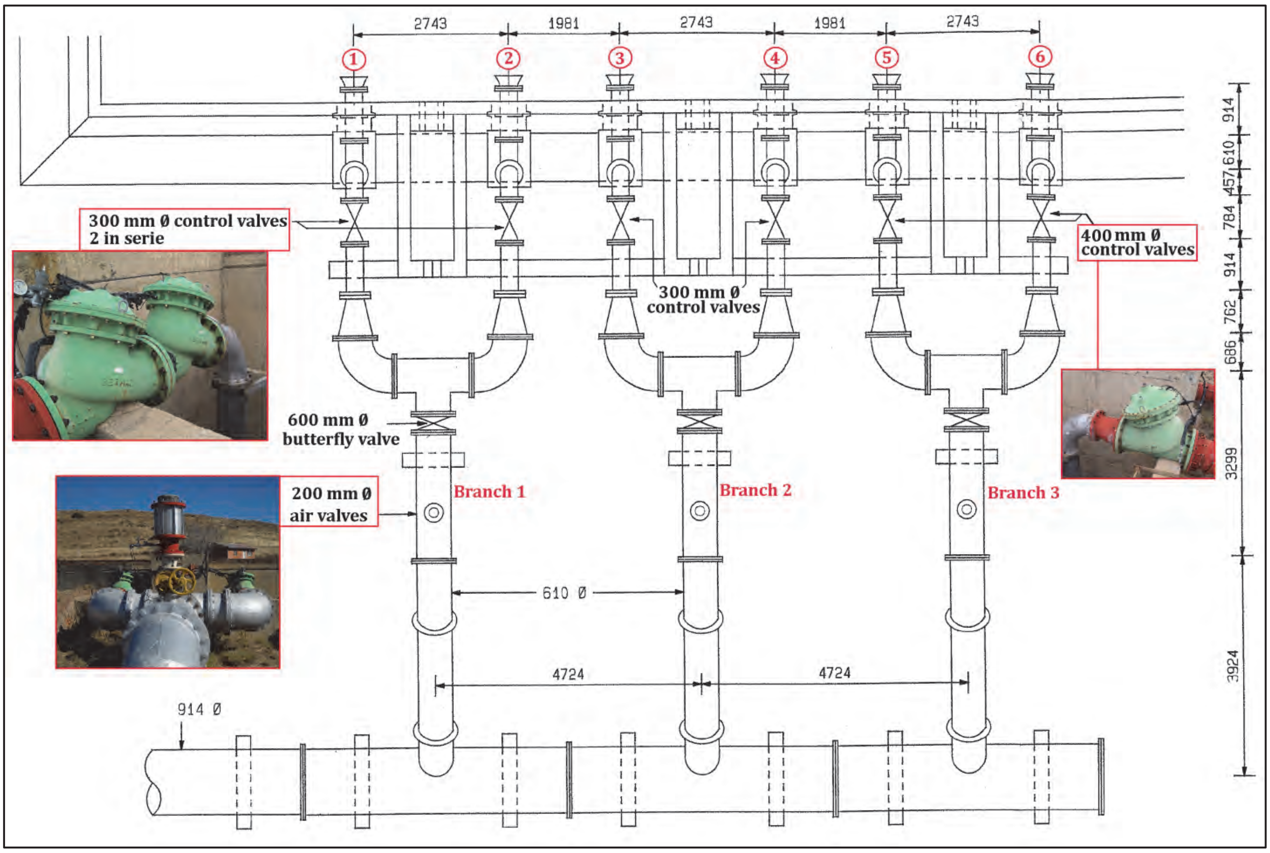


Figure 4-4: Schematic layout of control valve system

Figure 4-5: Control valves (branch 3) at Uitkijk Reservoir inlet

Table 4-1 describes the existing control valve station configuration as shown in **Figure 4-4**.

Table 4-1: Uitkijk Reservoir pressure control station

Branch	Leg	Pipe diameter (mm)	Valve 1	Valve 2	Current status
1	1	300 mm	Bermad/Class 16	Bermad/Class 16	Manually operated
	2	300 mm	Bermad/Class 16	Bermad/Class 16	Manually operated
2	3	300 mm	Bermad/Class 16	-	Manually operated
	4	300 mm	Bermad/Class 16	-	Manually operated
3	5	400 mm	Bermad/Class 16	-	Manually operated
	6	400 mm	Bermad/Class 16	-	Manually operated

Bloemwater has recently refurbished the pressure control stations replacing the pressure reducing valves.

The flow is measured with a magflow meter just downstream of the De Hoek Reservoir. The flow rate is dependent on the number branches in operation. The original design philosophy was to close the branches in the order 3, 2 and lastly 1 (Bloemarea Waterraad, 1992).

The system is operated on the premise that the Bermad level control valves, installed at Uitkijk Reservoir, are ensuring slow controlled transitions in the pipelines between static to fully dynamic conditions and vice-versa.

These controls do however not provide protection against external influences, such as manual closing or opening of line control valves or sudden surges attributable to pipeline ruptures. Uncontrolled surges therefore either cause a pipeline failure or cause structural deterioration of the pipeline or pipeline elements.

The longitudinal profile of the section of the Caledon-Bloemfontein gravity pipeline from De Hoek to Uitkijk Reservoir is depicted in **Figure 4-6**.

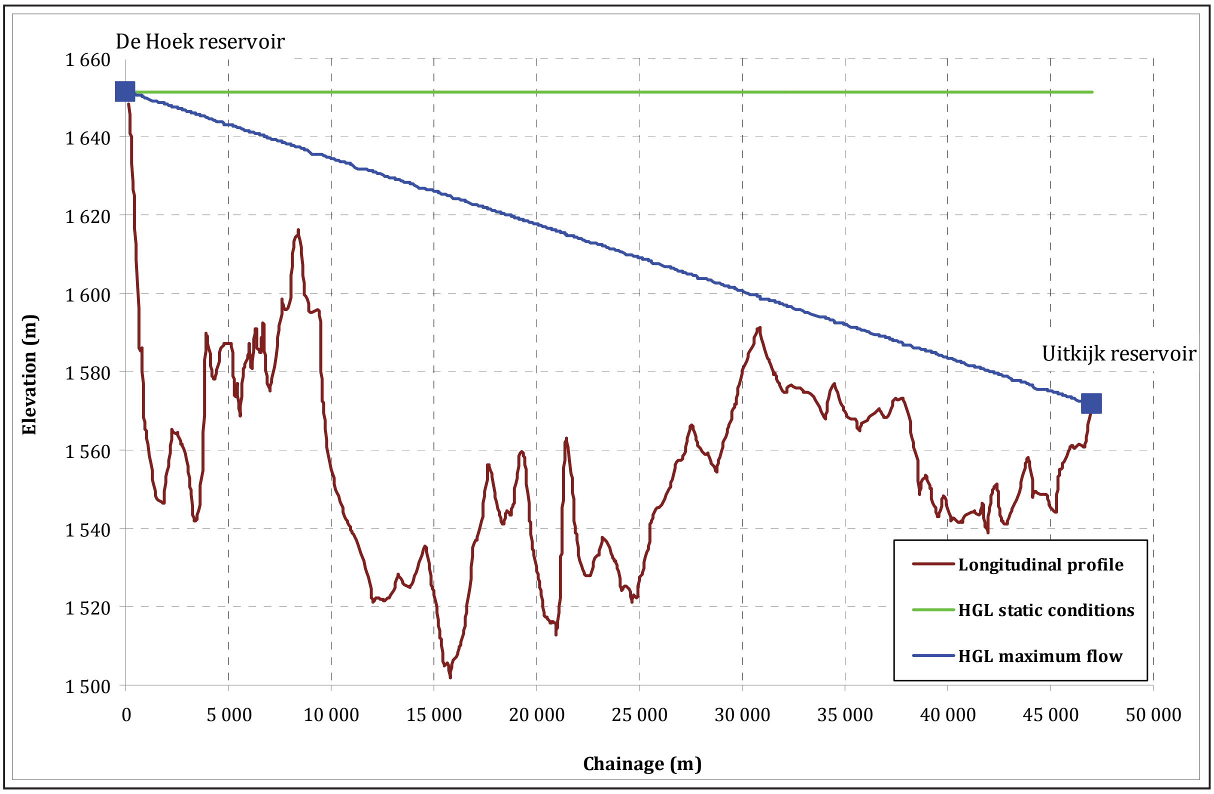


Figure 4-6: De Hoek to Uitkijk reservoir profile and gradelines

4.2.2 Description of the Brandkop Reservoir hydropower site

The Uitkijk-Brandkop pipeline system is downstream controlled by means of a series of level control valves at Brandkop reservoir. The control station at Brandkop Reservoir consists of 5 sets of control valves in parallel supplied via an inlet manifold (see **Figure 4-7**). A schematic drawing of the system shown in **Figure 4-8,** reflects the 5 parallel control branches. Branches 1 and 3 consists of a single Bermad control valve whilst branches 2 and 4 consist of a set of two Bermad control valves placed in series. Branch 5 consists of a single 400 mm diameter Bermad control valve as shown in **Figure 4-9**.

Figure 4-7: Inlet manifold at Brandkop Reservoir (with 5 branches)

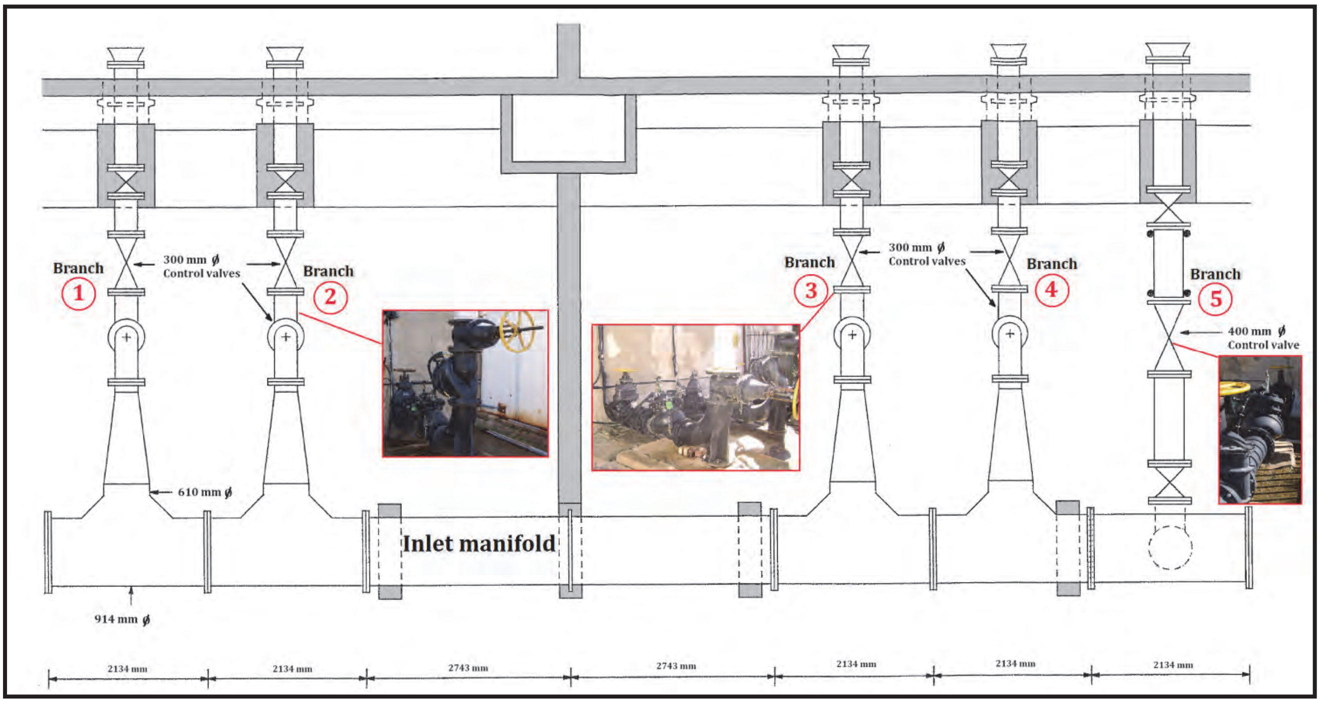


Figure 4-8: Schematic layout of control valve system

Figure 4-9: Control valves (branches 3, 4 and 5) at Brandkop Reservoir inlet

Table 4-2 describes the control valve station configuration as shown in **Figure 4-8**.

Table 4-2: Brandkop Reservoir pressure control station

Branch	Pipe diameter (mm)	Valve 1	Valve 2	Current status
1	300 mm	Bermad/Class 16	-	Manually operated
2	300 mm	Bermad/Class 16	Bermad/Class 16	Manually operated
3	300 mm	Bermad/Class 16	-	Manually operated
4	300 mm	Bermad/Class 16	Bermad/Class 16	Manually operated
5	400 mm	Bermad/Class 16	-	Manually operated

The flow is measured with a magflow meter just upstream of the inlet into Brandkop Reservoir. The flow rate is dependent on the number branches in operation. The original design philosophy was to close the branches in the order 1, 3, 2, 4 and lastly 5.

The system is operated on the premise that the Bermad level control valves, installed at Brandkop Reservoir, are ensuring slow controlled transitions in the pipelines between static to fully dynamic conditions and vice-versa. These controls do however not provide protection against external influences, such as manual closing or opening of line control valves or sudden surges attributable to pipeline ruptures. Uncontrolled surges therefore either cause a pipeline failure or cause structural deterioration of the pipeline or pipeline elements.

Bloemwater has recently refurbished the pressure control stations replacing the pressure reducing valves as shown in **Figure 4-10** and **Figure 4-11**.

Figure 4-10: Refurbished pressure control station at Brandkop Reservoir

The longitudinal profile of the section of the Caledon-Bloemfontein gravity pipeline from Uitkijk to Brandkop Reservoir is depicted in **Figure 4-12.**

Figure 4-11: Refurbished pressure reducing valves on Branch 1 and 2

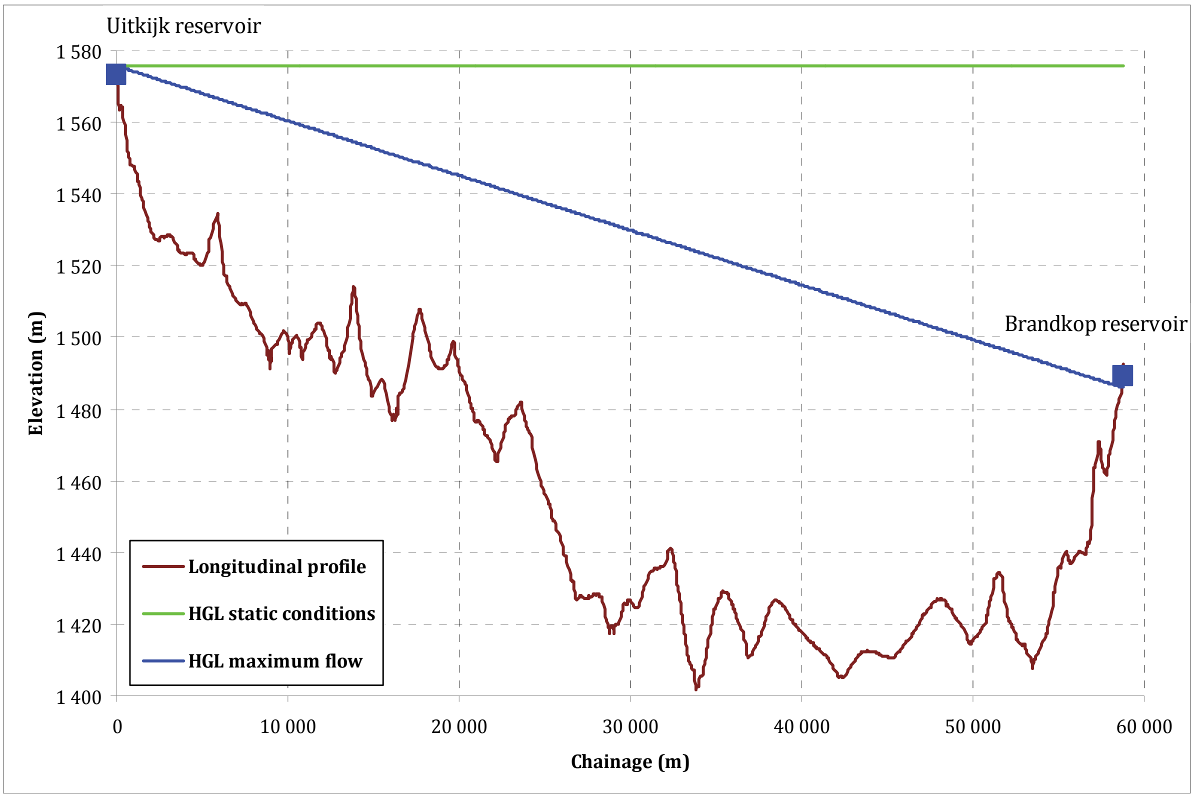


Figure 4-12: Uitkijk to Brandkop reservoir profile and gradelines

4.2.3 Hydraulic characteristics of the Caledon Bloemfontein pipeline

4.2.3.1 De Hoek to Uitkijk Reservoir

The De Hoek to Uitkijk pipeline has not been hydraulically reviewed since the installation of the pipeline in 1975. The hydraulic characteristics of the pipeline were obtained during field measurements on a separate study conducted for Bloemwater by the members of the project team.

Pressure transducers were connected to the pipeline at various locations (DU1 to DU7), see **Figure 4-13** and the flow was measured ±300 m downstream of the De Hoek Reservoir. A PORTAFLOW (Fuji Electric) Ultrasonic Flow Meter was installed on the supply manifold with sensors FLD51 installed in the V-type installation (**Figure 4-14**).

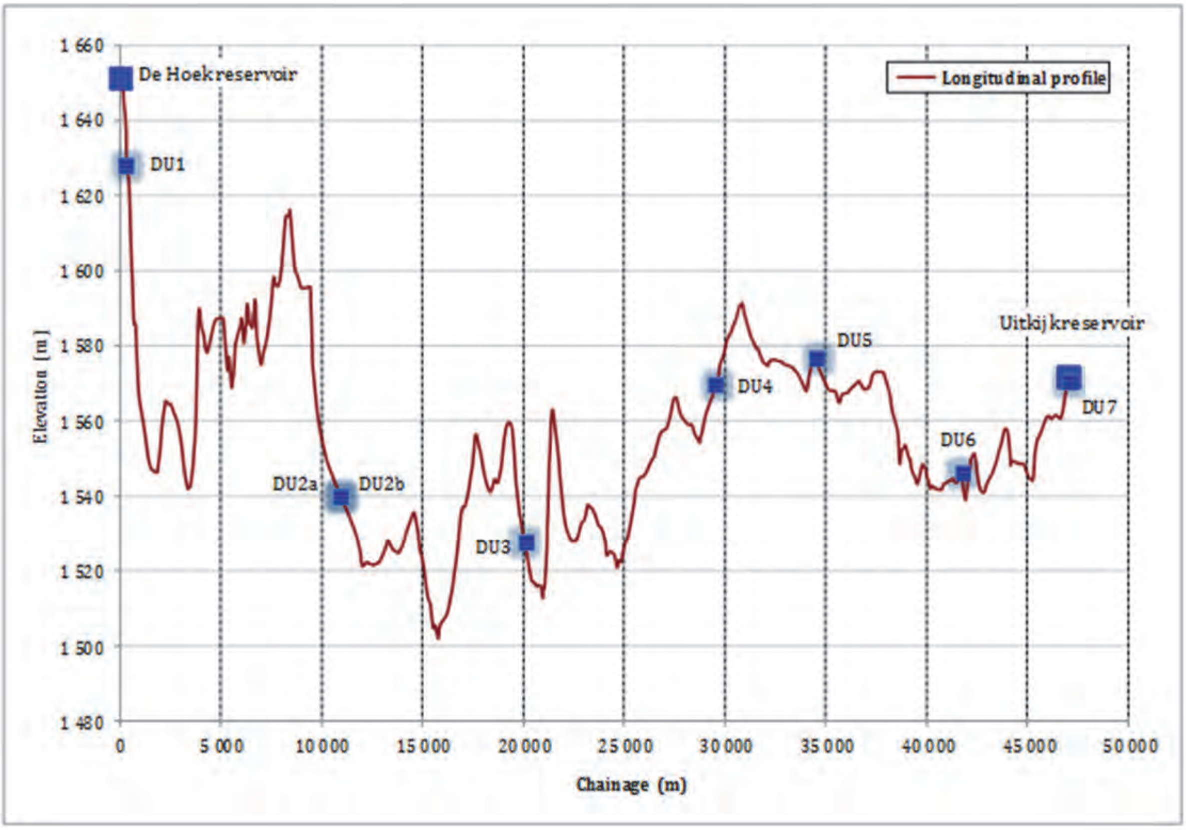


Figure 4-13: Location of measuring points (De Hoek – Uitkijk pipe segment)

Flow recordings were also obtained from the operation staff of Bloemwater.

Figure 4-14: Ultrasonic flow meter installation

A typical installation of a pressure transducer and data logger is shown in **Figure 4-15**, which is at DU7 at the Uitkijk Reservoir Pressure Control Station (air valve on manifold).

From the recorded flow and pressure recordings 5 distinct time periods were selected where pressures and flow could be compared between all the measuring points. **Figure 4-16** depicts the HGL's for different flow rates.

Figure 4-15: Setup of the pressure transducers at DU7

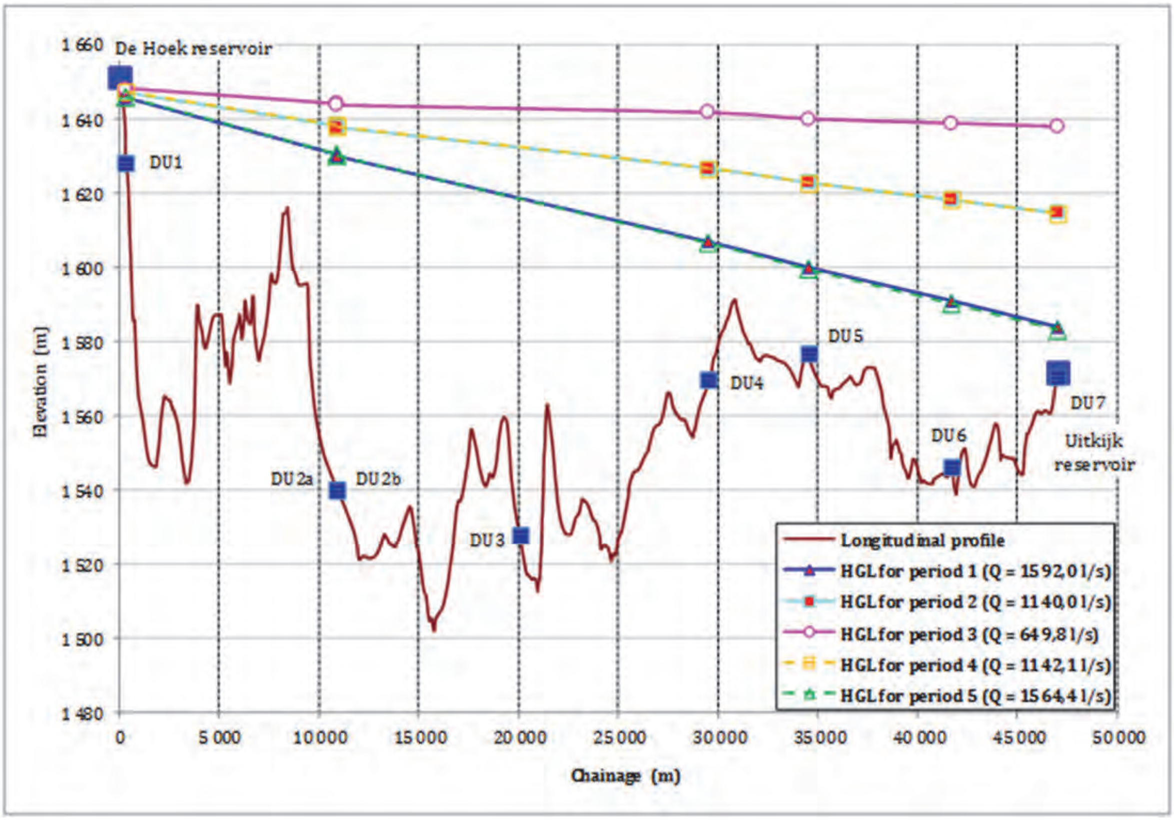


Figure 4-16: Hydraulic gradelines (discarding DU3)

The roughness was calculated for the various distinct discharge rates and is provided in **Table 4-3**.

Table 4-3: Calculated roughness parameters between DU1 and DU7

Parameter		Period 1	Period 2	Period 4	Period 5
Measured flow (l/s)		1592.0	1140.0	1142.1	1564.4
Calculated velocity (m/s)		1.485	1.063	1.065	1.459
Re		1 521 797	1 089 729	1 091 737	1 495 414
ΔH (m) – Between DU1 and DU7		61.755	32.433	32.787	62.724
H_L(m) – Total secondary losses		3.033	2.878	2.917	3.016
H_f (m)		58.722	29.555	29.870	59.708
S_f (m/m)		0.00126	0.00063	0.00064	0.00128
Friction factor (λ)		0.01308	0.01284	0.01293	0.01378
Absolute roughness – k_s(mm)	Kármán& Prandtl	0.184	0.167	0.173	0.238
	Colebrook-White transition	0.122	0.079	0.086	0.176
	Barr	0.114	0.073	0.080	0.167
	The Moody diagram	0.114	0.085	0.091	0.160
Manning – n ($s/m^{1/3}$)		0.0105	0.0104	0.0105	0.0108
Hazen-Williams - C		139.6	144.9	144.3	136.0

The velocity for Period 3 was low, resulting in friction losses of only 7.6 m. This result in an extremely flat hydraulic gradeline and it is subsequently difficult to accurately determine the roughness parameters with this data.

4.2.3.2 Uitkijk to Brandkop Reservoir

The hydraulic characteristics of the pipeline were obtained during field measurements on a separate study conducted for Bloemwater by the members of the project team.

Pressure transducers were connected to the pipeline at various locations (UB1 to UB8), see **Figure 4-17.** A PORTAFLOW (Fuji Electric) Ultrasonic Flow Meter was installed on the supply manifold, see **Figure 4-18**. Flow recordings were also obtained from the operation staff of Bloemwater. The data was obtained from the Magflow meter on the premises of Bloemwater just upstream of the inlet into the Brandkop Reservoir.

A typical installation of the pressure transducers and data loggers is shown in **Figure 4-19** which is at UB7 and UB8 at the Brandkop Reservoir.

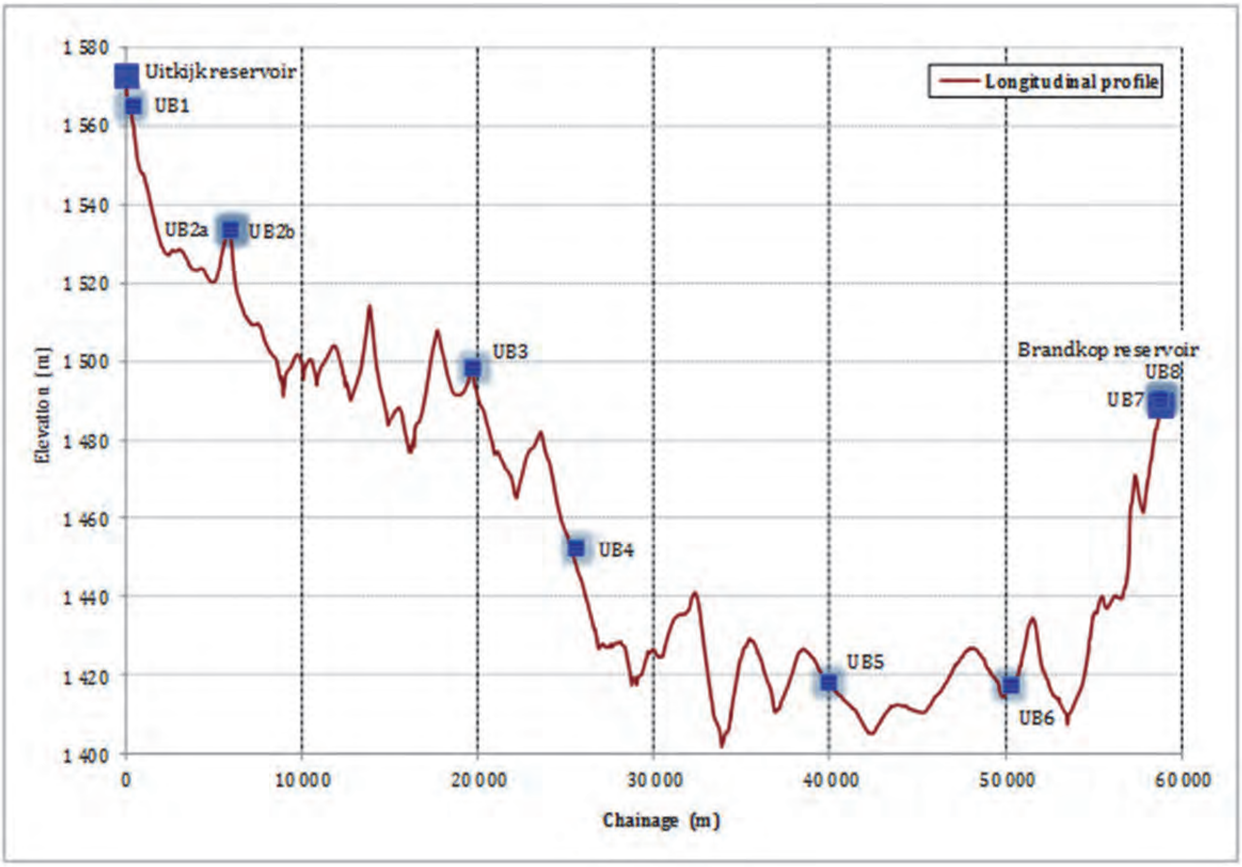


Figure 4-17: Location of measuring points (Uitkijk-Brandkop pipe segment)

Figure 4-18: Flow meter installation

Figure 4-19: Setup of the pressure transducers at UB7 and UB8 (at Brandkop Reservoir)

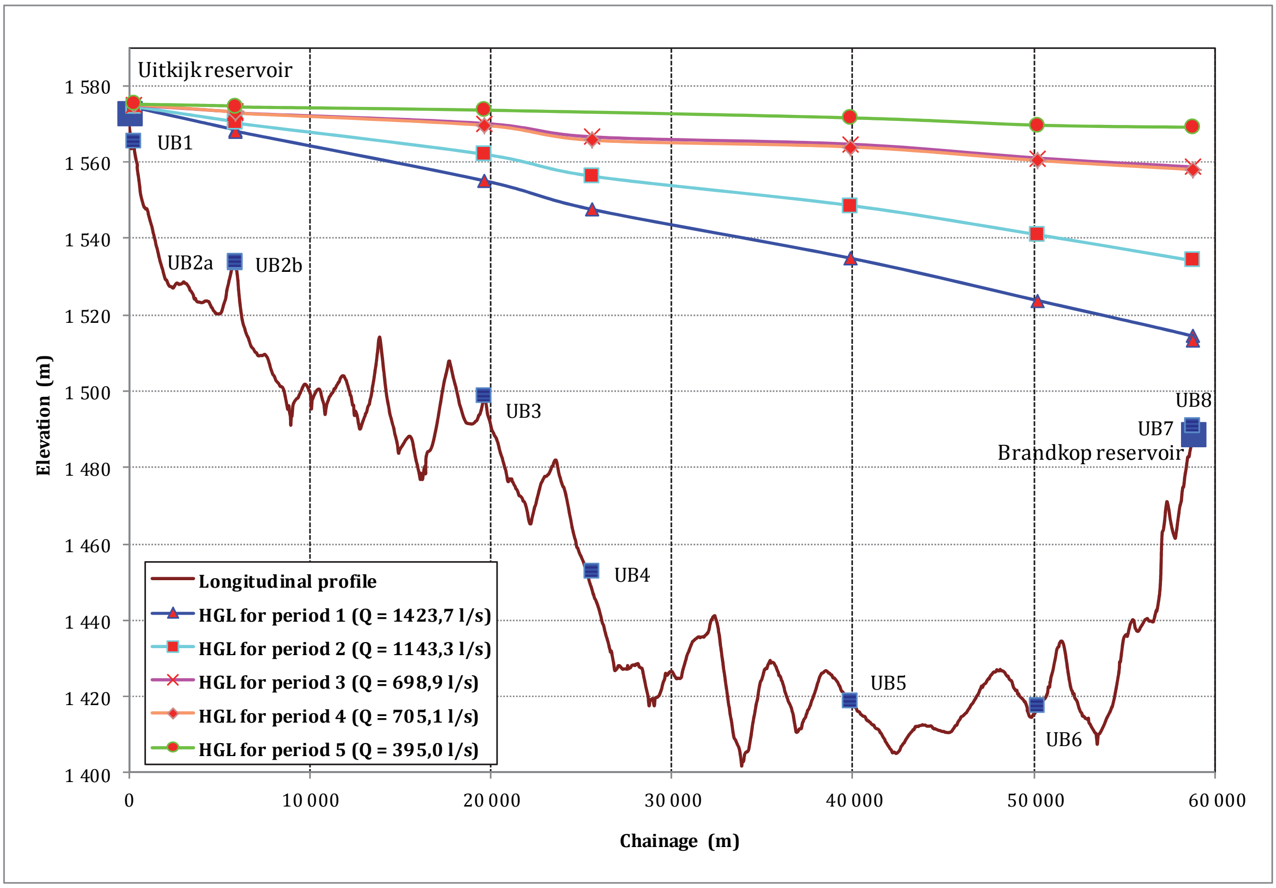


Figure 4-20: Combined graph with hydraulic gradelines

From the recorded flow and pressure recordings 5 distinct time periods were selected where pressures and flow could be compared between all the measuring points. The HGL's for the different flows are depicted in **Figure 4-27**.

The roughness was calculated for the various distinct discharge rates and is provided in **Table 4-4**.

Table 4-4: Calculated roughness parameters

		Period 1	Period 2
Flow (l/s)		1423.7	1 143.3
Velocity (m/s)		1.328	1.066
Re		1360919	1 092 884
ΔH (m)		60.950	40.243
H_L(m)		3.139	2.831
H_f (m)		57.811	37.412
S_f (m/m)		0.00099	0.00064
Friction factor (λ)		0.0129	0.0129
Absolute roughness – k_s(mm)	Kármán& Prandtl	0.168	0.171
	Colebrook-White transition	0.098	0.084
	Barr	0.091	0.078
	The Moody diagram	0.097	0.089
Manning – n ($s/m^{1/3}$)		0.0104	0.0105
Hazen-Williams - C		142.2	144.5

The velocities for Periods 3, 4 and 5 are low resulting in friction losses of only 13,681 m, 14,469 m and 3,768 m respectively. This result in extremely flat hydraulic gradelines and it is subsequently difficult to accurately determine the roughness parameters.

4.2.4 Historical flow and reservoir data

The in- and outflows from the three reservoirs on the Caledon-Bloemfontein supply system have to be balanced to ensure reliability of supply and the integrity of the pipe system. The monthly statuses, for the year 2011, of the three reservoirs are depicted in **Figure 4-21** to **Figure 4-23**.

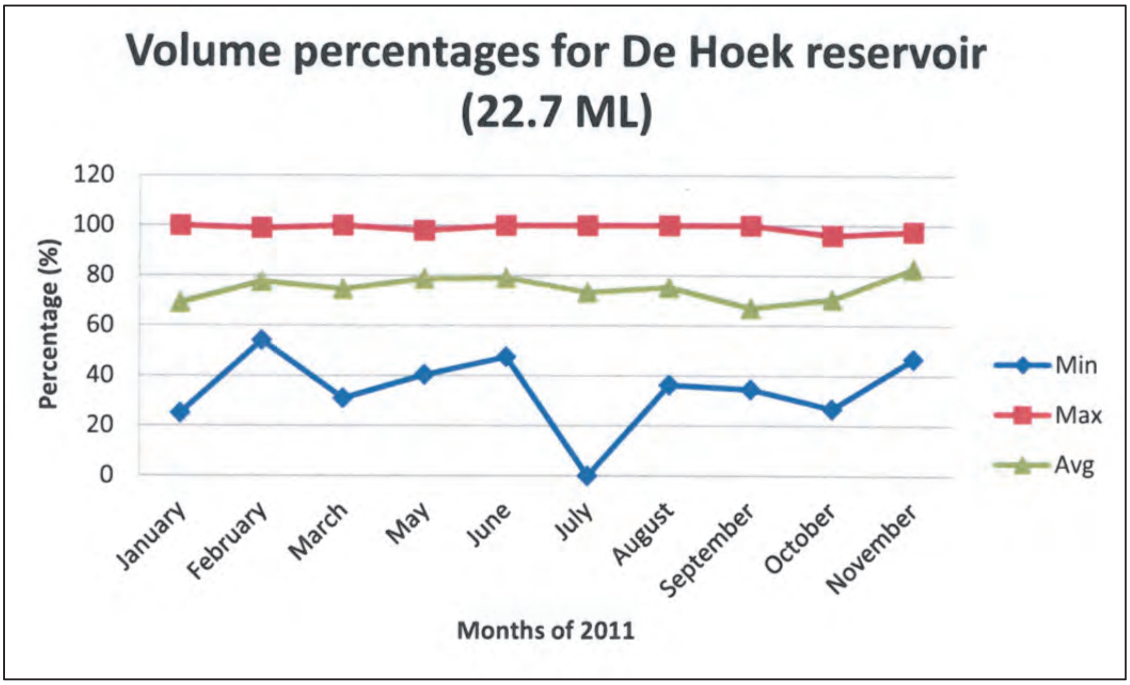


Figure 4-21: Status of De Hoek Reservoir

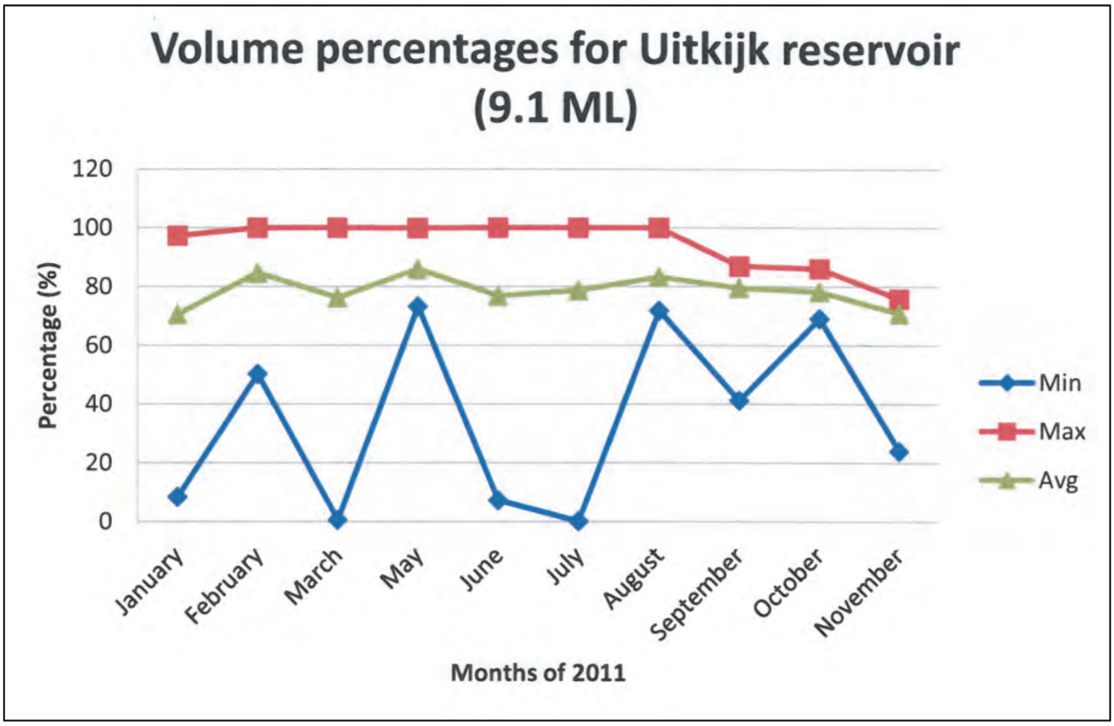


Figure 4-22: Status of Uitkijk Reservoir

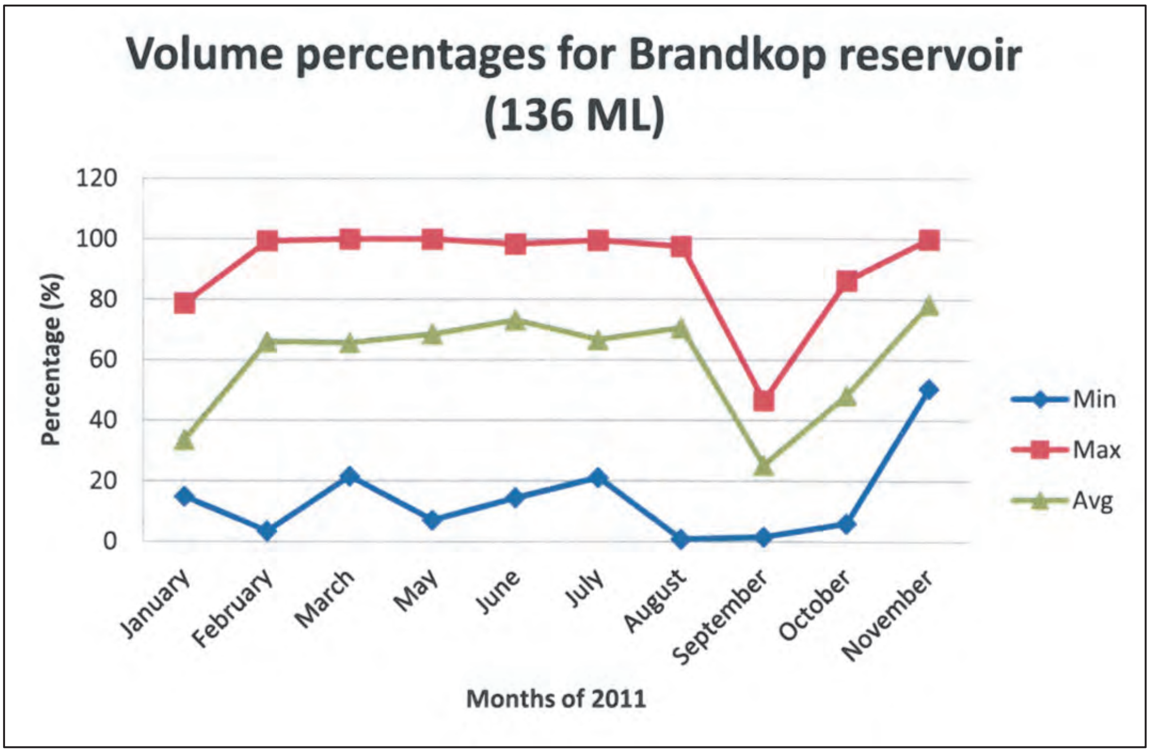


Figure 4-23: Status of Brandkop Reservoir

From the above figures it is clear that De Hoek, Uitkijk and Brandkop reservoirs were in 2011 on average 78%, 80% and 64% full respectively.

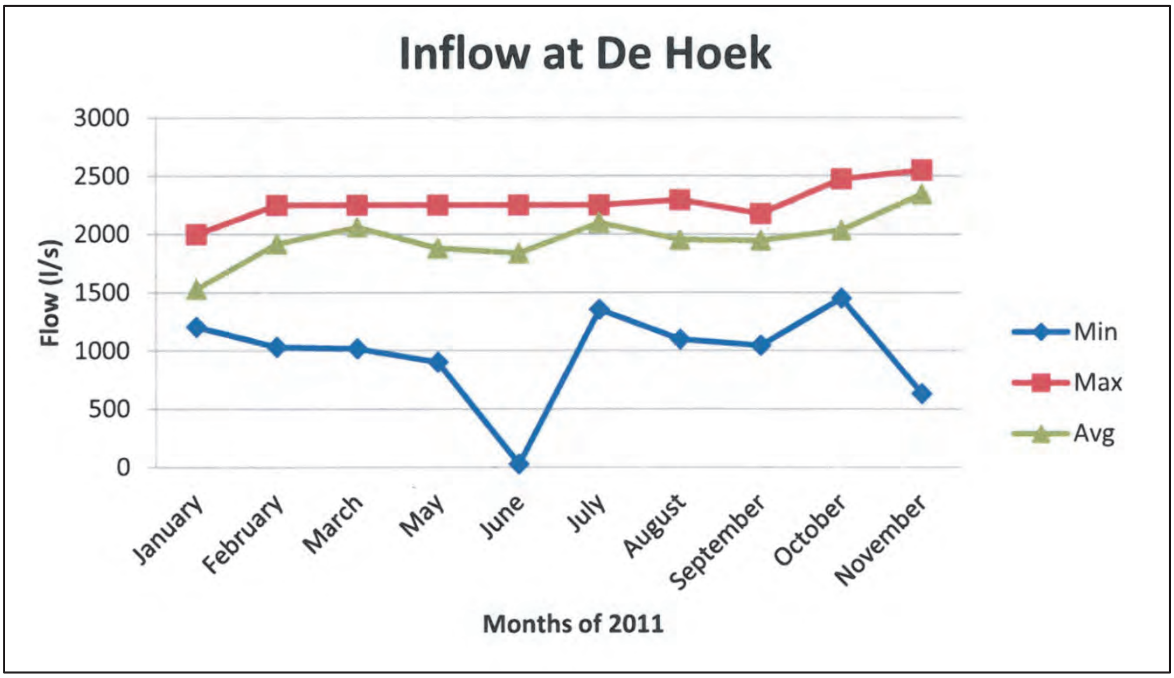


Figure 4-24: Inflow at De Hoek Reservoir

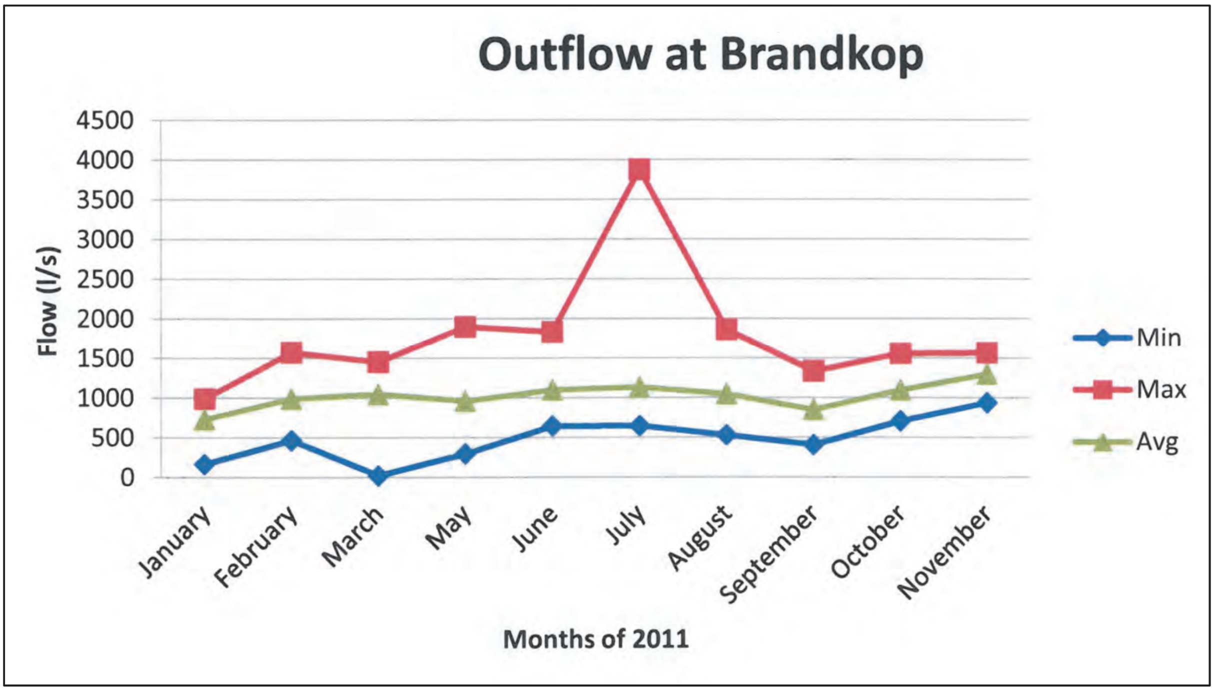


Figure 4-25: Outflow from Brandkop Reservoir

The average inflow at De Hoek reservoir was determined as 1959 l/s. This is however not the flow rate for 24 hours per day. The data was also used to determine the consumption at Brandkop. The Average Annual Daily Demand (AADD) was calculated as 1030 l/s. This information was used to determine a specification for selecting turbines suitable to operate in the calculated ranges.

As described in the above paragraphs 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.

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. 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.

A risk matrix will still be 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. Providing reliability of supply should be non-negotiable.

4.3 Conduit hydropower development options

The information above allowed the project team to provided Bloemwater with some development options.

Option 1: Construct a smaller pilot plant that would supply sufficient energy to provide the Bloemwater Head Office or site with electricity (initially thought that 32 kW would be required).

Option 2: Construct hydropower plants which will maximize income on this supply line (300 – 400 kW / site).

The Brandkop Reservoir had the following flow and head relationship:

- Maximum flow rate = 1.6 m^3/s
- Minimum operating flow rate = 0.6 m^3/s
- Average flow rate = 1.05 m^3/s
- Maximum pressure head 90 m (zero flow), not taking into account dynamic pressures.
- Pressure head of 78 m (at 0.6 m^3/s)
- Pressure head of 10 m (at 1.6 m^3/s), there are permanently installed orifice plates after PRVs
- Average pressure head of 46.5 (at 1.05 m^3/s)

The Uitkijk Reservoir had the following flow and head relationship:

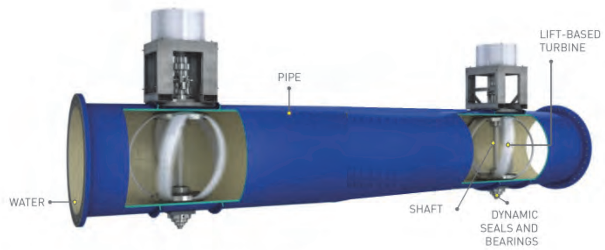
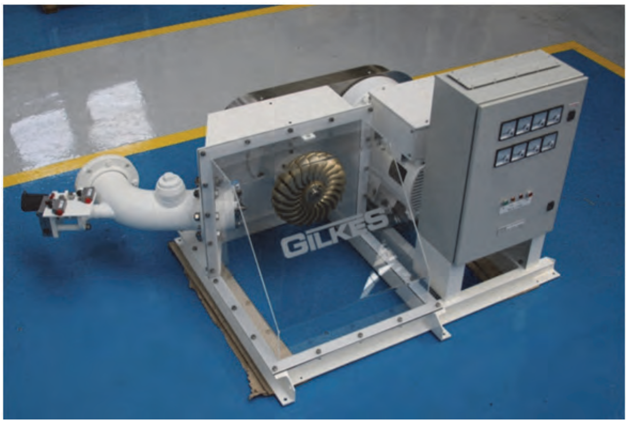
- Maximum flow rate = 1.6 m^3/s
- Minimum operating flow rate = 0.65 m^3/s
- Average flow rate = 1.05 m^3/s
- Maximum pressure head 80 m (zero flow), not taking into account dynamic pressures.
- Pressure head of 78 m (at 0.65 m^3/s)
- Pressure head of 10 m (at 1.6 m^3/s), there are permanently installed orifice plates after PRVs
- Average pressure head of 47.5 (at 1.05 m^3/s)

This information was used in identifying some alternative solutions for each one of the two development options.

4.3.1 Option 1 – Small pilot plant

The following options for the pilot plant development, **Table 4-5**, were investigated and presented to Bloemwater for consideration:

Table 4-5: Options for pilot plant development

Option	Picture
Option 1A - Cross flow (32 kW) Banki turbine with manual or automatic flow regulation. Three/single-phase, synchronous, self-exciting, brushless generator, with 4 poles, 400/230 Volt, 50/60 Hz. TBA models are equipped with three-phase asynchronous generators with 4 to 6 poles, 400/230 Volt 50/60Hz. DC electrically operated automatic main valve. Additional information is provided in **Appendix A**.	
Option 1B – LucidPipe (2 x 16 kW) Moving water turns the lift-based turbine, capturing excess head energy. Mechanical power is converted to electricity by the generator system. Power electronics create grid-ready, single, or three-phase power. This in-line turbine only has a small secondary head loss when not in operation. Additional information is provided in **Appendix A**.	
Option 1C - Turgo compact (32 kW) The Turgo turbine design is an impulse type machine with a higher specific speed than a Pelton. The design allows a larger jet of water to be directed at an angle onto the runner. The performance curve is flat giving high efficiency over wide flow and load variations. Smaller types such as "Plug-and-run" options are offered. Additional information is provided in **Appendix A**.	
Option 1D – Powerspout (10 x 1 kW) Pelton type turbine that can generate up to 1kW. A number of these turbines can be installed in parallel to utilize the potential at the site. Battery and grid enabled versions available. Additional information is provided in **Appendix A**.	

4.3.2 Option 2 – Large plants (maximum generation)

Turbine selection and pilot plant design

As a first order assessment of what turbines would be applicable for the range of flows to be expected on the two sites, the flow rates and heads were superimposed on typical selection diagrams, see **Figure 4-26** and **Figure 4-27**. A number of reliable suppliers were contacted to provide additional information regarding the selection of their specific turbines for both these sites.

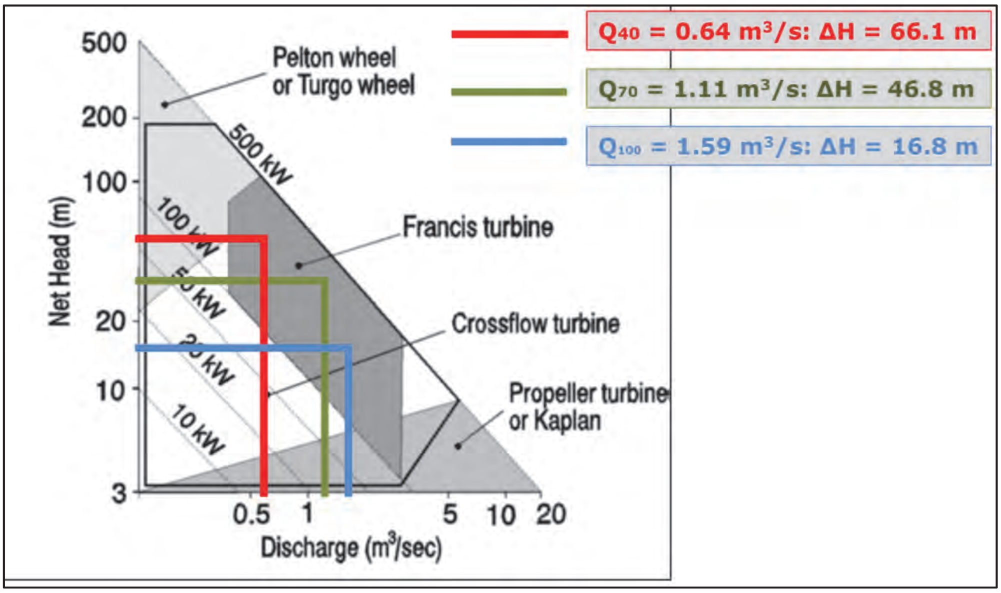


Figure 4-26: Selecting turbine for Uitkijk Reservoir site

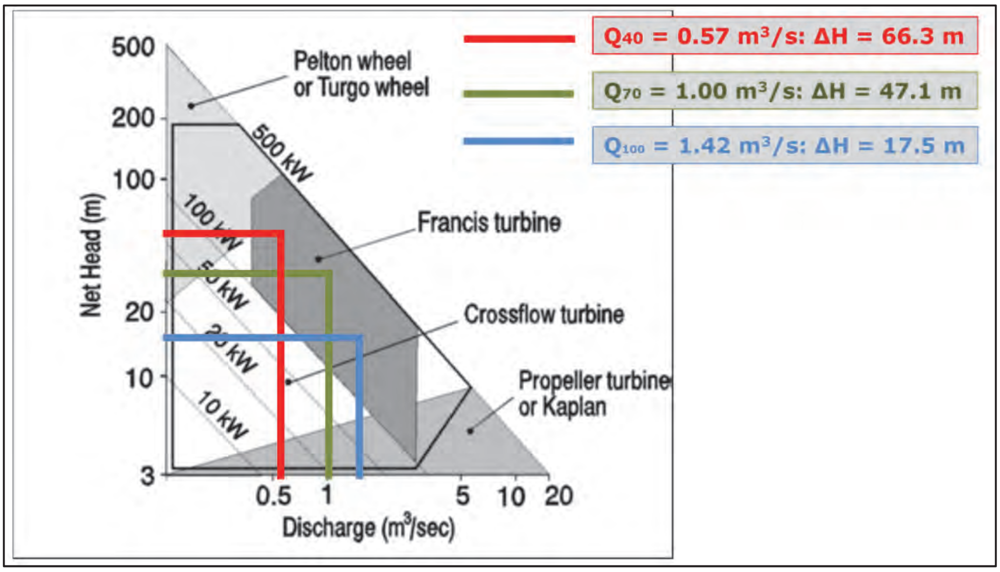
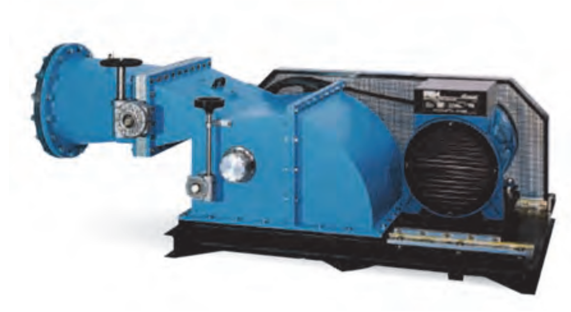
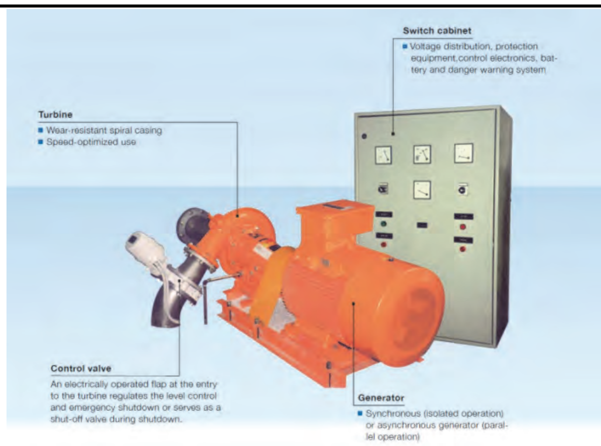


Figure 4-27: Selecting turbine for Brandkop Reservoir site

The following options for the large scale plant developments, **Table 4-6**, were investigated and presented to Bloemwater for consideration:

Table 4-6: Options for large plant developments (maximum generation)

Option	Picture
Option 2A - Cross flow (320 kW/site) Banki turbine with manual or automatic flow regulation. Three/single-phase, synchronous, self-exciting, brushless generator, with 4 poles, 400/230 Volt, 50/60 Hz. TBA models are equipped with three-phase asynchronous generators with 4 to 6 poles, 400/230 Volt 50/60Hz. DC electrically operated automatic main valve. Additional information is provided in **Appendix A**.	
Option 2B – Turgo (±400 kW/site) The Turgo turbine design is an impulse type machine with a higher specific speed than a Pelton. The design allows a larger jet of water to be directed at an angle onto the runner. The performance curve is flat giving high efficiency over wide flow and load variations. Additional information is provided in **Appendix A**.	
Option 2C – Pump as turbine (Up to 400 kW/site) Pump turbines offer robustness and wear resistance, high efficiencies, long life cycle and ease of maintenance seeing that they are similar to pump systems, known to water utilities. The pump as turbine plant has a compact design, suitable for isolated operation and for supplying to an existing power network. Additional information is provided in **Appendix A**.	
Option 2D – Francis (±380 kW/site) Francis turbines are used primarily for medium heads and large flows applications. Their special hydraulic characteristics result in relatively high-speed compact units. Additional information is provided in **Appendix A**.	

4.4 Brandkop hydropower development

The development process as illustrated in **Figure 2-8** was followed in developing the site at Brandkop reservoir. This required the following activities:

- Prefeasibility study and site evaluation
  - Pressure and flow measurements
  - Identifying the electricity use
  - Conceptual design of system (pipework, turbine room, transmission)
  - Preliminary costing
- Regulatory and permitting
  - NERSA licence application
  - Environmental impact assessment
  - Water use licensing
  - Public participation
  - Land ownership
- Detail system design
  - Dynamic analysis of pipeline system
  - Selection of turbine
  - Design of turbine room
  - Design of pipe and valve work
  - Optimisation of system
- Grid integration
  - Design of electric control boards
  - Design of regulator system
  - Design of electric transmission and grid connection
- Equipment procurement and construction
  - Equipment procurement
  - Construction of facilities
- Project and construction management
  - Overall project management
  - Site supervision
  - Commissioning and testing
- Operation and maintenance
  - Compiling of Operation and Maintenance manuals
  - Maintenance plan
  - Training
- Monitoring and evaluation
  - Recording of flow, pressure, energy, efficiency, reservoir levels etc.
  - Evaluation and optimising of plant operation

As indicated Bloemwater opted to develop Option 1 i.e. a hydropower plant that would provide sufficient electricity to the head office. The initial proposal for development was for a 32 kW unit.

For a couple of months pressure, flow and electricity consumption data at the proposed site was collected. As indicated the aim is to provide a hydropower generation facility to supply Bloemwater's offices with sufficient electricity.

Our initial estimate was in the order of ±R2 million for the implementation of the selected pilot hydro power scheme as presented during the CAPEX meeting. Thereafter more data was collected and some quotations for various turbine options were obtained. This allowed for the refining of the initial proposal and scope of work. These initial estimates came down but after collecting electricity consumption data this has increased again.

4.4.1 Electricity consumption data

Electricity consumption on the supply to the Bloemwater offices was recorded from 14 November 2012 up to 14 January 2013. **Figure 4-28** indicates the Kilowatt, Kilovolt-amperes, Kilovolt-amperes reactive and Peak Factor for this period.

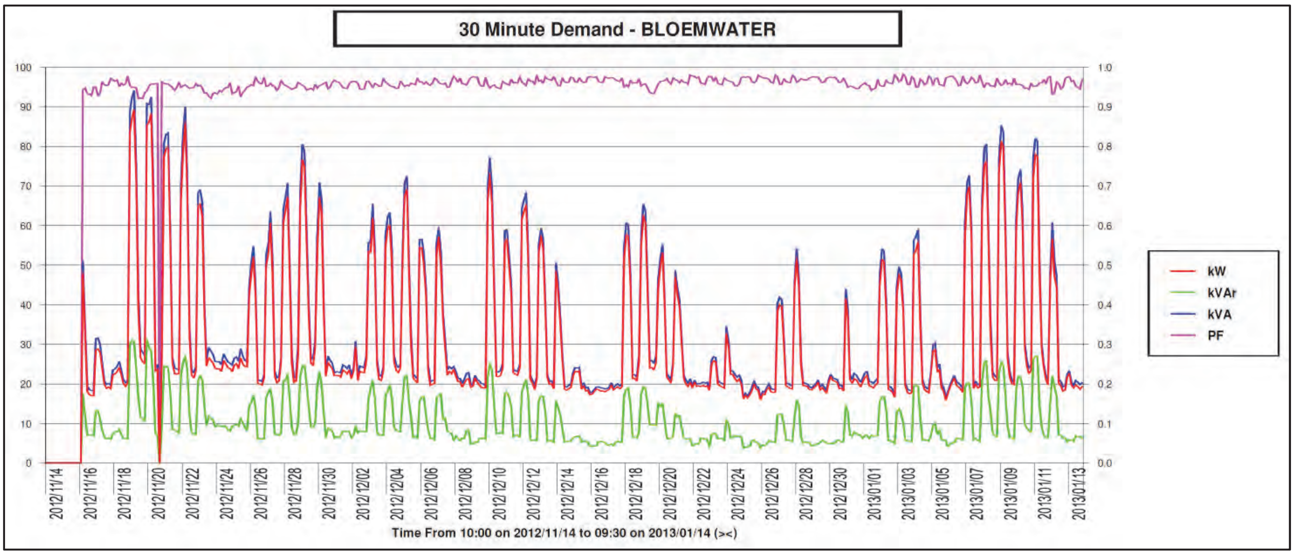


Figure 4-28: Electricity consumption data

Figure 4-28 provides some useful information regarding the electricity demand at the Bloemwater head office:

i) The 5 working days of the week are clearly visible.

ii) There is a constant base load of approximately 20 kW at the site. This is a constant demand as it is visible during weekends 24 hours of the day.

iii) The couple of days around Christmas the demand were significantly lower as to be expected.

iv) The highest recorded active demand was 89.2 kW on 15:00 on 2012/11/19

v) The highest recorded Kilovolt-amperes reading was 94.11 kVA on 15:30 on 2012/11/19.

The weekly averaged kilovolt-amperes values have been determined and are depicted in **Figure 4-29**. This indicates that the average kVA reading is between 50 and 60 kVA. This does however include the Christmas period where there were a number of low demands.

The demand frequency over the data recording period is shown in **Figure 4-30**. This is a very interesting figure since it for instance indicates that only 5% of the time the demand is greater than 65 kW. It also indicates that there is a high base load of approximately 20 kW. Again the data set does include the Christmas period where there were a number of low demands.

The sizing of the turbine unit as described later was based on supplying the full load.

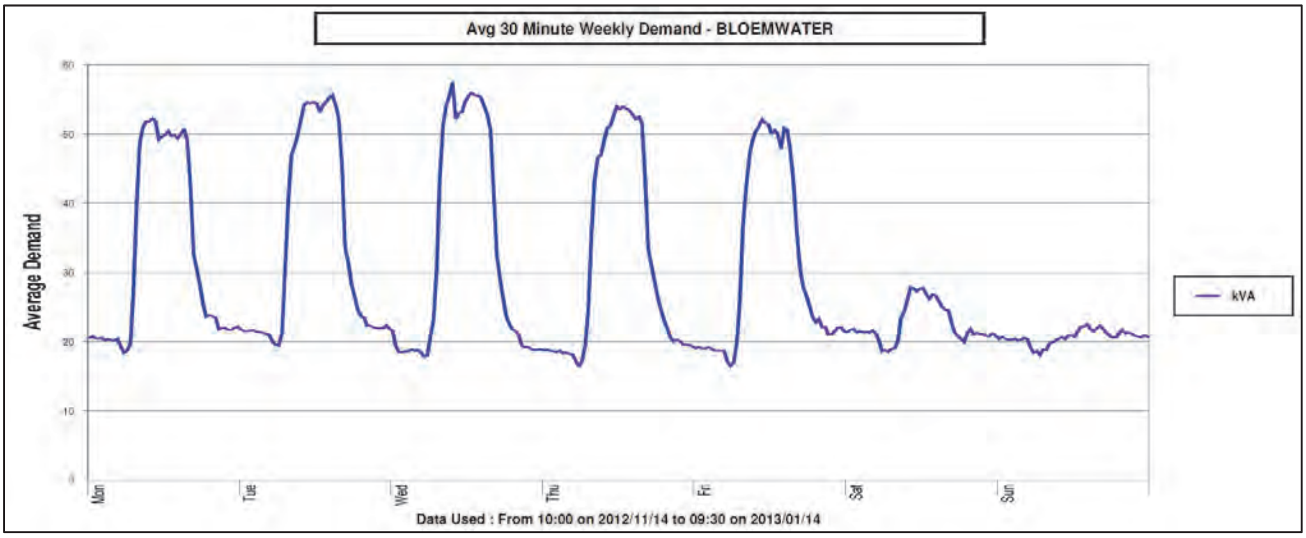


Figure 4-29: Weekly averaged kVA recordings

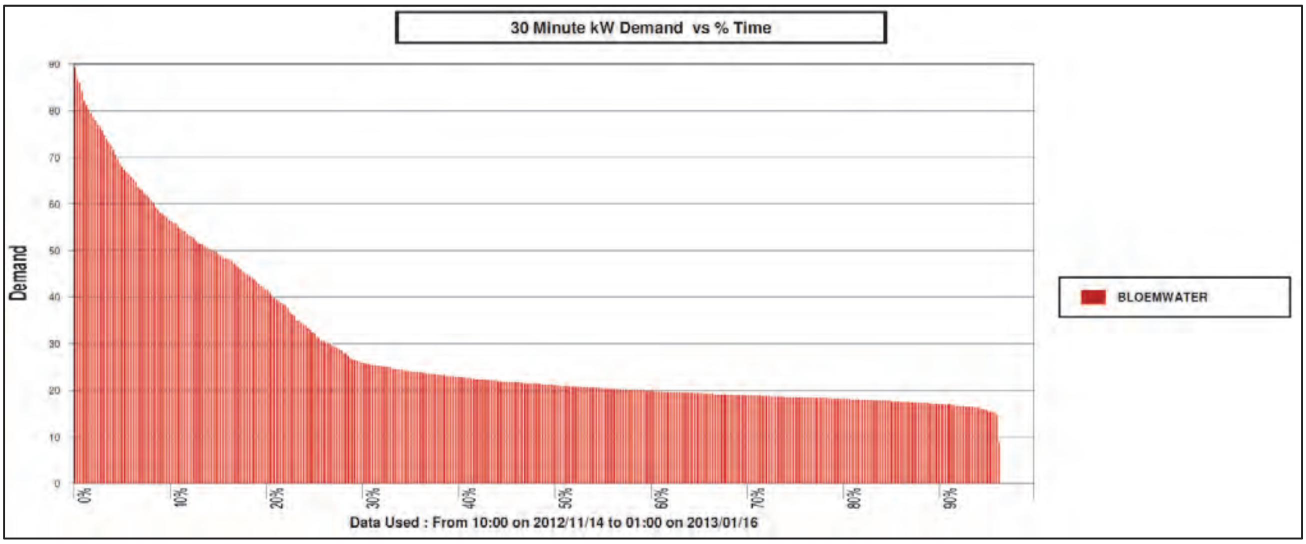


Figure 4-30: Demand frequency curve

4.4.2 **Pressure and flow data**

Two pressure transducers were connect at the air valve just before the T-piece at the proposed off-take point, see **Figure 4-31.** Data was recorded using two 10 bar absolute pressure transducers and a HOBO type industrial logger, shown in **Figure 4-32.** The period where valid pressure data was recorded at the site is from 12 – 21 December 2012 as shown in **Figure 4-33**.

Figure 4-31: Set-up point at upstream of T-piece at air valve

Figure 4-32: Pressure recording

The average pressure head for the first couple of days was 25.7 m. On the 13th of December 2012 at 12h30 the pressure head increased to 38.6 m and remained fairly constant until the 19th of December 2012. At 12h35 on the 19th it dropped to the lowest recorded pressure head of 12.8 m. These low pressures were only for approximately 2 hours before it increased again to a pressure head of 22 m. On the 20th of December the pressured head again increased to approximately 33.0 m with some short pressure spikes reaching a maximum of 54.5 m on the 21st of December.

Based on the pressure variation shown in **Figure 4-33** the theoretical power from a turbine with 70% efficiency, maximum pressure allowed of 40 m and a flow rate of 350 l/s is depicted in **Figure 4-34**. The average power generated is 79,4 kW for this 10 days of recorded pressure data.

From the previous studies that were performed it is known that for the pressure range at the Brandkop reservoir the flow rate would have varied between 0.6 and 1.4 m^3/s. This is more than the design flow rate of 0.35 m^3/s that will be by-passed through the turbine and into the reservoir.

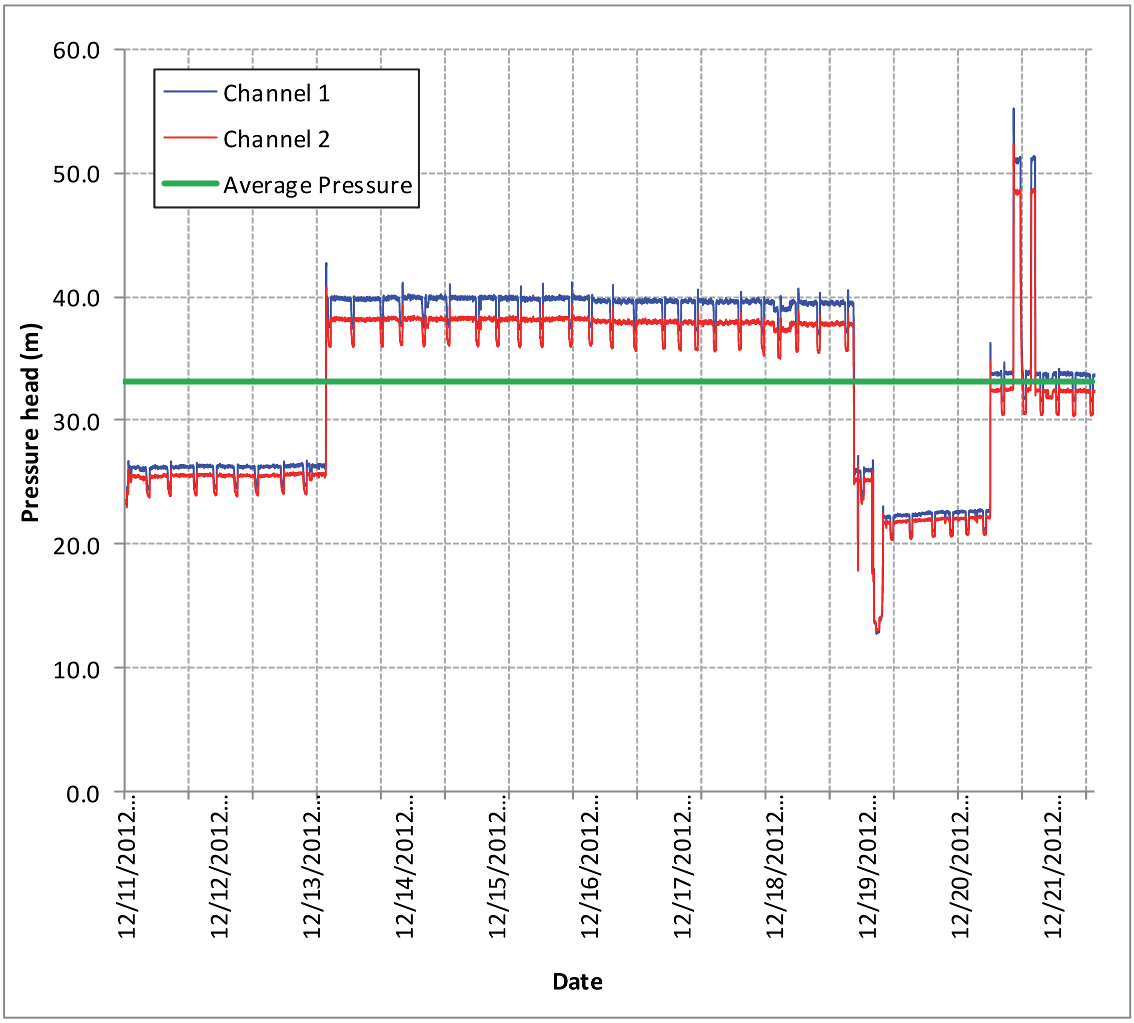


Figure 4-33: Pressure recordings at the proposed site

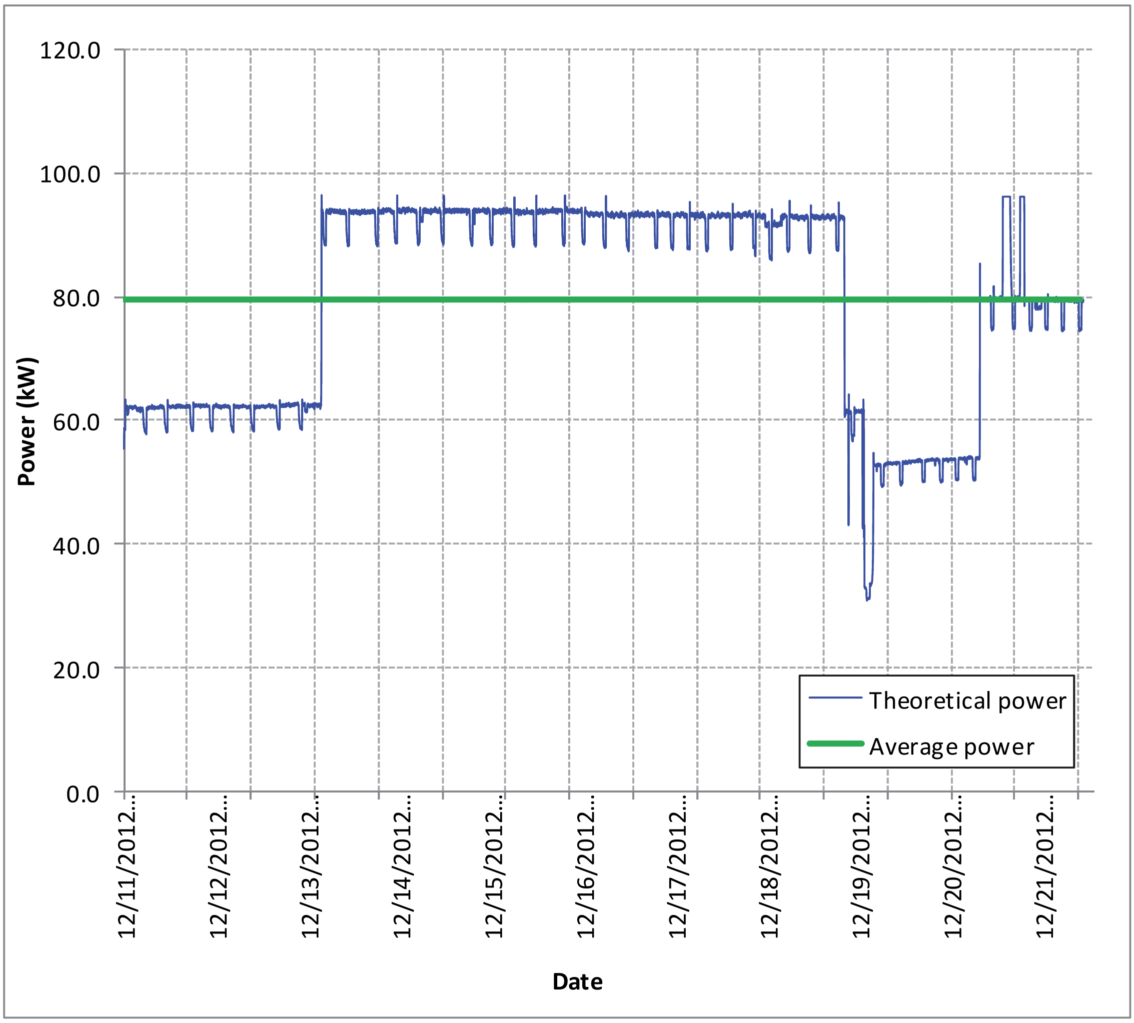


Figure 4-34: Generated power based on recorded pressure variation

4.4.3 Recommended hydroelectric plant

4.4.3.1 Turbine

Based on the potential lower heads at Brandkop during higher flow rates it was proposed to opt for a crossflow (Banki) turbine. The Banki turbine provides options for manual or automatic flow regulation from 0 to 100%. It was suggested to utilize a synchronous type brushless generator with 4 poles, 230 Volt, 50 Hz.

The turbine that has been selected is the IREM ECOWATT Micro hydroelectric power plant type TBS 4-0.5 with synchronous generator type AZ 100.

It was decided to include an automatically controlled shutoff valve with the guide vane. **Figure 4-35** indicates the selection chart indicating the type and size turbine that is suggested.

Originally the historical energy consumption suggested a 32 kW turbine installation should be sufficient. This estimate was however only based on the average monthly values and thus the daily peak values which have now been recorded indicate a significantly larger hydro plant i.e. 96 kW. The increased size is largely to accommodate the peak demand.

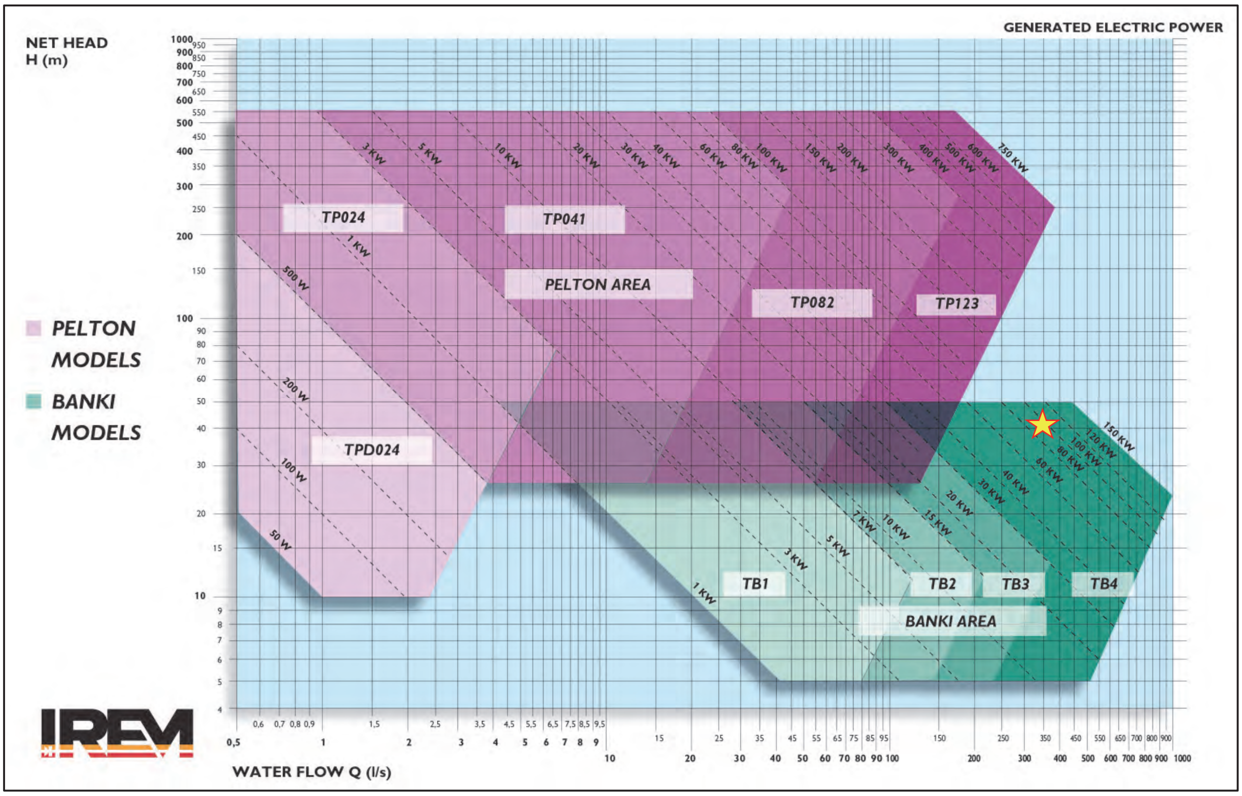


Figure 4-35: Turbine selection (96 kW)

4.4.3.2 Electronic regulators

Electronic Regulators are essential for dissipation of energy. Normally sufficient resistors are installed to take the full generating load. These are usually modular parts and can be connected together to provide the dissipating capability. It is suggested that water dissipation resistances be used (based on the size of resistors required), see example shown in **Figure 4-36**.

It is suggested to install an electronic regulating system consisting of 9 x RMP 12000/B i.e. with total capacity of 108 kW, supplied by IREM.

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

Figure 4-36: Resistor for water dissipation

4.4.3.3 Electric Boards

The electric control boards, **Figure 4-37**, provide the electric operation parameters of the plant. Three-single phase control boards fitted with instruments, alarms and protective devices.

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

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

Figure 4-37: Electric control board

It was suggested to install the IREM electric distribution board Mod. CT100.000 with a capacity of up to 100 kW. The integration of the generated electricity into the Bloemwater head office would still be investigated.

4.4.3.4 Turbine room and pipe and valve work

The most suitable location for the turbine installation would be in the south west corner of the Brandkop reservoir. This required an off-take from the main line with the turbine house and plant will be at ground level. The site location is illustrated in **Figure 4-38** with the off-take installed at the blank flange (**Figure 4-39**).

Figure 4-38: Hydropower plant location

Figure 4-39: Off-take point

The following pipe work and valves were required from the off-take point to the inlet to the turbine:

- 500 mm Ø stub (connection to blank flange)
- 90° bend (500 mm Ø)
- Isolating valve (500 mm Ø)
- 500 mm Ø distance piece (±800 mm)
- 500 mm Ø Equal T-piece (providing for air valve)
- 500 to 150 mm Ø reducer
- Isolating valve (150 mm Ø) for air valve
- 150 mm Ø air valve
- 500 mm Ø distance piece (±3000 mm)
- 2 x 45° bends (500 mm Ø)
- 500 mm Ø distance piece (±1618 mm)
- 500 mm Ø distance piece (4000 mm) with puddle flange
- 500 mm Ø distance piece (±1000 mm)
- 500 mm x 400 mm concentric reducer (at control valve), one end flanged
- 2 x 400 mm Ø VJ coupling
- 400 mm Ø distance piece (480 mm), one end flanged
- 400 mm Ø control valve (pressure and flow regulation)
- 400 mm Ø distance piece, one end flanged with puddle flange
- 400 mm Ø distance piece (2000 mm), one end flanged

As depicted on the drawings there is sufficient space to accommodate the turbine, control panel, regulators and tailrace chute (example shown in **Figure 4-40**).

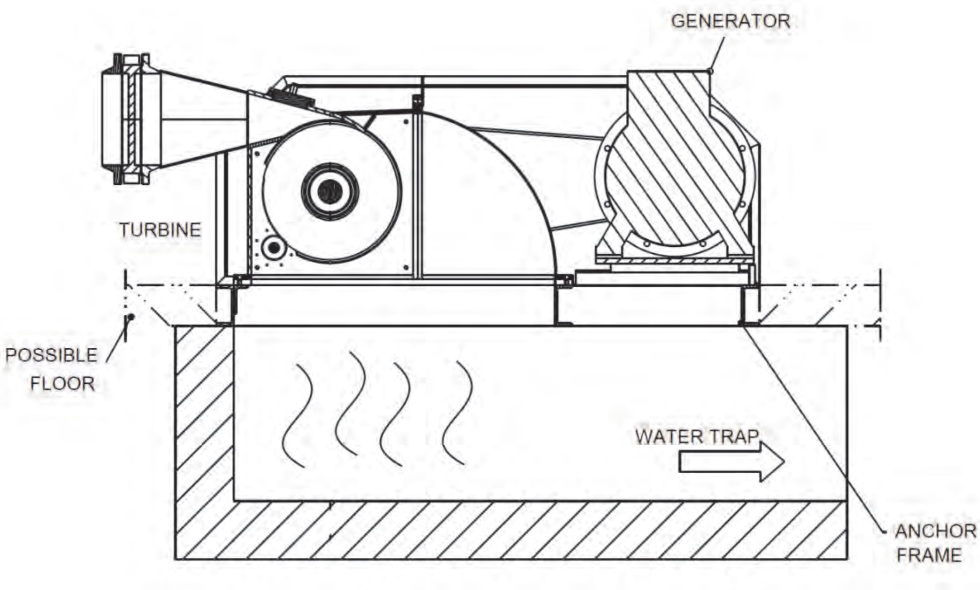


Figure 4-40: Turbine installation on chute

The turbine room drawings that were compiled are shown in **Figure 4-41** to **Figure 4-43**.

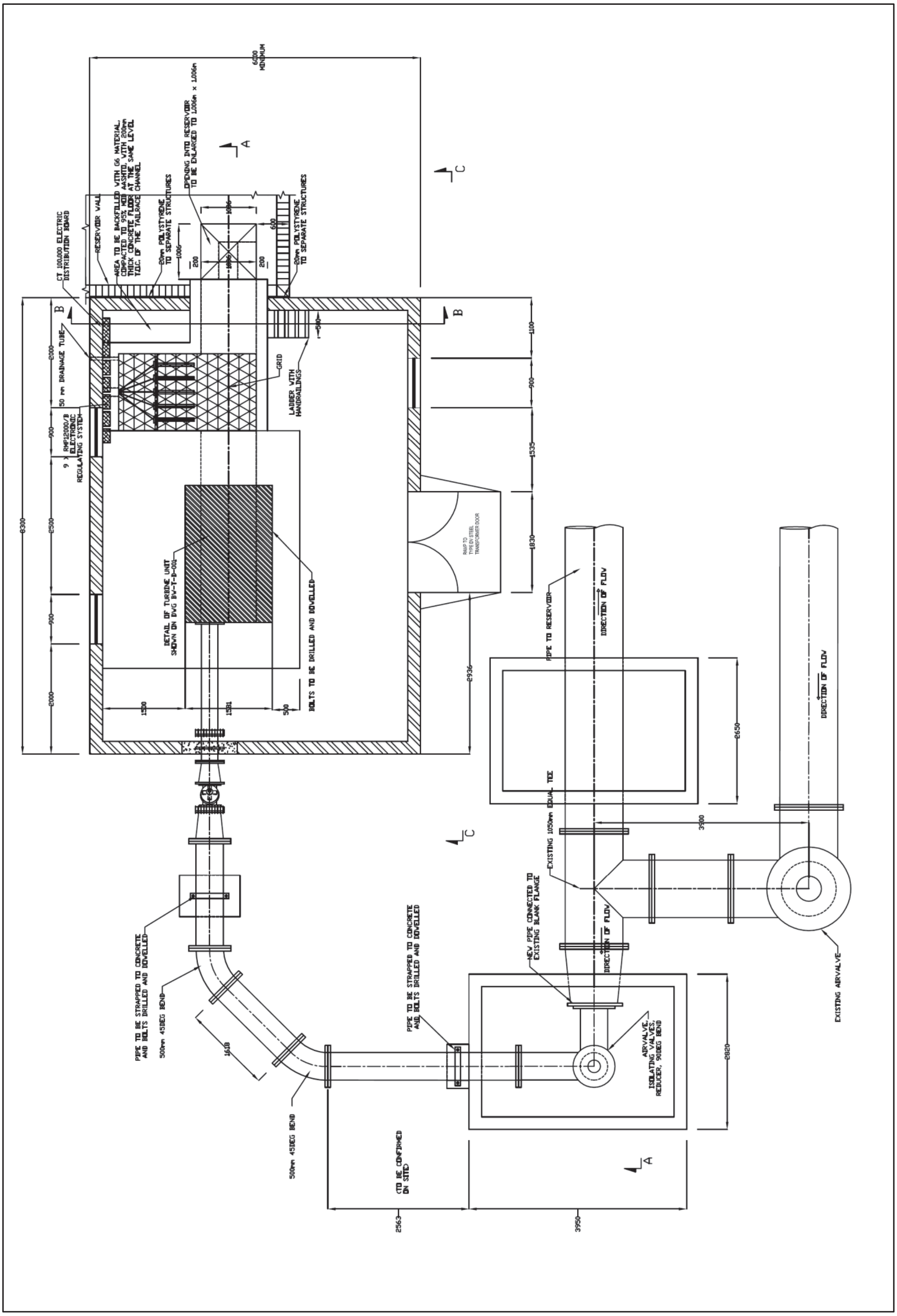


Figure 4-41: Plan view of turbine room

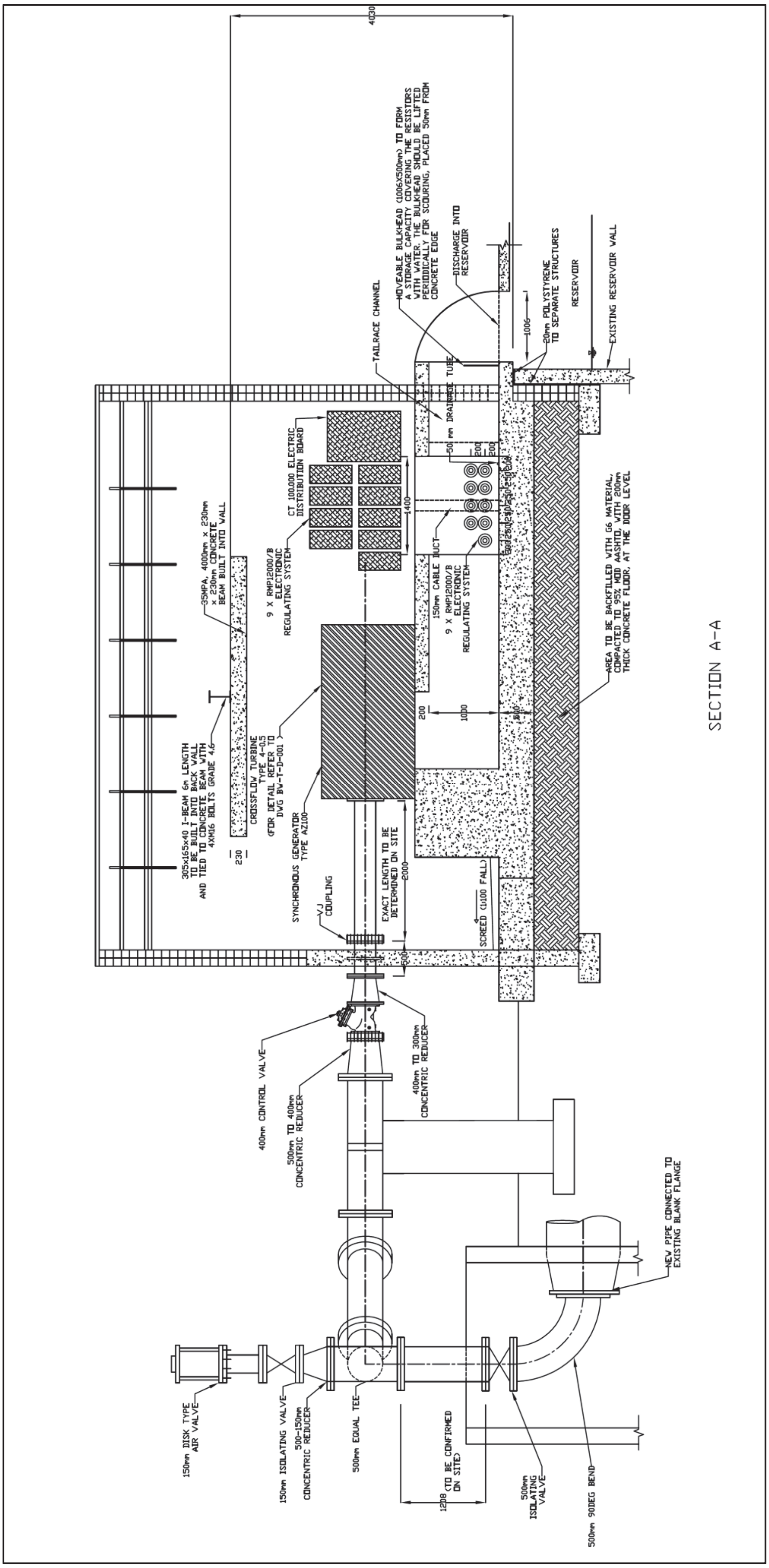


Figure 4-42: Side view of turbine room

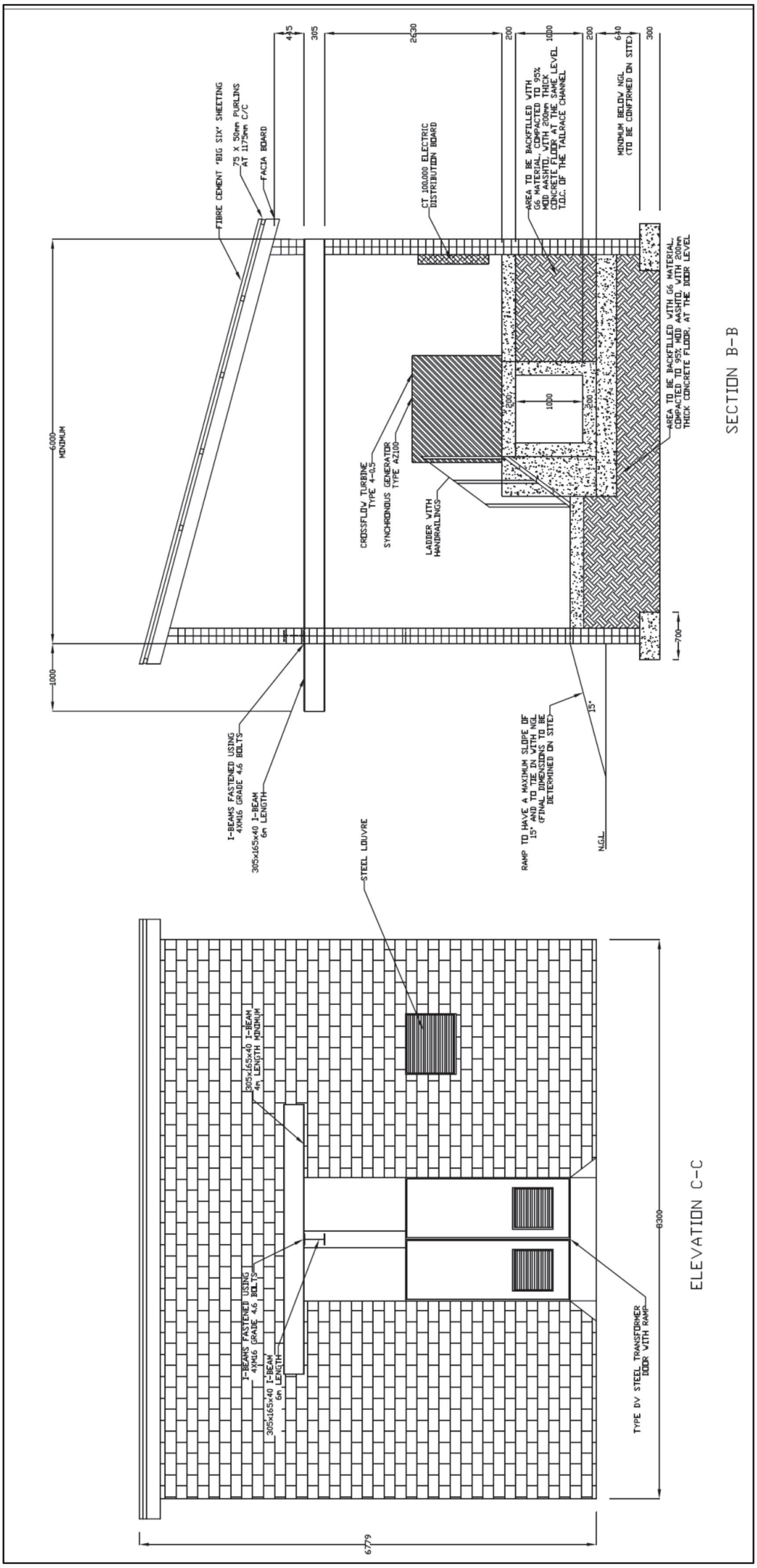


Figure 4-43: Turbine room

4.5 Constructing of the hydropower plant

Visual details of the progress on the construction of this hydropower pilot plant are shown in **Figure 4-44** to **Figure 4-61**.

Figure 4-44: Connection point

Figure 4-45: Recording electricity consumption of the Bloemwater head office

Figure 4-46: Turbine room foundation

Figure 4-47: Turbine room almost complete

Figure 4-48: Connection point fitted with reducer and isolating valve

Figure 4-49: offt-take connected to isolating valve

Figure 4-50: Air vakve on off-take for effective deaeration

Figure 4-51: Off-take linking into turbine room

Figure 4-52: Pressure/flow control valve regulating supply to turbine room

Figure 4-53: Pipeline upstream of turbine with ultrasonic flow meter

Figure 4-54: Crossflow turbine (belt driven)

Figure 4-55: Turbine and generator in position

Figure 4-56: Completed turbine installation

Figure 4-57: Turbine with automatic reguating valve

Figure 4-58: Control panel and regulator **Figure 4-59: Ultrasonic flow meter**

Figure 4-60: Outlet canal into reservoir **Figure 4-61: Turbine room with chute into top of reservoir**

4.6 Cost to project

Although no final total cost could yet be determined the main component costs have been summarized in **Table 4-7**.

Assuming a 7% discount rate on the investment of Bloemwater and the current spending of the Bloemwater head office on monthly electricity bills will result in a payback period of 72 months for this project i.e. approximately 6 years.

Table 4-7: Estimated cost of Brandkop Reservoir Conduit Hydropower Plant

Item	Description	Cost
Pressure and flow measurements	The available head versus flow relationship is required to select a suitable turbine.	R25 000
Electricity consumption data	A monitoring system was installed measuring the electricity consumption of Bloemwater head office. Peak electricity consumption and daily pattern is required.	R20 000
Dynamic analysis	A dynamic analysis is required to ensure the safe operation of the hydropower plant.	R40 000
Valve chamber	Modifications to existing valve chamber providing off take and valve chamber.	R40 000
Pipe and valve work	Supply and installation of off-take pipeline (500 mm diameter, 25 m long) including bends, isolating valve, reducers and pressure control/regulating valve (400 mm control valve).	R380 000
Cross-flow turbine	Manufacture and supply of cross-flow turbine with bottom outlet, synchronous 3-phase generator, electronic regulator and control panel.	R1 300 000
Electrical connection to BW offices	Providing and installing electrical cable connecting turbine room and BW head office (distance ±200 m). Modifications to electrical panels, switching between municipal and hydroelectric power.	R600 000#
Turbine room	The turbine, generator, electric control panel, monitoring equipment and regulator is housed in a brick walled lockable structure with safety signs, lighting, cameras etc.	R370 000
Monitoring system	Installing monitoring system of power output from generator, net power to the external load, system voltage, gross and net system current, status of all shutdown functions, system frequency, and turbine speed, and turbine guide vane position.	R20 000
Data logging and communication system	DataTaker DT85M logger with internal modem to capture data remotely installed in the Turbine room. Additional pressure transducers and data loggers were installed to record at existing pressure control station.	R40 000
Flow measurement	An ultrasonic FUJI flow meter was installed on the off-take to the turbine connected to the data logger.	R40 000
Design and implementation	Assistance with design, selection and implementation	R200 000
Total		**R3 075 000**

Final integration still to be finalized

Other alternative incentives have not yet been investigated such as the Integrated Demand Management from ESKOM. There are various initiatives aimed at optimizing energy use and balancing electricity supply and demand. For instance the Standard Offer which ESKOM promotes allows any energy user (customer), project developer or Energy Service Company (ESCo) that can deliver verifiable energy savings, from 50kW to 5MW, can propose projects, and if successful, will be paid the fixed amount per kWh over a period of three years. It is a performance-based programme for energy savings in the commercial, agriculture and small industrial sectors. The theoretical annual energy that can be generated with this plant is 837 500 kWh (based on average flow and pressure values).

5. NEWLANDS 2 RESERVOIR PILOT PLANT (ETHEKWINI MUNICIPALITY)

5.1 Introduction

The Project Team together with the Water Research Commission and the eThekwini Municipality implemented a conduit hydropower pilot plant installation in Durban. The site is located at the Newlands 2 Reservoir as indicated in **Figure 5-1**.

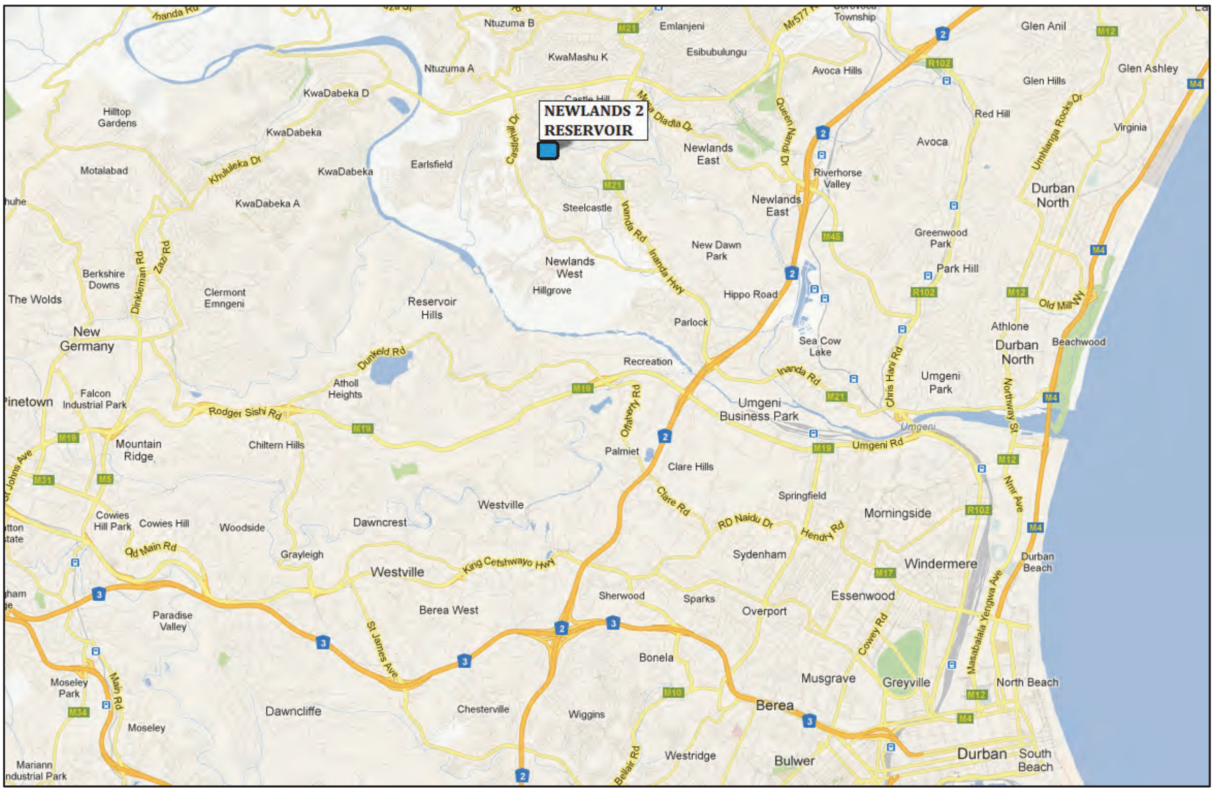


Figure 5-1: Location of site

The following is a summary of the hydro power plant:

- It is a demonstrative pico pilot plant.
- The turbines and equipment is housed in a steel, lockable container.
- A bypass line is installed from the pressure reducing valve chamber up to the turbine room (container).
- A Powerspout BE Micro Hydro Pelton System connects to an islanded grid (1 kW).
- A Powerspout GE Micro Hydro Pelton System connecs to eThekwini'sMunicipal 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) with Outback charge controller – FM60.

5.2 Design aspects and construction of pilot plant

The following was aspects which required exploration for such an installation:

- Pressure and flow data gathering;
- Site location selection;
- Turbine selection;
- Layout and design; and
- Interconnectivity with electricity.

5.2.1 Pressure and flow measurements

This was not really required for the planned installation since it was not planned to utilize the full generating potential at this site. Personal communication indicated that the pressure is approximately 60-70 m. It is assumed that 4.5 bar will be sufficient and approximately 10 l/s pass through the turbines.

5.2.2 Selection of turbine

The selected turbine was chosen as this type of turbine installation might be useful for other reservoir installations in the eThekwini Municipality's Water Distribution Network. The selected Powerspout Pelton turbine is shown in **Figure 5-2**.

Figure 5-2: PowerSpout Pelton turbine

The full generating capacity at the site is much higher than the ±2 kW installed system. As the intention was that this is only a demonstrative plant, the concept was to demonstrate grid connection as well as islanded system and thus two ±1 kW units were placed in parallel similar to the installation depicted in **Figure 5-3**.

Figure 5-3: Example of Powerspout turbines installed in parallel

The turbines are mainly for demonstrative purposes and thus one unit was selected which was connected to the municipal grid in a setup similar to that depicted in **Figure 5-4**. The second was connected to an islanded system for the site's energy needs, see setup in **Figure 5-5**.

5.2.2.1 Powerspout GE system

As indicated one unit, a PowerSpout GE, is connected to the municipal grid in a setup similar to that depicted in **Figure 5-4**.

The PowerSpout GE is designed to be connected to a grid-tied inverter to feed hydro generated power into the national grid. The PowerSpout GE has built in electronics to limit its output voltage to less than 400 V DC. The PowerSpout GE can be used in off-grid mini-island situations. Grid tied inverters include a MPPT function which automatically optimizes the PowerSpout GE for maximum electrical output.

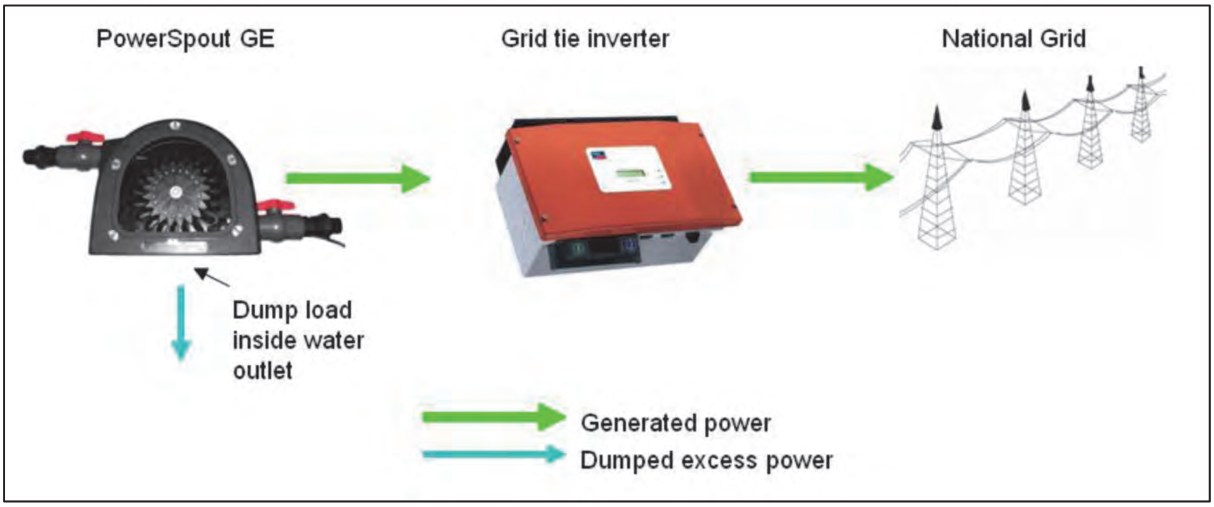


Figure 5-4: PowerSpout GE system setup

5.2.2.2 Powerspout BE system

The second, a PowerSpout BE, connects to an islanded system for the site's energy needs, see setup in **Figure 5-5**. The PowerSpout BE is the most common version installed. It connects directly to a battery bank with a diversion load controller for system regulation (in this case on this site a water dissipation regulator).

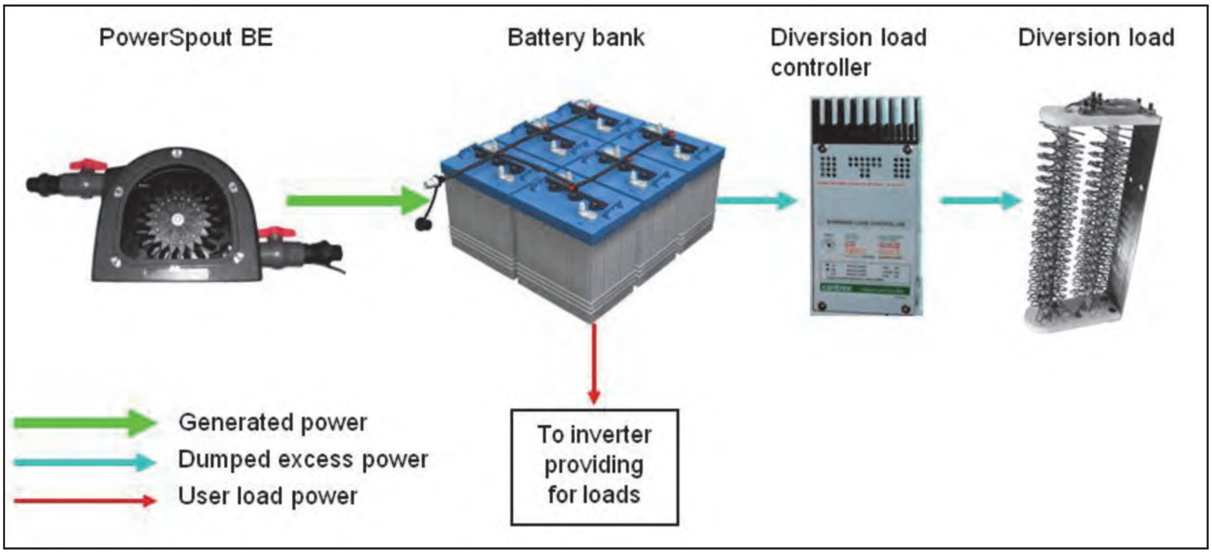


Figure 5-5: PowerSpout BE system setup

5.2.3 **Regulators**

Electronic Regulators are essential for dissipation of energy. Normally sufficient resistors are installed to take the full generating load. These are usually modular parts and can be connected together to provide the dissipating capability.
In this installation water dissipation resistances is used (based on the size of resistors required), see example shown in **Figure 5-6**.

Figure 5-6: Resistor for water dissipation

A diversion load is required to dissipate excess power. Typically, with micro-hydro units diversion occurs regularly due to the constant power generation and hence it is advantageous to divert to a hot water heater element (special element required) to make use of this excess power.

Some regulators also contain programmable relays that allow 230/240/110 V AC loads to be turned on when there is surplus power. For example, when there is excess power, a water pump or water heater can be turned on to soak up this surplus.

5.2.4 Dynamic analysis

The water supply to these units is small compared to the total flow into the reservoir. No dynamic analysis was performed but it is believed that no surge pressures are being generated by the operating of the proposed turbine units.

5.2.5 Location of hydro power plant

The project team considered a possible location for the turbine room as shown in **Figure 5-7**, **Figure 5-8** and **Figure 5-9**. An off take parallel to the existing supply to the reservoir supplies the hydropower plant. As shown in **Figure 5-9** the off take is made at the Pressure Reducing Station (PRS) chamber in the North-West corner of the property.

Figure 5-7: Aereal view of Newlands 2 Reservoir site

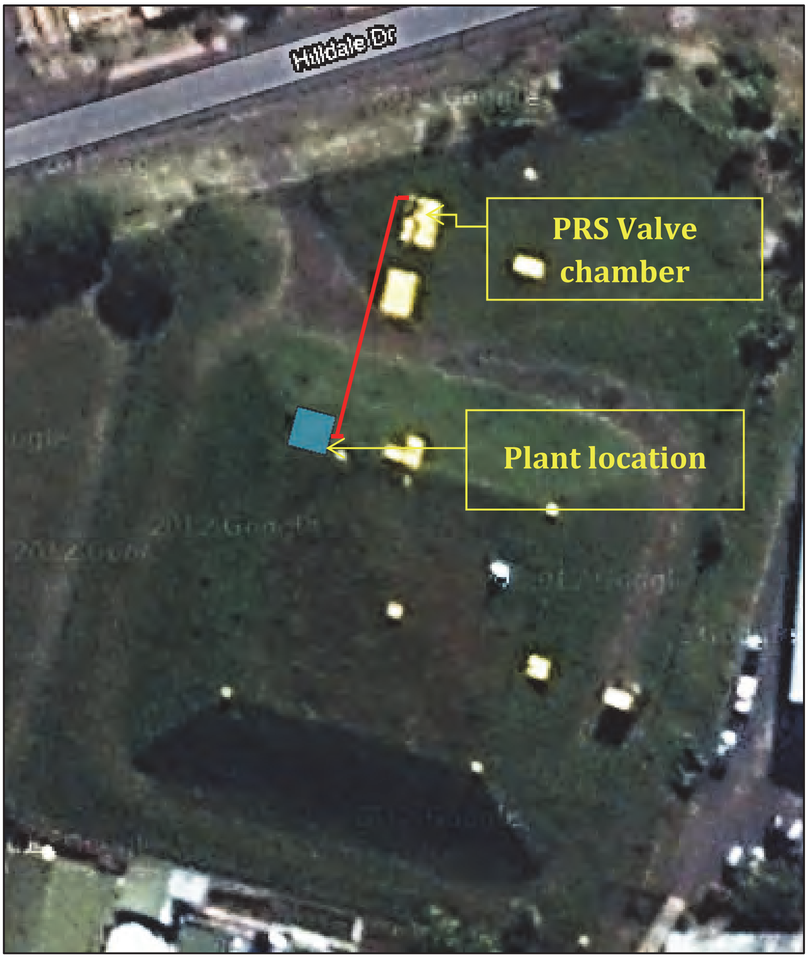


Figure 5-8: Pilot plant layout (pipe excavation in red)

Figure 5-9: Pipe excavation (red) and location for pilot plant

5.2.6 Pressure Reducing Station Chamber

The Pressure Reducing Stations (PRS) consists of a set of 150 mm diameter pressure reducing valves (PRVs) (see **Figure 5-10**). There are a number of cross connections in the PRS chamber which allows for operational flexibility (**Figure 5-11**).

Figure 5-10: Pressure Reducing Valve (PRV)

Figure 5-11: Cross connections in the PRS chamber

5.2.7 Reservoir inlet

After the energy has been dissipated through the PRVs the water is discharged into the top of the reservoir (see **Figure 5-12**).

Figure 5-12: Discharge point into the top of the reservoir (photograph taken before constructed hydropower station)

Due to the pilot plant only using a portion of the available potential a parallel pipe was constructed to supply the plant with sufficient pressure and flow for generating ±2 kW (two units of ±1 kW each). It was originally planned to provide for an off take inside the PRS with the off-take having an isolating valve and a separate PRV in order to control the pressure delivered to the pilot plant. **Figure 5-13** indicates the initially planned location of the off-take inside the PRS chamber.

It was however easier for the construction team to connect to the main supply line outside the PRS chamber as indicated in **Figure 5-14**.

Figure 5-13: Initially proposed location of off-take within PRS chamber

Figure 5-14: Connection point (off-take from main supply with isolating valve)

5.2.8 **Pipe and valve work**

From the off-take to the inlet of the turbine the following was required:

- 3x90 degree pipe bends (90 mm);
- 2x90x80 reducers for control valve;
- 80 mm Control valve (pressure reducing);
- Isolating valve (90 mm);
- Steel pipe for connections (90 mm); and
- HDPE or steel pipe, 50 m (90 mm).

All the pipe work within the turbine room is PVC pipe to be compatible with the turbine connections. After the control valve the 90 mm diameter inlet pipe connects to a T-Piece which splits into two 50 mm pipe sections. On each of the legs another T-Piece allowed for a pipe section to be built over the turbine as the turbine makes provision for connections on both sides simultaneously.

Before installing the plant in Durban the system was setup at the University of Pretoria's hydraulic laboratory as shown in **Figure 5-15**.

Figure 5-15: Pipework setup

5.2.9 **Turbine room**

The type of turbine selected is Pelton and thus this needs to be installed at a level higher than the water surface in the reservoir, impulse turbine discharging to atmospheric pressure. A concrete platform, 3 m by 3 m, was constructed by eThekwini Municipality on the North-West corner of the Reservoir as shown in **Figure 5-16**. At this corner of the reservoir there is an air vent. The hydro plant outlet is connected to this air vent on the North-West corner of the reservoir. For this a hole was made into the concrete air vent wall as shown in **Figure 5-17**.

Figure 5-16: Concrete floor for hydropower plant

Figure 5-17: Connnection into air vent

On this platform a steel container (3m x 3m x 2.49m), **Figure 5-18**, was placed which houses the turbine and electrical equipment. A duct was cast into the floor for connecting the electrical cables to the grids.

Figure 5-18: Turbine room (steel container) and connection point

Inside the turbine room a platform (table) was constructed on which the two turbines could be mounted as shown in **Figure 5-19**. The table was covered with fibre glass in case of any spillage. Underneath the table a wooden box (**Figure 5-20**) lined with fibreglass was installed. The two turbines discharge as shown in **Figure 5-21**, through openings in the platform into the collection box. The water is then discharged via a PVC outlet pipe (160 mm diameter), through the container wall and into the air vent where an opening was made (see **Figure 5-17**).

Figure 5-19: Turbine base platform

Figure 5-20: Collection box (underneath turbines)

Figure 5-21: Installed turbines in turbine room

The flow meters and individual isolation valves are placed on each turbine leg inside the turbine room.

5.2.10 **Assembling the PowerSpout turbines**

5.2.10.1 Installing bearing block, shaft and slinger

The turbine casing already has the bulk head attached. The stainless steel fixings from the bearing block and all other items were removed until one only have the bearing block, and installed shaft remaining.

Figure 5-22: Assembling of the seal into top cap and attaching to bulk head

From the back of the turbine casing (with the circular opening where the end cap attaches) the bearing block was inserted and aligned as shown in **Figure 5-22**.

5.2.10.2 Jet size

The jet-sizing tables supplied by the manufacturer enabled the determination of the approximate jet size required for the specific site i.e. at the head and available flow rate. Although it was not required at the Newlands site the plastic tapering jets can be cut on site with a sharp knife, see **Figure 5-23**. The jets are inexpensive so a trial and error approach can quickly determine the correct jet size. The manufacturer indicates that it is important to cut the jet to the correct size cleanly so that the water jet can break smoothly without spray. By holding the plastic jet within a spare holder sleeve and end cap will ensure that the jet is held firmly while cutting to size.

Figure 5-23: Cutting the jet to size and checking it with the taper gauge

5.2.10.3 Installing jet assemblies

The jet assembly was installed as shown in as shown in **Figure 5-24**. The PVC jet sleeve was mounted inside the turbine with the PVC ball valve on the outside. There is also a Jet 'O' ring which fits on the jet sleeve thread after being inserted into the casing. This 'O' ring ensures the valve and jet sleeve seals onto the casing and does not leak. The 'O' ring is on the outside of the casing.

Figure 5-24: Jet assembly in position

5.2.10.4 Installing the Pelton rotor

It is important to mount the Pelton rotor in the correct way. The water jet should hit the splitter (the straight knife edge) of the Pelton spoons. A bolt, spring washer and washers are installed to ensure that the centre of the jet aligns with the splitter of the Pelton spoons. The Pelton rotor was then attached to the shaft as shown in **Figure 5-25**.

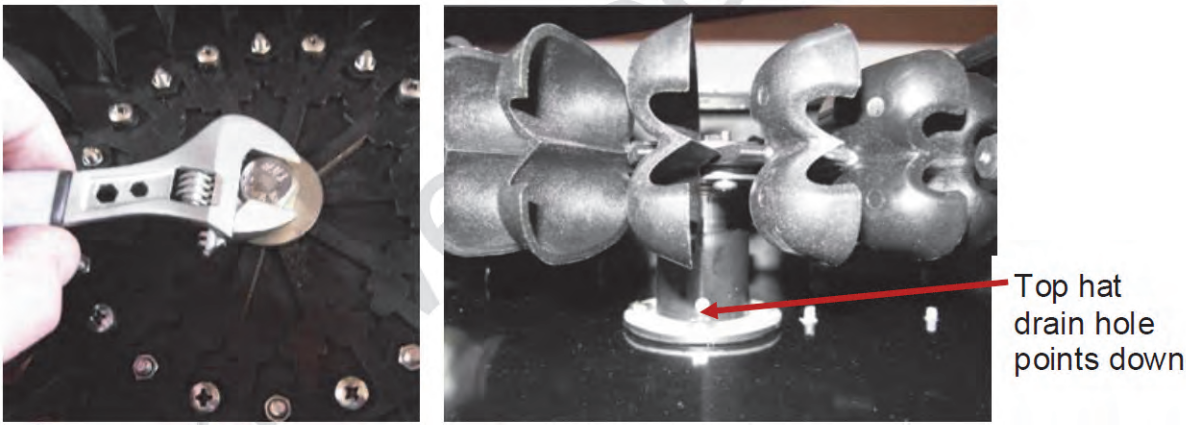


Figure 5-25: Attaching Pelton rotor to the shaft

The Pelton rotor alignment can be viewed by looking through the jet as shown in **Figure 5-26**. The water jet needs to hit the middle of the Pelton spoon splitter. If the jet was misaligned washers was packed to move the rotor across.

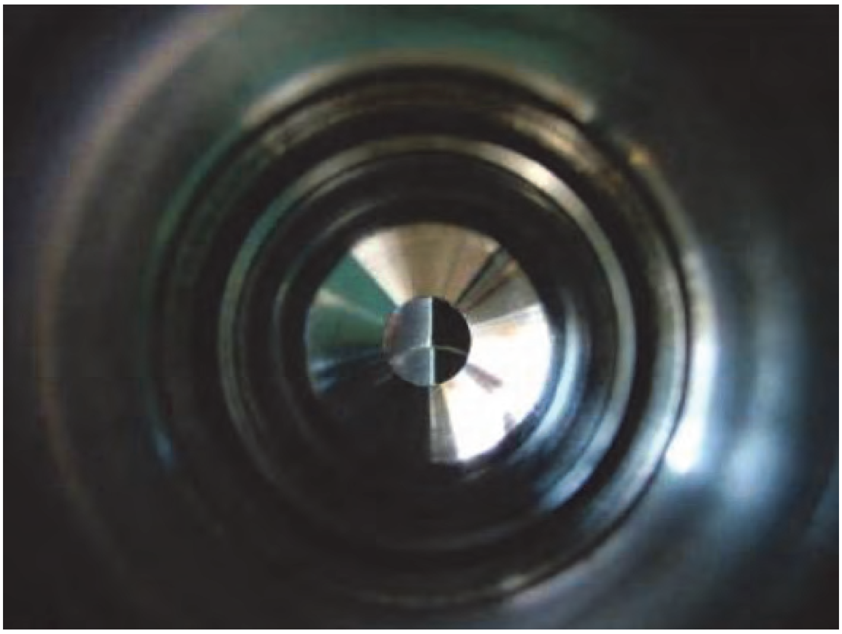


Figure 5-26: Pack Pelton rotor to align in middle of jet

5.2.11 Lubrication system

The lubrication components for the turbine was attached as shown in **Figure 5-27**.

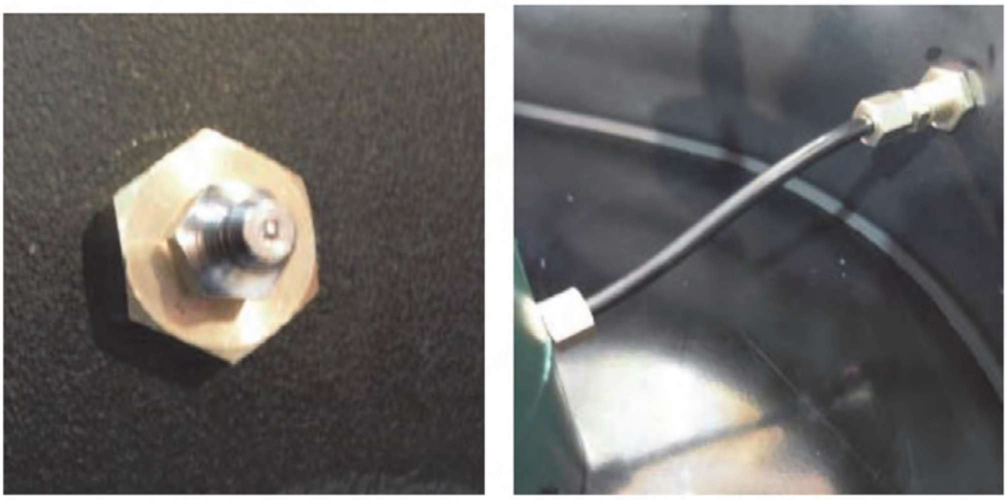


Figure 5-27: Grease lubrication system

5.2.12 Assembling rectifier, wire and plug lead

The pre-wired plug and flex was passed through the gland (mounted in the case wall), and the gland was tighten to restrain the cable. The rectifier wiring for the BE installation is shown in **Figure 5-28**.

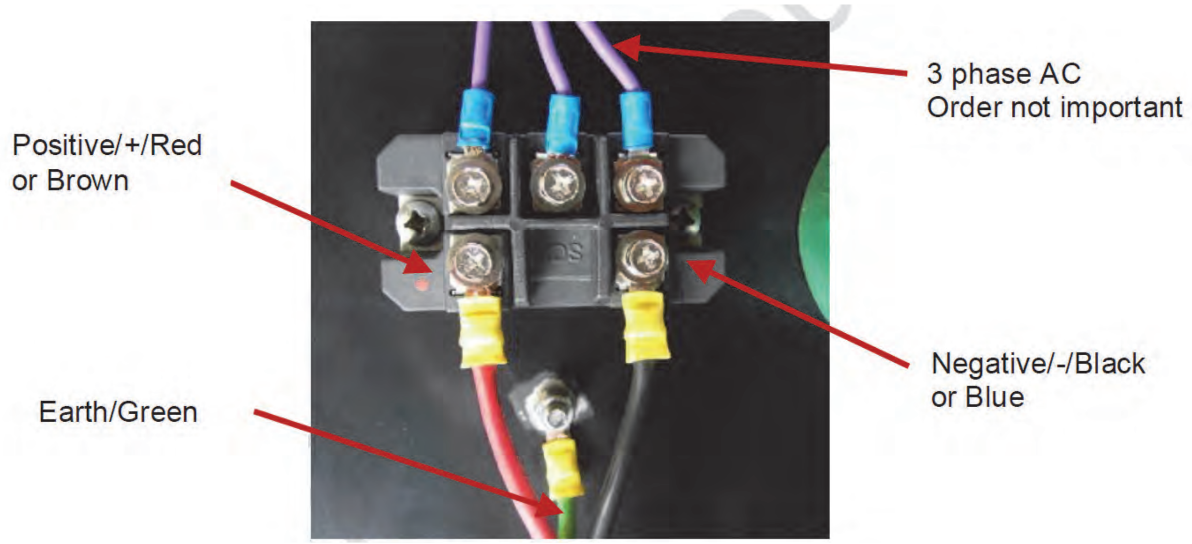


Figure 5-28: Rectifier wiring BE version

5.2.13 Installing rear cover

Once all internal components were installed the rear cap was attached, **Figure 5-29**. To prevent water leaking into the casing a sticky-backed sealing-strip was attached to the main casing. The lid is then held in place with fixings screws.

Figure 5-29: View showing rear cover installed

For the BE version the lid was removed while turbine performance was being optimized. The rear cap of this turbine forms part of an electrical enclosure and has warning signs indicating there are both rotational and electrical hazards present.

5.2.14 Installing front glazing

The front glazing enables the owner to see that the turbine is running at the correct speed and that the water jet is clean and hitting the Pelton rotor at the correct position, **Figure 5-30**.

For these demonstrative plants at eThekwini this is also ideal to demonstrate the technology. It however also protects anyone from accidently touching the rotating Pelton rotor and from getting wet.

Figure 5-30: View showing front glazing installed

Six toggle latches allow the quick attachment and removal of the front glazing for jet size optimization.

5.3 Connecting the turbines

5.3.1 Connecting the supply pipe to the PowerSpout

Two standard nylon pipe fittings were supplied with each turbine which allowed connection to a threaded ball valve on each inlet, connected to a 50 mm PVC manifold (**Figure 5-31**).

Figure 5-31: Ball valves and PVC mainfold

5.3.2 Electrical connection

The BE turbine system setup, **Figure 5-5**, was connected to an islanded grid. Site lighting and a billboard (still to be erected) will be connected to this to highlight hydropower generation at this site.

The GE turbine setup, **Figure 5-4**, was connected to the telemetry building; see **Figure 5-33**, where a municipal connection is available and energy can be fed into the grid.

The drawing, **Figure 5-32**, below shows the installation for the PowerSpout BE. This drawing shows a negative ground installation. Both fuse 4 and fuse 2 connected directly to the battery. The hydro turbine connects directly to the battery string. The cables used in each part of the circuit needed to be large enough to carry any currents that do not blow the corresponding fuses. The fuse has to be between the rating of the cable and the rating of the load/duty (cable highest, fuse middle, load smallest).

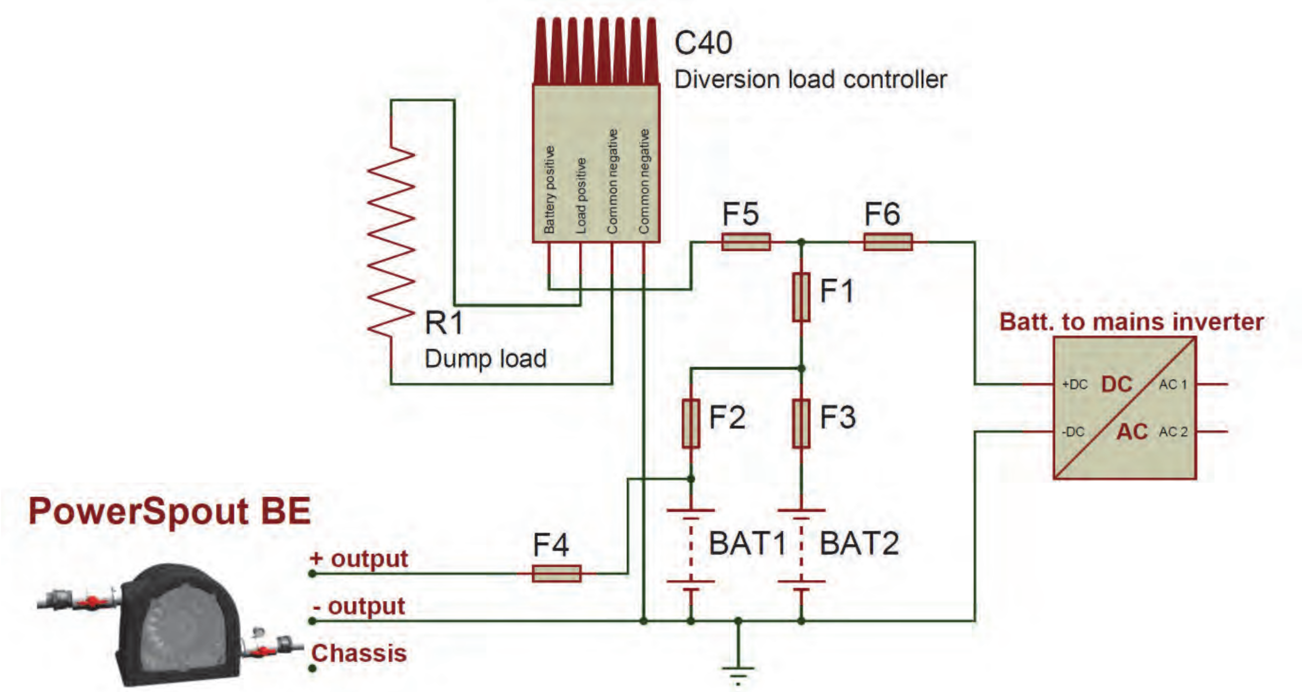


Figure 5-32: Wiring diagram for the Powerspout BE installation

Figure 5-33: Telemetry building

5.3.3 Regulators

Electronic Regulators are essential for dissipation of energy. Normally sufficient resistors are installed to take the full generating load. These are usually modular parts and can be connected together to provide the dissipating capability. In the Powerspout GE setup there is a dumb load element inside the turbine unit (**Figure 5-6**).

The Powerspout BE model supplies energy to the battery bank of four Deltec Lead Crystal Batteries (as shown in **Figure 5-35**). The Outback charge controller (**Figure 5-34**Figure 5-32**Error! Reference source not found.**) regulates this setup and if there is any excess energy this is diverted to the regulators.

Figure 5-34: Charge controller

Figure 5-35: Battery bank

5.4 Cost of project

Although no final total cost could yet be determined the main component costs are summarized in **Table 5-1**.

Table 5-1: Cost of the pilot conduit hydropower plant

Item	Description	Cost
Pressure and flow measurements	The available head versus flow relationship is required to select a suitable turbine. Sufficient information is available.	R0.00
Turbine room	Steel container	R16 000
Foundation	Construction of 150 mm thick concrete slab (3.0m x 3.0 m) and discharge point into reservoir	R5 000#
Pipe and valve work	Supply and installation of off-take pipeline (90 mm diameter, 50 m long) including bends, isolating valve and pressure control/regulating valve. An 80 mm control valve (pressure reducing).	R30 000#
Powerspout turbines *	Manufacture and supply of PowerSpout turbines with bottom outlet, control panel, battery bank and inverter.	R96 000
Electrical connection to islanded grid	Site lighting and connection.	R5 000#
Electrical connection to Municipal Grid	50 m cabling and connection.	R5 000#
Pipe and valve work inside turbine room	Supply and installation of pipe work and valves inside turbine room	R15 000#
Monitoring system	Installing monitoring system of power output from generator, net power to the external load, system voltage, gross and net system current, system frequency, and turbine speed.	R20 000
Flow measurement	Flow meter was installed on the off-take to each of the turbines.	R10 000
Installation and implementation	The project team assisting with the installation of the various components	R40 000
Monitoring and evaluation	The project team monitoring the working of the plant for a 3 month period.	R40 000#
Total (incl VAT)		**R282 000**

*Based on Rand/Dollar exchange rate of R9.30/$ and ZMSA quotation

Estimated

This total in **Table 5-1** excludes the manpower hours that was spend by the eThekwini Municipality personnel in designing and construction of this hydropower plant.

5.5 Turbine commissioning

It is important to commission the turbine and associated system to ensure it is working correctly prior to leaving the site. A record was taken of:

- Jets sizes installed
- Flow rate through turbine
- Output Watts (= amps x volts)
- Static pressure of pipe (turbine valves turned off)
- Dynamic pressure of pipe (turbine running)
- Generator equilibrium temperature
- Picture of installation
- Date for next service check

Once the turbine was mounted on the base platform, the pipes attached and secured, and the power cable connected to the inverter, MPPT regulator and battery bank the turbine was turned on. The guidelines in the installation manual were followed which indicated that the following should be done:

- Allow pipe to run and purge of air bubbles
- Check for current flow to the load.
- Check regulators are working.
- Check that the intake still has surplus overflow water. If not fit smaller jets so you are not drawing air into the pipe at the intake.
- Check for pipe and turbine fitting leaks, and remedy as required.
- Walk the pipe and lift sections to locate any air locks and fit riser vents as required.
- Check that the drain hole in the rear turbine case is at the lowest point. If condensing water from the bulk head pools onto the floor of the turbine case, drill a small hole at this low point to allow this water to drain out.
- Check there is no water leaking from the drain hole in the rear bearing block. If you see a leak make sure you have installed the slinger, top cap seal and tightened correctly

The installation process of the turbine is straight forward and there are videos of the turbine assembly available from the manufacturer's website (www.powerspout.com).

6. OTHER WATER UTILITIES WITH UNTAPPED CONDUIT HYDROPOWER OPPORTUNITIES

There are a number of water utilities and other entities whom are looking at conduit hydropower development at the moment:

- Rand Water Board (4 sites total 15 MW)
- Bloem Water (2 x 350 kW)
- Umgeni Water (various)
- Johannebsurg Water (various > 2 MW)
- Lepelle Northern Water (3 sites total 370 kW)
- City of Tshwane (5 sites total 1.6 MW + various others)
- Ethekwini Municipality (various)
- George Municipality (various)
- ESKOM (5.4-7.5 MW)
- City of Cape Town (upgrading existing installations at WTW)

As part of this research project Mossel Bay Municipality and Amatola Water were approached and potential sites were identified for possible conduit hydropower development. This was mainly desk top studies of the existing water infrastructure to identified viable sites

6.1 Mossel Bay – Water Distribution System Assessment

The Project Team visited Mossel Bay in January 2012 and after discussions with the Municipality visited a number of initially identified sites indicated in **Figure 6-1**.

Figure 6-1: Mossel Bay Municipality layout

A schematic layout of the water distribution system (WDS) is depicted in **Figure 6-2**.

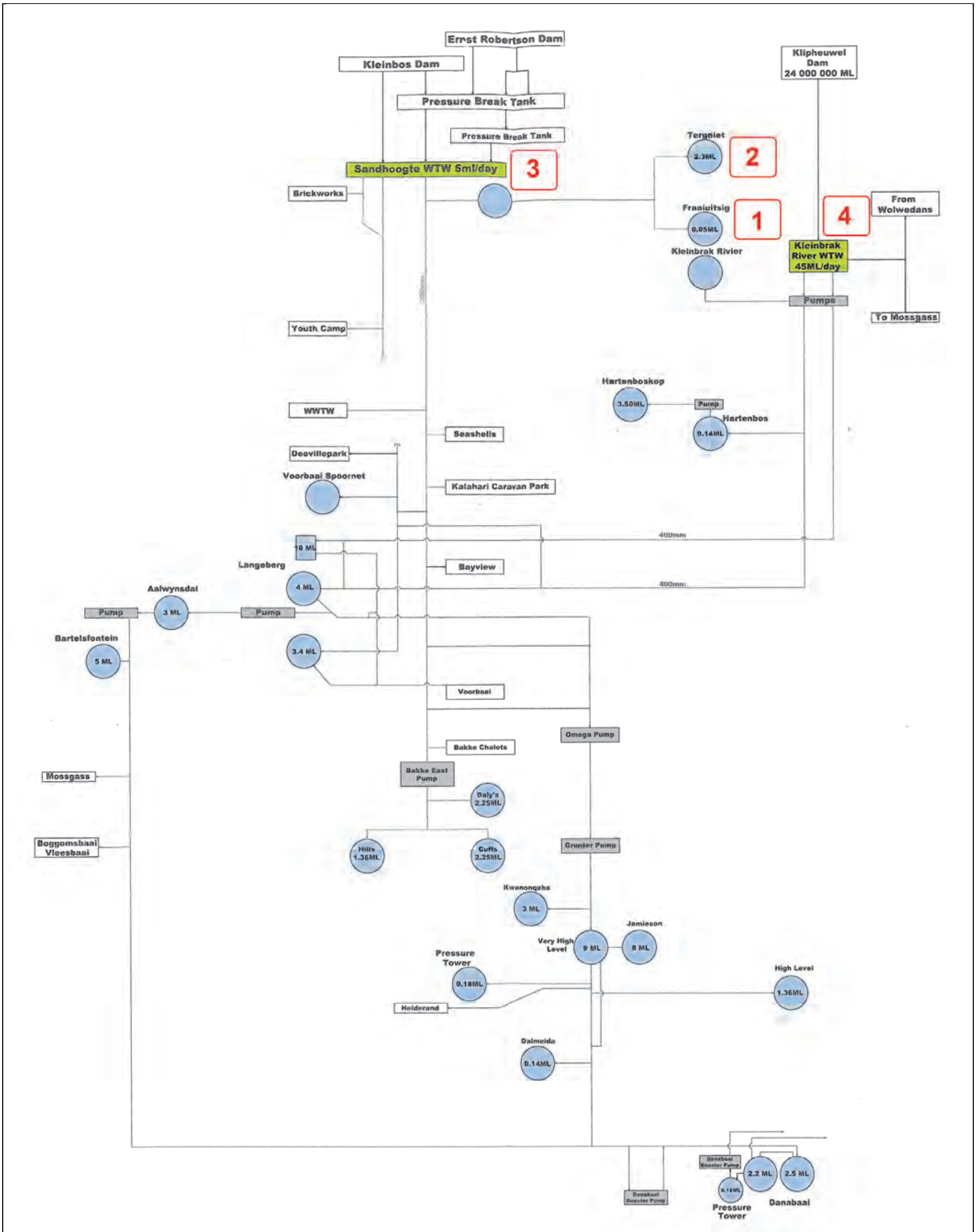


Figure 6-2: Schematic layout of WDS

The initial sites that were visited were:

- Fraaiuitsig Reservoir
- Tergniet Reservoir
- Sandhoogte WTW
- Klein Brak Reservoir & WTW

There are basically two main criteria in determining whether any site has any exploitable hydro power potential, namely:

- Reasonable continuous flow
- Excess pressure head

The reason for selecting the sites listed above were due to the sites having some pressure control function and are supplied under gravity. All the sites where water is pumped to the reservoir sites such as Langeberg or Bartlesfontein are thus not suitable sites.

The potential for each of the sites are described in paragraph 6.1.5.

6.1.1 Fraaiuitsig Reservoir

During the visit to this reservoir site, depicted in **Figure 6-3** to **Figure 6-6**, there was no flow. This is a relatively small reservoir (50 kl) but was visited since it is fed under gravity from the Sandhoogte WTW.

Figure 6-3: Fraaiuitsig reservoir

Figure 6-4: Pressure reducing station (Fraaiuitsig Reservoir)

Figure 6-5: Pressure reducing valve (Fraaiuitsig)

Figure 6-6: Fraaiuitsig Reservoir inlet

6.1.2 Tergniet Reservoir

During the visit to this reservoir site, depicted in **Figure 6-7** to **Figure 6-8**, there was no flow. This is a relatively small reservoir (2300 kl) but was visited since it is fed under gravity from the Sandhoogte WTW.


Figure 6-7: Tergniet Reservoir inlet


Figure 6-8: Pressure reducing valve upstream of reservoir inlet

Figure 6-9: Tergniet Pressure Reducing Station

6.1.3 Sandhoogte WTW

The area is supplied by the Sandhoogte Water Treatment Works, which receives its raw water from the Ernest Robertson Dam on the Great Brak River and the Kleinbos Weir (run-of-river scheme) on the Beneke River.

The water is gravitated from the Ernest Robertson Dam to the Sandhoogte WTW via a 40 km long, 250/300 mm diameter AC pipeline, see **Figure 6-10**. The supply pipelines from the Ernest Robertson Dam are about 50 years old and are in a bad condition. The plant has a design capacity of 5 Ml/d and treats 1.278 million m^3 of water per year. The Sandhoogte WTW is in a good physical condition.

Water from the Kleinbos Weir system is also gravitated to the Sandhoogte WTW via a 75 mm diameter pipeline.

Figure 6-10: Supply lines

Although there are break pressure tanks on the supply lines linking the Ernest Robertson Dam and the Sandhoogte WTW there is no pressure reducing station at the treatment plant (**Figure 6-11**).

Figure 6-11: Inflow into Sandhoogte WTW

6.1.4 Klein Brak Reservoir & Water Treatment Works (WTW)

The Mossel Bay Regional Water Supply Scheme (RWSS), supplying Mossel Bay, Danabaai, Hartenbos, the resorts of Vleesbaai and Boggomsbaai and the inland town of Brandwacht, is served by the Klein Brak WTW. The Klein Brak WTW receives raw water from the Wolwedans Dam and the Klipheuwel off channel storage dam, located close to the Moordkuil River, schematically depicted in **Figure 6-2**.

The Wolwedans Dam is owned and operated by DWA. The main source to the dam is the Great Brak River. The dam has been designed and constructed with theaim of meeting the future water requirements for the Mossel Bay Municipality. The allocation is 5.6 million m^3/a to PetroSA and 2.34 million m^3/a for the whole Mossel Bay RWSS.

The Klein Brak WTW has a design capacity of 45 Ml/d and treats 8.695 million m^3/a.

The Klein Brak WTW receives its raw water from the Wolwedans Dam on the Great Brak River and the Klipheuwel off-channel storage dam. Water is pumped via a 500 mm diameter pipeline from the Wolwedans Dam to PetroSA and the Klein Brak WTW, and also has an emergency supply connection to the Great Brak WTW.
The Wolwedans Dam is owned by DWA and the distribution pipeline is owned by PetroSA. The dam is jointly operated and maintained by both organizations.

Water is pumped from the Moordkuil River to the Klipheuwel Dam. Water from this dam is pumped via a 450 mm diameter, 4 km long pipeline to the Klein Brak WTW. Treated water is supplied to the Mossel Bay RWSS through various pumped or gravity bulk distribution pipelines to service reservoirs serving the reticulation zones.

Photo taken during the site visit is reflected in **Figure 6-13** to **Figure 6-18**.

Figure 6-12: Kleinbrak WTW layout

Figure 6-13: Klein Brak Reservoir which supplies Klein Brak WTW

Figure 6-14: Klein Brak Reservoir site

Figure 6-15: PRS on bulk supply pipeline from Wolwedans Dam

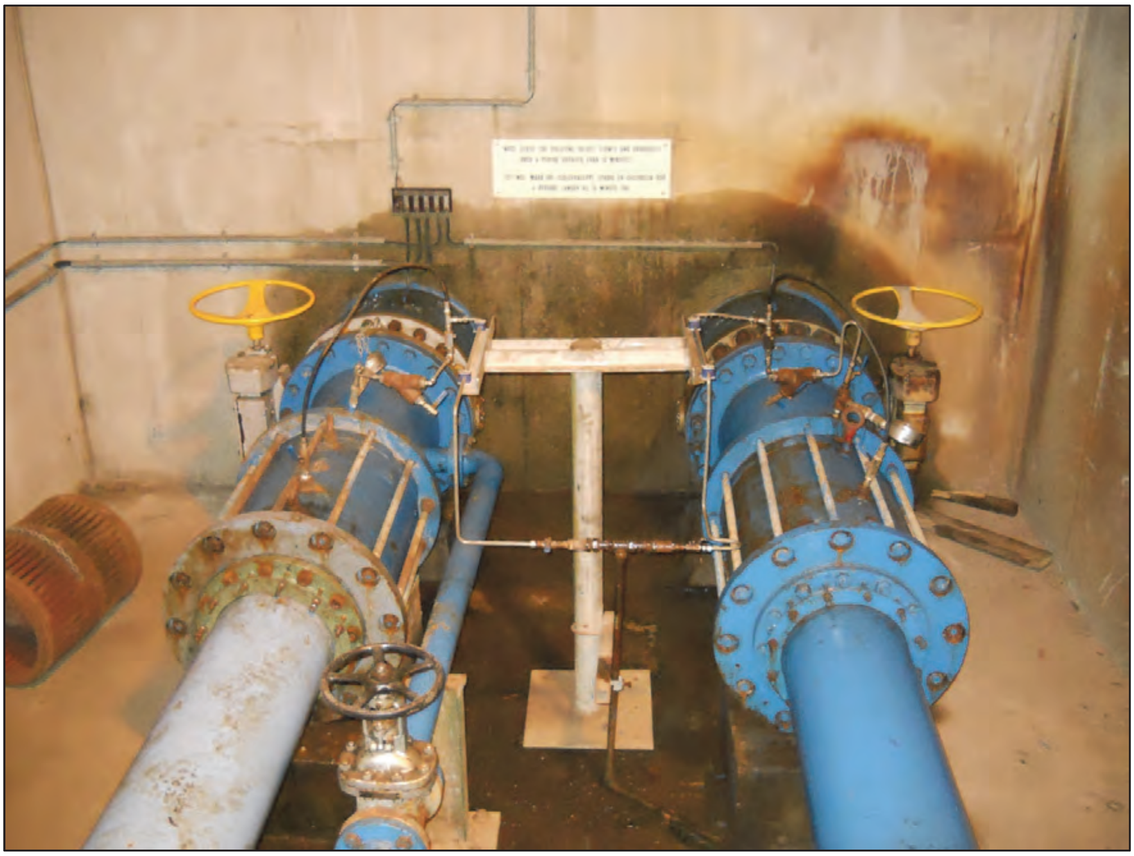


Figure 6-16: Two 300 mm Flexflo pressure control valves in PRS on bulk pipeline from Wolwedans Dam

Figure 6-17: Upstream pressure at PRS on bulk pipeline from Wolwedans Dam

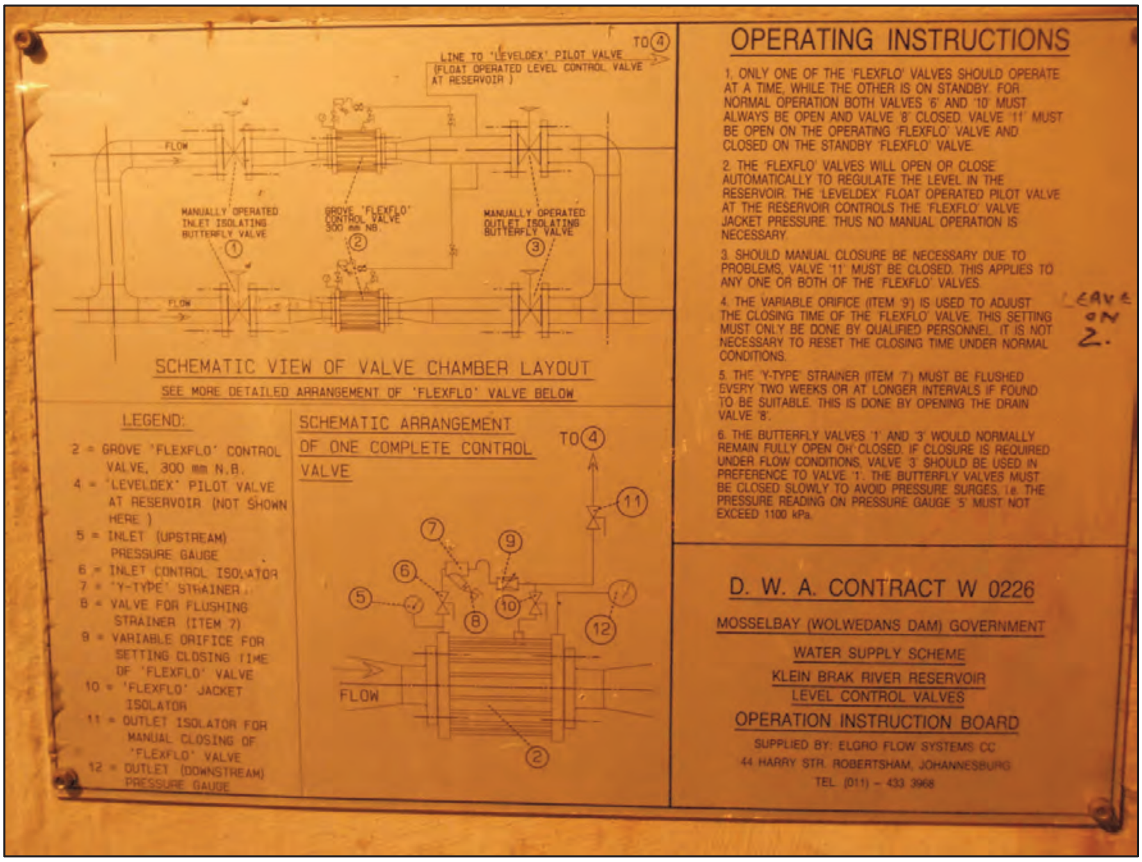


Figure 6-18: Operations Instruction Board

6.1.5 Mossel Bay – Conduit Hydro Power Potential

6.1.5.1 Fraaiuitsig Reservoir

This site does not have any economical conduit hydropower potential. The flow is intermittent and nominal. The reservoir site is situated in a residential area where access to the municipal grid is available and thus there is also no need for constructing a small hydro power plant to provide electricity for telemetry, alarm systems etc.

6.1.5.2 Tergniet Reservoir

This site, although slightly larger than Fraaiuitsig, also does not have any economical exploitable conduit hydropower potential. The flow is intermittent and nominal. Similar to Fraaiuitsig the reservoir site is situated in a residential area where access to the municipal grid is available and thus there is also no need for constructing a small hydro power plant to provide electricity for telemetry, alarm systems etc.

6.1.5.3 Sandhoogte WTW

The Sandhoogte WTW operates at 5 Ml/day which equates to approximately 58 l/s. There is currently no excess pressure available at the plant which could be utilized through a turbine installation. If in future the pipeline system which supplies Sandhoogte WTW is upgraded there could be potential. Installing a larger diameter would result in an increase in upstream pressure. This pressure should be at least 30 m to allow for the installation of a 13.5 kW turbine system for such a scenario.

6.1.5.4 Klein Brak Reservoir & WTW

The Klein Brak WTW itself does not have any potential. The bulk supply line supplying the Klein Brak WTW from the Klipheuwel Dam is a pumping line. The bulk pipeline supplying PetroSA does however have an exploitable hydropower potential.

This pipeline dissipates all excess pressure before discharging into the Klein Brak Reservoir (**Figure 6-14**).

The Hydraulic Gradeline (HGL) along this pipeline has a slope of 0.00175 m/m (i.e. 25.748 m pressure drop when operating at a flow of 0.609 m^3/s), depicted in **Figure 6-19**. Depending on the water level in the Wolwedans Dam the excess pressure at the Klein Brak Reservoir is dissipated in the pressure reducing station (PRS).

During the site visit the Wolwedans Dam water level was -1.9 m below the FSL of 98 m i.e. 96.1 m. The flow was approximately 800 m^3/h, which corresponds with the observed 79 m of pressure upstream of the control valves, see **Figure 6-17**.

From the longitudinal profile, **Figure 6-19**, it is evident that a minimum pressure of approximately 34 m downstream of the control valves is required to prevent the HGL intersecting the profile. The upstream pressure also varies based on the level in the Wolwedans Dam. **Table 6-1** provides the potential power based on a number of scenarios of the Wolwedans Dam.

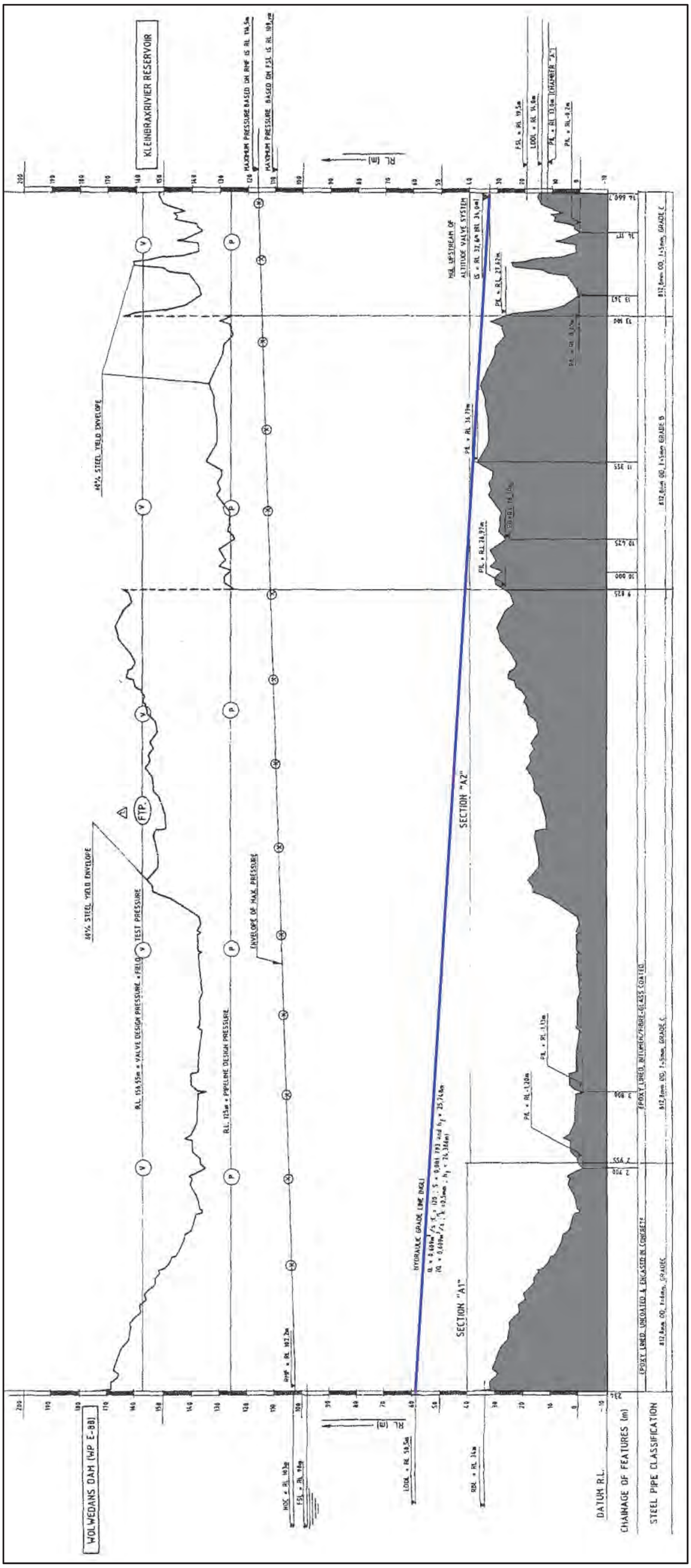


Figure 6-19: PetroSA bulk supply line from Wolwedans Dam

Table 6-1: Hydropower potential (Klein Brak Reservoir)

Flow (m^3/h)	Level in Wolwedans Dam (m)	Available head (m)	Potential power (kW)	Potential annual revenue (R)*
800	98 (FSL)	59.9	104	450 000
800	75	36.9	64.3	278 000
800	58.5	20.4	35.5	153 000

* Revenue based on 50c/kwh

A micro conduit hydro power installation typically costs R30 000/kW and thus the estimated cost of a hydropower plant at the Klein Brak Reservoir would be R3.12 Million. The generated electricity could be fed into the grid or directly to the Klein Brak WTW. Placing the hydropower plant at chainage 13 050 m would allow the utilization of an additional ±20 m of head increasing the potential with 35 kW.

6.1.6 Turbine options

There are various turbine types available, although there are no major local manufacturers of turbines in South Africa. Details are included in **Appendix A.**

6.1.7 Conclusion

Based on the preliminary assessment of the Mossel Bay Water Distribution System no economically exploitable conduit hydropower potential was found. Most of the bulk supply lines in the water distribution network are pumping lines and the few which are operating as gravity lines have insignificant and intermittent flow. These gravity lines also have insignificant head that requires dissipation and thus have no feasible hydropower potential.

The one potential conduit hydropower site which was uncovered is on the supply pipeline from the Wolwedans Dam just before it discharges into the Klein Brak Reservoir as described in paragraph 6.1.5.4. At this site there is sufficient flow and excess pressure head which warrants further investigation. As far as could be ascertained this pipeline belongs to PetroSA but any energy that is generated there could be utilized in the Klein Brak WTW and this opportunity should be considered.

The research team wishes to express their sincere thanks for the support received from the Mossel Bay Municipality personnel during the investigation.

6.2 Hydropower potential in the City of Tshwane's WDS

A scoping study by Van Vuuren (2010) was a first-order estimate of conduit hydropower potential in the CoT water-distribution network, as shown in **Figure 6-20**.

The scoping study identified the ten larger reservoir sites in CoT with pressure reducing stations. **Table 6-2** 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 6-21** and **Table 6-3** indicate the potential hydropower generation capacity at the ten most favourable sites in the City of Tshwane water-supply area.

Table 6-2: Assumptions used in the determination of hydropower generation capacities at CoT's 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 6-3: Potential hydropower generation capacity at the ten most favourable reservoirs in the City of Tshwane's 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	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 6-2**.*

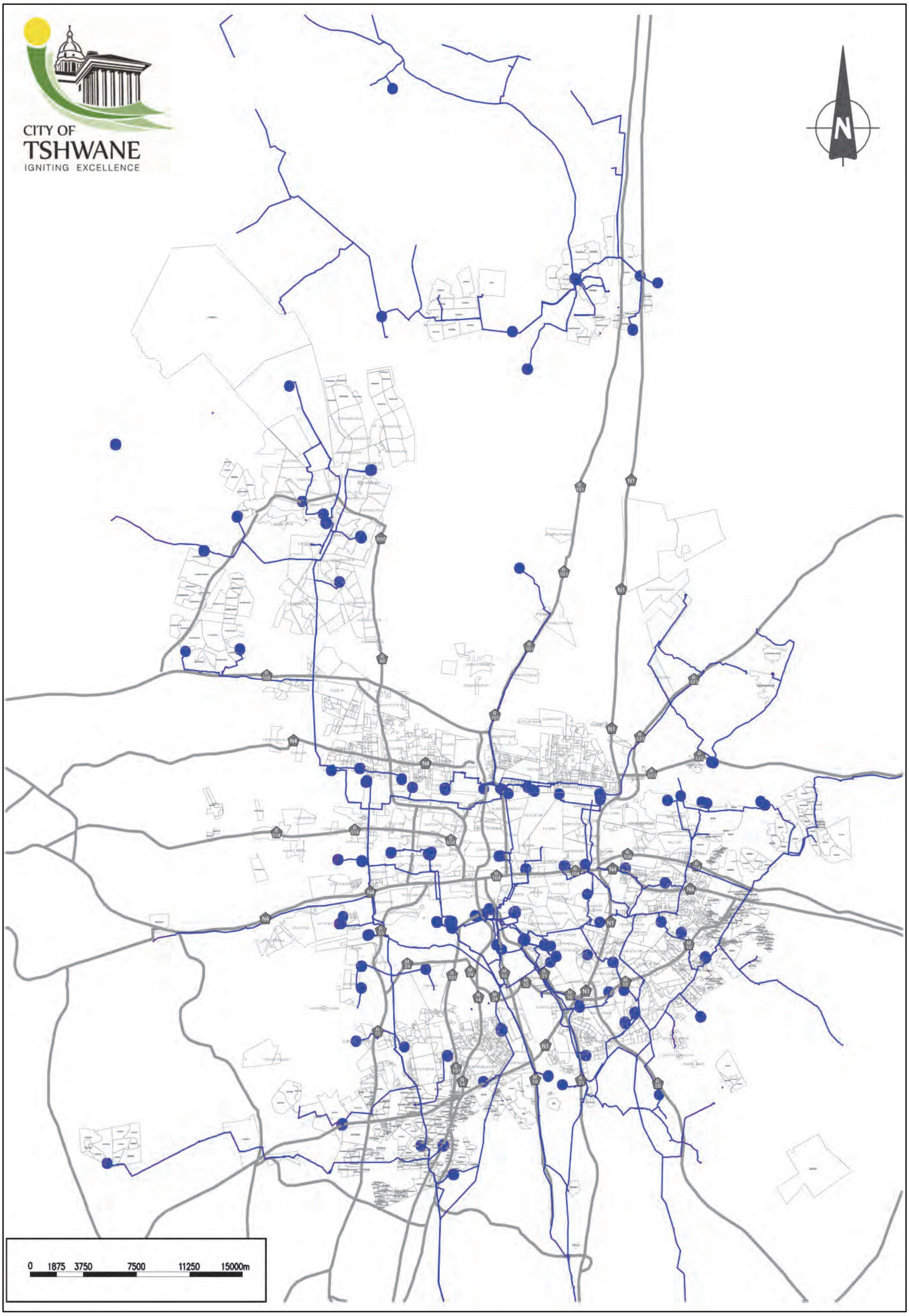


Figure 6-20: Reservoirs and bulk pipelines in the CoT WDS (Van Vuuren, 2010)

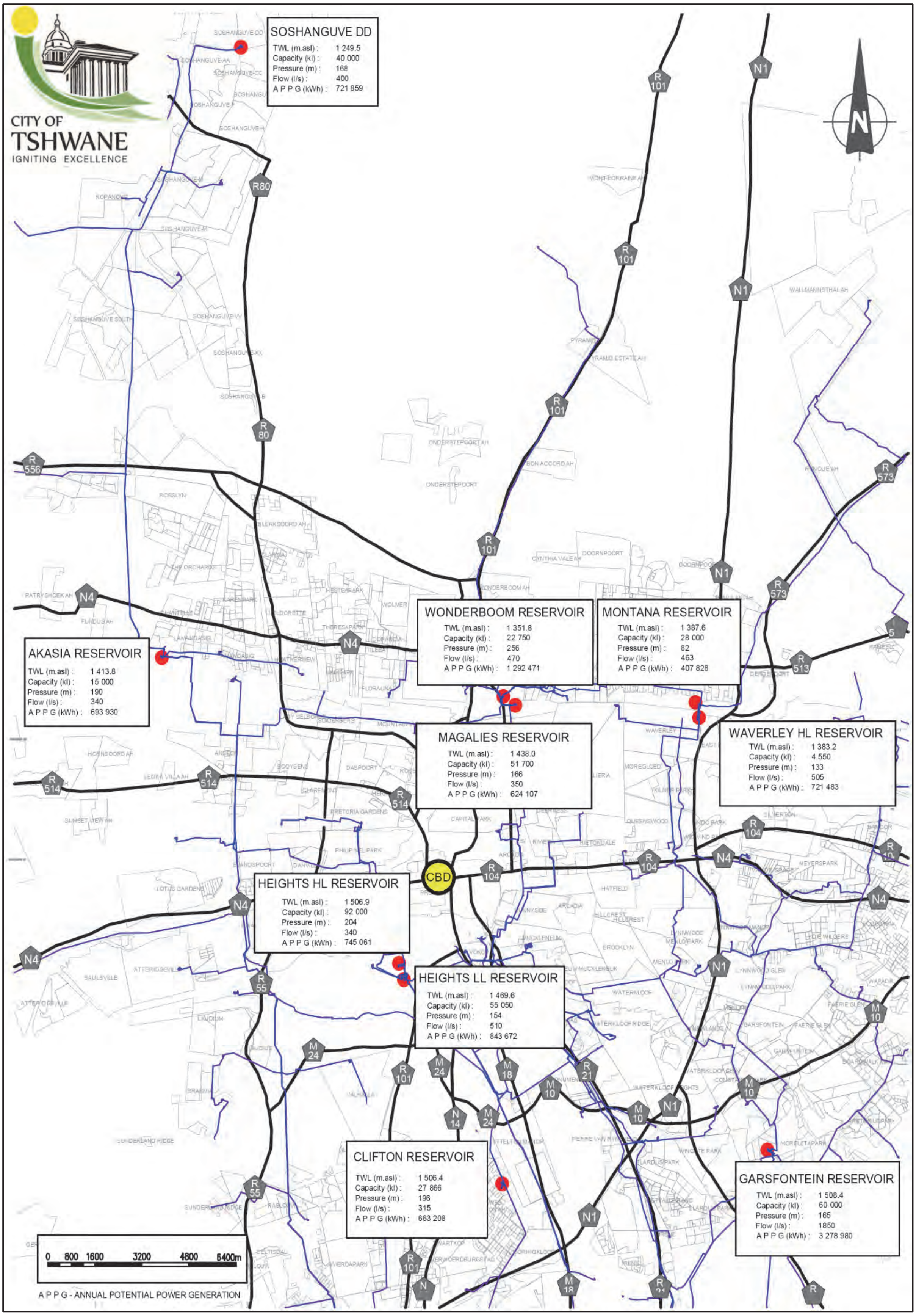


Figure 6-21: Hydropower generation capacity at different reservoirs in the CoT WDS (Van Vuuren, 2010)

6.3 AMATOLA – Water Distribution System Assessment

The Project Team visited East London in June 2013 and, after discussions with the Water Board, visited two initially identified sites. The visited sites are indicated in **Figure 6-22** and are:

- Nahoon Water Treatment Works (WTW)
- Sandile Water Treatment Works (WTW)

Figure 6-22: Amatola Water identified sites

There are basically two main criteria in determining whether any site has any exploitable hydro power potential, namely:

- Reasonable continuous flow
- Excess pressure head

The reason for selecting the sites listed above were due to the sites having some pressure control function and are supplied under gravity. All the sites where water is pumped to the reservoir would thus not be suitable sites.

The potential for each of the sites are described in Section 6.3.3.

6.3.1 Nahoon Water Treatment Works

The Nahoon WTW has a capacity of 33 Ml/day and treats water from the Nahoon dam. During the visit to this site, depicted in **Figure 6-23** to **Figure 6-25**, the flow was about 375 l/s.

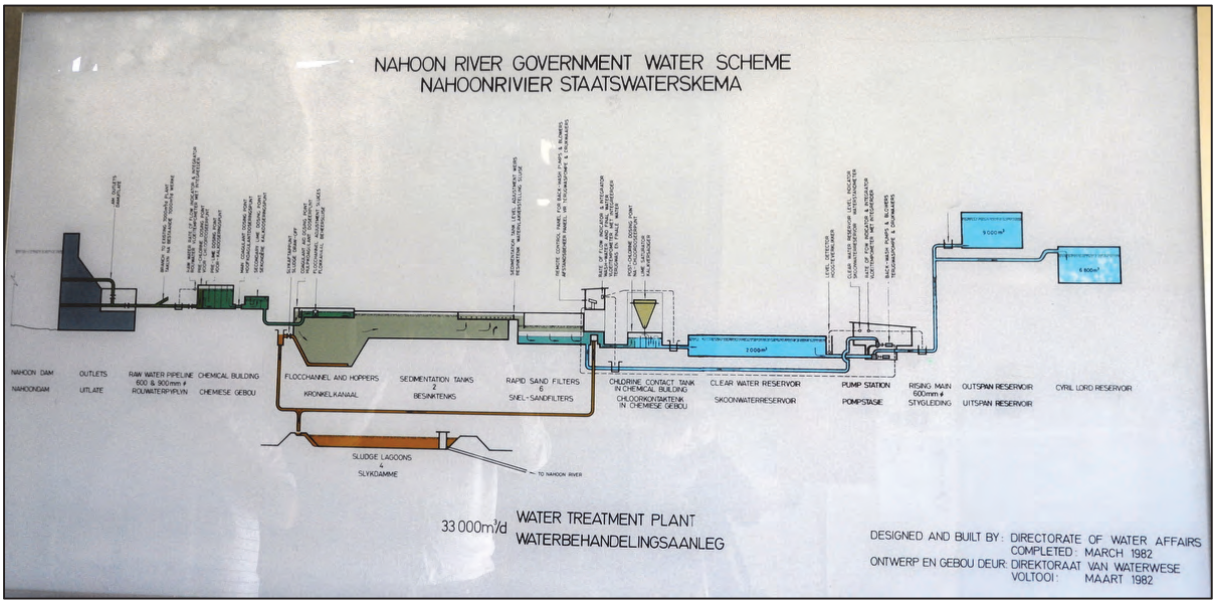


Figure 6-23: Nahoon WTW schematic layout

Figure 6-24: Control valve at Nahoon WTW

Figure 6-25: Chamber upstream of the Nahoon WTW

There is no pressure control valve upstream of the inlet chamber. Flow is controlled and excess pressure is dissipated by means of the butterfly isolating valve upstream of the inlet chamber (**Figure 6-24**). According to Amatola Water, the measured pressure upstream of the inlet chamber is 105 kPa (approximately 10.5 m) at a flow rate of 410 l/s.

6.3.2 Sandile Water Treatment Works

The water to be treated at the Sandile WTW (**Figure 6-26**) gravitates from the Sandile Dam via an approximately 6 km long pipeline which enters the plant at a low point in the North -Eastern side of the plant, where there is a control valve (**Figure 6-27**). The raw water goes through a control valve to a balancing tank on the South-Western side of the plant (**Figure 6-28**), from where it gravitates to the WTW (**Figure 6-29**). The plant has a design capacity of 18 Ml/day. From the WTW, water is pumped away to the distribution system using various pumps, the largest of which has a capacity of 385 kW (**Figure 6-30**).

Amatola Water indicated that the pressure upstream of the PRS is 800 kPa. This was confirmed during the site visit where the pressure was 750 kPa (**Figure 6-27**) upstream of the control valve at the low end (North-East) of the site. The pressure is reduced and discharged 200 m further downstream into the balancing tank (**Figure 6-28**), after passing through another PRV.

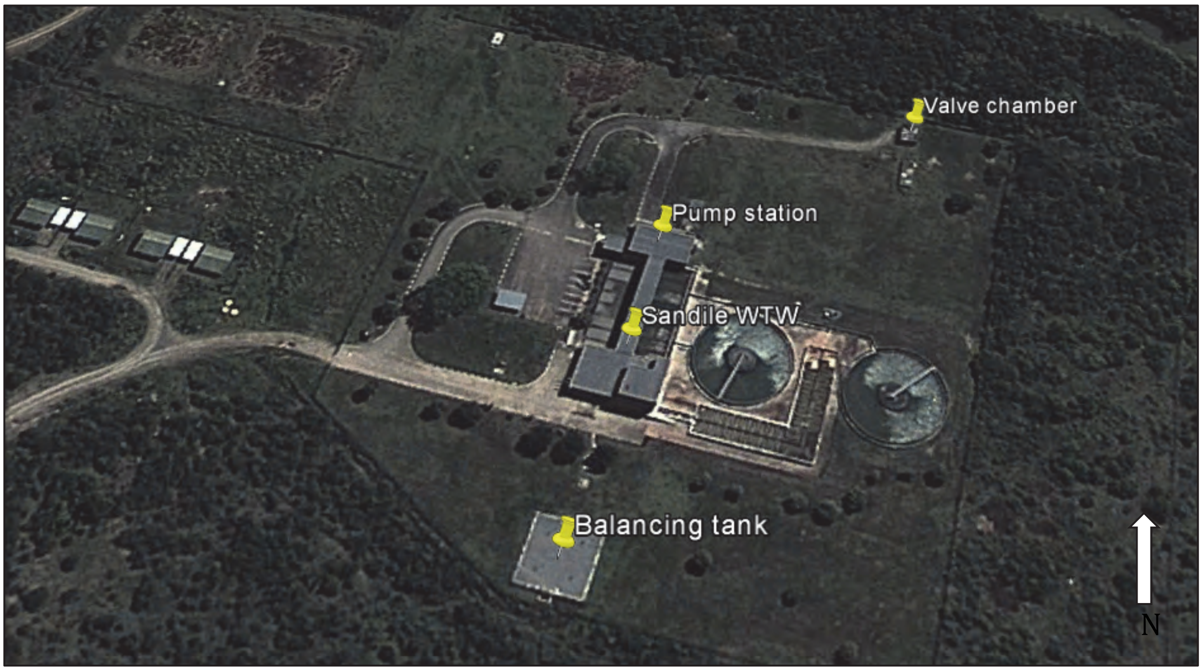


Figure 6-26: Layout of Sandile WTW

Figure 6-27: Control valve at Sandile WTW

Figure 6-28: Balancing tank at Sandile WTW

Figure 6-29: Sandile WTW

Figure 6-30: Sandile pump station

6.3.3 AMATOLA WATER – Conduit Hydro Power Potential

6.3.3.1 Nahoon WTW

Water gravitates from the Nahoon Dam to the Nahoon WTW, where it is controlled upstream of the inlet chamber (**Figure 6-31**). The pressure in the pipeline varies according to the flow in the system and the head in the Nahoon Dam. During the site visit the flow was approximately 1350 m^3/h (375 l/s).

Figure 6-31: Control valve upstream of Nahoon inlet chamber

Figure 6-32: Nahoon pipeline profile estimate generated on Google Earth

Table 6-4 provides the potential power based on a number of operational scenarios. Unfortunately, a profile drawing of the pipeline from the Nahoon dam to the WTW was not provided and therefore the pressure head could not be calculated accurately. A profile was generated using Google Earth to estimate a static pressure head between the dam and WTW (**Figure 6-32**). According to Amatola Water, the measured pressure upstream of the inlet chamber is 105 kPa (approximately 10.5 m) at a flow rate of 410 l/s and the average flow rate for the past three months was 400 l/s. With a required backpressure of 2.5 m downstream of a turbine installation at this site, a pressure of 8 m was used with the average flow for the first scenario. The other scenarios used estimated pressures and load factors.

The estimated pressure heads and proposed operational scenarios need to be studied by Amatola Water and a decision should be based on a feasible operational scenario that will ensure effective and uninterrupted water supply to the distribution area.

Table 6-4: Hydropower potential (Nahoon WTW)

Flow (l/s)	Load factor (% of time)	Available head (m)	Potential power (kW)	Potential annual revenue (R)*	Payback period (years)*
400	95	8	22.0	75 000	16
800	50	5	27.5	50 000	26
600	75	6	24.7	70 000	20

* Revenue based on 40c/kwh and energy escalation of 8%pa for the next 5 years

A conduit hydro power installation of between 20 kW and 50 kW typically costs R40 000/kW (although it can vary significantly depending on the turbine and site) and thus the estimated cost of a hydropower plant at the Nahoon WTW would be R0.88 Million for the first flow scenario (average flow of 400l/s). The generated electricity could be used for some of the electricity needs on site. The power generated could be fed into the electricity grid on site.

An upgrade of the Nahoon WTW is planned, which may improve the feasibility of a conduit hydropower installation at this site. Hydropower options should be considered during the upgrade.

6.3.3.2 Sandile WTW

Water gravitates from the Sandile Dam to the Sandile WTW, where control valves upstream of the balancing tank dissipate excess pressure in the pipeline, which varies according to the flow in the system and the head in the Sandile Dam. During the site visit the pressure upstream of the control valve at the balancing tank was 58 m (see **Figure 6-33**) at no flow.

With an average flow over the last three months being 250 l/s and assuming average friction losses of 7-8 m in the 6 km pipeline from the dam to the balancing tank, there should be approximately 50 m of head available for hydropower generation, depending on the level in the Sandile Dam.

Figure 6-33: Control valve upstream of Sandile balancing tank

Table 6-5 provides the potential power based on a number of operational scenarios, with the average flow and corresponding head being the first scenario. These operational scenarios need to be studied by Amatola Water and a decision should be based on a feasible operational scenario that will ensure effective and uninterrupted water supply to the distribution area.

Table 6-5: Hydropower potential (Sandile WTW)

Flow (l/s)	Load factor (% of time)	Available head (m)	Potential power (kW)	Potential annual revenue (R)*	Payback period (years)
250	95	50	85.8	290 000	8
500	50	27	92.7	170 000	15
375	75	30	77.3	210 000	10

* Revenue based on 40c/kwh and energy escalation of 8%pa for the next 5 years

A conduit hydro power installation with capacity between 70 kW and 100 kW typically costs R25 000/kW (although it can vary significantly depending on the turbine and site) and thus the estimated cost of a hydropower plant at the Sandile WTW would be R2.15 Million for the first scenario (average flow).

The generated electricity could be used for some of the electricity needs on site. The power generated could be fed into the electricity grid on site. Some turbine options are provided in **Section 6.3.4.**

6.3.4 Turbine options

There are various turbine types available, although there are no major local manufacturers of turbines in South Africa, some options are listed in **Appendix A**.

6.3.4.1 Nahoon turbine options

There is an existing chamber outside the Nahoon WTW (**Figure 6-34 (a)**), that may be ideally suited for an inline hydropower installation, such as the spherical turbine, see **Appendix A**. Alternatively, a PaT or Francis that can handle a backpressure of up to 3 m may be installed inside the building (**Figure 6-34 (b)**).

Figure 6-34: (a) Chamber outside building (b) Possible location in building

Although both these installations are technically possible, they do not seem economically viable at this stage, mainly due to the small capacity available at this site (a 16 kW spherical turbine costs approximately R850 000). However, conduit hydropower should be considered during the upgrading of the plant, bearing in mind that the higher the flow and excess pressure, the more hydropower potential there will be.

6.3.4.2 Sandile turbine options

There is an existing chamber at the Sandile WTW (**Figure 6-35**), that may be ideally suited for an inline hydropower installation, such as a PAT. However, it is suggested that a more practical installation could be at the entrance to the balancing tank (**Figure 6-36**), where an impulse turbine such as a Crossflow, Turgo or Pelton could be installed with a tailrace discharging water into the balancing tank, similarly to the drawing depicted in **Figure 6-37.**

The PRS in the North-Eastern corner can then be fully open, allowing all the excess pressure to reach the balancing tank. At this point a bypass can be constructed, forcing the water through the turbine and discharging into the reservoir. The main supply would then be closed and all water discharged through the turbine.

Figure 6-35: Chamber at Sandile WTW

Figure 6-36: (a) Manholes on balancing tank (b) space next to balancing tank

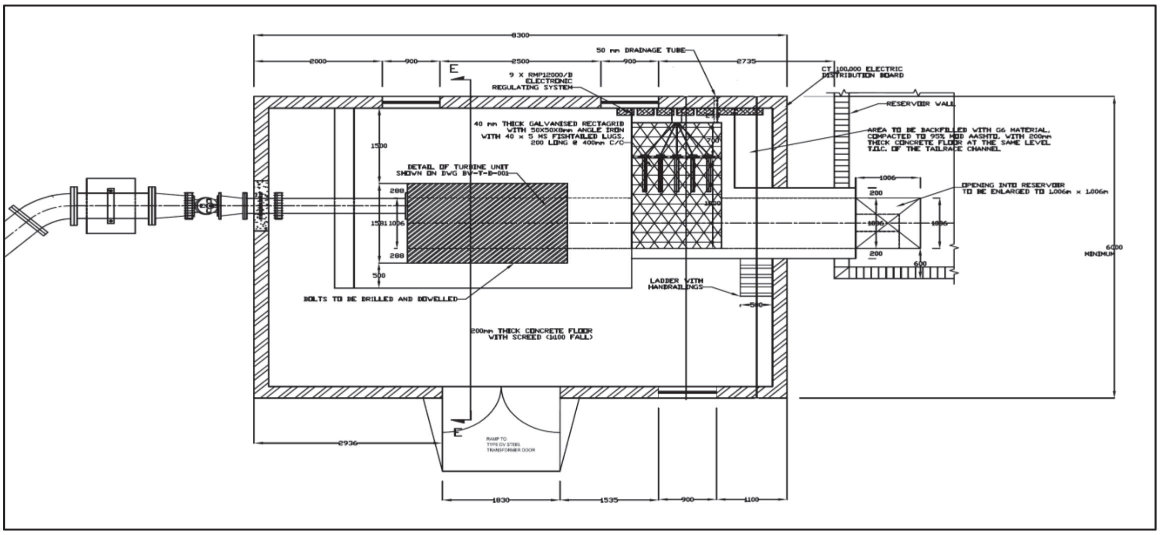


Figure 6-37: Typical impulse turbine layout

6.3.5 Conclusion

Based on the preliminary assessment of the two identified sites belonging to Amatola Water, economically exploitable conduit hydropower potential may exist.

- The preliminary assessment indicated technical potential for a 22 kW installation at Nahoon WTW, although it does not seem economically feasible at this stage. However, it is proposed that conduit hydropower should be considered during the upgrading of the plant, bearing in mind that the higher the flow and excess pressure, the more hydropower potential there will be.
- The Sandile WTW on the other hand has economically feasible potential for an 85 kW installation. It is recommended that Amatola Water gather the following information, before a full feasibility study is conducted:
  - consider current and possible future operational scenarios that would not affect water supply to the distribution areas;
  - record flow and corresponding pressure heads for these scenarios at both pressure reducing stations;
  - measure corresponding levels of the Sandile Dam for all pressure and flow measurements;
  - obtain a detail pipeline profile;
  - consider whether the grid at the penstock inlet is sufficient for water that would now flow through a hydropower turbine; and
  - reflect on preliminary layouts for the hydropower installation.

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36) Van Dijk, M., Van Vuuren, S.J and Van Zyl, J.E. (2008). "Optimising Water Distribution Systems using a weighted penalty in a Genetic Algorithm", Water SA, Vol. 34 No. 5.

37) Van Dijk, M., Van Vuuren, S.J., Bhagwan, J. and Kurtz, A. 2012b. Tapping untapped renewable energy. Civil Engineering, 20 (5): 19-23.

38) Van Vuuren, S.J. 2010. A high level scoping investigation into the potential of energy saving and production/generation in the supply of water through pressurized conduits. WRC Report No. KV 238/10. Water Research Commission, Pretoria, South Africa.

39) Van Vuuren, S.J., Blersch, C.L. and Van Dijk, M. 2011. Modelling the feasibility of retrofitting hydropower to existing South African dams. Proceedings of the Water Research Commission 40-Year Celebration Conference, 31 August – 1 September 2011, Kempton Park, South Africa. Available online: http://www.wrc.org.za. [Accessed 5 September 2012].

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)

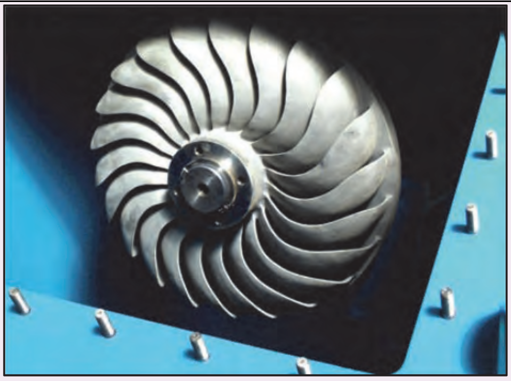
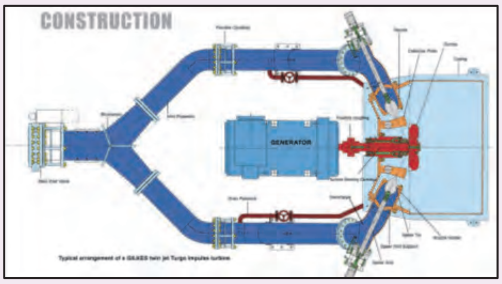
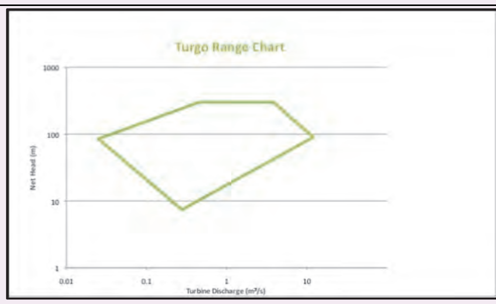
Turbine runner	High head	Medium head	Low head	Ultra-low head
	> 100 m	**20 m - 100 m**	**5 m - 20 m**	**< 5m**
Impulse	Pelton Turgo	Cross-flow Turgo Multi-jet Pelton	Cross-flow Multi-jet Turgo	Water wheel
Reaction	-	Francis Pump-as-Turbine	Propeller Kaplan	Propeller Kaplan

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

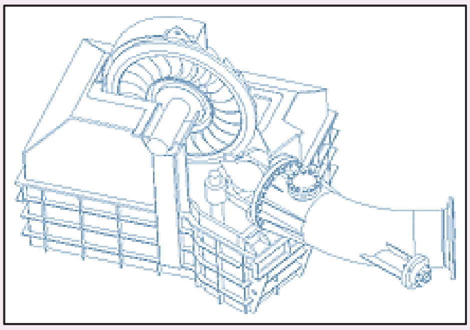
Turbine Name:	**TURGO TURBINE**
Company name:	**Gilbert Gilkes & Gordon Ltd**
Company Address:	Canal Head North Kendal Cumbria UK
Company Tel:	+44 (0) 1539 720028
Company E-mail:	enquiries@gilkes.com
Website:	www.gilkes.com
Turbine Description:	The Gilkes Turgo is a simple machine with high specific 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 m³/s to 6 m³/s
Power Range	Up to 10 000 kW
Illustrations, Photos and Applicable Graphs:	 *Turgo runner*  *Turgo turbine installation*  *Typical layout*  *Turbine range*

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

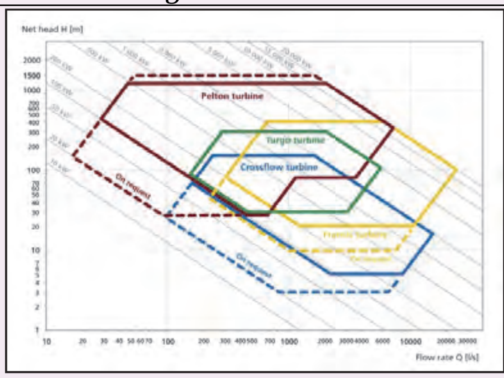
Illustrations and Applicable Graphs:

Turgo turbine room

Turgo turbine wheel



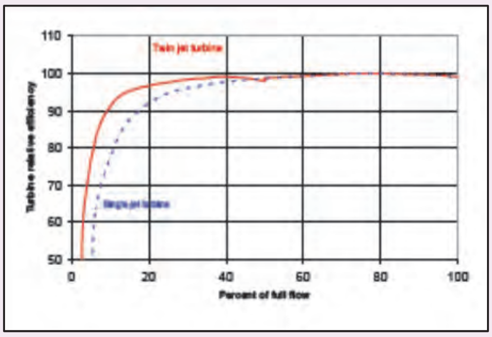
Typical turbine drawing



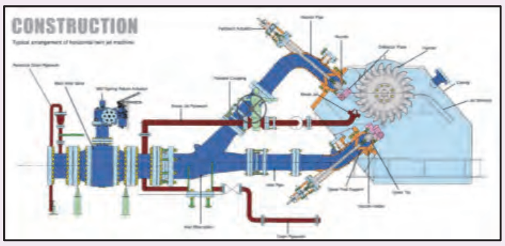
Wasserkraft Volk turbine ranges

<table>
<tr><th></th><th></th></tr>
<tr><td>Turbine Name:</td><td>PELTON TURBINE</td></tr>
<tr><td>Company name:</td><td>Gilbert Gilkes & Gordon Ltd</td></tr>
<tr><td>Company Address:</td><td>Canal Head North
Kendal
Cumbria
UK</td></tr>
<tr><td>Company Tel:</td><td>+44 (0) 1539 720028</td></tr>
<tr><td>Company E-mail:</td><td>enquiries@gilkes.com</td></tr>
<tr><td>Website:</td><td>www.gilkes.com</td></tr>
<tr><td>Turbine Description:</td><td>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.</td></tr>
<tr><td>Pressure Head Range</td><td>Up to 1 000 m</td></tr>
<tr><td>Flow Range</td><td>0.01 m^3/s to 10 m^3/s</td></tr>
<tr><td>Power Range</td><td>Up to 20 000 kW</td></tr>
<tr><td>Illustrations, Photos and Applicable Graphs:</td><td>

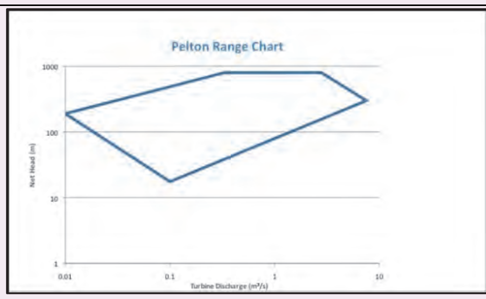
Pelton runner



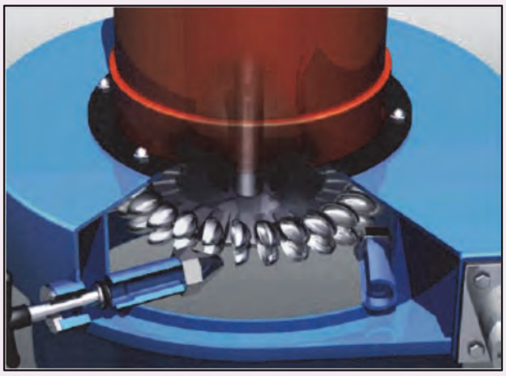
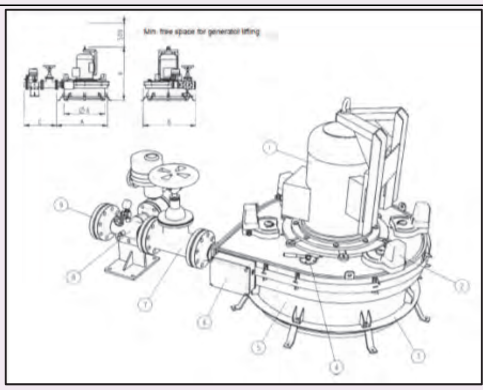
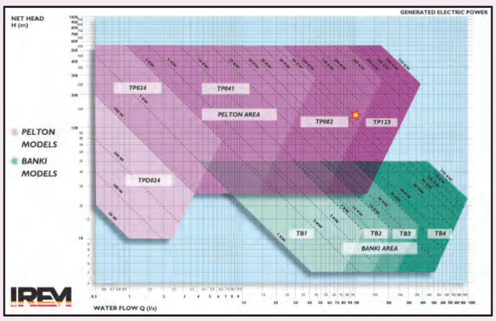
Pelton turbine efficiency



Typical layout

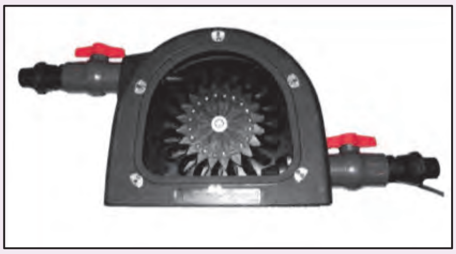


Turbine range
</td></tr>
</table>

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 m^3/s to 0.1 m^3/s
Power Range	Up to 100 kW
Illustrations, Photos and Applicable Graphs:	 *Pelton runner*  *Pelton turbine*  *Turbine components*  *IREM turbine range*

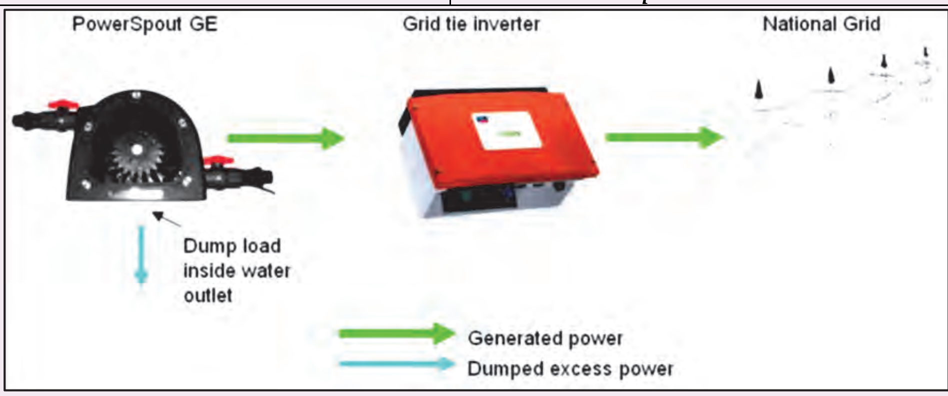
Turbine Name:	**POWERSPOUT PELTON TURBINE**
Company name:	**POWERSPOUT** (**Papersmith and Son (PTY) Ltd**. (South African Distribution))
Company Address:	PO BOX 72548 Parkview GT 2122 SOUTH AFRICA
Company Tel:	+27 011 2406900
Company E-mail:	jo@papersmith.co.za
Website:	www.powerspout.com
Turbine Description:	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 m^3/s to 0.01 m^3/s
Power Range	Up to 1.6 kW per turbine

Illustrations, Photos and Applicable Graphs:

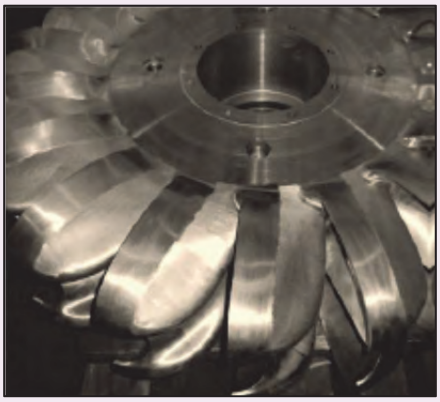
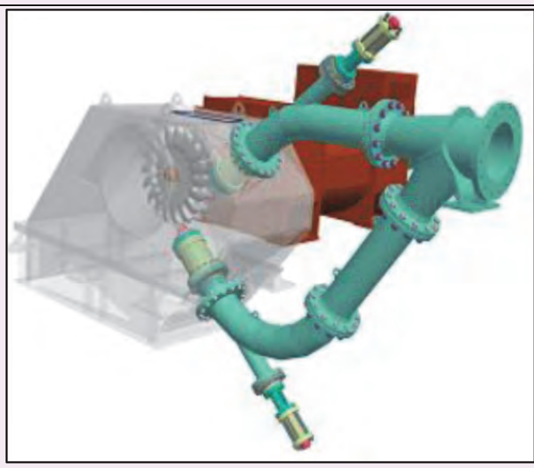
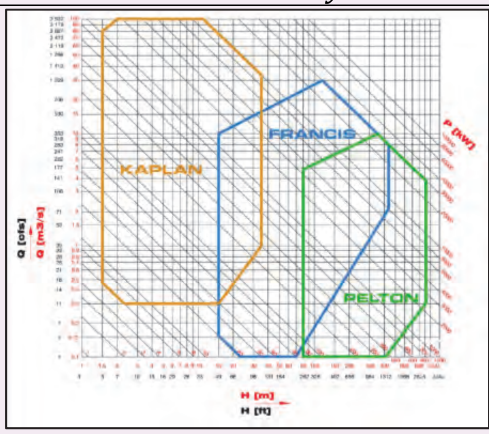


Pelton runner

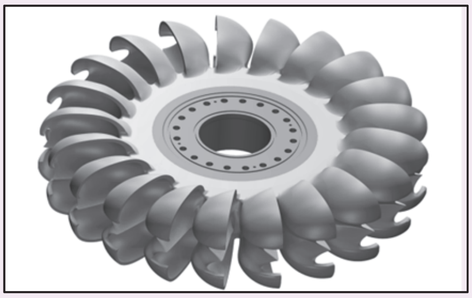
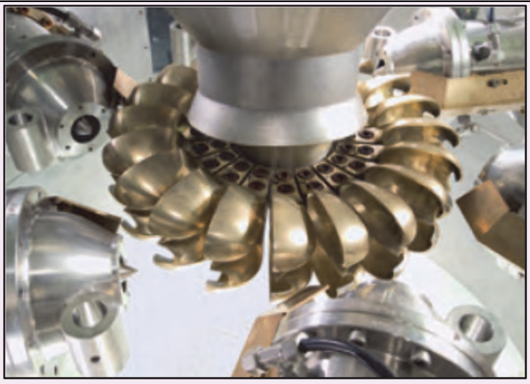
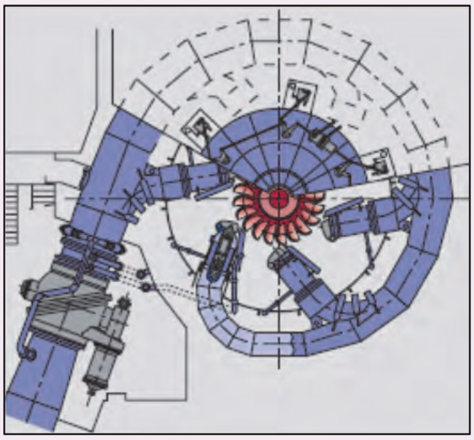
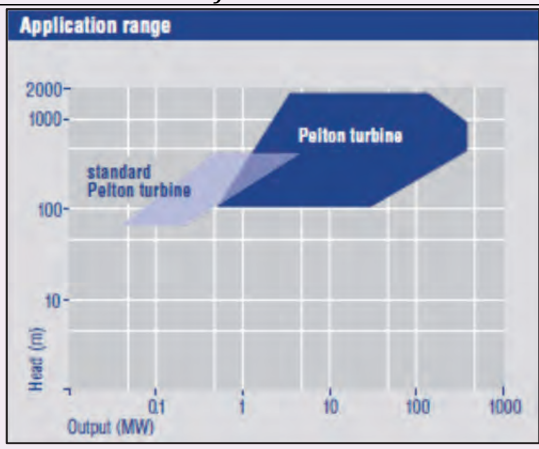
Powerspout turbine room

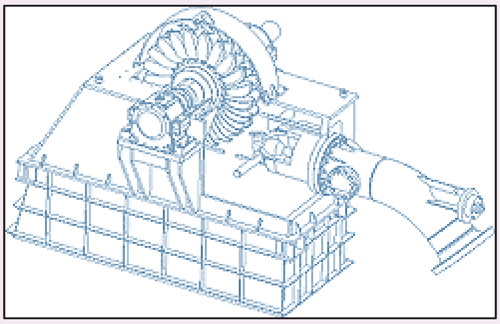
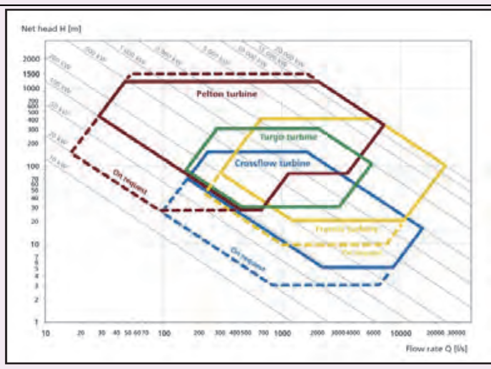


Turbine set-up

<table>
<tr><th></th><th colspan="2"></th></tr>
<tr><td>Turbine Name:</td><td colspan="2">PELTON TURBINE</td></tr>
<tr><td>Company name:</td><td colspan="2">Mavel Hydro Turbines (Scion Technologies (South African Distribution))</td></tr>
<tr><td>Company Address:</td><td colspan="2">Northbank 3rd Floor Northbank Lane
Century City, Cape Town
SOUTH AFRICA</td></tr>
<tr><td>Company Tel:</td><td colspan="2">+27 21 552 9993</td></tr>
<tr><td>Company E-mail:</td><td colspan="2">karenr@sciontechnologies.co.za</td></tr>
<tr><td>Website:</td><td colspan="2">www.mavel.cz</td></tr>
<tr><td>Turbine Description:</td><td colspan="2">Mavel Pelton runners are customized and can be configured either vertically or horizontally.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">80 m to 1000 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.1 m³/s to 10 m³/s</td></tr>
<tr><td>Power Range</td><td colspan="2">70 kW to 30 MW</td></tr>
<tr><td rowspan="2">Illustrations and Applicable Graphs:</td><td>
Pelton turbine runner</td><td>
Pelton turbine layout</td></tr>
<tr><td>
Installed vertical Pelton turbines</td><td>

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

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:	 *Pelton turbine runner*  *5-jet turbine*  *Drawing of 6-jet turbine*  *Turbine range*

<table>
<tr><th></th><th colspan="2"></th></tr>
<tr><td>Turbine Name:</td><td colspan="2">PELTON TURBINE</td></tr>
<tr><td>Company name:</td><td colspan="2">Wasserkraft Volk AG</td></tr>
<tr><td>Company Address:</td><td colspan="2">Am Stollen 13
D-79261 Gutach
GERMANY</td></tr>
<tr><td>Company Tel:</td><td colspan="2">+49 7685-9106-0</td></tr>
<tr><td>Company E-mail:</td><td colspan="2">mail@wkv-ag.com</td></tr>
<tr><td>Website:</td><td colspan="2">www.wkv-ag.com</td></tr>
<tr><td>Turbine Description:</td><td colspan="2">Wasserkraft Volk Pelton turbines can have up to six jets. These machines have high efficiency with fluctuating flow and can handle debris.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">30 m to 1 00 0m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.04 m³/s to 13 m³/s</td></tr>
<tr><td>Power Range</td><td colspan="2">Up to 20 000 kW</td></tr>
<tr><td rowspan="2">Illustrations and Applicable Graphs:</td><td>
5 WKV twin-jet Pelton turbines, total power about 40 MW</td><td>
Pelton wheel</td></tr>
<tr><td>
Typical turbine drawing</td><td>

Wasserkraft Volk turbine ranges</td></tr>
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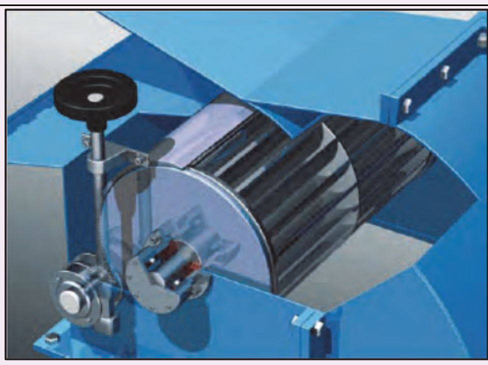
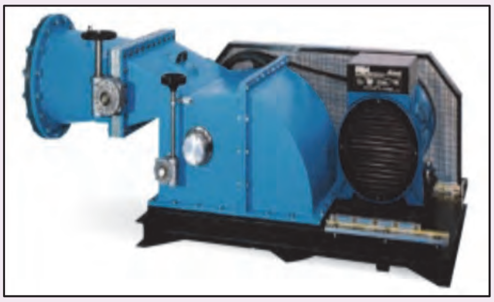
<table>
<tr><th></th><th colspan="2"></th></tr>
<tr><td>Turbine Name:</td><td colspan="2">BANKI (CROSS-FLOW) TURBINE</td></tr>
<tr><td>Company name:</td><td colspan="2">IREM SpA a Socio Unico</td></tr>
<tr><td>Company Address:</td><td colspan="2">Via Abegg 75
Borgone Susa
ITALY</td></tr>
<tr><td>Company Tel:</td><td colspan="2">+39 011 9648211</td></tr>
<tr><td>Company E-mail:</td><td colspan="2">irem@irem.it</td></tr>
<tr><td>Website:</td><td colspan="2">www.irem.it</td></tr>
<tr><td>Turbine Description:</td><td colspan="2">The IREM Banki turbine is connected to a belt driven synchronous or asynchronous generator shaft, depending on the electricity use.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">5 m to 60 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.01 m^3/s to 1 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">Up to 100 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs:</td><td>


Banki runner
</td><td>


Banki turbine
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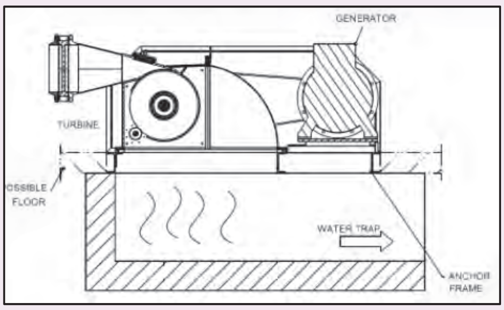
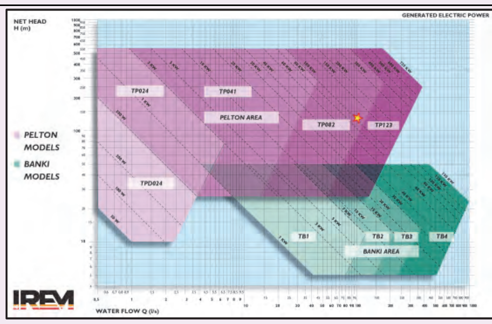
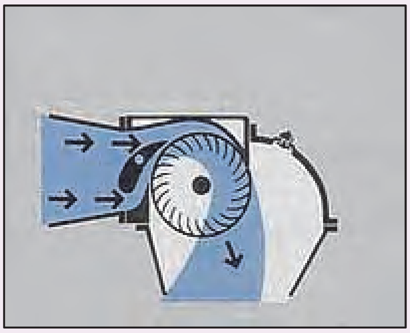
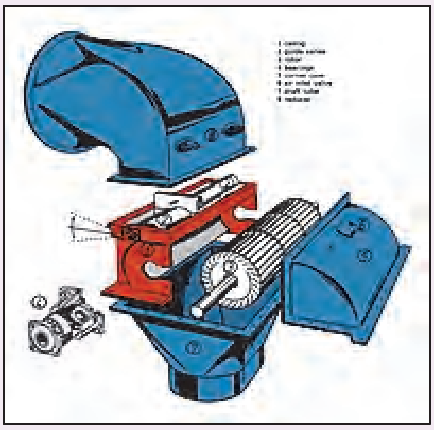
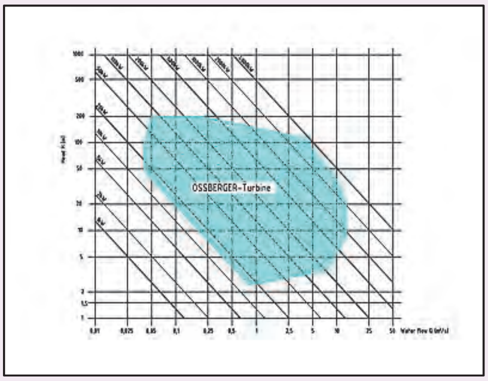


Turbine set-up
</td><td>


IREM turbine range
</td></tr>
</table>

<table>
<tr><th></th><th colspan="2"></th></tr>
<tr><td>Turbine Name:</td><td colspan="2">OSSBERGER-TURBINE</td></tr>
<tr><td>Company name:</td><td colspan="2">OSSBERGER GmbH + Co</td></tr>
<tr><td>Company Address:</td><td colspan="2">Otto-Rieder-Str. 7
91781 Weissenburg / Bavaria
GERMANY</td></tr>
<tr><td>Company Tel:</td><td colspan="2">+49 (0)9141/977-0</td></tr>
<tr><td>Company E-mail:</td><td colspan="2">info@ossberger.de</td></tr>
<tr><td>Website:</td><td colspan="2">www.ossberger.de/cms/pt/hydro/contact/</td></tr>
<tr><td>Turbine Description:</td><td colspan="2">Ossberger turbines are designed so that water passes through the runner twice.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">2.5 m to 200 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.04 m^3/s to 13 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">15 kW to 3 000 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs:</td><td>
Inflow horizontal</td><td>
Inflow vertical</td></tr>
<tr><td>
Two-cell Ossberger turbine</td><td>

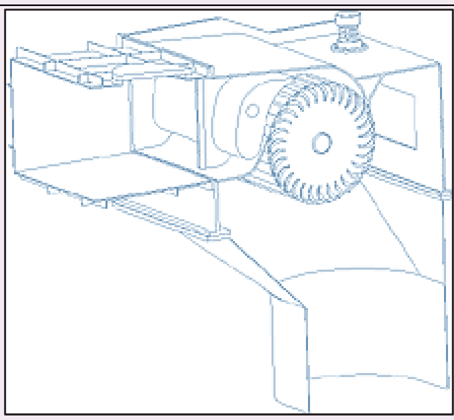
Turbine range</td></tr>
</table>

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

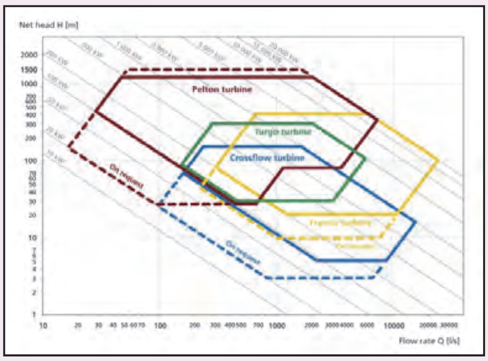
Illustrations and Applicable Graphs:

Crossflow turbine room

Crossflow turbine wheel



Typical turbine drawing



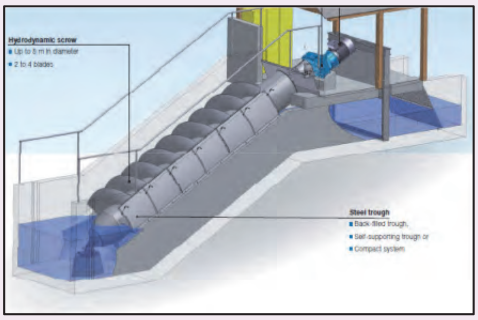
Wasserkraft Volk turbine ranges

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

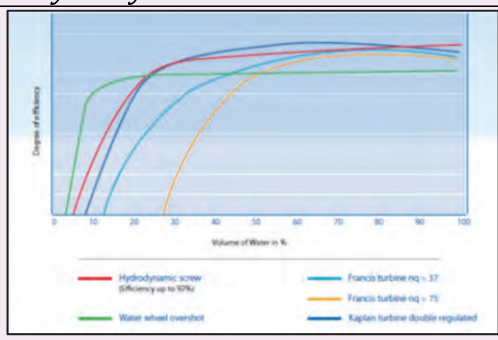
Illustrations, Photos and Applicable Graphs:

Hydrodynamic Screw

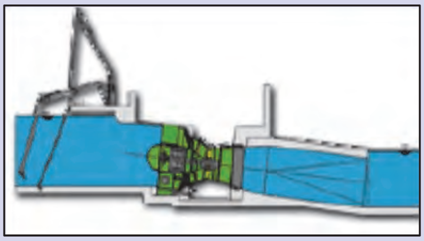
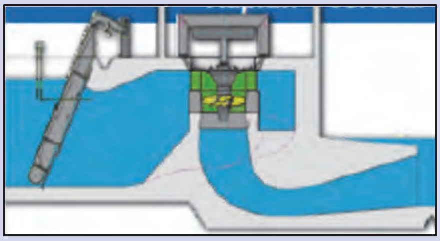
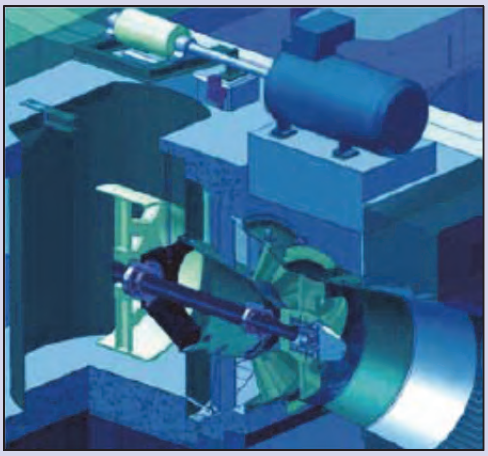
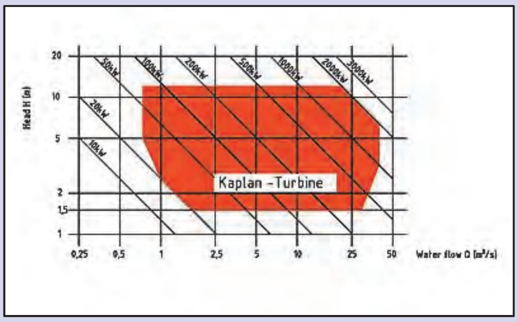
Hydrodynamic screw installation



Typical layout



Turbine efficiency

<table>
<tr><th></th><th colspan="2"></th></tr>
<tr><td>Turbine Name:</td><td colspan="2">KAPLAN TURBINE</td></tr>
<tr><td>Company name:</td><td colspan="2">OSSBERGER GmbH + Co</td></tr>
<tr><td>Company Address:</td><td colspan="2">Otto-Rieder-Str. 7
91781 Weissenburg / Bavaria
GERMANY</td></tr>
<tr><td>Company Tel:</td><td colspan="2">+49 (0)9141/977-0</td></tr>
<tr><td>Company E-mail:</td><td colspan="2">info@ossberger.de</td></tr>
<tr><td>Website:</td><td colspan="2">www.ossberger.de/cms/pt/hydro/contact/</td></tr>
<tr><td>Turbine Description:</td><td colspan="2">The Ossberger Kaplan turbine has a compact, low-maintenance construction and is easily installed.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">1.5 m to 20 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">1.5 m^3/s to 60 m^3/s</td></tr>
<tr><td>Power Range</td><td colspan="2">20 kW to 3 500 kW</td></tr>
<tr><td rowspan="2">Illustrations, Photos and Applicable Graphs:</td><td>
Inflow horizontal</td><td>
Inflow vertical</td></tr>
<tr><td>
Computer generated view of Kaplan</td><td>

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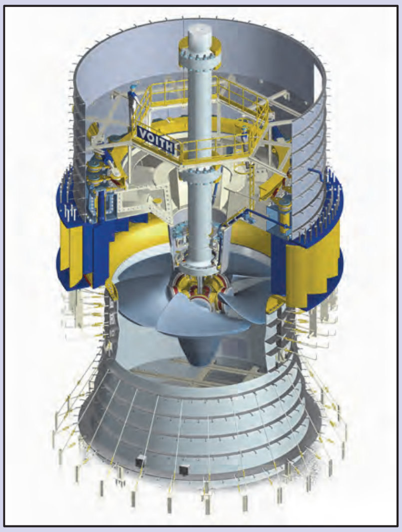
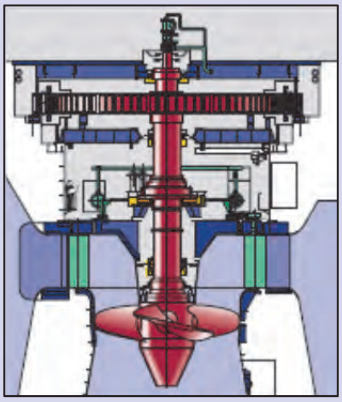
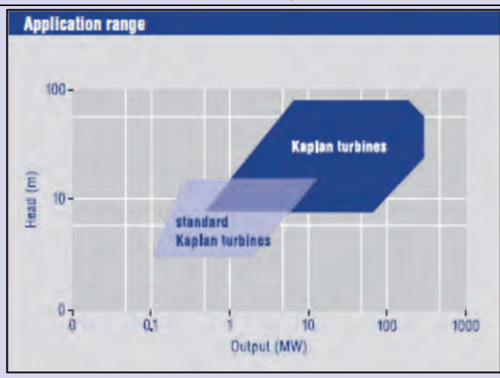
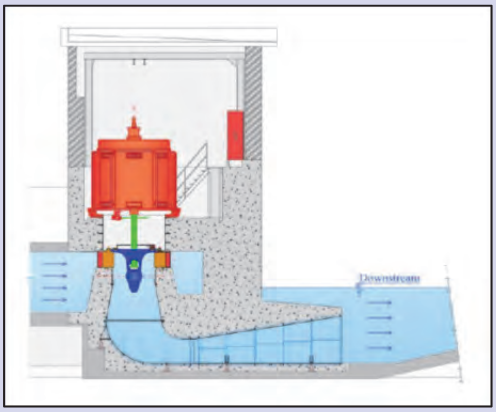
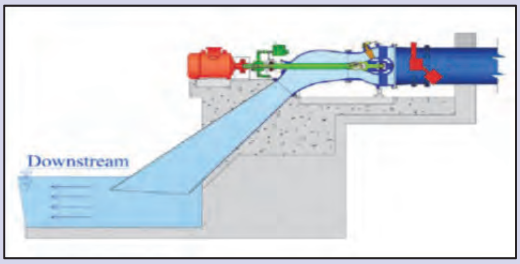
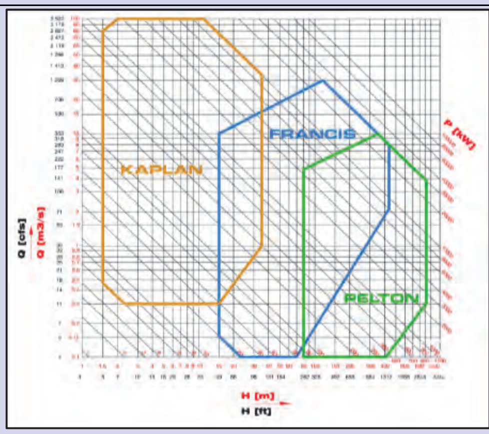
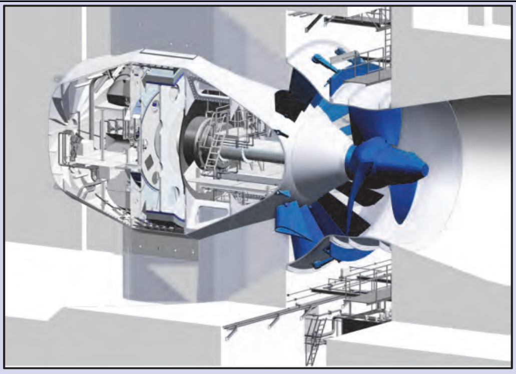
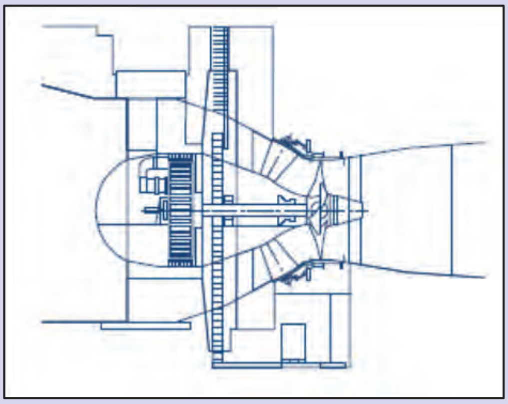
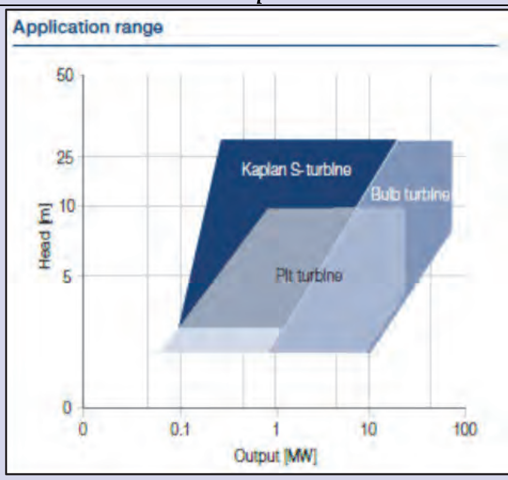
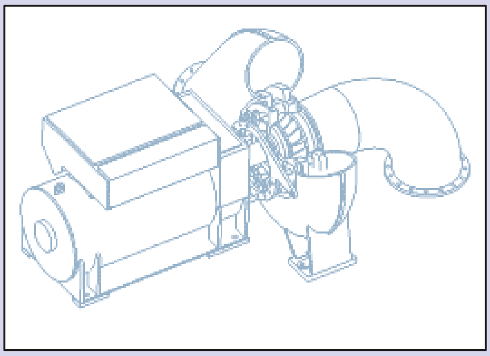
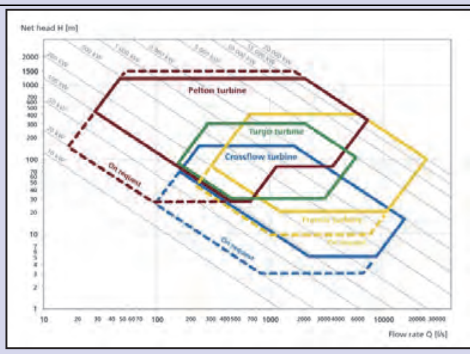
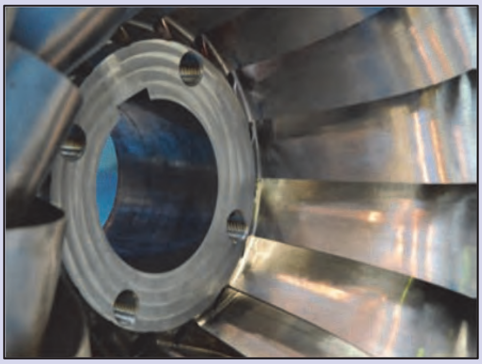
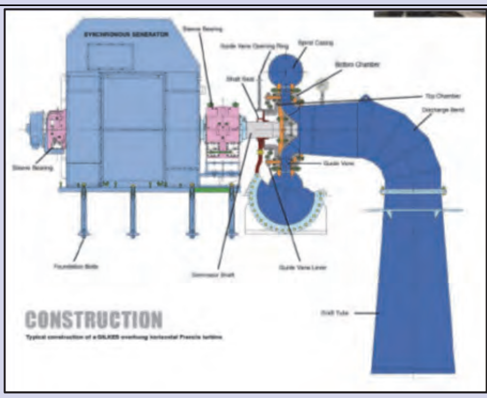
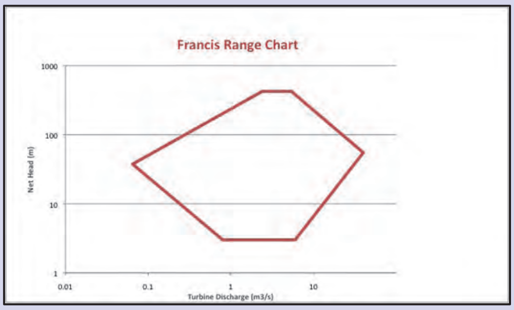
Turbine Name:	**KAPLAN TURBINE**
Company name:	**Voith Hydro Holding GmbH & Co. KG**
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel:	+49 7321 37 0
Company E-mail:	info.voithhydro@voith.com
Website:	www.voithhydro.com
Turbine Description:	Voith Kaplan turbines are designed to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

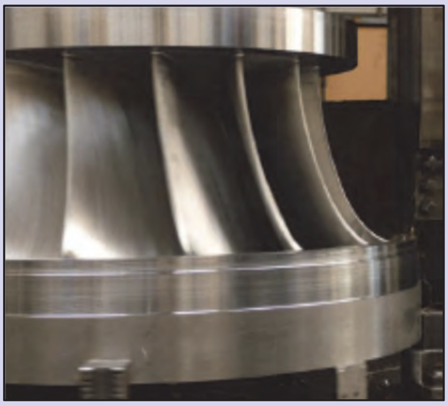
Turbine Name:	**KAPLAN TURBINE**
Company name:	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address:	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel:	+27 21 552 9993
Company E-mail:	karenr@sciontechnologies.co.za
Website:	www.mavel.cz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

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

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

Turbine Name:	**FRANCIS TURBINE**
Company name:	**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 m^3/s to 40 m^3/s
Power Range	Up to 20 000 kW
Illustrations, Photos and Applicable Graphs:	 *Francis runner*  *Francis turbine*  *Typical layout*  *Turbine range*

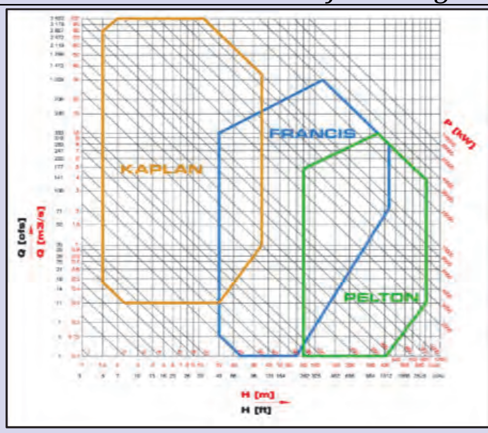
Turbine Name:	**FRANCIS TURBINE**
Company name:	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address:	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel:	+27 21 552 9993
Company E-mail:	karenr@sciontechnologies.co.za
Website: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



Francis runner

Francis turbine manufacturing

Typical layout

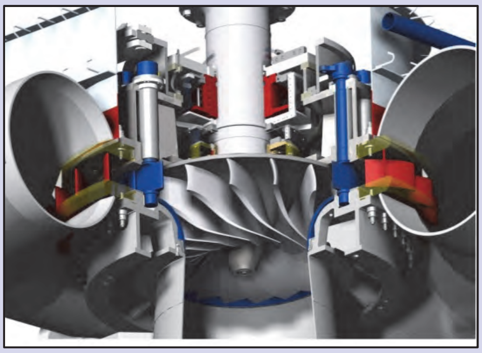


Turbine range

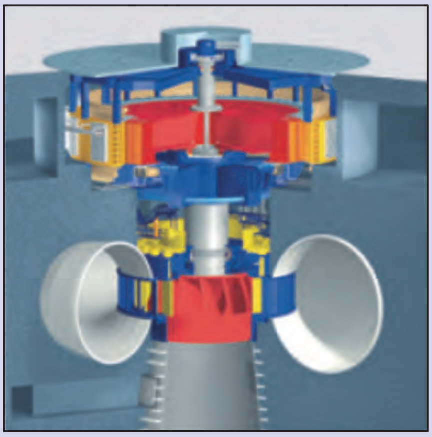
Turbine Name:	**FRANCIS TURBINE**
Company name:	**Voith Hydro Holding GmbH & Co. KG**
Company Address:	Alexanderstrasse 11 89522 Heidenheim GERMANY
Company Tel:	+49 7321 37 0
Company E-mail:	info.voithhydro@voith.com
Website:	www.voithhydro.com
Turbine Description:	The Voith Francis turbines are used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

Illustrations and Applicable Graphs:

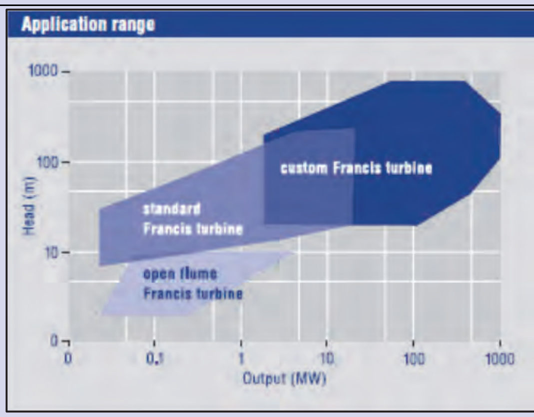
Francis turbine runner



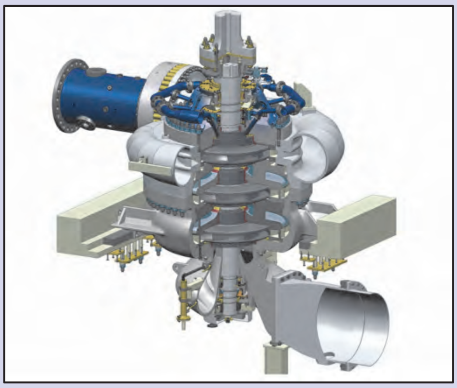
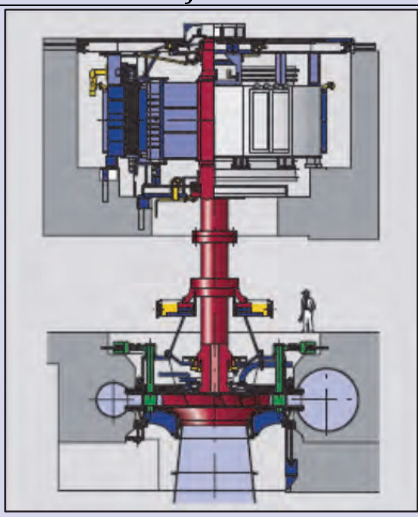
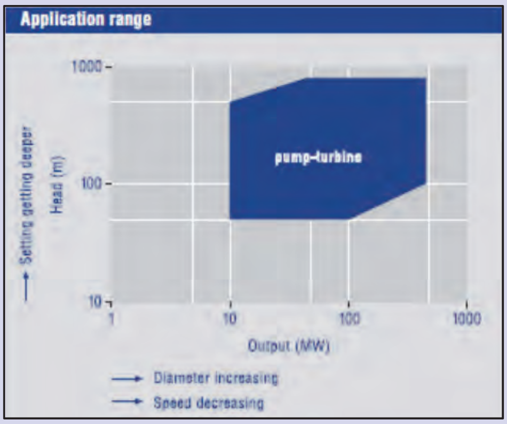
Turbine layout



Cross section of a Francis turbine



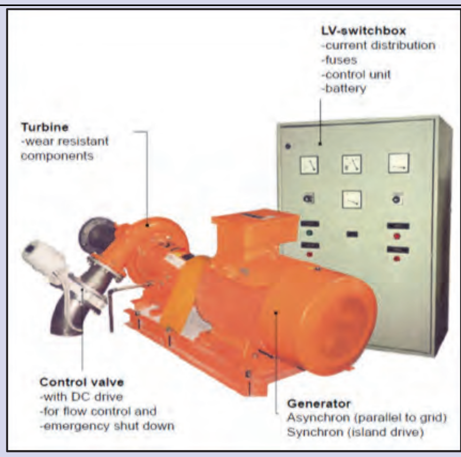
Turbine range

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:	 *Turbine runner for Palmiet, South Africa*  *Turbine layout*  *Cross of a variable speed pump-turbine runner*  *Turbine range*

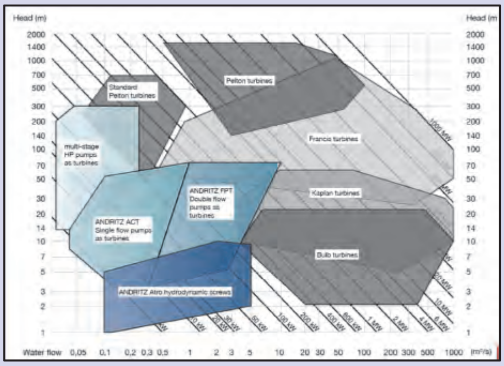
Turbine Name:	**PUMP-AS-TURBINE**
Company name:	**Andritz**
Company Address:	Penzinger Strasse 76 Vienna AUSTRIA 1141
Company Tel:	+43 (1)891 00 0
Company E-mail:	hydro@andritz.com
Website:	www.andritz.com
Turbine Description:	This turbine utilizes a centrifugal pump in reverse to generate electricity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

Illustrations and Applicable Graphs:

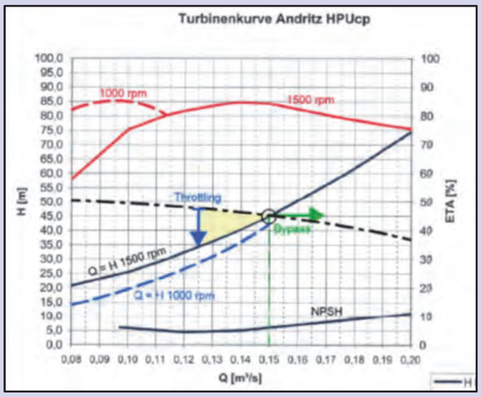
Installed turbines



Turbine components



Turbine range

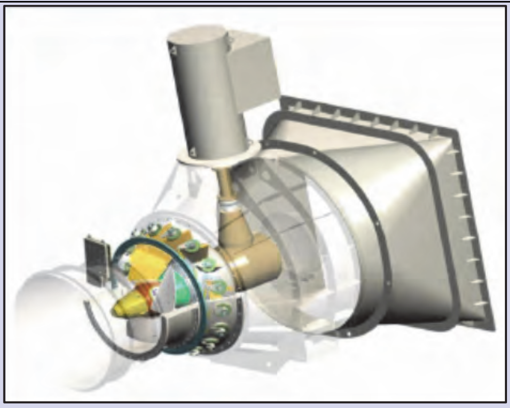


Turbine curve

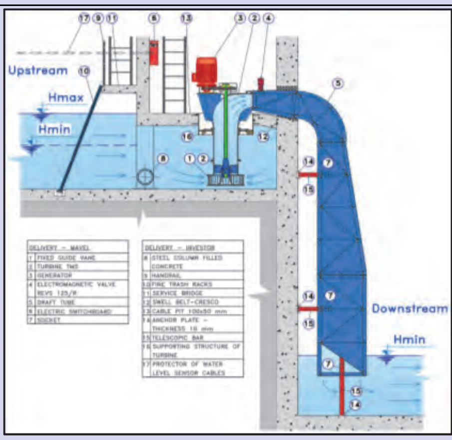
Turbine Name:	**SYPHON-TYPE TURBINE**
Company name:	**Mavel Hydro Turbines** (**Scion Technologies** (South African Distribution))
Company Address:	Northbank 3rd Floor Northbank Lane Century City, Cape Town SOUTH AFRICA
Company Tel:	+27 21 552 9993
Company E-mail:	karenr@sciontechnologies.co.za
Website:	www.mavel.cz
Turbine Description:	Mavel Micro turbines are designed to function with low head and work on the principle of 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:

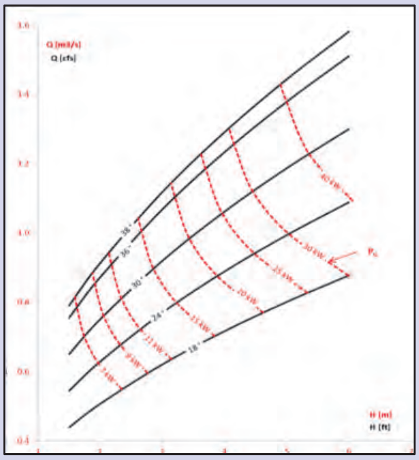
Three micro turbines in parallel



Turbine layout



Construction drawing of a syphon turbine



Turbine range (MT5)

<table>
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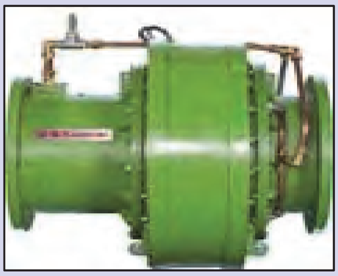
<tr><td>Turbine Name:</td><td colspan="2">RING HYDROTURBINE</td></tr>
<tr><td>Company name:</td><td colspan="2">Kawasaki Plant Systems Ltd.</td></tr>
<tr><td>Company Address:</td><td colspan="2">1-14-5, Kaigan, Minato-ku
Toyo
JAPAN</td></tr>
<tr><td>Company Tel:</td><td colspan="2">+81-3-3435-2111</td></tr>
<tr><td>Company E-mail:</td><td colspan="2">Not given</td></tr>
<tr><td>Website:</td><td colspan="2">www.khi.co.jp</td></tr>
<tr><td>Turbine Description:</td><td colspan="2">This high efficiency inline system is easily installed in small spaces and requires little maintenance.</td></tr>
<tr><td>Pressure Head Range</td><td colspan="2">3 m to 30 m</td></tr>
<tr><td>Flow Range</td><td colspan="2">0.14 m³/s to 2.8 m³/s</td></tr>
<tr><td>Power Range</td><td colspan="2">20 to 500 kW</td></tr>
<tr><td rowspan="2">Illustrations and Applicable Graphs:</td><td>


Ring hydroturbine
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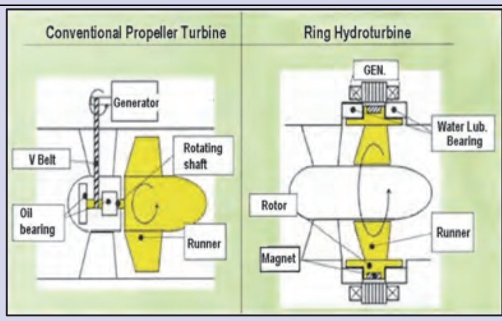

Ring and propeller comparison
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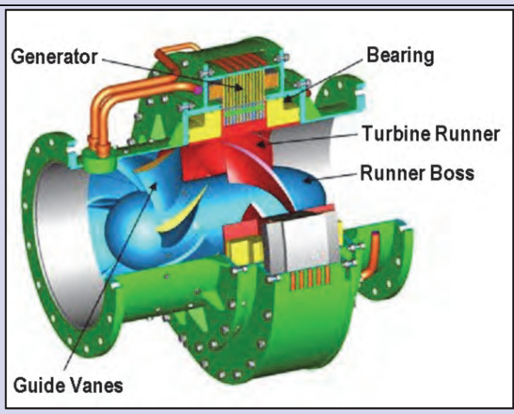

Turbine layout
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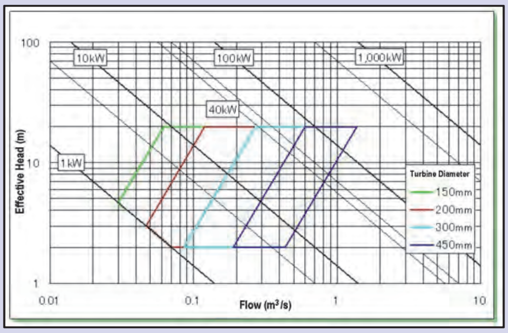

Turbine ranges
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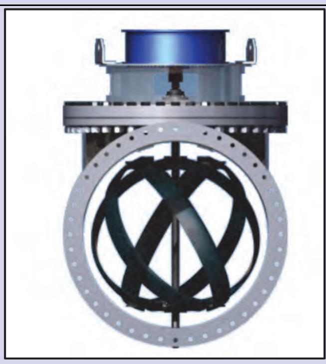
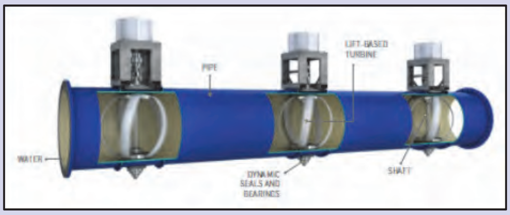
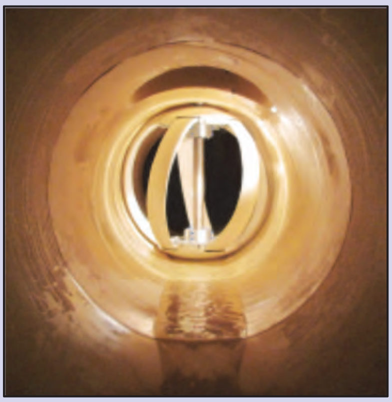
Turbine Name:	**LUCIDPIPE POWER SYSTEM**
Company name:	**LucidEnergy**
Company Address:	108 NW 9th Avenue Suite 201C Portland USA
Company Tel:	+1 574-238-5415
Company E-mail:	Josh.kanagy@lucidenergy.com
Website:	www.lucidenergy.com
Turbine Description:	These spherical turbines are installed inline in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

9781431205493