CONDUIT HYDROPOWER POTENTIAL IN A CITY'S WATER DISTRIBUTION SYSTEM

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Abstract
Energy is the lifeblood of worldwide economic and social development. When considering the current status of global energy shortages, the emphasis to reduce CO2 emissions and development of alternative energy generation methods are being adopted at all levels of the South African economy. Renewable energy technologies are without a doubt an important contributor to the means how the future economic development will be supported and energy demands satisfied.

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 pressurised or gravity conditions over large distances and elevations. In South Africa 284 municipalities, water supply utilities, mines, and the agricultural sector 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 may potentially 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.

The University of Pretoria (UP) supported by the Water Research Commission (WRC) is engaged in a research project investigating the potential of extracting the excess hydropower energy from water distribution systems.

The benefit of this hydropower generating application is that minimal civil works is required, leading to little impacts and normally no environmental or social mitigation being required.

A pilot plant has been completed in the City of Tshwane where approximately 15 kW is generated, showing promising results.

This technical paper describes the application of this technology in water distribution system and the development of a decision support system as part of guidelines that will assist in the identification and development of conduit hydropower sites in a city's water distribution system.

1. INTRODUCTION
Energy sustains worldwide economic and social development. When considering the current status of global energy shortages, the emphasis to reduce CO_2 emissions and development of alternative energy generation methods are being adopted at all levels of the South African economy. The improving of energy efficiency, optimisation of existing systems and seeking new approaches in conversion of one energy form into another are spheres of energy generation which could be labelled as renewable sources.

The increasing demands for energy, primarily driven by population growth and changing lifestyles have to be met in order to stimulate uninterrupted economic growth. The increasing energy demand can be satisfied by developing new generating capacity or by implementing renewable energy resources applying new technologies. The renewable energy technologies are without a doubt the means how the future economic development will be supported and energy demands satisfied. Among targeted renewable energy sources available for energy generation in South Africa are solar radiation, biomass, wind and also rather underrated hydropower.

South Africa is acknowledged to be not particularly endowed with the best hydropower potential in Africa due to the water scarcity. However, large quantities of raw and potable water are conveyed daily under either pressurised or gravity conditions over long distances and elevations. These water conveyance systems have to be operated under sustainable water supply regimes, which is a very important aspect in operation of any hydropower generation system.

In South Africa there are 284 municipalities and several water supply utilities, all owning and operating gravity water supply distribution systems which could be considered for small scale hydropower installations. Most of these water supply/distribution systems can 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. The University of Pretoria (UP) supported by the Water Research Commission (WRC) is engaged in a research project to investigate the potential of extracting the available energy from existing and newly installed water supply and distribution systems. The project aims are to enable the owners and administrators of the bulk water supply and distribution systems to install small scale hydropower systems to generate hydroelectricity for onsite use and in some cases to supply energy to isolated electricity demand clusters or even to the national electricity grid, depending on the location, type and size of installation. According to Briggeman et al. (2011) there are basically four areas where energy can be generated in the water supply and distribution system as shown in Figure 1.

1. Dam releases – conventional hydropower
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 or in the distribution network itself where excess energy is dissipated (typically with pressure reducing valve stations)
4. Treated effluent – cases where the treated effluent has potential energy based on its elevation above the discharge point.

To distinguish the type of hydropower that will be generated it is called "conduit hydropower" (NHA, 2011) as shown in Figure 1, at locations (2), (3) and (4).

A number of water authorities throughout the world have realised the potential of conduit hydropower and implemented generating schemes (NHA, 2011; Möderl et. al. 2012; Fontana et. al., 2012; and White, 2011). These conduit hydropower plant (CHP) installations were generally standalone systems.

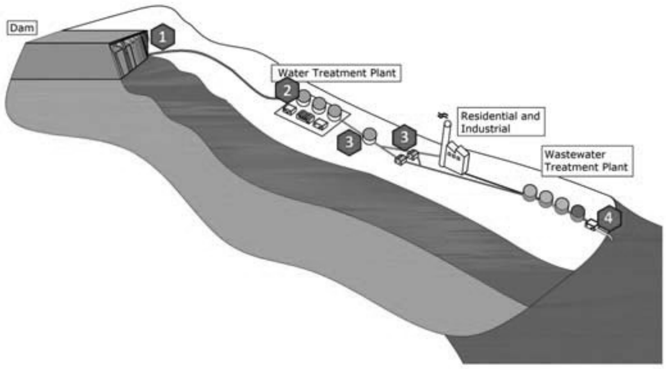


Figure 1: Location of energy generation potential

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

- Clean - Because hydropower utilises water to generate electricity, it doesn't produce air pollution or create toxic by-products like power plants that burn fossil fuels such as coal or natural gas.
- Renewable - Hydropower is renewable because it relies on the hydrological (water) cycle driven by the sun which provides a renewable supply of water. Hydropower facilities harness the natural energy of flowing and falling water to generate electricity. About 96% of the United States' renewable energy comes from hydropower.
- Reliable - Hydropower can meet changing demands because it can go from zero power to maximum output rapidly and predictably. Hydroelectric energy technology is proven technology offering reliable and flexible operations. Conduit hydropower uses the available water distribution infrastructure and thus as long as there is a demand for water electricity can be generated.
- Retrofitting - Conduit hydropower can be retrofitted into existing water infrastructure resulting in a minimal environmental impact.
- Efficient - Hydropower stations achieve high efficiencies.
- Design life - Hydroelectric stations have a long life – many existing stations have been in operation for more than half a century and are still operating efficiently.

An initial scoping investigation highlighted the potential hydropower generation at the inlets to storage reservoirs i.e. the bulk water distribution systems. Although it was a low budget pilot hydropower generation installation which was erected at Queenswood Reservoir (City of Tshwane Metropolitan Municipality) which was not optimised, the initial runs reflected the benefit and expected return from such an investment (Van Vuuren, 2010).

The focus of the Water Research Commission research project is on the potable water distribution system. This technical paper reports on the progress of the research project and focuses on the potential applications of this technology in South Africa.

2. NEED FOR RENEWABLE ENERGY DEVELOPMENT IN SOUTH AFRICA

Awareness on renewable energy development in South Africa was initiated in November 2003, when the South African Government, introduced the White Paper on Renewable Energy. This White Paper on RE stated inter alia a 2013 target of 10 000 GWh to be generated annually from the renewable sources namely biomass, wind, solar radiation and small scale hydropower.

South Africa as one of the signatories of the Kyoto Protocol (February 2005) committed itself in reducing emissions by 34% in 2020 below projected emissions level. The emissions level from all sources for South Africa as whole is currently estimated at about 500 000 000 tons of carbon dioxide equivalent (CO_2e) per annum. If the South Africa is to achieve its estimated targets a decrease in emissions should be at least 0,2% per annum. To provide suitable enabling environment for emissions reduction and reliable energy supply for the SA economy the Department of Energy (DoE) with the endorsement from the National Energy Regulator of SA (NERSA) introduced the Integrated Electricity Resource Plan (IRP) for South Africa 2010 – 2030. The IRP 2010 has been subjected to the public scrutiny and comments and eventually the whole process manifested in the Final Policy Adjusted IRP 2010: New-build Technology Mix. The DoE subsequently allocated different capacities across various renewable energy technologies from the total development capacity of 3725 MW. The hydropower sector has been allocated overall capacity of 75 MW to be commercially operational by June 2014. One of the critical qualification requirements is that only the small scale hydropower installations above 1 MW are to be included in the forthcoming selection process. Effectively all pico (up to 20 kW as shown in Table 1), micro (20 kW to 100 kW) and mini (100 kW to 1 MW) renewable energy installations are below the radar of interest from the authorities at this stage.

Table 1: Hydroelectric capacity applications from the small scale categories

Hydropower category	Capacity in power output	Potential hydropower use either as a single source or in a hybrid configuration with other sources of renewable energy
Pico	Up to 20 kW	10 kW network to supply a few domestic dwellings
Micro	20 kW to 100 kW	100 kW network to supply small community with commercial/ manufacturing enterprises
Mini	100 kW to 1 MW	1 MW plant can offset about 150 000 tons of CO_2 annually and will provide about 1 000 sub-urban households with reliable electricity supply.
Small	1 MW to 10 MW	1 MW to 10 MW network– electrical distributions will be at medium voltage ranging from 11 to 33 kV and transformers are normally needed. The generation must be synchronised with the grid frequencies (typically to 50 or 60 Hertz).
NB: All installations above 10 MW are classified as macro (or large) hydropower plants		

Internationally, the small hydro is considered to be best proven of all renewable energy technologies, ideal for the electrification of remote communities, assisting in peak supply and is more reliable in balancing out variations present in other renewable power production.

3. ADDING HYDROELECTRIC INSTALLATIONS TO EXISTING DAM STORAGES (CONVENTIONAL HYDROPOWER PLANT)

SA National Committee of Large Dams (SACOLD) reflected in June 2009 that 1033 medium size dams (12 to 30 m) and 192 large dams (30 m and higher) has been built in South Africa. Furthermore some 1225 water storage schemes were identified which may theoretically be suitable for hydroelectric development. The dams where water is released on regular basis for the sustainable ecosystem downstream of the dam and/or for the purposes of river abstraction by other downstream situated water users are most suitable for the hydroelectric plants. A recent study by Blersch et al. (2009) developed a model to determine the feasibility of retrofitting hydropower onto existing dams. The potential is available and needs to be developed.

It is estimated that about 60 medium to large dams in state ownership can be fitted potentially with the conventional hydropower equipment ranging between 300 kW and 3 MW. The overall potential annual generation output may amount to about 320 GWh which in a turn can supply some 200 000 middle class households and 500 000 sub-urban households. In comparing the international trends to similar local small scale hydropower potential, the cheapest and most sustainable in South Africa are pico, micro and mini hydropower schemes to be implemented in existing water supply and distribution systems.

4. HYDROELECTRIC INSTALLATIONS IN WATER SUPPLY LINE BETWEEN DAM IMPOUNDMENT AND WATER TREATMENT FACILITY OR SERVICE RESERVOIR

The turbine/generator set is typically installed just upstream of the inlet pipe to the service reservoir. Water is discharged into service reservoir under the atmospheric pressure. In SA, typically, several inter-basin water transfer schemes (WTS) can be considered for the hydroelectric development. The systems identified to date are mainly under corporate administration of ESKOM and DWA. The most suitable systems are as follows:

- Assegaai to Vaal WTS (KZN to Mpumalanga) – Hyeshope Dam to Geelhout Pumping Station with estimated hydroelectric potential of about 10 MW

- Usutu GWS – Barmoral Canal and pipeline to Morgenstond Dam with estimated hydroelectric potential of about 10.5 MW.
- Vaal River Eastern Sub-system Augmentation Project (VRESAP) – two prong gravity pipelines one to ESKOM and second conveying water to SASOL from the Knoppiesfontein Diversion Structure. Estimated hydroelectric potential is at least 1 MW at each site.
- Orange-Fish Tunnel Shaft 7- the pressure reducing valves located in the large underground chamber can be replaced by suitable turbine/generator sets with estimated potential of 10 MW plus.

5. HYDROELECTRIC INSTALLATION IN BULK WATER SUPPLY LINE AND WATER DISTRIBUTION SYSTEMS

Several water supply utilities (former water boards) and metropolitan municipal water supply systems with the configuration comprising a gravity pipeline connecting two reservoirs are suitable for the hydroelectric in-line installation. The turbine/generator set can be installed on the delivery or by-pass with the pressure at least two atmospheres. The excess pressure can be exploited for the hydroelectricity generation.

5.1 Rand Water

The utility determined that among its 58 service reservoirs that there is a firm hydroelectric potential of 15 MW. It has been subsequently estimated that further 50 MW of capacity is hidden within the utility's water supply and distribution systems.

5.2 eThekwini Municipality

eThekwini's Water and Sanitation Department is investigating a number of micro or mini hydroelectric installations within the eThekwini Potable Water system. Some of the proposed reservoir sites are at Sea Cow Lake, Kwa Mashu 2, Aloes, Phoenix 1, Phoenix 2 and Umhlanga 2 Reservoirs.

5.3 Bloem Water

Bloem Water is considering mini hydropower installations at the Uitkijk and Brandkop reservoirs on the Caledon-Bloemfontein Pipeline. The water is abstracted from the Welbedacht Dam situated in the Caledon River, purified at the Welbedacht Dam WTW and pumped 6.7 km to the De Hoek Reservoir (22.7 Mℓ). From here it gravitates via a 50 year old, 1 170 mm Ø pre-stressed concrete gravity mains 47 km to the Uitkijk break water reservoir (9.1 Mℓ) and a further 58.8 km to the Brandkop Reservoir (136 Mℓ) as shown in Figure 2. The two segments of the Caledon-Bloemfontein gravity pipeline are controlled on the downstream end, at the Uitkijk- and Brandkop Reservoirs, respectively. The control valves at Uitkijk Reservoir which can be bypassed and the water fed through a turbine is shown in Figure 3.

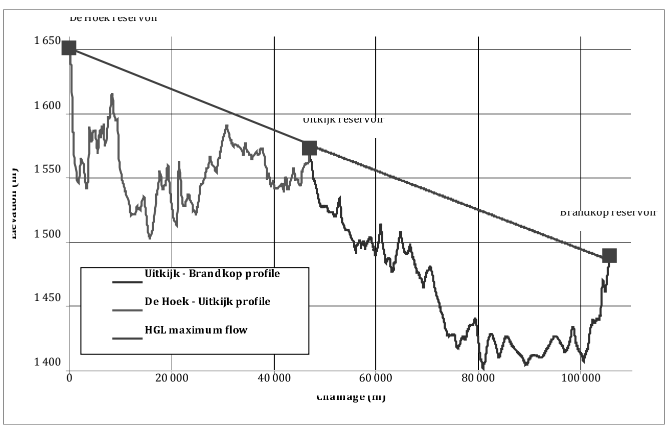


Figure 2: Longitudinal profile of the Caledon-Bloemfontein Pipeline

Figure 3: The six control valves on the 3 branches feeding into the Uitkijk Reservoir

It is still in the initial pre-feasibility stage of the projects but a bypass system is proposed with turbines at each of these reservoirs. The potential for the Uitkijk and Brankop Reservoir sites are 350 kW and 410 kW respectively based on 70% design flow rates. Payback periods of approximately 4 years are projected.

5.4 City of Tshwane

Geographically speaking the City of Tshwane has a lower elevation then the bulk service Reservoirs of Rand Water which is the main water supply. Water is then distributed through a large water system that includes 160 reservoirs, 42 water towers, 10 677 km of pipes and more than 260 pressure reducing installations (PRV's) that operates at pressures up to 250 m.

In the Tshwane Water Supply Area, there are a number of reservoirs receiving water from Rand Water at a pressure of up to 250 m. Assuming that only 50% of the available static head can be used to generate power and that generation can only be done for 6 hours per day allowed for the calculation of the potential annual hydropower generation from these pressurised supply pipelines. As a desktop study the ten larger reservoir sites in the City of Tshwane (CoT) were identified. The use of the potential energy stored in the pressurised close conduit water systems in Tshwane is however not limited to the 10 larger sites.

Table 2 and Figure 4 indicate the potential hydropower generation capacity at different reservoirs in the Tshwane Water Supply Area.

Table 2: Potential annual hydropower generation capacity at the ten most favourable reservoirs in the Tshwane Water Distribution System

Reservoirs	TWL (m.asl)	Capacity (kℓ)	Pressure (m)	Flow (ℓ/s)	Annual potential power generation (kWh)
Garsfontein	1 508.4	60 000	165	1850	3 278 980
Wonderboom	1 351.8	22 750	256	470	1 292 471
Heights LL	1 469.6	55 050	154	510	843 673
Heights HL	1 506.9	92 000	204	340	745 062
Soshanguve DD	1 249.5	40 000	168	400	721 859
Waverley HL	1 383.2	4 550	133	505	721 483
Akasia	1 413.8	15 000	190	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

The capacity of hydroelectric installations can vary to suit the application for the amount of power to be generated or needed. In some cases it a necessity to have communication with reservoirs in isolated areas due to various operation, maintenance and infrastructure management reasons. The hydroelectric potential could be exploited to power telemetry, pressure management, flow control and 24 hr monitoring/security systems.

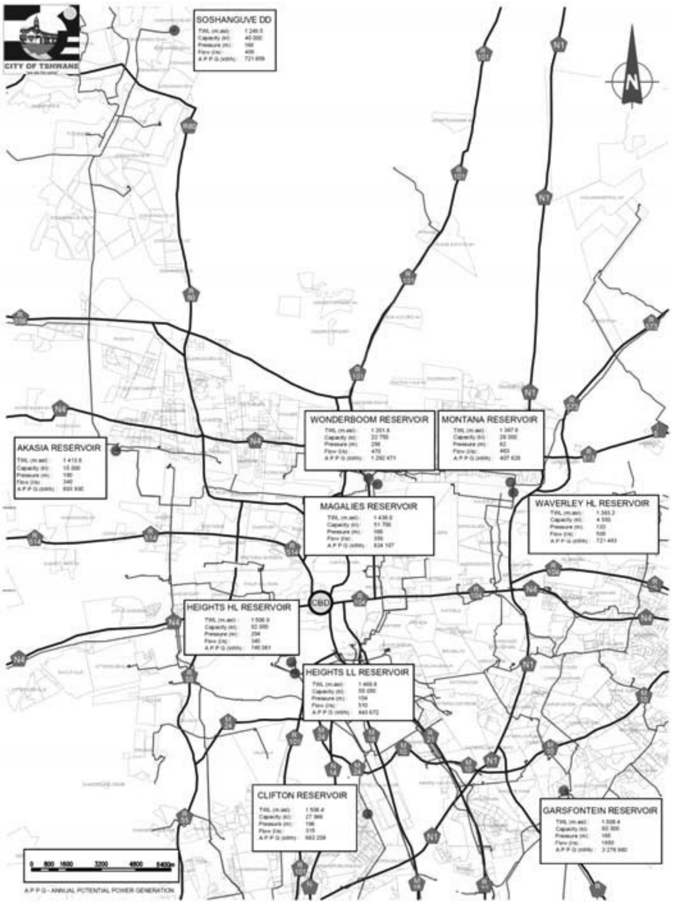


Figure 4: Hydropower generation capacity at different reservoirs in the CoT WDS

Pierre van Ryneveld Conduit Hydropower Plant

Although the site is not one of the top ten favourites as listed in Table 2, to utilise for power generation the site was selected due to the construction of a new 15 Mℓ reservoir near the existing reservoir. This provided the opportunity to construct a hydropower plant at the existing reservoir.

The generated power is utilised on site for lighting, alarm, communication, etc. The home owners association of the estate in which the reservoirs are situated have also indicated that they would like to utilise the power for street lighting.

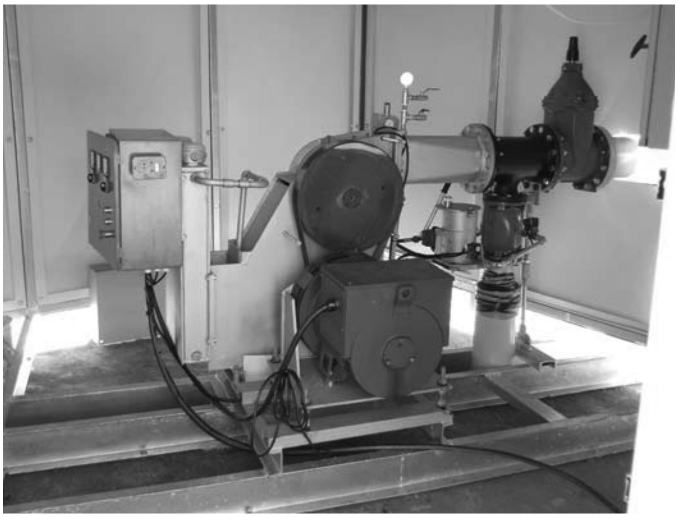


Figure 5: Cross flow turbine installation on top of old reservoir

6. CONDUIT HYDROPOWER RESEARCH PROJECT

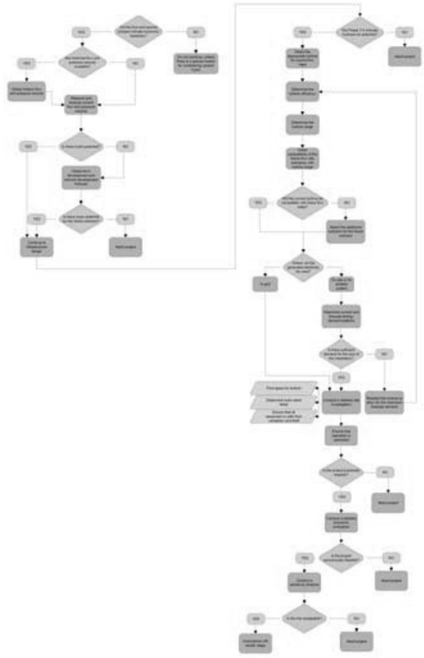
One of the Water Research Commission's goals is to provide new innovative solutions to address the challenges of the South African water sector through research and development. Identifying research projects that provide a sustainable development solution such as the project: *Energy generation from distribution systems* is important in achieving their desired outcomes. This project undertaken by the University of Pretoria and collaborating organisations (City of Tshwane, eThekwini Municipality and Bloem Water) has the following aims:

1. To prove that it is feasible and technically possible to generate energy from distributions systems.
2. Development of guidelines to identify locations which have potential for hydropower generation.
3. Development of an assessment model including a cost benefit tool.
4. To develop a tool for optimisation of the energy generation from a pressurised conduit by evaluating storage volumes, demand patterns, operating cycles and operating life of the control valves.
5. Demonstration of technology by means of full scale pilot plant installations.
6. Provide educational material to illustrate and describe the process.
7. To illustrate that the social and environmental benefits in installing a micro-hydropower scheme outweigh the logistical and technical complications.
8. To reduce risks and increase investor confidence in this type of micro-hydropower scheme by indicating the potential benefits and complications.
9. To show that the retro-fitting of a scheme onto an existing system is economically viable -the income generated through the sale of electricity and/or carbon credits outweighs the costs involved in the setting up of the scheme.

As an example to assist in the development of the guidelines (Aim 2) a decision support system is being developed which will guide water utilities and municipalities through three phases in the hydropower development process, see Table 3.

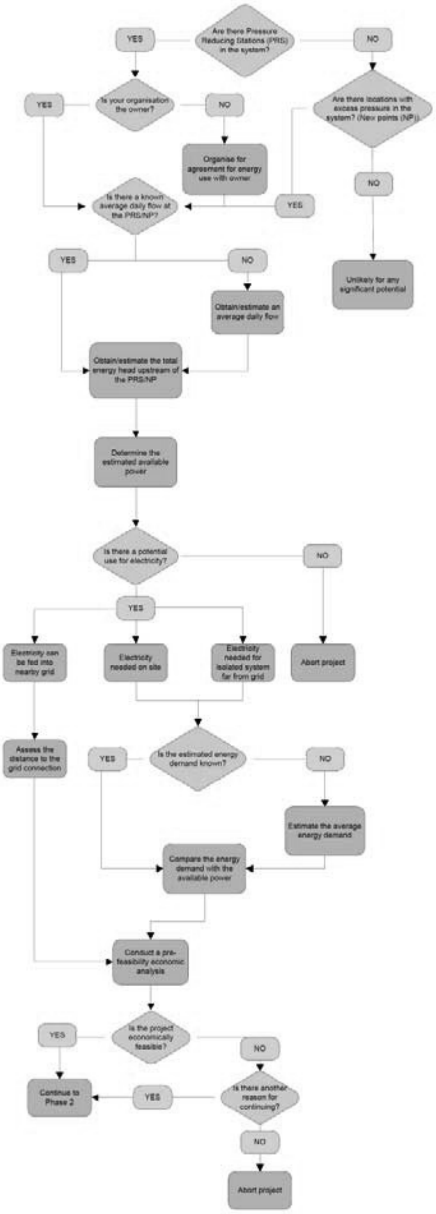
Table 3: Decision Support System for Conduit Hydropower Development

PHASE 3 (Detail design)



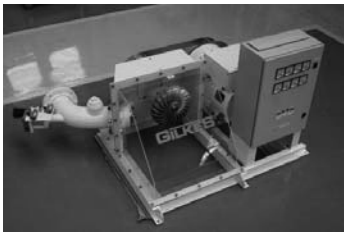
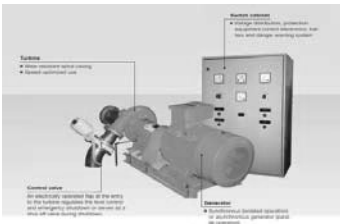
PHASE 2 (Feasibility)

PHASE 1 (Pre-feasibility)



The first pilot plant to demonstrate the technology (Aim 5) is the Pierre van Ryneveld Conduit Hydropower Plant described above. Two more pilot plants are envisaged using some typical innovative technologies such as shown in Table 4.

Table 4: A few turbine options for conduit hydropower development

LucidPipe 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.	
Turgo turbine (Gilkes) 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.	
PowerSpout A Pelton type turbine that can generate up to 1kW. A number of these turbines can be installed in parallel to utilise the potential at the site. Battery and grid enabled versions available.	
Pump as Turbine (Andritz) Pump turbines offer robustness and wear resistance, high efficiencies, long life cycle and ease of maintenance seeing that they are similar to pump systems normally used by water utilities. This self-sufficiency is offered by Mini-Turbine Plants, either for personal or for industrial use. The plant has a compact design, suitable for isolated operation and for supplying to an existing power network.	
Hydrodynamic screw type turbine (Andritz) The screw and trough can be embedded easily into the natural surroundings or at waste water treatment facility outlet. The water becomes enriched with oxygen which is a positive aspect improving the quality of the water. They reach high efficiencies of up to 92% with varying water heads and flows upstream and downstream having only a marginal effect.	
Kawasaki Ring Power This turbine can use small water flows that were considered as non-practical power source, and provide electric power to the home and private use. Comparing with other renewable energy sources, this system generates an electrical power more efficiently and more stable against the weather conditions.	

Furthermore a conceptual model for optimum operation of the hydropower generation plant will be developed. Similarly a cost-benefit model will be developed for hydro power schemes which quantifies all the costs and benefits associated with planning, construction, monitoring, maintenance and operation. This model will be in the form of a useful tool and would allow determining the feasibility of small, mini and micro hydro power project.

7. CONCLUSION AND RECOMMENDATIONS

Hydropower represents a nexus of water and energy and in municipalities and water boards there are several locations where a feasible conduit hydropower scheme can be implemented. A technically feasible scheme assist in reducing the higher operating costs, mainly due to energy increases, and provides a sustainable solution whilst having a positive environmental impact. A number of water utilities have started taking the initiative in developing this type of hydropower and it is believed that there is a significant potential in South Africa. The WRC research project aims to provide the necessary guidance in the development process and efficient operating of pressure-hydropower schemes.

8. ACKNOWLEDGEMENTS

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