A High Level Scoping Investigation into the Potential of Energy Saving and Production/Generation in the Supply of Water Through Pressurized Conduits

Report to the
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by

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Executive summary

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 we need to change the way we create and use energy. The demand for energy increases continuously and those demands need to be met in order to stimulate worldwide development. Fossil fuels contribute a large majority of the global energy, but due to the dangers of global environmental impacts, the expansion of fossil fuel as an energy source is in some cases resisted. This forces our current generation to focus on the development of renewable energy sources.

Renewable energy is the way of the future and the potential for its development is of great magnitude. Hydropower contributes only 3% of global energy consumption which is only a fraction of its potential. **Africa is the most underdeveloped continent with regard to hydropower generation with only 6% of the estimated potential exploited**. This is not a burden, but an opportunity. South-Africa has the potential to make a large contribution towards the lack of hydropower generation in Africa and the world.

Although Government has engaged in the process of identifying the need for the development of renewable energy, very little progress has been made and the goal set for 2013, to generate 10 000 GWh, might not be met. Many factors, including the global economic crisis, could influence the slow progress, but access to finance, the cost benefit of feeding into the national grid and numerous regulatory requirements also hamper this initiative.

Hydropower development has major potential benefits. In this scoping study the emphasis was on the potential power generation by retrofitting hydropower generation facility at existing dams and utilising the untapped energy on the supply side of storage reservoirs in water distribution systems where the excess heads are normally dissipated across control valves.

A **conceptual retrofitting model** (HRM) was developed to determine the viability of hydropower development by amongst other, considering environmental impact, cost and sustainability. This model was tested on the hydropower development at Sol Plaatjies and the

results reflected a good comparison with the practical results obtained during the investigation (**Appendix B**).

The potential hydropower generation at the inlets to storage reservoirs was evaluated with a pilot installation which was erected at the Queenswood Reservoir (Tshwane Metropolitan District), **Figure i**. The results from this scoping study highlight the untapped hydropower generating potential from pressurized conduits.

Figure i: Hydropower generation on the inlet side of the Queenswood Reservoir

Although the hydropower generation pilot unit, which was installed at Queenswood Reservoir, was not optimized, the results from the initial runs reflected the benefit and expected return from such an investment, even if the system is only operated at a duty of 50%.

Table i reflects the measured and calculated power generation and efficiency of the pilot system which was installed at Queenswood Reservoir.

Table i: Measured and calculated power generation at Queenswood Reservoir

		Measured output energy				Calculated input energy			Calculated minimum efficiency, %
Time	**Flow (l/s)**	**Volt**	**Amp**	**rpm**	**Watt**	**Head drop (m)**	**Maximum head drop (m)**	**Minimum energy generation (Watt)**	
10:52	29,57	195	15,5	1 648	3 022,5	25,54	37,60	10 908,33	27,71
11:15	27,97	176	13,2	1 533	2 323,2	25,06	27,91	7 657,48	30,34
11:27	27,55	203	13	1 500	2 639,0	26,93	30,54	8 252,73	31,98
12h05	28,54	208	13,1	1 500	2 724,8	25,04	27,77	7 773,64	35,05
12h10	32,49	275	16,44	1 762	4 521,0	30,94	45,25	14 423,40	31,34

Based on the AADD (Average Annual Daily Demand) from Queenswood Reservoir of about 180 m^3/hr, the potential energy generation can be determined as shown in **Table ii**.

Table ii: Potential yearly income from power generation at Queenswood Reservoir

Variable	Value	Units	
Head	80	m	
AADD	181,03	m^3/h	
	0,050286	m^3/s	
Efficiency	40	%	
Maximum available power	39,46	kWatt	
Available Head (m)	**Potential yearly energy production (kWh)**		
	% of AADD that could be used to generate electricity		
	40	**45**	**50**
40	27 656,8	31 113,8	34 570,9
50	34 570,9	38 892,3	43 213,7
60	41 485,1	46 670,7	51 856,4
70	48 399,3	54 449,2	60 499,1
80	55 313,5	62 227,6	69 141,9

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. **Table iii** reflects the conservative assumptions which were used to calculate the potential yearly hydropower generation from these pressurized supply pipelines.

Table iii: Assumptions used to determine the hydropower generation capacity at reservoirs and from pressurized supplies in pipelines

Variable used for the calculation of potential yearly income for power generation at Reservoirs in Tshwane	**Value**	**units**
Fraction of the available static head that can be used to generate power	0,5	
Hours per day when power can be generated	6	hours
Variable used for the calculation of potential yearly income for power generation from Rand Water Pipelines	**Value**	**units**
Fraction of the available static head that can be used to generate power	0,4	
Hours per day when power can be generated	6	hours
Average velocity in the supply pipeline	0,4	m/s

Based on the above assumptions, the potential yearly hydropower generation at reservoirs in the Tshwane Water Supply Area and from Rand Water pipelines, which feed water into the Tshwane Water Supply Area, were calculated. This analysis is a conservative low estimate of the hydropower generating capacity. In the case of the power generation form reservoirs in the Tshwane Supply Area, the fraction which has been used to calculate the hydropower generation is only 12,5% (0,5*6/24*100) of the potential maximum power generation. For the generation of energy from the pressurized pipelines from Rand Water, a factor of 10% was used. Capital and other costs were not reviewed in this study. **It will be required to conduct a thorough cost benefit analyses to prioritize the potential hydropower generation facilities.**

Table iv indicates the potential hydropower generation capacity at different reservoirs in the Tshwane Water Supply Area.

Table iv: Potential yearly hydropower generation capacity at ten reservoirs in the Tshwane Water Supply Area

Reservoirs	TWL (m. asl)	Capacity (kl)	Pressure (m)	Flow (l/s)	Yearly Potential power generation (kWh) #
Garsfontein	1 508,4	60 000	165	1850	3 278 980,2
Wonderboom	1 351,8	22 750	256	470	1 292 471,4
Heights LL	1 469,6	55 050	154	510	843 672,8
Heights HL	1 506,9	92 000	204	340	745 061,7
Soshanguve DD	1 249,5	40 000	168	400	721 859,0
Waverley HL	1 383,2	4 550	133	505	721 483,1
Akasia	1 413,8	15 000	190	340	693 930,0
Clifton	1506.4	27 866	196	315	663 208,0
Magalies	1438.0	51 700	166	350	624 107,3
Montana	1387.6	28 000	82	463	407 828,9
Total calculated yearly power generation in Tshwane from 10 reservoirs – (Nearest 10 000 kWh)					**10 000 000**

Note:

 # Refer to the assumptions listed in Table iii

Table v indicates the sensitivity of the assumption used in the calculation of the hydropower generation at the ten reservoirs listed in **Table iv** for a number of alternative scenarios.

Table v: Sensitivity analyses of the assumptions on the monitory value of power generation in the Tshwane Water Supply Area (10 reservoirs)

Variable	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Fraction of available head used for power generation	0,5	0,6	0,7	0,75
Generating hours per day	6	7	8	9
Fraction of the total potential generate able energy	**0,125**	**0,175**	**0,233**	**0,281**
Yearly power generation capacity, kWh	**10 000 000**	**14 000 000**	**18 640 000**	**22 480 000**

Table vi indicates the potential hydropower generation capacity from Rand Water pipelines supplying water to the Tshwane Region.

Table vi: Potential yearly hydropower generation capacity at ten of the Rand Water Pipelines feeding into the Tshwane Water Supply Area

Rand Water connections	Details				Yearly Potential hydropower generation (kWh) #
	On pipe (RW no.)	Supply from	Res.TWL (m. asl)	Static (m)	Inlet velocity 0,4 (m/s)
NO 3 VENTURI	H12	KlipFtn	1 694	243	159 559,7
KLAPPERKOP RESERVOIR	H7	VlakFtn	1 661	226	102 880,0
CITY	H3	EsslnPk	1 614	163	64 807,7
MAMELODI	H26	Bronberg	1 508	168	48 984,2
GARSFONTEIN RESERVOIR	R1	VlakFtn	1 661	164	47 817,9
WONDERBOOM RESERVOIR	H14	BrakFtn	1 596	157	45 906,4
SOSHANGUVE	H16	HartBH	1 406	137	40 061,8
MABOPANE	H16	HartBH	1 406	137	39 945,5
SAULSVILLE RESERVOIR	H22	BrakFtn	1 596	209	34 278,0
RESERVOIR (CLIFTON)	H12	KlipFtn	1 694	194	31 817,9
Total calculated yearly power generation in 10 or Rand Water Pipelines supplying to Tshwane – (Nearest 100 000 kWh)					**1 200 000**

Note:

 # Refer to the assumptions listed in Table iii

Tables iv and vi indicate that the hydro power generation potential at ten reservoirs in Tshwane Water Supply Area is 10 times more than what can be generated from the ten Rand Water pipelines feeding into the Tshwane Water Supply System. The focus should therefore be to install generation capacity at the reservoir sites first (infrastructure already exists at most of the reservoir sites).

If the same assumptions are used for say 5 other of the metropolitan areas in South Africa, the power generation capacity from water distribution systems which are fed under gravity, could be in excess of 10 000 to 22 500 MWh per annum. Table vii reflects

this potential hydropower source in relation to other existing and reinstated power generating facilities.

Table vii: Comparison of the hydropower generation capacity with other hydropower generation facilities

Hydropower facility	Installed generation capacity (MW)	Load factor	Power generation (MWh)
Generation from pressurised supply to reservoirs in 5 Metropolitan Areas	**Various**	**0,28**	**22 500**
Gariep Hydropower Station (Base Station)	**360**	**0,6**	**1 892 160**
Grootdraai Power Station (Reinstated)	**1200**	**0,9**	**9 460 800**
Colley Wobbles (Feed into the local grid)	**42**	**0,7**	**257 500**
Klipheuwel Windmill	**3,2**	**0,6**	**16 800**

In a memorandum from Rand Water (Trebicki, DDP) it was estimated that Rand Water is currently using about 165 MW to transfer water to various reservoirs of which a large proportion could probably be used to generate hydropower at the end of the gravity systems.

At the level of pico hydro power generation which could benefit rural communities where communication to the world is a primary concern, the first indications are that some energy can be generated from the low flow rate and low head tapped from the water supply. In these cases it will be possible to charge batteries and cell phones. **Figure ii** reflects this pico-hydro power generating facility. More research and development should be undertaken to review this option in more detail.

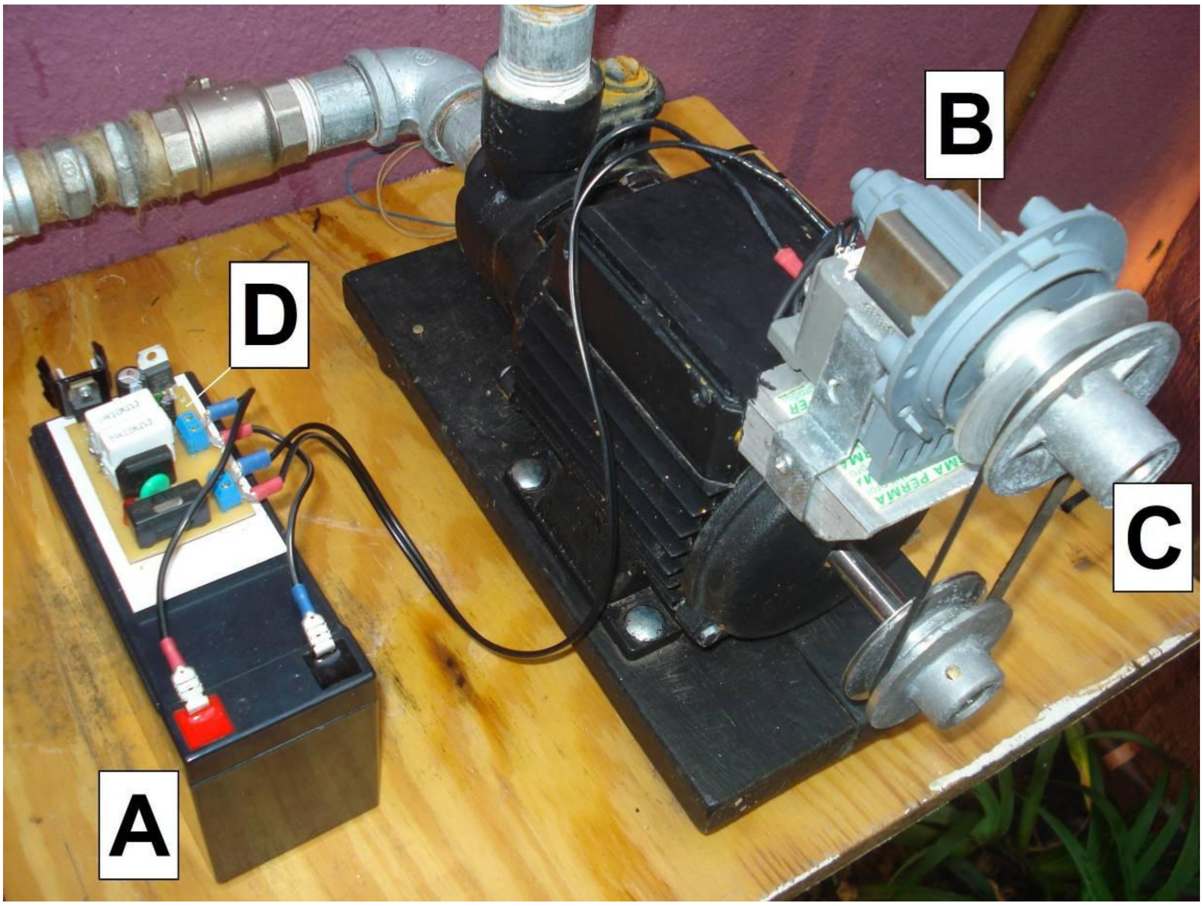

Figure ii: Pico hydropower generation unit to charge 12 Volt batteries and Cell phones in rural areas

The potential of hydropower generation from existing dams, pressurized conduits and other water infrastructure is under utilized in South Africa and the following actions need to be considered:

- Create a register of water infrastructure that has a potential for power generation;
- Establish the hydro power potential of these water infrastructure assets;
- Characterise the implementation potential for hydropower generation;
- Establish the optimum generating potential at storage reservoirs by assessing the parameters of storage volume, demand patterns and operating cycles and operating life of the control valves;
- Compile a cost benefit model for the development of these hydro power generation schemes (Quantifying all the cost and benefits);
- Generate mechanisms to develop it; and
- Provide incentives to invest in these schemes.

The WRC, who initiated this scoping review, should now, in cooperation with other Authorities and Interested Parties, extend the research in these fields.

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Acknowledgements

This scoping report was compiled for the WRC who undertook the project titled: **K8/839/3: 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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1 Introduction

1.1 Background

The current stress experienced in South Africa on the production and capacity of power, requires a review of all possible energy saving options, as well as the development of facilities which could transform available untapped energy into a useful format.

With regard to energy saving and production, a number of energy efficient products have been introduced varying from energy efficient globes, fuel efficient cars and high production breeds of modified plant material, as well as the use of alternate renewable energy sources.

Solar energy has been developed in South Africa as a local alternative source in remote areas but has not yet been harnessed to its full potential. The cost, reliability, security and operational requirements are restricting factors for the implementation of this promising technology.

The worldwide focus on carbon footprint minimization favours hydro-power – and nuclear power generation. In South Africa both these generating options have been employed, but little has been done to develop small – to micro-scale hydro-power facilities.

An untapped renewable energy source is the tapping of energy from high pressure piped conduits. This unexploited energy source is the focus of this scoping investigation.

South Africa has a substantial number of water transfer schemes which offer significant potential for exploitation, especially to the benefit of remote rural settlements requiring small quantities of energy. The focus thus is to establish the potential of how the unused pressure energy in the water transfer and distribution systems could be utilized as a potential power source by the end users through the retrofitting of micro- and pico- hydropower generating facilities.

The hypothesis for this high level scoping is that:

"***<u>unused and unwanted pressure energy at the end-users could be used to generate power by end users".</u>***

1.2 Methodology

The proposed method to investigate the hypothesis: "***unused and unwanted pressure energy at the end-users could be used to generate power"*** is to undertake the following tasks:

- Reviewing the status of energy generation in South Africa
- Conducting a local and an international review on the trends and development in small scale generation and storage of power, this will cover the definition of new equipment and defining the R&D requirements etc.;
- Developing a hypothetical model for energy generation from piped conduits.
- Mapping potential sites for this power generation in South Africa.
- Determining the economic viability of this micro scale power generation;
- Compiling a summary report on the findings and reflecting the research needs for the assessment of the potential implementation of micro hydropower generation, identifying of key opportunities and indicating the research needs and priorities.

1.3 Layout of report

This report consists of the following chapters:

Chapter 1:	Introduction
Chapter 2:	Overview of the power generation in South Africa
Chapter 3:	Trends in the development of hydropower
Chapter 4:	Conceptual and physical assessment of the potential generation of energy in pressurized water supply systems
Chapter 5:	First order estimate of the potential hydropower generating capacity from pressurized pipelines in the Tshwane Metropolitan District
Chapter 6:	Conclusions and recommendations
Chapter 7:	References

2 Overview of the power generation in South Africa

2.1 Introduction

Electricity, in the world of today, is a necessity for everyday life. Ensuring that all people have access to power is crucial for the economic development of any region or country. Electricity is generated in a variety of ways and because electrical energy cannot easily be stored in large enough quantities to meet demands on a national scale, the demand has to be supplied in real time, with a small amount of reserve in case of emergencies or normal maintenance.

Worldwide (developed and developing countries) there is still a vast dependence on fossil fuels to generate electricity, the most abundant fossil resource being coal (Lloyd & Subbarao, 2008). Eskom's document '*Understanding Electricity'* indicates that in South Africa, approximately 90% of electricity provided is generated in coal fired power stations. This is due to the relative abundance, availability and the low cost to mine coal in the country, thereby making other forms of electricity generation largely unfeasible.

2.2 Status quo

As stated in the Department of Minerals and Energy's White Paper on the Renewable Energy Policy (2003), South Africa relies heavily on coal and has developed an "efficient, large-scale, coal-based power generation system that provides low-cost electricity" right across the country. The result is that coal will remain economically viable and will continue to be the most attractive source of energy in South Africa from a financial perspective.

This low cost of coal, however, does not account for its role in the production of greenhouse gasses (GHG), which are generally accepted to be key contributing factors to global climate change. As indicated by Evans et al (2009), "coal is known to have the highest carbon dioxide emissions per kWh, as well as emitting other pollutants at high levels." It is also not environmentally sustainable as coal is a limited resource and will eventually be depleted.

Other than coal fired power stations, electricity supplied in South Africa is also generated in nuclear power stations, hydroelectric schemes, pumped storage schemes, open cycle gas turbines and wind farms. The most recent figures for the breakdown of GWh produced in

South Africa by the different electricity generating technologies were found in a report published by Statistics South Africa (2008). This report reflected electricity generation in South Africa in 2006. A total of 222 939 GWh was produced; Figure 2.1 shows the contribution from the different technologies.

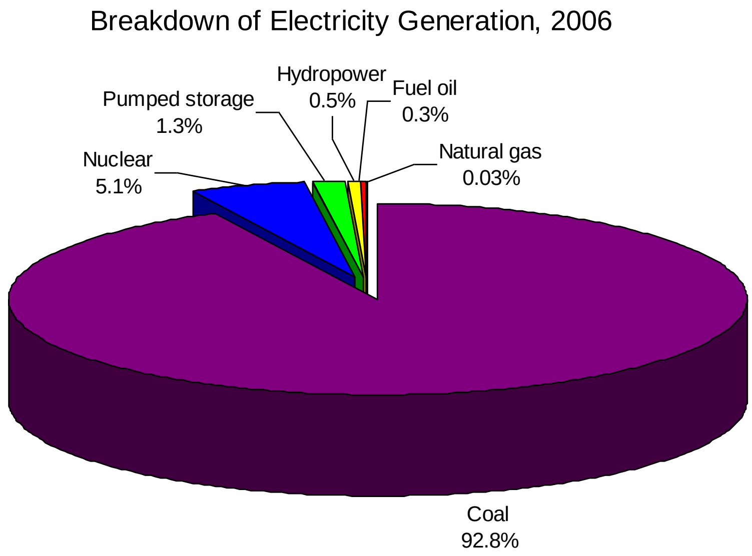

Figure 2.1: Contribution of energy generating technologies to electricity output for 2006 (Statistics South Africa, 2008)

The locations as well as the installed capacities of the various power stations in South Africa are shown in **Figure 2.2.**

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

Figure 2.2: Location of Eskom's power stations in South Africa (Eskom, n.d.)

The lower reserve margin resulted in the load shedding practices implemented country wide in 2008, emphasizing the dire situation that the South African electricity generation industry currently finds itself in. The solution to this problem is to relieve the stress on the network by either increasing the generation capacity or reducing the demand using Demand Side Management (DSM). Increasing the capacity can be done in a variety of ways: the first option is the refurbishment and upgrading of old coal-fired power stations where operation was discontinued at some stage in the past. These so-called ‘Return-to-Service’ stations are in the process of being re-commissioned to meet the increasing demand in electricity.

The second way that this increase in demand is being met is through the building of new large scale power stations (coal-fired as well as other technologies). The problem with this method is the long lead time from conception to commissioning of the stations. The feasibility study and approval process is lengthy and time consuming, due to all the legal requirements regarding environmental impact assessments (amongst others) and extensive civil engineering works that need to be undertaken. It is known that the construction of a new coal-fired power station; “could take eight to ten years” (Eskom Holdings Limited, 2008).

Alternative supply options also need to be considered, such as the use of small scale renewable energy technologies to augment electricity supply. There is significant opportunity for the use of renewable resources in South Africa which has remained largely untapped (NERSA, 2008) as it is not cost competitive due to the aforementioned economic feasibility of electricity generated from coal. This indicates that there is significant scope for research in the field of renewable energy technologies and their application in a South African context.

As people have become more aware of the detrimental environmental effects of GHGs, there has been a trend towards the use of more environmentally sustainable technologies and methods of energy production. The worldwide trend is to try to use the earth’s natural resources as effectively and efficiently as possible. The challenge will be to ensure that this trend extends with full force into South Africa and that the use of renewable resources to generate electricity is fully optimised.

2.3 Renewable energies

Renewable energies are defined by the Department of Minerals and Energy (DME) in the White Paper on the Renewable Energy Policy (2003) as "naturally occurring non-depletable sources of energy that are used to produce electricity, gaseous and liquid fuels, heat or a combination of these energy types." They offer an attractive alternative to conventional fossil fuel power generation because they produce little or no GHGs and rely on inexhaustible natural energy flows (Lloyd & Subbarao, 2008). The focus is now narrowed down to the use of renewable energy in electricity generation.

Internationally, renewable energy is recognized as being a major contributor in the protection of the environment and climate and provides "a wide range of environmental, economic and social benefits that will contribute towards long term global sustainability" (NERSA, 2008). The electricity crisis being experienced in South Africa highlights the role that renewable energy can play by augmenting electricity generation. The emphasis on renewable energy obtained momentum when DME (2003) stated that the Government has set a target of 10 000 GWh per annum to be produced from renewable resources by 2013.

The different types of renewable energy are briefly described below:

Solar energy: Photovoltaic systems are used to capture the energy in sunlight and convert it directly into electricity, or alternatively the sunlight is focused with mirrors to produce a high heat and drive a steam turbine producing electricity.

Wind energy: Modern turbines are placed in 'wind farms' and the energy of the wind is used to drive the windmills and generate electricity.

Biomass energy: Biomass is plant material and includes agricultural residues, wood waste, paper waste, municipal solid waste and methane captured from landfill sites. This can be used to generate electricity.

Hydropower: The flow of water under gravity through a turbine generates electricity.

Wave and tidal power: Technologies used to harness these energies and generate electricity are being developed for commercialization.

Geothermal activity: This comes from the heat in the earth's core, for example natural geysers and can produce steam to drive turbines and generate electricity.

Figure 2.3: Photovoltaic cells (Eskom, n.d.) **Figure 2.4: A wind farm (World Energy Council, 2007**

DME (2003) states that the Government has set a target of 10 000 GWh per annum to be produced from renewable resources by 2013, which is approximately 4% of the forecast for electricity demand in 2013 (41539 MW). This is to be achieved "primarily through the development of wind, biomass, solar and small scales hydro" (NERSA, 2008). There is therefore a need for the implementation of renewable energy projects in South Africa and their integration into the mainstream energy economy.

The major benefit of using renewable energy is that it will be crucial in contributing to GHG emission reductions as the result of declining dependency on fossil-fuels. It also promotes the ideals of sustainable development as defined by the Bruntland Commission:

> "To meet the needs of the present without compromising the ability of future generations to meet their own needs." [Bruntland (1987) as cited in Lloyd & Subbarao (2008)]

It is argued by Government that "electricity will have to be generated from renewable resources in a non-consumptive manner and with minimal impact on the environment and contribute to the mitigation of climate change" (NERSA, 2008). The question of whether renewable resources can ultimately replace traditional fossil fuels as a worldwide primary source of energy is not critical, as long as the general trend continues to move towards renewable resources with concerted effort.

The DME (2003) also promotes the use of renewable energy in South Africa as it will "contribute towards the diversification of electricity supply" and therefore also provide increased energy security to South Africa. This idea is supported in literature (Lloyd & Subbarao (2008)) that suggests that the driving forces behind renewable energy alternatives are global environmental as well as energy security concerns.

Due to the largely non-consumptive nature of renewable energy technologies, a further benefit resulting from their use is the saving of resources. "Conventional coal fired plants are a major consumer of water during their requisite cooling processes. It is estimated that the achievement of the 10 000 GWh target will result in savings of approximately 16.5 million kilolitres water, when compared with wet cooled conventional power stations" (NERSA, 2008). This is equivalent to a revenue saving of R26,2 million. Water is a precious resource in South Africa and all water conservation practices are beneficial.

Of the renewable energy technologies mentioned, hydropower is the most established and universalised (Paish, 2002). The focus of this scoping report will now be narrowed down to the use of hydropower as a renewable energy technology.

3 Trends in the development of hydropower

3.1 History of hydropower

In order to understand the significance of hydropower nine years into the 21st century, it is important to consider the history of hydropower and how it has developed over time, especially because its prevalence and use have both boomed and dwindled over time and its nature and scale has been constantly evolving and changing. The oldest form of hydropower is the wooden water wheel which was used for almost 2 000 years in Europe and Asia (Paish 2002). Over their many years of usage and with the event of the industrial revolution, water wheel technology developed until a point where almost 70 percent efficiency was being achieved. In the early 1800s, advances in engineering and a need for smaller wheels led to the development of the first single purpose hydroelectric plant in France in the 1820s, which was then called a “hydraulic motor” (Paish 2002).

By the end of the 1800s turbines had begun to obtain wider recognition and were replacing water wheels at many mills. Governments also began to consider how turbines could be used on a larger scale for electricity supply which led to the boom in hydropower development during the first half of the 1900s. There was a sudden burst in hydropower and dam construction throughout Europe and North America where almost 50 percent of the technically available hydropower potential was used (Paish 2002). The scale of projects continued to grow culminating in such milestones as Grand Coulee in America or the 12 000 MW Itaipu scheme in Brazil. After World War II, the pace of development and needs for electricity began to accelerate in developed countries and later in developing countries with the highest number of projects being commissioned between 1950 and 1985 (Oud 2002). This sparked the emergence of large equipment suppliers to support the lucrative market. These suppliers have since felt the bite of the emergence of oil as the primary source of fuel and various other factors which have caused a rapid decline in the industry especially with respect to small hydropower which can’t compete from an economical perspective with coal and nuclear power (Paish 2002).

Over recent years, global hydropower construction has faced a number of challenges which can be attributed to financial, social and environmental reasons. Looking from a financial perspective,

:

- Available sites for large dams: The developed world most of the potential sites for the construction of large dams for hydropower have been used. The sites that remain are less attractive and are thus less likely to be economically viable.
- Efficiency improvements: Thermal-electric projects have grown in their attractiveness through improved efficiency and an increase in the availability of natural gas. In particular, gas-fired combined cycle plants are growing in popularity.
- Cost of fossil fuel: low fossil fuel prices in the eighties and nineties also boosted the viability of thermal plants.
- Funding: There has been an increased dependence upon private sector funding which demands a short lead time and of course lower costs (Oud 2002). Although hydropower is extremely competitive in terms of operational and maintenance costs, the initial costs are high and the lead-times can be long.

From an environmental and social perspective:

- Cost of environmental and social impact studies: It is now required that much more comprehensive environmental and social impact studies be conducted for any project. This can increase the initial costs (especially if affected people and communities need to be compensated) as well as causing severe delays.
- Environmental interest: There has been a growing public interest in the environmental and social consequences of hydropower development, especially when considering communities that have to be displaced during the construction of dams, the flooding of large portions of land when dams fill or even simply the disruption of water flow and the impact this has on the environment and people downstream of a dam or plant. Public interest and campaigns by groups and Non Governmental Organisations have discouraged international agencies from getting involved and investing in hydropower projects (Oud 2002).

Although many factors put a strain on hydropower development, there is a renewed interest in hydropower in different countries. This interest is supported by:

- Depletion of the natural resources: Rapid depletion of oil and gas deposits worldwide due to continued careless use of resources will soon increase the cost of thermal plants which will inevitably make hydropower more economically attractive.
- Carbon credits: Hydropower emits no greenhouse gasses and thus with the current general global acceptance of the impact of human activities on climate change and thus the shift towards cleaner forms of energy, hydropower is becoming much more attractive. The introduction of carbon credits adds a valuable extra potential income to hydropower projects, which can turn an unattractive project into an economically viable one.
- Transfer costs of electricity: It is becoming cheaper to transport electricity through high voltage direct current transmission lines allowing for greater potential for large scale hydroelectric plants in more remote areas (which are often where the largest heads are available (Oud 2002)).
- Retrofitting of existing infrastructure: There is scope for placing hydropower on existing dams that don't have this added component or even introducing a hydropower component on new dams that are being constructed to meet the water needs of the earth's expanding population. If a dam has already been constructed, not only has the large cost of building a dam already been incurred but the negative environmental and social consequences have also already occurred.

Despite some of the issues facing hydropower development, it still has by far the greatest share in the contribution of renewable energy to global electrical power production. In 2006, the entire global technically feasible hydropower potential stood at approximately 14 368 000 GWh/year (The International Journal on Hydropower and Dams 2006). A similar figure, in 2000 equated to 100 percent of the world's total energy demand (Paish 2002). 8 576 000 GWh/year of this is economically feasible. In 2004 and 2005 on average 2 900 250 GWh/year were produced. (The International Journal on Hydropower and Dams 2006). Every other form of renewable energy combined amounts to only 2 percent of global consumption whereas hydropower supplies about 16 percent of the world's electricity (International Hydropower Association 2005). During the burst in production post 1950, most of the European and North American hydropower potential was exploited but in Asia, Africa and South America, large amounts of untapped potential still remains (Paish 2002). **Figure 3.1** shows the technical and economical available potential as the well as the exploited potential in 2006 for each continent (The International Journal on Hydropower and Dams 2006).

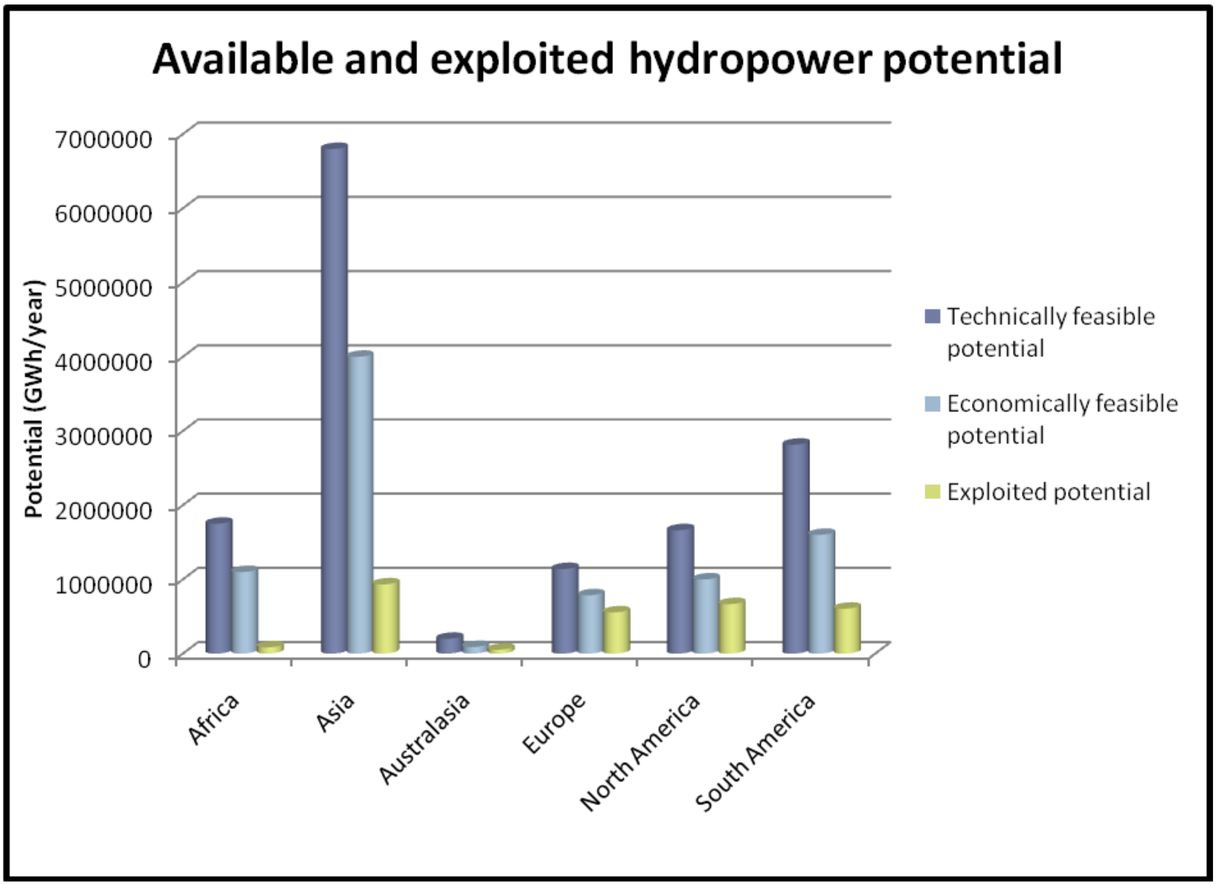

Figure 3.1: Available and exploited hydropower potential in 2006 (The International Journal on Hydropower and Dams 2006)

3.2 Advantages of hydropower

The benefit of hydropower to generate electricity is a carbon dioxide emission free technology and according to Barta (2005), "no other power generation technology is as versatile and cheap as hydropower." The various advantages/opportunities and barriers/challenges to hydropower development are discussed with particular reference to the South African context.

Before the status and contribution of hydropower in South Africa is considered, it is important to study the advantages that hydropower has over other forms of energy production in terms of economics, social and environmental impacts.

- Renewable source: hydropower is a form of renewable and sustainable energy. A renewable energy source can be defined as "one that consumes primary energy resources that are not subject to depletion" (Frey & Linke 2002). Hydropower makes use of the energy in water due to flow and available head without actually consuming the water itself and is therefore categorized as a form of renewable energy. As has been stated the most common definition for sustainability, from the Brundtland Commission in 1987 is "development which meets the needs of the present without compromising the ability of future generations to meet their own needs". In the context of electricity generation this would mean, producing electricity in a way at present that won't impact on future generations' ability to produce electricity. Again, because hydropower doesn't consume the resource it utilizes and has only minor environmental impacts, it can be classified as sustainable. Sustainability also involves leaving behind a positive legacy for future generations (Frey & Linke 2002). In this regard hydropower has an advantage over other forms of renewable energy because the dams, tunnels, reservoirs, canals and other structures that are built in order to generate hydroelectricity can remain for many years thus providing long term infrastructure for future generations. Sustainability is currently one of the most used words in governments and amongst planners, especially in developing countries like South Africa. It is no longer possible to simply construct and develop infrastructure without considering future generations and their needs. This gives hydropower a strong advantage in the 21st century planning climate.

- Greenhouse emissions: Hydropower is a clean form of energy because unlike the burning of coal, oil and natural gas, it does not emit any atmospheric pollutants including carbon dioxide, sulphurous oxides, nitrous oxides or particulates such as ash (Frey & Linke 2002). The total avoided green house gas emissions due to current global hydropower supplies amount to the total number of global passenger car emissions (Oud 2002). With the increasing global awareness of greenhouse gas emissions and their impact on climate change and health, the use of clean forms of renewable energy such as hydropower are gaining more focus.

- Operational life and efficiency: Hydropower schemes often have very long lifetimes and high efficiencies. Operation and maintenance costs per annum can be as low as 1 percent of the initial investment costs (Oud 2002).

- Flexible application of output: Another advantage is that hydropower schemes often have more than one purpose. Hydropower through water storage can help with flood control and supply water for irrigation or consumption and dams constructed for hydropower can also be used for recreational purposes (Frey & Linke 2002). Different forms of hydropower including reservoir, pumped storage and run-of-river systems of different sizes are available and can be used for different forms of electricity generation. These include feeding directly onto the grid, providing electricity during peak demand periods and improving the performance of thermal power plants by effectively following rapid demand variations (International Hydropower Association 2005).

3.3 Disadvantages of hydropower

Despite the aforementioned positive attributes, hydropower does have a number of <u>negative features</u>:

- Aquatic life: Hydroelectric plants can have a negative impact on aquatic life. For example, dams can disrupt migration of certain fish species such as salmon moving upstream to breeding areas or downstream to the ocean. Many fatalities of fish attempting to ascend dams have been observed and their success rate in reaching breeding grounds is almost zero (Sternberg 2007). It is important to note however that there are possible laddering and hauling systems that can be implemented to aid upstream movement and that screens and racks can be used to prevent fish from entering turbines (U.S. Department of Energy 2005). The flow and water quality can be affected if the hydropower plants cause low dissolved oxygen levels in the water which may harm riverbank habitats. This can however be combated by assuring sufficient aeration and maintaining a minimum downstream flow.

- River morphology: The construction of large dams for hydropower generation impacts the downstream flow of a river as well as the upstream area which is flooded as the dam fills. There are reservoirs that can extend over more than 150 km (Frey & Linke 2002). This can cause destruction of homes, flora and fauna and may affect historically and culturally significant areas (U.S. Department of Energy 2005). The flooding of farmlands and resettlement of communities can cause overcrowding of existing farmlands (Sternberg 2007). Thorough public consultation is thus required and objections from affected parties can cause disruptions in the planning process.

- Hydrological variability: Hydropower relies on there being a sufficient amount of water or flow to generate electricity. This results in a reliance on rainfall and very accurate climatic predictions must be made from the outset. Droughts can therefore cause disruptions in power generation which can have negative economic consequences (U.S. Department of Energy 2005).

3.4 Comparison of hydropower with other types of energy

Considering the advantages and disadvantages mentioned above, it is to compare hydropower to each competing form of renewable electricity production.

Thermoelectric plants burn fossil fuels, and therefore emit large amounts of greenhouse gasses which both contribute to global warming and may cause acid rain. If there are penalties in place for such emissions, then hydropower which, as previously explained, is a clean form of energy, has an economic advantage. This is particularly useful when competing with combined cycle gas plants which have low investments, good efficiency and short construction times, particularly when cheap gas is available. On the other hand, hydropower has a much stronger advantage over **coal fired power stations** which have high investment costs combined with long construction times (Oud 2002). It should also be noted that the burning of fossil fuels is not a sustainable or renewable form of energy production because it consumes the resource it requires. If all current hydropower plants were replaced with thermal ones, an additional 1 112 million tons of coal, 4 449 million barrels of oil or 756 million m^3 of natural gas would be used on top of current consumption (Frey & Linke 2002).

A last point is that the supply of non-renewable resources such as coal, oil and gas are affected by **political factors and intergovernmental disagreements**. This was highlighted in the 1970's with disruptions in oil productions in the Middle East (Frey & Linke 2002), in recent times with the fluctuation of the oil price and also in Europe in the winter of 2008 when natural gas supply from Russia was interrupted due to contractual disagreements resulting in a huge scare in Europe about stability of their energy supply to last through the cold winter. Hydropower is usually site specific and although up and downstream impacts must be considered, there is little inter-governmental cooperation required unless water resources from another country are being utilised.

Nuclear plants have a negative stigma surrounding them because of the unsolved issues surrounding the disposal of nuclear waste as well as the potential for catastrophic accidents. In terms of risk and public perception therefore, hydropower would be more favourable.

In terms of renewable energy, wind power, although free from emissions, can have minor environmental impacts such as interference with television reception and noise creation. Wind is also intermittent which can cause potential disruptions. However, in countries where tax incentives are provided for **wind power**, it is a serious competitor for hydropower.

Solar energy, in the form of photovoltaic and hybrid thermal solar plants, only really competes with hydropower in very remote areas where micro hydropower is viable. The costs are however very high, therefore despite having few negative environmental impacts, the benefits of solar energy can easily be outweighed by those of hydropower (Oud 2002).

3.5 Hydropower overview

Various articles related to micro power generation reflect international trends and developments pertaining hydropower development. It is paramount to start off with the definition of the size range of power generation facilities. Paish (2002) reflected that:

- No international definition for small hydropower has been formulated;
- The generating capacity for small hydro station could vary between 2,3 and 23 MW;
- Generally 10 MW is the limiting capacity that is widely used, although China uses 23 MW as their standard to identify small hydropower generation;
- Mini hydro-power generated is a facility of less than 2 MW;
- Micro hydro-power generated is a facility of less than 300 kW; and
- Pico hydro-power generated is a facility of less than 10 kW.

Table 3-1 reflects the classification in size according to a Technical Brief compiled by the Schumacher Centre for Technology and Development.

Table 3-1: Classification of hydro-power generating capacity (Schumacher Centre for Technology and Development)

Reference to Hydro-Power Capacity	Description
Large-hydro	More than 100 MW – feeding into a distribution grid.
Medium-hydro	13 to 100 MW – feeding into a distribution grid.
Small-hydro	1 to 13 MW – feeding into a distribution grid.
Mini-hydro	100 kW to 1 MW – Stand alone scheme or feeding into a distribution grid.
Micro-hydro	A few hundred watts applied to charge batteries or up to 100 kW used to supply small rural communities.
Pico-hydro	Generation capacity up to 10 kW.

Small hydro generation has been on decline (Paish, O (2002)) since 1960 and only a few counties have boosted the sector. The relative low cost of fossil fuelled power stations favoured this technology which is now challenged by the need to reduce carbon emissions. **A copy of the design guide for small hydropower station was developed by the European Small Hydropower Association (ESHA, 2004) is included at the back of this report on a CD.**

Except for hydro-power the other renewable energy technologies (RETs) which could be applied in remote rural areas are **solar energy, biomass and wind energy** (Islam M, R et al, 2006).

Paish O. (2002) indicated that **hydro-power remains by far the most important "renewable" form of energy**. The World Hydropower Atlas 2000 indicated that the economically feasible portion of the technically feasible hydro-power options of 14 370 TWh/a is about 8 080 TWh/a. It is further estimated that the exploited portion in 1999 was only 2 630 TWh/a, supplying 19% of the planet's electricity in comparison to the **combined other forms of renewable energy which provides less than 2% of the global consumption**. **Figure 3.2** reflects the potential and exploitable hydro-power per continent while **Figure 3.3** indicates the global energy contributions by generating sector (Otto, 2008).

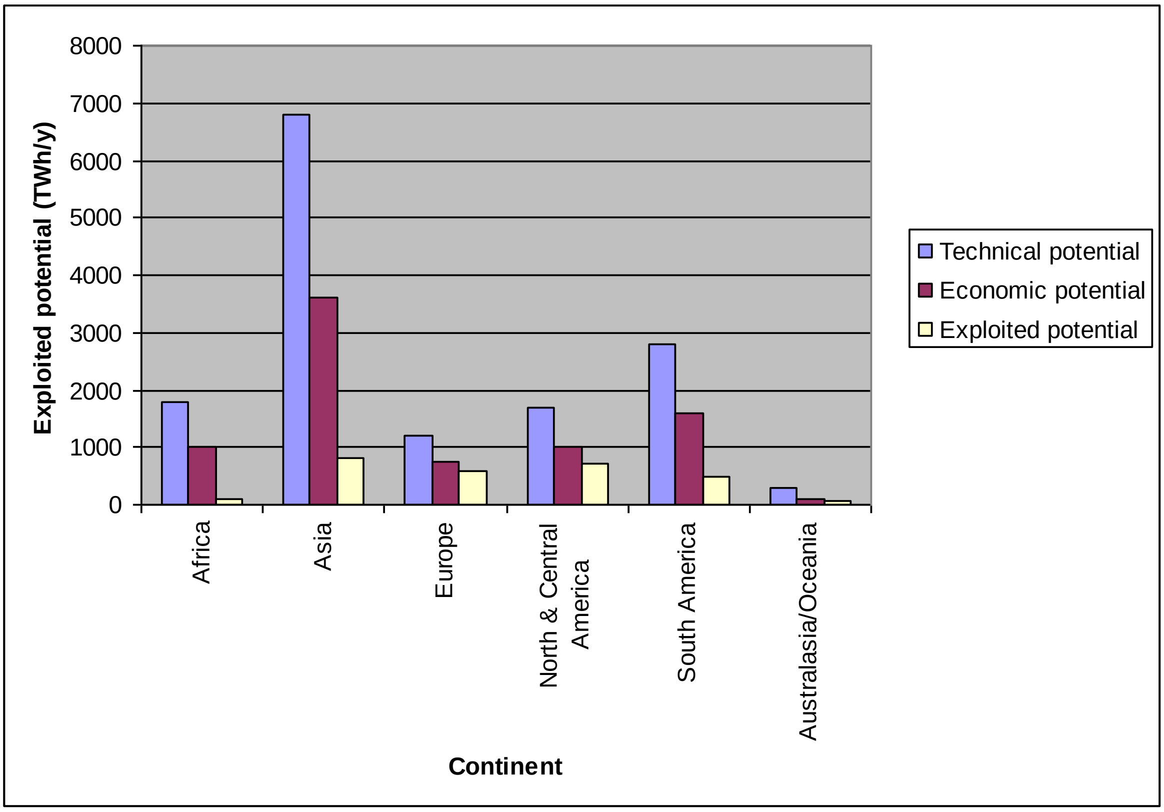

Figure 3.2: Potential and exploitable hydro-power per continent

Most countries have realised the potential and need for the development of renewable energy technologies. Global investment in renewable energy capacity has increased from 12 billion to a massive 120 billion U.S. dollars over the past 10 years (Otto, 2008).

World leaders like the United States, Germany and China have had huge success in creating and implementing renewable energy policies. South Africa has an untapped potential of renewable energy which could create a great economic stimulus which, in future could contribute to reduce the backlog in the creation of generating capacity. What is required is to set up a policy on how South-Africa will address the problem on a national scale. Some actions in this regard have already been taken (Otto, 2008).

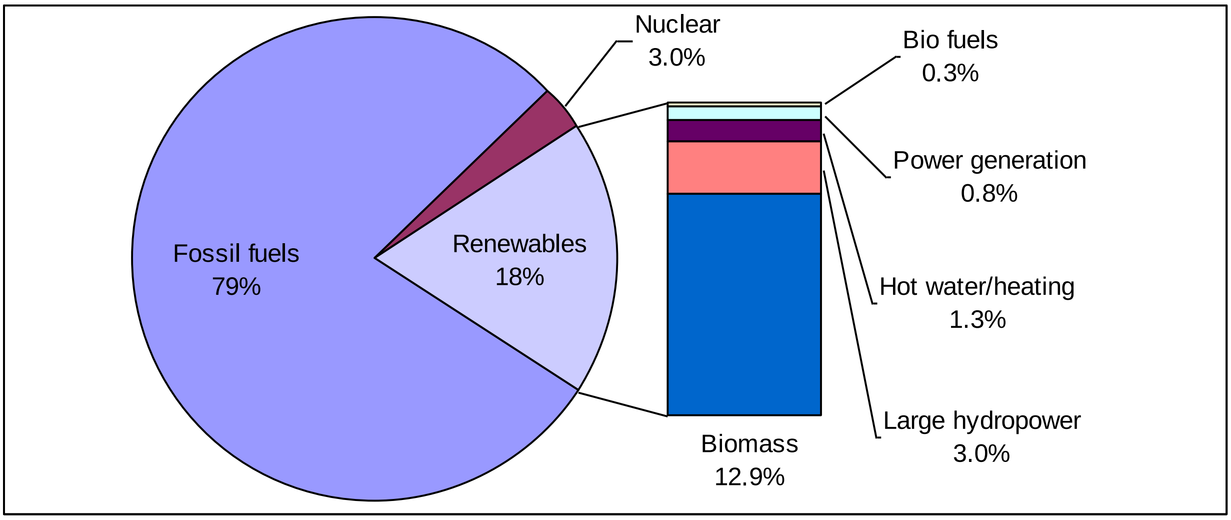

Figure 3.3: Global energy contributions (Opportunities in the Renewable Energy sector, 2008)

In November 2003 South-Africa's Department of Minerals and Energy published a White Paper (DME, 2003) on renewable energy in which the current state of renewable energy in South-Africa was discussed and the major objectives and goals of the endeavour to increase the utilization of renewable energy were discussed. **The following main focus areas were reiterated:**

- **Financial instruments**: "The goal is to promote the implementation of sustainable renewable energy through the establishment of appropriate financial instruments such as ensuring that an equitable amount of resources is invested in this field and the creation of an investment climate for the renewable energy sector that will attract local investors as well as foreign investors."

- **Legal instruments**: "The goal is to develop, implement, maintain and continuously improve an effective legislative system to promote the implementation of renewable energy with objectives such as developing and enabling legislative and regulatory frameworks for pricing and tariff structures and to integrate Independent Power Producers into the existing electricity system."

- **Technology development**: "The goal is to promote, enhance and develop technologies for the implementation of sustainable renewable energy with a few objectives. Firstly, promoting the development and implementation of appropriate standards, guidelines and codes of practice for the use of renewable energy technologies. Secondly, to promote appropriate research, development and local manufacturing to strengthen renewable energy and optimise its implementation."

- **Education and awareness raising**: "The goal is to develop mechanisms to create public awareness of the benefits and opportunities of renewable energy."

The South African Government decided during that meeting that the medium-term target of creating a renewable energy contribution of 10 000 GWh, should be obtained by 2013. The intended renewable energy contribution should be produced mainly from small-scale hydro, biomass, wind and solar energy (**Figure 3.4**). This is approximately 4% of the projected electricity demand for 2013.

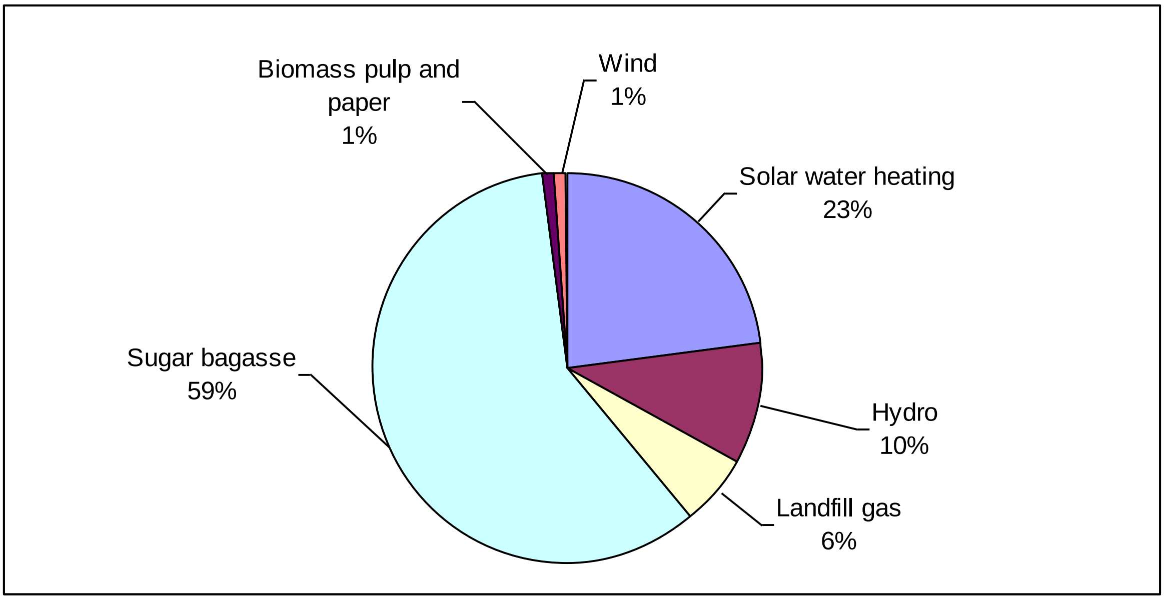

Figure 3.4: 10 000GWh Target for 2013 – Renewable energy contributions

Having this Renewable Energy Policy and setting a target for developing a productive renewable energy sector in South-Africa is a good start towards solving the current energy problems but monitoring the progress and stimulating the industry is paramount. The current situation is that the halfway mark has been reached with very little progress thus far. In an independent review (Otto, 2008) done in 2008 it was estimated that only 2.78% of the desired 10 000GWh was achieved during the first five years of the plan (**Table 3-2**).

Table 3-2: Percentage of 10 000 GWh renewable energy target achieved in 2008 (Otto, 2008)

Technology	Percentage of Target	Megawatts(MW) Achieved	GWh Achieved	Percentage of Target achieved
Solar water heating	23%	0	70	0,70%
Hydro	10%	21,5	113	1,13%
Landfill gas	6%	10,2	82	0,82%
Sugar biogases	59%	0	0	0,00%
Wind	1%	5,2	13	0,13%
Biomass pulp	1%	0	0	0,00%
	100%	**36,9**	**278**	**2,78%**

In the review the slow progress was accredited to the lack of regulatory frameworks, long term financing mechanisms, developmental financial assistance and manufacturing capacity.

It is clear that there is a need to develop and promote successful, big and commercially viable energy projects to build towards the target and to increase visibility for the public.

During March 2009, more than 400 delegates attended the "**2009 Renewable Energy Summit**" in Pretoria. The aims of the Summit were to undertake a mid-term review on the progress made since the approval of the White Paper on Renewable Energy in 2003 and to agree on a new set of resolutions, policy direction and action plans to rapidly streamline renewable energy in South-Africa. The Summit raised concerns about the slow pace at which plans were implemented and executed and agreed that all stakeholders needed to work together to address challenges in the renewable energy sector. With regard to technology development it was realised that there was a need to increase collaboration between the private sector, government and research institutions **to accelerate national research and development in renewable energy technologies.**

3.6 Basics of hydro-power generation

Hydro-power turbines convert the momentum from flowing water to mechanical energy to drive the electrical generator. The amount of momentum energy is dependent on the average velocity and the flow rate. As the velocity is directly related to the available pressure head, it can be derived that the potential to generate hydropower is dependent on the average flow rate and the head.

Hydro-power output is calculated with the following relationship:

$$P = \eta \rho Q H$$

Where:

$P = \text{power generated (Watt)}$

$\eta = \text{efficiency, a factor less than 1, indicating that energy losses will occures}$

$\rho = \text{fluid density, (kg/m}^3\text{)}$

$Q = \text{flow rate, m}^3\text{/s}$

$H = \text{energy head, m}$

Power generated can either be grid based or for onsite use. In the latter case the extend of the required voltage and frequency control is more challenging than for a grid based generation system.

3.7 Overview of hydro-power components

All grid based hydro-power systems have the following components:

- Water source – normally a fore bay or a dam;
- Elevation difference or input head used to feed the water trough the penstock to the power house (available energy head);
- A turbine which converts the kinetic energy to mechanical energy;
- A controller to dump the excess energy that is generated;
- A dump load facility to dissipate the unused/excess energy;
- Data recording equipment to record and reflect the energy that is generated; and
- An AC breaker panel which function to protect the system against any overload on the demand side.

Figure 3.5 reflects the components of a grid-tied micro-hydro power system.

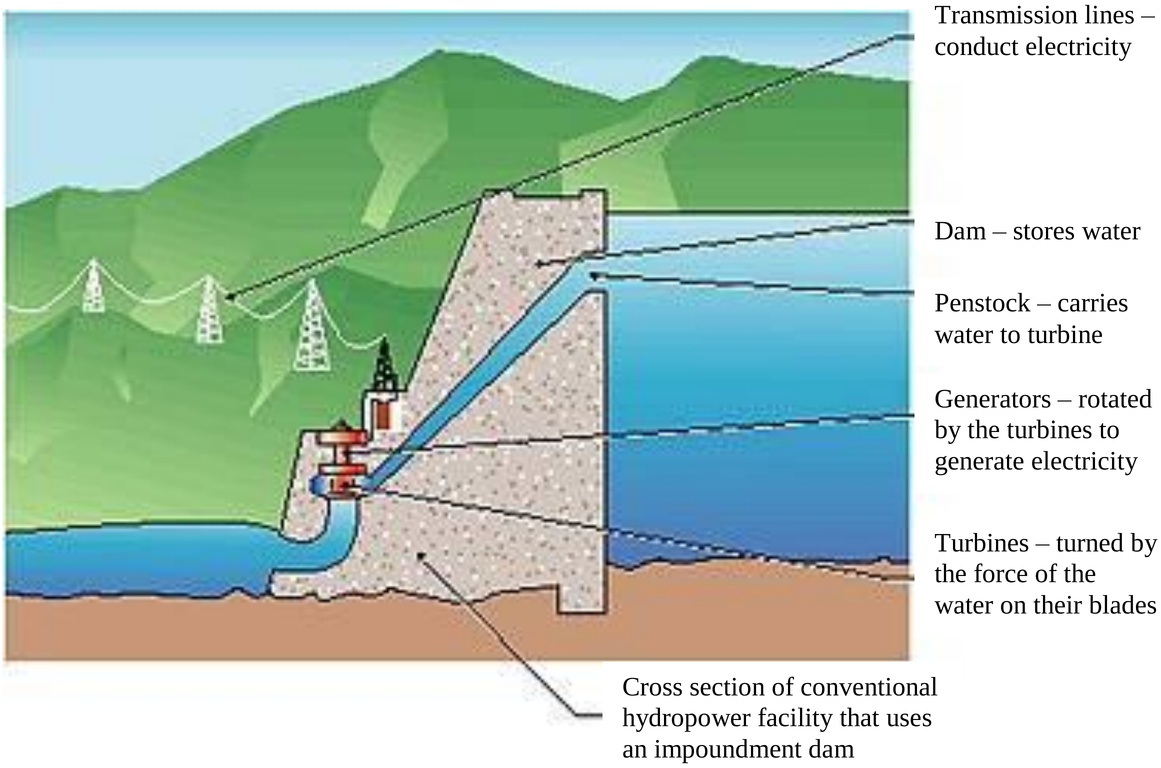

Figure 3.5: Components of a grid-tied micro-hydro power system *(U.S. Department of Energy, 2008)*

Most off-grid based hydro-power systems are battery-based with an inverter to create AC output. In such systems, a battery pack, meter and inverter are needed**. Figure 3.6** reflects the components of such a system.

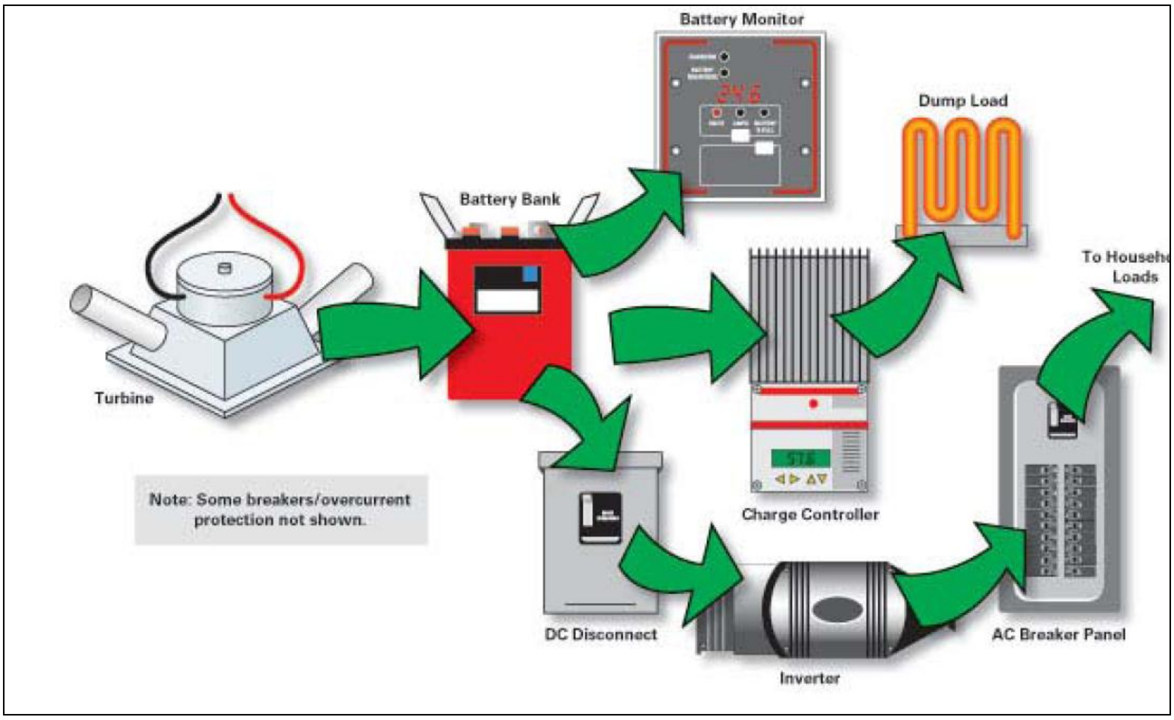

Figure 3.6: Components of an off-grid micro-hydro power system.

The power generation is controlled by the load control governors which regulate the speed of the generator with the objective to control both the frequency and voltage output.

The **load factor** reflects the relationship between what has been generated divided by the potential which could be generated. The higher the load factor (closer to 1) the higher the economic viability of a scheme will be.

Turbines are divided into two categories namely, impulse and reaction turbines which are briefly discussed below:

- **Impulse turbines** – converts the kinetic energy from a jet of water at atmospheric pressures to a blades or buckets of the turbine and
- **Reaction turbines** – blades are immersed and the liquid resulting that the angular and linear momentum is converted to shaft power.

Table 3-3 provides an overview of the application of the different turbines.

Table 3-3: Overview of the typical application of different turbines

Turbine Runner	Pressure head available		
	High	**Medium**	**Low**
Impulse	**Pelton** **Turgo** **Multi-jet Pelton**	**Crossflow** **Turgo** **Multi-jet Pelton**	**Crossflow**
Reaction		**Francis** **Pump-as-turbine (PAT)**	**Propeller** **Kaplan**

Figure 3.7 and Figure 3.8 graphically reflects the head flow characteristics associated with the different turbines and the different types of turbines.

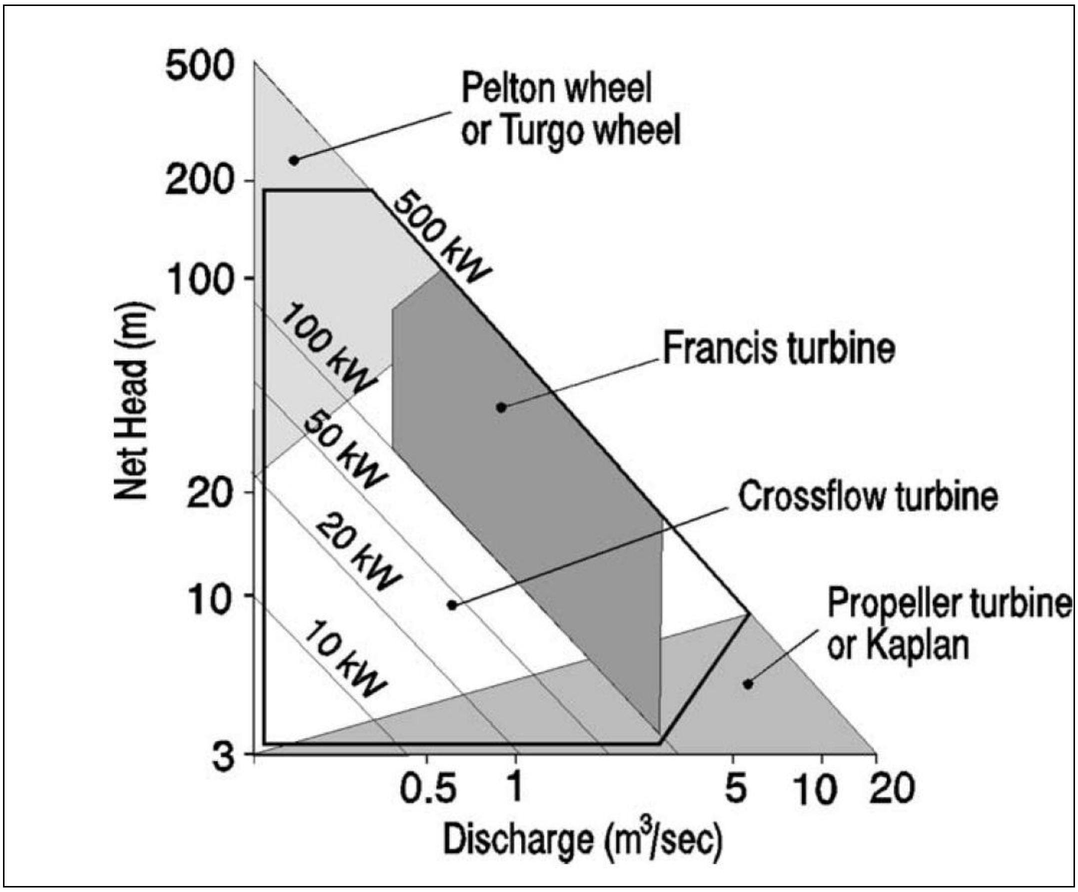

Figure 3.7: Head flow relationship for different turbines

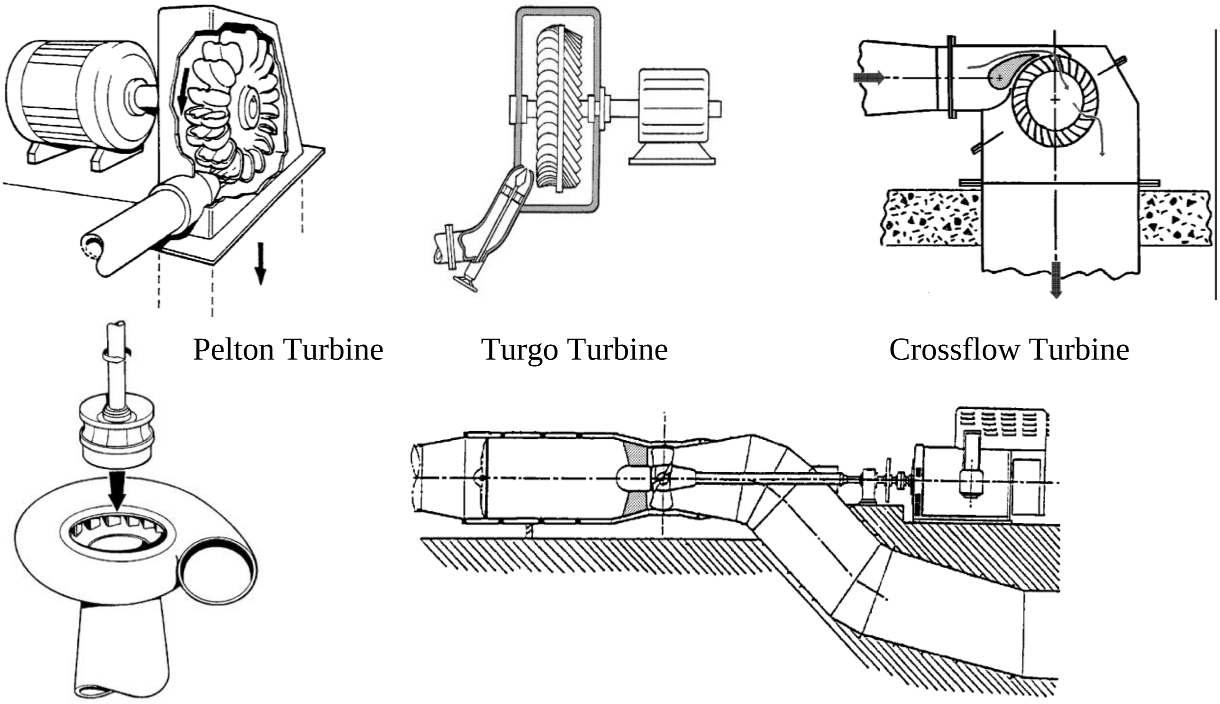

Figure 3.8: View of different turbines (Paish, 2002)

Figure 3.9 reflects the efficiency of the different hydro-power systems, obtained from manufacturer's data (ESHA, 2004).

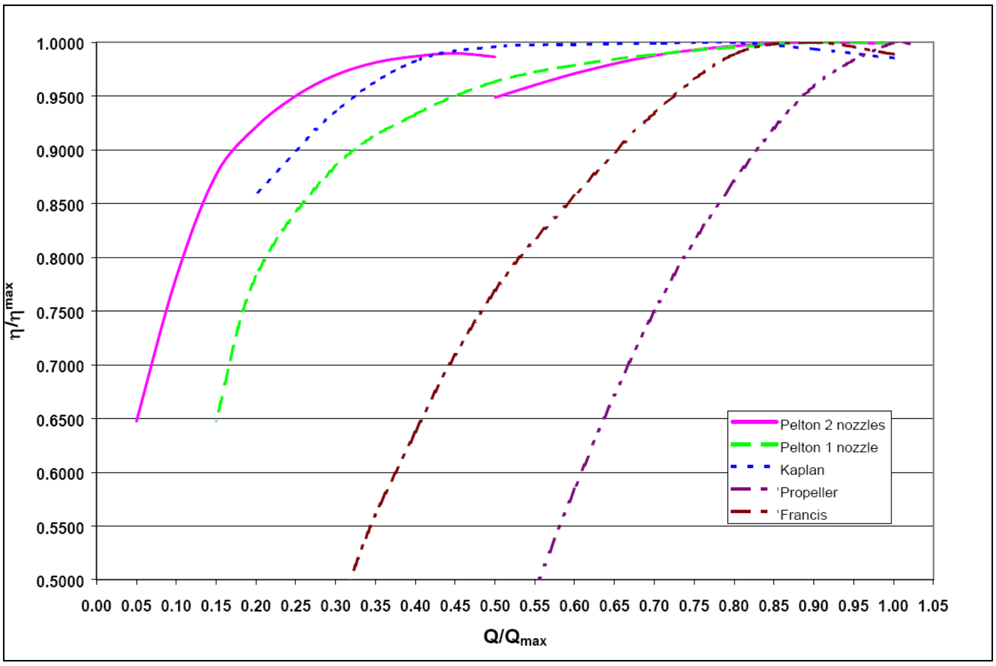

Figure 3.9: Efficiency of hydro-power facilities in South Africa (ESHA, 2004)

4 Conceptual and physical assessment of the potential generation of energy in pressurized water supply systems

4.1 Introduction

Water distribution networks in South Africa are, in the majority of cases, fed from a storage (service) reservoir. These service reservoirs will typically have a storage capacity between 24 to 48 h of the average daily demand from the supply is. Water is fed to these service reservoirs normally from pumping systems.

In the case of the Tshwane Metropolitan Council, which receives a large portion of the water consumption from Rand Water, the excessive head is dissipated at the inlet to these reservoirs. The supply pipelines to a number of service reservoirs are end-controlled by a series of control valves which dissipates the energy when the flow is throttled or when the inflow to the reservoir has to be isolated.

Two hydro power generating systems have been constructed and reviewed as part of the scoping review. A **micro hydropower generating system** (about 30 kW) has been developed with the support of Tshwane Metropolitan Council, Sulzer and Alstom at Queenwood reservoir. This generating unit is a “pump in reverse” configuration which could be implemented at a number of sites similar to Queenswood reservoir. The **second hydropower generating** unit generates electricity to charge a 12 volt battery which could be installed on the domestic water supply to any household.

The findings from these two case studies are first discussed followed by the discussion of a **conceptual model (HRM)** to evaluate the retrofitting option of existing dams.

4.2 Queenswood reservoir case study

4.2.1 Introduction

In the water distribution network in South Africa, water is often fed under gravity from a higher reservoir to another reservoir at a lower level. The high pressure head at the receiving reservoir is then dissipated through the control valves (altitude valves) or in some cases, orifice plates.

This investigation focuses on the practical and economic feasibility of hydropower generation achieved by the installation of a bypass with a turbine around the control valves.

The benefit of this hydropower generating application is that minimal civil works need to be done as the control valves are normally inside a control room/valve chamber. No negative environmental or social effects requires mitigation and the anticipated lead times should be short.

The only civil works necessary are the installation of a bypass onto the current line and the fitting of a turbine, generator and other required electrical equipment.

In the next section a description of the general layout at Queenswood reservoir is given. This is followed by typical flow and pressure values in the pipelines.

4.2.2 Site description at Queenswood reservoir

This experimental investigation was conducted at the Queenswood reservoir in Pretoria which has ideal layout for examining the potential of generating electricity from the energy that would otherwise be dissipated through the control valves. The investigation was done in collaboration with Tshwane Municipality Water and Sanitation division under whose jurisdiction the reservoir and the supplying pipelines fall.

The problem with doing a case study investigation on an actual reservoir is that there is minimal operator control on the different variables influencing the experiment. However, this has the advantage of giving a more reliable indication of the feasibility of actually implementing these schemes at reservoirs in South Africa, as it will point out potential problems and complications in the actual implementation of the scheme.

The assessment represents an observational ‘experiment’ or set-up to assess the potential use of hydropower generation from unused pressures in water distribution (bulk) mains.

Figure 4.1 reflects the supply area of Tshwane Metropolitan Council while **Figure 4.2** provides details of a typical valve chamber for pressure reduction on the inlet side to the storage reservoirs.

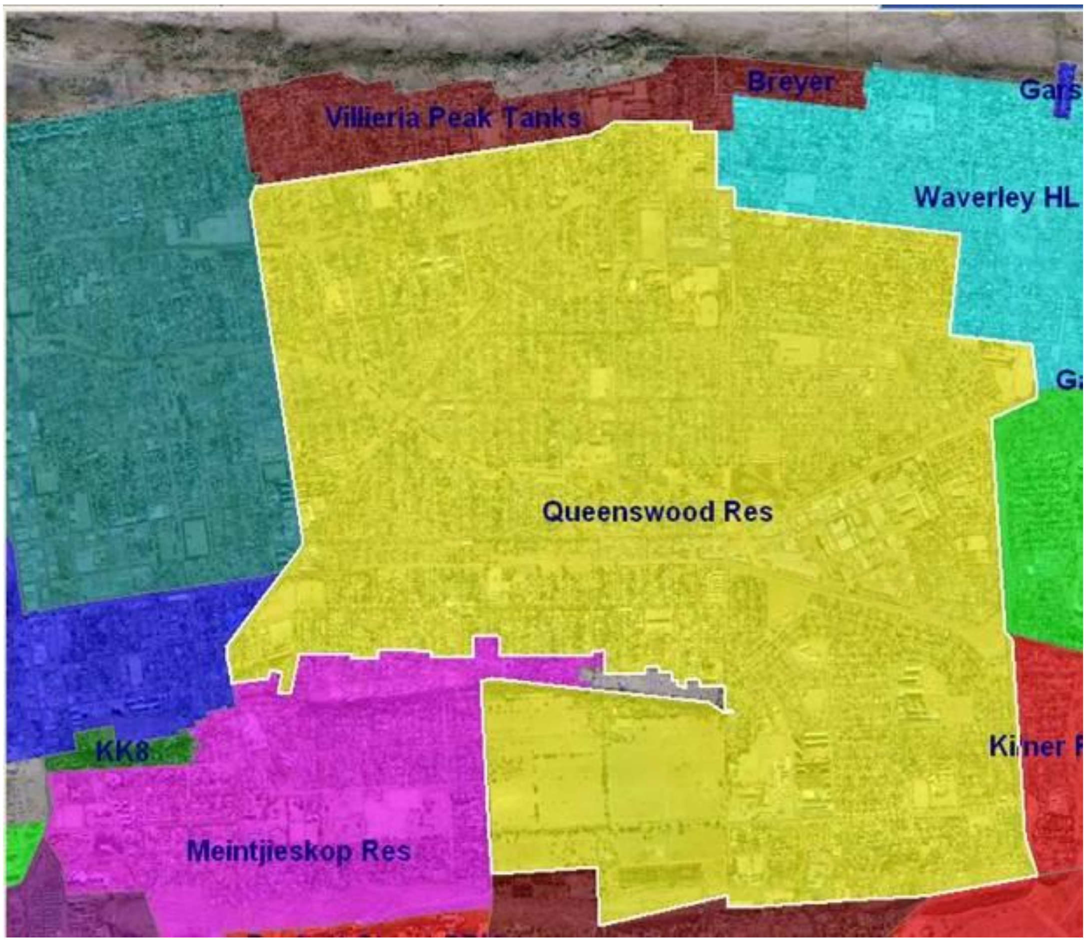

Figure 4.1: Region supplied by Queenswood Reservoir

Queenswood reservoir supplies water to the communities of Rietondale, Villieria and others in Pretoria. The reservoir has a capacity of 18 Mℓ and feeds the supply area under gravity. Water is supplied by Rand Water via a gravity supply pipeline from Garsfontein Reservoir, which is also at atmospheric pressure. The outlet elevation of Queenswood reservoir is 1385,0 m and the top water level is 1390,2 m.

The layout of the reservoir as well as all pipes supplying and delivering water to and from the reservoir in Queenswood reservoir are reflected in **Figure 4.2**. **Figure 4.3** shows a schematic layout of the pipework inside the control room; this figure will be used as the main reference for pipe flows and other properties. To simplify the correlation of information between various sources, the nodes have been labelled to match the schematic layout shown in **Figure 4.2**.

Figure 4.2: Schematic layout of pipe work in and around Queenswood reservoir

The bulk pipeline from Garsfontein is a 500 mm diameter steel pipeline, which splits into two 350 mm diameter pipelines inside the control room.

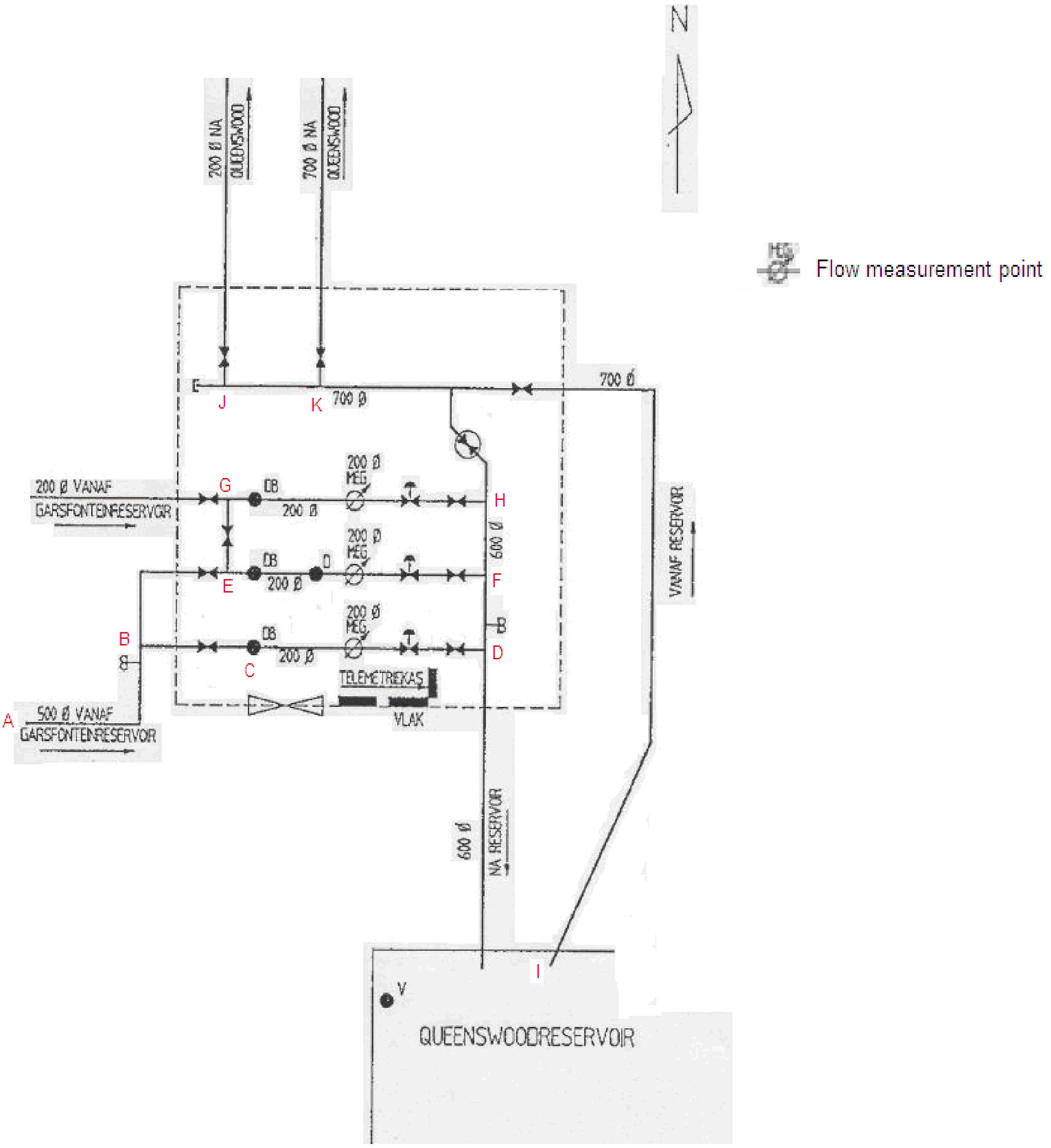

Figure 4.3: Schematic layout of pipe work in control room at Queenswood reservoir

Figure 4.3 shows the three pipes that enter into the control room from Garsfontein reservoir. The two pipes on the left are the branches from the main 500 mm diameter supply pipe from Garsfontein; on the far left is pipe BC and in the middle is pipe BE. The pipe on the far right is the 200 mm supply pipe that has been decommissioned. Each of the pipelines (CD, EF and GH) has been installed with a series of two 200 mm diameter altitude control valves, **Figure 4.4**. This allows for flexibility in the control of the current operating system. This also provides a backup in case of failure of one of the links. Isolating valves are in place to allow each pipeline to be individually isolated in case of maintenance or operating problems of the control valves without affecting operation of the entire scheme.

The (altitude) control valves automatically dissipate the higher inlet pressure to a steady lower downstream pressure when it is throttled. The altitude valves are set in such a way that they will sequentially close. When the service reservoir has been filled all the altitude control valves will be closed, ensuring that the reservoir does not overtop.

Figure 4.4: Altitude valve configuration in the Queenswood reservoir valve control room

Although this system is effective in controlling flow into the reservoir, problems arise due to the cavitation of the valves. One of the benefits which will hopefully arise when passing the water through a turbine is that the cavitation on the main control valves will be reduced and they will not have to be replaced as often as currently being experienced. **Although this aspect will not be investigated in depth during this scoping, this aspect has potential for further review.**

4.2.3 Characteristic flow and head at Queenswood reservoir

The power generated by the turbine depends on the flow rate and pressure difference across it; it is therefore important to know the flow rates and pressures and their ranges in the different pipelines in order to accurately estimate the potential for electricity generation in the proposed micro-hydropower scheme. These values that are predicted will be the norms to which the values measured in the experimental run will be compared.

The existing 500 mm diameter bulk line from Garsfontein carries a peak flow of 230 ℓ/s. As mentioned, water flows under gravity from Garsfontein reservoir, with a top water level of 1508,4 m, into Queenswood reservoir, entering at an elevation of 1385 m. This indicates that the maximum water pressure (static) is 123,4 m, which occurs when Garsfontein reservoir is full and no flow enters Queenswood reservoir. The minimum water pressure (dynamic) is 95,4 m. This gives the range of head to be considered for the selection of the appropriate turbine from 95,4 to 123,4 m which is highly favourable for hydropower generation.

The peak flow rates in each of the pipelines were obtained from Tshwane Municipality's bulk water supply system program, and are indicated on **Figure 4.5**. Note that these are not the actual flow rates in the pipes but the maximum flow rates that the pipes can handle.

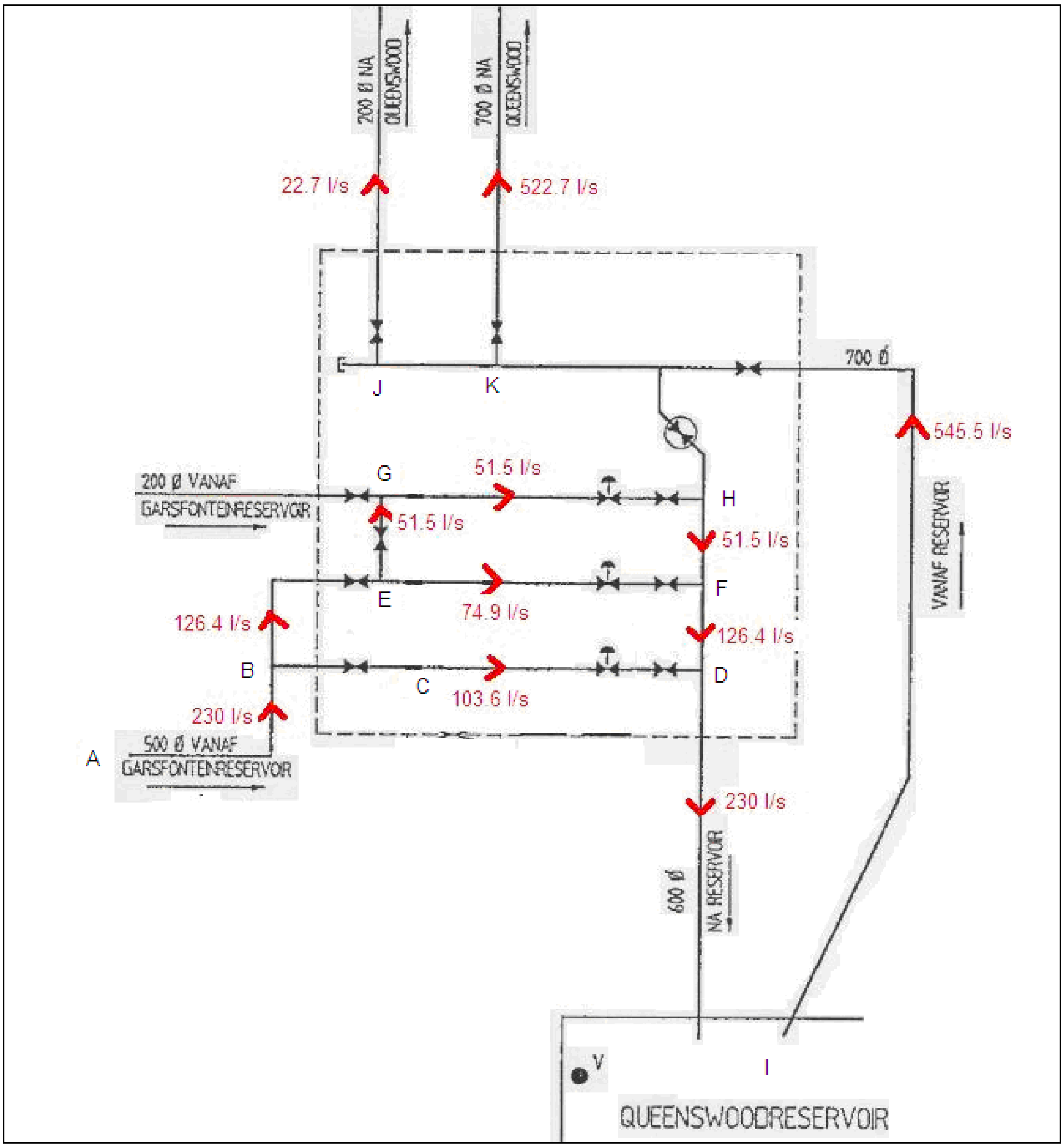

Figure 4.5: Schematic diagram of peak flows before installation of energy recovery system

The bypass which was built for the turbine comes off at node G and enters into the outlet pipe close to node K (**Figure 4.5)**. The maximum flow rate that can pass through the bypass is therefore about 51,5 ℓ/s (if pipeline GH is closed off); as this is a peak flow, the actual flow is likely to be less than this value.

Ideally what would be required is an exact break down of the flow passing through each of these points at 15 minute intervals so that a flow-duration curve could be set up and the sustainability and fluctuation in the flow rate during the day could be determined. This would enable a fairly accurate estimation of the electricity generation capacity of the proposed scheme – what flow it would run at and how many hours per day it would be in operation.

However, these graphs of the *average* daily supply, which are clearly incomplete and lacking data, are the only information obtainable on the flow history and will therefore have to suffice in the assumptions on the sustainability and fluctuation of flow.

Table 4-1: Annual Average Daily Demands shows the Annual Average Daily Demand (AADD) in each of the pipelines as obtained from Appendix B. It should be noted that although it is termed a daily *demand*, it is in fact a measure of the flow passing through each pipeline supplying the reservoir and not the demand being supplied to the community. It is assumed that this AADD is taken over 24 hours and was therefore been divided by 24 to get the average demand per hour. This was then converted into flow rate in ℓ/s.

Table 4-1: Annual Average Daily Demands

Flow meter	AADD (kℓ /day)	AADD (m^3/hr)	AADD (ℓ/s)
On pipe CD (valve 259)	2 429,92	101,25	28,1
On pipe EF (valve 260)	0,0 (not in use)		
On pipe GH (valve 261)	1 914,77	79,78	22,2

It can be seen that no flow passed through pipe EF, as it is obvious that this pipe is used only under extreme high demand situations, such as when the reservoir level is low. The flow in this pipe will therefore be ignored for the rest of the investigation.

In order to investigate the continuous 24 hour operation of the turbine, the minimum off-peak flow that goes into the reservoir needs to be determined. This shows the worst case scenario for electricity generation. Maximum capacity run occurs in the daytime, when the demand for water is the highest.

In order to determine the fluctuation in flow passing through the pipes throughout the day, it has been assumed that the supply into the reservoir is directly related to the outflow. The outflow from the reservoir is determined by the demand of the communities to which it supplies water. As Queenswood reservoir supplies water to mostly residential communities, it is assumed that the typical demand pattern curve for medium sized stand residential households, as has been described in the literature, applies. This typical demand pattern curve is shown in **Figure 4.6**.

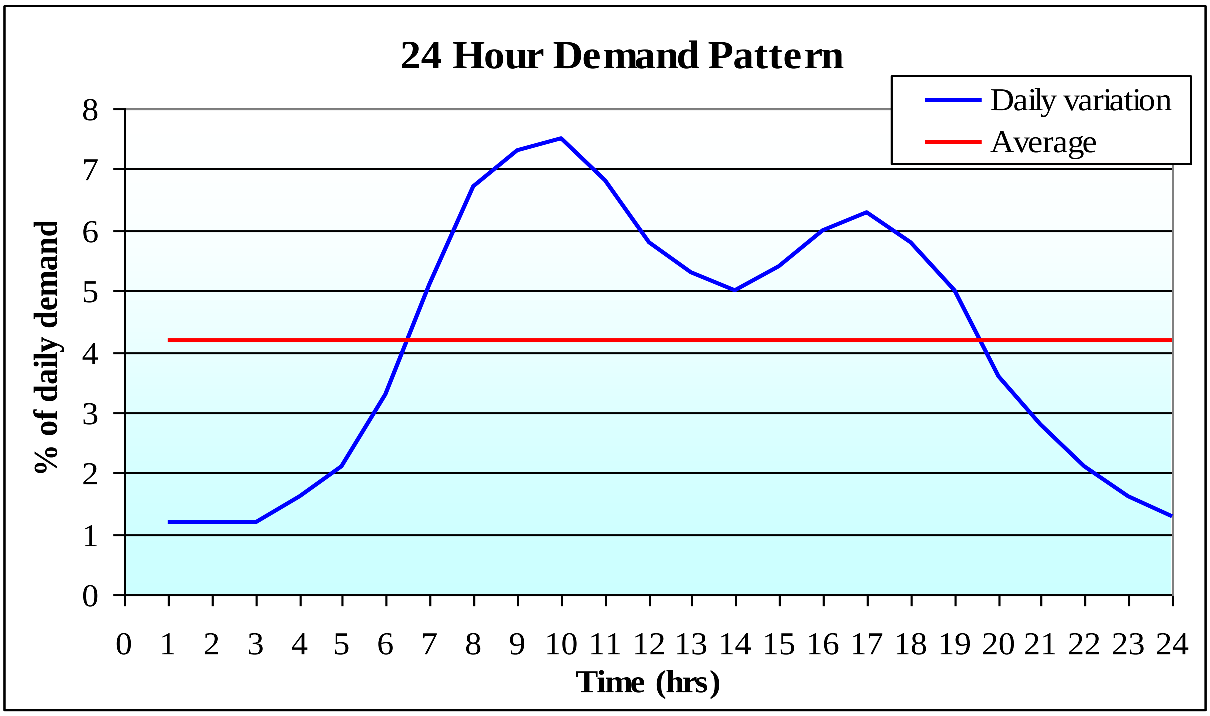

Figure 4.6: Generic demand pattern curve for medium sized stand residential households

As there is no data available for the flow variation through the day at Queenswood reservoir, this generic demand pattern model has been applied to the average daily flow rate in each pipe supplying the reservoir to obtain a calculated estimate of the flow rate variation throughout the day. The assumed hourly flow rates that were calculated are shown in **Tabel 4.2**.

Table 4-2: Assumed hourly flow rates distribution through pipes CD and GH

		AADD (ℓ/s) 28,1	AADD (ℓ/s) 22,2
Time	% of daily demand	Flow rate (ℓ/s)	Flow rate (ℓ/s)
		Pipe CD	Pipe GH
1	1,2	8,1	6,4
2	1,2	8,1	6,4
3	1,2	8,1	6,4
4	1,6	10,8	8,5
5	2,1	14,2	11,2
6	3,3	22,3	17,6
7	5,1	34,4	27,1
8	6,7	45,2	35,6
9	7,3	49,3	38,8
10	7,5	50,6	39,9
11	6,8	45,9	36,2
12	5,8	39,1	30,8
13	5,3	35,8	28,2
14	5	33,7	26,6
15	5,4	36,4	28,7
16	6	40,5	31,9
17	6,3	42,5	33,5
18	5,8	39,1	30,8
19	5	33,7	26,6
20	3,6	24,3	19,1
21	2,8	18,9	14,9
22	2,1	14,2	11,2
23	1,6	10,8	8,5
24	1,3	8,8	6,9

The minimum flow rate in the pipeline of concern to the bypass (Pipe GH), based on average daily data and the assumption of the demand pattern, is 6,4 ℓ/s occurring from 1h00 to 3h00. The maximum flow rate is 39,9 ℓ/s occurring at 10h00.

The values in **Table 4-2** were used to draw up a flow exceedance curve, shown in **Figure 4.7**. This can be used to assess the dependability of the power that is produced. It can be seen that the base flow (minimum flow that is continuously exceeded) is 6,4 ℓ/s. This would therefore be the flow rate to be considered for 24 hour continuous power generation. The flow rate that is exceeds 50% of the time is 26,6 ℓ/s.

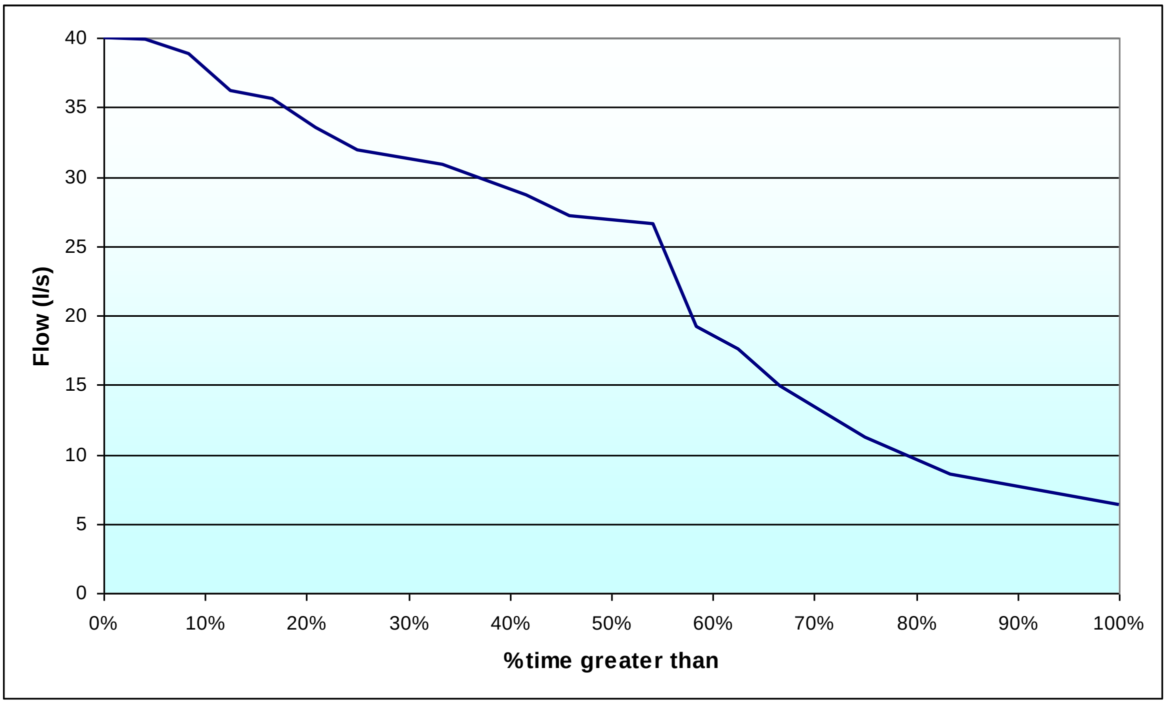

Figure 4.7: Flow exceedance curve for Pipe GH

As mentioned, it is important to know the pressures in the pipeline in order to assess power generation capabilities. **Table 4-3** shows the static pressure and the peak pressure (dynamic pressure) at each node as referred to in **Figure 4.3**. These values were also obtained from Tshwane Municipality's bulk water supply system program. As the upstream pressure has not been recorded by Tshwane municipality, there is no indication of the fluctuation in the net pressure available for power generation.

By analysing **Table 4-3**, it can be concluded that the maximum static pressure in the bypass with the turbine will be 123,4 m and the peak (or dynamic) pressure will be approximately 94,8 m.

Table 4-3: Pressure at each node (Figure 4.3)

<table>
<tr><th>Node</th><th>Static Pressure (m)</th><th>Peak Pressure (m)</th></tr>
<tr><td>A</td><td rowspan="8">123,4</td><td>100,5</td></tr>
<tr><td>B</td><td>95,4</td></tr>
<tr><td>C</td><td>95,0</td></tr>
<tr><td>D</td><td>94,7</td></tr>
<tr><td>E</td><td>94,9</td></tr>
<tr><td>F</td><td>94,7</td></tr>
<tr><td>G</td><td>94,8</td></tr>
<tr><td>H</td><td>94,7</td></tr>
<tr><td>I</td><td rowspan="3">5,2</td><td>5,2</td></tr>
<tr><td>J</td><td rowspan="2">5,1</td></tr>
<tr><td>K</td></tr>
</table>

In order to estimate the potential for electricity generation in the proposed hydropower scheme, the available hydraulic power is calculated according to the following relationship (as has been defined in the literature):

$$P_h = \rho \cdot g \cdot Q \cdot H$$

This hydraulic power is multiplied by the efficiency to determine the nett power output. This is then multiplied by the number of hours per day for which this power will be able to be generated by the turbine to obtain the kWh/day of electricity that will potentially be generated. This is multiplied by 365 (assuming the turbine works year round) to determine the annual kWh generated by the hydropower scheme, giving an indication of the electricity that can be sold and the potential income that can be expected.

Preliminary estimations using H = 94,8 m, Q = 0,0399 m^3/s, ρ = 1000 kg/m^3 and g = 9,81 m/s^2 indicate that **the maximum available hydraulic power is 37,1 kW**. A conservative estimation of the efficiency of 0,4 reflects that the power which can be generated is in the order of 15 kW. As indicated in the literature, **this size installation is regarded as micro-hydropower** and is able to supply a small community with commercial/ manufacturing enterprises.

Using the flow exceedance curve in **Figure 4.7**, a table was drawn up for different flow rates that are expected through the bypass (if pipe GH is closed off) and the number of hours per day for which the flow is greater than the selected flow rate. Using a pressure head of 95 m and an efficiency of 0,4 for the system, the expected power that will be generated per year if the turbine is operated consistently at each of the different flow rates is shown in **Table 4-4.** These expected values of flow, pressure and power generation will be the norms against which the observed data will be compared.

Table 4-4: Expected power generated for different flow rates and operating hours

Q (ℓ/s)	P (kW)	Hours generating per day	Electricity generated per day (kWh)	Electricity generated per year (kWh)
6,4	2,38	24	57,10	20 841
8,5	3,17	20	63,44	23 155
11,2	4,16	18	74,94	27 355
14,9	5,55	16	88,82	32 420
17,6	6,54	15	98,14	35 821
19,1	7,14	14	99,92	36 471
26,6	9,91	13	128,87	47 037
27,1	10,11	11	111,22	40 597
28,7	10,71	10	107,06	39 076
30,8	11,50	8	91,99	33 578
31,9	11,90	6	71,37	26 051
33,5	12,49	5	62,45	22 795
35,6	13,28	4	53,13	19 394
36,2	13,48	3	40,44	14 762
38,8	14,47	2	28,95	10 565
39,9	14,87	1	14,87	5 427

The maximum electricity generated per year is 47 037 kWh; this corresponds with a flow rate of 26,6 ℓ/s and the turbine operation for 13 hours per day. If it is assumed that the REFIT as discussed in the literature applies, the tariff that will be received is R0,94/kWh, amounting to a yearly income of R44 215. It should be noted that these calculations have been based on the assumption of a constant head of 95 m and an efficiency of 0,4; the reliability of these assumptions is not certain and needs to be verified during further testing and assessment of the system. However the power generation can be optimized by allowing a higher discharge through the generation loop and resetting the altitude valves. This was not investigated in detail.

It is also noted that if a REFIT is used, the trading of carbon credits in the form of CERs and TRECs can also be utilized to generate income.

An added advantage of this configuration is that allowing continuous flow through the turbine will reduce cavitation in the existing pressure control valves

4.2.4 Experimental methodology

4.2.4.1 Electro-mechanical equipment

As turbines used in small scale hydropower are fairly difficult to come by, are expensive and have long waiting times, it was decided to investigate using a pump in reverse as a turbine.

Due to the time constraints of this research project, it would be difficult to optimize the selection of a pump to be used in reverse and then to still acquire the pump, install it and run the system. It was therefore decided to utilize a pump that the University already has and to see how the system operates using this pump. Although this is not an ideal situation, it will still be able to give an indication of the feasibility of this type of hydropower system and point out potential benefits and complications with the implementation.

The pump which was used in the setup at Queenswood reservoir is the Sulzer AZ – 100/400 pump. Its best efficiency point (BEP) is at a flow rate of 180 m^3/hour and 50 m head with 34kW power required. The inlet diameter is 125 mm, the outlet diameter is 100 mm and the impeller diameter is 409 mm. It should be noted that because the pump is being run in reverse in order to operate as a turbine, what is normally the inlet of the pump (horizontal axis, 125 mm diameter) is now the outlet of the turbine and the outlet of the pump (vertical axis, 100 mm diameter) is the inlet of the turbine. The pump was donated to the University of Pretoria by Sulzer SA from whom the pump characteristic curves, shown in Appendix A have been obtained. Figure 4.8 reflects some details of the pump.

Figure 4.8: Sulzer pump that is used as a turbine(Sulzer AZ 100/400)

Tests have been done on pumps by the Sulzer Company to determine the performance characteristics of their pumps were run in reverse as turbines. The formulas and mathematical predictions are not available for publication or to the public, but estimates of characteristic curves for the selected pump operating as a turbine have been provided by Sulzer SA for the purpose of this research project. An approximation of the operational characteristics of a pump in reverse as a turbine in comparison to the original BEP (best efficiency point) is that that the required flow rate and head to obtain the similar hydropower will have to be increased by about 30%.

The turbine (pump) was connected to a motor running in reverse as a generator in order to generate electricity. The motor size required was estimated to be in the order of 25-30 kW. Alstom kindly agreed to donate a motor to the University of Pretoria to be used for this research project. The motor that is used is a 37 kW, 4 pole induction motor. It is a three phase motor and the output voltage is 380V. Figure 4.9 shows some details of the motor.

Figure 4.9: Motor from Alstom that is used as a generator

The pump and motor are connected using a flexible coupling; this allows for certain tolerances regarding vertical, horizontal and rotational misalignment of the shafts of the pump and motor. The pump shaft diameter is 40 mm and the motor shaft diameter is 60 mm. They are connected using an F90 tyre coupling purchased from BMG.

Initially it was considered to connect the output into the Electricity Distribution Network, obtaining the benefit of negating the need to include a complicated frequency control unit. It was however established that a connection into the distribution network is a lengthy process, requiring certain licenses and strict regulations and it would therefore not be viable within the allocated period of this scoping and hence it was decided to investigate an onsite generation facility.

As the purpose of this scoping is to investigate the feasibility of the potential generation of electricity of such a scheme, the required control system with automated feedback loops controlling the operation of the turbine and synchronizing it with the generator, as would be required in a permanent set-up, is beyond this investigation and therefore a simplified load system has been used.

In order to determine the power output of the generator, a ballast load was connected directly to the generator, effectively ‘throwing away’ the electricity generated. A load has to be connected in order to be able to measure the current and the voltage produced so that the power output can be calculated; one cannot simply measure the voltage to determine the power output. The ballast load used was six 4 kW geyser elements to the generator in pairs (in series) as shown in Figure 4.10. The geyser elements were placed in a tank with water, therefore consuming the electricity generated. This allows for the safe measurement of the electricity generated without it being overly complicated, therefore serving the purpose as required for the experiment.

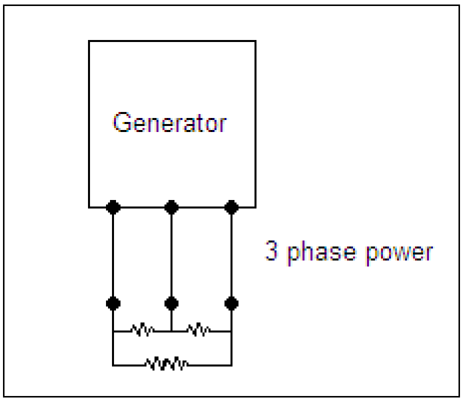

Figure 4.10: Ballast load connected to generator

Photographs of the ballast load system used and the electrical connection of the geyser elements are shown in Figure 4.11 and Figure 4.12.

Figure 4.11: Zinc basin with geyser elements used as ballast loads

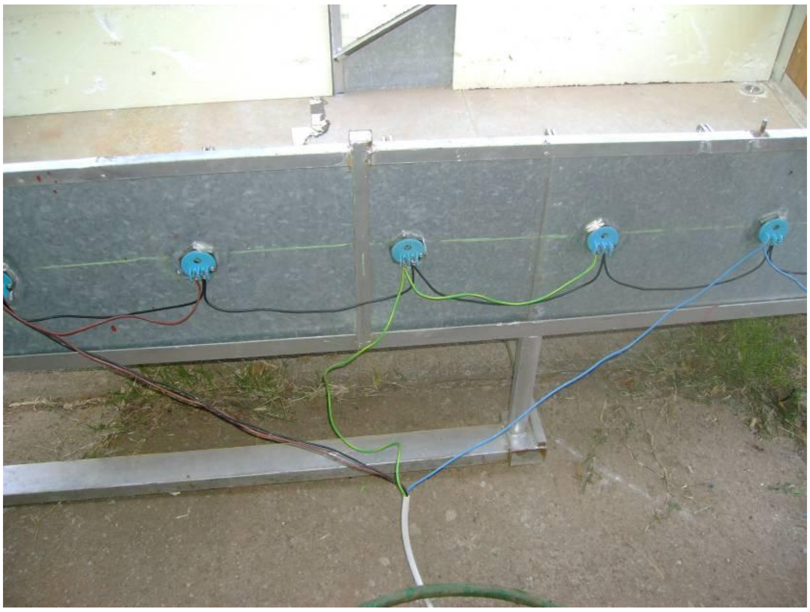

Figure 4.12: Electrical wiring of the elements

In the case of a permanent installation the output of the generator would have to be regulated to ensure that it is at the correct frequency (50 Hz). The generator output is an alternating current (AC), but because of the fluctuations in turbine operating conditions, the output of the generator also fluctuates and a variable frequency and voltage output is produced. For onsite generation the generator would have to be connected to a rectifier which converts the current into direct current (DC) and then connected to an inverter which converts the current back into AC but regulates the frequency to a constant and stable 50 Hz. Both the rectifier and the inverter have efficiencies and therefore to get the overall efficiency of the scheme, these need to be considered in conjunction with the efficiencies of the turbine and generator. The efficiency obtained through calculation will therefore be multiplied by 0,81 (assuming a 90% efficiency for the rectifier and a 90% efficiency for the inverter) to obtain a realistic prediction of the power that can be sold through the Distribution network if the scheme were to be installed as an electricity generator.

It is clear that in a real world situation, where the implementation of this micro hydropower scheme were to be permanent and used for long term electricity generation, the control system required on the scheme would be much more complicated that what is being used on the experimental setup. The experimental setup is not a true reflection of exactly what would happen in an actual implementation, but it gives a basic indication of factors to be considered and expected results.

4.2.4.2 System layout for hydropower generation at Queenswood Reservoir

The micro-hydropower system being considered has many similarities to the energy recovery scheme implemented at Barnacre in the UK that is described in the literature (Williams et al, 1998); therefore assumptions in the design of the scheme are based on the results described in the literature.

The turbine was installed on a bypass in parallel with the existing pressure reducing control valves. The bypass avoids interruption of the main flow and, as mentioned elsewhere in the literature, adding the bypass with the turbine in parallel to the existing altitude control valve increases the operating life of the control valves. Isolating valves were installed on both branches of the bypass to allow the turbine section to be entirely isolated from the existing network.

A portion of the flow through the main pipelines will be directed along the bypass and turbine. The flow rate in the main pipeline will be diverted into the bypass and flow through the turbine which will be measured during the experimental setup.

Reference is made to the use of a control valve for systems without an electronic load controller, where the flow into the turbine is regulated (Schnitzer, 1988). A pressure reducing valve was installed as shown in Figure 4.13.

Figure 4.13: Pressure reducing valve installed upstream of pump

Figure 4.14 shows the proposed layout of the micro-hydropower energy recovery scheme, including the components that will be installed on the bypass.

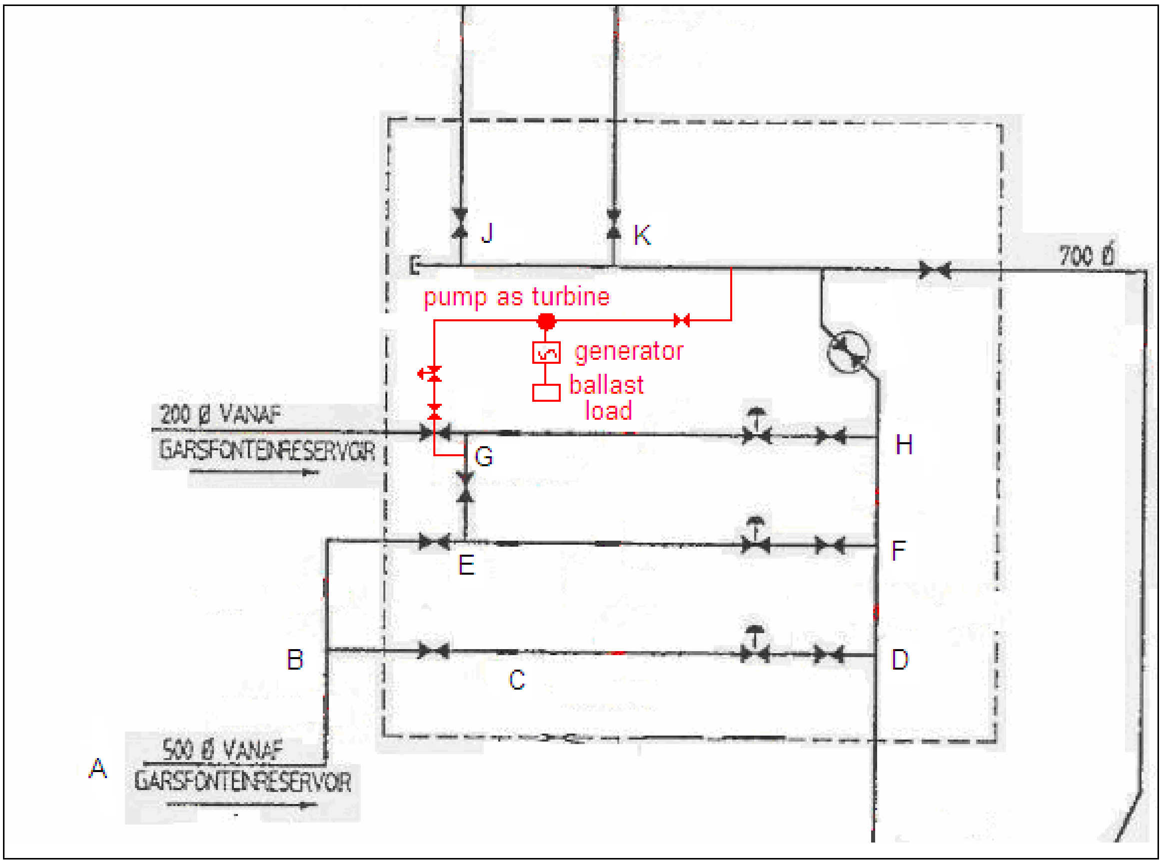

Figure 4.14: Layout of bypass with energy recovery scheme (Queenswood reservoir)

This pipe work was specially made up by welders on site. A pressure reducing valve was placed immediately after the isolating valve at the beginning section. A flow meter

(Figure 4.15) was installed after the first corner but before the turbine; it must be ensured that it is installed a sufficient distance away from the corner so that the flow through the meter is even ensuring that accurate readings are taken.

Figure 4.16 shows some components of the hydropower generating unit that was installed in the bypass loop around the existing pressure control valves. Figure 4.17 shows a close-up view of the connection between the pump and motor.

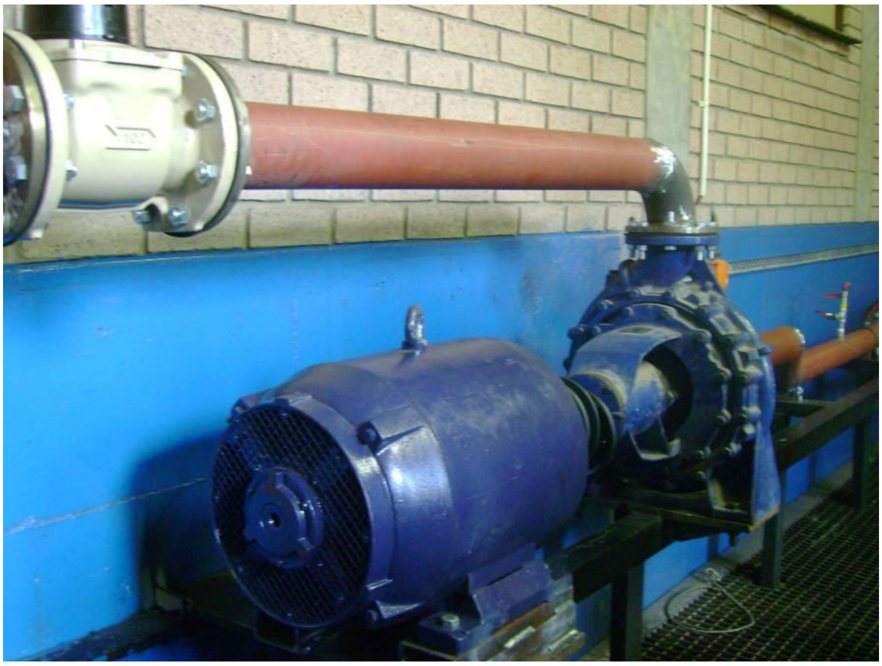

Figure 4.15: Flow meter to record the flow rate

Figure 4.16: Section of bypass before pump-as-turbine

Figure 4.17: Connection between pump-as-turbine and motor

To ensure adequate force transferal, the turbine and generator were securely anchored to base plates which prevent excessive vibrations of the turbine and generator. These base plates were built in the existing control room and bolted to the walls. It was ensured that the turbine was installed at the correct height and alignment to minimize forces in the bypass pipe sections, turbine and generator.

4.2.4.3 Initial data recordings

In order to accurately evaluate the performance of the system, all variables which influence the power generation need to be recorded. The flow rate in the bypass, the pressure difference across the turbine, the rotation speed and the power output has to be recorded. The frequency control created unforeseen problems and the data recording was unsuccessful. The induction motor was replaced with a generator with a 20 kWatt capacity. The generation for different flow rates and pressures were recorded and are included in the Executive Summary.

The data will facilitate the calculation of the turbine efficiency, η, and the power generated from the following relationship:

$$P = \rho \cdot g \cdot Q \cdot H \cdot \eta$$

The potential application of hydropower generation that should be reviewed further in the Tshwane Water Supply Area are summarized in Table 4-5

Table 4-5: Reservoirs in the Tshwane supply are where the energy on the inlet has to be dissipated by control valves

Reservoir	Storage volume (Ml)	Inlet pressure (Bar)	Pressure control
Queenswood	40	11 to 16	Two series installed control valves on each inlet line
Voortrekkerhoogte	20	12 to 18	Two series installed control valves on each inlet line
Waterkloof reservoirs	60	10 to 12	Two series installed control valves on each inlet line

4.3 Identification of potential untapped energy sources for micro hydro power

4.3.1 Generation at individual households

Thousands of households use water every day for various applications. This provides the opportunity to make use of the high pressure water to generate hydropower by developing a unit that can be installed directly into the main water supply line of a house to generate electricity whenever water is used in that household.

The power generated will be directly proportional to the product of the residual head and the volume flow rate (Williams, 1996). In such a domestic setup, the flow rate available for power generation will dependent on the demand patterns and the available head will relate to the supply pressure characteristics of the system.

4.3.2 Typical domestic demand patterns

In 2006 GLS Consulting (Pty) Ltd, a Stellenbosch based firm of consulting engineers specialising in the analysis, planning and management of water related systems, conducted a survey in the Gauteng area to determine the demand patterns for households in South-Africa. Four different size classifications were identified as indicated in **Table 4-6**.

Table 4-6: ***South-African households: Sizes and daily demands (GLS, 2006)***

Size	Daily demand (litres/day)
Large residential	2400
Medium residential	1600
Small residential	1200
Low cost housing	750

The possibility to generate power in the pressurized supply line to domestic consumers was investigated for a medium and a large residential household.

4.3.3 Typical pressure fluctuations recorded

The available pressure or residual head depends on the distribution characteristics and the water supply source. The normative standards (CSIR, 1994) indicates the required minimum pressures in water supply systems under peak demand has to be 40 m and under peak demand and fire flow 20 m, reflecting that if the peak demand does not occur, excess heads will be available. In theory the pattern of the available head during times of consumption should be the inversely related to the demand patterns.

Two domestic consumer sites were identified; Diana road 386, Menlopark, Pretoria and Singa drive 55, Matumi, Nelspruit. The Diana road site was classified as the medium residential household and the Singa drive site as the large residential household.

At both these sites a data logger and pressure transducers were installed to record the pressure at a frequency of 0,1 Hz over a 24-hour time period.

4.3.4 Model requirements for a household pico hydropower generation unit

The objective was to design and construct a power generating unit which could be installed onto the main water supply conduit of a household. The unit has to meet the following basic requirements:

- It has to be able to withstand the pressure experienced in the distribution network;
- Should not significantly reduce the flow rate and pressure;
- The unit should be able to convert the generated mechanical energy into electrical energy that can be stored for consumption.

The two main elements of the pico hydropower generation unit are the mechanical component and the electrical component, which are briefly discussed below.

4.3.5 Mechanical component

The mechanical component consists of the inlet and outlet pipes, impeller, shaft, impeller and shaft casing, pulley and rubber belt, **Figure 4.18**. The component is mounted on a solid base plate for stability.

The mechanical components are defined as follows:

- Inlet and outlet pipes: The inlet and outlet pipe diameters should be similar to the household pluming (**A** and **B** – **Figure 4.19)**;
- Impeller: The impeller is a crucial and will convert the pressure and flow of the water into the desired mechanical energy. An impellor made of copper, with a diameter of 60 mm and width of 6 mm was used, **Figure 4.19**. The impeller should preferably utilize a large proportion of the available excess head (**C** – **Figure 4.19)**;
- Shaft: The shaft is connected to the impeller and serves as a medium to which the generated mechanical energy from the impeller is transferred to. The 10 mm diameter stainless steel shaft was designed and manufactured for the purposes of this experiment. The shaft has two bearings, one on either side of the casing (**D** and **E Figure 4.21);**
- Shaft and impeller casing: A high pressure pump casing was used to house the impeller and shaft. The motor of the pump was removed and the casing served to stabilise the shaft. The pump is utilised in reverse, **Figure 4.21;** and
- Pulley and rubber belt: A pulley, 40 mm diameter, is attached to the opposite end of the shaft. The pulley will act as the guide for the rubber belt which in turn will be connected to the electric motor responsible for generating electricity, (F and G **Figure 4.21)**.

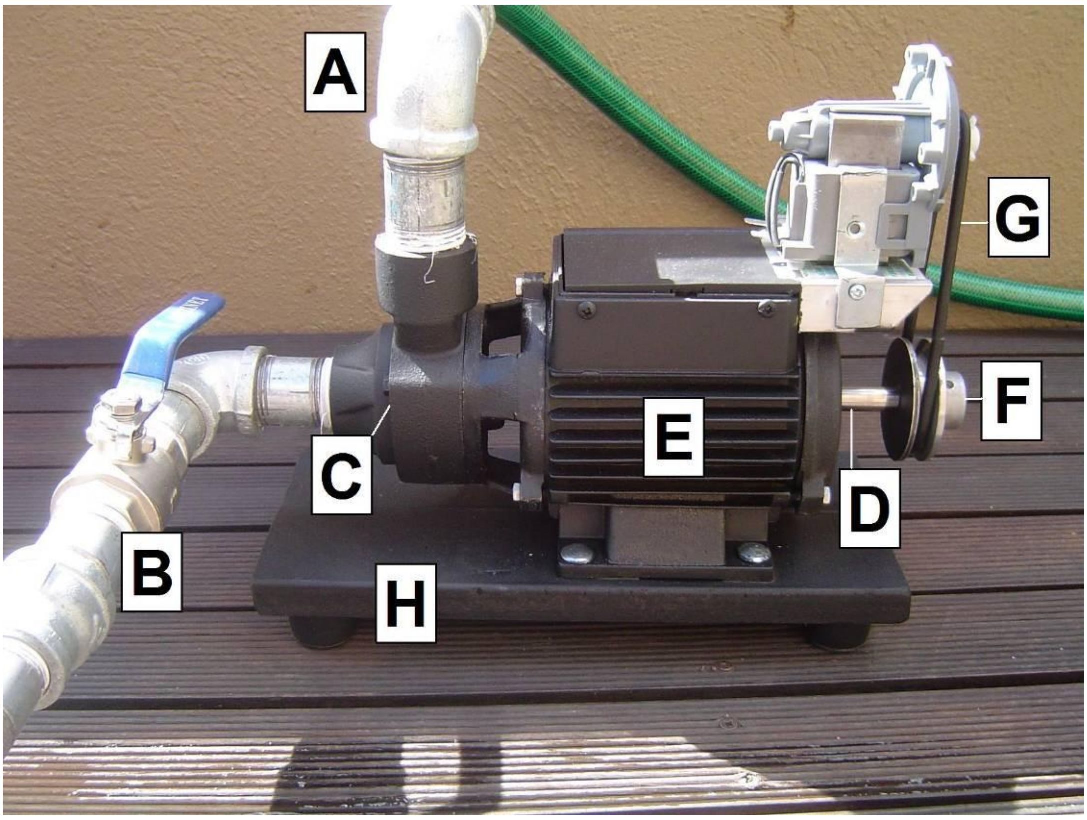

Figure 4.18 : The mechanical configuration of the model

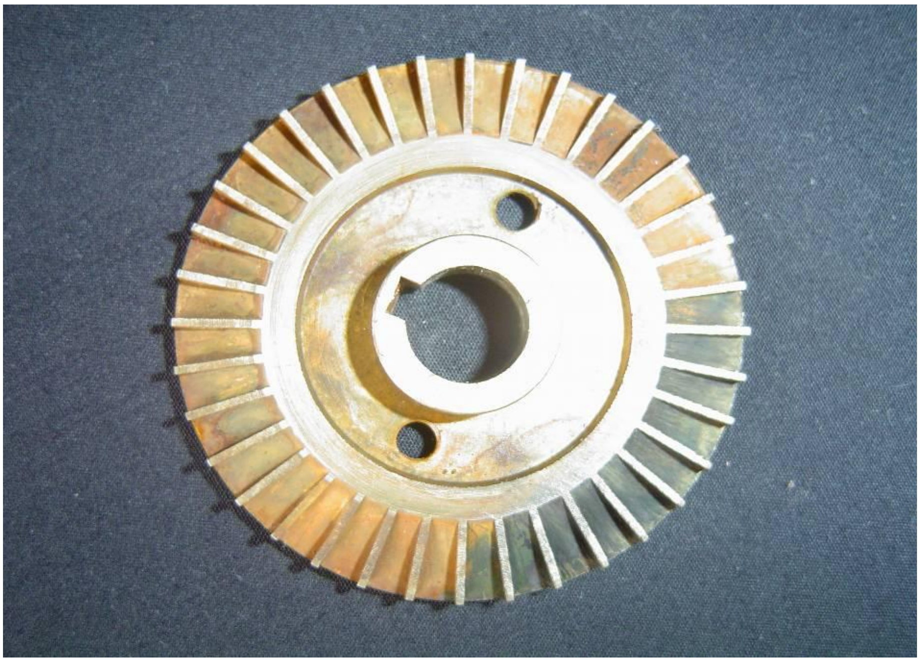

Figure 4.19: The impeller

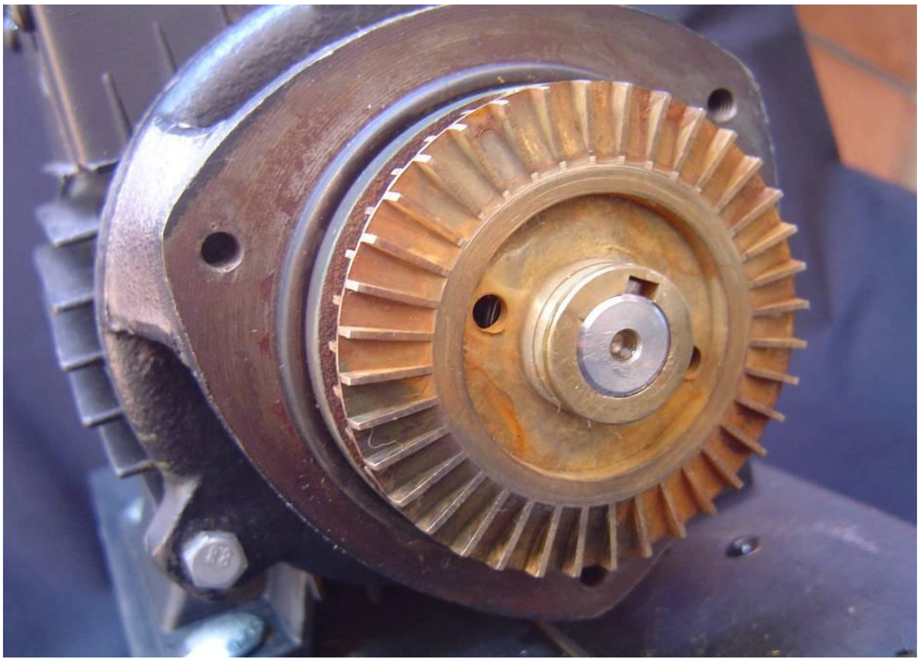

Figure 4.20: The impeller in its casing connected to the shaft

Figure 4.21: The shaft with its bearings on either side of the casing

4.3.6 Electrical component

The electrical components consisting of an electrical motor, a control board and a rechargeable battery, **Figure 4.26**. An electrical motor from a washing machine pump was used as the electricity producing unit. Connecting the rotating pulley of the mechanical configuration to the impeller axle of the motor with the rubber belt, cause the motor axle to rotate and generate electricity. The connection with the rubber belt is simplified by replacing the existing impeller of the washing machine pump with a pulley, similar to the one used on the shaft. The motor has a rated voltage of 220V to 240V alternating current and rated electric current of 0,2A which equals approximately 45 watts of power produced. The power generated from applying the motor in reverse is of similar magnitude as its rated potential.

The battery cannot be connected directly to the electric motor because the motor produces an AC output of up to 220V and the battery requires a steady direct current input of 12V. To convert the AC output to the desired 12V DC a regulating circuit needs to be installed. **Figure** 4.22 reflects the regulator control board which will only charge the battery until it is fully charged and will then dissipate the generated energy.

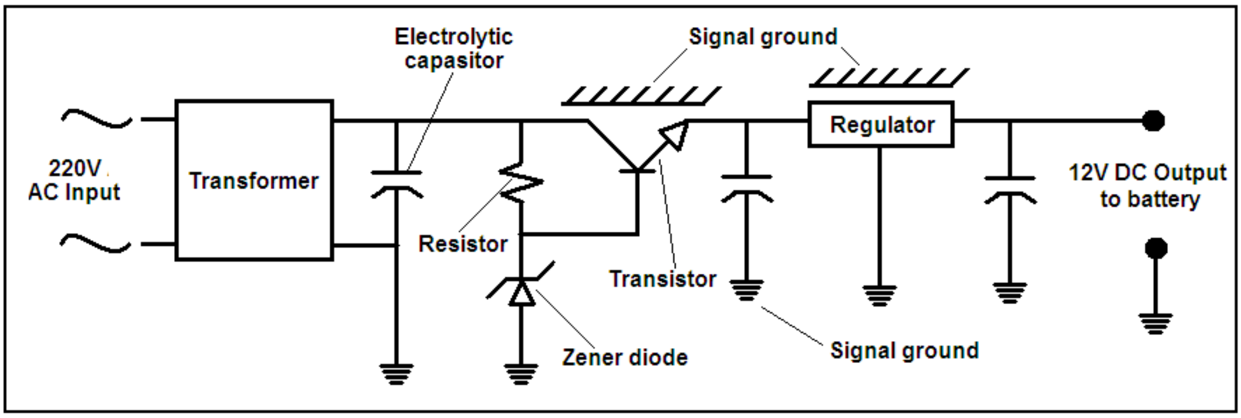

Figure 4.22: Current regulating circuit

This circuit works as follows (Venter, 2009): The electricity generated by the motor is in alternating current. In AC the flow of electric charge periodically changes direction which causes its waveform to be a sine wave **Figure 4.23**. The resistor, zener diode and transistor together make up the rectifier of the circuit which does the rectifying of the signal.

This configuration accommodates half wave rectification, **Figure 4.23**. The electrolytic capacitor is used to average out the half wave rectified signals and the result is DC voltage. The blue line has a slight slope because the capacitor discharges some of the current. In the bigger scale this is not important because the regulator takes care of this by putting out a constant DC voltage.

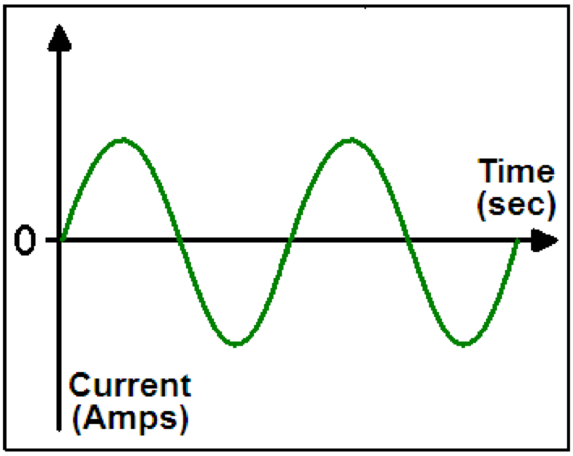

Figure 4.23*: AC waveform – sine wave*
(solarpower2day, 2009)

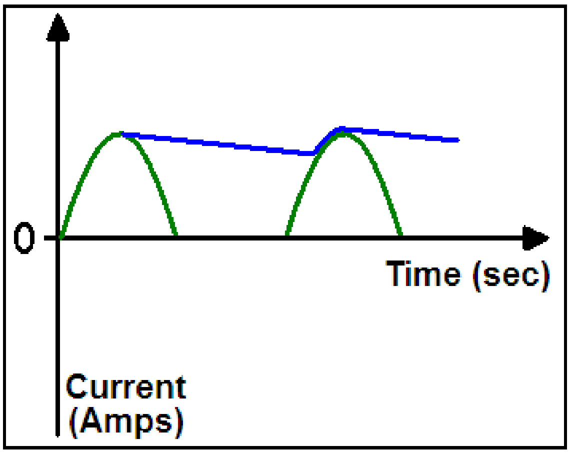

Figure 4.24*: Half wave rectified signal*
(solarpower2day, 2009)

The regulator takes this direct current voltage as an input and changes it to a lower DC voltage that is suitable for the 12V battery, **Figure 4.23**. The last electrolytic capacitor ensures the consistency and performance of the output by eliminating any of the output noise like signal or DC fluctuations. Finally the circuit produces the desired output of 12V.

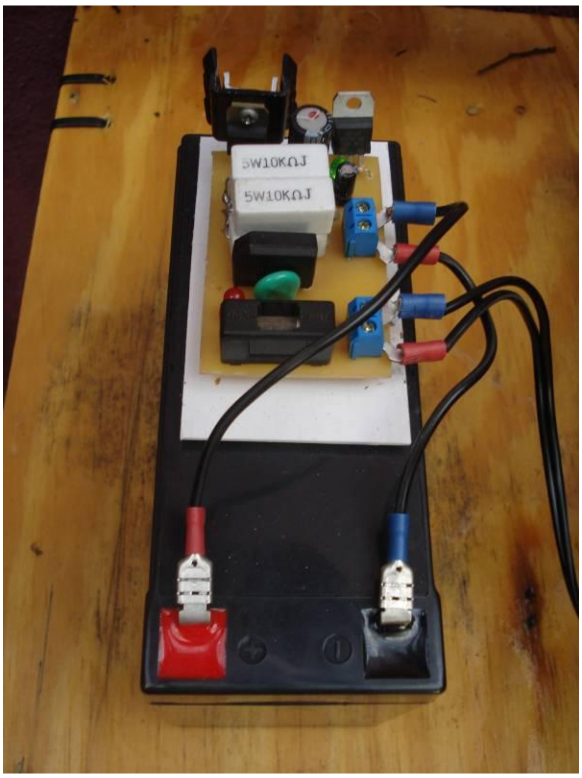

Figure 4.25: Output regulating circuit and storage facility in the form of a 12V battery

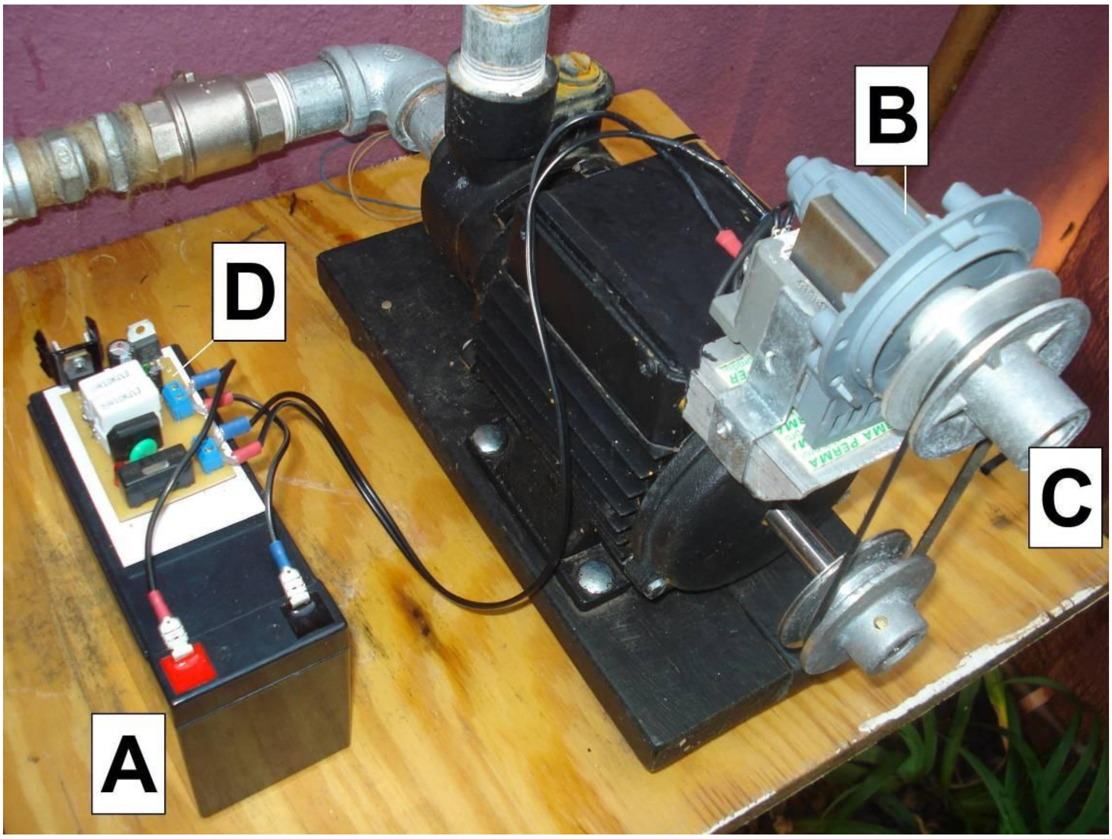

Figure 4.26: The electrical configuration of the model pico hydropower generating unit

4.3.7 Installation of the pico power generating unit

The pico hydropower turbine (pico turbine) was installed into the main supply of the two households. This ensures that all the flow that occurs is utilised for conversion into energy. It is of the essence to ensure that the user has the option to let the water pass through the instrument or not. This is achieved by not placing the instrument directly in the main supply line, but rather in a diverted conduit and by then controlling the flow with valves, Figures **Figure 4.27** and **Figure 4.28**. The setup ensures that the user doesn't experience any discomfort when a problem occurs with the instrument due to the fact that the main or diverted conduit can be implemented when required.

Figure 4.27: Installation at Diana road 386, Menlopark

Figure 4.27 reflects the installation at 38 Diana Road 386 and **Figure 4.28** shows the installation at 55 Singa drive.

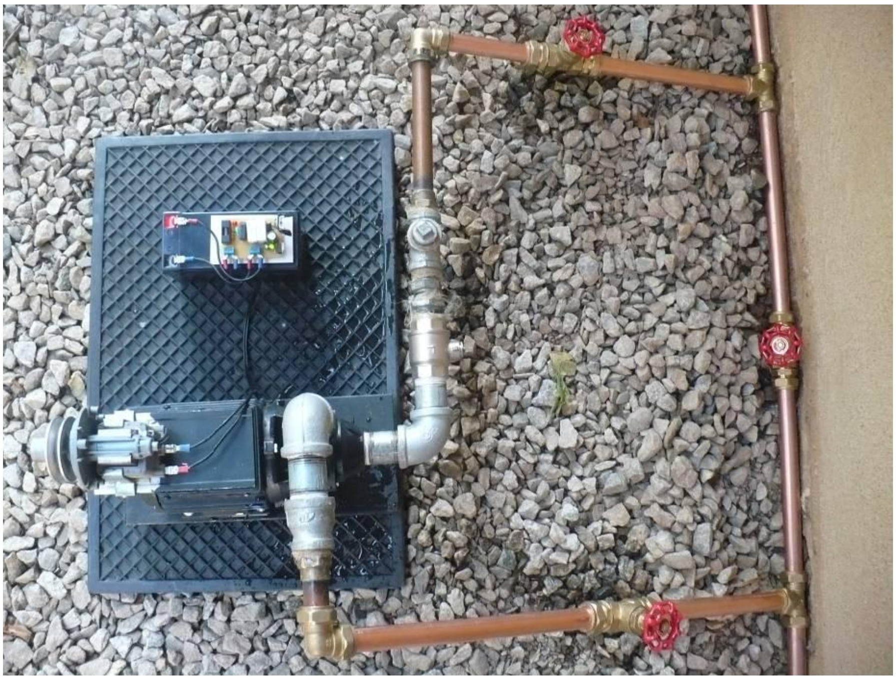

Figure 4.28: Plan view of installation at Singa drive 55, Matumi, Nelspruit

4.3.8 Data evaluation of the pico hydropower generation unit

4.3.8.1 Pre-installation

The assessment of the flow-head relationship prior to the installation of the pico generation unit reflects the system characteristics which can be used to review the influence of the pipco generation unit on the flow and pressure which the consumer will experience. These variations are briefly discussed below.

Based on the accepted demand variation for different domestic consumers **Figure 4.29,** compiled by GLS (2006) the average flow rate at 386 Diana road was calculated as 0,00059 m^3/s while the average flow at 55 Singa drive is 0,00078 m^3/s.

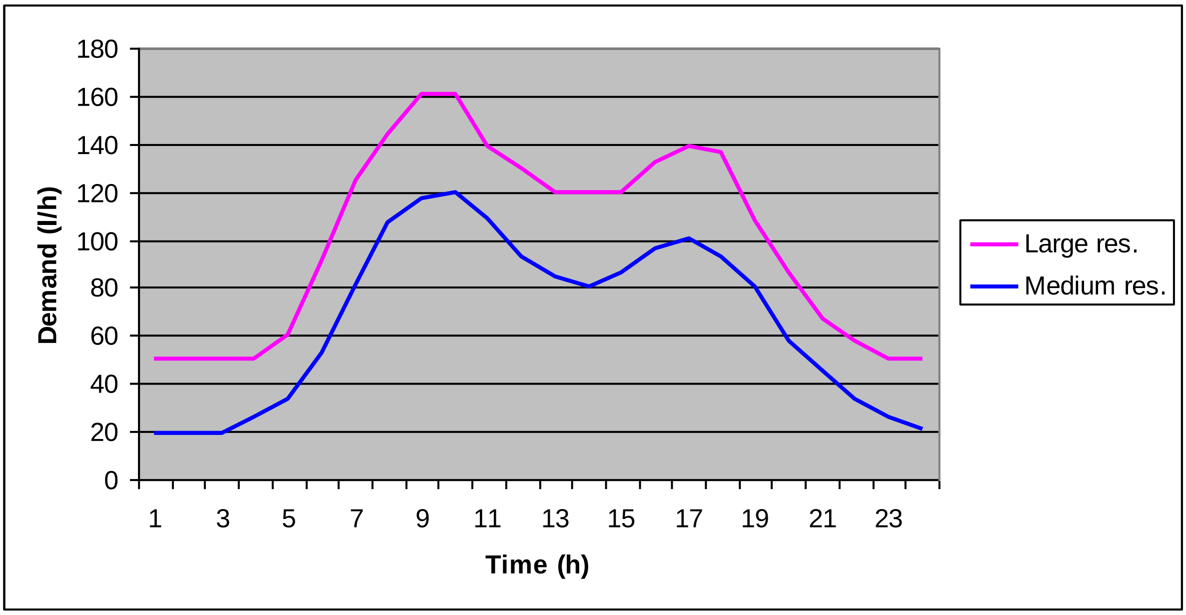

Figure 4.29: Demand patterns (medium and large res.) Portion of daily demand in litres (GLS, 2006)

Pressure is the major variable that needs to be monitored during the development process of the pico hydropower unit and hence the pressure needs to be recorded.

A data logger was installed together with the pressure transducers to log pressure readings at 10 second intervals over a 24-hour time period. The data is recorded in milli Amp and needs to be converted into pressure head (m). The combined results indicated that the pressure pattern followed the inverse path of the demand patterns with the least pressure being available during peak demand times. The head available during demand periods was measured at 15 m to 30 m (22 m average) for the medium residence and 10 m to 25 m (18 m average) for the large residence.

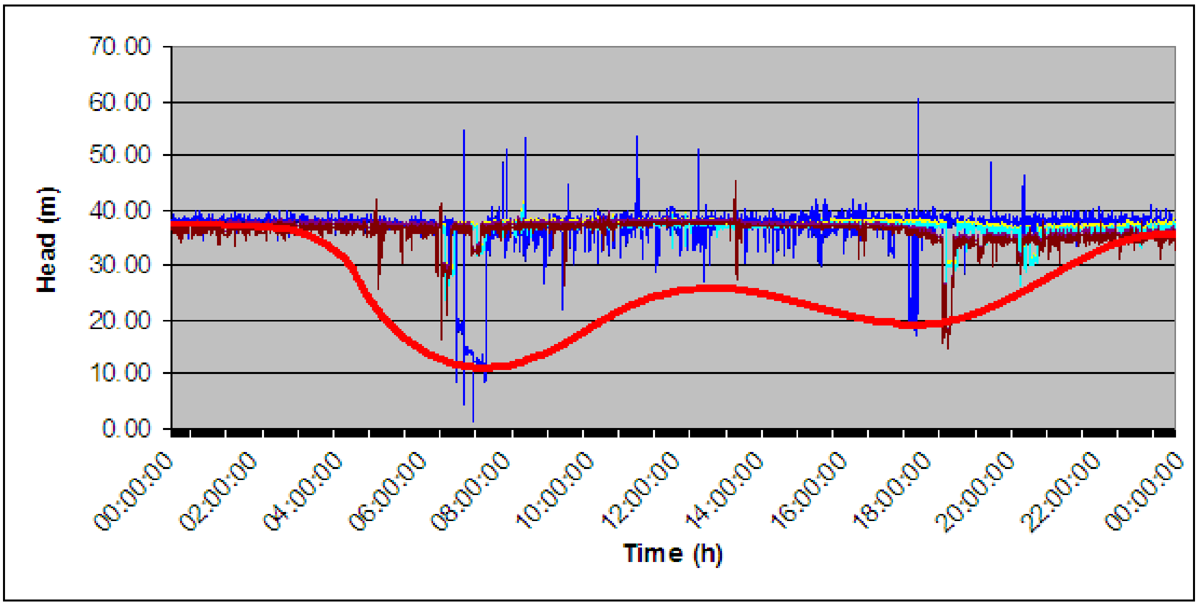

Figure 4.30: Combined 24-Hour Residential pressure pattern for Diana 386 and Singa 55.

4.3.8.2 Post-Installation

After the installation of the pico hydropower generation unit at the two locations the flow and pressure data was compared with the pre-installation condition with the objective to establish the influence of the generation unit on the flow and pressure which the consumer will experience.

The flow rate was only marginally decreased due to the losses through the pipco generation unit, while the pressure head dropped with about 0,6 m indicating the ineffectiveness of the pump that was used.

Based on these data obtained, the potential average daily power generation was calculated to be equal to 37,70Wh for the Singa 55 site and 30,70Wh for the Diana 386 site.

4.3.8.3 Electricity generation and battery charging

Electricity generation was only measured at the Singa 55 site due to the fact that the expected power output at the Diana site was not achieved. The storage facility, or cell, that needs to be charged is a 12V lead acid battery.

The rate at which the battery is charged by the instrument needed to be determined. Flow was applied continuously at a flow rate of 0,00078 m^3/s until the total charge of the battery increased by 3V. It took 3 h41 mins to increase the charge of the battery from 6,7V to 9,7V. The total estimated time required to charge the battery is 14 h44 mins at a constant flow rate 0,00078 m^3/s. Under normal demand variation it is estimated that the time required to charge the battery will be 400,2 hours.

The results prove the usefulness for future endeavours regarding the generation of hydropower on this scale. The Singa 55 site was classified as a large residential household. The pico generating unit was able to charge the 12V battery. These results from this first prototype pico generation unit indicate the possibility to tap this renewable energy. Water consumption of the end-user creates to possibility to generate and store electricity in small quantities.

4.4 Hydropower as retrofitting option on existing dams and other Water Infrastructure

4.4.1 Untapped hydropower potential of existing water resources

South Africa being a water scarce country, with highly variance in the yearly weather patterns and seasonal rainfall resulted in the construction of a number of fairly large reservoirs. Seen against the background of the shortfall in power generation, the possibility of using the storage volume and available head as a renewable energy source creates an exciting new dimension in terms of retrofitting the dams to be able to harness the energy.

4.4.2 Untapped hydropower potential from other water infrastructure

The existing extend of the inter-basin transfers schemes and long pipelines running in close vicinity of rural communities is an untapped source of renewable energy. It is envisaged that by retrofitting to these systems, the need in local communities could be partly addressed. The generation of power from these systems should not reduce the volume transfer or hamper the integrity of the systems. By defining the operational regime and capacity of these systems an option to tap some of the renewable source could be developed.

4.4.3 Retrofitting hydropower model

It was felt that the need to develop a conceptual model, referred to as HRM (Hydropower Retrofitting Model) which list the essential inputs (political, licensing, technical aspects, environmental concerns, social impacts and financial viability) is essential to assist the decision makers who consider the development of renewable energy generation facilities. In this scoping report the following aspects will briefly be highlighted pertaining the potential renewable energy by referring to the Case study of the Bethlehem Hydropower Project (**Appendix B**):

- Theoretical discussion of relevant components and considerations for hydropower retrofitting on existing dams which have been included in the conceptual Hydropower Retrofitting Model (HRM); and
- Assessing the application of HRM on a case study – Bethlehem hydropower option.
- Relevant components and considerations for hydropower retrofitting (HRM)
- The assessment of the possible retrofitting of existing dams to harness the potential generates able hydropower has to consider the following aspects:
- Legislative framework: Requires permission to be obtained by the dam owner, with a water licence, who has been granted the option to generate and with a power purchase contract;
- Electromechanical equipment: Understanding the basic concepts to select the optimal components for generation;
- Civil works: Houses and protects the equipment and created a safe operational environment;
- Environmental and social aspects: Required documentation to ensure limited impact;
- Financial considerations: Consideration of all costs and income to determine economic viability and return on investment. Creating cost functions for different hydropower generation elements.

The assessment of some of these variables is complex but the intention with the development of a HRM is to be able to compare different potential sites with a common procedure.

In the HRM, all the important variables which could influence the decision to develop the generation facility are reviewed with regard to the importance, nature and importance of the impact. The HRM was tested on a number of hydropower schemes that are currently being investigated or constructed. **The procedures that have been identified in the HRM should be further researched to create a decision tool on the viability of the retrofitting at existing dams to generate power.** **Appendix B** includes an assessment of the Bethlehem Hydropower Project.

5 FIRST ORDER ESTIMATE OF THE POTENTIAL HYDROPOWER GENERATING CAPACITY FROM PRESSURISED PIPELINES IN THE TSHWANE METROPOLITAN DISTRICT

5.1 Introduction

The tariff structure for energy in South Africa has been developed for different consumers (Eskom, Tariff Structure). The total cost for energy includes aspects such as:

- A seasonal differentiated cost for active energy (c/kWh);
- A seasonal differentiated energy demand charge (c/kVA);
- A Transmission network charge (R/kVA/month);
- A Distribution network access charge (R/kVA/month);
- A subsidy for electrification and rural benefit (c/kWh);
- An environmental charge based on the active energy supplied (c/kWh);
- A service charge (R/day); and
- An administrative charge (R/day).

This complicates the assessment of the economic benefit of hydropower generation for a Local Authority.

The energy cost for a small Local Authority for the tariff components dependant on the active energy used can be between R0,34 and R1,35/kWh. Although it is possible that the active energy costs might be higher for certain cases, these values are used for this scoping review. Furthermore, the capital cost, installation and operation cost have not been reviewed. Neither has the cost saving on the maintenance and replacement of control valves been quantified.

5.2 Reservoir data

Table 5-1 reflects details of the reservoirs in the Tshwane Metropolitan District where excess energy heads are available and where the possibility exists to incorporate hydropower generation.

Table 5-1: Ten reservoirs in the Tshwane Water Supply Area where hydropower can be generated

Reservoirs	TWL (m. asl)	Capacity (kl)	Pressure (m)	Flow (l/s)
Garsfontein	1 508,4	60 000	165	1850
Wonderboom	1 351,8	22 750	256	470
Heights LL	1 469,6	55 050	154	510
Heights HL	1 506,9	92 000	204	340
Soshanguve DD	1 249,5	40 000	168	400
Waverley HL	1 383,2	4 550	133	505
Akasia	1 413,8	15 000	190	340
Clifton	1506.4	27 866	196	315
Magalies	1438.0	51 700	166	350
Montana	1387.6	28 000	82	463

Rand Water supply water under gravitational flow to the Tshwane Metropolitan Council. On these delivery pipelines, it will also be able to generate hydropower. **Table 5-2** reflects the potential pipelines where hydropower can be generated.

Table 5-2 : Rand Water Pipelines feeding into the Tshwane Water Supply Area where there is potential for hydropower generation

Rand Water connections	WATER SOURCES			
	On RW pipe	Supply from	Res.TWL (m. asl)	Static (m)
No 3 Venturi	H12	KlipFtn	1694	243
Klapperkop Reservoir	H7	VlakFtn	1661	226
City	H3	EsslnPk	1614	163
Mamelodi	H26	Bronberg	1508	168
Garsfontein Reservoir	R1	VlakFtn	1661	164
Wonderboom Reservoir	H14	BrakFtn	1596	157
Soshanguve	H16	HartBH	1406	137
Mabopane	H16	HartBH	1406	137
Saulsville Reservoir	H22	BrakFtn	1596	209
Reservoir (Clifton)	H12	KlipFtn	1694	194

5.3 Potential power generation

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. Based on the assumptions in **Table 5-3** the potential monitory value of hydropower generation was calculated.

Table 5-3: Assumptions used to determine the potential monitory value for hydropower generation at reservoirs and from the delivery pipelines

Variable used for the calculation of potential yearly income for power generation at Reservoirs in Tshwane	Value	units
Fraction of the available static head that can be used to generate power	0,5	
Hours per day when power can be generated	6	hours
Variable used for the calculation of potential yearly income for power generation from Rand Water Pipelines	**Value**	**units**
Fraction of the available static head that can be used to generate power	0,4	
Hours per day when power can be generated	6	hours
Average velocity in the supply pipeline	0,4	m/s

Based on the above assumptions, the potential yearly income from hydropower generation at reservoirs in the Tshwane Water Supply Area and from Rand Water pipelines, which feed water into the Tshwane Water Supply Area, were calculated. Capital and other costs were not reviewed in this study. **It will be required to conduct a thorough cost benefit analyses to prioritize the potential hydropower generation facilities.**

Table 5-4 and 5-5 respectively indicates the potential hydropower generation capacity.

Table 5-4: Potential yearly income from hydropower generation at reservoirs in the Tshwane Water Supply Area

Reservoirs	TWL (m. asl)	Capacity (kl)	Pressure (m)	Flow (l/s)	Yearly Potential power generation (kWh) #
Garsfontein	1 508,4	60 000	165	1850	3 278 980,2
Wonderboom	1 351,8	22 750	256	470	1 292 471,4
Heights LL	1 469,6	55 050	154	510	843 672,8
Heights HL	1 506,9	92 000	204	340	745 061,7
Soshanguve DD	1 249,5	40 000	168	400	721 859,0
Waverley HL	1 383,2	4 550	133	505	721 483,1
Akasia	1 413,8	15 000	190	340	693 930,0
Clifton	1506.4	27 866	196	315	663 208,0
Magalies	1438.0	51 700	166	350	624 107,3
Montana	1387.6	28 000	82	463	407 828,9
Total calculated yearly power generation in Tshwane from 10 reservoirs (Nearest 10 000 kWh)					**10 000 000**

Note:

 # Refer to the assumptions listed in Table 5-3

Table 5-5: Potential yearly income from hydropower generation at Rand Water Pipelines feeding into the Tshwane Water Supply Area

Rand Water connections	Details				Yearly Potential hydropower generation (kWh) #
	On pipe (RW no.)	Supply from	Res.TWL (m. asl)	Static (m)	Inlet velocity 0,4 (m/s)
NO 3 VENTURI	H12	KlipFtn	1 694	243	159 559,7
KLAPPERKOP RESERVOIR	H7	VlakFtn	1 661	226	102 880,0
CITY	H3	EsslnPk	1 614	163	64 807,7
MAMELODI	H26	Bronberg	1 508	168	48 984,2
GARSFONTEIN RESERVOIR	R1	VlakFtn	1 661	164	47 817,9
WONDERBOOM RESERVOIR	H14	BrakFtn	1 596	157	45 906,4
SOSHANGUVE	H16	HartBH	1 406	137	40 061,8
MABOPANE	H16	HartBH	1 406	137	39 945,5
SAULSVILLE RESERVOIR	H22	BrakFtn	1 596	209	34 278,0
RESERVOIR (CLIFTON)	H12	KlipFtn	1 694	194	31 817,9
Total calculated yearly power generation in 10 or Rand Water Pipelines supplying to Tshwane – (Nearest 100 000 kWh)					**1 200 000**

Note:

\# ***Refer to the assumptions listed in Table 5-3***

5.4 Potential financial benefit

Based on the conservative assumption used in the calculation of the potential monitory value of hydropower generation at reservoirs and on supply pipelines in the Tshwane Water Supply Area, it is clear that this **untapped energy source is to be researched for implementation**.

If the same assumptions are used for other of the metropolitan areas in South Africa, the value of power generation from water distribution systems which are fed under gravity, could be in excess of R60-R150 million per annum. Although this source of power generation on a national level is small, it is currently wasted.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Energy is the lifeblood of worldwide economic and social development. When considering the current status of global energy shortages, generation methods and consumption, it is clear that we need to make a change in the way we create and use energy. The demand for energy increases continuously and those demands need to be met in order for the stimulation of worldwide development. Fossil fuels contribute a large majority of the global energy, but due to the dangers of global environmental impacts, the expansion of fossil fuel as an energy source is not feasible. This forces our generation to focus on the development of renewable energy sources.

Renewable energy is the way of the future and the potential for its development is of great magnitude. Hydropower contributes only 3% of global energy consumption which is only a fraction of its potential. **Africa is the most underdeveloped continent with regard to hydropower generation with only 6% of the estimated potential exploited**. This is not a burden but an opportunity. South-Africa has the potential to make a large contribution towards the lack of hydropower generation in Africa and the world.

South-Africa has a substantial supply of high pressurised water flowing on a daily basis to domestic dwellings through piped conduits. The flow available due to the consumption can be converted into electricity in small quantities. By applying the theory of hydropower generation together with the innovative development of small generation unit, as was shown with the experimental model, it is possible to make a contribution to the use of renewable energy. This model is allowing consumer to generate energy whenever they consume water within the household. Although it might seem trivial to generate such small amounts of electricity, collectively it will make a noticeable difference. Each person has the responsibility to contribute in any way possible to the global energy crisis. A collective effort towards a sustainable future is required.

Further development of the HRM to review the hydro potential of South Africa's existing surface water resources and other water infrastructure will create stimulus to the required focus on renewable energy and could be developed into a tool that will prioritise the hydropower development options in South Africa.

6.2 Recommendations for further research

The potential hydropower that can be generated at inlet to service reservoirs where energy is dissipated across a control valve should become a priority in terms of the design and retrofitting of such control features.

It is recommended that

- the system that has been constructed at Queenswood Reservoir be implemented fully and that performance data be obtained for the next twelve months;
- another two or three sites be identified, in co-operation with Tshwane Metropolitan Council, evaluated and retrofitted with hydropower generation units;
- field data be gathered and compiled from which a guide for the generation of hydropower in water supply systems can be produced.

The generation of pico-power from household supplies is minimal and could be harnessed. The following alterations should be considered:

- Increasing the size of the impellor to subsequently increase the power output of the generator setup.
- Investigating the use of a different electric motor which could ensure an increase in the generated output.
- Increasing the number of sites will contribute towards a better understanding of the potential and will contribute to the development of this technology.
- Increasing the total efficiency of the instrument to ensure a larger power output.

The biggest untapped available hydropower potential is the release of pressurised flow from the storage reservoirs and from numerous pipelines which transfers large flow rates.

In this regard it is recommended that

- The potential of all storage reservoirs in the Tshwane Metropolitan Council's Water Supply Area be reviewed. The review should include the description of the required alterations, physical challenges and a first order cost assessment of the retrofitting. In this regard the HRM could be used as the base for further development of procedures to assess the potential of hydropower generation.

- The potential sources of renewable energy along the pipelines used to provide inter-basin transfers under gravitational flow as well as the pipelines which runs past rural communities in need for energy should be identified and the potential for power generation be determined.
- Industrial and commercial barriers to the development of hydropower should be defined and the processes preceding the investment in hydropower should be described and proposals to streamline the process should be identified.

Such a research project could be conducted over a period of about 3 to 4 years and at a budget in the order of R2,5 to R3,5 million.

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