UNIVERSITY OF PRETORIA

DEPARTMENT OF CIVIL ENGINEERING

INTEGRATION AND OPTIMISATION OF HYDROKINETIC TURBINES IN CANALS IN SOUTH AFRICA

CHANTEL MONICA NIEBUHR

INTEGRATION AND OPTIMISATION OF HYDROKINETIC TURBINES IN CANALS IN SOUTH AFRICA

CHANTEL MONICA NIEBUHR

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OF ENGINEERING (WATER RESOURCE ENGINEERING)

In the

FACULTY OF ENGINEERING, BUILT-ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

January 2018

DISSERTATION SUMMARY

INTEGRATION AND OPTIMISATION OF HYDROKINETIC TURBINES IN CANALS IN SOUTH AFRICA

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Degree: Master of Engineering (Water Resources Engineering)

Small-scale hydrokinetic (HK) energy systems is a renewable energy source which has never before been explored in South Africa, mainly due to former low-cost coal-powered electricity. This renewable energy option makes use of the kinetic energy from flowing water rather than potential energy, which is more often used in conventional hydropower. This allows installations into existing water infrastructure with very little civil works. Approximately 66% of South Africa's water supply is used by the agricultural sector with canal systems running through many areas which are in dire need of alternative energy sources.

The objective of this study was to install a HK turbine into an existing irrigation canal in South Africa and test the integration thereof. It was hypothesized that these small-scale HK systems could function as a practical renewable energy option in existing water infrastructure in the country, having minimal risk and environmental impact and an overall positive social influence.

The selected installation site lies in the upper region of the Boegoeberg irrigation canal, in the Northern Cape province of South Africa, which lies in one of the poorer regions of South Africa. With a largely unemployed population, the !Kheis Local Municipality (LM) has very little income to provide basic electricity needs to its citizens. The canal system is seen as a possible untapped source of HK energy development. A series of steps were followed to identify a suitable site for implementation and testing of these devices. A canal section in close proximity to the Groblershoop water treatment works (WTW), which supplies water to a large majority of the Groblershoop Town citizens, was chosen for implementation. This could aid the LM in reducing high electricity costs which are a consequence of the WTW pump station.

The HK turbine selected for implementation and testing developed by Smart Hydropower GmbH, was designed to function in canal systems. After initial site selection and preparation, the turbine was installed at various orientations and the outputs and a few influences were recorded. Once installed possible practical optimisation techniques were tried to test the functioning of these systems where the desired operating velocity range is not readily available, starting with altering the turbine itself and thereafter altering the canal section. The results were evaluated and aspects such as power output and upstream damming levels were compared to establish which optimisation measures prove most effective from a practical, financial and sustainable viewpoint.

The data collected allowed analysis of the functioning of such a system within the South African environment and legislation. Although the single installation cannot be representative of the country, it does provide a clearer image of important factors to be considered during the design of future HK installations in South Africa. The outcome of the study proved that with certain alterations to the turbine design and adequate pre-feasibility studies of the site details, implementation of these units within existing canal infrastructure in South Africa could be a practical and sustainable renewable energy source.

DECLARATION

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- The work contained in this thesis is my own original work;
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- Where other people’s work has been used this has been properly acknowledged and referenced;
- I have not allowed anyone to copy any part of my thesis;
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ACKNOWLEDGEMENTS

I wish to express my appreciation to the following organisations and persons who made this dissertation possible:

a) My supervisor and mentor Mr Marco van Dijk, for his continued support and guidance through my entire project and for always believing in my capabilities.

b) My fellow Water Resources Engineering post-graduate students, Sebastian Janke, Deon Bonthuys and Anke Klingenberg who assisted me with site work and kept me company on all the long trips to site.

c) UP civil laboratory technician, Rikus Kock, for his help with the control systems and measuring equipment.

d) The !Kheis Municipality, for allowing implementation of the project within their municipality.

e) The Water Research Commission for financial support during the study.

f) This dissertation was completed in conjunction with the Water Research Commission and the !Kheis Municipality in the Northern Cape, however the opinions expressed are those of the author and do not represent the policy of the entities involved.

g) My family and friends for their encouragement and support during the study.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

LIST OF ABBREVIATIONS

AC	Alternating Current
C&I	Commercial and Industrial
CCRWP	Climate Change Response White Paper
CEC	Current Energy Conversion
CFD	Computational Fluid Dynamics
DAFF	Department of Agriculture, Forestry and Fisheries
DC	Direct Current
DEA	Department of Environmental Affairs
DM	District Municipality
DME	Department of Minerals and Energy
DoE	Department of Energy (New DME)
DWS	Department of Water and Sanitation
EG	Embedded Generator
emf	Electromagnetic field
EMS	Electrical Management System
ERA	Electricity Regulation Act
GDP	Gross domestic product
HK	Hydrokinetic
IGCC	Integrated Gasification Combined Cycle
IHA	International Hydropower Association
IPP	Independent Power Producer
IRP	Integrated Resource Plan
IRR	Internal Rate of return
LCC	Life Cycle Costing
LCOE	Levelized cost of Energy
LM	Local Municipality
LTMS	Long Term Mitigation Strategy
MoR	memorandum of Agreement
NEMA	National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NPV	Nett present Value
NWA	National Water Act
PMG	Permanent Magnet Generator
PV	Photo Voltaic
REIPPP	Renewable Energy Independent Power Producer Programme
SHS	Small Hydropower Systems
TSR	Tip Speed Ratio
WB	Water Board
WEC	Wave energy conversion
WSA	Water Service Authority
WSP	Water Service Provider
WTW	Water treatment works
WUA	Water User Association

1 INTRODUCTION

1.1 BACKGROUND

The demand for energy in South Africa is increasing whilst the availability of fossil fuels such as coal is decreasing. According to environmental statistics South Africa is among the top 20 countries with the highest level of carbon dioxide emissions, also being the highest emitter of GHGs in Africa due to the current fossil-fuel powered economy (MEAAI, 2011). In 2010 the South African National Department of Minerals and Energy (DME) released an Integrated Resource Plan (IRP) to increase renewable energy sources to 17.8Gigawatts by 2030 (Koko & Kusakana, 2014). This allows a large opportunity for the development of renewable energy such as biomass, wind, solar and hydropower. Details of the DME targets and evolution of the electrification goals in South Africa is summarized in Figure 1-1.

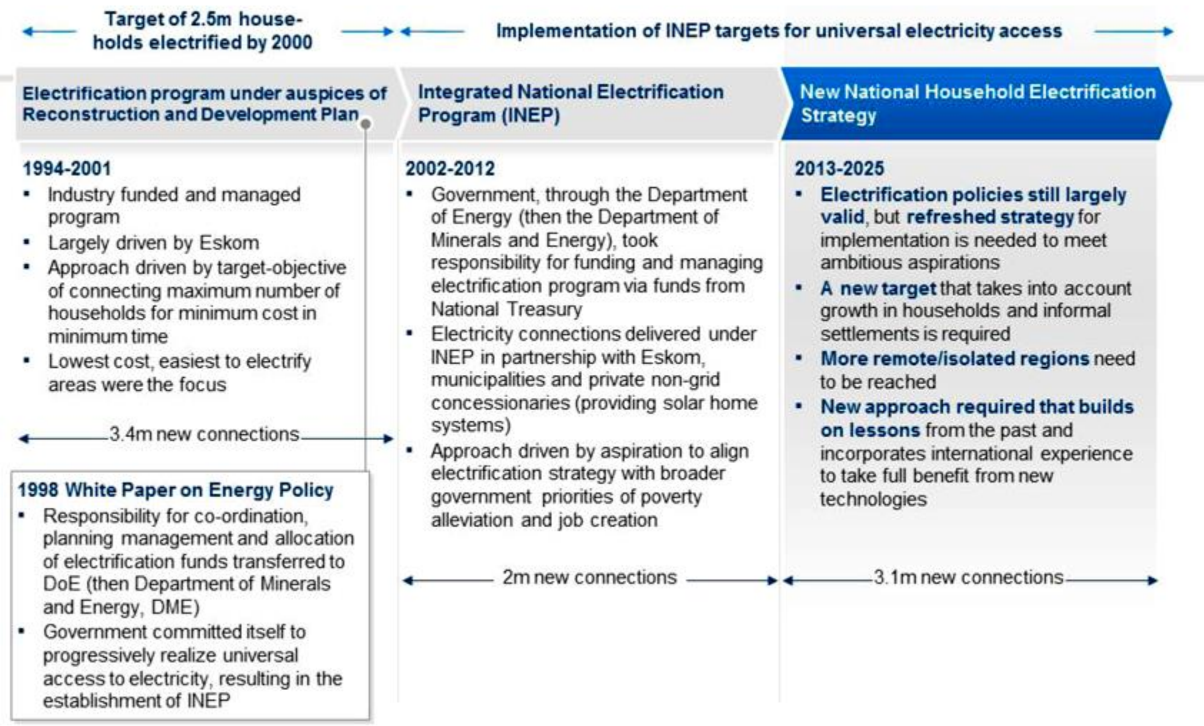


Figure 1-1: Evolution of electrification in South Africa (IFC, 2013)

Hydropower is a trusted technology with significant potential in South Africa (White, 2011). It is a form of clean renewable and sustainable energy making use of the available flow or head in water without consuming or polluting the water itself. Often these systems have long lifespans and high efficiencies with low operating costs (van Vuuren, et al., 2011).

Hydrokinetic (HK) systems are defined as in-flow turbines which are placed in the flow of water thus harnessing the kinetic energy of flowing water, or hydroelectric energy, to produce electricity (Kartezhnikova & Ravens, 2013). The basic working procedure of a HK system can be seen in Figure 1-2.

An untapped opportunity in HK resources lie in the canal conveyance systems in South Africa. Approximately 66% of South Africa's water supply is used for irrigation purposes with canal systems running through many rural municipal areas, which are in dire need of alternative energy sources. This hydropower opportunity has never before been used for energy generation due to previously low-cost coal electricity production in South Africa (DWS. 2017).

Figure 1-2: Basic concept of HK systems (SHP, 2016)

HK systems involve the use of kinetic devices to capture the energy directly in flowing water. This method has a smaller environmental impact as it does not require alteration of watercourses, block fish migration or modify the climate in the specific area (Ahmed, et al., 2016).

HK energy devices are straightforward and easily understood. They are ideally suited for remote locations and do not require large construction works. HK turbines have a close similarity to wind turbines with regard to the basic principles of operation and electrical hardware. The difference lies in water having a density approximately 800 times greater than air. Due to this , water turbines are more efficient than wind turbines even under low currents (Ahmed, et al., 2016). The typical layout of a HK turbine can be seen in Figure 1-3.

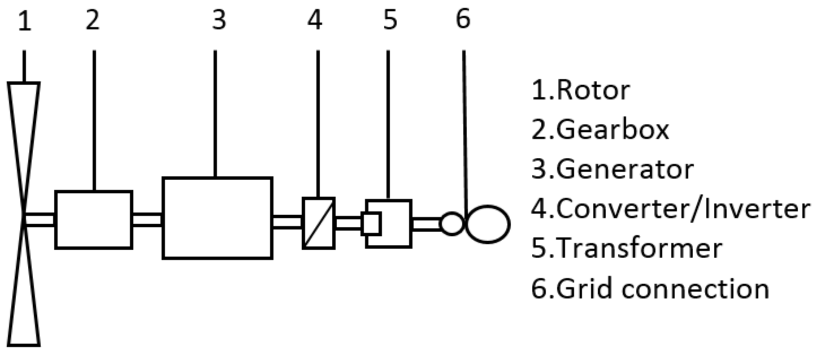


Figure 1-3: HK turbine layout (Ahmed, et al., 2016)

1.2 STUDY MOTIVATION

In South Africa, there is a great lack of knowledge on hydropower and especially HK systems. There was no existing HK installation in South Africa, although the country was previously reported to have a great potential thereof (Kusakana & Vermaak, 2013). South Africa is a water scarce country and therefore the water infrastructure is highly protected. Hydropower is also misunderstood in many cases and believed to consume or pollute water resources which is not a true representation, as hydropower systems only temporarily divert flow or extract energy (slow water flow) and do not consume or pollute the water.

The general perception is that hydropower is not fit for installations in South Africa due to the lack of availability of components required for installation; and the drawn out regulatory and legislative procedures. It is believed that all these problems arose due to lack of knowledge of hydropower systems (due to scarcity of existing systems) and therefore the inability to predict any environmental/social impacts thereof.

1.3 HYPOTHESIS

The hypothesis for the study is: "Small-scale HK systems can be integrated into existing water infrastructure in South Africa and optimized to prove as a practical renewable energy generation option having minimal risk and environmental impact and an overall positive social influence".

1.4 OBJECTIVES OF THE STUDY

This study's objective was to integrate a HK turbine that is designed and optimised to function as a sustainable electricity source in existing canals in South Africa. The recent electricity crisis in the country allowed for funding opportunities and thereby an introduction of innovative and sustainable technology to provide renewable electricity where otherwise not feasible. A pilot project was implemented in an applicable section on the Boegoeberg irrigation canal in the Northern Cape Province and tested for optimum functionality and correct application.

This research includes the evaluation procedure followed for site selection, appropriate technology procurement and integration of water infrastructure with the HK turbine. Furthermore, the possible integration with alternative power sources (solar power) was considered thus increasing reliability. The legislative process will be discussed and the impact on the rural municipality assessed.

The aims of the study will be:

i. Showcase the technology by means of a full pilot installation;
ii. Evaluate the various dimensions of sustainability of these installations in terms of the technical, social and environmental aspects;
iii. Investigate and demonstrate means of increasing system efficiency and power output;
iv. Ensure a successful, working, sustainable system is developed.
v. To prove the feasibility of the system as an alternative small- scale power source in the current changing South African legal and regulatory environment.

1.5 SCOPE OF THE STUDY

The study entailed the identification of sites with small-scale HK potential in a specific municipality. The site selection was thus limited to sections of the Boegoeberg irrigation canal in the !Kheis Municipality. The focus of the study was on developing a system with a generating capacity of less than 50kW to aid the municipality and prove success of such an installation. The scope of the study involved site selection and installation of the HK device additional to all components required for the design life within the South African legal and regulatory framework and current economic state.

With regard to optimisation measures, due to time and cost constraints the most basic and practical optimisation methods were used in the testing procedure to possibly indicate the success of each mechanism which could be further designed and refined to further improve the system efficiency. Although a budget was allocated to the project a financial analysis was not included in the study as HK energy is a new technology in South Africa and all components were imported due to availability and time constraints, thus adding a great deal to component cost (which could in future be developed/ manufactured locally).

1.6 METHODOLOGY

The following describes the methodology followed during the research:

i. Potential sites for installation of HK turbines were identified within the !Kheis Local Municipality (LM). The Boegoeberg irrigation Canal was chosen as the installation infrastructure and points along the canal which are in close proximity to unelectrified or “power hungry” areas where electricity usage or distribution costs could be saved.

ii. The final site selection criteria involved choosing an option based on multiple criterion, the most important being an installation site with low transmission line costs, existing security measures and location where optimisation techniques could be tested.

iii. HK turbines designed for canal installations were selected based on the flow data from a Department of Water and Sanitation (DWS) gauging station upstream of the installation point.

iv. The site was prepared for installation and all components procured and installed. A flow meter and level sensors were installed, together with a data logging device to allow testing of the flow characteristics on a regular basis to obtain accurate and continuous readings.

v. Numerical modelling of the upstream effects of blockage during each testing phase was analysed to uncover possible critical sections and system overtopping upstream of the testing section.

vi. The installation and optimisation of the turbines was completed in 3 phases. Initially the turbine was installed as specified by the manufacturer (phase 1), after which optimisation techniques were applied on the turbine itself (phase 2) and there after modification to the canal section (phase 3).

vii. The turbines were installed and each optimisation method as well as failure scenarios (such as full turbine blockage) were tested. The effects of the failure scenarios and success of each optimisation method was recorded, analysed and evaluated. Where certain optimisation measures did not perform the design was altered to obtain better results.

viii. A final analysis of the installation, optimisation, maintenance and overall practicality of integrating a HK turbine in a canal was analysed and discussed and HK development guidelines developed.

1.7 ORGANISATION OF THE REPORT

The report consists of the following chapters and appendices:

i. Chapter 1 serves as introduction to the report. It provides a background to the study as well as the hypothesis, objectives and scope of the study.

ii. Chapter 2 serves as a literature review of the basic theory of HK energy and all components. Also, the literature found on various optimisation measures and aspects of consideration to such an installation are scrutinized.

iii. Chapter 3 describes the experimental design, from the site selection process undertaken to the final design including turbine selection, civil works, electrical aspects and the legislative procedure. The testing schedule and measuring equipment used for the final installation and optimisation testing is also included.

iv. Chapter 4 describes the construction of the experimental setup as described in Chapter 3.

v. Chapter 5 contains all data collected and analysed during the installation and testing phases, consisting of power output data and damming analysis at the installation point and upstream system (due to subcritical flow conditions).

vi. Chapter 6 serves as a project discussion and analysis chapter. The development process, problems encounters and overall analysis is done and future improvements and modifications of such an installation are discussed.

vii. Chapter 7 serves as a conclusion to the study, including recommendations for future HK installations in canal systems in South Africa.

viii. The list of references follows at the end of the report.

ix. Appendix A contains details of the civil works design for the HK installation

x. Appendix B contains the calculation procedure followed to determine the maximum area of canal narrowing used in phase 3 testing.

xi. Appendix C contains the calculations used to determine the plate size for phase 2 optimisation.

xii. Appendix D contains the draft Policy on Sustainable Hydropower Generation as the project acted as a pilot study on the application of the policy.

2 LITERATURE STUDY

This section provides a review of the literature studied to supplement the study. A brief introduction to small-scale hydropower is followed by the theory of HK energy production, which is the focus of the study. Properties of consideration during the development of a HK system which were considered to be relevant to the study are discussed and a summary of possible optimisation methods investigated. The section is concluded with a summary of all factors of importance.

2.1 INTRODUCTION TO HYDROPOWER

Hydropower is a broad aspect of renewable energy which can be further divided into multiple forms, from pico-systems (small-scale) to large macro installations producing more than 10 Megawatts of electricity. According to the International Hydropower Association (IHA), conventional Hydropower can broadly be divided into 4 categories, which often overlap, these being (IHA, 2017):

i. Run-of-river hydropower: This involves constructing a facility which diverts water from a river through a canal or penstock to a turbine. Typically, these installations have no storage facility. These schemes generally provide a constant, continuous supply of electricity.
ii. Storage-hydropower: These are typically large systems which make use of a dams or similar storage facilities. Electricity is produced by releasing water from a reservoir through a turbine which in turn activates a generator. These systems allow flexible application as a continuous (base load) supply can be produced or the system can be started up to suite the demand of the system.
iii. Pumped-storage hydropower: These systems are designed to provide peak load supply by harnessing water which is cycled between a lower and upper reservoir by pumps. The pumps use surplus electricity during low demand and the water is once again released during high demand, producing electricity.
iv. Offshore-hydropower: This is a less established, growing form of hydropower, which uses the power of waves or currents to generate electricity in oceans.

These hydropower opportunities can be found in a great amount of existing water infrastructure as shown in Figure 2-1. However, with the ever-increasing seeking of renewable energy, some new categories of hydropower have emerged (referred to as “unconventional” or “alternative” hydropower). Riverine Hydrokinetic (HK) or kinetic hydropower falls into this category, which is the focus of the study.

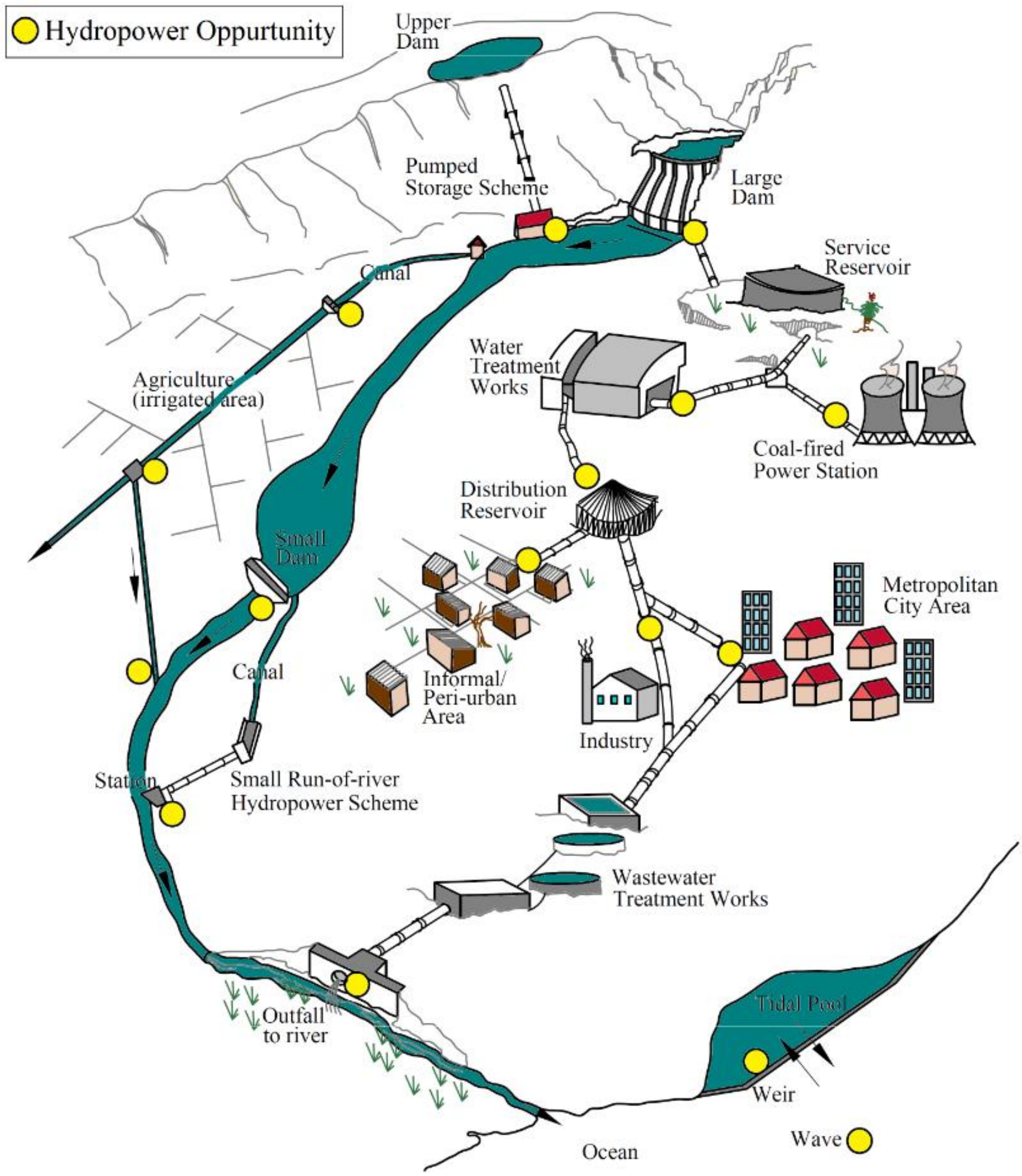


Figure 2-1: Hydropower types and opportunities (van Vuuren, et al., 2013)

Globally the renewable energy generation increased at the highest level in history in 2016 with an estimated 161 Gigawatts (GW) of added capacity. This increased global capacity to 9%, of which 62% of net additions were renewables, the largest components of this amount were a total of 47% solar Photo Voltaic (PV), wind 34% and hydropower 15.5%. Due to rising energy demand and renewable energy support mechanism, well-established technologies such as hydropower and geothermal energy have become cost-competitive with fossil fuel energy production (which have plentiful resources) (REN21, 2017).

In a study done by Lumbroso et al. (2014) an example of the levelised cost of hydropower and more specifically micro-hydropower for the first quarter of 2013 can be seen in Figure 2-2, showcasing the competitiveness of hydropower in the energy market.

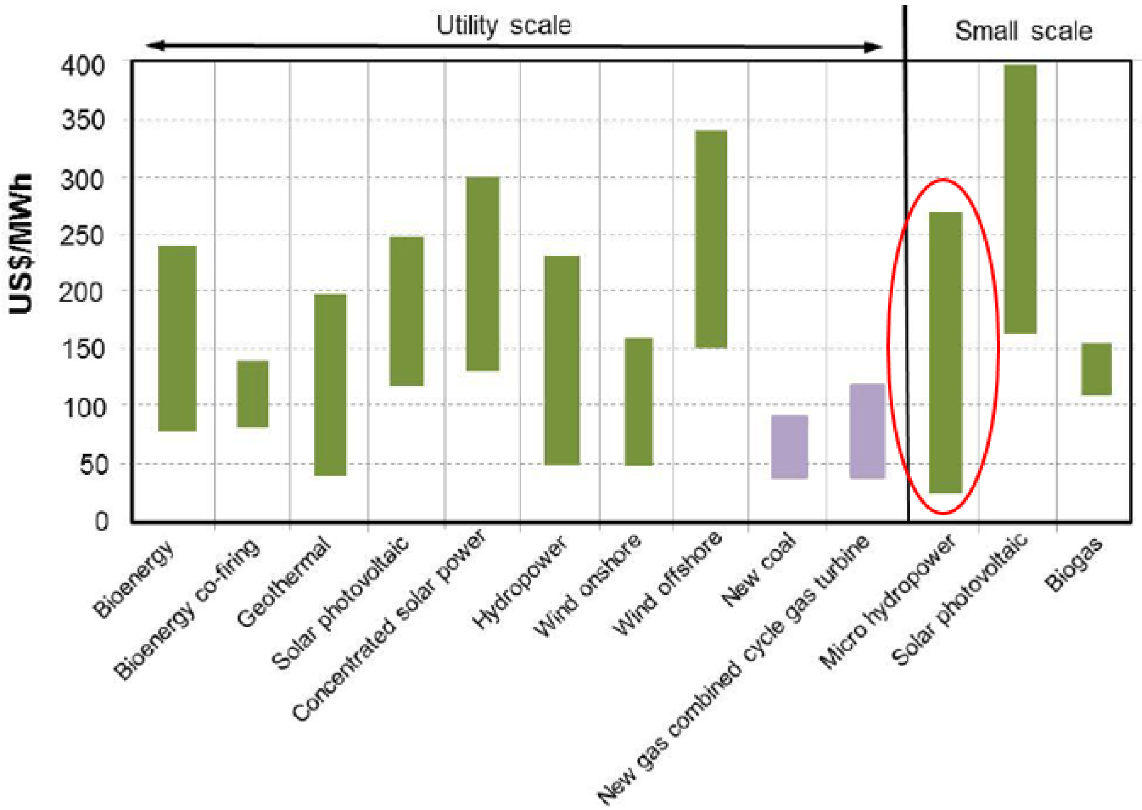
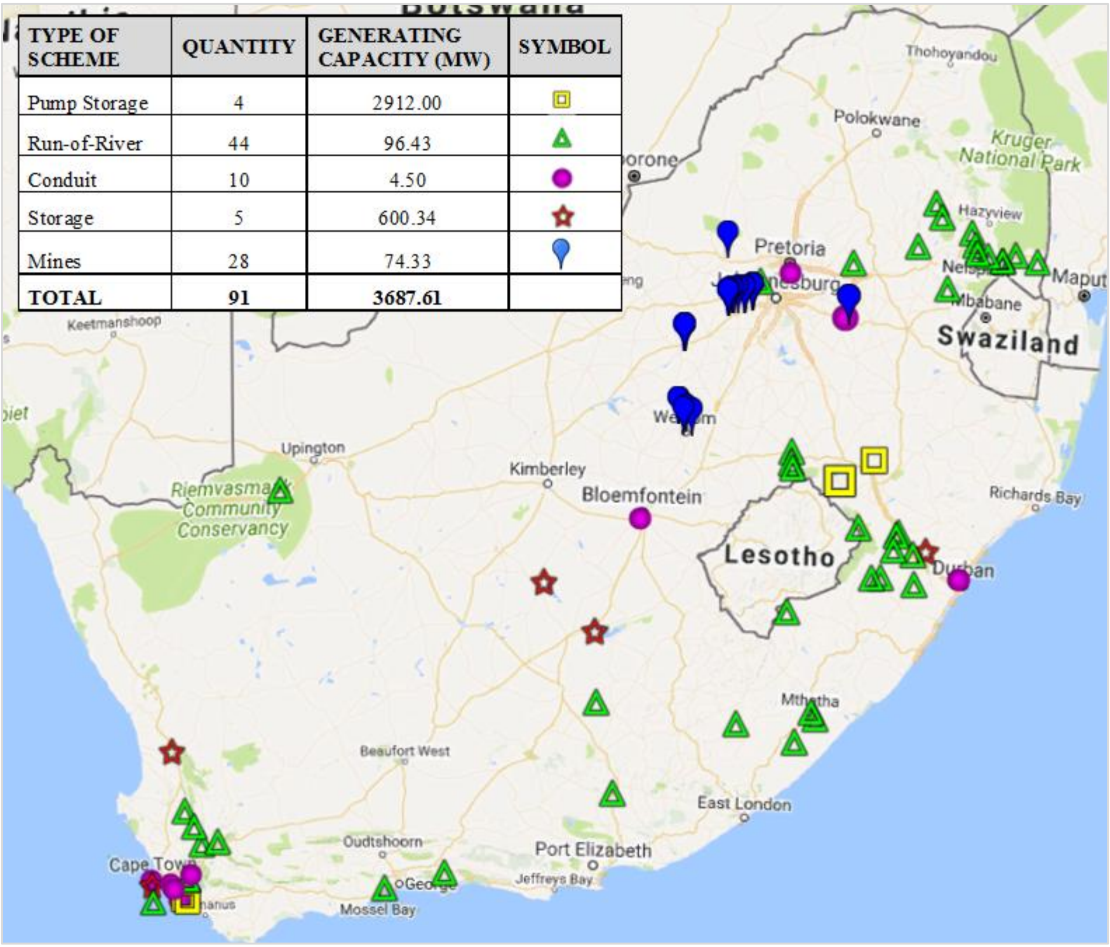


Figure 2-2: Global levelised costs of power generation for a range of power generation techniques (Lumbroso, et al., 2014)

2.2 HYDROPOWER IN SOUTH AFRICA

The primary resource for electricity generation in South Africa is fossil fuels. However, the availability of renewable energy resources is abundant and can be used to help solve issues such as climate change, reducing greenhouse gas emissions and having larger energy security by diversifying the supply (Kusakana & Vermaak, 2013).

In 2012 Kusakana and Vermaak found approximately 6000-8000 potential sites for traditional hydropower installation in South Africa. The DME revealed South Africa has a considerable potential for small and large-scale hydropower generation, however no major hydropower development had been undertaken in the last 30 years (DME (2003); Koko & Kusakana (2014)). Currently about 3700MW of installed hydropower exists in South Africa as shown in Figure 2-3 (Hydro4africa, 2017).



TYPE OF SCHEME	QUANTITY	GENERATING CAPACITY (MW)	SYMBOL
Pump Storage	4	2912.00	
Run-of-River	44	96.43	
Conduit	10	4.50	
Storage	5	600.34	
Mines	28	74.33	
TOTAL	**91**	**3687.61**	

Figure 2-3: Hydropower installations in South Africa (data from Hydro4africa (2017))

2.2.1 Water situation in South Africa

South Africa receives an annual rainfall of 492mm, with certain areas receiving more than others. The average rainfall in the rest of the world is around 985mm, South Africa's rainfall is less than half of this value, proving it is a water-stressed country. In addition to this water scarcity, in most regions hot, dry conditions result in a high evaporation rate. Scientists predict that with the climate change phenomena South Africa will be exposed to wetter wet seasons and drier dry seasons, which means an increase in extreme weather conditions such as droughts and flooding (Rand Water, 2009).

South Africa receives most of its rainfall in short time periods, which result in floods, due to the water-scarce conditions, these bursts of high water availability must be contained. Presently there are a large number of dams that store this water. The water stored must be reticulated to users and therefore a large network of transfer schemes consisting of pumps, pipes and canals exist moving water from one catchment to another (Rand Water, 2009). This rainfall behaviour also results in greatly varied flow levels and dam levels throughout the year, which must be analysed carefully prior to any potential hydropower development.

The water usage in South Africa is divided as shown in Table 2-1. Approximately 66% of water is used for agricultural use and distributed through numerous conveyance infrastructure schemes, such as canals (DAFF, 2015).

Table 2-1: Water use in South Africa (DWS, 2017)

WATER USE	PERCENTAGE
Agricultural use (including irrigation)	66
Municipal/Domestic use (urban and rural)	27
Industrial use (including power generation and mining)	7

2.3 KINETIC HYDROPOWER IN SOUTH AFRICA

Currently there is no existing HK installation in South Africa. Kusakana et al. (2013) investigated the possibility of HK hydropower development for rural and isolated loads in South Africa. The case studies proved where adequate water resources are available in South Africa, HK power generation could be the best, most cost-effective supply option in relation to wind, PV and diesel generators, (Kusakana & Vermaak, 2013).

Ideal HK installation locations are in deep strong rivers or immediately downstream of an existing conventional hydropower plant where electric transmissions etc. exist. Therefore, from the potential of traditional forms of hydropower proved in section 2.1 theoretically an even greater number of sites with HK potential could exist (Kusakana & Vermaak, 2013).

In a report on the assessment of HK turbines in open channel applications prepared by the United States Department of Energy it states "*Hydrokinetic energy from flowing water in open channels has the potential to support local electricity needs with lower regulatory or capital investment rather than impounding water with more conventional means*." (Gunawan, et al., 2017).

2.3.1 Canal infrastructure in South Africa

A large network of canal systems exists in South Africa, the Department of Water and Sanitation (DWS) asset management study database revealed a total of 47 schemes with a network of more than 6500km's of canals as shown in Figure 2-4. This reveals the extent of potential for HK installations in canal systems available in South Africa. In these canal systems 21 286 structures such as tunnels, syphons, weirs. control gates, chutes and drops exist, which hold a large unexploited HK potential.

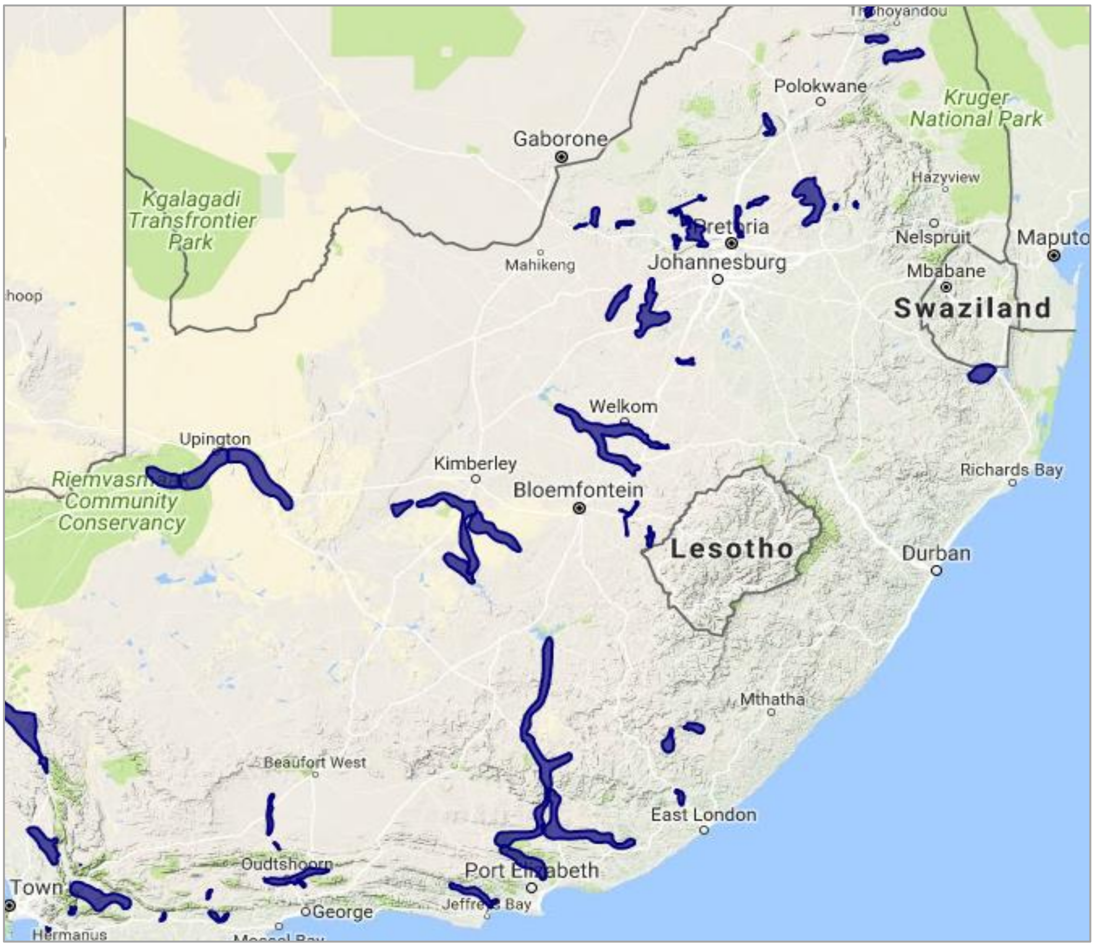


Figure 2-4: Canal schemes in South Africa

As an example of the potential available three of the larger canal schemes are summarized below:

i. <u>Sand-Vet scheme</u>:
Established in 1957, the scheme serves a total area of 13 200 hectares (ha) of irrigation land and additionally provides water for the towns of Theunisen, Welkom and Virginia. The scheme distributes water through two main canals; the Vet canal and the Sand Canal. Water is abstracted from the Allemnaskraal Dam (174.2million m^3 capacity) and the Erfenis Dam (207.5 million m^3 capacity) as shown in Figure 2-5. Typical photos of the canal section can be seen in

Figure 2-6. The total water allocation for the Sand-Vet irrigation scheme is 75.9 million m^3/annum (DWS, 2016a).

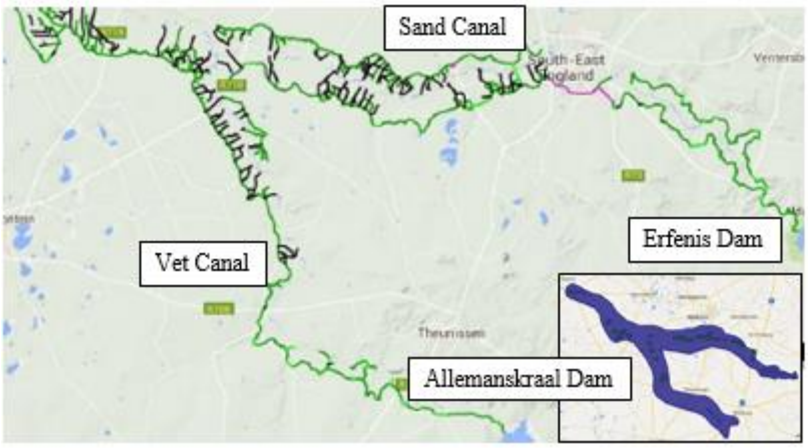


Figure 2-5: Sand-Vet scheme (DWS, 2016a)

Figure 2-6: Sand-Vet scheme photos (DWS, 2016a)

ii. <u>Orange-Riet scheme</u>

The Orange-Riet scheme was established in 1987 and is about 112km long as shown in Figure 2-7. The canals convey water from the Vanderkloof dam (3 200 million m^3 capacity) and serves irrigation water to an area of around 13 300 hectares in addition to supplying to the Riet River Settlement. The canal can transfer 370 million m^3/annum when operating under full capacity. The first 74km of the canal has a capacity of 16m^3/s and provision has been made to increase this to 24m^3/s. Typical canal sections can be seen in Figure 2-8 (DWS, 2016b).

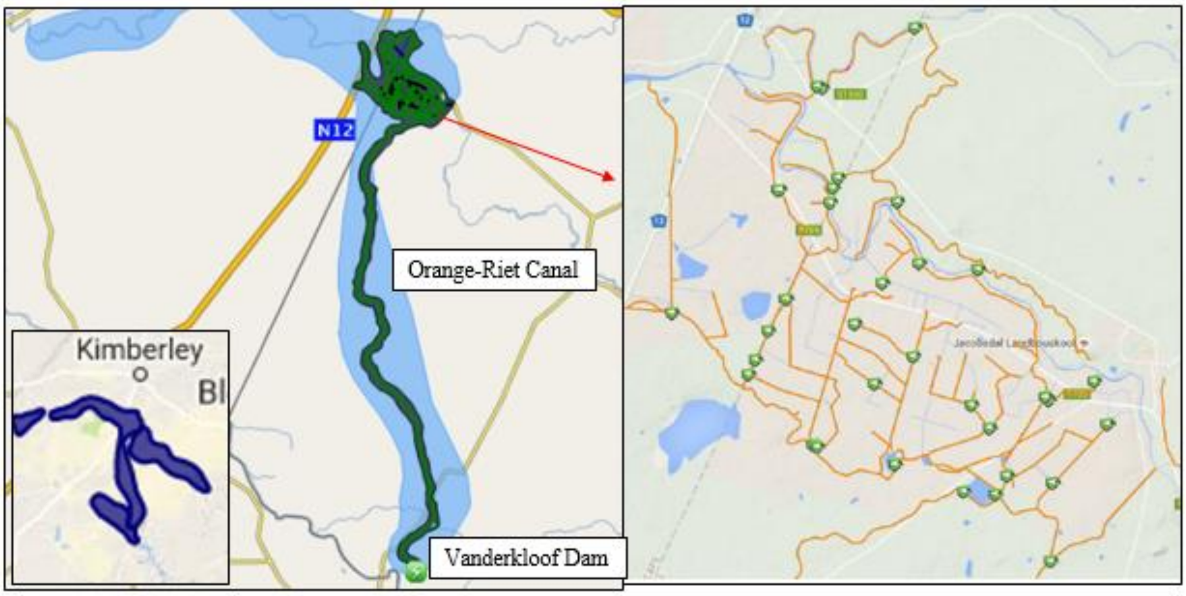


Figure 2-7: Orange-Riet scheme (DWS, 2016b)

Figure 2-8: Orange Riet scheme photos (DWS, 2016b)

iii. <u>Hartebeespoort scheme</u>

The Hartebeespoort water scheme established in 1898 is situated in the North West province and comprises of two main canals, generally referred to as the East and West canals. Water is fed from Hartebeespoort dam (195 million m^3 Capacity) to around 13 9115 ha of irrigation land. The West Canal is about 56km long and the East Canal 43km, an extension of the East canal spans another 30km resulting in a total length of 532km (Figure 2-9). A total yield of around 86.3 million m^3/annum is transferred through the scheme. Pictures of the canal can be seen in Figure 2-10 (DWS, 2016c).

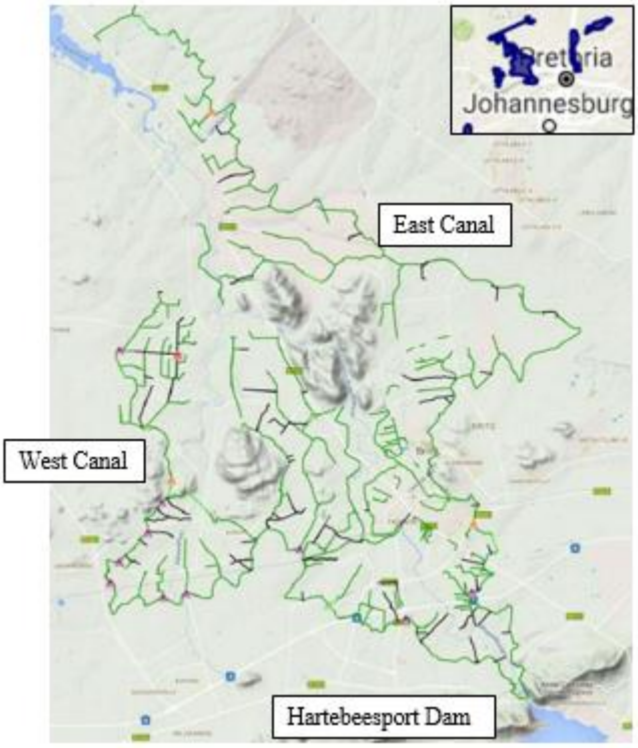


Figure 2-9: Hartebeespoort scheme (DWS, 2016c).

Figure 2-10: Hartebeespoort scheme Photos (DWS, 2016c).

2.3.2 Alignment with National commitments towards renewable energy generation

The construction and implementation of sustainable energy sources, in this case HK energy generation, has a large untapped prospective in South Africa, not only due to its sustainable nature but also its alignment with current legislative goals.

Since 1994 a great amount of renewable energy plans and goals were established by the South African Department of Energy (DoE). A roadmap of these documents and policies can be seen in Figure 2-11.

An event which changed the focus of infrastructure development was a goal set by the DoE of 100% electrification by 2014 in South Africa. In 2013 the Cabinet approved the "new household electrification strategy" of the DoE, which entailed altering the target of 100% to 97% with 90% of households being connected to the grid (this includes over 300 000 households) and the remainder having a connection to non-grid technologies, including any possible cost-effective technology. The target date was changed from 2014 to 2025 (DoE, 2013) (Scharfetter & van Dijk, 2017).

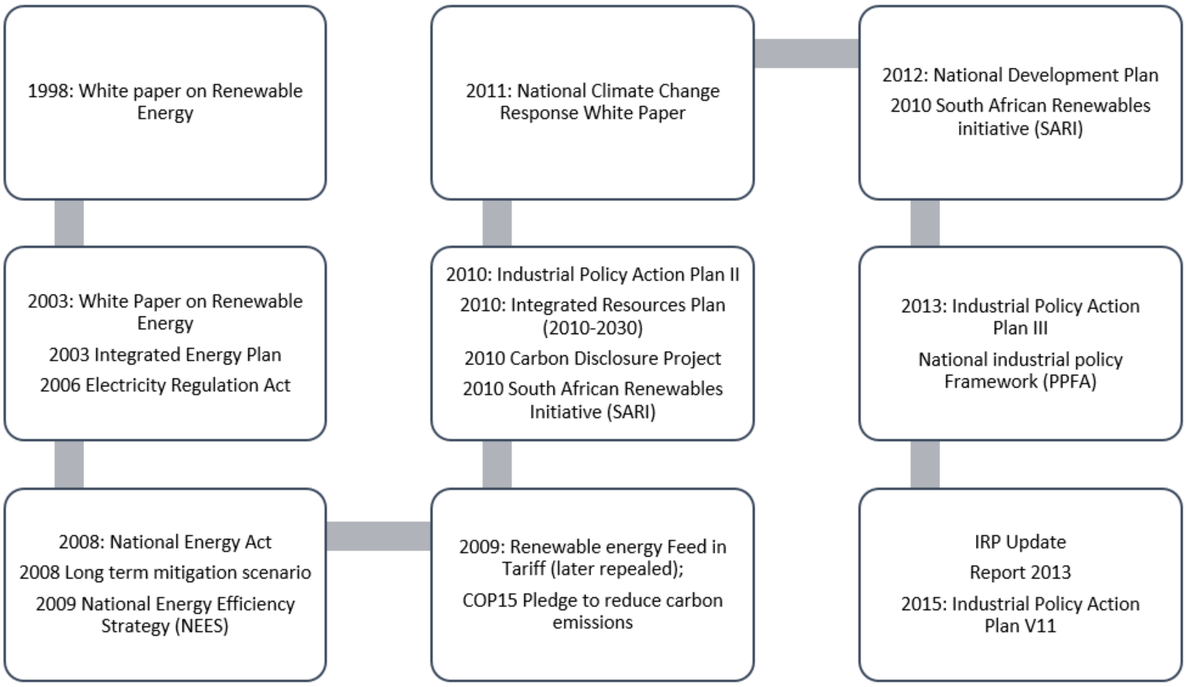


Figure 2-11: Renewable energy Policy roadmap for South Africa (Nhamo & Mukonza, 2016)

One of the programmes developed to promote renewable energy in South Africa is the Renewable Energy Independent Power Producer Programme (REIPPP) established by the DoE to contribute to meeting the national renewable energy targets and encourage foreign investment. Small-scale hydropower is one of the technologies listed under this program and is therefore a strong motivation of the development of HK energy.

Furthermore, as most of the existing water distribution infrastructure used in the agricultural sector exists in rural areas it allows an opportunity which aligns with the Department of Agriculture, Forestry and Fisheries (DAFF) objectives of the Irrigation Strategy with regard to these specific purposes (DAFF, 2015):

- *"Increase the contribution of irrigated agriculture to the Gross Domestic Product (GDP) (at least in absolute terms), poverty alleviation…"*

- "*Optimize irrigation water use efficiency with a view to long-term sustainability of irrigated agriculture*."
- "*Improve planning and investment co-ordination in the following: Phasing in and expanding systemic interventions of water use efficiency and management*."

Focusing on small-scale hydropower, a 2016 updated general authorization by the Department of Water and Sanitation of South Africa (DWS), allowed a simpler process of attaining regulatory compliance in terms of the NWA by the inclusion of small-scale hydropower schemes (SHS) used for rural electrification (Scharfetter & van Dijk, 2017). This allows simpler approval for installation and creates a greater appeal to the concept of small-scale hydropower development.

In addition to the requirements of the National Environmental Management Act (NEMA), which provides for cooperative environmental governance on matters impacting the natural environment, the principles of South Africa's Climate Change Response White Paper (CCRWP) and the Long-Term Mitigation Strategy (LTMS) developed by the Department of Environmental Affairs (DEA) need to be recognized and considered. Both the policy- and strategy document stress the importance of curbing anthropogenic green-house gas emissions by committing sector departments to specific targets and objectives towards climate change mitigation and adaptation.

2.3.3 Constraints/problems in South Africa

In South Africa a large problem lies in maintenance of canals and water infrastructure in general which is operated by the DWS, which leads to failed systems as shown in Figure 2-12. The Western Cape Premier Helen Zille stipulated the maintenance of water infrastructure such as canals, weirs and dams has fallen behind because it is cash-strapped. However, the DWS stated that the cleaning of canals falls within the responsibility of provincial Departments of Agriculture, who don't have the funds for the necessary maintenance. The biggest problem is sedimentation, which requires regular removal (allafrica, 2017).

An additional constraint of HK installations in canals in South Africa lies in the variance in water supply throughout seasons. Also in some cases the canals are regulated by irrigation boards who only supply water when necessary and requested by downstream farm owners. This results in inconsistent flow patterns as demand varies which in turn affects electricity supply. A suitable user for this varying electricity supply is thus required.

The problems and constraints vary from site to site and therefore it is a prerequisite to have reliable historical flow data of any potential HK installation site prior to development, to ensure a predictable, working system.

Figure 2-12: Canal lack of maintenance (DWS, 2016)

2.4 THEORY OF HYDROKINETIC ENERGY GENERATION

HK systems are a specific category of “unconventional” hydropower where energy is extracted from the kinetic energy of flowing water rather than the potential energy of falling water, similar to the function of wind turbines. These systems can be easily installed in free-flowing rivers or streams to enhance energy extraction (Kusakana & Vermaak, 2013). By harnessing this form of energy HK energy production avoids many of the challenges faced with more traditional forms of hydropower such as high civil works costs and the need for an acceptable water head (potential).

HK turbines are relatively simple designs with no reservoir or spillway requirements. The environmental impact is minimal and they are simple to install and maintain at a low cost, therefore these systems hold value in rural or remote areas (Kusakana & Vermaak, 2013). The basic working of the systems can be seen in Figure 2-13.

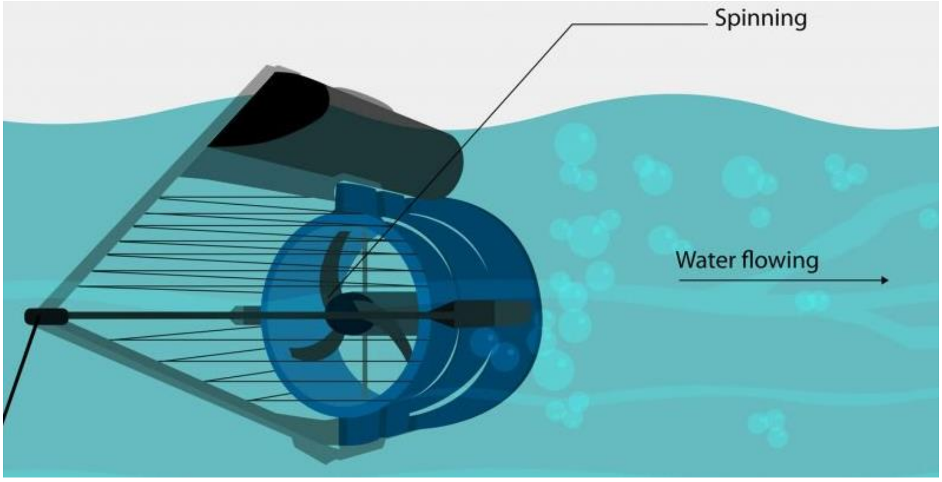


Figure 2-13: Basic working of HK turbines (SHP, 2016)

This technology is applicable to rivers, tidal and ocean currents and man-made channels which enables installation at sites which do not hold possibilities for other technologies. There are two primary classifications of HK turbines as shown in Figure 2-14.

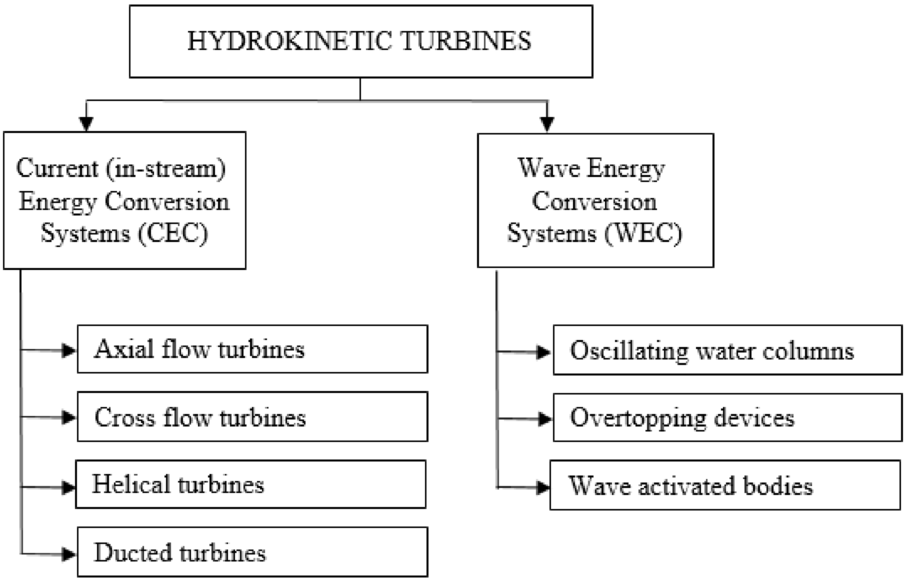


Figure 2-14: HK turbine classification (Yuce & Muratoglu, 2015)

For the study only current (in-stream) turbines will be considered. There are two primary types of instream turbines which link to the two classical categories of rotating machinery, (Lago, et al., 2010). The turbine category employed can be characterized by its rotational axis orientation with regard to the water flow direction:

i. Axial flow turbine: The axis of rotation is parallel to current direction. Therefore, the rotor must be controlled to follow the direction of the current to increase power conversion efficiency.
ii. Cross flow water turbine: Rotational axis is perpendicular to the current. This turbine rotation is not dependent on flow direction and can operate at any flow direction (especially used in tidal applications).

Both these HK turbine types can be deployed in rivers and canals. Additional consideration during design work may be required to maximize the energy generated (Gunawan, et al., 2017). These categories can be further divided as shown in Figure 2-15.

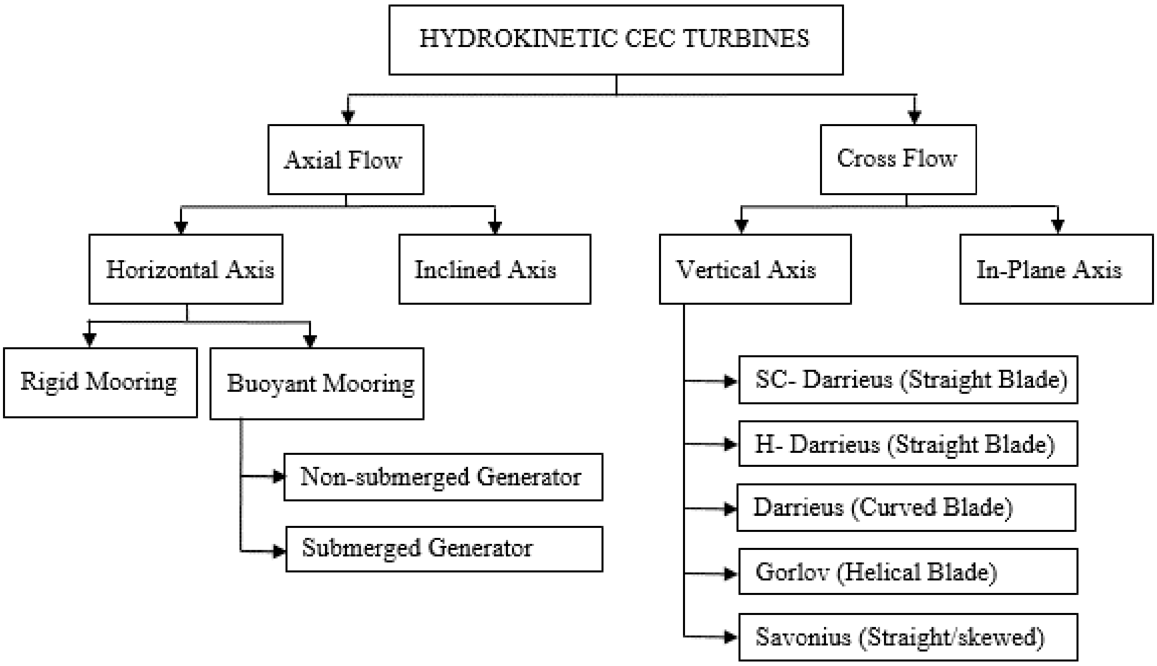


Figure 2-15: HK turbine classification (Khan, et al., 2006)

According to Khan et al. (2008) other turbine based systems can be categorized as follows:

i. Venturi systems
ii. Gravitational Vortex systems

And in the non-turbine category there are the following:

i. Flutter-Vane
ii. Piezoelectric
iii. Oscillating-Hydrofoil
iv. Fan-Belt
v. Paddle wheel systems

The two most commonly found and used turbines remain axial and cross flow turbines. Axial flow turbines, also referred to as horizontal axis turbines employ propeller type rotors, some arrangements can be seen in Figure 2-16. The inclined axis turbine (a) has mostly been studied for small riverine applications, where (b)(c) and (d) are more similar to wind turbines in structural design aspects ((Koko & Kusakana, (2014); Vermaak et al., (2014)).

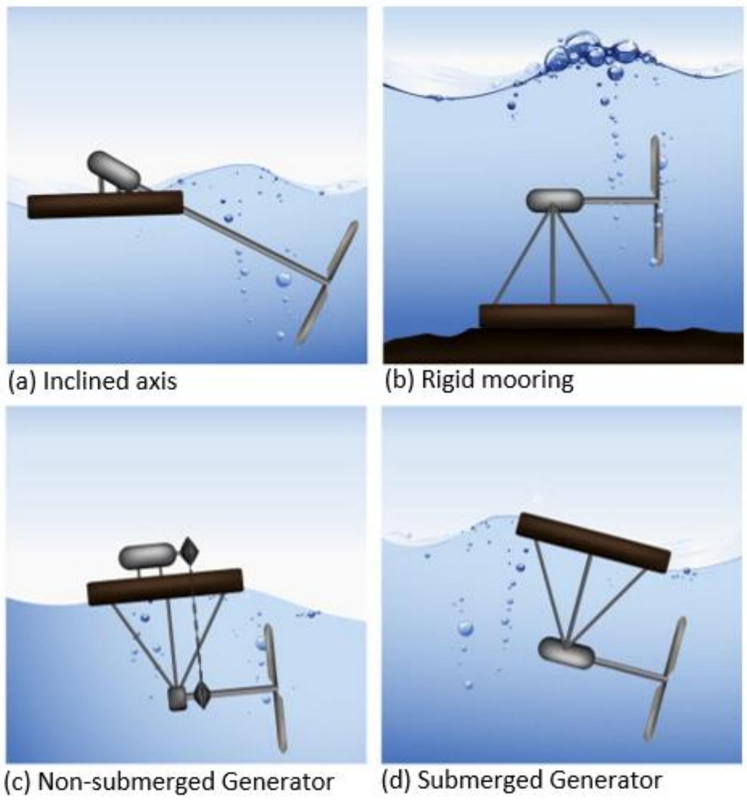


Figure 2-16: Axial flow turbines (Vermaak et al., 2014)

Cross flow turbines, also referred to as vertical axis turbines, can be further divided into vertical axis and in-plane axis turbines, examples of these can be seen in Figure 2-17, where (a) is an in-plane axis turbine which is generally a drag based device and the remaining (b,c,d,e,f) are vertical axis turbines with the Darrieus type turbines being the most commonly used ((Koko & Kusakana, (2014); Vermaak et al., (2014)). In cases where water flow rate is limited the H-Darrieus type turbine can be useful (Gueney & Kaygusuz, 2010).

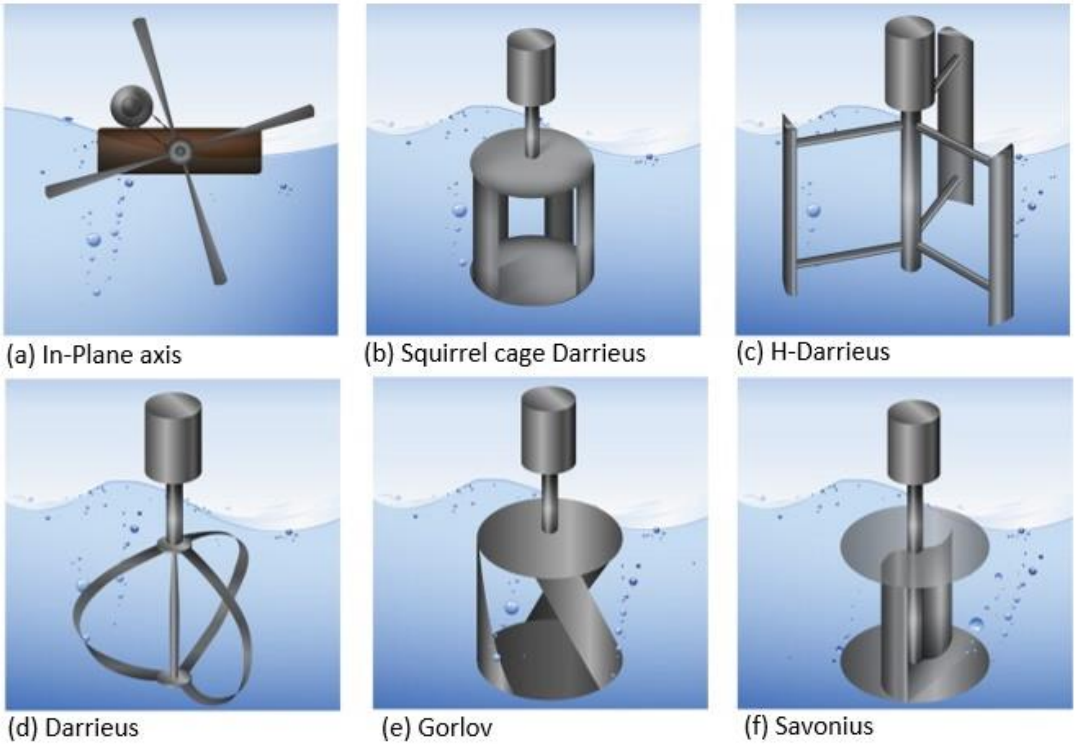


Figure 2-17: Cross flow turbines (Vermaak, et al., 2014)

General characteristics comparisons between these two common turbine types can be seen in Table 2-2, these characteristics must be considered in each specific case when selecting a turbine for installation. Some typical horizontal and vertical axis turbines available on the market as pre-designed systems which are typical standardized units are shown in Table 2-3.

Table 2-2: Turbine characteristics comparison (Anyi, 2013)

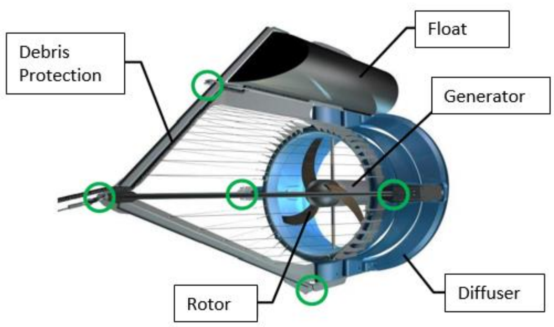
GENERAL CHARACTERISTICS	HORIZONTAL AXIS TURBINE	VERTICAL AXIS TURBINE
Minimum operating current velocity	0.5m/s	1m/s - need higher velocity to self-start
Operating tip speed ratio (TSR)	Faster (TSR up to 4.5)	Slower (TSR below 3)
Coefficient of power C_p	46%	35%
Water to wire efficiency	25% (calculated) due to less efficient transmission and generator	26% (claimed)- due to efficient transmission and generator
Debris resistant	Poor	Good
Torque ripple	Smoother	Pulsating
Rotor simplicity	Fairly complex	Simple

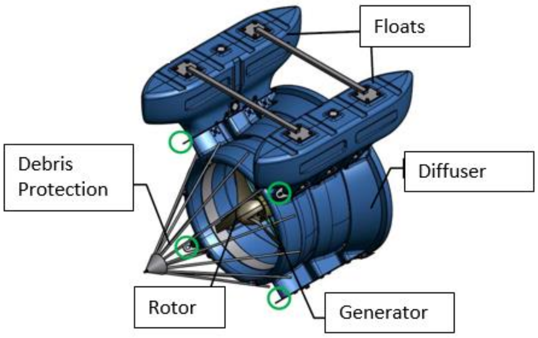
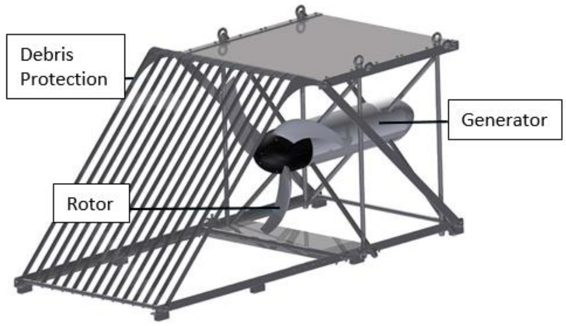
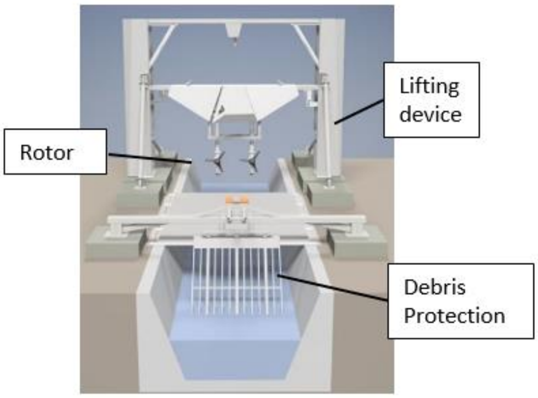
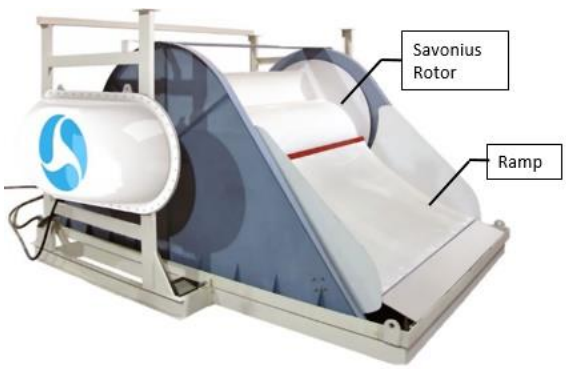
GENERAL CHARACTERISTICS	HORIZONTAL AXIS TURBINE	VERTICAL AXIS TURBINE
Material quantity and cost	Less	More
Weight	Less	More
Pontoon	Smaller due compactness	Larger
Mechanical power transmission	Complex	Simple
Turbine safety	Blades coning and swinging	Not possible
Debris Management	Using swept blade and nose cone	Not possible

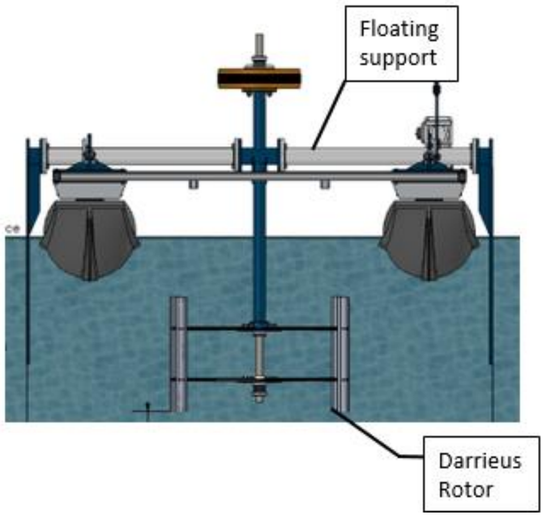
The coefficient of Power (C_p) is a factor commonly referred to into HK design. It is the ratio of actual electric power produced by the turbine divided by the total water power flowing into the blades at a specific speed. It represents the combined efficiency of the HK power system components (blades, shaft bearings, generator and gear train). This value is in most cases measured or calculated by the manufacturer. The C_p value can be used to calculate the predicted power output when the speed of flow is known.

Additional advanced technologies and leading designs in HK turbine development for larger scale products can be seen in Figure 2-18, indicating the advancement in development of larger scale applications, however smaller applications do not hold the same truth.

Table 2-3: HK turbines on the market (SHP (2016); CaptaHydro (2017); New Energy Corporation (2017) & Waterotor,(2017))

TYPE	COMPANY	NAME	FEATURES	APPLICATION	PICTURE
Axial Turbine	Smart Hydropower	Monofloat	3.1x1.6x2m Weight= 300kg. 3 rotor blades 1000mm diameter. 5kW maximum output at 2.8m/s.	Scope of application can be adapted, usually river applications.	

TYPE	COMPANY	NAME	FEATURES	APPLICATION	PICTURE
		Duofloat	3 rotor blades. 1000mm diameter. 5kW maximum output at 2.8m/s.	Scope of application can be adapted, usually river applications.	
		Freestream	2.6x1.12x1.1m Weight = 300kg. 3 rotor blades. 1000mm diameter. 5kW max output at 3.1m/s.	Placed in the bottom of a river/canal, expandable system .	
	Capta Hydro	Capta SC	5-50kW system. No Gates. Min flow=3m/s. Minimum water section 60x60cm.	Supercritical flow canals with concrete lining, or equivalent. However, the scope of application can be adapter.	
Cross flow	Waterotor Energy Tech.	Waterotor	Ramp for concentrated flow. Applicable to as little as 0.89m/s (1.1kW). 0.8-3m/s Single savonius rotor.	Applicable to very slow-moving water.	

TYPE	COMPANY	NAME	FEATURES	APPLICATION	PICTURE
	New Energy Corporation	EnviroGen Series	Floating/fixed support. Units available for 4-125kW (depending on available area) 0.75m Blade - 5kW at 3m/s.	Unit can be mounted on floating or fixed support, suitable for all riverine/canal applications.	

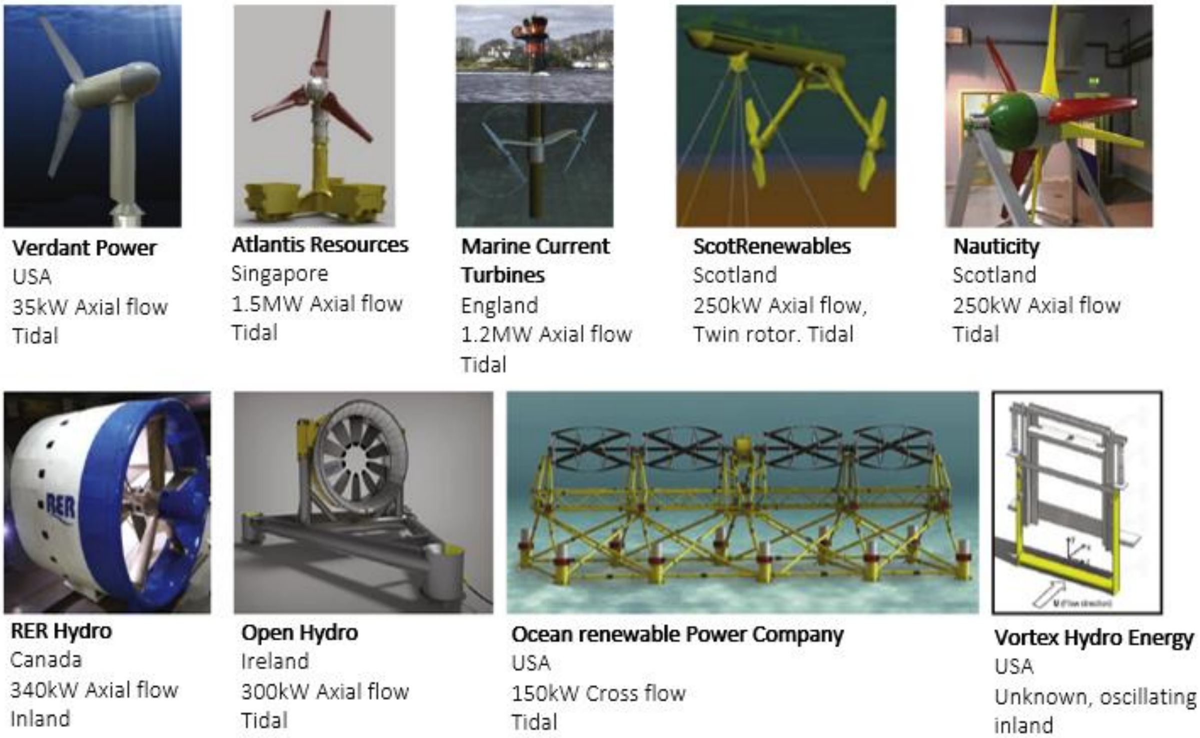


Figure 2-18: Advanced HK industry designs (Laws & Epps, 2016)

For correct and feasible installation of a HK system a number of factors are of importance, from the environmental aspects, sectional properties and flow characteristics to the system size (multiple turbines) and effects of the turbine on the water and ecosystem. These important factors of consideration will be discussed in subsequent sections.

2.4.1 Advantages and disadvantages of HK systems

HK turbines have a great number of advantages over traditional hydropower systems, however are also prone to a number of disadvantages, most of which will differ from installation to installation. When designing a HK system and evaluating a potential installation site, the advantages and disadvantages shown in Table 2-4 should be considered. Where disadvantages apply countermeasures should be designed for.

The largest and most common disadvantage is possible clogging of a turbine due to debris. This can be prevented by installing a sieve or grid type structure upstream, however, Anyi (2013) after a study on the clogging of HK turbines concluded that a grid or screen protected turbine could solve the clogging issue in fast flowing water, however may cause problems in low velocity current, which was proved with case studies. In an example where fish screens were used on a ducted Darrieus turbine the turbine efficiency reduced by 12% (Kirke, (2011); Anyi, (2013)). This proves the influence of countermeasures on the system must be considered before installation.

Table 2-4: Advantages and disadvantages of kinetic hydropower over traditional hydropower (Pant et al. (2014); Ferreres & Font (2010))

ADVANTAGES	DISADVANTAGES
i. No Dam/ reservoir required as HK devices drive on the flow of running water. ii. Does not require large capital investment (minimal civil works). iii. Less maintenance cost than traditional hydropower. iv. Reduces environmental and ecological complications due to small scale and application type. v. HK ability to work in conjunction with other hydropower plants and agricultural water usage.	i. Possible Clogging of the turbine from floating debris. ii. HK devices can have possible negative influences on aquatic ecosystems, possibilities of fish going through the system which could cause fish death and can result in turbine damage. However, this problem does not always apply to canal installations. iii. High quality materials required for long term durability and consistent high efficiency. iv. The specific location for the HK installation is a very important factor that requires extensive testing and research. v. A constant water supply is needed. vi. In most cases a high velocity is required to obtain a feasible output which is not always possible.

2.4.2 HK turbine power output

The Power available per swept area for a HK device is termed the HK power density ($P_{HK,}$) which is a function of fluid velocity, density and device efficiency as shown in equation 2.1 (Kartezhnikova & Ravens, 2013):

$$P_{HK} = E \times \frac{\rho}{2} \times V^3 \tag{2.1}$$

Where:

P_{HK} = Power density (W/m^2)

E = Device efficiency (%)

V = Fluid velocity (m/s)

ρ = Fluid density (kg/m^3)

The equation can also be explained in a similar way (Koko & Kusakana, 2014):

$$P_{HK} = \frac{\rho}{2} \times A \times V^3 \times C_p \tag{2.2}$$

Where:

ρ = Fluid density (kg/m^3)

A = Hydrokinetic turbine swept area (m^2)

V = water speed (m/s)

C_p = Power coefficient of a hydrokinetic turbine

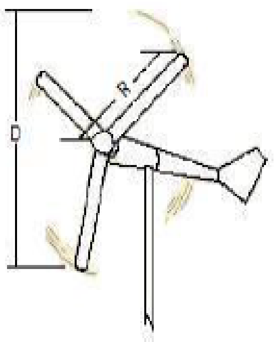
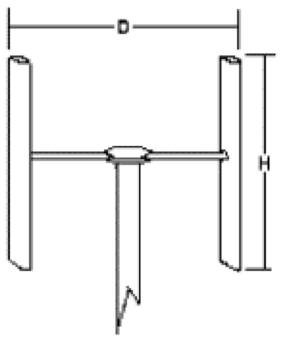
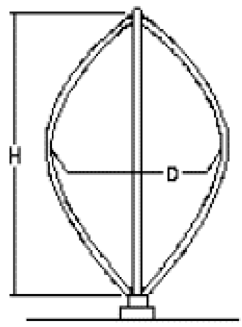
The swept area is determined based on the turbine configuration as shown in Table 2-5

Where:

D = Turbine diameter (m)

H = Turbine height (m)

Table 2-5: Swept area calculation for relevant blade configurations (Koko & Kusakana, 2014)

ROTOR BLADE	Conventional rotor	H-Darrieus Rotor	Darrieus Rotor
ARRANGEMENT			
SWEPT AREA	$A = \pi \times \frac{D^2}{4}$	$A = D \times H$	$A = 0.65 \times D \times H$

From a mechanical viewpoint, the turbine power performance tests are typically measured by the drag (thrust) force which is acting on the turbine and the approach flow hydrodynamic force over a range of tip speed ratios (TSR). This is necessary to assess the performance and calculate possible annual energy production (Gunawan, et al., 2017) The instantaneous turbine power P_T, is calculated as follows:

$$P_T = \tau \times \omega \tag{2.3}$$

Where:

τ = The instantaneous torque (N.m)

ω = The instantaneous angular velocity (rad/s)

It must be noted that as the HK system extracts power from the flowing water, changes can occur in flow velocity, water elevation (damming effect), sediment transport and other properties (Kartezhnikova & Ravens, 2013).

2.4.3 HK turbine placement and spacing theories

The decision of where to install the HK turbines within a canal/river section and if multiple turbines are installed (the spacing and placement of the devices) is a complex and site dependent principle. The spacing especially, is one of the most important remaining questions for many HK products and applications (Mangold, 2012). The determination of the spacing is site dependant and subject to the type of turbine used, rotor blades, flow velocity etc. It is not essential that the canal regain complete laminar flow (and very rare), however it must regain most of the velocity as this is what drives the power production as exhibited on a typical power curve of a HK device in Figure 2-19.

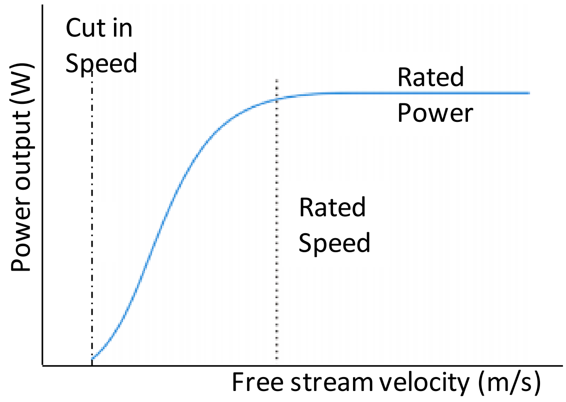


Figure 2-19: Typical power curve of a HK device (Yuce & Muratoglu, 2015)

When an array of turbines are placed in close proximity to one another the turbines interact primarily through their wakes. The wake length is the recovery distance to the point where the velocity has almost recovered to prior installation conditions as shown in Figure 2-20. According to Myers & Bahaj (2012) axial flow turbines which are similar to wind turbines typically recover 90% (arbitrary value deemed acceptable recovery) of its velocity after 20 diameters distance downstream of the rotor. Neary et al. (2013) suggests a wake recovery of 85% is sufficient. Their findings that lower velocity recovery occurs between 10-15 diameters downstream allows the option of accepting a 30% decrease in incoming kinetic energy when the distance between the turbines is halved. This reduction in spacing is crucial for reduction of the cost of arrays of HK turbines ((Neary et al. (2013); Myers & Bahaj (2012)).

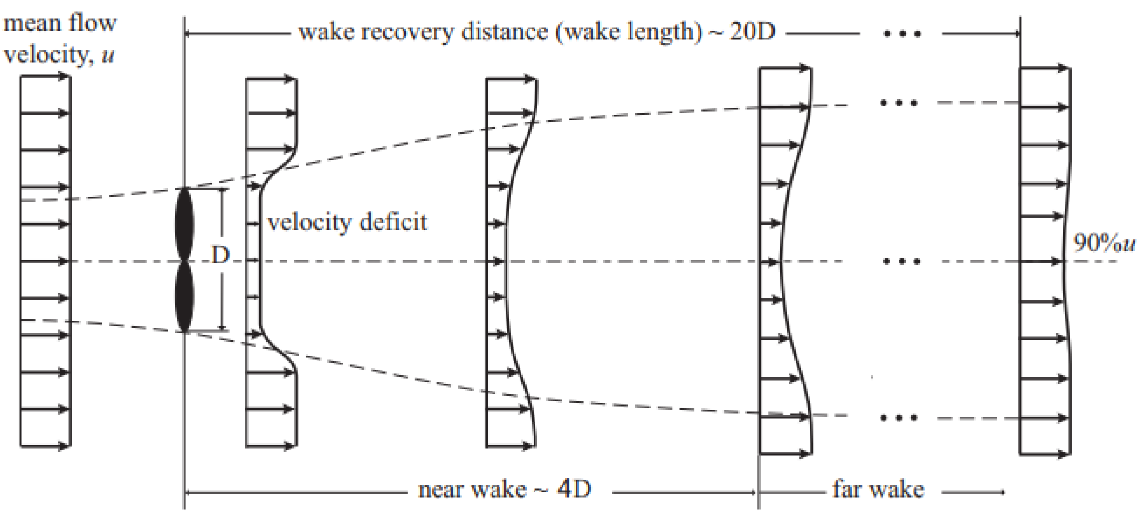


Figure 2-20: Definition of wake characteristics (Laws & Epps, 2016)

In a study done by Gunawan on a float-suspended HK turbine in the concrete lined Roza Canal, USA, the velocity contour 10 meters downstream of the turbine, which in that case was approximately 3 turbine diameters downstream, can be seen in Figure 2-21, although this influence is site dependant the principle of turbine influence on velocity contours is exhibited (Gunawan, et al., 2017).

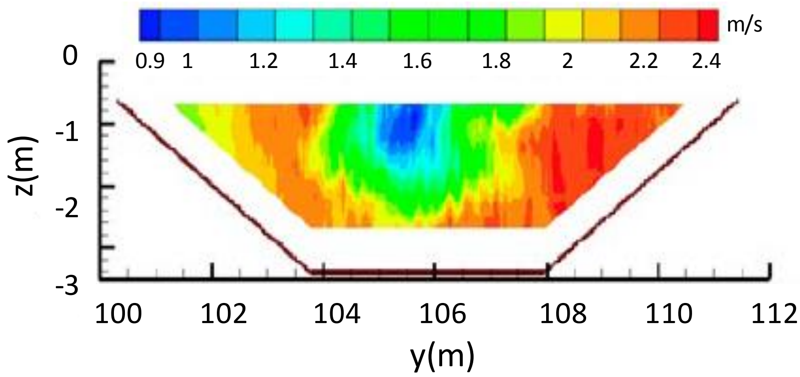


Figure 2-21: Spatiotemporally-averaged velocity contour in the Roza Canal USA 10m downstream of a turbine (Gunawan, et al., 2017)

When evaluating sites close to bends, contractions, expansions or slope changes basic hydraulic laws can be used to find the optimal position of installation. As an indication of the phenomenon resulting from these effects the velocity contours from a Computational Fluid Dynamics (CFD) model done by Gandhi et al. (2010) can be seen in Figure 2-22.

From (a), (c) and (d) in Figure 2-22 a pattern of the typical velocity distribution over a canal cross section can been seen. This proves the logical explanation of faster velocity occurring in the canal centre, as drag resulting from friction losses on the canal parameter will slow down adjacent flow. The magnitude of drag will be dependent on the specific canal/river of application and its roughness value. The optimal ‘zone’ of turbine placement can be determined from this.

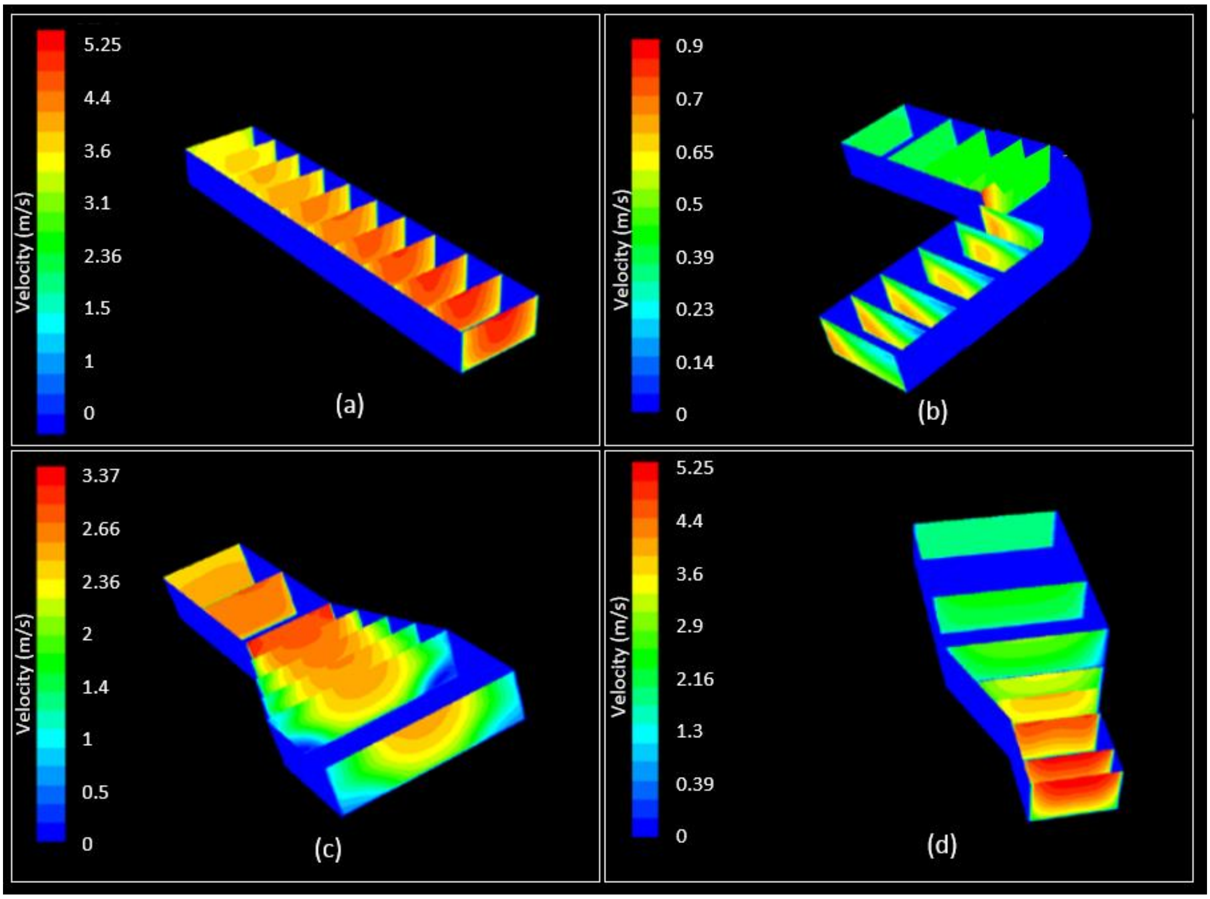


Figure 2-22: CFD modelling results (a) steep slope 1/75 (b) 90 degree bend (c) divergence to double width (d) convergence to half width (Gandhi, et al., 2010)

2.5 HK SYSTEM COMPONENTS

The HK energy conversion systems consist of 5 subcategories of components (Lago, et al., 2010):

i. The turbine itself
ii. The support structures (flotation device in some cases)
iii. Electric power converter (control systems and generator)
iv. Transmission systems
v. Remote communication and control link

Optional components can include a shroud or diffuser type optimisation measure and protection structures such as a grid, depending on the application. The basic components of a HK system can be seen in Figure 2-23.

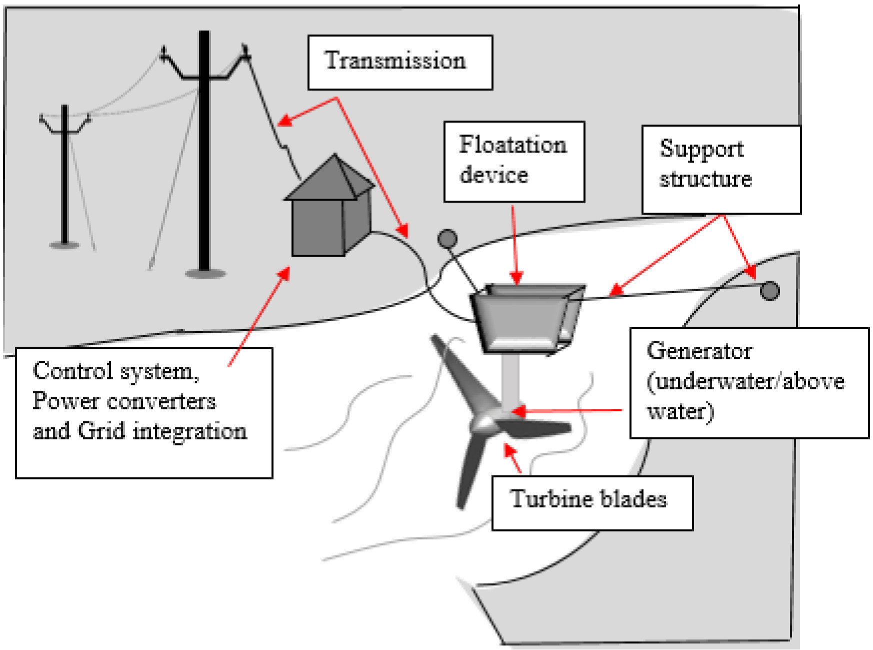


Figure 2-23: Components of a HK system

2.5.1 HK turbine design

A number of turbine manufacturers are designing various types of HK turbines for numerous applications focussing on design aspects such as the number of blades, blade thickness and orientation. In most literature, HK turbines are described as similar to wind turbines, however, these two have some significant design differences, in terms of fluid density, working velocities, flow variability, clog-impacts by debris and speed limitations due to cavitation (Anyi, 2013).

The number and length of blades on a specific horizontal axis turbine can be varied to suit the site specifications, these parameters determine solidity, affects the fluid dynamic efficiency and shifts the TSR at which the maximum efficiency will be achieved. As an example, the change in power output from various blade numbers of a conventional rotor can be seen in Figure 2-24. The TSR relates to flow speed and the C_p value relates to the turbine efficiency.A variable commonly referred to in HK turbine design optimisation is the Betz Limit. It is the theoretical limit to the percentage kinetic energy which can be extracted from the flowing fluid comparing to the maximum energy available in the fluid.

During HK turbine design the Betz limit is used as a practical upper limit on the highest efficiency attainable. As an example, shown in Figure 2-25 the area (Area1) between the Betz limit and the power curve is minimized to maximize the turbine efficiency (Sale, et al., 2009). This allows prediction of the desired flow speed of installation to obtain the highest possible efficiency.

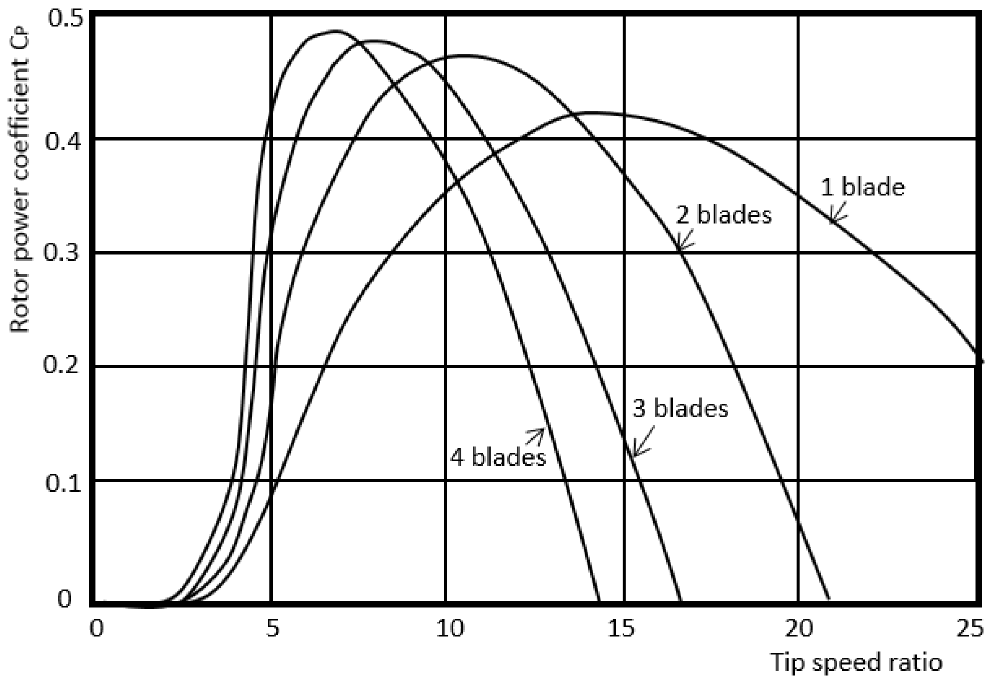


Figure 2-24: Influence of blade number on power coefficient (Hau, 2000)

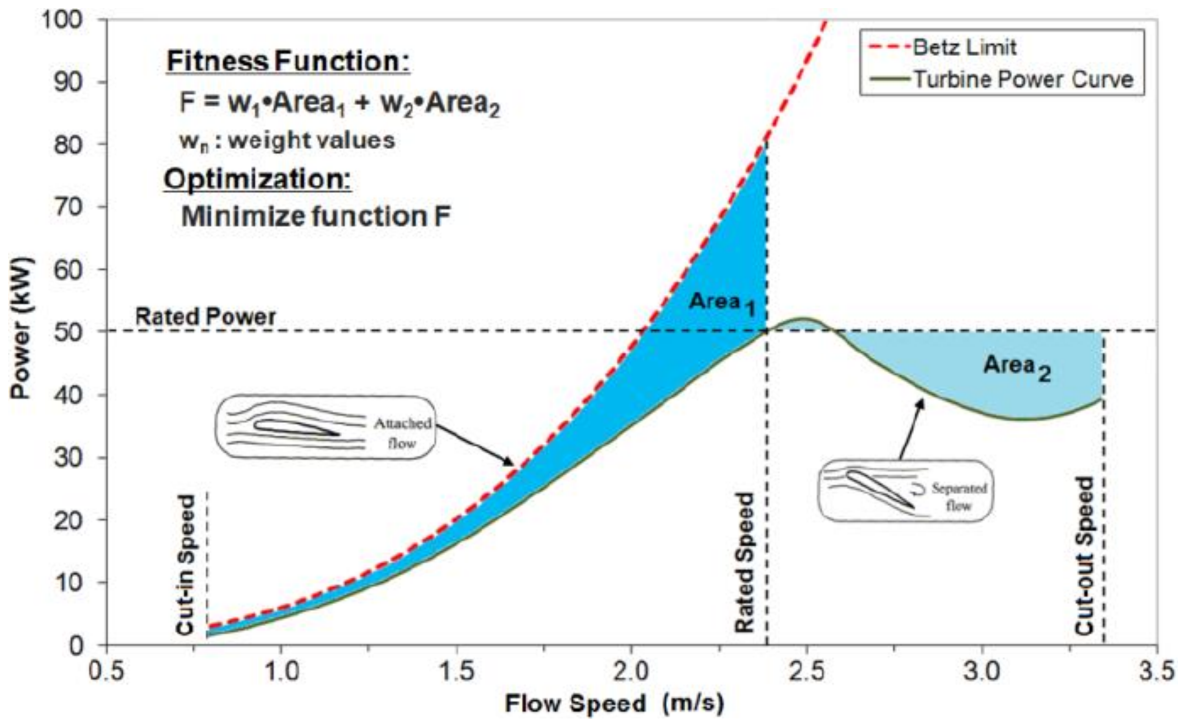


Figure 2-25: Example power curve for a HK turbine (Sale, et al., 2009)

2.5.2 HK turbine generator

Electric generators convert mechanical energy to electrical energy. The selection of a generator involves multiple factors such as (Koko & Kusakana, 2014):

i. Prime mover speed;
ii. Required output power and
iii. Range of operation and use.

Generators can provide direct current (DC) or alternating current (AC) output. DC generators are generally used to charge batteries in small plants and are restricted to low transmission efficiency and high maintenance of brushes and commutator segments. Due to this the most commonly used generators for wind and HK turbines are synchronous and induction (asynchronous) generators (both AC output) (Koko & Kusakana, 2014). Synchronous generators are the conventional generators used in small and large power plants (Anyi, 2013).

The working principle of generators is usually based on Faraday's law of electromagnetic induction, where by rotating an electric conductor in a magnetic field an electromagnetic field (emf) is induced, thus creating flow of charges. Both AC and DC generators follow electromagnetic principles but differ in their means of collecting and transferring the induced emf. The most common HK generator types, descriptions and the advantages and disadvantages of each application are shown in Table 2-6.

Table 2-6: Advantages and disadvantages of generator types (adapted from Koko & Kusakana (2014); Hussein et al. (2013))

GENERATOR TYPE AND DESCRIPTION	ADVANTAGES	DISADVANTAGES
(AC) Field excited Synchronous Generator: Rotation of field poles (Rotor) around a stationary conductor (Stator) inducing an alternating current resulting in electrical power generation.	• No extra field excitation needed • Higher efficiency and low inertia due to the direct drive permanent magnet. • Can operate at lower speeds. • Lower maintenance cost due to absence of brushes. • High torque density minimizes the size. • Simple to use and provide reliable power. • Longer lifespan due to high quality magnets.	• Frequency inverters and rectifiers needed during variable speed. • Large number of poles and increased turbine radius required to get suitable frequency at low speeds. • The field created by the magnets is not controllable.

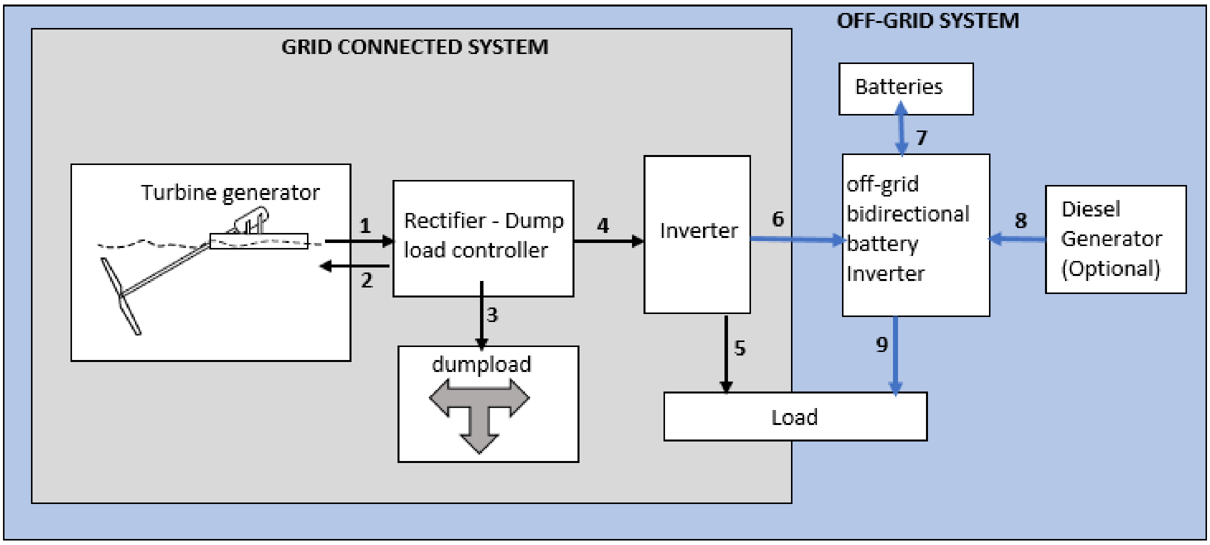
GENERATOR TYPE AND DESCRIPTION	ADVANTAGES	DISADVANTAGES
(AC or DC) Permanent Magnet (Synchronous) Generator: Magnetic field generated by a permanent magnet converted to mechanical energy and finally electrical energy.	• Flexibility. • No current flowing in rotor, therefore no need for brushes which improves reliability. • Increased efficiency. • Can operate at varying rotational speeds. • Simple structure and high-power density.	• Challenges increase as turbine size increases. • Coil insulation system is sensitive to vibration and thermal changes. • Complex cooling system for certain rotor designs.
(AC) Induction Generator (Asynchronous): Similar concept to a motor, manually cranked rotor turning faster than synchronous speed from the stator induces a strong current which is then converted to electrical energy.	• Can supply constant voltage and constant frequency at variable speeds. • High reliability. • Low cost and simple design.	• Lower efficiency to synchronous generator. • Requires faster speed than synchronous speed, at low river flow speeds, a need for speed increase exists. • Consumes reactive power leading to poor power factors.
(DC) Direct Current Generator: Uses electromagnetic induction, current flows as the magnetic rotor rotates in a fixed field of coils, energizing the coils to convert mechanical energy to electrical energy (brushless DC generator).	• Can be separately or self-excited. • Good option for charging purposes. • Functional in supplying larger motors. • Newer technology removes necessity of commutators. • Better voltage regulation.	• Lower transmission lengths (large losses over distances). • Some may require high rpm speeds and are not very efficient.

2.5.3 HK system control equipment

The control equipment required varies through the type of installation, namely grid-connected system or off-grid system. The grid connected system entails connecting the turbine to an existing grid where the turbine acts as an extra power source, whilst the off-grid system is a stand-alone system where the turbine generator powers its own mini-grid.

A general layout of these systems and a description of each item is included in Table 2-7.

Table 2-7: HK system layout (adapted from SHP (n.d))



1	The turbine generator supplies power to the rectifier, along this connection a switch could be connected which functions as the turbine break, which, when engaged, short circuits the generator which causes the rotor to rotate very slowly, simply as a safety feature.
2	This is the low voltage DC going back to the turbine, (feature used as a safety mechanism) as long as power is supplied to the relay the turbine runs as normal, in the case where the cable is disconnected the relay will open, putting the turbine into open circuit and no power will be generated, also preventing stray power from leaking into the water.
3	Excess electricity is diverted to the dump-load to be dissipated (in most cases as heat, through heating elements) this will occur when: • Grid-connected and off-grid: to protect the grid tie inverter when the voltage exceeds 600V. • Off-Grid: When the power produced is not used up.
4	The rectifier converts the unstable current from the turbine generator to unstable DC current (if required) which is supplied to the grid tie inverter.
5	The inverter supplies AC as required (50Hz in South Africa)
6	The inverter supplies AC as required to the off-grid inverter.
7	The off-grid inverter will use the batteries to stabilize the system, either by charging excess energy into the batteries or using energy from the batteries when insufficient power is supplied by the HK system.
8	A backup input may be used by connecting a diesel generator (or alternative back-up source) which will turn on automatically when enough energy is not supplied from the batteries and HK system.
9	The inverter supplies AC as required (50Hz in South Africa)

2.5.4 HK power transmission

Transmission lines will either be used to form a mini-grid in an off-grid installation or erected to transfer the electricity produced to the grid connection. In either case an adequate transmission line must be used to safely transfer the electricity produced the required distance whilst minimizing transmission losses.

When selecting a cable, the following must be considered (Powertech, n.d.):

i. The size and type of load to be supplied: Either directly in Amps, kW or kVA.
ii. Permissible voltage drop (length of transmission).
iii. Prospective fault current (short circuit current).
iv. Circuit protection (above ground/underground installation).
v. Environmental considerations of installation:
    - Wet/dry conditions;
    - Sunlight or erosive soils.

The length of transmission must be considered in the pre-construction feasibility study, due to transmission costs being expensive over long distances (depending on the amount of power which must be transmitted).

2.5.5 HK turbine support structure

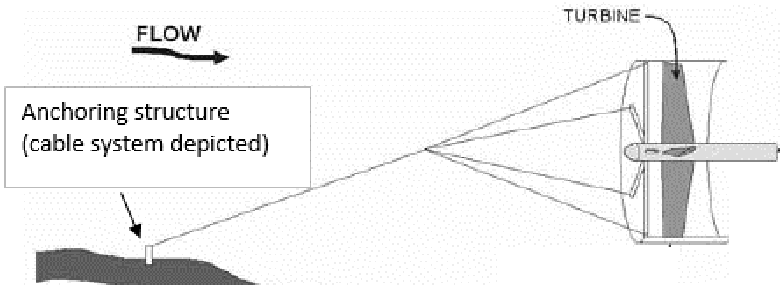
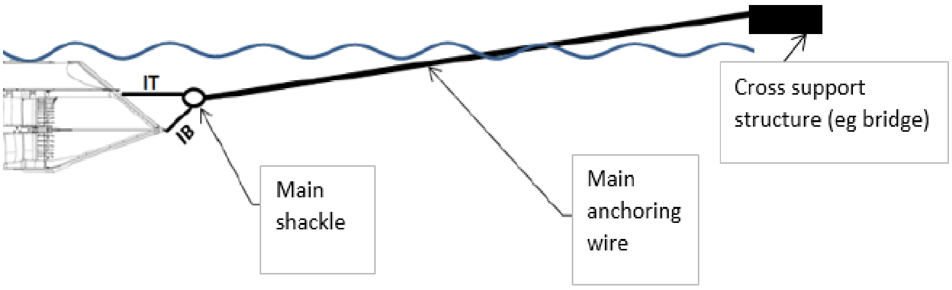
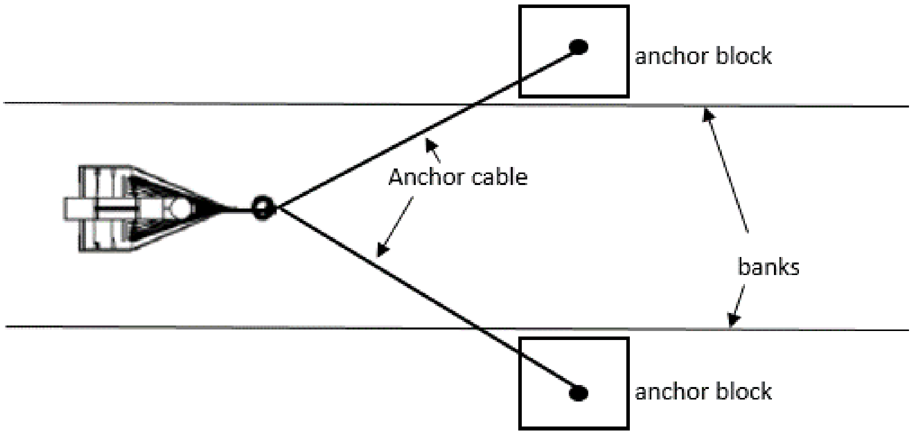
The anchoring structure of a HK turbine is very much site dependent and should be considered as part of the site evaluation. The type, strength and method of anchoring will be dependent on the following factors (SHP, n.d.) (Gaden, 2007):

i. River bed structure characteristics (sand, mud or stone).
ii. Type of shore:
    - Surface grass or sandy.
    - Distance of anchoring point above water level.
    - Space availability (sufficient space for cement block if side anchoring is used).
iii. Turbine weight and type.
iv. River bank rate of erosion.
v. Depending on the turbine weight, if bottom anchoring is considered a crane may be necessary for installation.
vi. Activity on the river (boat traffic etc.).
vii. For top anchoring, an overhead structure is needed.

viii. It must be noted when using a fixed side anchor instead of bottom anchor the system will be exposed to added moment forces which increase the cost.

Some common methods used for anchoring of HK turbines can be seen in Table 2-8.

Table 2-8: Anchoring mechanisms (adapted from SHP (n.d.) & Gaden, 2007))

ANCHORING MECHANISM	EXAMPLE
Bottom anchoring	
Top anchoring	
Side anchoring	

2.6 SITE PROPERTIES

As the focus of the study is on HK installation in canal systems the properties of the canal which play a great role in the installation are discussed below. The bulk flow, section geometry and general canal properties must be analysed to ensure an effective installation. The following sections define factors which govern flow characteristics and the viability of HK installations.

2.6.1 Infrastructure geometry

The section geometry of the potential site which is considered for HK installation can vary as shown in Figure 2-26. From lined fixed canal sections (a, b, c, d) to rounded earth excavated sections (e) which can vary greatly in geometry. Some examples of geometry effects on HK installations include the following (Laws & Epps, 2016):

i. Level or curved canal beds govern the fastening mechanism (Rigid or buoyant mooring);
ii. The geometry of the section governs wake characteristics by possibly affecting turbulence intensity and recovery;
iii. Structures obstructing flow result in velocity deficit (rocks obstructing stream lines) and all interactions between the wake, freestream and bounding surfaces and
iv. Abrupt geometry changes affecting preliminary numerical modelling studies of potential sites.

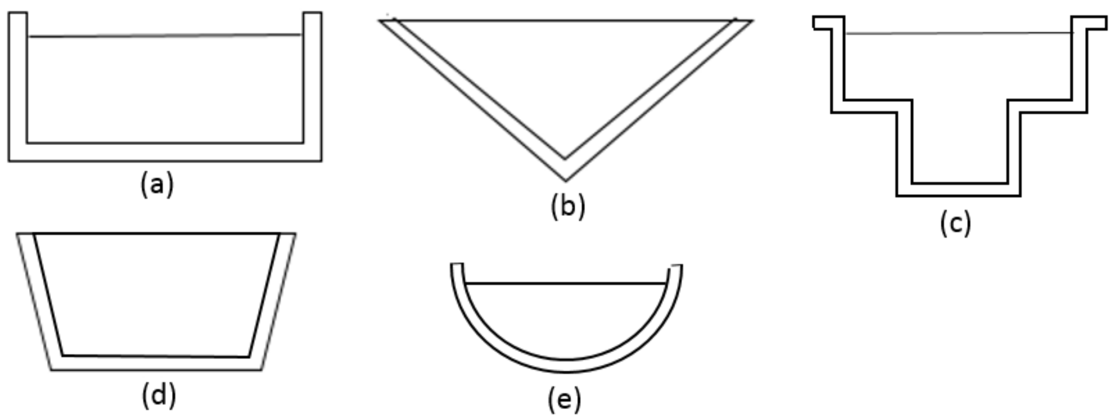


Figure 2-26: Section geometry

2.6.2 Bed roughness

The relevant infrastructure lining or bed material will influence the passing flow due to the roughness causing drag forces, this can be quantified by the Manning "n" value or absolute surface roughness "k_s". The n-value of canals is not easily computed in desktop estimates when specific site details are unknown and thus to select an appropriate roughness value for a specific site a number of factors must be considered among these (Depeweg et al. (2014); USACE (2016)):

i. Size and shape of the material forming the wetted perimeter.
ii. Vegetation of the bed and sides.
iii. Surface irregularities due to localized erosion/deposition, bed forms, poor construction or maintenance etc.
iv. The cross-section shape and water surface width/water level ratio.
v. Canal alignment, size and shape, degree of variation in the longitudinal direction.
vi. Scour and deposition.
vii. Obstructions.

Manning values should be calibrated whenever gauged data is available, where data is not available computed n values as shown in Table 2-9 may be used as guides. An extensive list of values can be found from relevant literature (Chow (1959) ; Fasken (1963); Hicks & Mason (1991) & Sturm (2001)).

Table 2-9: Manning roughness determination (adapted from USACE (2016))

TYPE OF INFRASTRUCTURE	COMPOSITION	DESCRIPTION	MINIMUM	NORMAL	MAXIMUM
Natural streams	Natural main channel	Clean straight, full	0.025	0.03	0.033
		Sluggish reaches, weedy deep pools	0.05	0.07	0.08
		Very weedy reaches, deep pools	0.07	0.1	0.15
Lined or build-up channels	Concrete	Gravel finish	0.015	0.017	0.02
		Unfinished	0.014	0.017	0.02
		Gunite, good section	0.016	0.019	0.023
		On irregular excavated rock	0.022	0.027	
		Trowel finish	0.011	0.013	0.015
	Asphalt	Smooth	0.013	0.013	
		Rough	0.016	0.016	
	Brick	Glazed	0.011	0.013	0.015
		In cement mortar	0.012	0.015	0.018
	Vegetal lining		0.03		0.5
Excavated or dredged channel	Earth	Clean and uniform	0.016	0.025	0.033
		Winding and sluggish	0.023	0.03	0.05

The roughness of the canal may affect the damming level due to higher drag from the canal bed and sides, which could result in lower velocities and higher water levels (Shahrokhnia & Javan, 2006), in turn affecting the turbine output (as this is highly dependent on velocity). The direct influence of the n-value on velocity can be seen in equation 2.4.

$$V = \frac{1}{n} \times \left(\frac{A}{P}\right)^{\frac{2}{3}} \times S_O^{\frac{1}{2}} \qquad (2.4)$$

Where:

V = Flow velocity (m/s)

A = Area (m^2)

P = Perimeter (m)

S_o = Longitudinal slope of the riverbed/canal (m/m)

n = Manning roughness ($s/m^{1/3}$)

2.6.3 Flow characteristics

For application of HK turbines in open channels the properties must be analysed, such as the flow regime and the bulk flow properties that characterize a specific section. The average velocity is a crucial value for HK installation and is calculated simply as:

$$V = {}^{Q}/_{A} \qquad (2.5)$$

Where:

Q = Cross sectional flow rate(m^3/s)

A = Cross sectional area (m^2)

V = Average velocity (m/s)

To calculate the cross-sectional flow area the following section parameters must be measured:

i. Flow depth
ii. Top width
iii. Hydraulic depth
iv. Wetted perimeter
v. Hydraulic radius
vi. Manning n-value

Methods for estimating the flow resistance parameter (Manning n-value) may be found as described in section 2.6.2. Depending on flow uniformity and steadiness the bulk flow properties can be found to vary or stay constant at certain points.

The flow state and flow regime are additional parameters of importance which must be calculated to determine the non-dimensional parameters which indicate the flow state and flow regime. These being the Reynolds number (Re) and Froude number (Fr) which are calculated as follows for canal sections (Gunawan, et al., 2017):

$$Re = \frac{V(4 \times \frac{A}{P})}{\nu} \tag{2.6}$$

$$Fr = \sqrt{\frac{Q^2 \times B}{g \times A^3}} \tag{2.7}$$

Where:

P = Wetted perimeter (m)

Q = Flow rate (m^3/s)

g = Gravitational acceleration ($9.81 m/s^2$)

A = Hydraulic cross-sectional area (m^2)

B = Water surface width (m)

ν = Kinematic viscosity of liquid (m^2/s)

For Re values above 4 000 inertial forces dominate over viscous forces which result in unstable and turbulent flow. Canals with fast moving (turbulent) flow are most ideal for HK deployment (Re values well over 10^5).

The Fr value dictates sub or super critical flow types. Where the Froude value is below 1 it indicates the wave celerity (c=$\sqrt{g \times D}$) or speed of propagation of a small surface wave is greater than the bulk velocity, meaning gravitational forces dominate (over inertia). Most man-made structures are designed for subcritical flow to reduce scour (Gunawan, et al., 2017). The flow conditions have the following properties:

i. Subcritical flow conditions: Reduce scour; upstream flow dictated by what occurs downstream.
ii. Supercritical flow conditions: Downstream flow influenced by occurrences upstream.

When a HK turbine is placed in subcritical flow it causes a local obstruction and therefore influences what occurs upstream (damming, velocity drop etc.) When placed in supercritical flow, downstream effects will occur.

When considering a specific canal for installation the change in velocity over points may be determined using the energy equation as shown in Figure 2-27. Where the total energy over points 1 and 2 remain constant:

$$\frac{V_1{}^2}{2g} + Y_1 + Z_1 = \frac{V_2{}^2}{2g} + Y_2 + Z_2 + \sum h_{f_{1-2}} + \sum h_{l_{1-2}} \tag{2.8}$$

Where:

V= Velocity (m/s)

g = Gravitational acceleration (m/s^2)

Y= Water level (m)

Z = Height from datum line to the bottom on the water level (m)

h_f = Friction losses over section (m)

h_l = Local losses (m)

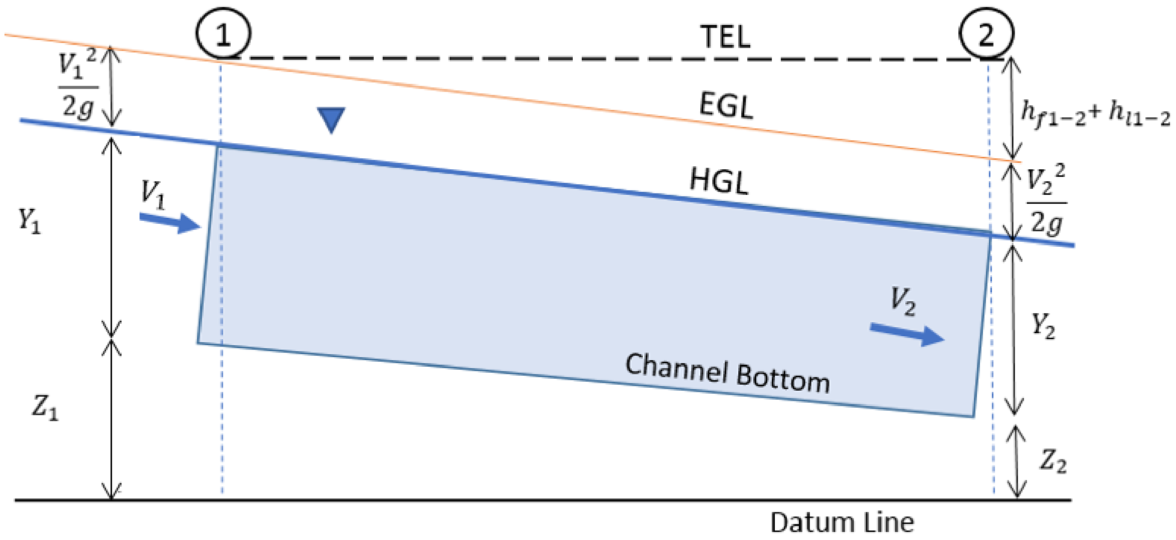


Figure 2-27: Energy grade line evaluation between cross sections

The hydraulic grade line (HGL) in open water flow refers to the water surface (which would indicate any potential for overtopping) the energy grade line (EGL) is the sum of the velocity head and HGL. The total energy line (TEL) is the sum of all components as portrayed in the energy equation (equation 2.8) which is equal between any two points along a section (for a closed section).

For the HK installation the scenario shown in Figure 2-27 will change to a scenario similar to that indicated in Figure 2-28. Between sections 1 and 4 the following will occur:

Section 1 - A certain distance upstream a scenario similar to Figure 2-27 section 1, with possible damming starting to occur;

Section 2 - Highest level of damming occurring at a certain distance upstream of the HK turbine, the velocity is slowed (smallest $\frac{V^2}{2g}$ component);

Section 3 - At the HK turbine installation section energy is abstracted, resulting in a drop in the EGL as shown (energy abstraction in the form of a local loss h_l);

Section 4 - After a certain distance the velocity and water level will stabilize as shown at this section.

The pattern may change with varying turbine sizes, where large installations could result in critical flow forming between sections 3 and 4 and in large installations a hydraulic jump forming before stabilization at section 4. For smaller installations the pattern in Figure 2-28 should hold true.

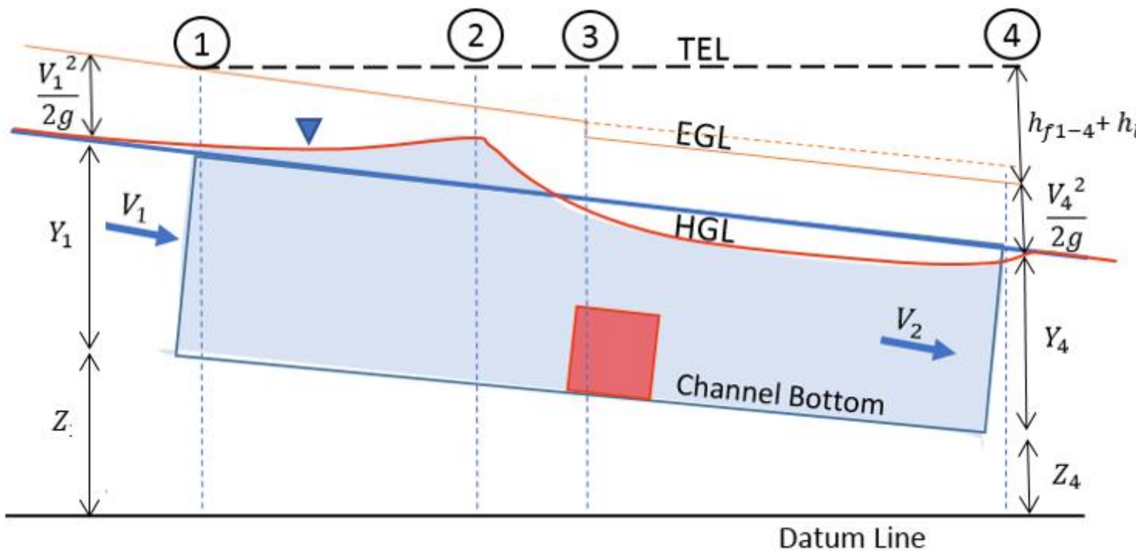


Figure 2-28: Energy grade line evaluation between cross sections with HK device

A hydrodynamic assessment must be done for both baseline (before installation) and turbine operation conditions, this is necessary to understand the water level changes/damming caused by the installation and any possible hydraulic changes which could occur (as described through Figure 2-28). Simultaneously water level measurements should be taken at various points upstream and downstream of the installation section to ensure accuracy of model assessments (Gunawan, et al., 2017). The far-field hydraulic impacts of a hydrokinetic device may be modelled in various ways to determine the design elements/effects of installation.

To determine the “after installation” scenario proves a challenge as the exact effect of the turbine is not always simple to model. Kartezhnikova & Ravens (2013) developed a technique which represents the hydrokinetic device as a high value canal-bed manning roughness coefficient. This allows modelling of the device impact in standard hydraulic calculation procedures. As shown previously in equation 2.4 (the manning equation adapted by the continuity principle Q=VA), an increase in the bottom roughness causes a reduction in velocity. In a river setting where the discharge is considered constant, this reduced velocity will then be compensated for with an increase in upstream water depth. However, this coefficient varies for different turbine types and sizes and requires calibration from field tests.

The velocity component of the installation section remains one of the most important factor of consideration for HK installation as the velocity governs the power output produced. As shown in Figure 2-29 three flow regions can be used to define the power output of a typical HK device (Polagye, 2009):

Region I - Region below cut-in speed, no power produced.

Region II - Power extracted proportional to HK power incident on the rotor swept area.

Region III - The rated speed and power extraction is constant.

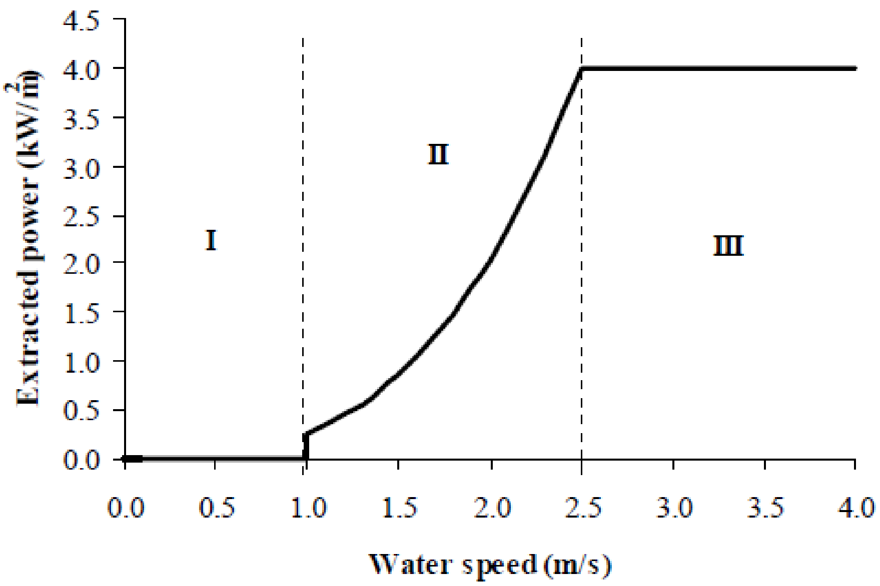


Figure 2-29: Representative turbine power curve (Polagye, 2009)

2.6.4 Environment Impact

The environmental impact is a combination of two important considerations:

i. The impact of the environment of the HK device;
ii. The impact of the HK device on the environment.

For the first consideration the environment of the HK installation is an important design factor as it will govern the maintenance and to an extent operational life of the components. The overall impacts on the environment caused by the HK turbines are minimal due to the installation having no reservoir, spillway or emissions. The site selection is therefore also less restrictive than other hydropower technologies. A river/canal of consistent velocity is preferred for installation to eliminate the need for energy storage capacity. A number of environmental factors should be considered during the design (Gaden & Bibeau, 2006):

- For riverine applications:
  i. The installation of HK turbines must accommodate diverse flow conditions including floods and seasonal variations.
  ii. There is no control of upstream flow conditions in a natural river and therefore foreign debris, silt and seasonal turbulence (flooding) due to change of riverbed must be considered during the design.
  iii. It can pose an unknown risk to fish, vegetation and other possible river inhabitants, which must also be considered. An example of weeds in riverine applications can be seen in Figure 2-30.
  iv. Possible harsh water conditions which could lead to turbine corrosion must be considered.

Figure 2-30: Weeds on turbine in the UK (Anyi, 2013)

Application in bulk water canals or transfer schemes eliminates a large amount of risks mentioned above as the upstream conditions are controlled, therefore the flow will remain stable and debris will be controlled to a certain extent in cases where a sieve/grid is used at the canal inlet.

- For canal applications:
  i. Although debris might be controlled upstream at the canal entrance the prospect of debris falling in over the length of the canal should be considered.
  ii. Possible harsh water conditions which could lead to turbine corrosion must also be considered.
  iii. Each specific case should be tested for possible marine life.
  iv. Blockage could occur which could result in overtopping and possible flood damage.

In terms of river contamination HK devices should not pose as a risk unless possible additional components should add this risk. This must be considered during design and the incorporation of these components avoided.

In areas where fish passage is a concern, solutions such as "fish-friendly" turbines should be considered (An example is shown in Figure 2-31). These turbines were tested in a study done by Jacobson et al. (2012) showing less than 5% fish mortality rates, which is comparable with other experimental units being tested currently which were designed with the objective of reducing harm to fish (Jacobson, et al., 2012).

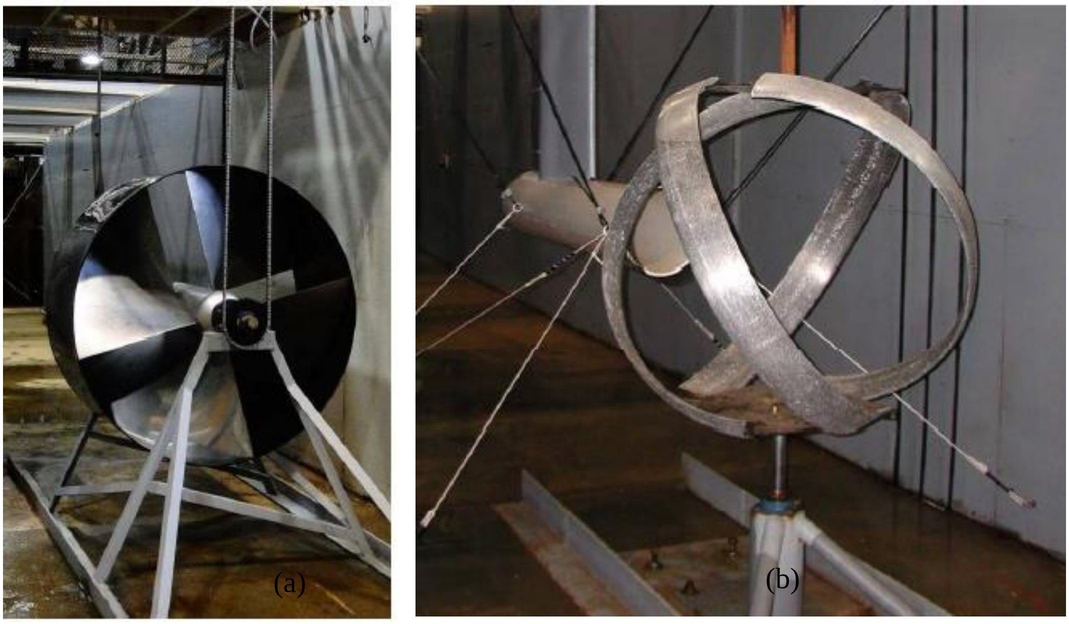


Figure 2-31: Turbine proving as "fish-friendly" (a)Welka UPG turbine (b) Lucid spherical turbine (Jacobson, et al., 2012)

2.7 HK SYSTEM OPTIMISATION

The development of HK turbines is governed by certain existing mechanisms of similar nature such as wind turbines, ship propeller designs and more. However, there is a limit to its relevance. For example, wind turbines do not have HK turbine spatial limitations, where rotor diameters could be increased in wind turbines it may not be an option in confined river or channel applications. Additionally, in river/channel applications the entire network is affected, as damming effects or diversion of flow could affect the turbine performance (Gaden & Bibeau, 2009). Due to spatial confinement or limited available velocity, optimisation measures may be necessary, which are relevant only to HK devices.

Sale et al. (2009) defines 15 optimisation variables for HK turbines related to the turbine configuration, such as chord, twist and percentage thickness distributions of the blade hub, tip etc. all relating to the blade geometry. These aspects are considered during the design stages of the turbine and are difficult to alter during implementation. Additionally, optimizing a rotor for maximum hydrodynamic efficiency does not necessarily result in a turbine with the highest annual energy production, this is rather related to maximizing the turbine efficiency (Sale, et al., 2009) thereafter “after-market” aspects such as the use of components to decrease flow area, in turn increasing velocity or forcing/guiding flow in a certain direction could be investigated.

These optimisation techniques (which can be applied during the installation phase) are explored in this section. An important aspect to consider when applying optimisation measures such as a shroud or guide plate mechanisms is the increase of total drag which in turn increases the cost of anchoring the turbine as forces are increased. This must be weighed up against the possible increase in power output to obtain the most economical solution (Gaden & Bibeau, 2006).

HK optimization installations are a relatively unexplored concept and therefore very few field tests have been done on optimisation techniques, however many physical and numerical modelling tests have been analysed and these theoretical results can, to an extent, be used as a basis for optimisation. The production of HK energy directly links to the available velocity of the water. Faster velocities produce exponentially higher power output, which directly influences economic viability. Mechanisms such as a diffuser/ guide plates were in many cases considered as a means to increase power density of the turbine (Gaden & Bibeau, 2009). The increase in velocity by these applications is particularly important because unlike wind power where economies of scale are used, HK devices are usually governed by spatial limitations (Gaden, 2007).

2.7.1 Confinement

Confinement refers to placing the turbine in a confined structure such as circular confinement (duct) as shown in Figure 2-32. A simulation of a ducted model was investigated and reported to increase the power output by up to 38% (Kumar & Sachendra, 2017). Another study proved the maximum power increasing from 166W to 249W for ducted models.

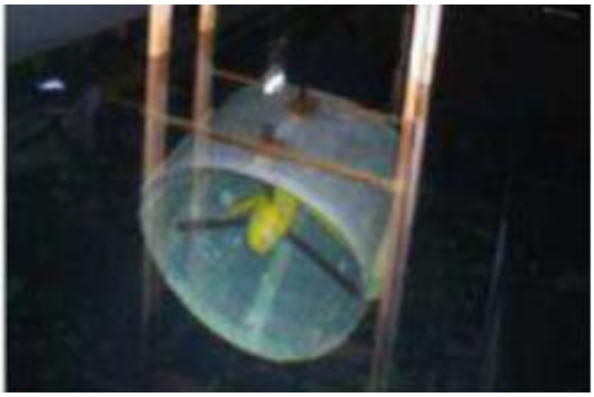


Figure 2-32: Ducted HK turbine (Kumar & Sachendra, 2017)

A contradictory model study using BEM-RAS model (Bellloni & Willden, 2016) indicated a duct exhibiting inferior hydrodynamic force on axial flow, decreasing the power output from 0.97 to 0.61. Another recent study (Fleming & Willden, 2016) showed a duct increasing the power coefficient by 0.85%. This proves the deviation of results in varying environments and model types. Ducts can also shield the rotor from debris or extreme flow conditions which may be present. This should be noted as an added advantage of confinement. (Kumar & Sachendra, 2017).

This theory is mostly used in tidal applications, despite several companies developing concepts of duct designs there remains a lack of literature defining hydrodynamic analysis of optimisation through using ducts. These hydrodynamic qualities are complex, a basic conceptual design of a duct can be seen in Figure 2-33 (Shives, 2008).

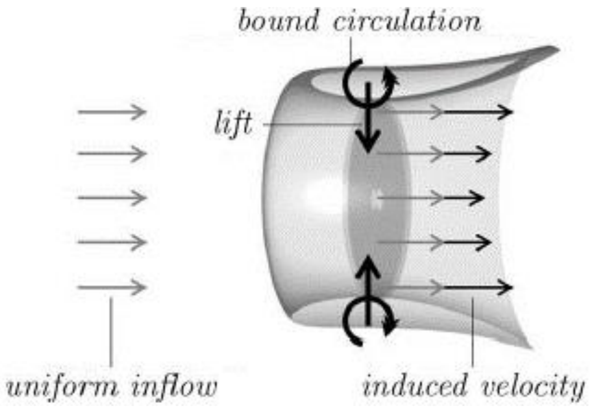


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Figure 2-33: Conceptual design of duct (Shives, 2008)

2.7.2 Shroud mechanism

A potential improvement of the efficiency of HK technologies is achieved by the use of a shroud mechanism. If carefully designed it may increase the flow velocity passing through the turbine. The concept is similar to that of a ducted fan. As indicated previously the power available is proportional to the cube of the velocity, due to this even a small increase in velocity relates to a large increase in power output. The application of a shroud may also reduce maintenance and operational costs as it can be designed to act as a floatable structure, simplifying anchoring and retrieval of the turbine.

There is little literature on optimisation of shrouded HK turbines, however multiple studies have been done on shrouded wind turbines and the theory of this is therefore well understood, however contradictions have been found between theoretical analysis and experimental results. Phillips et al. (1996) did a simplified one-dimensional analysis showing power output increasing fourfold, but experimental data did not show such optimistic results. Additionally Bet et al. (2003) and Grassman et al. (2003) proved aerodynamic features improve power output by a factor of 2 and 5 using numerical studies, however experimental results showed a boost of only 1.25 (Grassman et al. (2003); Bet & Grassman (2003); Philips et al (1999))

Gaden (2007) found the effect can be demonstrated by the use of thrust ratios. By enclosing the turbine in a shroud, the total thrust is shared between the turbine and shroud resulting in a greater power output as shown in Figure 2-34 (Gaden, (2007); Lewis et al., (1977)).

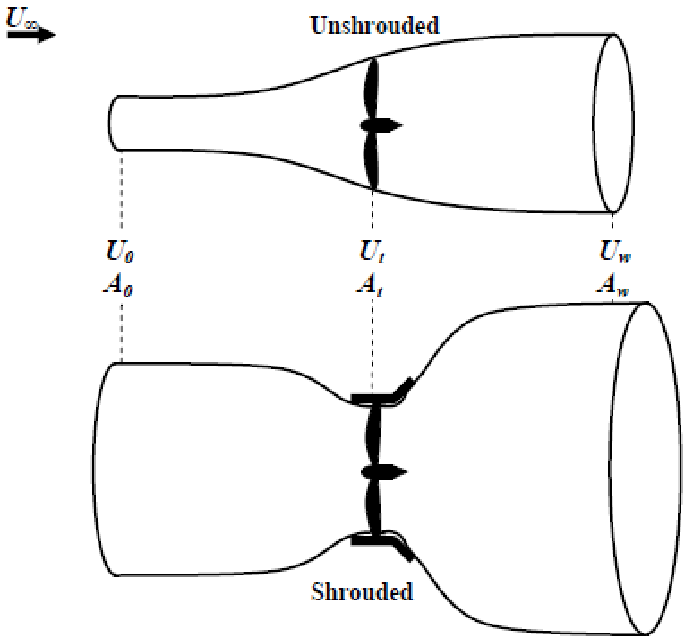


Figure 2-34: Shroud effect on streamlines (Gaden, 2007)

2.7.3 Diffuser mechanism

A diffuser is similar to a shroud in the subject of containment however differs in the placement being at the downstream end of the turbine, enclosing and diverging outwards at a specified angle. The effect of a diffuser on the axial velocity as found by Gaden (2007) can be seen in Figure 2-35. The maximum axial velocity in this scenario was 2.8m/s with no diffuser comparing to 4.1m/s with a diffuser allowing use of a smaller turbine with similar output to a larger unit with no diffuser.

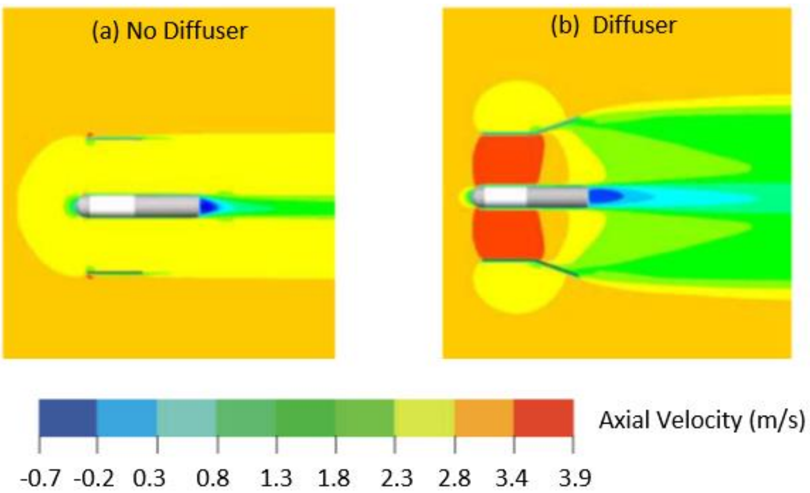


Figure 2-35: Velocity around a turbine with and without a diffuser (Gaden, 2007)

A study done by Gaden et al. (2009) proved that a diffuser configuration under certain circumstances produces 3.1 times more power than a turbine without the diffuser. In the study a scaling analysis was completed which proved a turbine with an attached diffuser out performs a larger size turbine without a diffuser. The optimum configuration found in this study proved to be a 20° diffuser with an area ratio of 1.56 or a 3-metre diameter diffuser, which resulted in a 3.1 ratio increase. The overall efficiency was 86.5% where the power produced was 51.3kW of which the freestream power available was 59.3kW. This was well above the Betz limit; however, the difference lies in the fact that the Betz Limit is based on area swept by the turbine rotor alone, not the diffuser area. Another study showed a diffuser with area ratio 1.54 provided a 48% power increase (flange length of 0.1 rotor diameters) (Riglin, et al., 2014).

Damage to the diffuser must be considered as this could add to maintenance costs. A shallower angle diffuser is also less prone to damage due to it being less likely exposed to strong impacts. (Gaden & Bibeau, 2009). However, the use of a diffuser mounted at the turbine trailing edge increases the size of the turbine, this must be assessed when considering the benefit of diffuser use.

The phenomenon of optimisation using a diffuser can be explained by the alteration of the "wake back flow" of the turbine. The turbulent kinetic energy along the centre plane of a diffuser setup modelled in a computational domain (as depicted in Figure 2-36) proves the power produced is greater with a lower TSR. The c) scenario indicates the least energy scenario, which relates to the peak operating condition where the most energy is being converted to mechanical power, resulting in less energy existing in the wake.

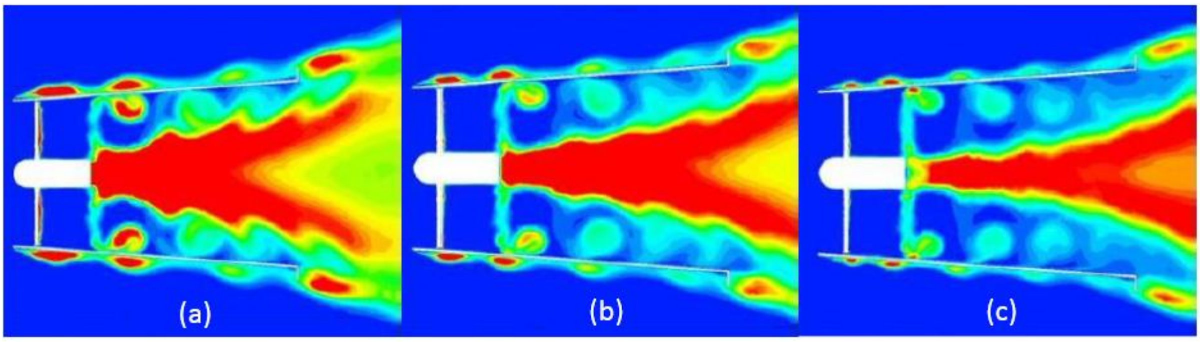


Figure 2-36: Turbulent kinetic energy contours along the central plane with 2m/s free stream velocity and a) 1.5 b) 2 and c) 2.5 tip speed ratios (Riglin, et al., 2014)

A contradiction to this was found in Gaden (2007) as shown in Figure 2-37, where scenarios (a) shroud (b) shroud and diffuser (c) no alterations (d) diffuser as shroud; are shown to increase output in the followed order. This difference could occur due to the turbine model/design; however, it must be noted these are fields test results where previously mentioned results are mostly found from computational modelling.

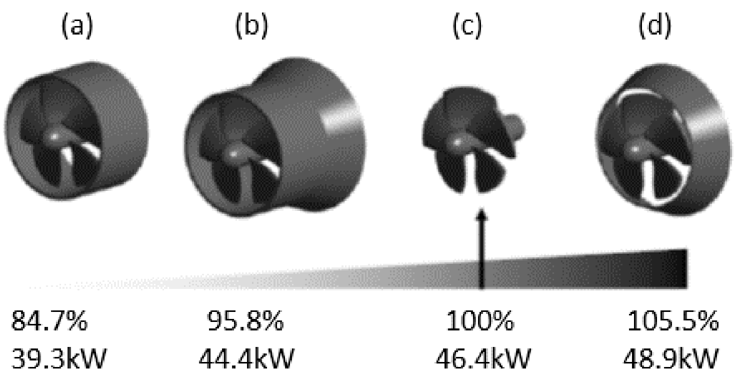


Figure 2-37: Effect of diffuser and shroud mechanism (Gaden, 2007)

Khan et al. (2006) stated in a technology review written on HK turbine systems in river applications that detailed investigation of the optimal size and shape of augmented canals/diffuser mechanisms has not been done and is still an unsolved problem (Khan, et al., 2006).

2.7.4 Channel modification

Modified channels are used to induce a sub-atmospheric pressure within a constrained area to increase flow velocity. Placing a turbine in a similar channel would increase the velocity around the rotor thus increasing the power generation. Typical augmented/modified shapes for both vertical and horizontal axis turbine applications to are shown in Figure 2-38.

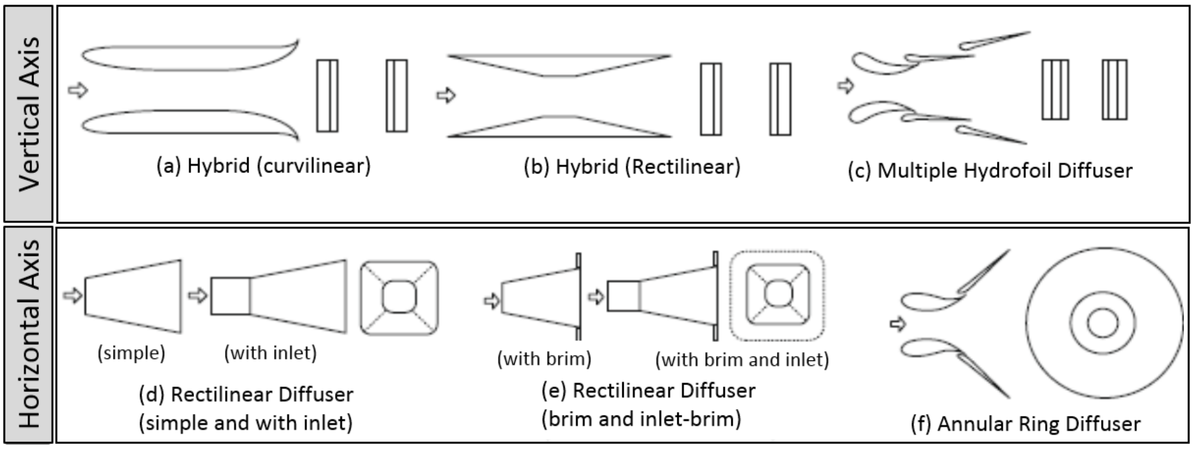


Figure 2-38: Channel shapes (Khan, et al., 2009)

This augmented application follows the venturi principle used to increase velocity over a short section by reducing the channel width and thereby choking the flow. Figure 2-39 demonstrates when the flow in a venturi is altered from sub to supercritical flow. In order for the flume to control the discharge (rather than the channel) critical flow must occur in the flume, for this to occur the specific energy (E_s) in the throat must be a minimum ($E_{min(throat)}$) (Chadwick, et al., 2004).

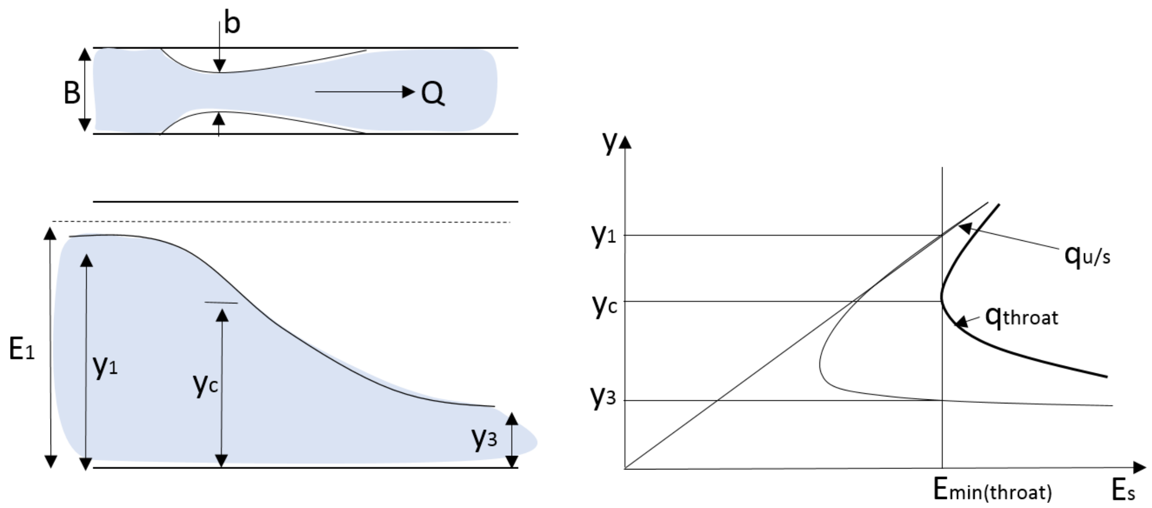


Figure 2-39: Venturi flume

For calculation purposes the broad crested weir equation may be used (if critical flow occurs):

$$Q = C_d C_v \frac{2}{3}\sqrt{\frac{2g}{3}}bh^{\frac{3}{2}} \tag{2.9}$$

Where:

C_d and C_v = coefficient of discharge and velocity

b = width in throat section (m)

Q = discharge (m^3/s)

h = water height (m)

g = Gravitational acceleration (m/s^2)

Following the principle of energy and continuity as shown in Figure 2-39 the flow area decreases in the venturi flume and therefore there is an increase in velocity as the flow rate remains constant.

A principle problem with this design is the possible formation of a hydraulic jump downstream of the section. A solution to this is the design of a narrow throat with a small expansion angle in the exit transition, however this can become expensive due to size (Chadwick, et al., 2004). The standard convergence angle of a venturi tube is 21 degrees, for a smooth transition (Reader-Harris, et al., 2001). Generally, the approach angle is steeper than the downstream section, this shallower downstream angle reduces the turbulence by decelerating the flow smoothly. This smooth transition (approach) is more efficient than the option of a step (similar to an orifice plate) due to the streamlined form allowing it to manage more flow (Crabtree, 1997).

Over a closed system the flow remains constant therefore as the area decreases the velocity must increase and thus for canal alterations two options exist:

i. Narrowing the canal:
   This theory is applicable to Venturi effects.
ii. Lifting the canal bed:
   This theory applies to subcritical flow conditions as shown in Figure 2-40. Point "A" on the curve represents the conditions at point 1 and zone 2 will lie on either B or B' on the curve. This is dependent on the Froude number, whether the new flow regime will be sub- or super-critical flow. To arrive at point B' implies the step height (Δz) must be less than the change in Energy (E_{s1}-E_{s2}) which is not physically possible. Therefore, the flow depth should correspond to point B. This theory follows the Bernoulli equation:

$$E_{s1} = E_{s2} + \Delta z \qquad (2.10)$$

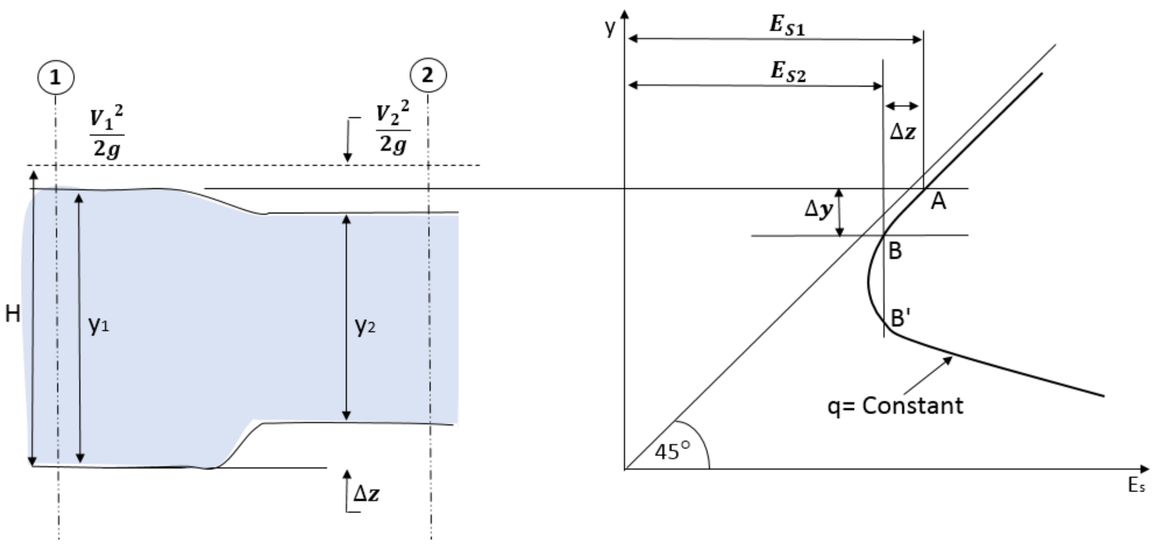


Figure 2-40: Flow transition over bed raise

For this type of flow optimisation, the flow transition must be considered. Studies on the flow patterns through a venturi can be further investigated to optimize the use of this measure (Gibson & Reader-Harris, 2006).

2.7.5 Multiple turbine application

The influence of adding multiple turbines in a single cross section has been shown to affect energy output in certain studies, relating to the Betz limit. HK tidal applications have been considered and applied at a larger scale than riverine applications, however the applications are similar and results from these tests can be applied to riverine applications to a certain scale.

Previous numerical analysis in tidal HK systems modelled as channelised flow between two basins, one finite and the other semi- infinite, proved as the number of turbine increased, the channel flow rate decreased (as the drag on the system is increased with each added turbine) however, results indicated that as the number of devices increased there was a peak in energy production and thereafter a decline (Kartezhnikova & Ravens, 2013). This finding opens a window to the possibility of considering multiple turbines over a single section (up to a limit) relating to the Betz limit thus increasing the turbine output.

To further understand the behaviour and allow investigation of multiple turbine application, the effect of a single turbine placed in a streamflow of a certain cross section must be understood. Researches have investigated the relationship between the power extracted from the flow and the total power which is dissipated by the presence of these HK devices. Garrett and Cummins (2007) and Polagye (2009) noticed the HK device inflow generated a low velocity zone in the wake, when this low velocity zone mixed with the high velocity zone flowing around the device, significant energy dissipation occurred. Polagye (2009) concluded that as the turbine operated at an efficiency close to the maximum theoretical limit the dissipated and extracted power can be approximated as shown in equation 2.11. (Garret, et al., 2007) (Polagye, 2009).

$$\frac{P_{extracted}}{P_{dissipated}} = \frac{2}{3(\,1+\varepsilon)} \tag{2.11}$$

Where:

ε = The blockage coefficient (fraction of river area occupied by HK devices)

$P_{extracted}$ = Extracted Power (W)

$P_{dissipated}$ = Power dissipated (includes extracted power and additional dissipation due to mixing) (W)

2.8 HK CASE STUDIES

A number of HK turbines have been installed throughout the world and a summary of a few case studies of these applications are included in Table 2-10. Many of the application were short term testing procedures which makes an evaluation of long term working of these units difficult to predict, it does however provide example of successful installations in obtaining the design output and practical application.

Table 2-10: HK case studies

DESCRIPTION AND REFERENCE	RANGE: ROTOR DIAMETER, VELOCITY, OUTPUT	PURPOSE	PICTURE
Verdant Power Hydrokinetic Model (Sale, et al., 2009).	V=1-2.2m/s. P= 6x 35kW tidal turbines. 5m diameter.	Tidal application, testing purposes.	
Horizontal Axis turbine in the Nile River (Anyi, 2013).	unknown	Pumping irrigation water to Egypt, Sudan and Somalia.	
Horizontal Axis HK ducted Turbine Brazil (Anyi, 2013).	0.8m diameter V = 2m/s P =1kW .	Demonstration purposes by the University of Brasilia.	

DESCRIPTION AND REFERENCE	RANGE: ROTOR DIAMETER, VELOCITY, OUTPUT	PURPOSE	PICTURE
Hydrovolts turbine in the Roza Canal, Oregon, USA. (Johnson, et al., 2007).	V =2m/s P =5kW	A 6-week test installation.	
EnCurrent Floating Barge Kinetic turbine, Manitoba, Canada. (Johnson, et al., 2007)	1.5m Diameter V = >2m/s P = 5kW	The turbine was in place for less than a year, removed prior to river icing.	
Smart Irrigation Project in Neiva, Colombia (SHP, 2017).	Duofloat 1m rotor diameter. V= 1.7m/s average annual generation of 1.1kW. Operation = 5 years to present.	Powering off-grid irrigation pumps.	

DESCRIPTION AND REFERENCE	RANGE: ROTOR DIAMETER, VELOCITY, OUTPUT	PURPOSE	PICTURE
Smart monofloat grid-connected project Roseheim, Germany (SHP, 2016).	Monofloat 1m rotor diameter. Flow varies from 0.7-3.5m/s producing 2kW at 2.1m/s.	Power produced feeds into national grid compensated by the German feed-in-tariff policy. Operating since July 2013.	

2.9 ECONOMIC ANALYSIS

Electrification of rural areas consisting of a largely poor population is being carried out in numerous developing or under-developed countries, with monetary help in the form of subsidies and investments coming from more developed countries. Due to the majority of people in these areas not being able to afford electricity supply it is necessary to bring the most cost-effective form of energy to these areas to alleviate poverty (Vermaak, et al., 2014).

HK energy extraction is a simplified process therefore the cost of energy extraction is low. Due to its modular nature the initial installation cost and deployment time is short as it does not require significant infrastructure construction. It also allows an easily scalable energy output but limits any decrease in capital cost per kW output (Gaden & Bibeau, 2006). The cost is lower than traditional hydropower forms and more economical when compared to solar power (Kusakana & Vermaak, 2013)

The commercial application of HK turbines has not reached a mature phase and therefore it is difficult to predict accurate estimates of costs as this is varied greatly over applications due to availability of components and potential importing costs. Laws et al. (2016) found the average cost of a tidal HK system to be $1150/kW where Ramierez et al. (2016) found small riverine applications to be range between $3000-$7000/kW. (Ramirez, et al., 2016). Lazard (2016) put together a levelized cost of energy chart with the unsubsidized costs of conventional and alternative energy sources as shown in Figure

2-41, which could be an average baseline to cost estimations. This allows comparison to other sources of renewable energy proving the lower levelized cost associated with microturbines.

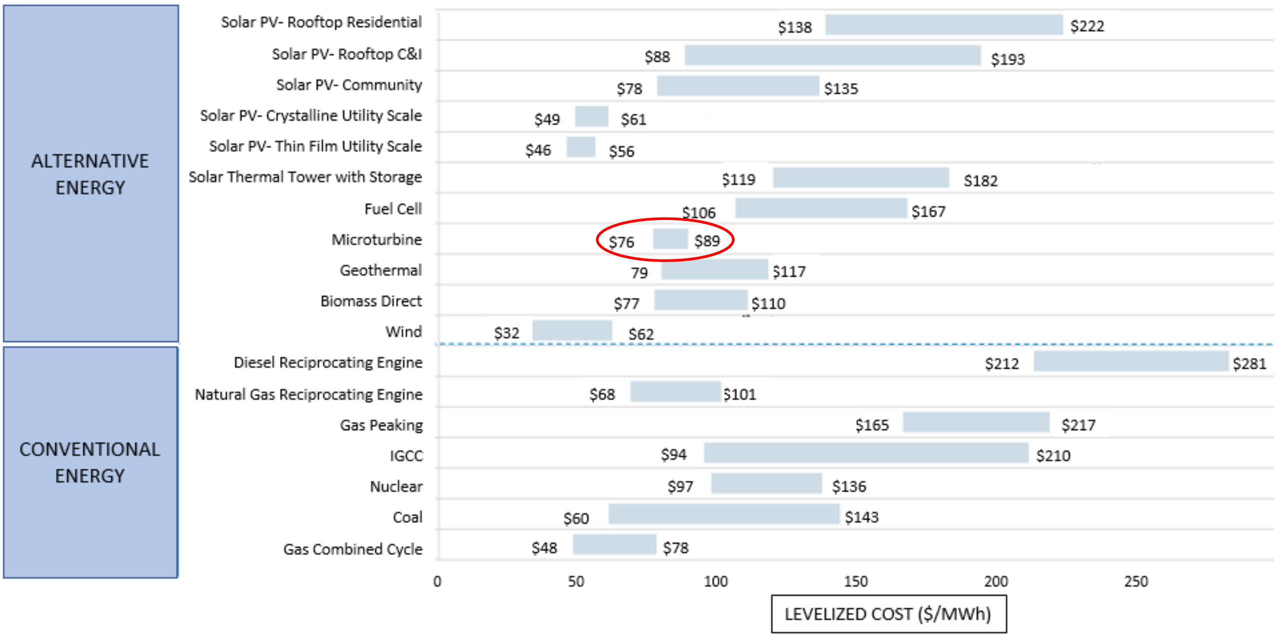


Figure 2-41: Unsubsidized levelized cost of energy comparison (Lazard, 2016)

2.10 SMALL SCALE HYROPOWER REGULATORY AND LEGISLATIVE ASPECTS

A simplified overview of the legislative and regulatory process which should be followed for the installation of HK turbines in canals in South Africa, as well as energy generation legislation for small-scale installations is briefly described in this section. South African legislation is prone to frequent restructuring due to continual changes in leadership and therefore thorough investigation into the current legislation should be done in any given year of installation. The goal of the structure of this section is to underline the important entities within the South African Water and Energy sectors which influence HK installation.

This section focuses on the regulatory requirements applicable to municipal generators of electricity from predominantly pico-, micro- or mini hydropower installations located within, or retrofitted to, waterworks owned by the Department of Water and Sanitation (DWS), a Water User Authorities (WUA) or a Water Board (WBs) with a generating capacity between 10kW and 1MW, for islanded use, own use or for interconnection with a municipal electricity distribution network.

Where:

Municipal / municipality:

A municipality is an organ of state within the local sphere of government exercising legislative and executive authority within an area determined in terms of the 25 Local Government: Municipal Demarcation Act, 1998 (South Africa, 2000).

Generator:

Means a person who generates electricity and where generation means the production of electricity by any means (DoE, 2011).

Distributor:

Means a person who distributes electricity and where distribution means the conveyance of electricity through a distribution power system excluding trading (DoE, 2011).

Waterworks:

Means a dam, canal or weir.

Islanded use:

Electricity generated for “islanded use” is completely independent of municipal or Eskom distribution networks (DME, 2006).

*Eskom- South African public utility electricity supply commission.

Own use:

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

Electricity distribution network:

(or distribution power system) “*means a network for the conveyance of electricity which operates at or below a nominal voltage of 132kV*” (DoE, 2011).

Numerous regulatory and legislative requirements govern the implementation of small-scale hydropower schemes in South Africa. Pertinent legislation that needs to be adhered to includes the Constitution of the Republic of South Africa, the Electricity Regulation Act (ERA), the National Water

Act (NWA) and the National Environmental Management Act (NEMA). These Acts set out the roles and responsibilities, of National- and Local Government in the electricity sector, as well as distinguishing between the powers and functions of District- and Local Municipalities and services authorities and services providers.

The following sections will summarize the major aspects of considerations being:

i. Electricity generation licencing
ii. Water use authorisation
iii. Environmental authorization
iv. Land use

2.10.1 Electricity generation licencing

Electricity generation licencing is largely based on installation size as shown in Table 2-11. The focus of the study is on Pico and Micro installations, which simplifies the process significantly.

Table 2-11: Hydropower installation size

SMALL-SCALE TYPE	SIZE
Pico	Up to 20kW
Micro	20kW to 100kW
Mini	100kW to 1MW

The following form the South African electricity sector (van Vuuren, et al., 2014):

i. The National Energy Regulator of South Africa (NERSA): NERSA is a regulatory authority established under the National Energy Regulator Act (Act 40 of 2004). NERSA regulates the Electricity, Piped-Gas and Petroleum industries as per the relevant acts. The Electricity Regulation Act as amended, describes, the responsibilities and powers of NERSA, specifically in regards to the processing and issuing of electricity generation-, transmission- and distribution licences.

ii. Department of Energy (DoE): The mandate of the DoE is to ensure secure and sustainable provision of energy for socio-economic development, by formulating energy policies, regulatory frameworks and legislation and overseeing their implementation to ensure energy security, promotion of environmentally-friendly energy carriers and access to affordable and reliable energy for all South Africans. This implies that the DoE is responsible for the development of laws and regulations which govern, direct and guide the sector towards common objectives:

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

iii. Eskom Holdings Limited: ESKOM is a public company and a state-owned enterprise in terms of the Public Finance Management Act, that owns and operates the National Electricity Grid. Eskom generates, transmits and distributes electricity to all sectors of South Africa's economy.

iv. Independent Power Producers (IPPs): IPP means any person in which the Government or any organ of state does not hold a controlling ownership interest (whether direct or indirect), which undertakes, or intends to undertake the development of New Generation Capacity pursuant to a determination made by the Minister to section 34(1) of the ERA (DoE, 2011).

v. Electricity Services Authority and Electricity Services Provider Distribution Supply Authority and Electricity Distribution Utility or Electricity Distributor): The Municipal Systems Act establishes municipalities as services authorities and introduces an option for the municipality to either provide municipal services themselves, or to appoint appropriate service providers to undertake those municipal services on their behalf, through a service delivery agreement between the municipality and the service provider. This Act therefore, introduces the concepts of services authority and services provider. (South Africa, 2000)

For small-scale hydropower installations, the purpose of electricity generation and the end use of the power governs the process which must be followed. Generated electricity can be used for islanded use (completely independent network), own use (electricity that is used by the operator or owner of the facility and is not sold) or connected to the municipal network (DoE, 2012). For the purpose of the study only electricity used for "own-use" by the municipality is considered. The legislation currently exempts "own use" electricity generators from requiring a NERSA generation licence if the generation capacity is less than 1MW (Electricity Regulation second amendment Bill). Therefore, for HK applications typically no generation licences are required.

In cases of interconnection with the Municipal distribution network, which is defined as an "Embedded Generator" (EG) also defined as "*a legal entity that operates a generating plant that is or will be connected to the Distribution Network"* (Eskom, 2011) the following is true:

i. For size 10kW-100kW: EG systems installed on the host side do not require an electricity generation licence. The EG must be logged and reported to NERSA.
ii. For side 100kW- 1MW or more: EG must apply for an electricity generation licence with NERSA.

Additional opportunities are available to certain parties. Water Service Authority's(WSAs), Water Boards (WBs) and Water User Associations (WUAs) have the opportunity to wheel electricity through the Eskom grid to a municipal network to be purchased by the municipalities (provided generators have the appropriate licences to generate and trade from NERSA). The private sector generation also has multiple benefits through the Independent Power Producer (IPP) Procurement Program listed in the Integrated Resource Plan (IRP) (van Vuuren, et al., 2014).

Considering the municipality itself as an electricity supplier the South African Constitution, Act No. 108 of 1996 states the distribution of electricity to consumers in a specified municipal area of jurisdiction is a municipal function (South Africa, 1996). Except where electricity generation is incidental to the local government function municipalities have no 'original competence' to do so. A municipality can however receive competence to generate electricity through a parliamentary executive delegation or legislative assignment (Scharfetter & van Dijk, 2017)

2.10.2 Water use authorization

Important considerations must be given to the following water sector entities prior to small HK installation. Permission from the relevant entities must be obtained prior to the use of water infrastructure. These include (van Vuuren, et al., 2014):

i. Department of Water and Sanitation (DWS): The DWS is the custodian of all surface and ground water resources. It is primarily responsible for the formulation and implementation of policies governing the water sector. It also has oversight responsibility for water services provided by local government. The DWS owns waterworks infrastructure throughout the country which could be retrofitted appropriately with hydropower technology.

ii. Water Services Authorities (WSAs): In South Africa, electricity distributors may be Eskom, or the municipal electricity service provider (SABS, 2010), either in their capacity as DoE's Implementing Agents on the Integrated National Electrification Programme. Confusion exists in the electricity sector as to which municipalities have electricity services authority status; this due to the fact that a process to allocate authority status to either local Municipalities (LMs) or district Municipalities (DMs) was not initiated due to the anticipation that the electricity supply industry would be restructured. WSAs have the constitutional responsibility for ensuring access, planning and regulating provision of water services within their area of jurisdiction. They may provide water services themselves and/or contract external Water Services Providers (WSPs) to undertake the provision function on their behalf.

iii. State owned regional water service providers(WSP's): WSPs are the organisations that assume operational responsibility for providing water and/or sanitation services (DWAF, 2003).

iv. The Water Board(WBs): WBs are state-owned WSPs providing both bulk services to more than one WSA and retail services on behalf of a WSA. Water Boards typically operate extensive water infrastructure, primarily bulk potable water supply or wastewater systems.

v. Water User Associations (WUA) (former Irrigation Boards): A WUA is a statutory body established by the Minister of DWS. It is a grouping of water users who wish to work together because of a common interest. The water users 'co-operate' in undertaking water-related activities at the local level for their mutual benefit. The main function of a WUA is to ensure fair and reliable water supply to its members, who are mostly irrigation or livestock farmers.

Other entities of importance may include:

vi. Regional and local WSP's
vii. Municipal Water Services Entities (WSE)
viii. Public Water Utilities (WU)
ix. Private Water Services Companies

HK installations do not require any water storage, do not consume any water and additionally the water is not diverted through an intake, therefore the risk associated with development is minimal. Additionally, following the Water Act (Act 54 of 1956) distinction is made between private water and public water and the legal requirements of authorizations change. As canal systems fall under section 21(a) of the National Water Act (NWA) the infrastructure falls into an existing Water Use Licence which will have been attained by the infrastructure "owner" or WUA and thus should not require an additional licence and is limited to approval from the relevant owner/ WUA.

Even though three different types of water use authorisation categories exist, only two are of relevance for the development of small-scale hydropower projects. (The first category requires no licencing and no registration for water uses as defined in Schedule 1 of the NWA. Schedule 1 water uses are mainly domestic in nature, with minimal risk and impact on the water resource) as shown in Figure 2-42.

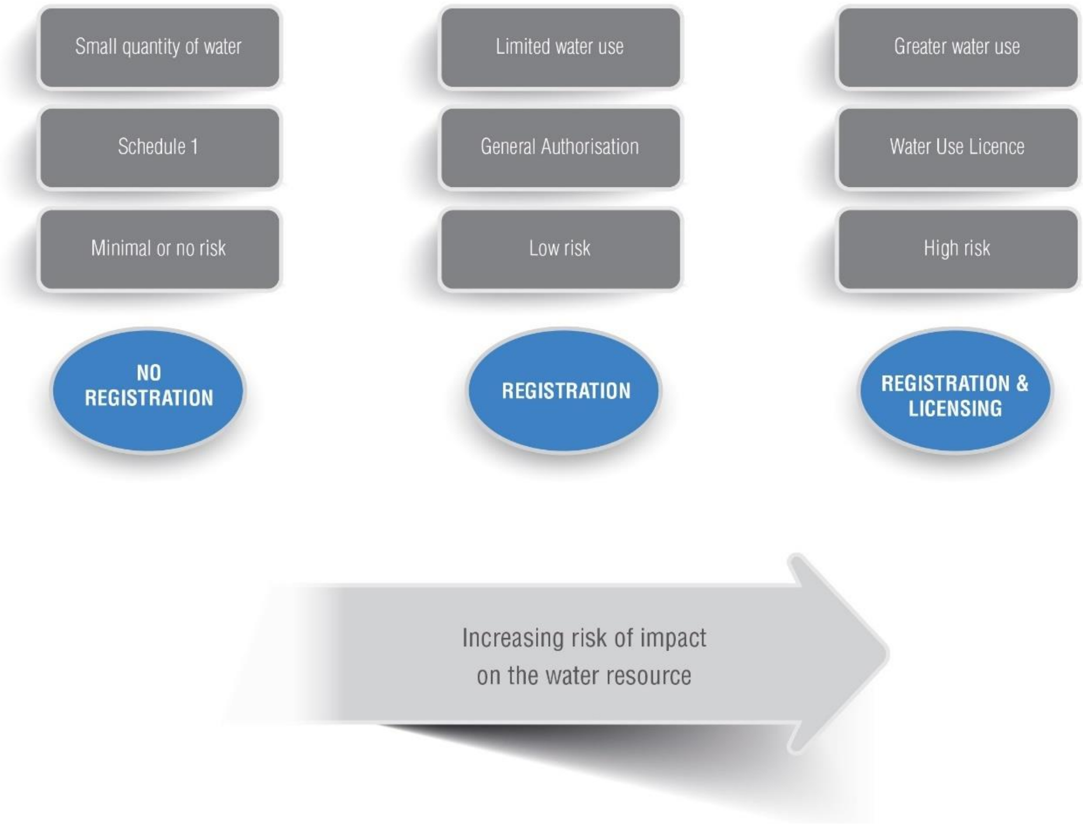


Figure 2-42: Three types of water use authorisations

2.10.3 Land use

For all applications (e.g. Electricity generation licence, water use authorization) it must be shown the permission of the land-owner has been attained. It is important to know who owns the property and which land use rights the owner is subject to.

The important entities being:

i. <u>The owner of the land:</u> The holder of the title deed of the land. Where possible construction of civil works may be required, authorization must be obtained.

2.10.4 Environmental authorization

An Environmental Authorization may be required by the NEMA, however based on the electricity and distribution activity listings of GN983 and GN984 it is likely that neither an Environmental Impact Assessment (EIA) or Basic Assessment (BA) may be required. A general authorization will be required for the construction of the electricity generation and distribution components of a small-scale hydropower plant. Depending on the scope of work a BA may possibly be required (Scharfetter & van Dijk, 2017). If after initial screening an EIA or BA is necessary the typical process followed is as shown in Figure 2-43.

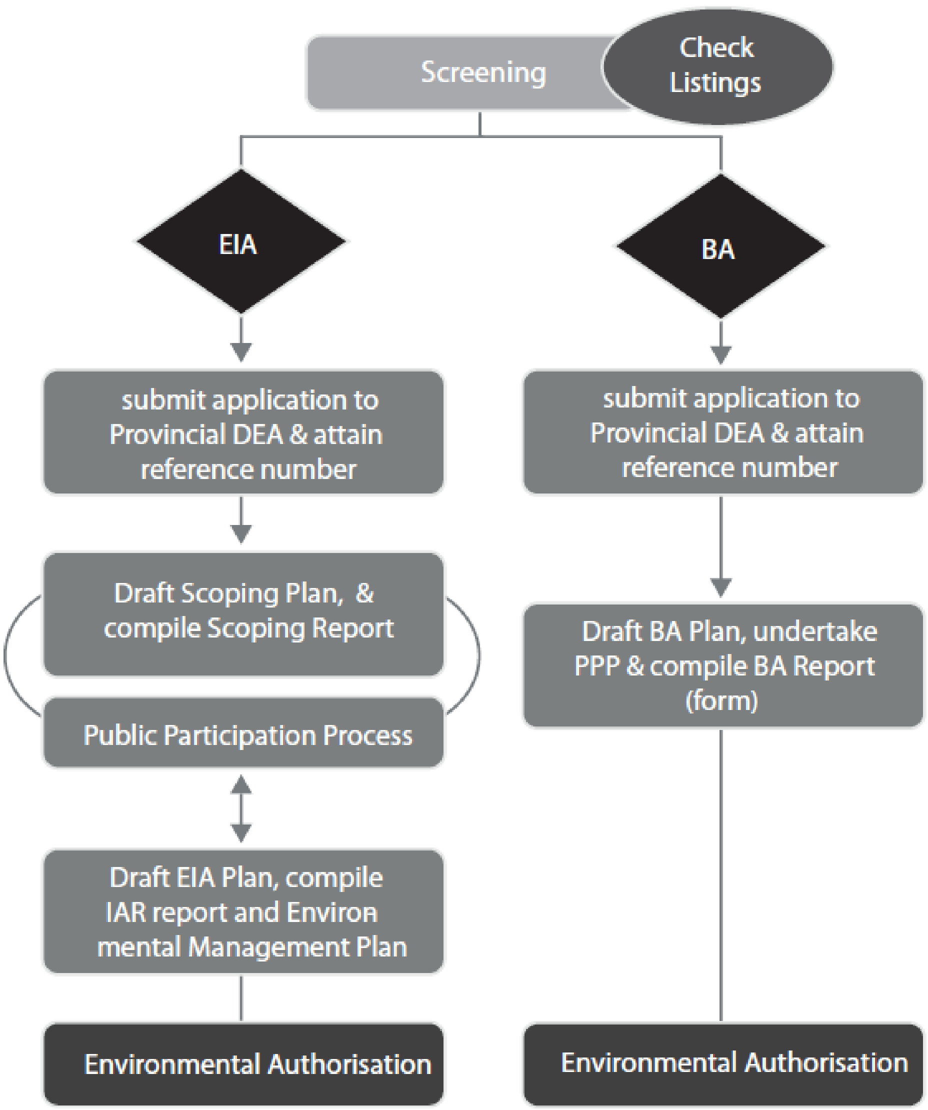


Figure 2-43: Typical processes associated with an EIA or BA (Scharfetter & van Dijk, 2017)

The important environmental entities include:

i. Department of Environmental Affairs (DEA): DEA is mandated with formulating, coordinating and monitoring the implementation of national environmental policy programmes and legislation. It is also responsible for the protection and conservation of natural resources and for balanced sustainable development through equitable distribution of benefits derived from natural resources.

2.11 LITERATURE SUMMARY

As shown in the literature study a large opportunity exists for new technologies such as HK installations in South Africa. Because HK systems are a relatively new technology, testing is required to allow better understanding of the application and prediction of the behaviour of the technology. From previous physical and numerical applications and testing, certain theories and important design aspects were found. The most important of these are shown in Figure 2-44, these were discussed in previous sections and are summarized below.

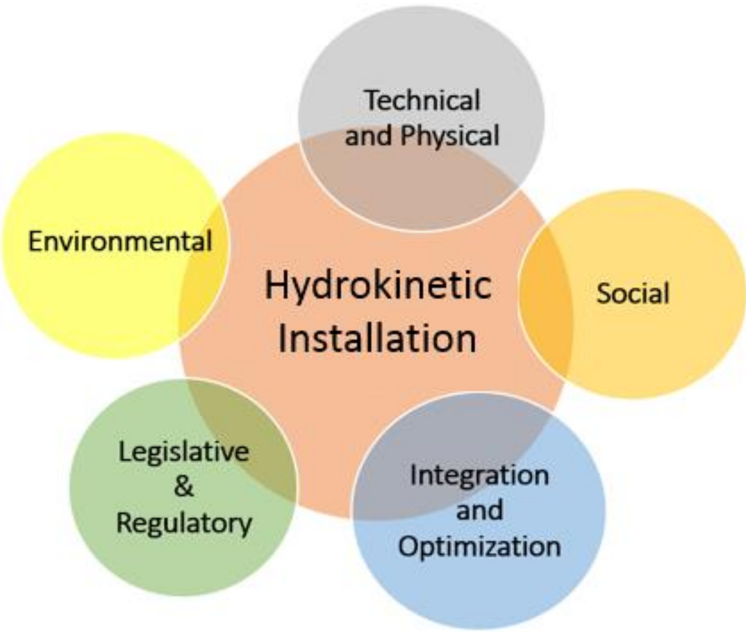


Figure 2-44: HK installation considerations and requirements

An important aspect of any renewable energy source is the social and environmental (S&E) considerations. As the main purpose of the energy production is to meet the social requirements of electricity supply, the electricity needs, uses and availability in the relevant area must be considered. Renewable energy is a driving factor for sustainable development, thus the S&E aspects and influences of these aspects in reducing carbon emissions, alleviating poverty and overall sustainable growth is in a way the most important development aspect, meaning each project should be centred around having the least negative environmental influence and the most positive influence on social growth and meeting electricity requirements.

As depicted, HK energy production has very little negative influences on the environment and where possible influences exist, measures of mitigation such as “fish-friendly” turbines and non-polluting components are available.

After the initial S&E requirements for HK installations are met, certain physical and technical requirements must be adhered to, allowing production of a system that is feasible and able to produce the design output. The physical properties of the relevant infrastructure must be considered and analysed, a summary of these being:

i. Flow characteristics from a hydrological analysis of the system:
   - Flow velocity;
   - Seasonal variation.
ii. Canal geometry.
iii. Roughness influence on flow.
iv. Environment:
   - Water quality;
   - Debris.

Additional to physical requirements, technical aspect variations and possibilities must be considered, such as:

i. The turbine itself, as a variation of blade types and orientations which are dependent on:
   - Available velocity;
   - Debris exposure;
   - Available area and geometry of the canal.
ii. The possible influence of the HK turbines on the relevant water infrastructure purpose.
iii. The scale of the project and its possible influence on the infrastructure workings.
iv. The transmission length needed (as this can be high cost if long distances).
v. The electromechanical parts applicability to installation:
   - Generator type and size variations;
   - Power output requirements (e.g. AC or DC output);
   - Grid-tie or stand-alone system.

vi. The support structure requirements:
  - Space availability;
  - In situ soil strength.

After the initial site selection is completed possible integration with an existing grid (grid-tie) or integration with other forms of renewable energy may be considered. Where required, further optimisation techniques may be considered such as:

i. Turbine blade confinement;
ii. Shroud Mechanisms;
iii. Diffuser Mechanisms;
iv. Modification of the canal infrastructure;
v. Multiple turbine application.

Finally, for SHS development in South Africa certain legislative and regulatory requirements must be adhered to and the following major aspects must be considered (if applicable):

i. Electricity Generation licencing;
ii. Water Use Authorizations;
iii. Environmental Authorization;
iv. Land use.

A multitude of additional factors and considerations can be found to be applicable to certain installations, as with any new technology a great deal is still to be learnt on the application of this technology, especially in the South African context and the use of existing infrastructure. This allows an opportunity for a study such as this, to prove the potential of this technology in South Africa; provide an example or pilot of the success or failure of this application. Additionally, the social “acceptance” of the technology has a large influence on the viability of a project.

This study looked at all the aspects as included in Figure 2-44, to design and develop a working HK installation operating at as high as possible efficiency.

3 EXPERIMENTAL DESIGN

The chapter describes the process followed in development of the experimental design of the HK testing installation, which will later become a permanent installation supplying power to the local Municipality (LM). This chapter will focus on the following aspects:

i. Site selection.
ii. Design of system.
iii. Placement of turbine.
iv. Turbine constraint and foundation.
v. Electromechanical equipment integration.
vi. Optimisation designs.
vii. Testing setup and procedure.

3.1 !KHEIS MUNICIPALITY AND THE BOEGOEBERG CANAL

The !Kheis Local Municipality (LM) in the Northern Cape has been allocated relevant funding for small-scale hydropower development therefore a site in this area was selected. !Kheis is an administrative area of the ZF Mgcawu District of the Northern Cape in South Africa (shown in Figure 3-1).

Figure 3-1: !Kheis Local Municipality (Google Earth, 2016)

The !Kheis LM has a similar problem to numerous other municipalities throughout the country, this being a lack of revenue due to large sections of the community being unemployed and not able to pay for services.

The Boegoeberg irrigation canal runs adjacent to numerous towns and small settlements in the municipality. Small-scale hydropower schemes (SHS) along these routes could allow a sustainable means of allowing at least a supply to free basic electricity for rural areas within reach. An alternative would be for municipalities to implement such systems at areas of high electricity usage, thus reducing their reliance and financial dependence on Eskom sources. Areas such as pump stations where usage is high during peak tariff periods are high costs zone for the already struggling municipalities. A pilot study introducing HK technology for municipal use in this way builds the basis of this dissertation.

Water is abstracted from the Boegoeberg Dam (Figure 3-2) and fed into the Boegoeberg canal system (Figure 3-3). The canal system is about 180 km in length and the larger sections run through the !Kheis District Municipal area. Within these sections lies the opportunity to install HK type turbines where there is sufficient freeboard and flow velocities available (typical canal properties in the proposed installation sections is shown in Table 3-1). It is believed that from available velocities measured at around 3m/s in this canal the typical small (1 m diameter) HK turbine can generate approximately 5 kW and these can be installed in series i.e. at a number of places down the canal system (This approximation is calculated from the selected turbine power curve see Section 3.3.1).

Figure 3-2: Boegoeberg Dam abstraction point

Figure 3-3: Typical section of the Boegoeberg canal

Table 3-1: Typical canal section parameters

PARAMETER	VALUE
Typical flow area	6.44 m^2 (1.4 m height by 4.6 m width)
Lining type	Concrete lining
Manning roughness coefficient (assumed)	0.018
Flow type	Subcritical
Typical bed slope	$7.7x10^{-4}$ m/m

3.2 SITE SELECTION

The process followed for site selection along the canal can be seen in Figure 3-4, each element of the process is described in subsequent sections.

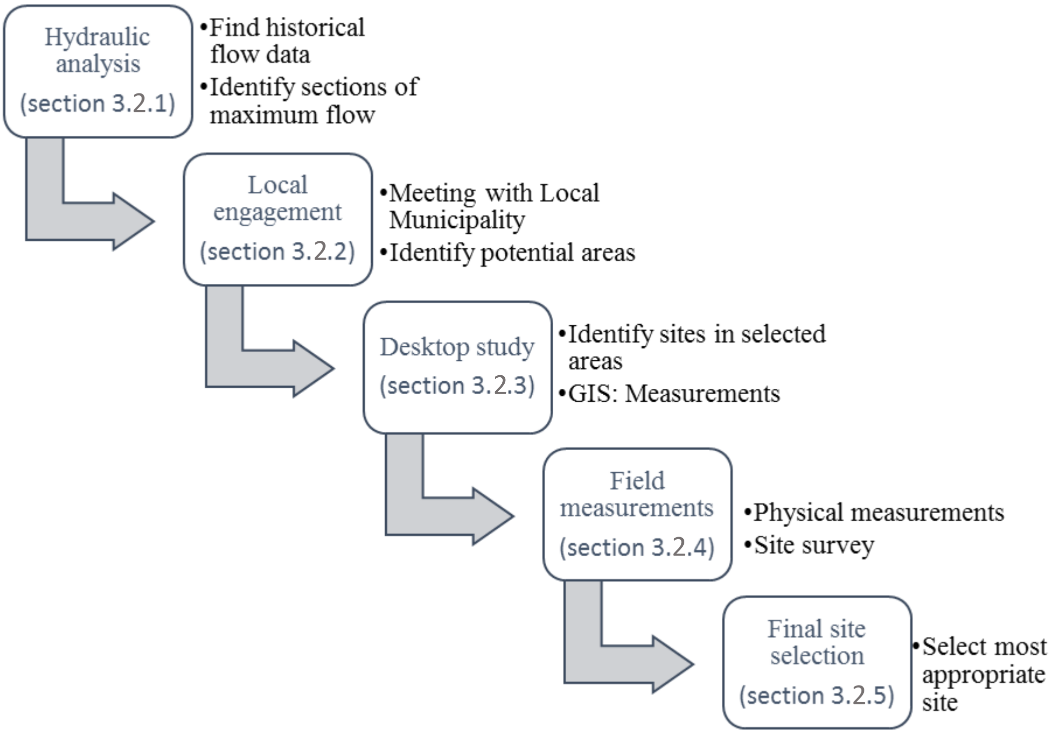


Figure 3-4: Site selection process

3.2.1 Hydraulic analysis

The DWS gauging station flow records were used to obtain statistical information on the flow available in the canal. Only 1 DWS gauging station D7H17 (position depicted in Figure 3-5) exists on the canal section which was utilised in determining the hydropower generating potential.

Initial estimates were indicated by members of the Boegoeberg WUA stating the flow velocity is about 8 km/h (2.22 m/s) with a freeboard of ±10 cm in the upper canal sections passing the !Kheis Municipality Towns (where site selection occurred).

The typical flow rate pattern in the canal is illustrated in Figure 3-6. The corresponding average flowrate for the period depicted in Figure 3-6 was 12.15 m^3/s (on days when there was water flowing) and the maximum flowrate was 13.34 m^3/s.

Figure 3-5: Gauging station D7H17 on the Boegoeberg canal system (flow direction indicated) (Google Earth, 2016)

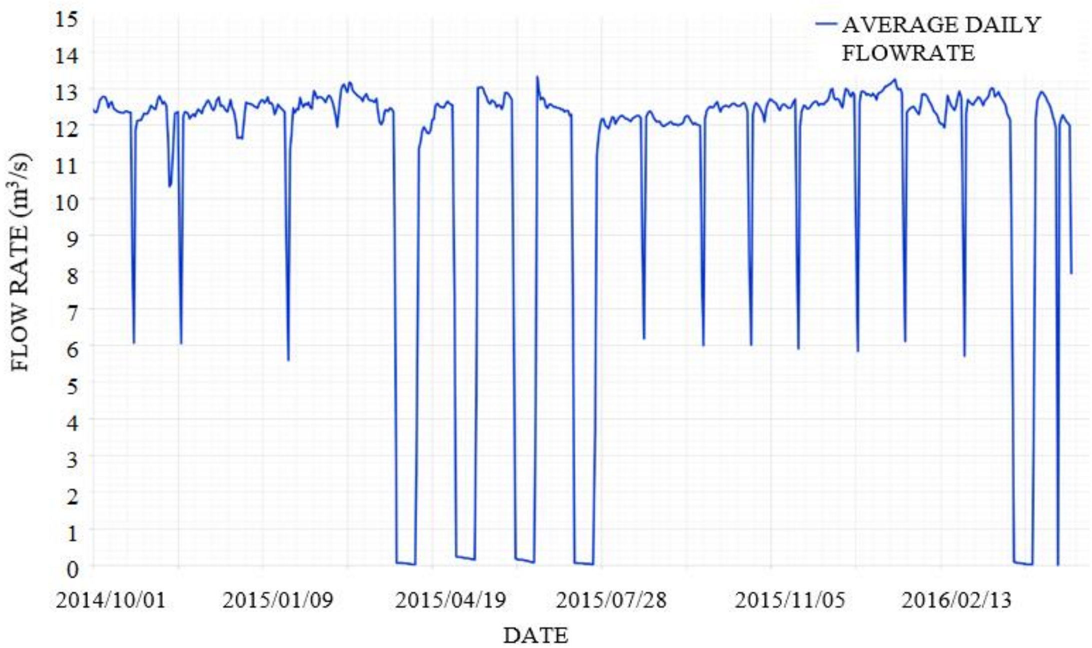


Figure 3-6: Flowrate in the Boegoeberg canal (Oct 2014 to April 2016)

The canal is shut off for a series of short periods throughout the year for mosquito elimination and canal maintenance purposes. The flow records provided details of the number of active days, which indicated the canal is operational an average of 89% of the year as shown in Table 3-2.

Table 3-2: Active days of the Boegoeberg canal system

YEAR	ZERO FLOW DAYS	ACTIVE FLOW DAYS
2005	46	319
2006	50	315
2007	37	328
2008	12	353
2009	49	316
2010	37	328
2011	34	331
2012	56	309
2013	44	321
2014	29	336
2015	48	317
2016	45	320
Average	**40.6**	**324.4**

3.2.2 Local engagement

To provide a site which will be maintained and cared for appropriately local engagement was a crucial part of the project. Meetings were set up with members of the LM to identify areas of high electricity usage during peak hours (leading to high electricity costs) or small settlements with no access to electricity which lie in close proximity to the canal.

In this process 3 possible sites were identified:

i. Groblershoop Water Treatment Works (WTW) (site 1)
   - High electricity usage
   - Pumping during peak hours

ii. Wegdraai WTW (site 2)
   - High electricity usage
   - Pumping during peak hours

iii. Opwag Village (site 3)
   - Small settlement with no grid connection
   - In close proximity to the Boegoeberg canal

The location of the 3 sites can be seen on Figure 3-7.

Figure 3-7: !Kheis Municipality identified sites (Google Earth, 2016)

3.2.3 Desktop study

The three sites identified during the meeting with the municipality were identified on GIS as well as additional sites with possibilities for future electrification. A great number of small homesteads/villages were found along the canal which could also benefit from localised energy generation. A few examples of these can be seen in Figure 3-9.

Figure 3-8: Groblershoop site (Google Earth, 2016)

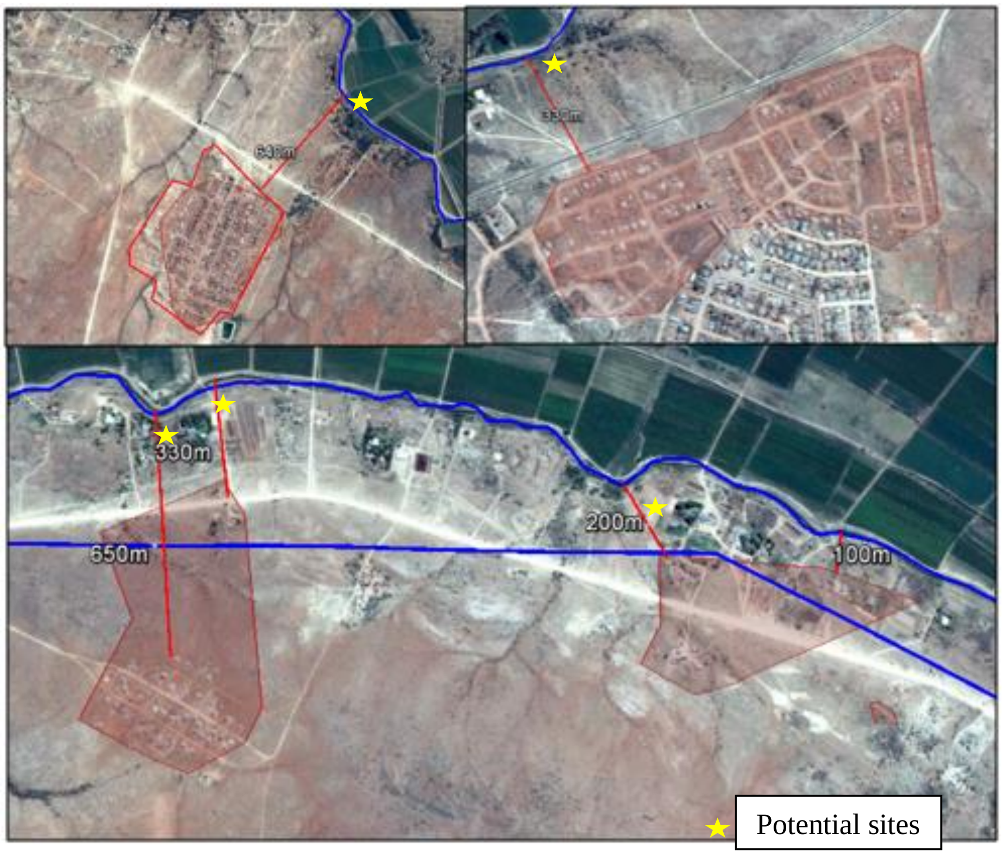


Figure 3-9: Potential sites (Google Earth, 2016)

Due to time constraints and practicality purposes for this study only the 3 sites shown in Figure 3-7, as discussed in section 3.2.2 were considered for further assessment:

i. <u>Groblershoop WTW</u>

The Groblershoop WTW site lies in the town of Groblershoop. This plant supplies water to the majority of the surrounding areas. The site location can be seen in Figure 3-8. The WTW pump station is currently partially supplied by a small solar generation plant erected at the water treatment facility. The town of Groblershoop lies approximately 38km downstream from the canal offtake (Boegoeberg Dam). The approximate electricity usage of the pumps at the WTW is 25kW.

The Groblershoop WTW site was chosen as a feasible option for the following reasons:

- A section of the canal runs in close proximity to the facility (approximately 100m away).
- !Kheis Municipality indicated insufficient power output from the solar plant to supply the plant through the night, whereas the hydropower option could supply the plant 24hours a day and is not dependent on available sunlight.

- The existing control systems from the solar plant could be utilized allowing for cost savings as no additional control system would be required.
- The project will assist the plant in achieving its goal of running off-grid.
- The site lies in close proximity to the Municipal offices and has 24hour operator/security at the WTW.

ii. Wegdraai WTW

A WTW close to the town of Wegdraai, situated about 13km from Groblershoop, poses as another viable site for HK turbine installation. The canal system forms a flume structure just before the WTW and the flume exit lies about 20m from the WTW as shown in Figure 3-10. The approximate electricity usage of the pumps at the WTW is 22kW. This specific site was taken as a feasible option for the following reasons:

- The narrowed flume induces an increase in the velocity of the water in the canal system by reducing the flow area. Therefore, turbines placed in the flume, or at the exit will be exposed to a higher flow velocity than in other nearby sections which will result in higher power output.
- The WTW is currently completely dependent on Eskom and has been subject to a great number of outages which affects water supply in the town.
- The WTW lies approximately 50m from the installation site, which allows for lower distribution costs.
- The site has an operator/security guard at the WTW during the day.

Figure 3-10: Wegdraai Site (Google Earth, 2016)

iii. Opwag Village

The Village of Opwag lies approximately 650m from the nearest canal section, between the towns of Groblershoop and Wegdraai. It is an informal settlement with no grid connection or water supply (Figure 3-11). The village was chosen as a potential site for the following reasons:

- The !Kheis Municipality cannot afford to electrify the village in the near future.
- Most of the people living at the Opwag settlement are working for the grape farmers in the area and therefore only have seasonal harvesting jobs and no continuous income to afford electricity costs.
- The village lies in close proximity to the canal (650m).

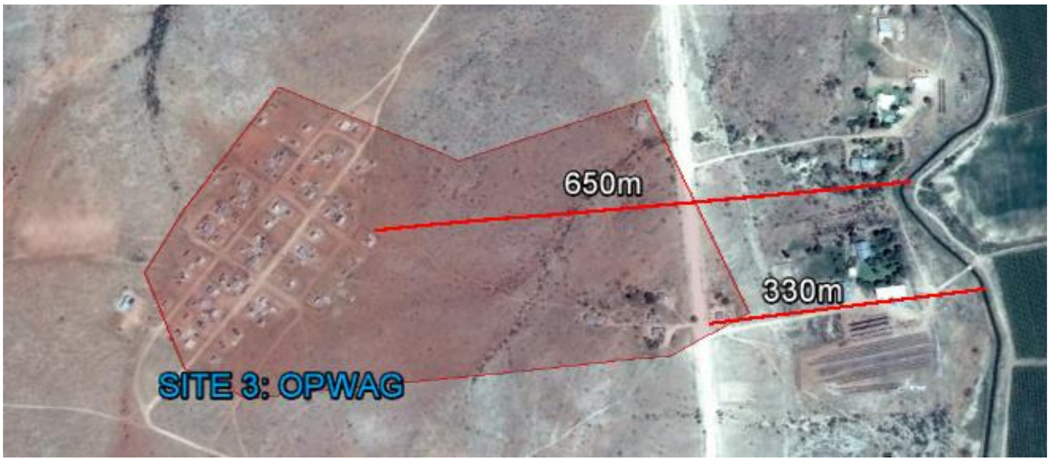


Figure 3-11: Opwag Site (Google Earth, 2016)

3.2.4 Field measurements

For final analysis, the 3 potential sites were visited and necessary measurements were taken as discussed below. A summary of measurements is listed in Table 3-3.

i. Canal Dimensions

The dimensions of the canal where measured during a canal shut-off period and these dimensions were compared with dimensions specified on the original canal drawings as shown in Figure 3-12 obtained from the Boegoeberg WUA.

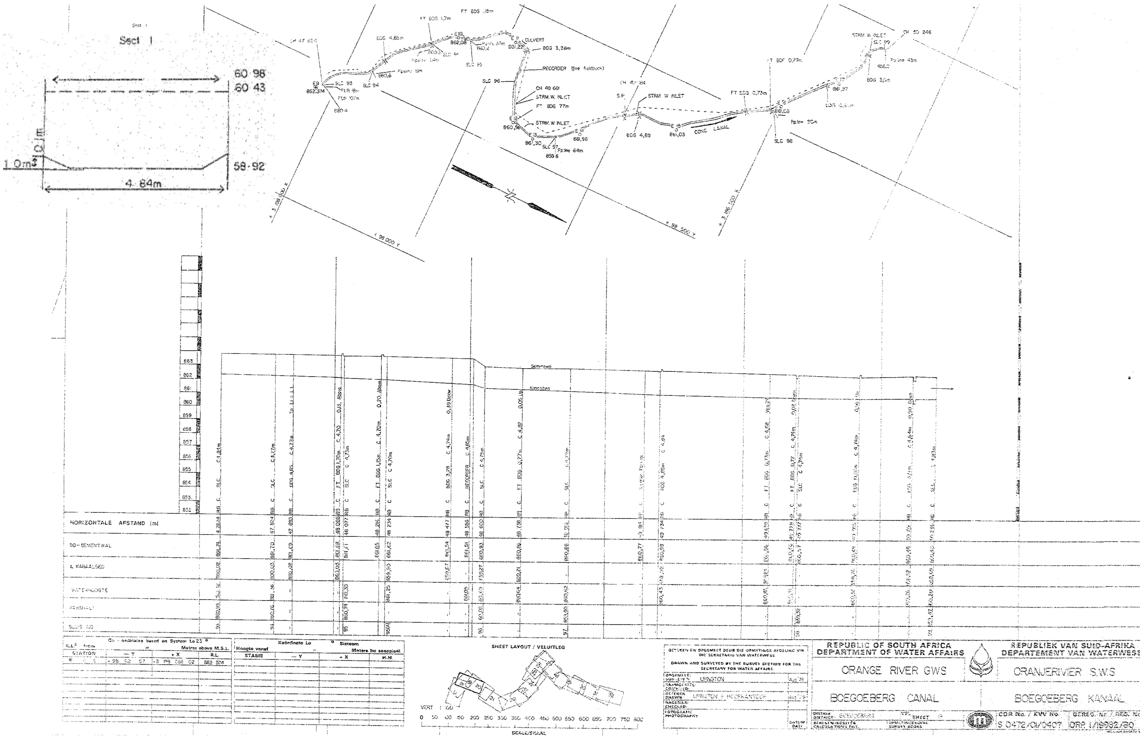


Figure 3-12: Original Canal drawings obtained from Boegoeberg WUA (contextual purpose)

ii. <u>Water Depth</u>

The depth of water was measured as a distance from the canal wall top edge to the water level the average water line could be seen and was used as a measurement basis, this was then subtracted from the canal depth to obtain the water height, the water level does vary slightly throughout the seasons. The canal is slightly deeper in the centre in certain sections.

Figure 3-13: Water depth measurements at sites

iii. Calculated Velocity

Site 1, 2 and 3 are approximately 36km, 42km and 54km from the gauging station (Figure 3-14). As no records of abstraction points along the route were attainable the exact flow at all sites could not be calculated. However, it was stated by the Boegoeberg WUA that the flow should be fairly constant throughout these sites as most of the abstraction points are further downstream. Therefore, the velocity was calculated from the flow records shown in section 3.2.1.

Figure 3-14: Distance from gauging station to sites (Google Earth, 2016)

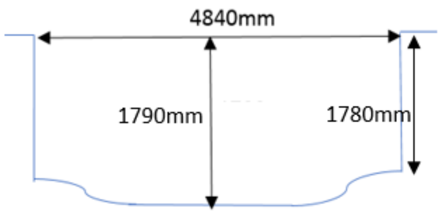
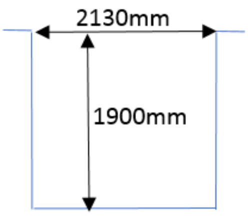
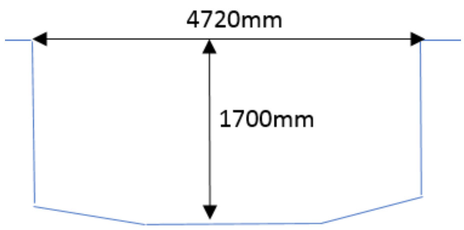
iv. Measured Velocity

The velocity at the canals was measured in the centre of the flow area with a pitot tube (Figure 3-15) and the floating object test during a site visit. These measurements were taken during a normal operational period to allow an indication of the available flow as this remains fairly consistent.

A summary of all results described above can be seen in Table 3-3, these measurements were taken during site visits, and assumed representative as an initial study, due to the flow at the times of measurement being under normal operating conditions. No other data was obtainable.

Figure 3-15: Pitot tube measurements

Table 3-3: Field measurements summary table

SITE	CANAL DIMENSIONS	WATER DEPTH	CALCULATED VELOCITY	MEASURED VELOCITY
Groblershoop WTW		1460 mm	(assuming 12.5 m^3/s) V= 1.8 m/s	2.2 m/s (1.8kW potential per turbine)
Wegdraai WTW		1710 mm	(assuming 12.5 m^3/s) V=3.43 m/s	3 m/s (4.9kW potential per turbine)
Opwag Village		1550	(assuming 12.5m^3/s) V= 1.7m/s	1.2m/s (0.178kW potential per turbine)

3.2.5 Final site selection

Final site selection was based on the following criterion:

i. Technical Viability:
   - Adequate flow velocity (directly correlating to generation potential);
   - Adequate cross section (large enough for turbine).

ii. Sustainability of system:
   - Anti-theft/ anti-vandalism;
   - Community support;
   - System integration effect on canal functioning (water supply should not be compromised by addition of system).

iii. Site resilience:
   - Overflow protection of damming effect;
   - Accessible to municipal workers in case of emergency (e.g. Blockage).

iv. Project specifications:
   - A representative section of what is available in most areas;
   - A section which has room for optimisation and improvement (not perfect conditions).

A summary of important aspects considered during site selection in Table 3-4.
For the first installation, developed for research and testing, the Groblershoop WTW site was selected due to the reasoning in Table 3-4 and more specifically:

i. Low transmission costs due to the nearby pump station (direct need for electricity on site).
ii. Existing abandoned pump station buildings next to the installation section which can be used for control systems housing, resulting in a large construction saving Figure 3-16.
iii. The existing solar scheme allows an alternative off-grid system where the hydro scheme can tie into (sync with) when the grid is off.
iv. Theft is a large problem in this area and the existing WTW and solar plant has a 24-hour operator/security guard, therefore this site was considered the safest.
v. The large cross section of the canal allows possible installation of multiple turbines over a single cross section, reducing costs by allowing a more compact system.
vi. The Municipality headquarters are less than 1km from the site, allowing quick access in case of emergencies and more reliable supervision of the test installation.

Table 3-4: Site selection summaries

SITE	GROBLERSHOOP WTW	WEGDRAAI WTW	OPWAG VILLAGE
VELOCITY ESTIMATION (m/s)	2.2	3.0	1.2
GENERATION POTENTIAL PER TURBINE (W)	1840	4906	177
TRANSMISSION LENGTH (m)	40	20	650
AVERAGE ELECTRICITY USAGE (kW)	25	22	None 63 houses 1 Creche
POSITIVE FACTORS	i. Secure installation site. ii. Closest site to dam offtake therefore should have the highest flow rate, and less fallen debris. iii. Grid connection back up during canal shut down times. iv. Solar plant could assist grid-connected system running during grid shut-off.	i. Fairly secure installation site. ii. Flume section results in higher velocity. iii. Grid connection back-up during canal shut down times.	i. Not grid connected (in dire need of electrification). ii. Directly benefitting rural community
NEGATIVE FACTORS	i. Great distance from gauging station, unknown flow.	i. Great distance from gauging station, unknown flow. ii. Flume section elevated over bridge crossing, therefore no overflow possibilities.	i. Great distance from gauging station. ii. No secure section along the canal for installation (anti-theft). iii. Fairly large transmission costs. iv. No grid connected back-up.

Figure 3-16: Existing pump station building

The reasons for not using site 2 and 3:

i. Although the Wegdraai site has the flume section which is ideal as the water velocity should be greater, the flume section is elevated with no overflow alternatives, which could result in problems when a blockage occurs over the turbine and water cannot be diverted back into the canal.
ii. The Wegdraai canal section is also narrow and therefore the blockage effects of the turbine will be more evident and could pose as a risk.
iii. The Opwag site is a greater distance from the homesteads and will therefore have high transmission costs. Additionally, a back-up energy source during canal shut off times must be provided, resulting in higher costs.
iv. The canal section of the Opwag site is similar to the Groblershoop site, however the site is 6km further downstream with a number of offtakes in between resulting in lower flow rates, which makes the Groblershoop site more feasible.
v. Theft and vandalism is a large problem in the area, where both site 2 and 3 do not have permanent security/protective measures at the site.

After long discussions with the LM and Boegoeberg WUA the conclusion was reached that the Groblershoop site would be best for an initial installation where the effect of the turbine can be tested with less risk and the LM officials can keep a close eye on the project as it is in close proximity to their HQ’s.

3.2.6 Groblershoop installation site

After site selection the Groblershoop site was further analysed to obtain more reliable site details. The layout of the site can be seen in Figure 3-17. As shown the canal section considered for installation is a combination of two straight sections, this is ideal for installation as there is less turbulence in these sections. In addition, the bend allows testing of the influence of a canal bend on the power output. The downstream canal section and the bend can be seen in Figure 3-18. Sections further upstream were not considered as this is further from the control room and would result in large transmission lengths (and therefore higher costs).

Figure 3-17: Groblershoop site (Google Earth, 2016)

Figure 3-18: Canal system at the Groblershoop site

The WTW facility as shown in Figure 3-17 consists of a package treatment plant and two pump stations (Figure 3-19). Pump room 1 has 2 pumps with a usage of approximately 7.5kW each, the solar plant supplies one of these pumps with off-grid electricity. Pump room 2 has 4 pumps each with a usage of 2.5kw resulting in a total of 25kW required for the pumps when operating.

Figure 3-19: Pump station room 1 and 2

As mentioned previously, the Groblershoop WTW already has a facility where power is generated by means of solar panels (Figure 3-20). The plant is complete with 3 inverters all set to the required sinus wave sequence to produce the required 3-phase electricity for the pumping scheme.

Figure 3-20: Existing solar plant

3.3 FINAL EXPERIMENTAL DESIGN

After initial site selection the final experimental setup was designed as described in this section. Although this serves as an experimental design, all components were designed for permanent installation, as the setup will be permanently installed after testing. Other than the HK turbines, numerous components were required for operation and maintenance of the turbines. Safety and ease of maintenance is a concern in the area, therefore additional safety measures must be put in place. The canal system is cleaned at specific maintenance intervals and repaired where necessary. The infrastructure components required for the installation of the HK turbines are listed in three sections namely civil components, electro-mechanical components and electrical components:

i. Electro-mechanical Components
   - SHP free stream turbine
     a. Equipped with 5kW underwater generator
     b. Rotor

ii. Civil Components
   - Concrete block foundation for cable hoist
   - Turbine lifting system

iii. Electrical Components
   - Turbine control equipment
   - Flow meter
   - Level sensors

The process from initial possibilities to final design of the components was completed by a process of discussion and elimination, a summary of this process can be seen in Table 3-5. The subsequent sections describe only the final design. Details of the design of the civil works undertaken for the installation can be seen in Appendix A.

Table 3-5: Design considerations

COMPONENT	DESIGN OPTIONS	DESIGN CONSIDERATIONS	FINAL DESIGN
Turbine selection (refer to Table 2-3, SHP selected as supplier).	SHP Floating axial flow turbine.	SHP was chosen as the turbine supplier and indicated the freestream was designed specifically for canal application and fits the operating range. It is less prone to debris build-up (due to most debris floating, and grid deflection device) and better for the specific application.	SHP Freestream turbine.
	SHP freestream axial flow.		
Anchoring structure	Bottom anchoring onto canal bed.	Initially the Boegoeberg WUA requested no alterations be done on the canal itself. In addition, an anchoring system outside of the flow would be simpler for accessibility purposes.	Side Anchoring.
	Side anchoring with concrete anchor blocks.		
Lifting system	Gantry permanent structure.	Extremely large cost due to large width of canal.	Portable crane.
	Gantry on rails over all turbines.	Extremely expensive and would require only straight level sections (existing site has a bend).	
	Portable crane.	Second hand crawler crane available at low cost, single crane can be used for all turbines (for future installations).	
Turbine placement (multiple turbines)	Centre placement (one behind the other at specific spacing).	Fastest velocity in centre section of canal.	Centre placement due to possible wingwall application (all options still a consideration, further testing will be done).
	Staggered placement (staggered behind each other).	Staggered placement could result in less interference between turbines and could allow closer placement.	
	Adjacent placement (multiple turbine in single cross-section).	Recommended by supplier, increasing the Betz limit.	

3.3.1 Electro mechanical components

The turbine selected for the site is shown in Figure 3-21 and is specifically designed for canal systems. It is placed in the bottom of the canal. System specifications can be seen in Table 3-6. The turbine is equipped with an underwater generator providing AC power to the system. To achieve maximum power output from the system a flow velocity of 3.1 m/s is required. Estimates of the current velocity in the canal indicated an average speed of flow of about 2 m/s therefore the addition of a structure before the system such as implementing guide plates or narrowing the canal would create a venturi effect, speeding up the flow entering the turbine to achieve an increased power output. The output curve of the generator is provided in Figure 3-22.

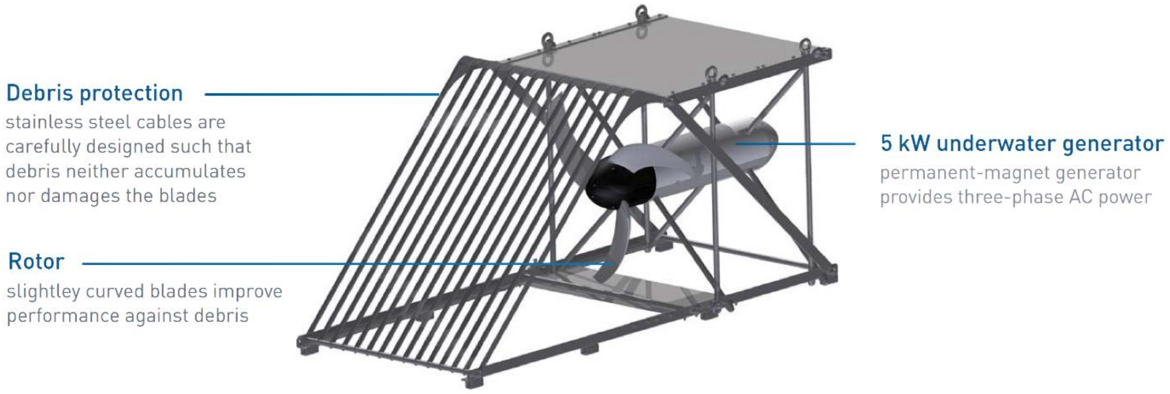


Figure 3-21: Kinetic turbine for deployment in canal (SHP SMART free stream turbine) (SHP, n.d.)

Table 3-6: Turbine specifications (SHP, n.d.)

OUTPUT (W)		250-5000
DIMENSIONS	LENGTH (mm)	2640
	WIDTH (mm)	1120
	HEIGHT (mm)	1120
ROTATIONAL SPEED (RPM)		90-230
WEIGHT (kg)		300
NUMBER OF ROTOR BLADES		3
ROTOR DIAMETER (mm)		1000

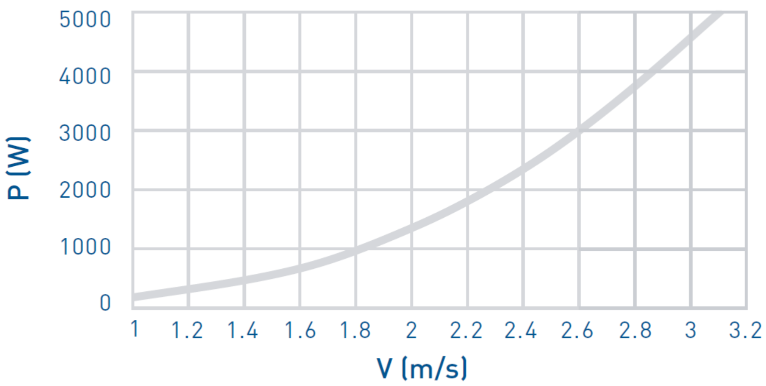


Figure 3-22: Generator capability (SHP, n.d.)

A generating capacity of around 4kW is aimed for, by increasing the velocity onto the turbine blades (by means of optimisation techniques) to 2.83 m/s and thus enabling a generating potential of 4 kW per installation. This will allow an annual energy production of 29 784 kWh per turbine unit (assuming 85% load factor).

3.3.2 Electrical aspects

The Groblershoop WTW already has a facility where power is generated for one of the pumps by means of solar panels, it is also grid connected to supply the remaining pumps. This allows possible integration of the HK plant with the existing system. Additionally, the grid connected system could be synchronized with the solar plant when the grid is off and allow further power generation and therefore pumping can continue off-grid. The system workings are further described below.

The Electrical Management Systems, or EMS, are the intelligence of this renewable energy systems (Figure 3-23). It maximizes the usage efficiency by balancing the supply of electricity between the varying user demands. The proprietary load management system developed for the SMART EMS allows for loads to be prioritized according to the usage profile, optimizing energy consumption.

Integrated inside the electrical cabinet is a reverse control (to remove accumulated debris from the blades), optional auxiliary devices, customizable battery storage interface (it has a built-in battery charger) and monitoring system. The basic layout of the installation is depicted in Figure 3-24.

Figure 3-23: Electrical management system (Control panel) (SHP, n.d.)

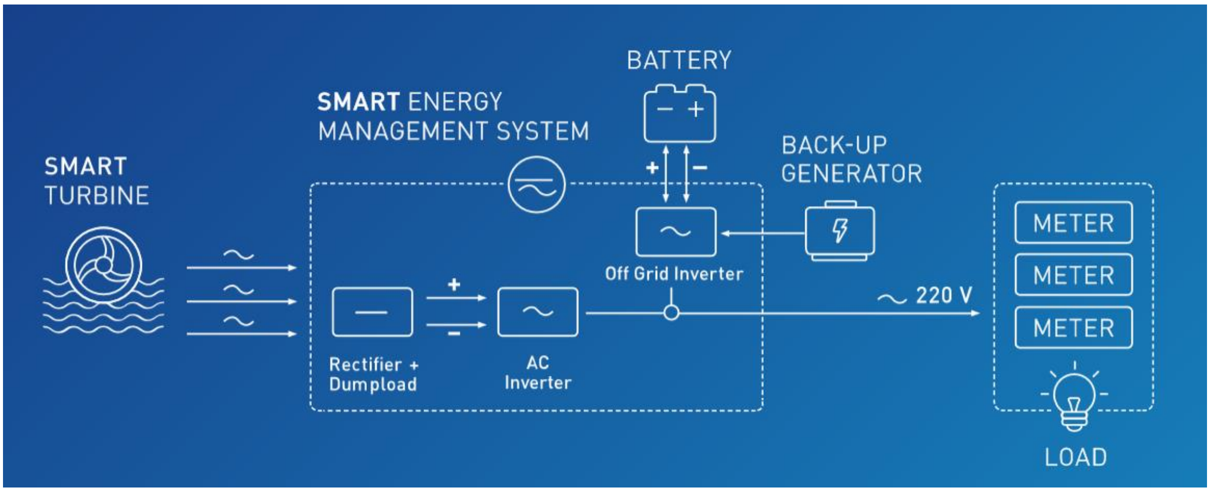


Figure 3-24: System layout (SHP, n.d.)

The system was designed as a grid-tied system. The electrical layout schematic designed for the installation can be seen in Figure 3-25. Grid-tie inverters will be used for controlling grid stability with dump loads to ensure a constant load as no actuators will be present at the turbines. Two operating modes will be used to ensure maximum generated energy usage:

i. Normal Mode (Eskom supply):

Seven turbines in future phases will be connected to the entire WTW and will then also be able to theoretically feed energy back into the grid when no power is used at the WTW. The reverse power feed is highly unlikely as the load of the WTW is larger than 50 kW and have to operate constantly to supply potable water. Grid-tie inverters are also designed to disconnect when no grid is available for safety of Eskom personnel in an outage scenario.

ii. Micro Grid Mode (No Eskom supply):

When Eskom has an outage, the new grid will be formed by the solar plant batteries and their inverters. The inverters at the solar plant can only support their rated load of 15 kW (of which the maximum supplied by the solar plant is 7.5kW) and therefore only about 3 turbines can be grid tied to the Solar network in the event of no power from the supply authority. Contactors were used to disconnect turbines and an automatic transfer switch is used to disconnect all the turbines from the Eskom Grid and re-connect to the Solar Grid. Once power is restored the plant will operate in normal mode again with all 7 turbines.

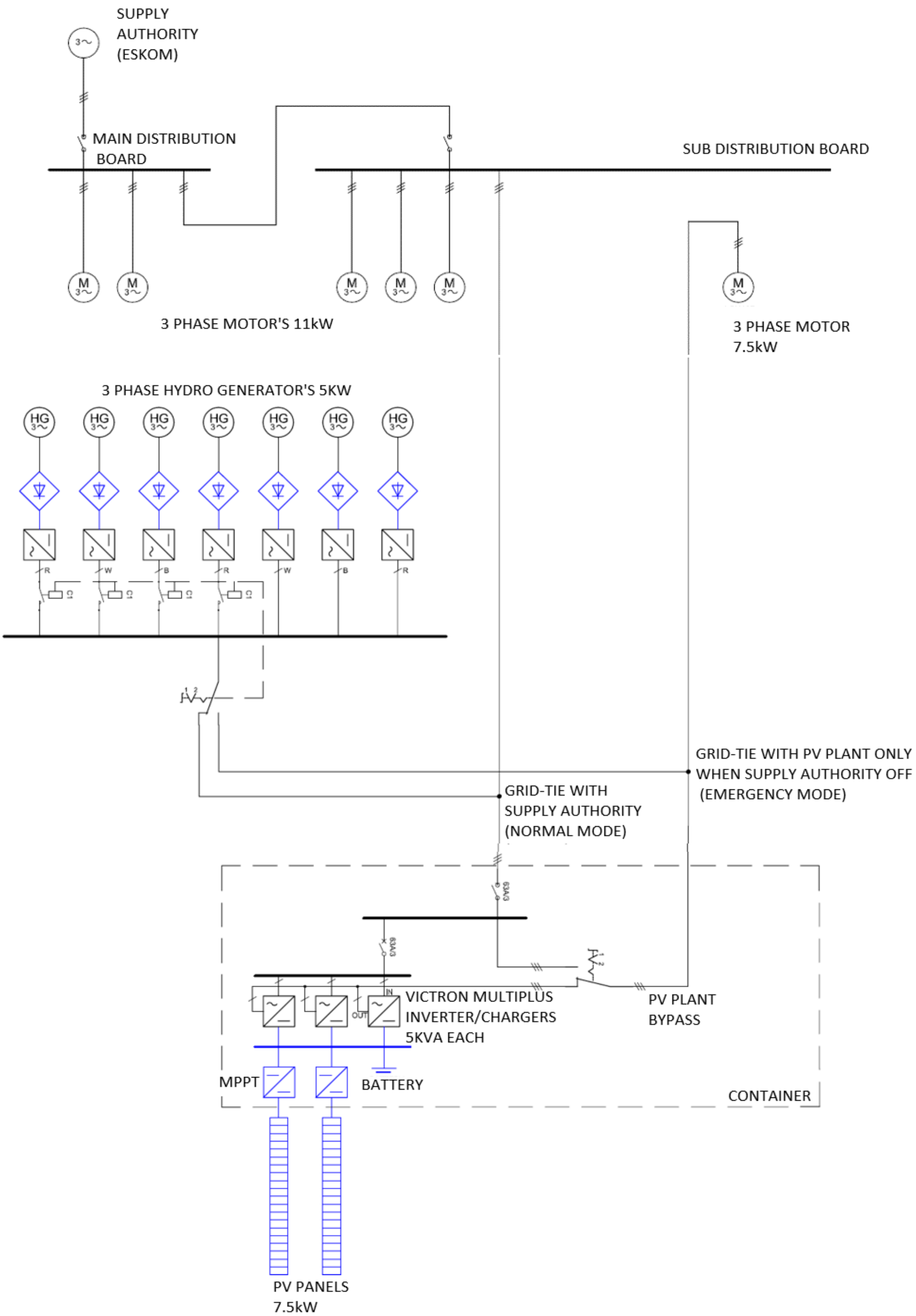


Figure 3-25: Schematic layout of the electrical system

3.3.3 Institutional stakeholders and legislative process

For hydropower projects developed at local level, the institutional powers, functions, roles and responsibilities of municipalities are of utmost importance. In the context of the four major regulatory requirements necessary to initiate and implement small-scale hydropower projects, namely a Water Use Licence (in terms of the NWA), an Environmental Authorisation (in terms of the NEMA), an Electricity Generation Licence and an Electricity Distribution Licence (in terms of the ERA), the DWS (or the regional departmental offices or the Catchment Management Agency, where these are established and have the authority), the provincial office of the DEA and NERSA, would be the primary stakeholders involved in this type of hydropower project, over and above the project initiator.

In the context of local electrification through small-scale hydropower technologies, the DWS is a primary stakeholder. The DWS has the mandate to protect and manage South Africa's water resources. Furthermore, the DWS owns waterworks across South Africa such as weirs, irrigation canals and dams which could be utilised to generate electricity (in this case the Boegoeberg irrigation canal). For this study, the project specific institutional stakeholders are identified in Table 3-7. The roles of each stakeholder during the project is shown under project specification. The project formed part of the *"Draft policy on sustainable hydropower generation"* (Appendix D) which allowed a simpler process of approval.

Table 3-7: Project specific institutional stakeholders

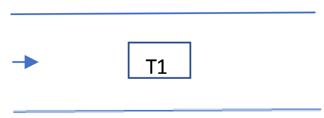
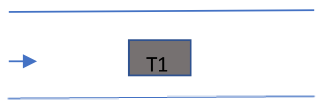
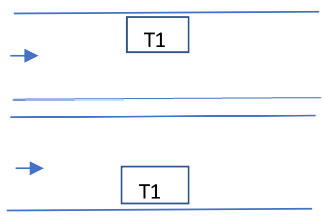
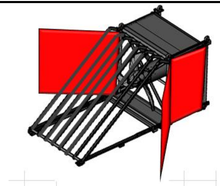
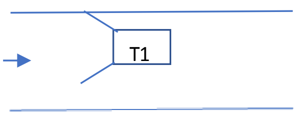
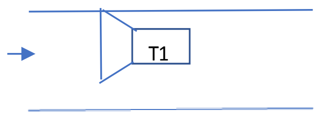
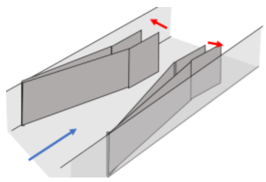
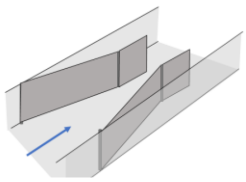
GROBLERSHOOP WATER TREATMENT WORKS			
#	STAKEHOLDER	ROLE & RESPONSIBILITY	PROJECT SPECIFICATION
1	Department of Science and Technology (DST)	Funder	Funds obtained for the project duration.
2	WRC	Implementing Agent for the DST.	• Reports submitted.
3	DWS	• Owner of irrigation canal; • Owner of land on which the irrigation canal is located; • Custodian of the water resource.	• A series of meetings set-up to obtain approval. • Signee on the Memorandum of Agreement (MoR) between all entities involved to ascertain approval.
4	!Kheis LM	• Hydropower project owner (asset will be listed onto the LMs Asset Register) • All regulatory submissions would be in the name of the !Kheis LM and for the !Kheis LM. • Operation & Maintenance of hydropower generation plants and the electricity transmission infrastructure.	• A series of meetings were set-up to obtain approval and knowledge of municipal roles and responsibilities concerning the installation. • Co-signee of MoR

GROBLERSHOOP WATER TREATMENT WORKS			
#	STAKEHOLDER	ROLE & RESPONSIBILITY	PROJECT SPECIFICATION
5	Citizens of the !Kheis LM	Beneficiaries of the project's service delivery outcomes	Local laborers were hired and trained to perform maintenance on such an installation
6	Boegoeberg WUA	Operator of Boegoeberg canal.	• Meetings were set-up to inform WUA of all construction plans and obtain approval. • Notified and requested approval during any modification/alteration to canal • Co-signee of MoR
7	NERSA	Electricity regulator.	No licence required as the electricity produced is for "own-use" (refer to section 2.10.1) and small scale of generation.
8	Eskom	Electricity distributor.	No approval/licencing required, no Eskom owned distribution lines used.
9	Northern Cape Provincial DEA	Provision of an environmental authorisation should a listed activity according to the NEMA be triggered.	No triggers for this authorisation, therefore not required.
10	University of Pretoria	Planning and design engineers.	Responsible for project implementation.

3.4 TESTING SCHEDULE

A proposed testing procedure was developed based on literature (Table 3-8). The main objective of the testing procedure is to obtain information on the influence of different positions, blockage damming effects and the influence and success of possible optimisation measures. During the planning of this testing schedule it was presumed each phase will follow the last only if results from the previous phase allow for further testing without interfering with the canal operation.

Table 3-8: Proposed testing procedure

PHASE	NO.	TESTING ASPECT	SETUP	PICTURE
1	I	NORMAL INSTALLATION: test level and power output as bought from the supplier.	Place turbine in the canal centre.	
	II	BLOCKAGE: Testing the influence of complete system blockage.	Block the turbine completely and place it in the centre of the canal.	
	III	OFFSET: Placing the turbine at an offset (on the side of canal) to test power difference to centre installation to measure 1) change due to drag caused by the side walls 2) .influence of bend (inner and outer bend)	Place the turbine on the left and right edges of the canal, testing the influence.	
2	I	TEST GUIDE PLATE MECHANISM: Test power output influence of addition of guide plates, and velocity change at the turbine.	Place turbine in canal centre with attached plates.	
	II	OFFSET: Placing the turbine on the outer bend to test the influence of the change in velocity.	Place turbine against outer edge of the bend.	
	III	TEST GUIDE PLATE AND TOP PLATE MECHANISM: Test power output influence of addition of the top plate, and velocity change at the turbine.	Place in the canal centre.	
	IV	OFFSET: Placing the turbine on the outer bend to test the influence of the change in velocity.	Place turbine against outer edge of the bend.	
3	I	NARROW CANAL SECTION IN INCREMENTS: Test the power output and damming effect of the change in canal flow area.	Slowly vary the reduction in width in increments to test the effect of narrowing.	
	II	NARROW CANAL SECTION: Test the power output and damming effect of the change in canal flow area.	Extend the plates to the maximum narrowing of 1.2m on each side and test the effect on power output.	

The design of the system developed over time depending on the result of the experimental procedures. These designs will be described in phases as follows:

3.5 PHASE I: TURBINE PRIMARY INSTALLATION

This phase involved installing the turbine as specified by the manufacturer (SHP). Various scenarios were tested to observe the turbine performance over various positions in the installation cross section. In addition the effects of possible blockage on the system was tested and the damming effects analysed.

3.6 PHASE II: TURBINE UNIT OPTIMISATION

This design phase involved improving the system by altering the turbine through the addition of components to further optimize the system. This was done in two stages:

i. Adding guide plates to the turbine: Diverting a greater amount of flow through the turbine by reducing the area of flow.
ii. Adding a top plate to side guide plates: Further confining the flow through the turbine not allowing flow to divert over the tops of the guide plates (canal bottom assumed to act as bottom plate).

The design of the components is described in the next sections.

3.6.1 Optimisation by the addition of guide plates

A summary of the optimisation measures considered, based on the theory described in section 2.7 is shown in Table 3-9.

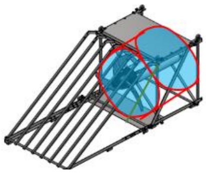
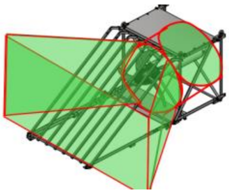
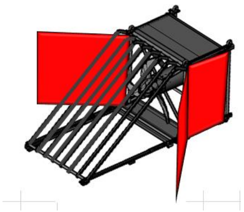
A final decision of optimisation by using guide plates was selected due to the application of the other options resulting in difficult assembly and requiring removal of the debris protection.

Guide plate structures were attached to the turbine at an angle of 35degrees in an attempt to improve the flow velocity through the turbine in order to achieve a higher power output, as was shown in Figure 2-38. The maximum angle of 35degrees was selected for the following reasons:

i. No specific literature on guide plate application or the best angle of reduction was found.
ii. The typical venturi angle of 21degrees was considered, however this would result in a long plate necessary to result in any significant blockage.
iii. To allow maximum blockage with as little length as possible.

Therefore, the angle of 35degrees was selected. The application in this case can be seen in Figure 3-26.

Table 3-9: Turbine optimisation options considered

OPTIMISATION FORMS	PICTURE	DESIGN THEORY
Confinement		Confining the turbine blades as explained in section 2.7.1 results in less turbulence and back flow on the blades and therefore greater power output.
Square to hollow section		A square to hollow section is assumed to be the best application as flow is completely confined and forced through the blades.
Guide plate and confinement		Addition of guide plates with turbine side plates is assumed to mimic confinement by closing the sides (where top and bottom is already closed) and guiding a large amount of flow through the rotor

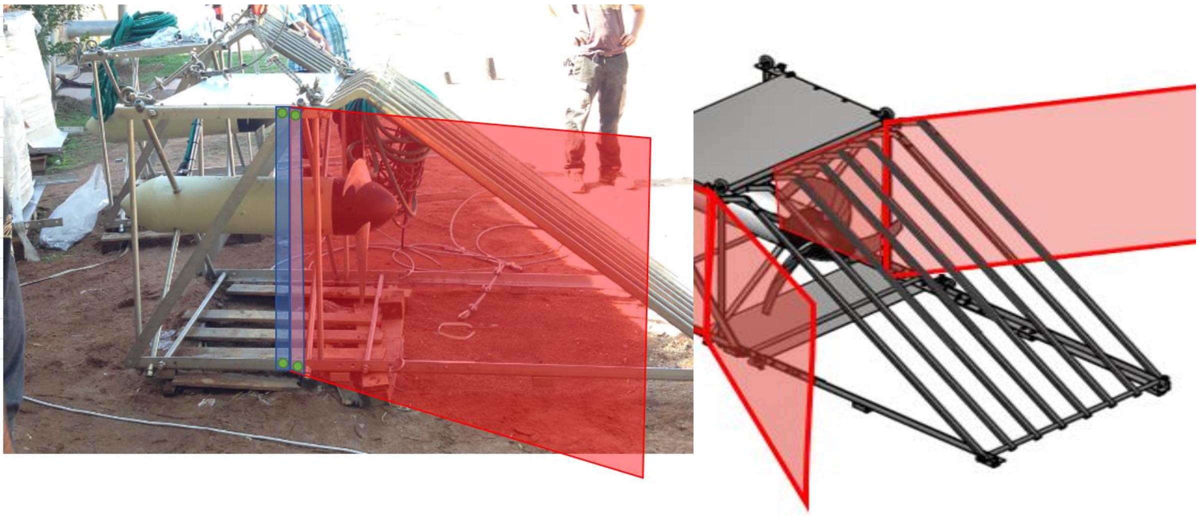


Figure 3-26: Guide plate application

The guide plates were designed based on the following considerations:

i. The guide plates should extend to the sides of the turbine to create a confined flow effect, imitating the application of confined flow.

ii. The angle of reduction (convergence) should be sufficient to allow smooth flow transition, an angle of 35degrees was assumed sufficient.

iii. The plates had to be designed to fit within the constraints of various bolts/plates and parts of the grid which protrude in the area of application as shown in Figure 3-27.

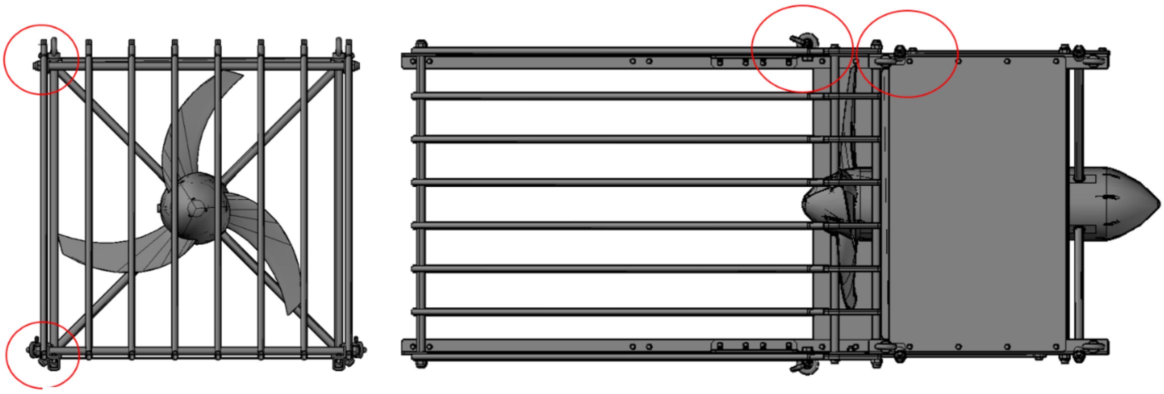


Figure 3-27: Protruding areas of the free stream turbine

iv. The plates (with added top plate) and added turbine weight had to fall within the lifting weight constraints of the crane used to place the turbine.
v. The plate size should not be too large as to make the turbine impractical.
vi. A plate length limit of 2000mm was selected and the plates designed accordingly, the calculations of the design and theoretical plate size required to obtain optimum velocity can be seen in Appendix B.

A number of constraints limited the design these being:

i. The practicality of HK devices being small modular units must be kept a priority, therefore an extremely long structural element added to the turbine would result in a large, difficult to handle unit.
ii. The weight of the steel plates limited the size, the maximum lifting load of the crane had to be considered.

The final guide plate design can be seen in Figure 3-28.

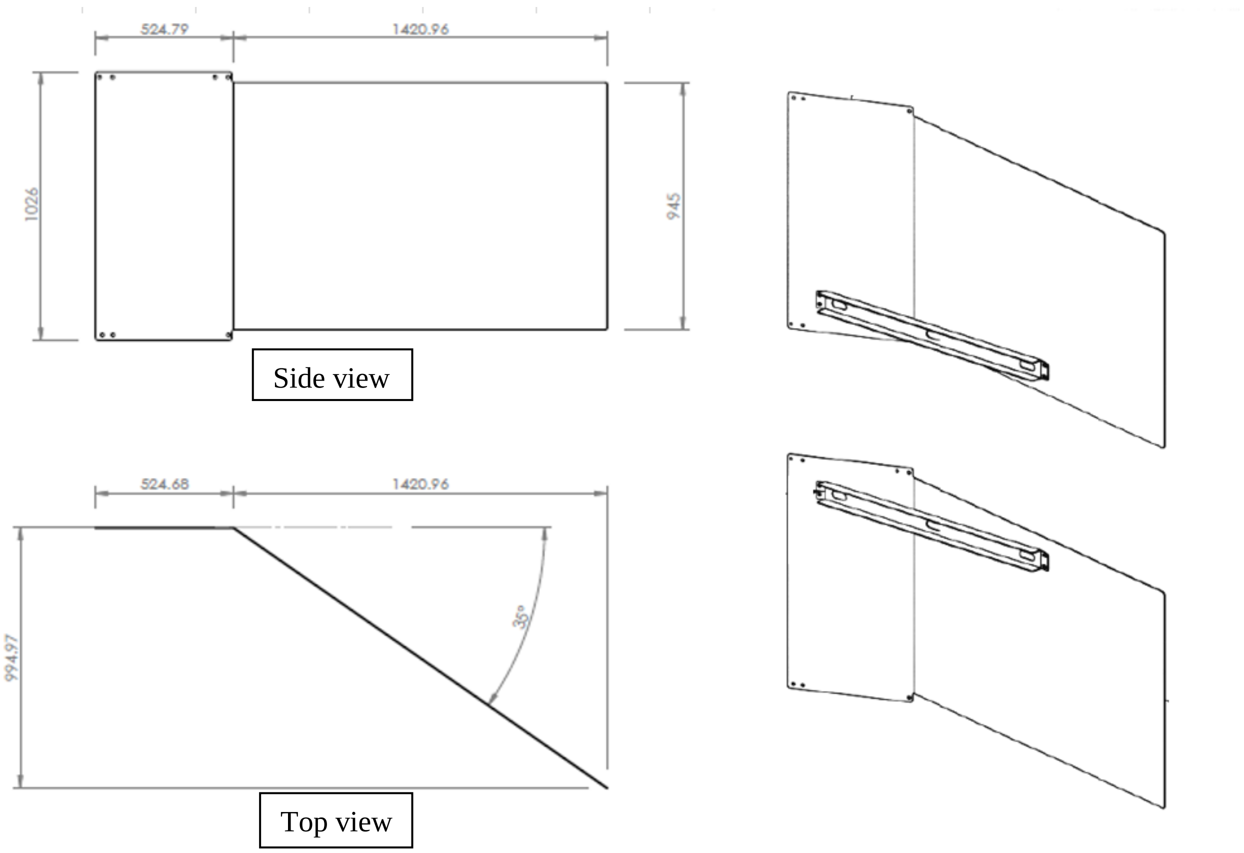


Figure 3-28: Final Guide plate design

3.6.2 Optimisation by addition of top plate

For further optimisation a top plate was added to observe the influence of further flow confinement, imitating a shroud mechanism. The protrusion of the grid over the turbine top resulted in having to design a top plate with a small gap between the plate end and turbine top plate as shown in Figure 3-29.

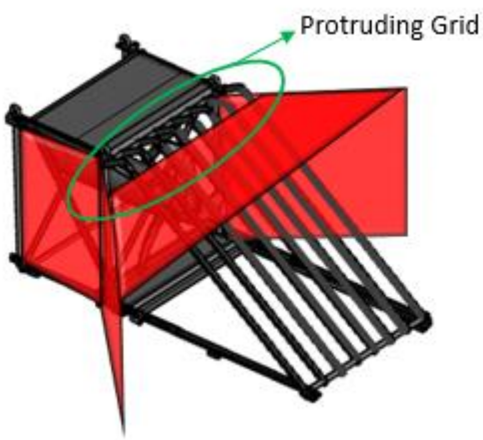


Figure 3-29: Top plate and side plate schematic

The addition of the top plate together with the canal bed acting as a bottom plate is assumed to almost completely confine the flow on the outer guide-plate area and divert a large amount of the flow through the converging section which should further increase the velocity. This influence was tested and in theory should result in a higher output than the guide plate only option.

The design on the top plate can be seen in Figure 3-30.

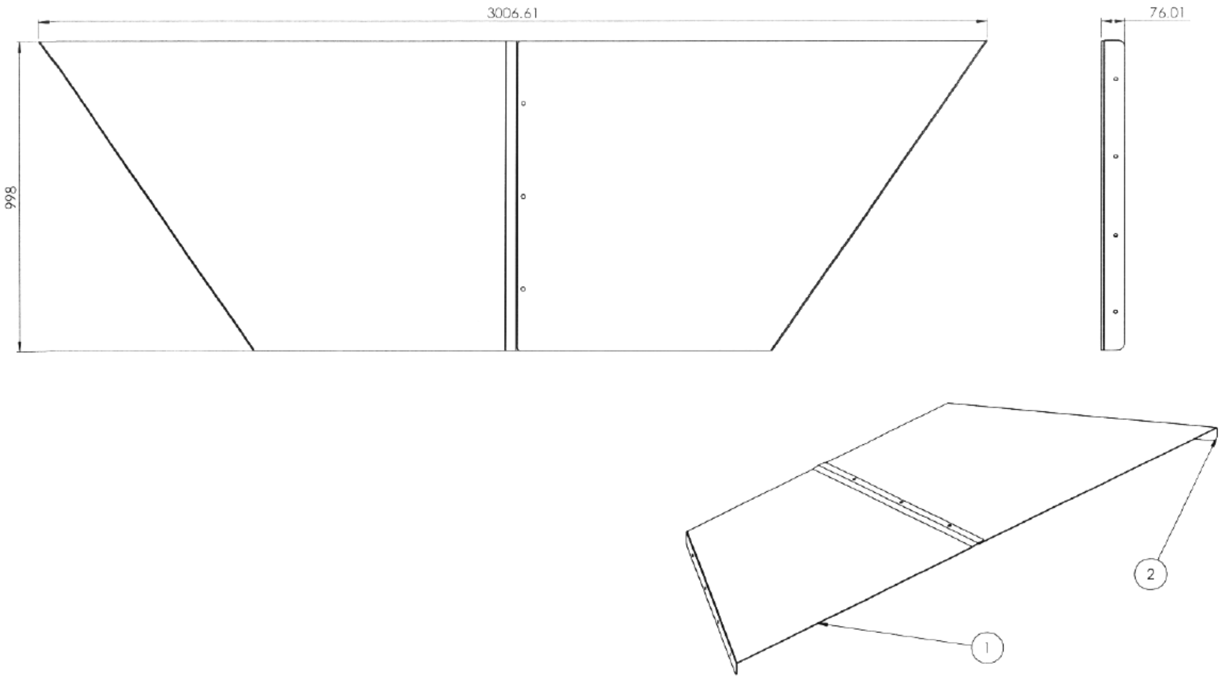


Figure 3-30: Top plate design

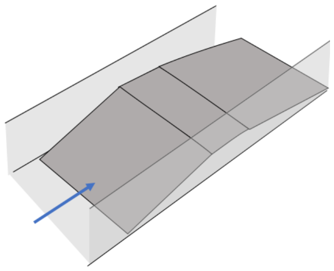
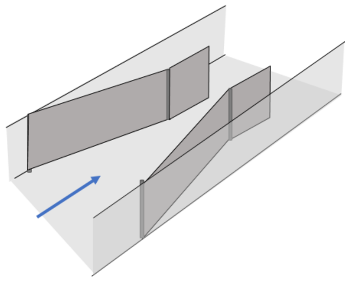
3.7 PHASE III: CANAL OPTIMISATION

Phase 3 consisted of alternative measures of increasing the flow velocity using other possible hydraulic theories related to altering the canal itself.

3.7.1 Optimisation by canal alterations

A summary of the canal optimisation options considered can be seen in Table 3-10. These techniques are used to narrow the flow area, mimicking a venturi flow phenomenon.

Table 3-10: Canal optimisation options considered

OPTIMISATION FORMS	PICTURE	DESIGN THEORY
Lifting canal bottom		The flow in the canal is subcritical therefore this theory applies where the bottom level is raised causing the phenomenon. For the design of the "ramp" type structure to raise the channel bed a typical venturi design was considered with a convergence angle of 21degrees
Narrowing canal sides		By the narrowing of the canal sides the flow area is reduced over a short distance thus increasing the flow velocity. A system was designed where the canal can be narrowed to a total selected blockage of 2.4m (1.2m on each side) thus theoretically increasing the velocity without causing the canal to overtop (Appendix C).

For practical purposes and ease of operation the option of narrowing the canal sides was used.

3.7.2 Design considerations

The following factors on the design and working of the system with the added optimisation method was considered:

i. Adding a canal narrowing effect could result in blockage from large debris which would otherwise pass the large width sections.

ii. It must be ensured the reduced water level still allows for turbine submergence (reduced level in throat section).

iii. The foundations and fastening cables was initially designed to function under extra load for testing purposes and therefore was assumed sufficient for this testing phase.

iv. Due to the flat slope of the canal the backwater effect is great and critical sections where little freeboard exists upstream could overflow, maximum narrowed width was selected accordingly.

v. The balance between water level drop and upstream damming levels relative to the obtainable velocity had to be found to ensure an optimal narrowed section.

The final selection of an optimal narrowing of the plates was done through a series of hand calculations and numerical modelling using HEC-RAS (details seen in Appendix C). The freeboard available and maximum damming at a series of narrowed widths were considered and the optimal scenario where freeboard is not exceeded and the highest velocity is obtained was found to be a narrowed width of around 2.5m, further narrowing resulted in overtopping possibilities. The details of the calculation can be seen in Appendix B.

3.7.3 Optimisation by canal narrowing

For the final design of this phase a system of plates with a jacking system was designed which can vary the narrowed width of the canal. The maximum extension of the jacks was decided based on calculations (Appendix C).

The final designs can be seen in Figure 3-31 and Figure 3-32.

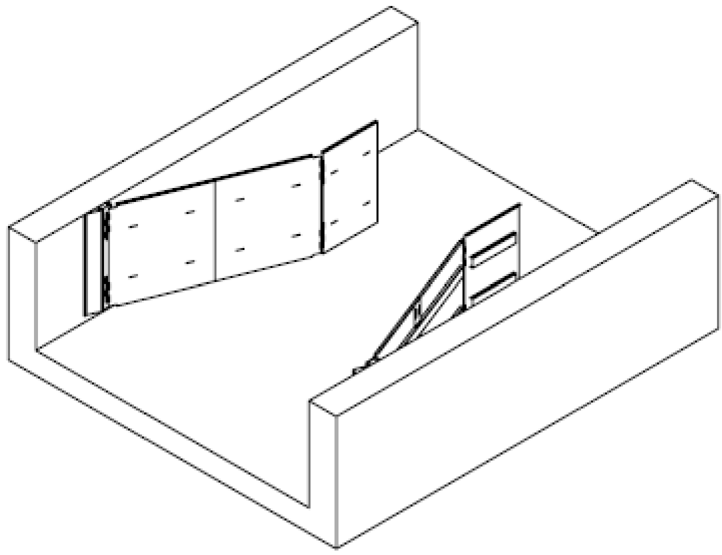


Figure 3-31: Side plate design

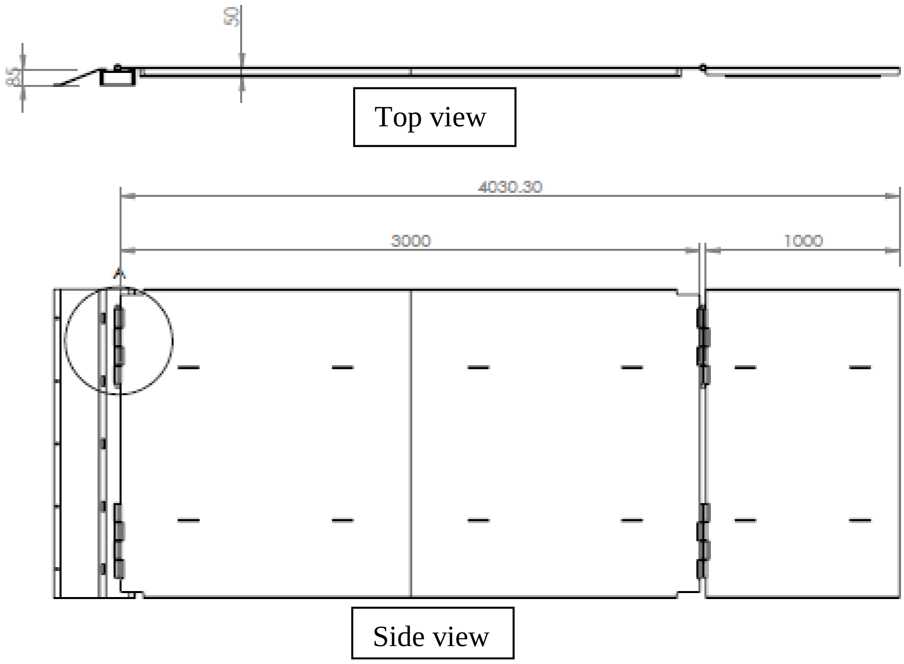


Figure 3-32: Side plate design and dimensions

3.8 NUMERICAL MODELLING

A section of the Boegoeberg canal was modelled on HEC-RAS software to allow a better understanding of the resilience of the canal, backwater effect and overall properties of the canal testing section. The exact blockage of the operating HK turbine with spinning blades is unknown, as mentioned previously numerous theories to modelling this have been assumed. However, for this study only the effects of the grid blockage of the turbine were analysed.

The HEC-RAS 1D model allows precautionary testing of the effects of possible turbine blockage on the canal system. This was done to give an initial indication of possible overtopping with the available freeboard during any testing phase or during the working life of such an installation (resulting from turbine grid blockage).

3.8.1 Boegoeberg canal model

The Boegoeberg canal section is a concrete lined canal of relatively uniform cross section (around the HK testing section). The canal design drawings were used to obtain cross sectional details and bed slopes of the modelled section as shown in Figure 3-33. A typical cross section can be seen in Figure 3-34. Each cross section ranged in reach lengths (between cross sections) varying between 50m and 400m (which were supplied on the drawing). Cross sections at smaller intervals were then interpolated where necessary to obtain more exact results.

The properties of the canal were assumed from photos/site visits during the project pre-feasibility study. These can be seen in Table 3-11. The flow was found from the first of the datasets measured on the site-installed flow meter (as shown later in section 5.1)

It should be noted the model was based on plan drawings of the canal, which might vary to actual dimensions/slopes of the existing canal system. This model was developed as a reference only, to allow pre-development insight on possible overtopping which should be monitored during installation and testing.

Figure 3-33: HEC-RAS model

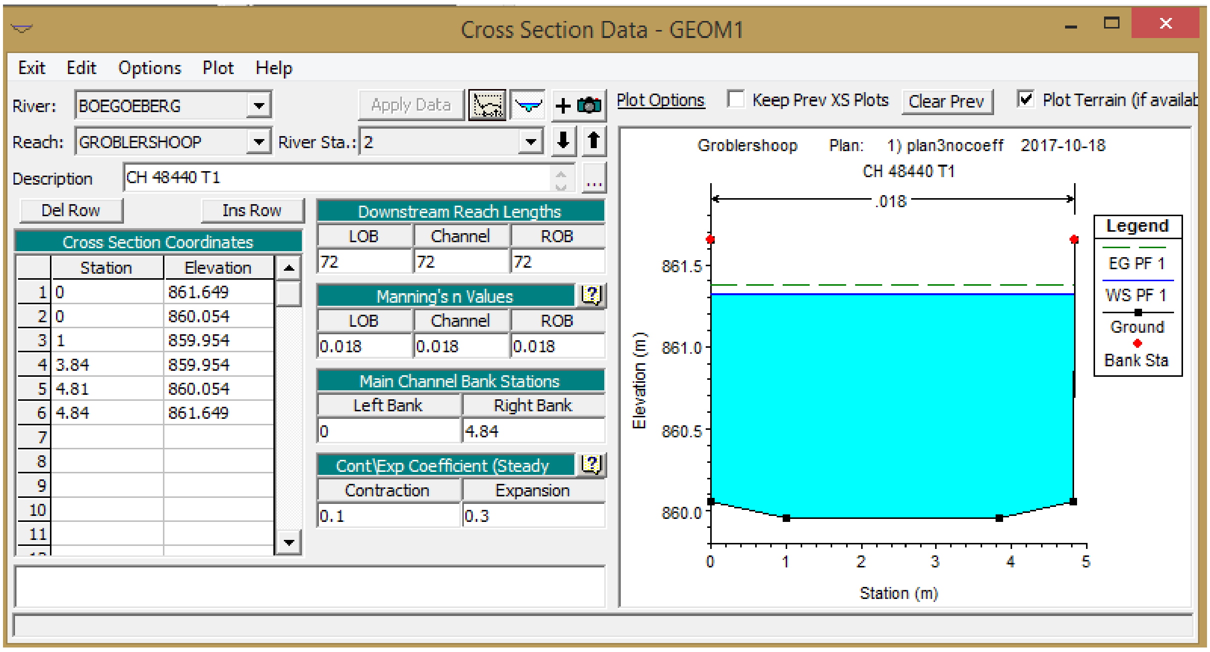


Figure 3-34: HEC-RAS model typical cross-section

Table 3-11: HEC-RAS model properties

PROPERTY		VALUE
Flow (m^3/s)		6.6
Manning roughness values	Left bank	0.018
	Channel bed	0.018
	Right bank	0.018
Coefficient of contraction		0.1 (very slight)
Coefficient of expansion		0.3 (very slight)
Flow regime		Mixed (for possible critical flow sections)
Upstream boundary condition		Fixed flow

The canal testing section lies in a relatively flat section of the canal where up to 1kilometre upstream the average canal bed slope is less than 0.0013m/m with the canal bed elevation difference 2km upstream being 1m.

3.8.2 Phase 1 numerical model

For phase 1 of the project the "worst case" of full turbine grid blockage was modelled by an inline structure with the same dimensions as the turbine grid and housing as shown in Figure 3-35. The length of the blockage was chosen as 3metres which is the length of the turbine plus an additional 0.75 metres allowing for possible debris build up (trees, shrubs etc.)

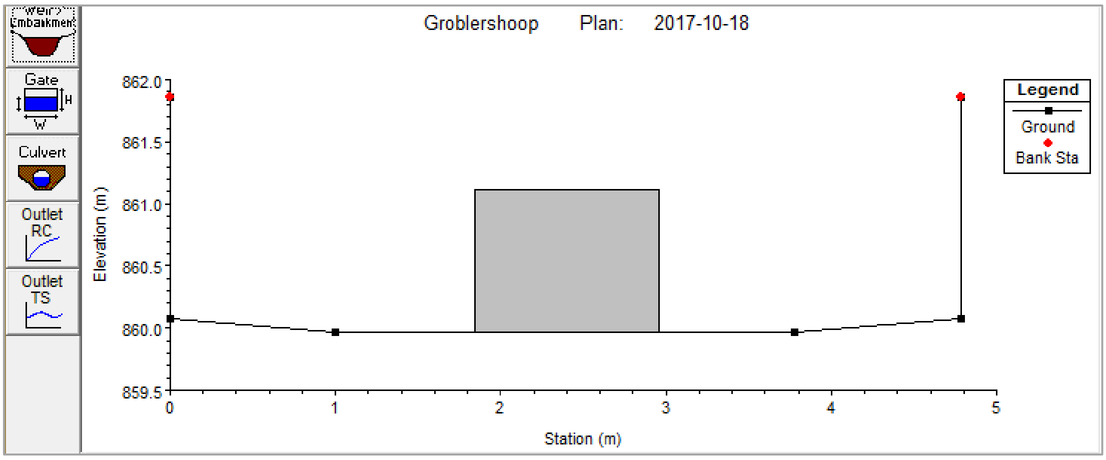


Figure 3-35: Phase 1 blocked turbine HEC-RAS model

The HEC-RAS model included the properties shown previously in Table 3-11. The maximum damming level was found to be 40mm just upstream of the turbine, which then returns to normal flow depth approximately 2.7km upstream of the installation point. This large backwater effect resulted from the relatively flat canal and subcritical flow pattern. The highest damming levels lie within the available freeboard and therefore no overtopping is expected. The damming levels comparing to the "no turbine" scenario can be seen in Figure 3-36.

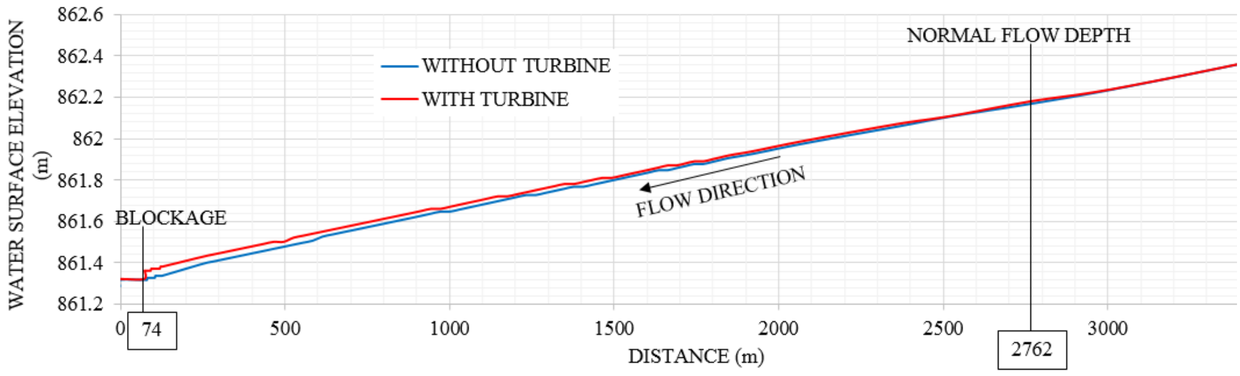


Figure 3-36: Phase 1 blockage damming levels

3.8.3 Phase 2 numerical model

Phase 2 of the project involved the addition of guide plates to the turbine. By this addition a higher blockage is experienced in the canal. Once again, an inline structure was used to model the blockage (Figure 3-37). The blockage effects of the turbine with the guide plate addition can be seen in Figure 3-38. The maximum blockage just upstream of the turbine was found to be 260mm and the backwater recovery distance at 5.77 kilometres.

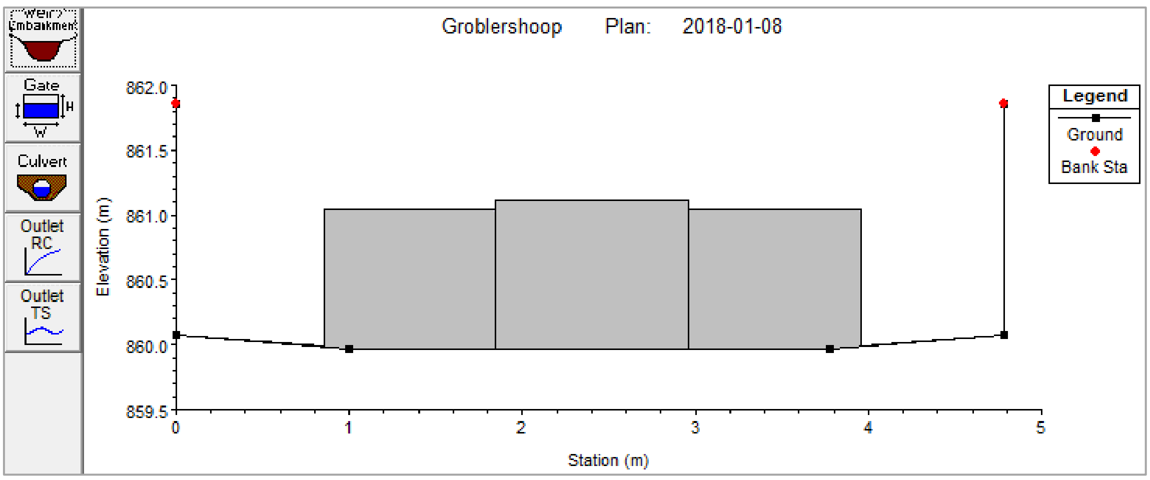


Figure 3-37: Phase 2 blocked turbine HEC-RAS model

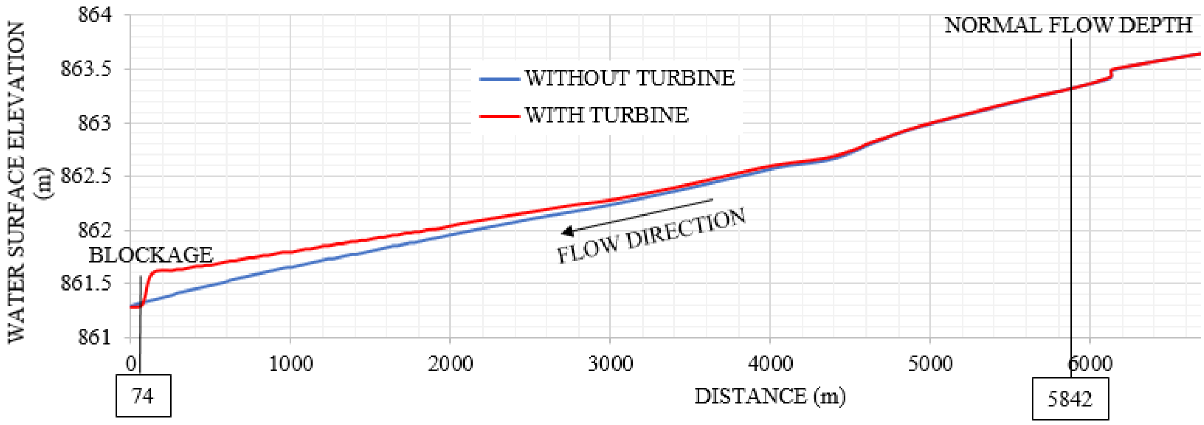


Figure 3-38: Phase 2 blockage damming levels

A number of critical regions with little freeboard were identified, where the canal walls should be heightened to prevent possible overtopping as shown in Table 3-12

Table 3-12: Phase 2 critical sections

DISTANCE (m)	FREEBOARD AVAILABLE (mm)	DAMMING (mm)
917	70	160
1177	90	140
1206	80	140

3.8.4 Phase 3 numerical model

The canal was narrowed during phase 3 of the project. To model the narrowed width new cross sections were added to the HEC-RAS model to simulate the new section, as shown in Figure 3-39. The blocked turbine was added to the narrowed section similarly to phase 1 and 2, as shown in Figure 3-40.

Both scenarios at the narrowing of the canal with no turbine and with a fully blocked turbine can be seen in Figure 3-41. The maximum damming level of the phase 3 canal narrowing with a fully blocked turbine grid was found to be around 290mm just upstream of the blockage and the recovery distance of damming levels was 6.3km upstream. For the scenario of narrowing alone without the turbine the damming was found to be around 70mm with a recovery distance of 4.2km upstream.

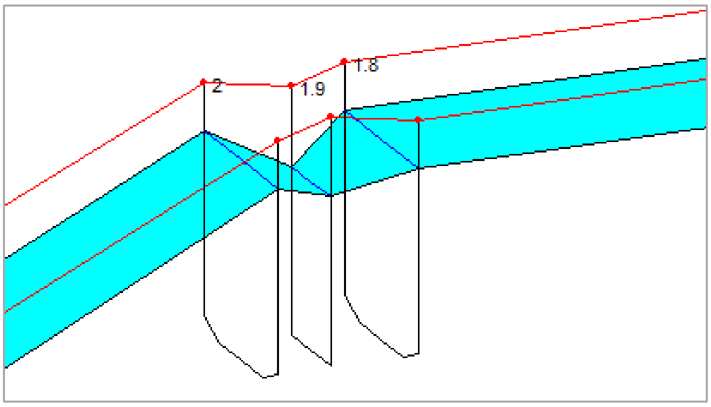


Figure 3-39: Narrowed section

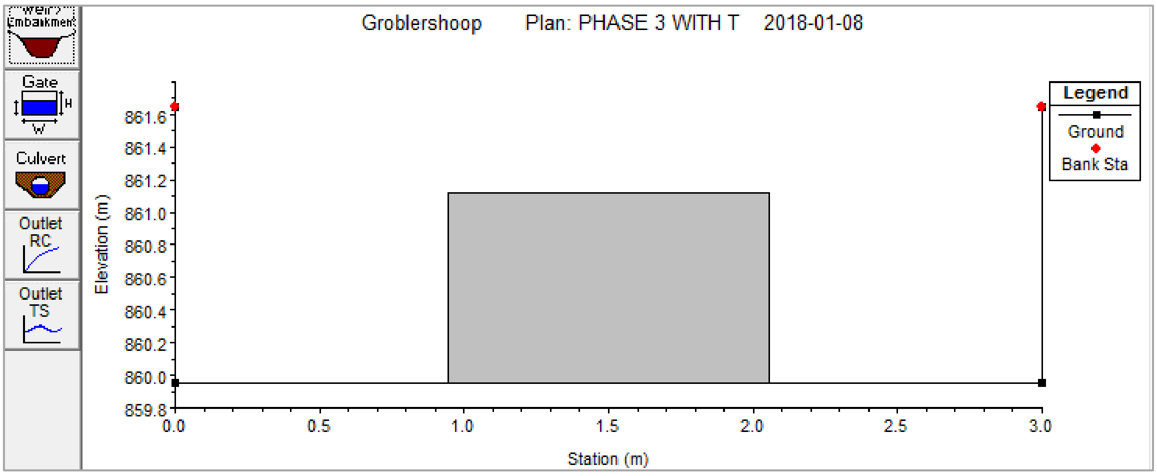


Figure 3-40: Phase 3 blocked turbine HEC-RAS model

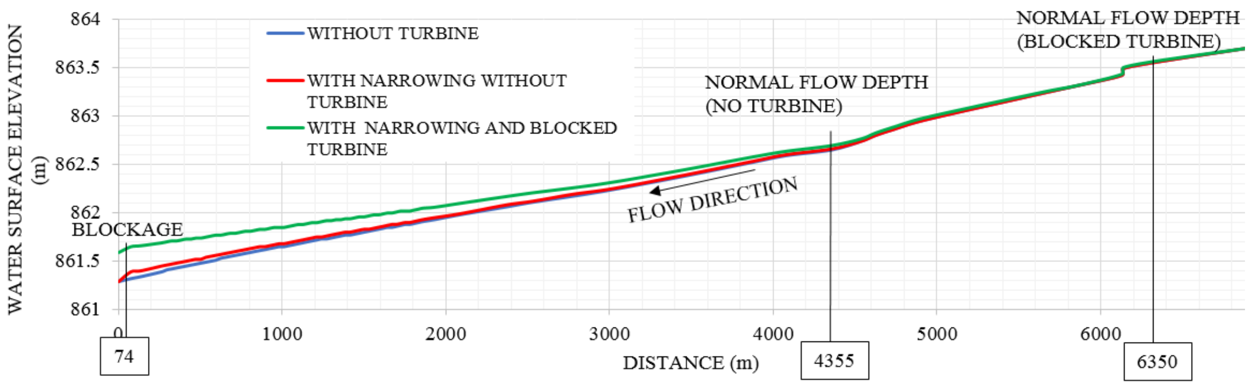


Figure 3-41: Phase 3 blockage damming levels

During the blocked turbine phase 3 scenario with the narrowed width, the canal showed overtopping at distances 440-1800m which lies about 360-1700m upstream of the blockage. Consideration to heightening of this section should be made when permanent narrowing is considered, however it must be noted the original canal drawings were used to create the model, and alterations (in terms of heightening the canal wall) could have been made since initial construction. Additional critical sections can be seen in Table 3-13.

Table 3-13: Phase 3 critical sections

DISTANCE (m)	FREEBOARD AVAILABLE (mm)	DAMMING (mm)
440-1800	None (overtopping)	130-260
74-135	10-70mm	290-320
1800-3500	0-80mm	70-130

3.8.5 Numerical model results summary

The results of the testing of blockage effects using HEC-RAS is summarized in Table 3-14.

Table 3-14: HEC-RAS blockage modelling results

BLOCKAGE SCENARIO	PHASE 1	PHASE 2	PHASE 3
Maximum damming level (mm)	±40	±260	±290
Occurrence of maximum damming	At installation section	At installation section	At installation section
Recovery distance of damming (m)	2762	5770	6273
Occurrence of overtopping	None	None	Distance 440-1800m
Critical sections (chainage; freeboard available)	None	• 917m; 70mm • 1177-1206m; 80-90mm	• 74-135m;10-70mm • 1800-3500m; 0-80mm

3.9 MEASURING EQUIPMENT USED

During the experimental procedure the instrumentation shown in Table 3-15 was used. As shown in the table the power output from the inverters was measured, this power output will include a certain amount of losses due to the rectifier conversion of the unstable AC generated by the turbine conversion to DC and thereafter back to stable AC. Additional sensor specifications (layout etc.) are described in Appendix A.

Table 3-15: Measuring equipment

MEASURING EQUIPMENT	OUTPUT	PICTURE
Hand-held propeller type velocity meter.	Point velocity (m/s) at any point in flow.	
Level sensors.	Water level sensor and recording device to measure water depth and possible damming.	
Fixed Speedy velocity sensor.	Fixed velocity sensor to measure average velocity (m/s) of flow over a representative cross section. Back calculated flow rate (Q).	

MEASURING EQUIPMENT	OUTPUT	PICTURE
Inverters.	RS485 Port together with power monitor software used to measure the power output of each turbine (W) This measures Power output at 4second intervals.	
Logging station	An array of Campbell Scientific loggers was connected to log all fixed flow and level sensors at a specific set time interval	

4 EXPERIMENTAL CONSTRUCTION

After the design of the experimental setup, the testing station was constructed, as is summarized in this chapter.

4.1 CIVIL WORKS

The civil works required for the installation can be seen in Table 4-1, the processes were completed concurrently until the site was complete and ready for installation and testing.

Table 4-1: Civil works construction processes

ITEM	IMAGES
Site clearance: The surrounding area was cleared from overgrowth and levelled to allow access to the area.	
Building refurbishment: The old pump station buildings were refurbished, cracks were filled, it was cleaned out, painted and security doors were installed.	
Paving: The cleared site was paved to allow easy walking/driving on the area around the turbine installation points.	

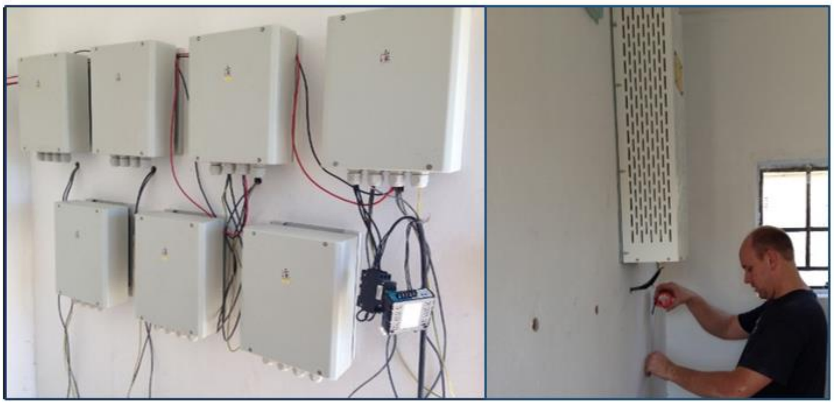
ITEM	IMAGES
Security measures: Palisade fencing was erected around the installation section as a preventative measure for theft and also to form a barrier between accessible areas and the installation section to prevent potential swimming people.	
Installation of electrical duct: The site was cleared and paved under which an electrical duct pipe of 110mm was place along the canal section, connecting the canal section to the turbine equipment room. This will allow safer installation of cables which will then be protected against possible theft (as it is not visible) and tampering.	
Turbine assembly: With the help of the manufacturers the turbines were assembled, which included assembling the front grid structure and fixing the turbine “nose”.	
Concrete block foundation: The concrete block foundations and steel reinforcing was designed as specified and cast.	

4.2 MEASUREMENT AND CONTROL EQUIPMENT INSTALLATION

The installation of the fixed measuring equipment and control equipment required for the HK turbines can be seen in Table 4-2. The installation of the measuring equipment had to be done during a canal dry period and was done as soon as was possible to allow accurate measurement of flow and water levels prior to installation.

Table 4-2: Installation of measuring and control equipment

ITEM	IMAGES
Installation of velocity meter: The speedy velocity sensor was fastened with screws onto the canal bed parallel to the flowlines. The communication cable was inserted into a garden hose for extra protection which was also fastened on the canal bottom.	
Installation of level sensor: The level sensor was fastened onto a steel plate which was bolted onto a steel angle iron spanning the width of the canal.	
Mounting and configuration of measuring station and inverters: inverters and measuring/data logging equipment was mounted and joined in the required sequence.	

ITEM	IMAGES
Mounting and configuration of rectifiers: The rectifiers were mounted and joined in the required sequence to the inverters and dump load's.	
Mounting and configuration of dump loads: dump loads were mounted and joined in the required sequence.	

5 TESTING AND DATA COLLECTION

After initial site preparation and installation of the measuring stations, flow data in the testing section was collected and analysed. Thereafter, the testing procedure shown in section 3.4 was carried out in the proposed phases. The results of testing and data collection are represented and discussed in this chapter.

5.1 FLOW DATA

During the turbine test installation in August 2017 the flow meter was installed in the turbine installation section to obtain accurate readings of the flow rate at the site. The flow rate measured from 06/08/2017 to the 04/11/2017 is depicted in Figure 5-1. The average flow rate (in the intervals where the canal is under operation) is 6.6m^3/s which is significantly lower than what had been recorded at the upstream gauging stations (as shown in Figure 5-2), the following could be contributing factors for the reasoning of this:

i. Numerous legal/illegal abstraction points exist between the upstream gauging station and the installation point which (were not known).
ii. Inaccuracies of the gauging station.
iii. The canal could have leakage losses between the gauging station and point of installation.
iv. Evaporations losses (extremely hot climate)

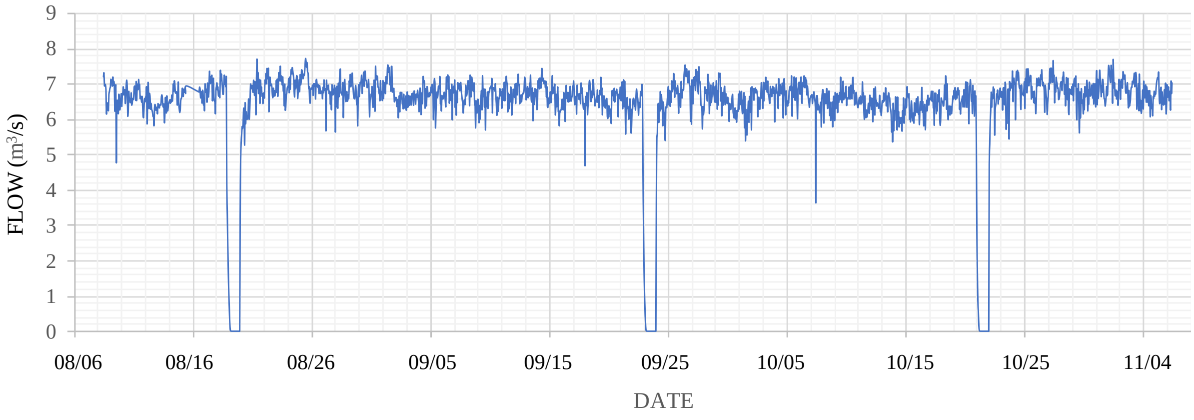


Figure 5-1: Measured flow rate

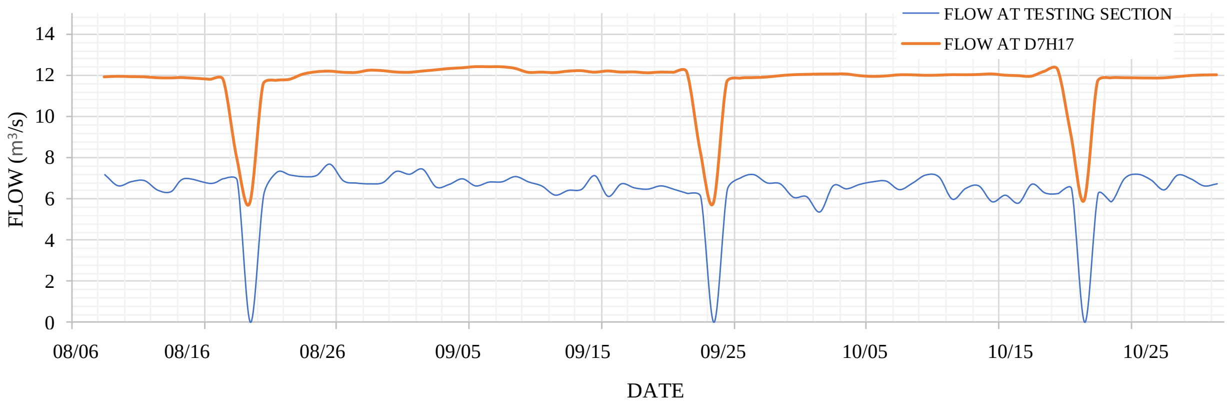


Figure 5-2: Comparison of flow data at the testing section to upstream gauging station

5.2 VELOCITY DATA

From the flow data shown in section 5.1 the average flow velocity at the testing section which lies in a straight section 50 meters upstream of the turbine installation point was found to be 0.95m/s (excluding the canal “shut-off” periods). The velocity during the testing period can be seen in Figure 5-3.

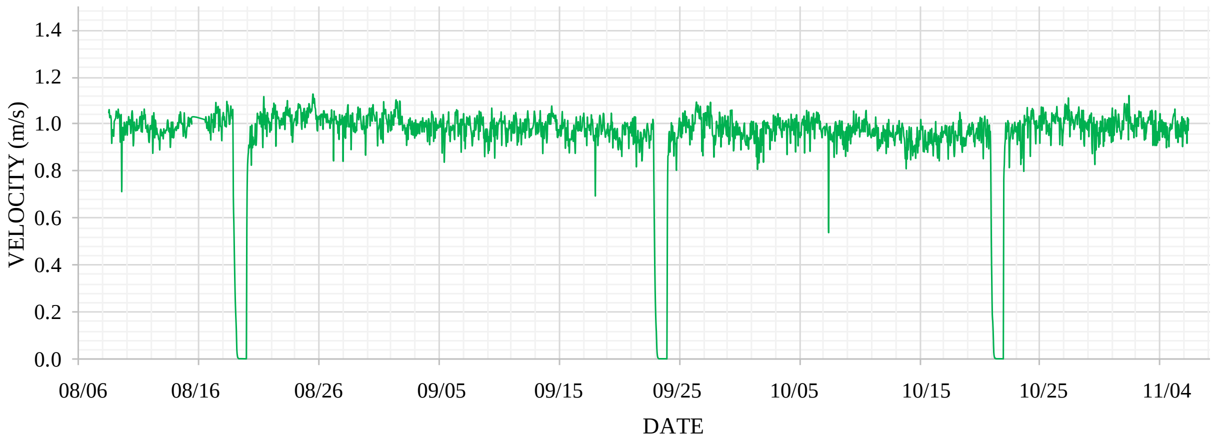


Figure 5-3: Measured flow velocity

The point velocity at the left, right and centre positions over the installation section were measured with a portable propeller type velocity meter (as described previously in Table 3-15). The average readings over a representative period were taken and these displayed in Figure 5-4. The flow during the measurement period was measured and can also be seen on Figure 5-4 (for comparative purposes). The influence of the bend can be seen in this velocity distribution.

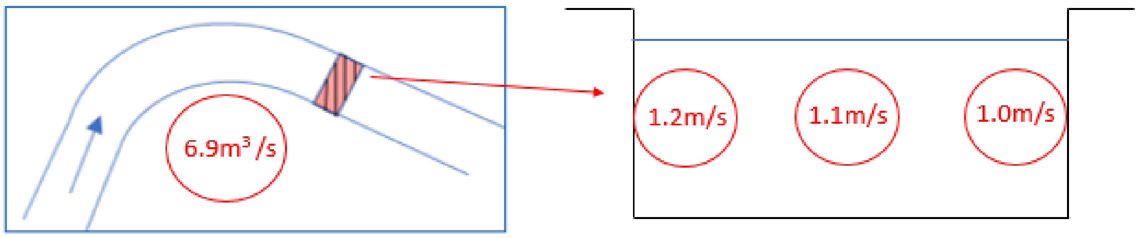


Figure 5-4: Velocity distribution

5.3 PHASE 1: TURBINE PRIMARY INSTALLATION

As was described in Table 3-8, phase 1 involved installing and testing the turbine as provided by the manufacturer, without alterations.

5.3.1 Testing procedure

The following tests were done on the unaltered turbine as numbered in the proposed testing schedule under phase 1, the placements (A, B, C) can be seen in Figure 5-5:

I. Turbine placement in the centre of the canal (Position A)
II. Completely blocked turbine grid placed in the canal centre (Position A)
III. Turbine placement at the right edge of the canal (outside of the bend) (Position B) and at the left edge of the canal cross section (inside of bend) (Position C)

As depicted in Figure 5-5 the test section is situated at the exit of a roughly 90-degree bend. For test 3.III the turbine is placed the canal bed edge which is slightly raised thus causing the turbines to be placed slightly skewed, however this should have no effect on power production as the rotors remain perpendicular to the flow lines.

At these positions, the following measurements were taken:

i. Power output (when relevant);
ii. Level/damming at positions (1) (2) and (3) as shown in Figure 5-6;
iii. Damming level 50m upstream.

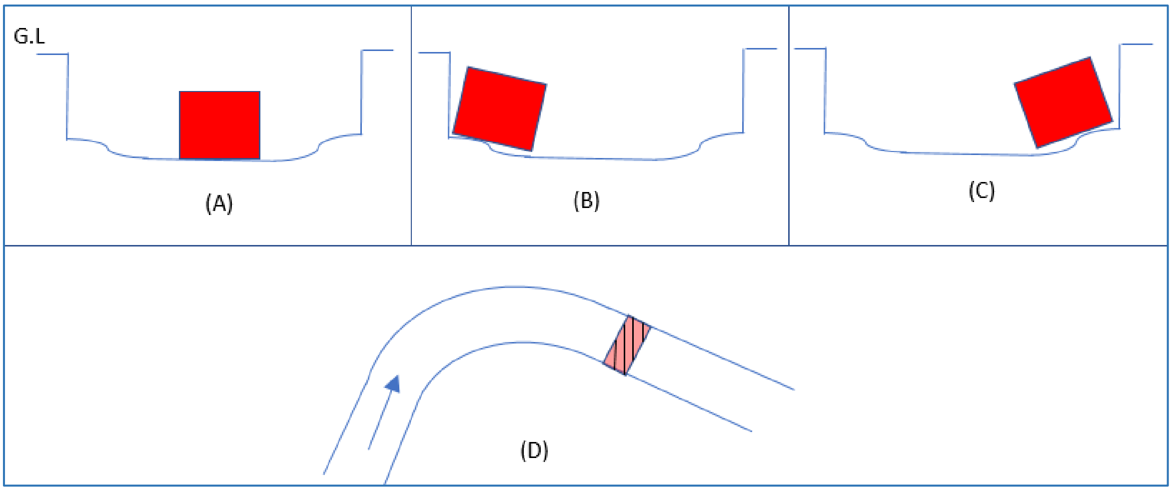


Figure 5-5: Phase 1 placement of turbine (A) centre (B) left (C) right and (D) position of test section in the Boegoeberg Canal

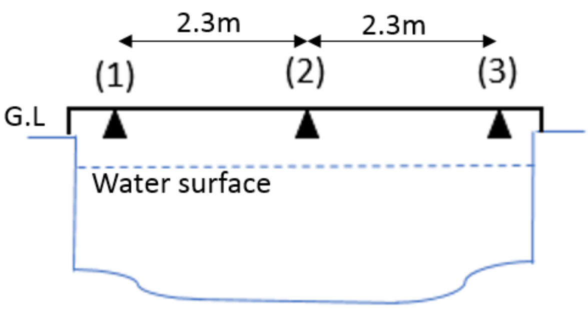


Figure 5-6: Level sensor placement

5.3.2 Results

The results from the phase I testing were as follows:

i. Flow rate

The average flow rate (measured in the installation section) over the Phase 1 testing period was 6.58m^3/s.

ii. Power Output

The power measured using the Power Monitor 011.0.1 application, can be seen in Figure 5-7. The power output line of best fit over the field measurements is shown in dotted lines. The average power output of each position is also shown in Table 5-1. Each timestep shown in Figure 5-7 relates to 4 seconds resulting in a total run time of 200seconds for each test.

Table 5-1: Phase 1 power output at various turbine positions

TEST	TURBINE POSITION	POWER OUTPUT (W)	FLOW RATE (m^3/s)
1.I	A	166	6.56
1.IIa	B	228	6.47
1.IIb	C	127	6.52
1.III	A	0	6.29

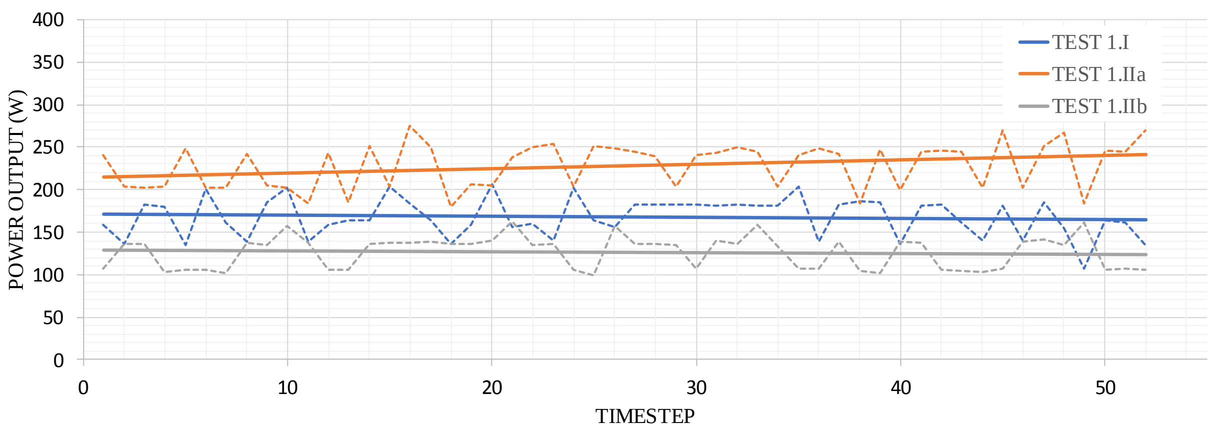


Figure 5-7: Phase 1 graphical power output

In test 1.IIa the power output seems to rise over the time interval, however the flow rate during this interval was relatively constant (not increasing). This could indicate the turbine efficiency increases over a specific start-up time.

iii. Water level at the installation point

The water levels measured using the Pulsar ultrasonic level sensors throughout the testing scenarios can be seen graphically in Figure 5-8. It must be noted these levels were adjusted relative to the most recent "no-turbine" scenario around that time point, as the flow does vary over time and testing was done over a number of days (the flow rate changes during each test can be seen in Table 5-1).

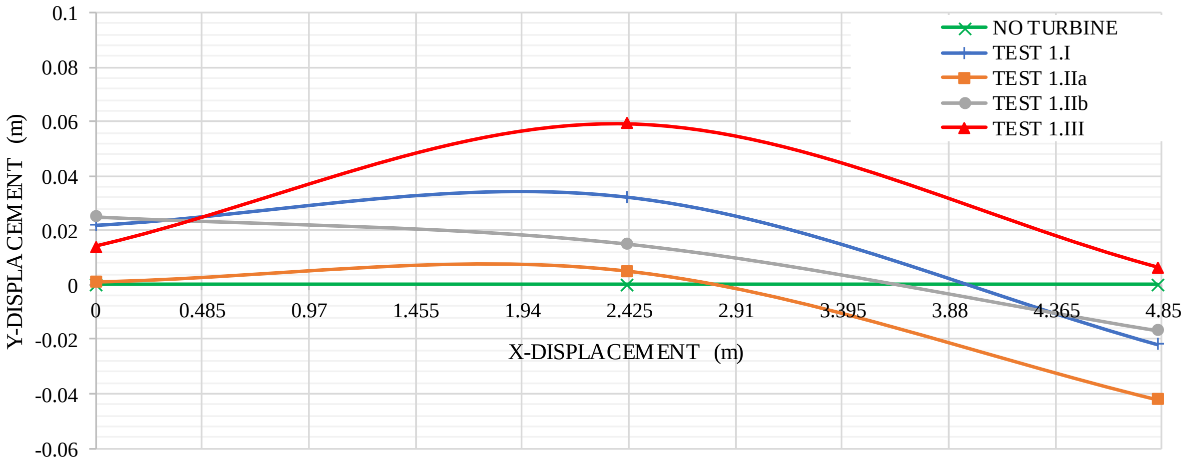


Figure 5-8: Phase 1 testing water levels

As observed in Figure 5-8 the water levels rise slightly on the outer bend (position 1 sensor) and lower slightly on the inner canal bend (position 3 sensor). However, as the blockage is increased (Test 1.III) the damming levels return to a more symmetrical displacement.

The maximum blockage observed with the operating turbine placed in the canal is a 30mm rise in water level during test 1.I. Although test 1.IIa produced the highest power output, the damming levels over the turbine during test 1.I were slightly higher (30mm comparing to 25mm on the outer edge) however the flow rate was slightly higher during test 1.I which could be a cause for the minor change.

The maximum damming resulting from a completely blocked turbine was found to be around 60mm. which falls well within the available freeboard.

iv. <u>Water level 50m upstream</u>

The waters level 50m upstream of the turbine at the flow meter installation point were measured and allow indication of upstream damming levels. The water level was measured at a point in the centre of the canal (Figure 5-6 position (2)). The average water level during each scenario can be seen in Table 5-2. The upstream levels are shown relative to the bottom of the canal centre as indicated in Figure 5-9.

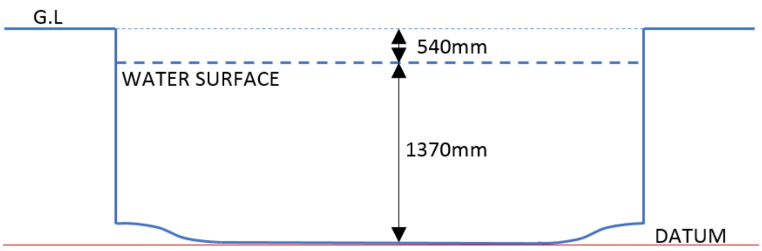


Figure 5-9: Phase 1 datum 50m upstream ("no turbine" scenario)

Table 5-2: Phase 1 water levels 50m upstream of installation

SCENARIO	AVERAGE LEVEL (m)	FLOW (m^3/s)	RELATIVE DAMMING (mm)
No Turbine	1.37	6.31	0
Test 1.I (centre)	1.40	6.56	30
Test 1.IIa (left)	1.39	6.47	20
Test 1.IIb (right)	1.40	6.52	30
Test 1.III (blocked)	1.42	6.29	50

A maximum upstream damming level of 30mm was observed during the operating turbine testing phase and 50mm damming during turbine blockage. These levels are comparable to the damming levels at the installation point. Proving the high backwater effect due to a relatively low canal bed gradient operating at subcritical flow conditions.

v. Numerical model blockage comparison

Test 1.III (turbine blockage) allows comparison of the field test damming levels and the HEC-RAS model results. The comparison of results can be seen in Table 5-3. The results differ by 20mm, however a 10mm constant difference in damming over the 50m section in results is observed which when taken as a percentage of hydraulic depth results in 99.3% accuracy.

Table 5-3: Phase 1 HEC-RAS blockage model comparison

SCENARIO	MAX DAMMING LEVEL AT THE INSTALLATION POINT (mm)	MAX DAMMING LEVEL 50m USTREAM OF THE INSTALLATION POINT (mm)
HEC-RAS Model	40	30
Field testing	60	50

The difference in results could be due to:

- A flow change during the testing phase and numerical analysis phase.
- Inaccuracy of estimated parameters (roughness values);
- Slope differences from the Boegoeberg canal section and pre-construction drawings (which were used to model the system);
- The upward angle on the grid (which was measured as a vertical wall on HEC-RAS) could also had to this difference.

This change could indicate an under-estimation of damming levels from numerical modelling, therefore the effect of blockages should be carefully monitored.

vi. Visual inspection

During the testing procedure a visual analysis on the flow behaviour was done and can be observed in Table 5-4.

Table 5-4: Phase 1 visual inspection

SCENARIO	PICTURE
Test 1.I- Turbine centre installation: • No significant visible damming or interference in flow path caused by the turbine.	
Test 1.III- Turbine centre installation with full blockage: • Wood was fastened to the grid to simulate a grid blockage scenario.	

<table>
<tr><th>SCENARIO</th><th>PICTURE</th></tr>
<tr><td>Test 1.III- Turbine centre installation with full blockage:
• Some turbulence is observed over the turbine.
• The blockage does not have a significant damming effect on the canal.</td><td></td></tr>
</table>

5.3.3 Phase 1 conclusions

During the phase 1 testing period the following observations were made and conclusions drawn:

i. The turbine was installed as provided by the manufacturer and proved to have an extremely low power output, with a maximum (single test average) power output of 228W when placed on the left edge of the installation section where the highest flow velocity was measured (due to the upstream bend in the canal). This lower power output was expected due to the low available velocity in the installation section.

ii. During Test 1.IIa the power output trendline increased slightly which could indicate the turbine requiring a start-up period until a stable average is obtained, however, the data from test1.I and 1.IIb did not indicate the same trend.

iii. No significant critical damming resulted from full turbine grid blockage when exposed to a flow velocity of around 1m/s.

5.4 PHASE 2: TURBINE OPTIMIZATION

Phase 2 (as described in Table 3-8) involved attaching specifically designed and manufactured steel guide plates to the turbine. Theoretically this should increase the power output by reducing the flow area thus guiding more flow through the turbine, thereby increasing the flow velocity.

5.4.1 Testing procedure

The following tests were performed on the altered turbine as numbered in the proposed testing schedule under phase 2. The placements can be seen in Figure 5-10:

I. Turbine with guide plates: Turbine placement in centre of the canal (Position A);

II. Turbine with guide plates: Turbine placement of the right edge of the canal on the (outside of the bend) (Position B);

III. Turbine with guide plates and top plate: Turbine placement in centre of the canal (Position A);

IV. Turbine with guide plates and top plate: Turbine placement of the right edge of the canal on the (outside of the bend) (Position B).

The turbine will be slightly skewed when placed on the canal edge as the canal bed is curved on the edges (Figure 5-10). The turbine was only tested on the outer bend and centre as the crane cannot support this weight (of added plates) over the reach required to place the turbine on the right edge. Also, it was previously revealed the worst generating potential occurred on the right edge and it will therefore not be considered for installation.

At these positions, the following measurements were taken:

i. Power output (when relevant).
ii. Level/damming level at (1) (2) and (3) as was shown in Figure 5-6.

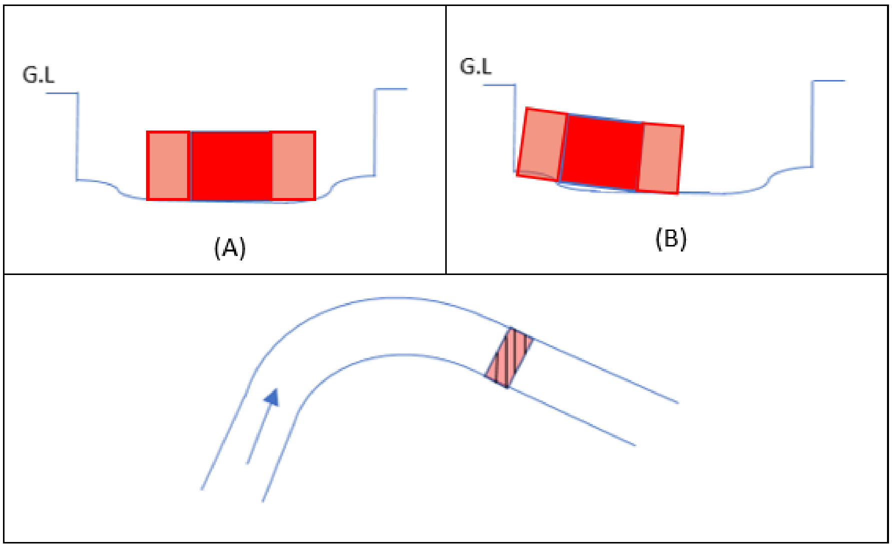


Figure 5-10: Phase 2 placement of turbine (A) centre (B) left position of test section in the Boegoeberg canal

5.4.2 Guide plate addition results

The results from phase 2 testing are as follows:

i. Flow rate

The average flow rate over the phase 2 testing period was 6.68m^3/s.

ii. Power Output

The power output measured using the Power Monitor 011.0.1 application for each test can be seen in Figure 5-11. The average power output can be seen in a linear line (showing the moving average power) over the field measurements indicated. The average power output of each position is shown in Table 5-5. Each timestep measured (as in Figure 5-11) is equal to 4 seconds, resulting in a total run time of 200 seconds for each test.

Table 5-5: Phase 2 power output at various turbine positions

TEST	TURBINE POSITION	POWER OUTPUT (W)	FLOW RATE (m^3/s)
I	A	159	6.67
II	B	298	6.69

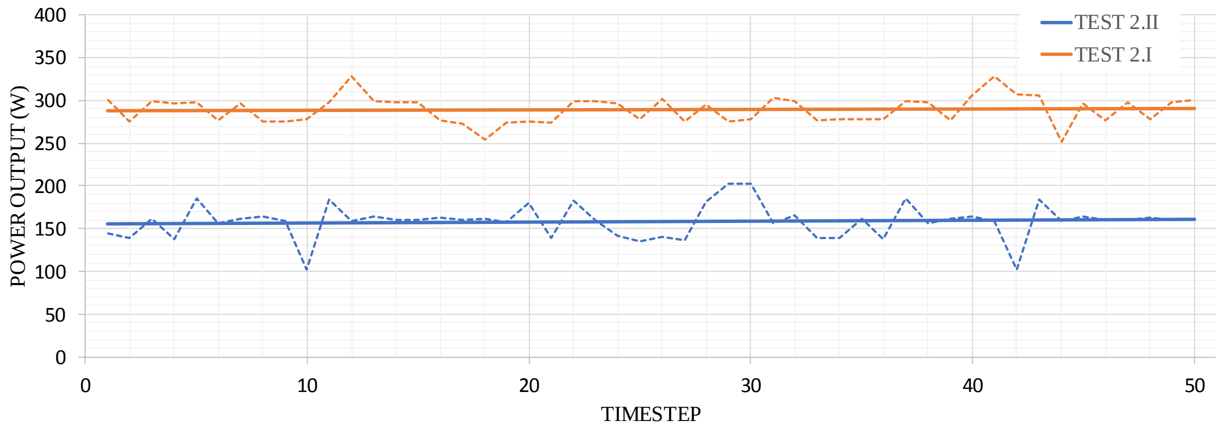


Figure 5-11: Phase 2 graphical power output

iii. Water level at installation point

The water level at the installation point during phase 2 testing with the attached guide plates can be seen in Figure 5-12. The sensor positions once again refer to those specified previously in Figure 5-10.

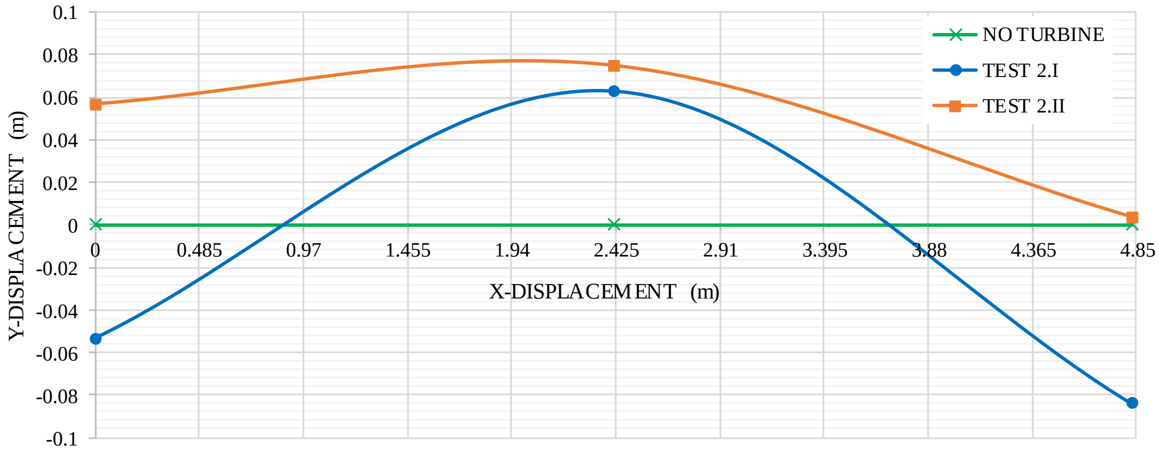


Figure 5-12: Damming levels upstream of turbine with guide plate addition

The maximum damming level observed during test 2.I (centre installation) is 63mm and 75mm during test 2.II (outer bend installation). When the turbine was placed at a slightly higher flow velocity (at the outer bend) the power output increased by 38%. This increase in power output resulted in a 10mm level increase (with a relatively constant flow rate between tests).

iv. Water level 50m upstream

The water levels 50m upstream of the turbine at the flow meter installation point were measured, allowing observation of any significant damming upstream of the system. The water level was measured at a point in the centre (sensor position (2)) of the canal. The average water level during each scenario can be seen in Table 5-6.

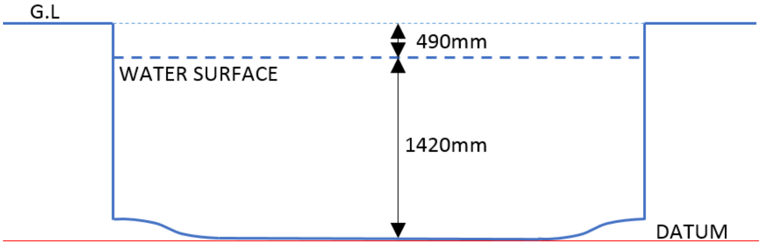


Figure 5-13: Phase 2 datum 50m upstream ("no turbine" scenario)

Table 5-6: Phase 2 water level 50m upstream of installation

SCENARIO	AVERAGE LEVEL (m)	FLOW (m^3/s)	RELATIVE DAMMING (mm)
No Turbine	1.42	6.68	0
Test 2.I (centre)	1.46	6.67	40
Test 2.II (left)	1.47	6.69	50

v. Visual inspection

During the testing procedure a visual inspection was done as shown in Table 5-7.

Table 5-7: Phase 2-I and 2-II visual inspection

SCENARIO	PICTURE
Test 2.I- Turbine centre installation with guide plates: • Turbulence formed behind guide plates, proving the plates act as a weir, with most of the flow moving over the plate. • The slight damming upstream of the turbine is clearly seen. • Left and right level sensors measure levels downstream of the plates and therefore do not measure the relative damming upstream caused by the blockage.	
Test 2.I- Turbine with guide plates lifted after testing: • A flat iron welded to both plates had to be added to the system to prevent the guide plates from bending outwards. • Debris collection on guide plate edges and front retaining structure observed. • Debris collection on lifting system observed.	

SCENARIO	PICTURE
Test 2.II- Turbine on outer edge of the bend with guide plates: • Damming can be observed. • The turbine was swivelled clockwise slightly (facing downstream) caused by the faster flow at the canal left edge (pushing against the left guide plate). Thus resulting in the blade not spinning perpendicular to the flow lines, which could influence power output.	

5.4.3 Top plate addition results

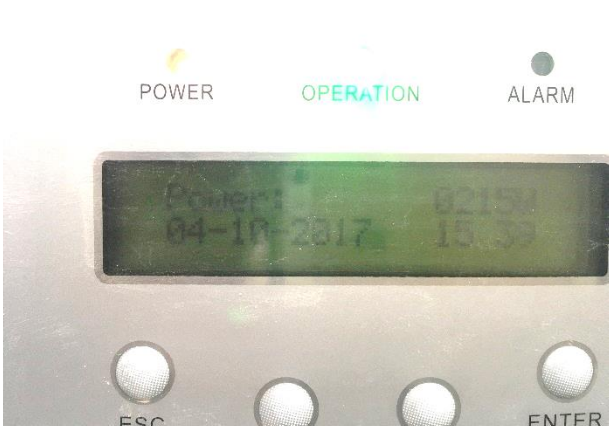
Collection of results with the added top plate were not possible as the turbine was extremely unstable when placed in the canal with the top plate, the turbine moved laterally and a short visual reading of the power output showed no significant increase in power output. Only a visual inspection of this phase was done:

vi. Visual inspection

During the testing procedure the flow behaviour could be observed as shown in Table 5-8.

Table 5-8: Phase 2-III and 2-IV visual inspection

SCENARIO	PICTURE
Test 2-IV-Turbine offet installation with guide plates and top plates: • A large amount turbulence formed as the turbine was attempted to be placed in position.	

SCENARIO	PICTURE
Test 2-III- Turbine centre installation with guide plates and top plates: • The turbine was front-heavy as the top plate addition added a large amount of weight which then resulted in difficult placement at the plates touched the water.	
Test 2-IIII- Turbine centre installation with guide plates and top plates: • The turbulence resulted in the turbine moving laterally as it was attempted to be placed.	
Test 2-III- Turbine centre installation with guide plates and top plates: • The maximum output reading was 215W, however the turbine was unstable and moving laterally as the reading was taken which is not an accurate depiction of the obtainable output from this optimisation measure.	

5.4.4 Phase 2 conclusions

The phase 2 testing of a possible optimisation technique led to the following conclusions:

i. The addition of guide plates to the modular turbine unit resulted in a maximum power output of 298W at a section with point velocity of 1.2m/s (canal left). And 159W when placed in a section with the velocity of 1.1m/s (canal centre).
ii. The guide plate addition resulted in debris collection over the short testing period, which could indicate problems when used for longer time periods.
iii. For a higher power output (Test 2.II) a slightly higher damming level was observed. This could prove a relationship between higher rpm relating to higher damming levels, as would be expected.
iv. The overall structure resulted in the turbine unit being difficult to place at the correct orientation in the flow path due to turbulence. It was also difficult to handle due to the large weight addition to the structure.
v. The plates seemed to act as a weir, diverting more flow over the plates than through the turbine, proving the plates should be placed at a flatter angle to the direction of flow, or more confinement is required.
vi. Attempting to add the top plate thereby causing a more confined reduction in the flow area resulted in an unstable unit when using only anchor cables to keep the turbine unit in place. This may be due to the large size of the modifications made to the turbine.

5.5 PHASE 3: CANAL OPTIMIZATION

Phase 3 involved altering the canal system to allow higher streamflow velocities through the turbine. This was done by narrowing the canal in increments by the use of steel plates and jacks. Once again theoretically this should increase the power output by reducing the flow area (resulting from increased flow velocity).

5.5.1 Testing procedure

The testing procedure involved using a set of lifting cushions and 4x4 jacks to adjust steel plates at various reaches from the canal wall thereby narrowing the flow area. The following tests were done on the altered canal as numbered in the proposed testing schedule:

I. Turbine placed between plates, vary angle of plates (vary plate extension from 0 to 1.2m);
II. Turbine placed between plates extended 1.2m from canal edge.

During the testing variations, the following measurements were taken:

i. Power output (when relevant);
ii. Level/damming level at (1) (2) (3) and (4) as shown in Figure 5-14;
iii. Point velocities where possible and relevant.

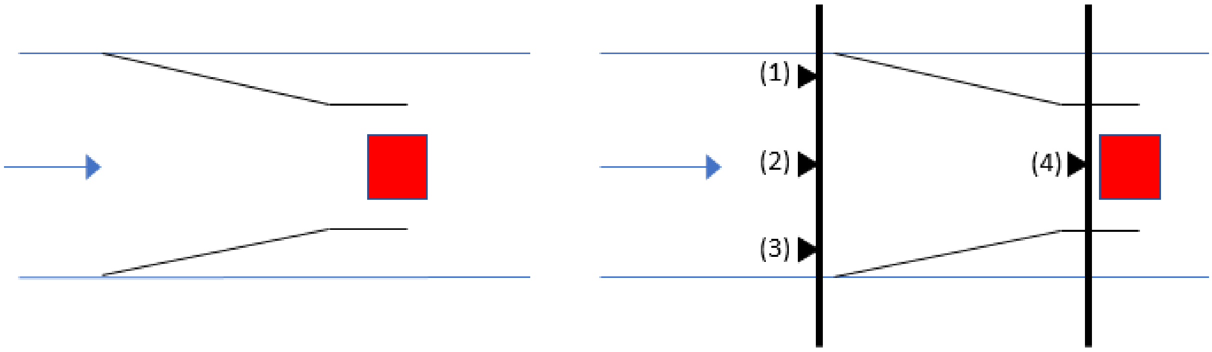


Figure 5-14: Phase 3 level sensor positions

5.5.2 Canal alteration results

The results from the phase 3 testing are as follows:

i. Flow rate

The average flow rate over the Phase 3 testing period was 7.02m^3/s, which is slightly higher than previous testing periods.

ii. Power Output

The power output recorded can be seen in Figure 5-15. A linear line of best fit can be seen over the field measurements portrayed with dotted lines. The average power output of each scenario is shown in Table 5-9 with the relevant flow width of each narrowed scenario. Each test was done over a period of 80seconds. The flow rate during each test interval is shown in Table 5-9.

Table 5-9: Phase 3 power output at various turbine positions

TEST		SCENARIO	FLOW WIDTH (m)	POWER OUTPUT (W)	FLOW RATE (m^3/s)
I	a, b	0.5m	3.81	322	7.05
I	c	0.6m	3.61	615	7.00
I	d	0.85m	3.11	837	7.01
I	e	1m	2.81	860	7.04
II		1.2m	2.41	1025	7.00

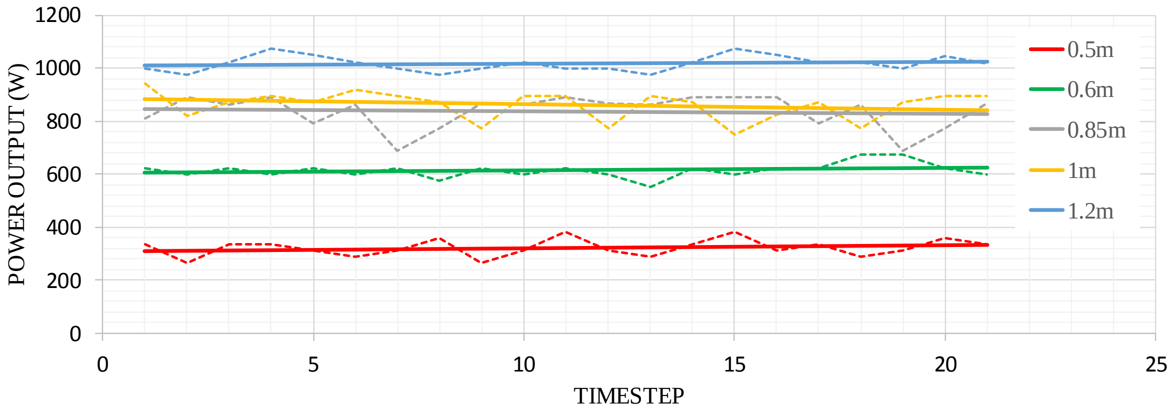


Figure 5-15: Phase 3 graphical power output (Test I and II)

iii. <u>Water level at installation point</u>

The water level was measured at 4 points around the installation area as portrayed in Figure 5-14. The available average water level of each of the three points at the point of narrowing can be seen in Figure 5-16 and the level at the turbine is shown in Table 5-11(sensor 4). Table 5-10 links the flow width of the narrowed section to the scenario title used in the results.

Table 5-10: Testing scenario flow widths

TEST	SCENARIO	FLOW WIDTH (m)
-	No Turbine no alteration	4.81
Test 3.Ia	No turbine 0.5m side narrowing	3.81
Test 3.Ib	Turbine 0.5m side narrowing	3.81
Test 3.Id	Turbine 0.85m side narrowing	3.11
Test 3.II	Turbine 1.2m side narrowing	2.41

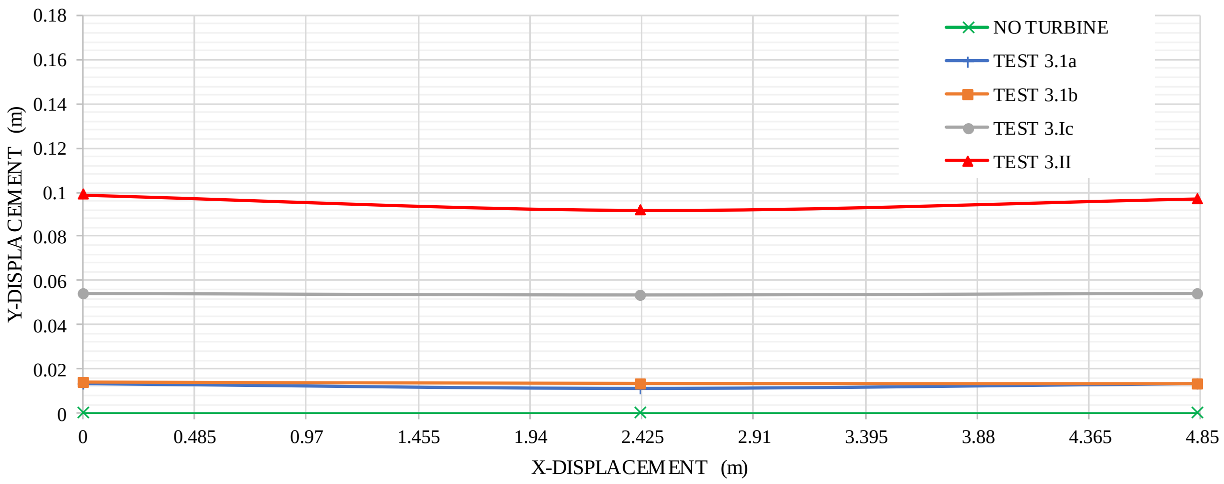


Figure 5-16: Phase 3 damming levels (sensors (1) (2) and (3)))

Table 5-11 contains the levels as were measured with sensor 4 above the operating turbine. To allow comparison the datum level is shown in Figure 5-17 which was recorded before any narrowing occurred.

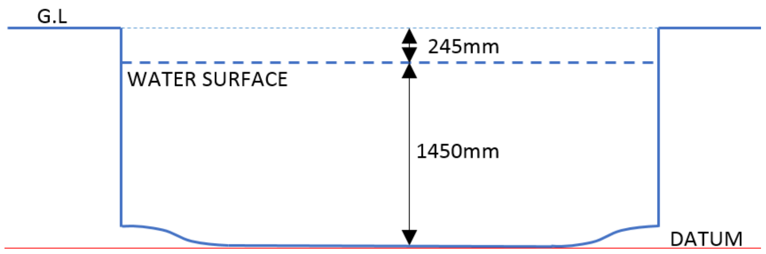


Figure 5-17: Phase 3 datum over turbine installation point (“no turbine” scenario)

Table 5-11: Damming over the turbine (sensor (4))

TEST	SCENARIO	FLOW WIDTH (m)	WATER LEVEL (m)	FLOW RATE (m^3/s)	RELATIVE DAMMING (mm)
-	No Turbine no alteration	4.81	1.45	7.08	0
Test 3.Ib	Turbine 0.5m side narrowing	3.81	1.53	7.05	80
Test 3.Id	Turbine 0.85m side narrowing	3.11	1.48	7.01	30
Test 3.II	Turbine 1.2m side narrowing	2.41	1.41	7.00	- 40

iv. Water level 50m upstream

The water level 50m upstream of the turbine at the flow meter installation point was measured allowing observation of any significant damming upstream of the system. The water level was once again only measured at a point in the centre of the canal. The average water level during each scenario can be seen in Table 5-12. The datum level is shown in Figure 5-18.

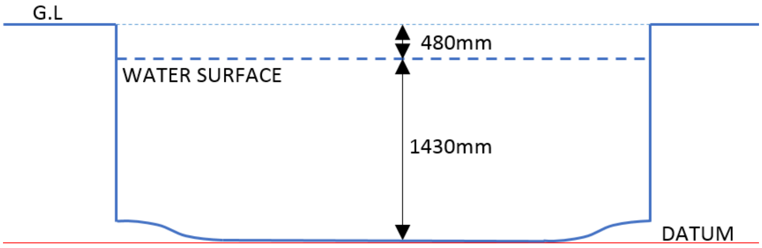


Figure 5-18: Phase 3 datum 50m upstream ("no turbine" scenario)

Table 5-12: Phase 3 water level 50m upstream of installation

TEST	SCENARIO	AVERAGE LEVEL (m)	FLOW RATE (m^3/s)	RELATIVE DAMMING (mm)
-	No Turbine no alteration	1.43	7.08	0
Test 3.Ia	No turbine 0.5m side narrowing	1.45	7.05	20
Test 3.Ib	Turbine 0.5m side narrowing	1.46	7.05	30
Test 3.Id	Turbine 0.85m side narrowing	1.50	7.01	70
Test 3.II	Turbine 1.2m side narrowing	1.54	7.00	110

v. Velocity distribution

The velocity distribution measured during each testing period with a handheld velocity sensor is shown in Figure 5-19. Accessible points of measurement at the turbine, at the narrowing and 5m upstream at an existing bridge were selected.

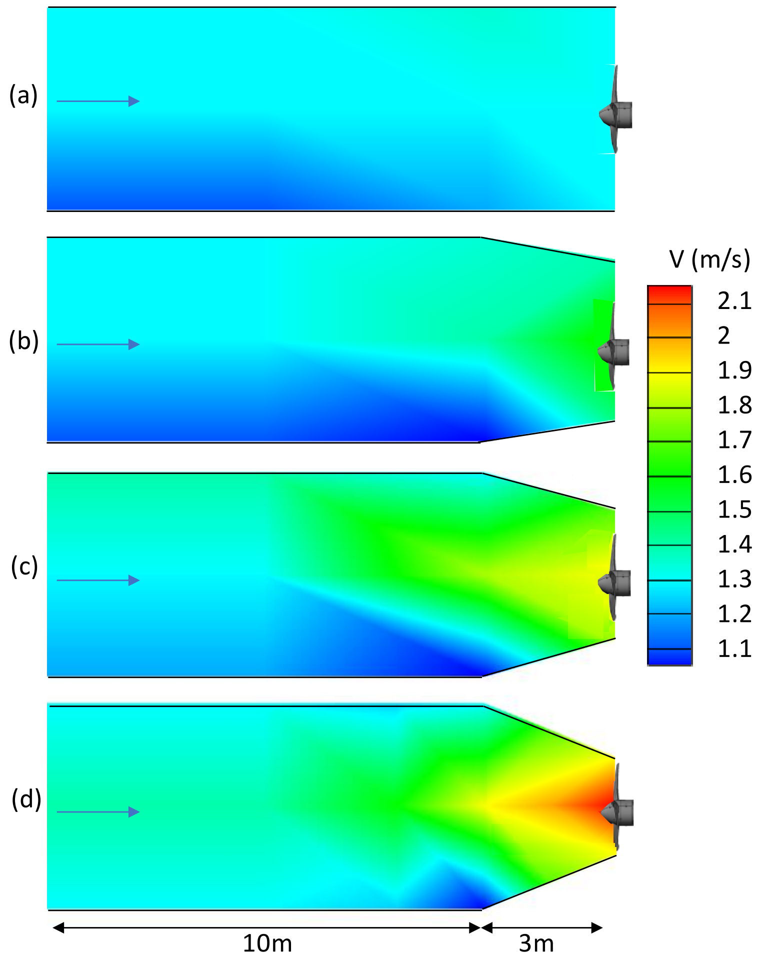


Figure 5-19: Velocity distribution at narrowed widths of (a) 4.81m (b) 3.71m (c) 3.11m and (d) 2.41m

vi. Visual inspection

During the testing procedure the flow behaviour was observed as shown in Table 5-13.

Table 5-13: Phase 3 visual inspection

SCENARIO	PICTURE
Test 3.Ib- Turbine centre installation with 0.5m narrowing on each side: • Smooth flowlines observed toward the turbine (assumed adequate narrowing angle). • Slight turbulence downstream of the turbine. • No significant damming observed.	
Test 3.Id- Turbine with 0.85m narrowing on each side: • Significant damming effect is visible. • Smooth flow lines observed towards the turbine (assumed adequate narrowing angle).	
Test 3.II- Turbine with 1.2m narrowing on each side: • Significant damming is observed. • Turbulence downstream of the turbine. • Slightly bent plates, resulting in a smaller reduced area than expected. • Right level sensor interference caused by anchoring cables, readings could be affected.	
Test 3.II- Turbine with 1.2m narrowing on each side, upstream view: • Significant damming resulting in some critical regions upstream of the installation section. • Excluding the critical regions, available freeboard allows for permanent narrowing in section.	

5.5.3 Phase 3 conclusions

Phase 3 involved altering the canal, by narrowing the flow area by means of steel guide plates, the following conclusions were drawn:

i. By narrowing the flow area by means of steel plates the velocity was observed to increase to 2.2m/s. theoretically this should reach a velocity of 3.1m/s. However, due to the slight bending of the plates and possible turbulence interference this theoretical value was not reached.
ii. The power output increased as the canal was narrowed.
iii. The power output obtained at the velocity of 2.2m/s was found to be an average of 1025W.
iv. For the 0.5m and 0.85m narrowing scenarios (Test 3.I) the velocity measured was significantly higher than the HEC-RAS model (Appendix C), this could be due to a higher velocity point (where the propeller type velocity sensor measured flow velocity, whereas HEC-RAS assumes a uniform velocity over section) at a point in the narrowed section. If true, this point should be found and aimed as the optimal point for turbine installation.
v. The water level at the turbine increased at small increments during the canal narrowing and then proceeded to decrease to a relative level of 40mm below the initial water level, resulting from the narrowing effect (venturi theory).
vi. The maximum damming observed at the hinged point of narrowing was around 100mm (at the canal left edge).
vii. The maximum damming 50m upstream was observed to be 110mm, which was higher than the installation point, proving the backwater effect of the blockage and the most critical damming point may not be at the installation point, but slightly further upstream.
viii. Critical sections where limited freeboard is available pose as a threat for overtopping if permanent canal narrowing is done and blockages occur. These sections should be heightened.

5.6 IMPACT OF FLOW VARIATION ON DATASETS

As shown in the relevant phase results tables the flow varied slightly over the testing period (as shown comparatively in Table 5-14), as this is not a controlled laboratory environment this is to be expected. Therefore, adjustment of the data was considered.

Table 5-14: Flow change over testing period

PHASE	MINIMUM (m^3/s)	MAXIMUM (m^3/s)	CHANGE (MAX-MIN) (m^3/s)
1	6.29	6.56	0.27
2	6.67	6.69	0.02
3	7.00	7.05	0.05

PHASE	MINIMUM (m^3/s)	MAXIMUM (m^3/s)	CHANGE (MAX-MIN) (m^3/s)
INTERPHASE	6.29	7.05	0.76

5.6.1 Damming level

A graphical presentation of the effect of flow increase on damming levels can be seen in Figure 5-20. A representative section of a 700-minute dataset was selected (where no testing occurred) and plotted with an ascending flow rate, the moving average of the level data shows the overall trend of the data. The extremities of the value indicate as the flow varies by 1.46m^3/s the levels change by less than 65mm. The flow variation over the testing period for each phase and maximum change between phases can be seen in Table 5-14, which indicates a maximum change of 0.76m^3/s. The corresponding damming level average change over a flow variation of 0.76m^3/s was found to be 20mm (taken as an average relationship change over multiple points of variation in flow), with no clear relationship as shown in Figure 5-20 (although an upward trend is observed). Additionally, the majority of this change in flow occurs around the extremities, which could be error outliers. Due to highly variable changes in damming levels (as the flow changes), the data was not changed as a clear relationship between small changes in flow and damming levels was not obtainable. Instead the flow rates were mentioned in each case and were considered during the analysis.

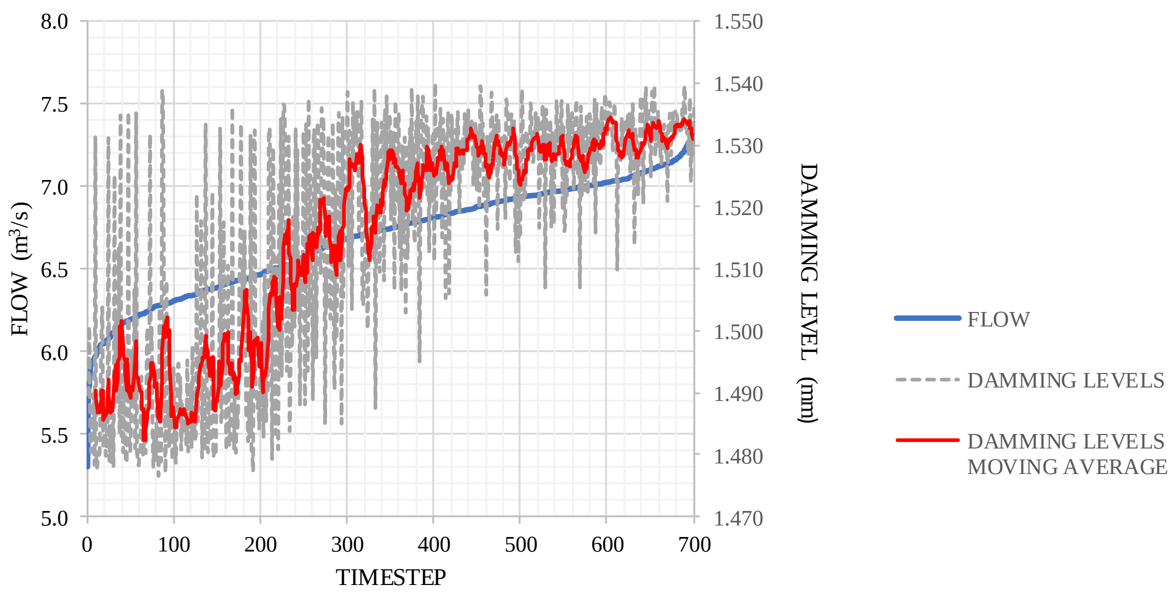


Figure 5-20: Influence of flow on damming levels

5.6.2 Power output data

The effect of changes in flow on power output for a 90-minute testing period (during phase 1) can be seen in Figure 5-21. As shown the small increases in flow have little to no clear effect on the power output. Due to the lack of a noted relationship the power data was not adjusted, rather the change in flow rate recorded and mentioned during analysis.

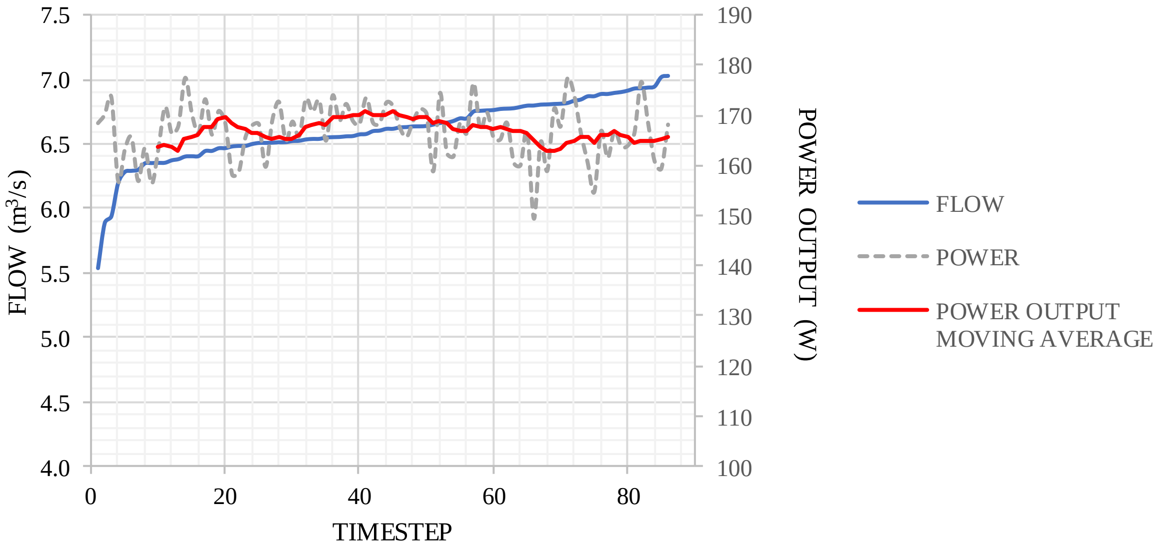


Figure 5-21: Relationship of flow and power output

5.7 RESULTS SUMMARY

A summary of the results obtained during testing of the various HK turbine setups can be seen in Table 5-15.

Table 5-15: Testing results summary

PHASE		PROCEDURE	OUTPUT (W)	CHANGE IN POWER OUTPUT RELATIVE TO PHASE 1I (%)	CHANGE IN POWER OUTPUT RELATIVE TO PHASE 1 (%)	MAXIMUM WATER LEVEL INCREASE AT THE TURBINE (mm)	MAX WATER LEVEL INCREASE 50m UPSTREAM (mm)
1	I	Turbine in centre	166	-	-	30	30
	II	Turbine outer bend (Left)	228	37% increase	-	25	20
		Turbine inner bend (Right)	127	-24% decrease	-	18	30
	III	Blocked turbine	-	-	-	60	50

PHASE		PROCEDURE	OUTPUT (W)	CHANGE IN POWER OUTPUT RELATIVE TO PHASE 1I (%)	CHANGE IN POWER OUTPUT RELATIVE TO PHASE 1 (%)	MAXIMUM WATER LEVEL INCREASE AT THE TURBINE (mm)	MAX WATER LEVEL INCREASE 50m UPSTREAM (mm)
2	I	Turbine with guide plates in centre	159	-4% decrease	-4% decrease	63	50
	II	Turbine with Guide plates outer bend	298	80% increase	38% increase	75	40
	III & IV	Turbine with Guide plates and Top plate in Centre/offset	-	-	-		-
3	I	0.5m Narrowing	322	94% increase	-	13	30
		0.85m Narrowing	837	404% increase	-	54	70
	II	1.2m Narrowing	1025	517% increase	-	100	90

5.8 RESULTS DISCUSSION

The preceding sections contain all data collected during the testing phase. Conclusions and observations relevant to each significant phase were mentioned in previous sections. The purpose of this section is to allow comparison of inter-phase results and discuss these relationships.

5.8.1 Validation of power curve

The power outputs obtained for various velocities were plotted on the initial SHP freestream turbine power curve supplied by SHP to allow comparison of the turbine performance (Figure 5-22).

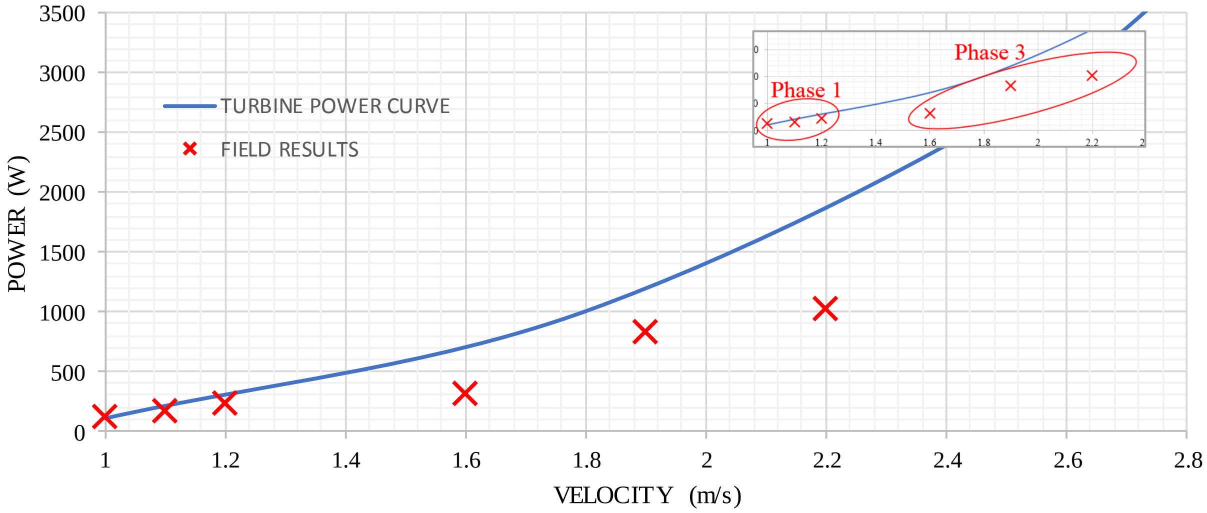


Figure 5-22: Turbine power curve comparison to field tests

As portrayed on Figure 5-22 phase 1 results tend to follow the curve, however the phase 3 recorded outputs are significantly lower (at the available velocities measured) than specified, the following could be the cause of this lower output:

i. SHP prescribes installation in a straight canal section with no bends. The non-uniform streamflow caused by the narrowed section at the installation point could result in turbulent conditions generating a lower power output.

ii. The turbine was not placed at the optimal position of highest velocity (point velocity was measured infront of the grid) as concluded in section 5.5.3. When the HEC-RAS design velocities for each scenario are used the test 3.I results fall on the curve (Figure 5-23). However the Test 3.II result still falls short of the curve, this could be due to the plates bending and due to this maximum velocity was not optained at the bottom of the canal where the turbine was placed.

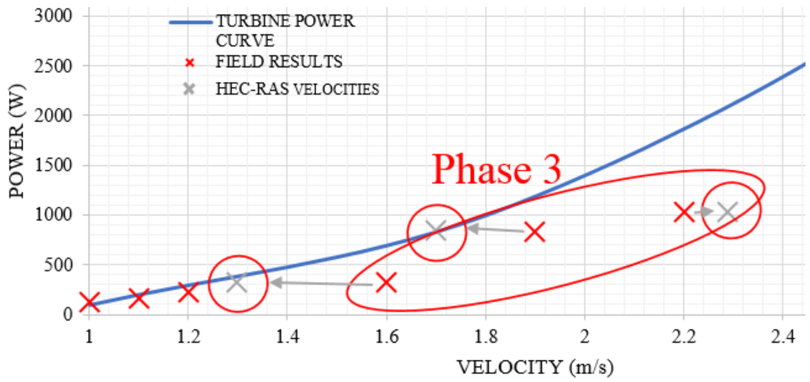


Figure 5-23: Power curve HEC-RAS velocity comparison.

iii. The turbine does not perform to the stipulated standard.

For phase 2 results when compared to the turbine power curve the increase in velocity resulting from the addition of guide plates can be seen in Table 5-16. Theoretically through the application of the plates (if all flow was guiding onto the turbine area) the velocity flowing through the turbine should increase to 2.7 and 2.9m/s respectively (test 2.IIa and 2.IIb), the power curve output for these velocities and the theoretical to actual velocity increases can be seen in Table 5-16.

The results show higher percentage increases occur when the altered turbine is placed in higher velocity flows.

Table 5-16: Phase 2 theoretical power curve comparison

SCENARIO		PHASE 2.IIa	PHASE 2.IIb
Canal velocity (m/s)		1.1	1.2
Theoretical power curve results	Theoretical power output from power curve (W).	151	209
	Theoretical canal velocity due to guide plates (m/s).	2.7	2.9
	Theoretical power output due to guide plates from the power curve (W).	3254	4148
Field test results	Power output due to plate addition (W).	159	298
	Power curve velocity relating to output (m/s).	1.11	1.31
Comparison of guide plate addition results	Theoretical percentage increase in canal velocity (%).	145.5%	141.7%
	Percentage increase in canal velocity (%).	0.9%	9.2%

5.8.2 Optimisation technique comparison

The optimisation techniques tested during the study were analysed and compared, the advantages, disadvantages and comparisons can be seen in Table 5-17.

Table 5-17: Optimisation technique comparison and analysis

OPTIMISATION MEASURE	GUIDE PLATES		GUIDE PLATES AND TOP PLATES	CANAL NARROWING		
BLOCKED AREA	1.88m^2 surrounding turbine		1.88m^2 surrounding turbine and confined	1.45m^2	2.5m^2	3.5m^2
TEST	Test 2.I	Test 2.II	Test 2.III	Test 3.Ib	Test 3.Id	Test 3.II
MEASURED/ AVAILABLE VELOCITY (m/s)	1.1	1.2	1.1	1.65	1.9	2.2
DESIGN VELOCITY (m/s)*	2.7*	2.9*	2.7*	1.3*[2]	1.75*[2]	2.3*[2]
THEORETICAL POWER OUTPUT (W)	3254	4148	3254	234	704	2135
ACTUAL POWER OUTPUT (W)	159	298	215 (inaccurate)	322	837	1025
POWER INCREASE *[3]	-4%	38%	N/A	94%	404%	517%
ADVANTAGES	• No alteration to infrastructure necessary. • Lower cost (smaller unit).		• No conclusions made.	• In similar application permanent narrowing does not have extremely large upstream effects. • No alterations needed on the turbine unit.		
DISADVANTAGES	• Results in an impractical unit. • Increases turbine weight significantly. • Higher maintenance due to debris build-up on plate edges.		• Unstable unit when large plates are used. • Results in impractical unit which is difficult to manage due to large size. • Large weight addition to turbine unit. • Higher maintenance due to debris build-up on plate edges.	• Spacing between narrowed regions must be large due to upstream damming effects. • Water infrastructure must be altered (possibility of more paperwork/ approvals). • Lower output than prescribed power curve observed (lower efficiency). • More risk of overtopping and blockages.		
PREFERRED USE	• Where small increases in velocity are required, small units can be added to turbine (functions better with higher velocity).		• In areas with extremely low velocity. • Where damming levels are critical.	• In steeper canal sections, where the backwater effect is not as great/critical.		
IMPROVEMENTS	• Curved plates that cannot bend outwards with front grid to deflect debris.		• More specifically designed unit, such as a smaller square to round section,	• A more gradual angle of reduction and add a gradual angle of expansion to reduce turbulence.		

OPTIMISATION MEASURE	GUIDE PLATES	GUIDE PLATES AND TOP PLATES	CANAL NARROWING
	• More gradual angle of reduction. • More confined angle of reduction.	guiding flow directly onto the blades. • A more rigid structure to hold the turbine in place.	

* The design velocities used in phase 2 are very optimistic and assume all blocked flow is diverted through the turbine (which will not occur).
*[2]HEC-RAS velocity approximation.
*[3]This is a power output comparison to the initial resulted obtained, which were extremely low, at higher velocities this increase may not be as extreme.

5.8.3 Damming effect analysis

The damming levels from the installation point (distance 0) to 50m upstream (distance 50), can be seen in Figure 5-24.

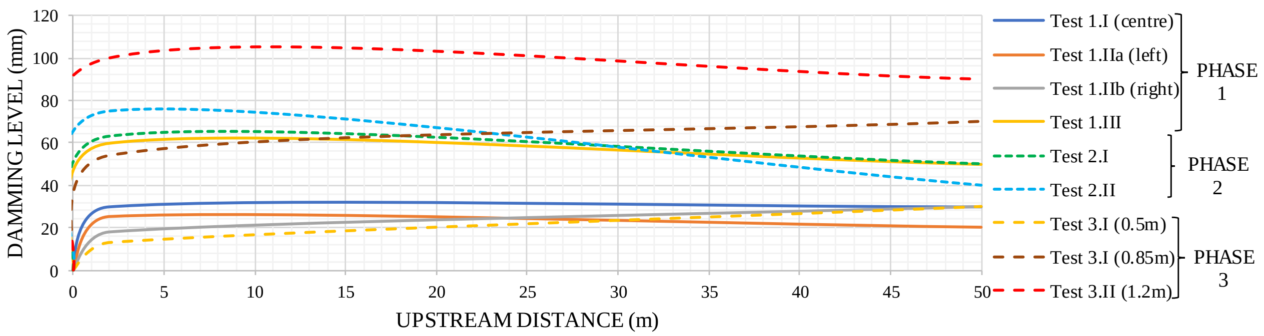


Figure 5-24: Damming levels over testing period

From the damming levels the following conclusions are made:

i. The upstream damming levels over phase 1 seem to be constant 50m upstream over the 3 turbine positions (when considering the flow change during testing).
ii. For small blockages at lower velocities the upstream damming is higher than the installation point, whereas for larger blockages at higher velocities (eg. Test 3.II and Test 2.II) the opposite is true.

From the damming results it can be deduced that the highest damming effect is not necessarily at the point of installation and may be further upstream, especially for smaller installations. This should be considered during system design in areas where freeboard is limited, however the maximum damming fell within the available freeboard and was not observed as a problem during this installation.

5.8.4 Environmental analysis

An analysis of the environmental influences of the HK installation proved the following:

i. No fish life deterioration, due to the canal inlet grid blocking most of the riverine fish population, except for smaller species, which generally are not affected by the spinning blades.
ii. No habitat destruction caused through the use of man-made canal systems (artificial waterways) and not riverine applications.
iii. No sediment disruption of the surrounding area from installation as canal is concrete lined and sides are used for fastening.
iv. No altering, impeding or diverting of waterways was done during installation and no major damming caused which could result in flooding.
v. No toxic release of any chemicals (no anti-biofouling, hydraulic fluids etc. used)
vi. No loud noise from the turbines (no noise pollution) during operation.

Since hydropower generation does not burn fossil fuels, carbon dioxide (a greenhouse gas) is not directly produced. While some carbon dioxide is produced during manufacture and construction of the project, this is a tiny fraction of the operating emissions of equivalent fossil-fuel electricity generation. The installation proved to have no significant negative influence on the environment and the production of “clean” renewable energy rather than use of the largely fossil-fuel driven current electricity supply used in the area far outweighs any minor environmental impacts which may have been missed.

5.8.5 Social analysis

The social aspects of the project remain one of the most important factors of renewable energy development, especially in developing countries where funded projects such as this aid poverty stricken areas where the majority of the population is not able to afford basic electricity needs. During this specific project the social impacts were observed as shown in Table 5-18.

Table 5-18: HK installation social factors

POSITIVE FACTORS	NEGATIVE FACTORS
• The use of local labour for project development allowed an income for unemployed locals and also a sense of pride and protectiveness of the installation from the locals in the small community. • The system usually requires little maintenance and allows a constant supply of electricity through the majority of the year(although the	• The HK devices are a risk to children swimming in the canals (sharp fast flowing propeller blades could result in injury). • The largely poor area results in potential theft of components during canal dry-times. • Higher maintenance may be required due to debris.

output is currently low this can be improved by use of better sections/alternative turbines), aiding the poor municipality financially. • The project functions as a pilot of possible renewable electricity technologies which could promote the market for HK systems in South Africa. • Benefits to the !Kheis Municipality would include reducing their reliance on the national power grid, as well as reducing their electricity costs and thus mitigating their risk of not being able to supply water to their communities.	

An overall social analysis proved the positive factors outweigh negative factors which can mostly be solved with small redesigns in the system and theft prevention measures.

5.8.6 Economic analysis

The objective of the small-scale HK schemes is to develop a system which poor municipalities could use as a sustainable, cheaper source of electricity with low operating and maintenance costs. If optimal sections in the canal are selected where HK units can be placed to produce around 4kW each. This would provide the municipality with around 31 140kWh per annum per turbine (when considering an average of 324 active days), with several of these systems installed and minimal initial and running costs, these systems could potentially save the LM on operational expenses, especially during peak hour periods.

As an indication of the costs of the basic installation in an effective section (with the required velocity available) the cost per kW output can be seen in Table 5-19. With a load factor applied to account for operational/non-operational periods a cost of R46 000 per kW is obtainable. However, when importing costs are removed and turbines are produced locally costs could be substantially reduced.

The implementation of small-hydropower systems has been recommended by many international organisations such as the World Bank and United Nations Industrial Development, with proof of the start-up costs of small hydropower systems being almost half that of wind and solar where potential is available (Elbatran et al, 2015). This alternative power source could aid in overcoming the lack of power supply to required areas and lighten financial burdens (in terms of electricity costs). Installation of these units not only supports sustainable development but promotes innovative research which is an important step in forming a stronger self-sustaining economy.

Table 5-19: Costs

Cost per turbine for a typical array of 7 turbines				
Item	total	no. of units	per unit	Cost per kW (R/kW)
Smart Hydro turbine and generator	R 961 092.00	7	R 137 298.86	
Turbine control system	R 226 278.36	7	R 32 325.48	
Import and delivery	R 143 840.00	7	R 20 548.57	
Anchor cables and shackles	R 20 470.80	7	R 2 924.40	
Anchor blocks	R 14 525.00	7	R 2 075.00	
Electrical cabling	R 48 000.00	7	R 6 857.14	
Construction and labour cost	R 15 000.00	7	R 2 142.86	
TOTAL COSTS			**R 204 172.31**	
Total power output per turbine (kW) (Ideal)			**5.00**	**R 40 834.46**
Total power output per turbine (kW) (load factor applied)			**4.44**	**R 46 001.79**

5.8.7 Conclusions

From the results obtained and analysed the following technical observations were made:

i. The flow velocity of the water in the canal was significantly lower than initially calculated from the upstream gauging station, thus resulting in a significantly smaller power output. With the actual velocity of 1.1m/s a rated power of 230W is obtainable as shown in Figure 5-25.

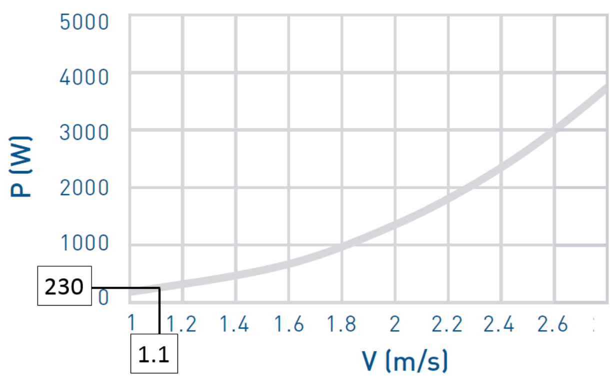


Figure 5-25: SHP power curve comparison to available velocity

ii. From the results it was clearly shown that the faster streamflow on the left edge of the canal after the bend resulted in a higher power output. Generally, HK turbines are not placed close to bends and it is always preferred to place the turbines in cross sections with linear streamlines (no turbulence from bends). However, comparing to the SHP results from the same velocity with straight streamlines (Figure 5-22) the results proved to be similar to the power curve supplied by the manufacturers. Therefore, it could be considered a possibility to place these units at outer bends to obtain higher power outputs.

iii. Optimisation measures may be used in specific cases but may result in higher risk of overflow or large impractical units, which derails the small modular nature of these units.

iv. Abrupt changes in flow (such as small guide plates at flat angles) may decrease power output at low velocities.

v. Placing the turbine in narrowed sections may result in lower efficiencies where the angle of reduction and expansion are not small.

vi. Extensive field velocity measurements at potential sites before installation are a necessity in South Africa, due to lack of maintenance, inaccurate gauging stations and illegal abstraction points.

vii. HK energy development in poorer areas in South Africa has an overall positive environmental and social impact.

viii. For a HK installation not just the installation section but the canal system as a whole (effects upstream/downstream) must be considered.

6 INTEGRATION AND OPTIMISATION OF HK SYSTEM

The focus of the study involved integrating a HK system into an existing canal in South Africa. In Chapter 5 data on the working and optimisation of the system was collected and analysed. This chapter includes analysis of the success of integration of the system and all aspects of importance learnt during the study on HK installation in the South African context. Additionally, optimisation techniques are compared and assessed.

6.1 INTEGRATION

Integration of HK systems in a typical irrigation scheme in South Africa involves a range of aspects from technical, social, environmental and legislative conditions, the influences of the system must be considered to prove the success of such an installation.

6.1.1 Development process

Figure 6-1: Canal HK system development process

The development process of a HK installation varies throughout the world, as each country's laws and regulatory processes have to be followed. As HK implementation is still a relatively new technology in

South Africa, the development process is not yet streamlined. An outline of the development process is depicted in Figure 6-1 followed by a summary of each aspect as was found during the study.

1. Site-selection and pre-feasibility study:
   The site used for HK installation should be carefully selected, as proved in the study it may be a difficult task when optimal velocities are not available. HK turbines usually require a velocity of around 2-3.5m/s. Sites at existing narrowed sections (such as flume sections or syphon outlets) are usually more likely to have these velocities readily available, examples of these sites are shown Table 6-1. However, when selecting site such as these, several issues such as high damming or interruption of the infrastructure operation (before installation) may occur. Therefore, finding a site which has a higher velocity along a uniform section where only a small fraction of the cross section is used for the HK installation remains the best installation option.

Table 6-1: Sections with higher velocities

POTENTIAL SITE	PICTURE
Steep sections: examples include canal outlets to balancing dams, or sections of higher gradients.	
Flume sections: Where a narrowing in the canal occurs, higher velocities may be present.	
Siphon/pipe exits: Where siphons are used between canal sections narrowed section at exits may be considered as potential sites.	

In conjunction with site selection, a pre-feasibility study of each potential site should be undertaken, this includes:

i. Velocity and flow measurements;
ii. Identification of electricity use and transmission length;
iii. Preliminary costing of components;
iv. Conceptual design.

The pre-feasibility study should be carefully completed and all costs should be calculated and weighed against the output before final design and implementation of the HK system. The main cost considerations are shown in Figure 6-2.

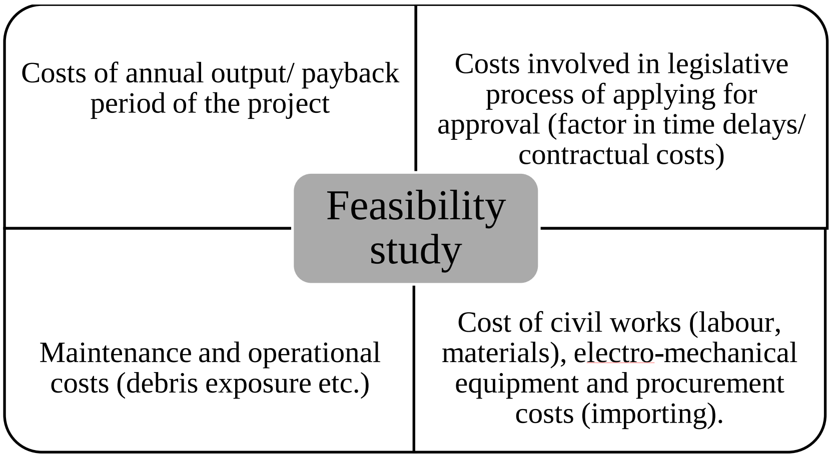


Figure 6-2: Feasibility study cost considerations

2. <u>Turbine Selection</u>

The HK turbine type should be carefully considered before selection. As these devices are not currently readily available in South Africa high importing costs drive up the capital cost. Modular units may be imported, or units can be designed and manufactured locally (where the project owner has a broad knowledge of HK workings). A summary of some available modular turbine units is shown in section 2.4 (Table 2-3). The typical ranges of common available turbine units can be seen in Figure 6-3.

To suit the design power output the rotor diameters may be increased, as an example of this the power curve for various rotor diameters for an axial flow turbine designed by Capta Hydro can be seen in Figure 6-4.

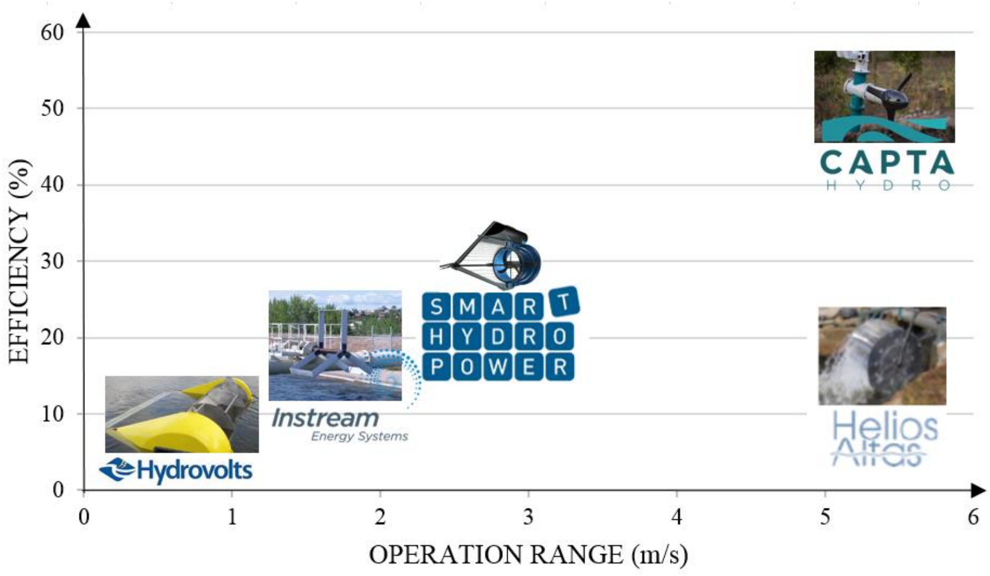


Figure 6-3: HK turbines (CaptaHydro, 2017)

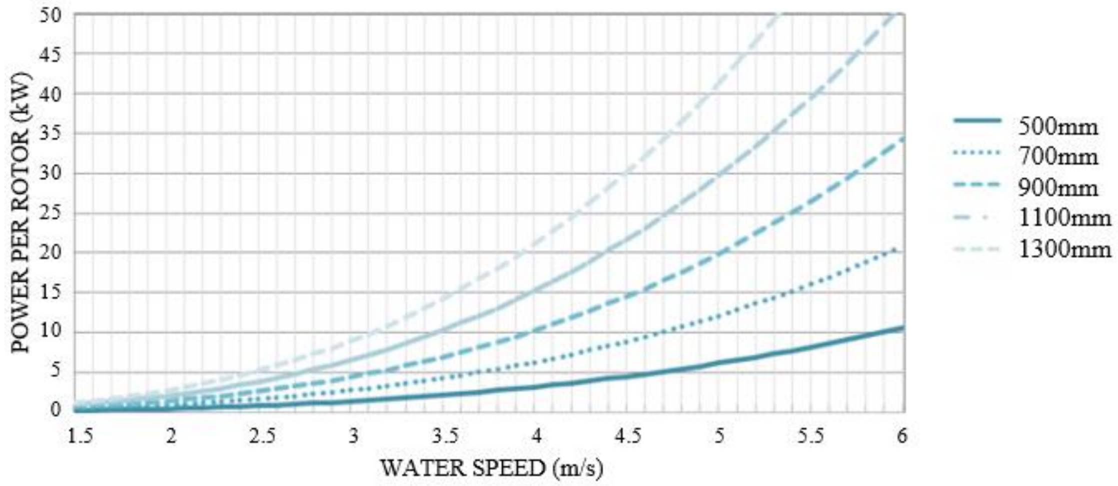


Figure 6-4: Axial flow rotor diameter comparisons (CaptaHydro, 2017)

3. <u>Grid integration</u>

   The control systems for the HK device are designed according to the use of electricity, which falls within the grid integration selected method:

   i. Islanded stand-alone:
      - This will require the development of a mini-grid for the distribution of the power produced.

   ii. Grid-connected system:
      - Stand-alone system requiring grid connection to sync frequency.

- Usage of existing transmission lines to feed electricity to the end user (may require additional approvals)

When the grid integration method has been selected the following should be designed:

i. Electric control boards;
ii. Regulatory system;
iii. Electric transmission
iv. Grid connection.

4. Legislative assessments and approval

   In South Africa certain legislative and regulatory requirements may be applicable when installing a HK system in canal systems. The entities which must be considered are listed in Table 6-2 (it must be noted that this may change as changes in legislation are introduced and the entities involved may vary as the use of electricity and the size of HK system varies).

Table 6-2: Small-scale HK assessment and approval guidelines

ASPECT	ENTITY	REQUIREMENT
Water/infrastructure use	DWS	(If) DWS is the owner of the Canal, the user (may) require written permission from DWS to use the canal as an infrastructural basis to anchor the HK turbines for hydropower generation and to provide access to the land.
	WUA or WB involved	The project owner may require the statutory body's (as described in section 2.10.2) written permission to non-consumptively make use of the water in the canal, to access and modify the canal and receive acknowledgment and approval for the project.
Environmental	Provincial DEA	Provision of an environmental authorisation should a listed activity according to the NEMA be triggered.
Electricity	NERSA	Needs to be informed of the project and depending on the extent of the electricity generation and distribution infrastructure provided, issue licences for these activities.
	Eskom	May be consulted if grid-integration; wheeling or feed-in is considered.

5. Meeting with stakeholders

   When all stakeholders have been identified, meetings should be arranged with each relevant entity to obtain the required approvals and complete the paperwork.

   Due to the large changes in process and legislation as the project owner varies (municipality/ private entity) it must be noted the development process described assumes the municipality as project/asset owners for the purpose of the dissertation (and this process may vary in other cases).

6. Capital procurement

   This phase involves procurement of all equipment required for installation of a complete HK system. This may include (but is not limited to) the following:

   i. Procurement of materials and equipment required for civil works:
      - Procurement of labourers for site work;
      - Anchor block/foundation material.
      - Turbine fastening equipment (e.g. Anchor cables)

   ii. Electrical and transmission equipment:
      - Turbine control equipment (regulators, inverters, dump-loads);
      - Transmission lines/ grid connector /mini grid;
      - Measuring and monitoring equipment and cabling.

   iii. Mechanical equipment:
      - Turbine (blades, generator).

   iv. Spare parts required for maintenance.

7. Project implementation

   During project implementation the considerations shown in Figure 6-5 are of importance and must be considered. After which the project can be implemented and tested for correct functioning.

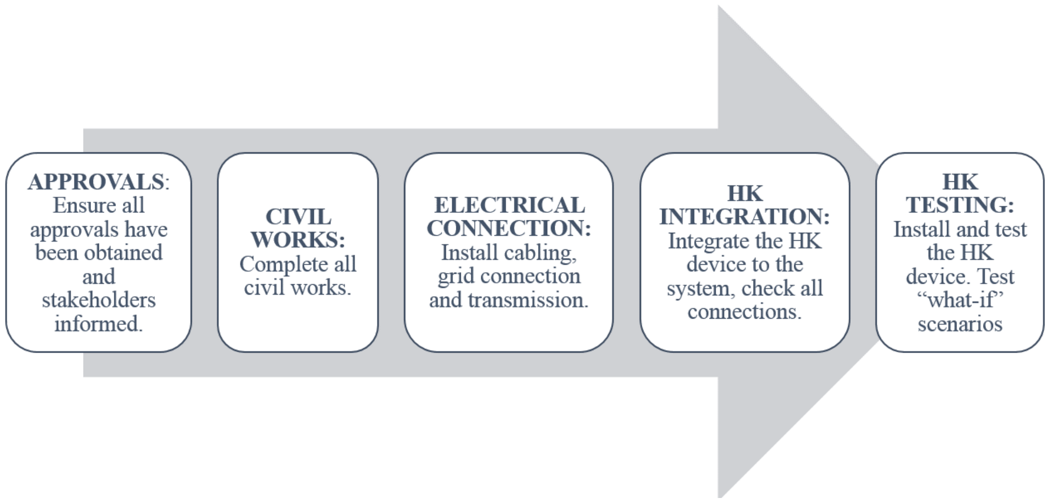


Figure 6-5: Implementation procedure

8. <u>Operation and Maintenance</u>

The operation and maintenance of the HK installation will govern the lifespan and functioning of the device. The following aspects of importance form this procedure:

i. Training of operation and maintenance staff.
ii. Maintenance plan and schedule of inspections.
iii. Issuing maintenance and operating manuals.

During the first year of project implementation, additional problems (such a seasonal debris variations) should be evaluated and the relevant mitigation measures put into place. Correct operation and maintenance of the system will result in an efficient system with a long working life.

9. <u>Monitoring and evaluation</u>

For new technologies such as HK systems in South Africa, monitoring and evaluation of the system over its operational life is an importance step to understanding the system functioning within the South African environment. This will result in the construction of more reliable systems in the future once a clearer understanding of the operational life exists.

Additional to this, monitoring systems will allow risk mitigation by allowing quick response times in blockage or potential canal overflow situations, it will also allow reporting when unplanned maintenance may be required due to observed drops in system outputs. Some important technical aspects which should be monitored include the following:

i. Power output and relevant velocity at specific time intervals;
ii. Damming levels (allowing blockage monitoring).

For future feasibility studies monitoring and data collection of the following aspects could be valuable:

i. Costs incurred over the operational life (maintenance/ operational costs).
ii. Problems encountered during operational life (blockages/ floods/ overtopping/ theft).

6.1.2 Applicability in South African canal systems

As shown in the literature study (Section 2.3.1) a large network of canal systems exists in South Africa, most of which are used for conveyance of irrigation water. These largely lie in non-electrified rural areas, resulting in an untapped renewable energy source which could be used to benefit these areas.

HK applications in canal systems, rather than riverine flow, where water levels and velocities vary between seasons, allow a more uniform controlled environment where a constant flow pattern is exhibited throughout most of the year, resulting in a more constant power output. Although these canals are prone to interval shut off times, this can be planned for and remains a controlled environment.

A large negative factor lies in the lack of high velocities, as was found in this project. However, this can be avoided with the careful selection of steep or narrowed sections where a higher velocity can be obtained. Additionally, the option of "low flow" HK turbines exist, such as the Waterotor turbine, which are designed for lower velocity applications.

Not only does HK hydropower development allow for electrification of rural homesteads, but also the use of small HK schemes to assist in water management in the form of electrified metering in off-grid areas etc. which allows better control/management of water sources (which remains a major problem in South Africa). Additionally, irrigation by its nature, is concentrated in rural areas not connected to the grid thereby opening an opportunity of rural electrification. The provision of basic electricity through hydropower to rural communities in South Africa fulfils the local governments constitutional mandate in providing services to communities in a sustainable manner and promoting social and economic development in a safe and healthy environment (Scharfetter & van Dijk, 2017)

6.1.3 Improvements and modifications

During the completion of the design of the experimental setup various alternative improvements and modifications to the chosen designs were considered. This included evaluating size, ease of operation and blockage mitigation:

i. Utilising larger flow area:

Due to the large width and low flow in the section an alternative turbine which is designed for this scenario could be used as portrayed in Figure 6-6. A H-Darrieus type rotor would allow a greater use of the extent of the canal width, whereas the rotor blades of the selected turbine required equal height and width and the size is therefore limited. The H-Darrieus could thus produce a greater output.

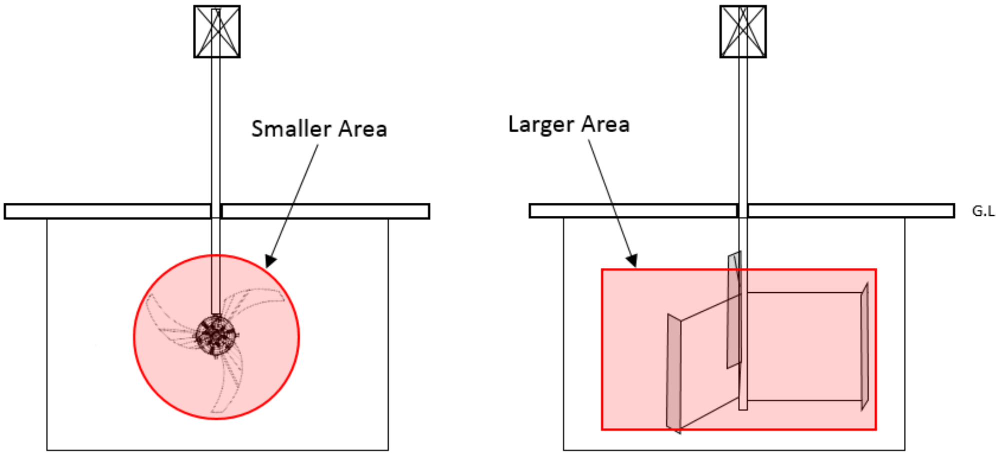


Figure 6-6: Improved rotor selection

ii. Ease of operation

A large cost of the project resulted from procuring the necessary equipment to place and remove the turbine, as the modular HK turbine unit weights more than 300kg. Due to this removal issue, redesign of the turbine could be considered (as shown in Figure 6-7). The modification involves a turbine with a counterweight (or the generator) placed on the opposite end of a rod which is fastened to a beam spanning over the canal. This would allow easier installation and removal of the turbine during blockages (as it could be swivelled out of the flow by a single operator). This would also allow easier access to the turbine (via the beam, which could act as a bridge access point) and easier installation in narrower sections of the canal. It would also omit large costs of a permanent gantry structure to remove/maintain the turbine.

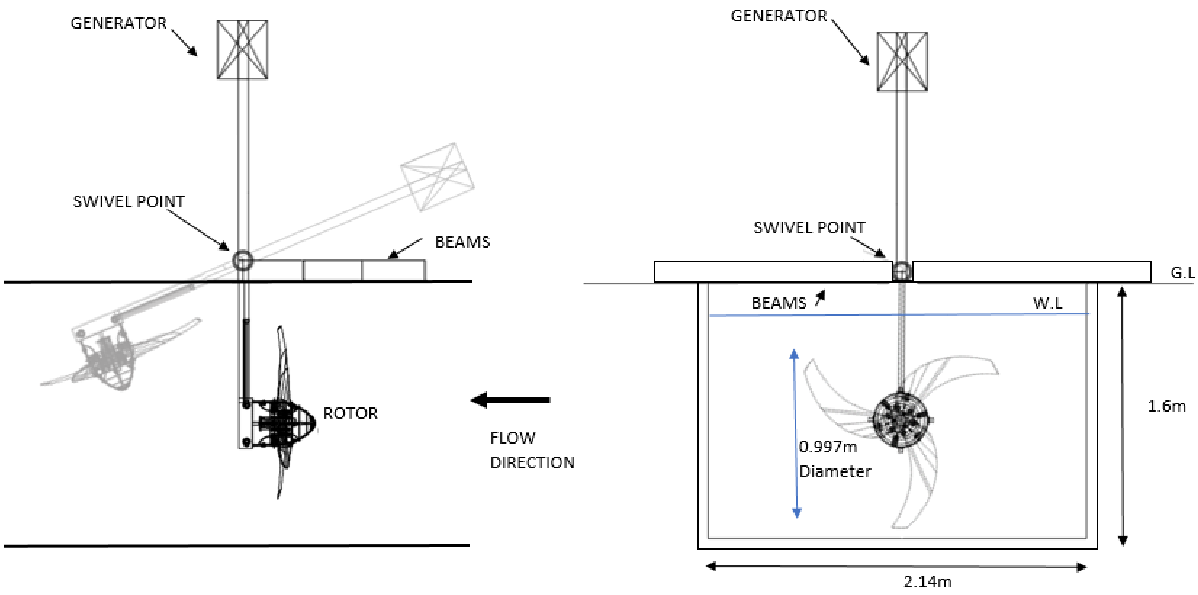


Figure 6-7: Improved turbine concept for narrow section

iii. Blockage mitigation

Linked to the above concept (Figure 6-7) a safety switch or alternatively automated swivel mechanism could swivel the turbine out of the flow path to quickly clear blockages without any “heavy lifting”. Alternatively, a grid could be placed upstream over a section of the canal where cleaning and maintenance is done over interval time periods, rather than additional weight of a grid attached to the turbine. This would also prevent any potential swimmers from entering the installation section (as the grid would cover the cross-section).

6.1.4 Risks and other factors

During the HK test installation various problems were encountered which in some cases led to delays in the project, or resulted in additional costs, these include:

i. Theft and vandalism of the testing site during experimental setup construction, this resulted in large expenses for fencing and additional security to prevent further interference.

ii. The installation site lies downstream of a school in the town of Groblershoop. In summer temperatures rise above 40 degrees Celsius and children tend to swim in the canal systems. Measures had to be taken to prevent swimming in the section (to prevent injury or fatalities from spinning blades) and additional protective casing on the turbine (resulting in larger costs).

iii. On one occasion during a testing phase, deceased livestock was washed down the canal. After questioning locals it was made clear this is a fairly common occurrence due to livestock and wildlife drinking from the canal (as no barrier exists around the canal) and falling in. This could potentially result in turbine blockages; therefore, a warning system must be included in a permanent installation to allow for quick removal in such cases.

iv. During the project development, obtaining the approval in the form of a Memorandum of Agreement (MoA) between the !Kheis Local Municipality, the Boegoeberg Irrigation Board and the DWS proved to delay the project significantly as no turbine could be placed into the canal without the signing of the document and due to shifts in power and positions at the DWS this process took longer than expected. However, due to the nature of the project no other legislative and regulatory requirements were necessary, which could pose a delay in future projects of similar nature.

v. Due to a lack of specific policy in-stated in South Africa, which would allow a streamlined process of installation, delays in the process of installation may occur.

vi. The low velocities in most canal sections result in low power output systems, however as narrower sections or confined sections where a greater velocity exists are selected for installation, additional problems such an complete blockage (due to the turbine covering the majority of the smaller cross section) and large damming effects may occur. Due to this the risk of overflow and thus water loss to the WUA increases and thus the viability of the project decreases (civil works costs increase), it can also result in reluctance of the WUA to agree to the installation.

vii. Maintenance of the HK system remains a problem in South Africa, municipalities do not have the money and thus not the workforce to complete maintenance of the systems. The debris during short testing periods was evident which could result in large debris build-up over time and with no maintenance this could result in an inefficient system which is prone to blockages.

viii. Canal systems developed in the future should accommodate HK systems by designing parts of the canal for faster velocities and higher canal walls in anticipation of damming.

6.2 OPTIMISATION

In addition to the integration of HK devices within South African canal systems, this project involved the optimisation of these devices, to allow functioning in areas were high velocities are not readily available.

6.2.1 Power output and optimisation

In canal sections which do not have the required velocities readily available, optimisation techniques may be considered. A range of optimisation measures found in literature are discussed in section 2.7, due to practicality and time limits three techniques of optimisation that were relatively simple to implement were selected for testing. From the study certain applications were found to suit specific scenarios better than others. The techniques and main conclusions reached were described in section 5.8.7. From the results the following is assumed:

i. At extremely low velocities:
   - Rather than optimisation, consider selection of turbines designed for lower flow velocities.
   - It is difficult to increase the velocity significantly, as this would require alterations in the canal section (narrowing of canal).

ii. Higher velocities:
   For small increases in velocity, optimisation measures such as:
   - Diffusers or shrouds attached to the turbine;
   - Forming a guide vein on the turbine front and
   - Explore additional options such as placing multiple turbines in a single cross section could be considered.

From the study results, the potential use of optimisation could:

i. Allow for more sites to be viable for integration of these systems into existing infrastructure. As systems can be optimised even where flow velocities are low.
ii. Potentially reduce transmission line costs by allowing installation at a site in close proximity to the point where electricity is required.
iii. Reduce costs by optimizing a single turbine rather than using multiple turbines.

6.2.2 Problems encountered

Potential optimisation techniques increase the efficiency of the system, however as found in this study, implementation of these techniques can lead to a number of additional problems. The following difficulties were encountered during the study, which should be considered in future installations:

i. The use of guide plates/shrouds or canal narrowing results in an additional blockage, which can have large upstream damming effects.
ii. When altering the turbine itself the structure can increase in weight and size which then defeats the object of a modular unit, making it more difficult to handle.
iii. Additions to the turbine/canal should be carefully designed to prevent debris build-up, edges where debris cannot pass should be avoided.

7 CONCLUSIONS AND RECOMMENDATIONS

South Africa, the country with the second largest installed hydropower capacity in Africa, produces less than 5% of its total electricity demand from hydropower. This clearly highlights the lack of and the need for hydropower installations in Africa. In South Africa, mainly due to a relative scarcity of surface water, there is a prevailing perception that the potential for hydropower development is rather low. The largest percentage (>60%) of water is made available for the agricultural sector delivered through an extensive water supply network consisting of weirs/intake structures, pipelines, tunnels, siphons, canals, chutes, etc.

HK potential had not previously been investigated as South Africa mostly uses electricity from low-cost coal generation, despite having in excess of 6 500km's of canals to be potentially exploited. HK hydropower is a promising alternative renewable energy source which is capable of producing electricity with minimal environmental impact. Due to its modular nature and rapid deployment capabilities, it is an attractive source of energy for areas with existing potential. Additionally, the use of optimisation techniques considered during installation in low flow conditions could allow for HK installation in a large variety of flow conditions and velocities, thus allowing integration of these systems into a great number of existing infrastructure.

Although there is much HK potential, there is little technical literature or validation of successful installations of HK systems. The objective of this dissertation was to address this problem. It was hypothesized that small-scale HK systems can be integrated into existing water infrastructure in South Africa and optimised to function as a practical renewable energy source, having minimal risk and environmental impact and an overall positive social influence.

Literature on small-scale hydropower and specifically HK systems both locally and internationally were reviewed. Although no HK installation had been done in South Africa, the potential of these systems in rivers has previously been investigated (Koko & Kusakana, 2014) and a DWS asset management study proved the vast network of canals allowing further HK potential in the country.

To provide a pilot project showcasing the installation possibilities, a site in the Northern Cape province within the !Kheis Municipality was selected. All procurement of necessary equipment, materials and HK devices was done and the system was installed. The working of the device was tested in three phases, while each phase involved testing periods where the power output, velocities and damming levels were recorded. The first phase comprised of testing this device by placing the modular unit as produced into the canal system. The second and third phases involved possible practical optimisation techniques. Phase two incorporated the optimisation of the turbine, by adding guide plates thus increasing the velocity of flow through the turbine; whereby the third phase included optimizing the canal section by reducing its cross section in increments, thus increasing flow velocity once more.

As a result of the methodology followed during the study the following conclusions have been made. These conclusions should be read in context of the study and are used to authenticate the purpose and hypothesis of the study:

i. The modular HK system was installed with all required aspects to operate the system on a permanent basis. This allowed a showcase of the technology in the South African context.
ii. The technology has been proved to have very little to no environmental impact and an overall strong social impact by educating locals on the technology and more specifically the possibilities of renewable energy. Although the output was lower than initially expected the possibilities of the system was exhibited.
iii. Optimisation means were used to demonstrate the possibility of HK potential at sites with lower velocities. Some techniques proved to function more effectively than others in certain applications (such as lower and higher velocities) and require further testing over a range of applications. The increases in efficiency and limited effect on the supply of water proved these units could potentially be installed with optimisation measures (where required), however the influence not only as the site but on the entire system should be carefully analysed.
iv. With the required maintenance met (from debris/blockages) and the correct site selection (sections with higher velcoities), HK technology could be used as an additional sustainable renewable energy source in South Africa.
v. As the majority of canal systems pose as a controlled environment with a constant uniform supply of water (except during short shut -off intervals), with careful site selection and feasibility studies, HK energy systems in canal networks in South Africa can be a feasible alternative energy source. With projects such as these posing as pilot installations, the road to a streamlined, simplified regulatory and legislative process for the installation of HK systems in South Africa is slowly being formed.

As a result of the study and the conclusions found in this specific installation the following final conclusion was made:

Small-scale HK hydropower is a feasible alternative for existing water infrastructure in South Africa where the potential exists and maintenance requirements are met. Where lower potential exists these systems can be optimized (to an extent) to function as a reliable renewable energy *source with minimal environmental impact succeeding in the introduction of an additional technology showcasing the vast renewable energy possibilities in South Africa, however due to immaturity of the technology in South Africa, turbine importing costs and costs associated with "learning" during installation make the technology currently difficult to prioritise financially above other renewable sources.*

In light of the conclusions made, the following recommendations are made when considering the implementation of small-scale HK units.

Firstly, the purpose of the electricity produced should be carefully considered and it is recommended it be for "own-use" purposes, as this significantly reduces the legislative and regulatory aspects of the implementation. Also, a sustainable structure should be developed for the operation of these units to be implemented on a municipal level.

Additionally, the process of careful site selection should not be taken lightly, although optimisation can be considered as an alternative, the costs and maintenance requirements are reduced significantly when sites of optimum velocity are used for implementation.

In conclusion it is believed that the study met its objectives in developing a pilot study and introducing the concept of HK technologies to canal systems in South Africa. It is further hypothesized that careful selection or design of the HK device, to suit the specific application, will govern the functioning and efficiency of the implementation and should be carefully considered. Recommendations for further research that emerged from the study are:

i. Further study on possible optimisation measures on varying available flow velocities.
ii. Studies on the upstream damming effects of HK turbines at higher velocities.
iii. Comparison of cross flow and axial flow HK turbines in high velocity and low velocity applications.
iv. Field testing of efficiency effects when multiple turbines are placed on a single cross section.
v. Testing of the influence of canal bends on HK systems.

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APPENDIX B:
CALCULATIONS ON TURBINE ALTERATION

Civil works

The following civil works components and processes must be completed:

i. Site accessibility

The site lies on a point on the Boegoeberg irrigation canal nearest to the Groblershoop WTW. All points of the canal are accessible by foot however must be cleared at required zones to allow vehicle travel to the various installation points. The site requires preparation for installation as follows:

- The section adjacent to the canal system must be cleared, levelled and paved by local labour, this will allow vehicular access to the points of installation.
- The area is overgrown and prone to vandalism and therefore it must be cleared to allow visibility of the installation from the WTW which has 24hour security.
- The old pump building must be refurbished, which has 2 ventilated rooms of which one will be used for the energy dissipation elements and the other for all relevant equipment (inverters, controls etc.) this building lies about 10 metres from the first turbine installation point.

ii. Measuring structures

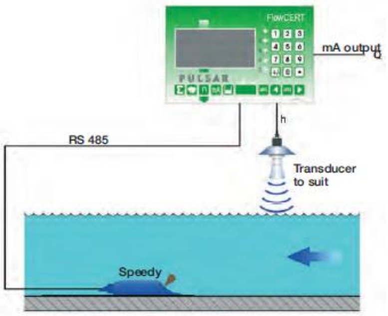
Permanent level sensors will be installed at relevant cross sections along the installation section to allow for data collection of the site specifics during the life of the turbines. A level sensor will be placed at each turbine to measure the damming effect at the point of installation. This will allow the operator to be notified immediately if any excess damming occurs, which could indicate a blockage/problem.

A flow meter will be placed at the site to measure the exact flow available at any specific point in time to allow measurement of the turbine working. Only one installation is necessary as the flow does not vary along the section (no off-takes along the relevant section, infiltration rates not considered as distances are small).

The measurement components in Table A-1 are selected for the above.

Table A-1

ITEM	DESCRIPTION	DETAILS	QUANTITY
Level Sensors	Pulsar 130 DS Controller.	i. c/w Display. ii. Supply of 110/220V AC power or 11 to 28V DC. iii. 2 programmable relays.	7

ITEM	DESCRIPTION	DETAILS	QUANTITY
		iv. 4 to 20 mA output.	
	Pulsar DB3 Transducer.	i. 0.12 to 3m range. ii. 5 metre cable. iii. Inclusive Bracket (150mm reach).	7
<u>Open Channel Flowmeter</u> 	Pulsar Flowcert Controller.	i. Supply of 110/220V AC power or 18 to 30V DC. ii. 2x4 to 20 Ma Isolated output. iii. 5 programmable relays.	1
	Pulsar Mach 3 Transducer.	i. 2500mm range. ii. 10 metre cable.	1
	Speedy Velocity Sensor.	i. 10 metre cable. ii. 0.2 to 6m/s velocity range.	1

The installation point for the flow meter requires a section with relatively linear flow lines (not in a bend) and no turbulence (not at turbine installation points) therefore the point shown in Figure A-1 was selected. It is approximately 50m upstream of the first turbine testing installation point and there are no offtakes over this section. The velocity sensor is placed in the middle of the canal bed and the level sensor in the middle over the section.

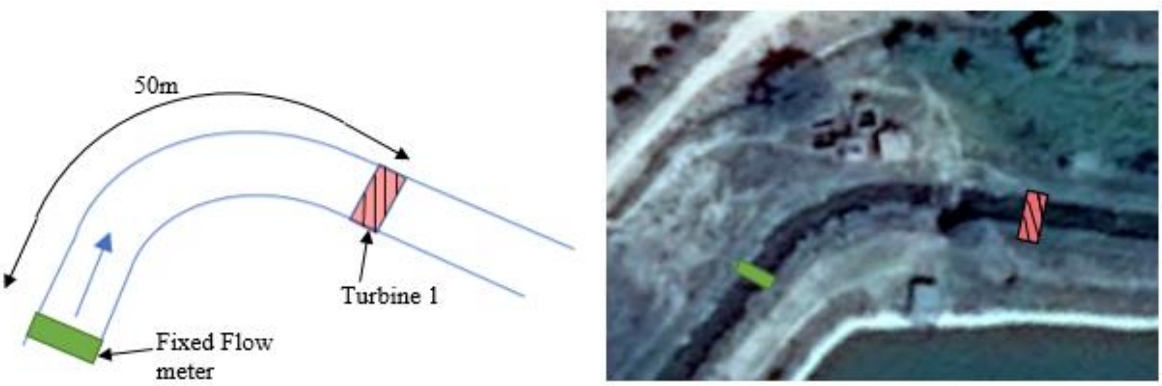


Figure A-1: Fixed flow meter installation point

iii. Anchoring structure

Various options exist in anchoring the turbine such as side anchoring by the use of cables or bottom/top anchoring with a permanent structure erected to hold the device in place. For this installation, the side anchoring option was selected due to this installation having minimal impact on the Boegoeberg irrigation canal infrastructure.

Proper anchoring is crucial as an improper anchored turbine can be lost to the forces of the water. The turbine suppliers, Smart Hydropower GmbH (SHP) have developed a graphical presentation of the anchor force at different flow velocities (Figure A-2).

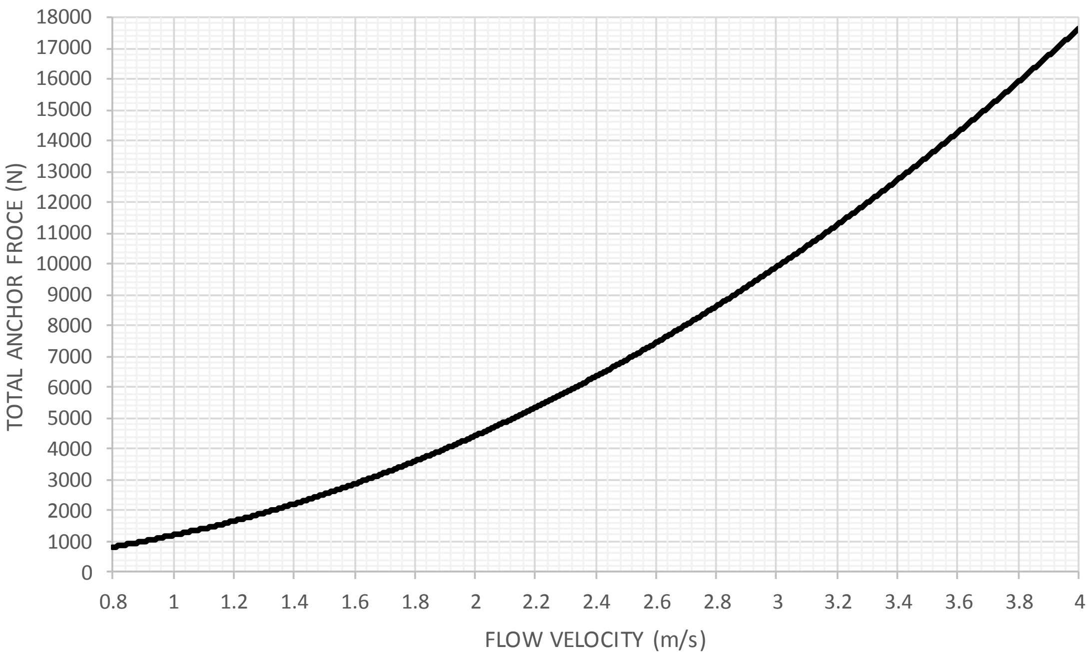


Figure A-2: Anchoring force vs flow velocity (SHP, n.d.)

Using this force with a safety factor of 1.5 ensures the turbine is securely anchored. According to the installation manual, prepared by the turbine supplier, the side anchoring system should withhold 3 tons of force under any circumstances due to the density differences in submerged conditions. Construction of a concrete block at the canal edge is recommended, as this is the cheapest solution.

iv. Concrete anchor block

The anchor cables must be attached to a concrete block cast off the banks of the canal. Therefore, concrete foundation blocks were cast on site into the in-situ material along the canal system. The required size of the concrete block was calculated by assuming full blockage of the turbine surface area (assumed as the worst-case scenario) with an added factor of safety of 1.5. The calculation can be seen in Table A-2. A final size of a square block 650x650x650mm was selected (this also takes into account possible guide plate blockage forces by a factor of safety of 1.5).

Table A-2: Anchor block area required

AREA BLOCKED	1.32	m^2
FORCE OF WATER (12m^3 flow in section)	8279.25	N
FORCE ON EACH CABLE	4.14	kN
DENSITY OF CONCRETE	2400	kg/m^3
MASS CONCRETE REQUIRED	421.98	kg
VOLUME	0.18	m^3
FACTOR OF SAFETY	1.5	(factor)
MASS OF CONCRETE	623.97	kg
VOLUME (FOS)	0.26	m^3
LENGTH/BREADTH/WIDTH (FOS)	0.64	m

The concrete mix design used was a C34/35 XS2 concrete mix design which is sufficiently strong under constant submersion (assuming in situ soil is saturated). By hand a nominal mix ratio of 1:1:2 Cement/sand/gravel is roughly equal to strength C35.

v. Anchoring cables

The anchoring structure will be installed as shown in Figure A-3 and Figure A-4. Eight-millimetre diameter stainless steel cables with a 7500kg max working load were used, which is more than effective for this application. Each cable is 5m long. The lengths of cable were selected on the basis of the following factors:

- Slack needed for removal of turbine out of the flow (without removing cable attachments).
- Longer cables allow for easier installation.
- The angle between the horizontal position and the cable running from the block foundation to the turbine should be less than 30degrees (to prevent cable effects on the flowlines)

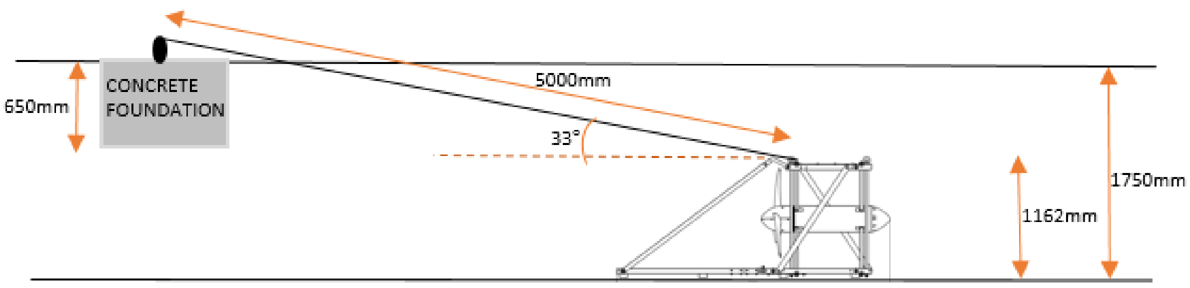


Figure A-3: Anchor detail side view

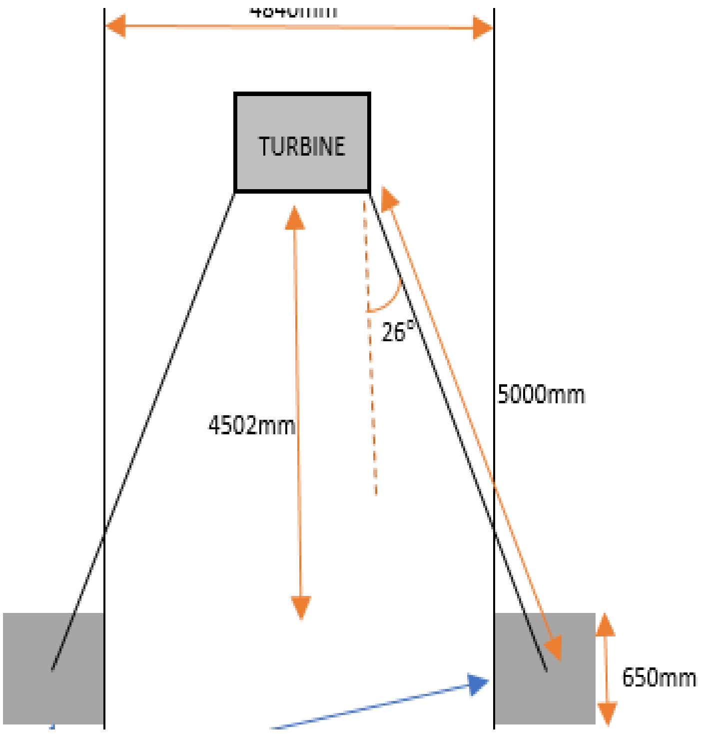


Figure A-4: Anchor detail top view

vi. Turbine protection

The standard turbine has a grid structure on the front as shown in Figure A-5. However, as an additional protective measure (for humans and debris) steel bars were attached to the turbine casing sides as shown.

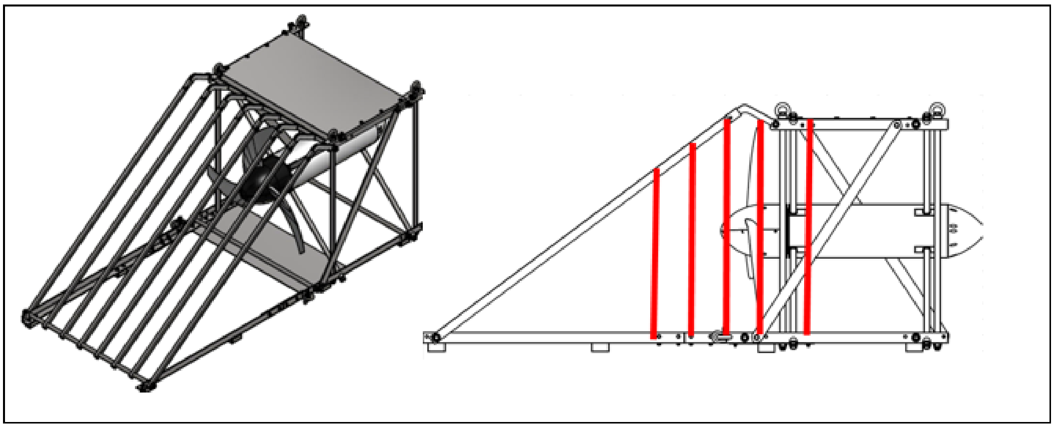


Figure A-5: Turbine protection

vii. Signage

Due to possibility of people swimming in the canal, signage indicating the danger of swimming (Figure A-6) or entering the canal was included at the installation site.

Figure A-6: Signage

iii. Lifting system

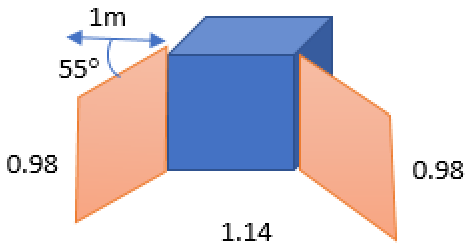
A gantry or similar type of system was necessary to lift the turbine out of the canal when necessary, the turbine weighs around 300kg and therefore requires a strong system to remove. As described in Table 3-5 various lifting systems were considered. Due to practicality and cost reasons a TOA Crawler Crane was procured for all installation and testing and maintenance purposes as shown in Figure A-7.

Figure A-7: TOA Crawler crane

APPENDIX B:
CALCULATIONS ON TURBINE ALTERATION

TURBINE OPTIMIZATION

TURBINE GUIDE PLATE CALCULATIONS: GROBLERSHOOP SITE



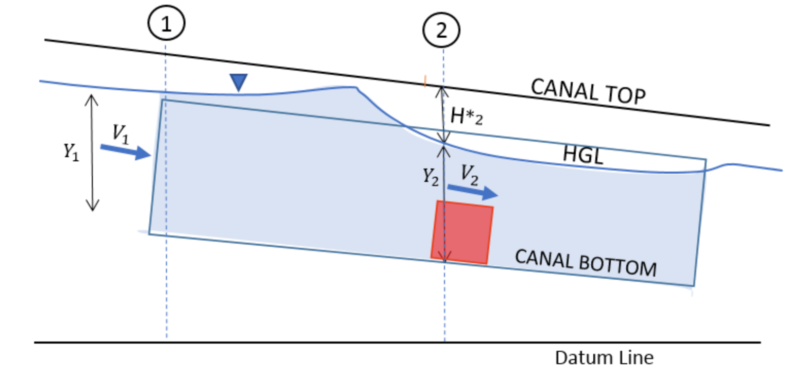
CONSTANT	VALUE
Flow (m^3/s)	6.6
V_1 (m/s)	1.2
Max plate height due to grid constraints (m)	0.945
Max plate length due to constraints (m)	1

TURBINE ESTIMATIONS		
Area of turbine	±1.32	m^2
MEASUREMENTS TAKEN		
Canal flow area	7.7	m^2
Measured flow in section	6.6	m^3/s
Flow through turbine	1.13	m^3/s
Measured velocity	1.2	m/s
Flow rate per m^2	1.2	m^3/s per m^2
ADDITIONAL AREA REQUIRED		
Desired velocity	3.10	m/s
Desired flow through turbine	4.11	m^3/s
Additional flow required	3	m^3/s
Additional area required	2.5	m^2
Blocked width required (per side)	1.32	m
GUIDE PLATE DESIGN		
Height	0.945	m
Blocked width (per side) due to weight and practicality constraints	1	m
Total blocked area	1.89	m^2
Theoretical flow rate through turbine	3.4	m^3/s
Theoretical velocity	2.6	m/s

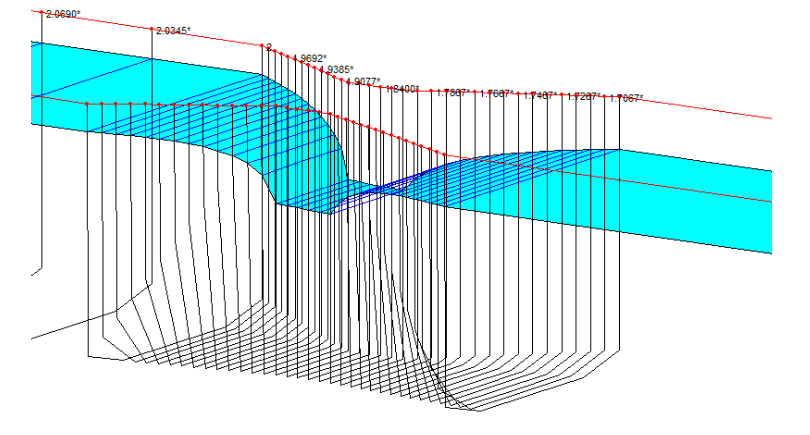
APPENDIX C:
CALCULATIONS ON CANAL ALTERATION

CANAL NARROWING

CANAL NARROWING CALCULATIONS: GROBLERSHOOP SITE



CONSTANT	VALUE
Y_1 (m)	1.3
FLOW (m^3/s)	6.6
V_1 (m/s)	1.9
MAX HEIGHT AVAILABLE UNTIL TURBINE EXPOSED (mm) (H^*_2)	414.8 (Canal top to turbine top)



CONSTANT	VALUE
HEC-RAS COEFFICIENTS OF EXPANSION/ CONTRACTION	0.1-0.3
NARROWING LENGTH (m)	2.5
EXPANSION LENGTH (m)	3
FLOW (m^3/s)	6.6

NARROWED WIDTH (m)	Y_2 (m)	V_2 (m)	HEIGHT (H^*_2) (mm)	DETAILS
3.8	1.35	1.29	94 (sufficient)	No overtopping
3	1.3	1.74	144 (sufficient)	No overtopping
2.5	1.16	2.29	284 (sufficient)	No overtopping
2	1.07	3.13	374 (sufficient)	Upstream overtopping

APPENDIX D:
DRAFT POLICY ON SUSTAINABLE HYDROPOWER GENERATION

General Notices • Algemene Kennisgewings

DEPARTMENT OF WATER AND SANITATION

NOTICE XXX OF 2016

DRAFT POLICY ON SUSTAINABLE HYDROPOWER GENERATION

I, Nomvula Paula Mokonyane, in my capacity as Minister of Water and Sanitation, and duly authorized by the National Water Act (Act No. 36 of 1998) hereby give notice of intention, to publish a draft Sustainable Hydropower Generation Policy as contained in the scheduled hereto, for the purposes of comment and consultation with interested and affected parties.

Members of the public are invited to submit to the Minister, within 60 (sixty) days after the publication of the notice in the gazette, written comments or inputs to the following addresses:

By Post to:
The Director-General
Department of Water and Sanitation
Private Bag X313
Pretoria
0001

Or hand delivered to:
Department of Water and Sanitation
185 Francis Baard Street,
Sedibeng Building, Room 914
Pretoria
0001

Marked for the attention: MR ANIL SINGH: DDG: WATER SECTOR REGULATION

By email: SinghA3@dws.gov.za or by fax to: (086 561 4745) or
Alternative email: Brisleym@dws.gov.za or by fax to: (086 216 9765)

All enquiries in connection with the draft Sustainable Hydropower Generation Policy can be directed to Mr A.B Singh at (012 336 7360) or Ms M.E Brisley at (012 336 8768)

Comments received after the closing date may not be considered.

Nomvula Mokonyane
Minister of Water and Sanitation
Date: 28.05.16

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

DRAFT SUSTAINABLE HYDROPOWER GENERATION POLICY

Gazetted for Public Consultation

July 2015

Table of Contents

page numbers

1. Introduction and Background

The global shift towards renewable energy and the ongoing South African energy crisis have created an environment where renewable energy projects including hydropower projects, such as those which are retrofitted to existing dams, are both environmentally and financially attractive due to existing suitable infrastructure.

With South Africa experiencing serious electricity shortages currently, the National Development Plan sets a target of 20 000MW of new-build generation capacity from renewable sources by 2030. This is half of the overall new-build capacity target. The Green Energy Strategic Infrastructure Project aims to deliver a third of this (6.9GW) through independent power producers by 31 March 2019. These renewable technologies include on shore wind, solar photovoltaic, concentrated solar power, biogas, biomass, landfill gas, and **hydropower**. Furthermore the President of the Republic of South Africa, in his State of the Nation address made a commitment that the state will invest and look into the development of hydropower as one of the sustainable renewable energy generation methods. Different forms of hydropower including reservoir, pumped storage and run-of-river systems of various sizes are available and can be used for different forms of electricity.

South Africa has a potential to develop hydropower at existing DWS infrastructure such as dams, canals, pipelines as well as making use of the water resources in SA including the shared river basins. Instead of dams being constructed for the purpose of hydropower, existing reservoirs that are used for other purposes can be fitted with hydropower plants in order to augment electricity supply towards meeting peak electricity demands. This is in line with multiple-use approach enshrined in the 2013 National Water Policy Review. Hydropower is a renewable economic, none polluting and environmentally friendly source of energy.

In order to ensure optimisation of the water resource use, a policy is required. This has prompted Department of Water and Sanitation (DWS) to develop this Policy for the sustainable development of hydropower technologies in the South African water and sanitation **sector.**
Irrespective of the type of any prospective installation, hydropower development in South Africa will require authorization in terms of the National Water Act, 1998 (Act No. 36 of 1998) and amendments.

Hydropower generation can contribute not only to the Strategic Infrastructure Projects but also to the Department of Energy's universal electrification and energy efficiency strategy.

2. Purpose

The purpose of this document is to provide Policy position for the Department of Water and Sanitation on the establishment and development of hydropower on existing DWS infrastructure as well as within the water resources of South Africa as part of long term interventions by the Department to support sustainable power supply in South Africa.

3. Scope of the Policy

The policy provisions will be applicable to prospective and existing hydropower generators in relation to describing the DWS authorisation process for hydropower development on DWS owned infrastructure utilisation and water resources optimisation with regards to water transfer schemes which include dams, barrages; rivers, irrigation systems (canals and conduits) as well as run-off-river schemes.

It encourages energy efficiency initiatives in the water and sanitation sector which includes but not limited to: Conduit hydropower in development opportunity within Water and Sanitation services infrastructures *and water distribution networks.*

This Policy will address all issues ranging from very small-scale run-off-river projects to the large-scale retrofitted dams. The Department does not foresee dams being constructed for the sole purpose of hydropower however the feasibility of potential hydropower generation at newly planned dams will be required.

The scope of this Policy excludes tidal lagoons, harbours and wave energy systems but further investigations of suitable hydropower in these systems is encouraged.

4. Key Policy Considerations

The key consideration of the policy is to:

a) Ensure that Hydropower development and its operation is in accordance with the principles of National Water Act no 36 of 1998 i.e. Sustainability, Equity and Efficiency (SEE).
b) Ensure that hydropower and its operation is in accordance with the DWS sustainable hydropower generation policy.
c) To contribute towards development of clean energy in order to mitigate green house gas emissions.
d) DWS application and approval process, and requirements for authorization.
e) Consider and support the existing national energy legislation, policies, strategies and plans

5. Relevant Legislative framework

5.1 DWS Mandate

The Department of Water and Sanitation (DWS) is the custodian of South Africa's water resources. It is primarily responsible for the formulation and implementation of policy governing the development and management of the water and sanitation sector. It also has a responsibility to regulate and support provision for water services provided by local government.
The National Water Act (NWA) (Act 36 of 1998) provides a framework for the protection, use, development, conservation, management and control of water resources for the country as a whole.
Integrated water resource management (IWRM) is described in the Act as the means to effect the aim of the NWA, and is operationalised through the **National Water Resource Strategy (NWRS)**, which inter alia:

- determines how much water is- to be “reserved”, allocated for international commitments, and available in each water management area;
- provides for the establishment of water resource management institutions such as Catchment Management Agencies (CMAs);

- sets principles for water conservation, ***water use*** and water quality.

The **National Water Resource Strategy** provides the overall framework for water resource management in the country.

Box 1: Hydropower in the NWRS

The 2013 NWRS includes provisions for hydropower generation at DWS owned infrastructure facilities, and specifically DWS owned dams. Key excerpts from the NWRS are reproduced here for ease of reference.

An objective of the NWRS is to "*promote the optimal development of hydro-electricity generation at all sites in South Africa where this is economically viable and can make a useful contribution to electricity generation*."

"…The installation of small-scale hydro-electric plants to take advantage of the head available and flow from existing dams is being considered in cooperation with the Department of Environmental Affairs (DEA), National Treasury, Eskom, the Central Energy Fund and private sector partners."

"*…The Department of Energy (DoE), together with the DWS and the National Treasury (NT), commissioned an investigation of the prospects for retrofitting hydroelectric generation equipment at existing DWA dams with hydroelectric power potential. The DOE has shortlisted 14 sites for further detailed evaluation.*
The services of Independent Power Producers (IPP) will be procured to construct and operate the hydroelectric power stations that are the most favourable and viable. The IPPs will be required to enter into agreements with the DOE and Eskom for the sale into the national electricity grid of the electricity to be produced."

5.2 Planning Framework: The National Development Plan Vision 2030

The 2015-2019 Medium Term Strategic Framework (MTSF) encapsulates the intermediate electricity infrastructure milestones in the context of the NDP and **the Integrated Resource Plan (IRP)** 2010 long-term planning framework. The main target for electricity infrastructure development is "*to increase the electricity generation reserve margin from 1% (2014) to 19% in 2019 to ensure the continued, uninterrupted supply of electricity in the country. The corresponding MTSF interim delivery targets for Outcome 6 (an efficient, competitive and responsive economic infrastructure network) therefore require the development of 10 000 MWs additional electricity capacity to be commissioned by 2019 against the 2010 baseline of 44 000 MWs – of which 5 000 MW should be from renewable energy sources*." (IPPPP Unit 2015)

Box 2: The 2011 IRP 2010-2030 (IRP1)

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

The IRP, inter alia, defines the amount of electricity that is to be developed as new-build capacity for each technology type up to 2030.

5.3 Energy Policies and Legislation

The energy policies and interventions in the country, reflecting South Africa's transition to a green economy, include:

White Paper on the Energy Policy of the Republic of South Africa December (1998)
The *White Paper on Energy Policy* (DME, 1998) sets out Government's policy with regards to the supply and consumption of energy for the next decade. The policy strengthens existing energy systems in certain areas, calls for the development of underdeveloped systems and demonstrates a resolve to bring about extensive change in a number of areas. The policy addresses all elements of the energy sector.

White Paper on Renewable Energy November (2003)
The White Paper on Renewable Energy supplements the Government's overarching policy on energy as set out in its *White Paper on the Energy Policy of the Republic of South Africa* (DME, 1998), which pledges 'Government's support for the development, demonstration and implementation of renewable energy sources for both small and large-scale applications.'

The White Paper on Renewable Energy sets out Government's vision, policy principles, strategic goals and objectives for promoting and implementing renewable energy in South Africa; it proposes that Government include private energy producers into the electricity generation mix, and that the electricity generation mix should include renewable energy technologies.

It has the following two goals: *to inform the public and the international community of the Government's goals,* and *how the Government intends to achieve it, and; to inform Government agencies and Organs of State of these goals, and their roles in achieving it.*

The White Paper furthermore commits Government to a number of enabling actions to ensure that renewable energy becomes a significant part of its energy portfolio over the period of ten years and beyond. It supports the aim of the Government to set proper boundaries within which the renewable energy industry can operate and grow, thus contributing positively to the South African economy and to the global environment.

National Climate Change Response White Paper (NCCRP) (2011)
Government's National Climate Change Response Policy was approved and gazetted in October 2011.
The White Paper represents the culmination of an iterative and participatory policy development process that was started in October 2005 which involved ground-breaking modelling and research activities, national conferences, numerous workshops and conferences in every province, extensive bilateral and stakeholder engagements.

National Climate Change Response White Paper highlights that South Africa's response to climate change has two objectives:

a) To effectively **manage the inevitable climate change impacts** through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity; and
b) To **make a fair contribution to the global effort to stabilise greenhouse gas (GHG) concentrations** in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner.

Furthermore the National Climate Change Response White Paper committed key sectors, including **electricity, water,** health, bio-diversity and agriculture to compile climate change sector plans to identify and prioritise short and medium term sectoral adaptation initiatives. These sectoral plans should be developed in the context of sectoral legislation and strategies; in the case of the electricity sector, this will be, inter alia, the National Electricity Regulation Act, the National Energy Efficiency Strategy, the Integrated Resource Plan and the Integrated Energy Plan. (Department of Environmental Affairs 2011)
Two of the 8 near-term priority flagship programmes defined in the NCCRP, namely the "renewable energy flagship programme" and the "energy efficiency and energy demand management flagship programme" relate specifically to electricity sector specific objectives. It is argued that the Department of Energy's (DoE) **Renewable Energy Independent Power Producers Procurement Programme (REIPPPP)** can be considered to be the DoE's response to the energy objectives in the NCCRP, though originally initiated from the concepts of the **Renewable Energy White Paper of 2003**.

Electricity Regulation Act
The Electricity Regulation Act, Act 4 of 2006 and the Electricity Regulation Amendment Act, Act 28 of 2007 as amended (ERA), describes the responsibilities and powers of the National Energy Regulator specifically in regards to the processing and issuing of electricity generation, transmission and distribution licences. Inter alia, the Act requires that electricity generation licence applications must include evidence of compliance with **the Integrated Resource Plan (IRP)** of the time **or provide reasons for any deviation for the approval of the Minister.** (Department of Minerals and Energy 2006)
Chapter 4 of the Act introduces the powers and function of both the Minister and the Regulator with regards to New Generation Capacity, including the power to determine the type of energy mix that will make up the capacity need, the extent of participation of the private sector in the generation of the capacity, as well as the means through which this energy is to be procured and bought.

Box 3: REIPPPP

Section 34 of the Electricity Regulation Act 4 of 2006 (South Africa, 2006), as amended by the Electricity Amendment Act 28 of 2007 (South Africa, 2007), refers to "New Generation Capacity":
"(1) The Minister may, in consultation with the Regulator-
a) Determine that New Generation Capacity is needed to ensure the continued uninterrupted supply of electricity;
b) Determine the types of energy sources from which electricity must be generated and the percentages of electricity that must be generated from such sources;
c) Determine that electricity thus produced may only be sold to the persons or in the manner set out in such notice;

d) Determine that electricity thus produced must be purchased by the persons set out in such notice;

e) Require that New Generation Capacity must-

- *Be established through a tendering procedure which is fair, equitable, transparent, competitive and cost-effective;*
- *Provide for private sector participation."*

In August 2011, the Minister of Energy determined that 3 725MW of renewable energy was to be procured through an IPP Procurement Programme 2011, and bought by Eskom. This signified the operationalization of the Renewable Energy Independent Power Producer Procurement Programme, or REIPPPP; designed to contribute towards the target of 20 000MW of additional electricity capacity that is to be generated from renewable energy projects by 2030 as defined in the National Development Plan. A second determination of 3 200MW was made in January 2013, and a third determination of 6 300 MW was made in August 2015.

The programme aims to reduce the country's reliance on fossil fuels, stimulate an indigenous renewable energy industry and contribute to socio-economic development and environmentally sustainable growth, whilst also contributing to the broader national development objectives of job creation, social upliftment and broadening of economic ownership.

6. Hydropower Guiding Principles

The following policy principles will apply to all institutions (Private or Public) in the interest of balancing the sustainable water resource protection, water and sanitation provision and hydropower generation

6.1 Water Support for Integrated and Sustainable Power Generation

Problem Statement

As part of broader government initiative to stimulate energy mix as outlined by National Development Plan (NDP), Hydropower has not been explored to its full potential. There is vast potential of hydropower development in the specific areas within DWS water management catchments and water and sanitation infrastructure (DWS owned and Non DWS) between different government departments at the national, provincial and local levels. The existing delegation of powers between different government departments at the national, provincial and municipal levels on authorization is unclear. However the initiation and implementation of Hydropower generation may place additional responsibilities on DWS in terms of monitoring and management. Realisation and achievement of NWA principles remains a challenge and is ongoing. What is the guarantee? To ensure that Hydropower development and its operation is in accordance with the principles of National Water Act no 36 of 1998's principles i.e. **Sustainability**, Equity and Efficiency (SEE)

Policy Principle

DWS will support the development of hydropower as part of both social and economic development within the context of water scarcity and water infrastructure challenges without compromising sustainable protection of water resources and water and sanitation services provisions. The roles and responsibilities relating to the full process should be defined at every stage of the generation process to ensure sustainable operation. This encompasses all stages from Planning, Construction/Development, Operation & Maintenance and Decommission stages satisfying all required activities.

6.2 Differentiated authorisation process

Problem statements

The current DWS authorisation/licensing process does not differentiate between Authorisation which will result in the Utilisation of DWS, Other Government institution, Private institution or partnership between Private and Government or Government to Government Institution. The hydropower projects results in generation of different capacity ranging from Pico (less than 25 kilo watts (kW) to Mega (more than 1000 Megawatts (MW) projects. In the view of the above challenges DWS needs proper classification of Authorisation and projects to afford clearing of its roles and level of involvement.

Policy Principle

The current authorisations as per National Water Act will be supplemented to differentiate utilization of DWS Infrastructure and the categorization of the projects. The Hydropower generation projects will follow the current application process as per NWA. On the projects classification DWS will authorize/license all the projects of all classes with capacity ranging from Pico (up to 20 kilo watts (kW) to Mega (more than 10 Megawatts (MW) projects. Furthermore, DWS shall develop conditions on the approval/ authorization of hydropower development applications, which will determine application process that will be followed by both private and public institutions.

The following table highlights the hydropower installation classification for purposes of this policy and will be adopted as outlined in the Department of Energy Hydropower implementation guide, in order to further guide the DWS hydropower development, regulation and all related process.

Hydropower Category	Capacity in Power output
Pico	Up to 20KW
Micro	20kW to 100 kW
Mini	100Kw to 1MW
Small	1MW TO 10 MW
All installations above 10 MW are classified as macro(Large) hydropower plants	>10 MW *The large hydropower development has also its history in South Africa and manifested over the years in installation of several significant hydroelectric plants developed together with the large dams. Two most significant large hydroelectric installations Gariep (360 MW) and Vanderkloof (240 MW) are situated on the Orange River in the Northern Cape Province. The smaller existing operational plants are all situated in the Eastern Cape Province namely the Mbashe (42 MW), First and Second Fall (6.4 and 11 MW) and Ncora (2.4 MW).*
Adapted from: The sustainable energy resource handbook, volume 2 (Barta,2010)	

6.3 Integrated Hydropower Authorisation and Licensing process

Problem statement

As outlined in the National Water Act, 1998 (Act no 36 of 1998), any hydroelectricity project require Water Authorisation. **Licensing:** National Energy Regulator of South Africa (NERSA) is the sole authority, to approve applications for the generation of electricity. Any person who generates, distributes, transmits, imports, exports or trades electricity can only do so with a licence granted by NERSA. Unaligned and non-integrated and un-catered for process for consideration of water use licences, relating to exploitation of hydropower generation activities.

This policy principle provides for the concurrence between the Ministers, the Minister responsible for Water Resources (DWS) and the Minister responsible for Energy (DoE) for consensus on process to be followed to integrate the process of approval. In further emphasising NWA requirements, a person may only use water relating to hydropower upon following the NWA authorisation process. In the interests of co-operative governance, DWS will activate (define) arrangements with Department of Energy (DoE) through their regulator, National Energy Regulator South Africa (NERSA), to combine their respective authorisation requirements.

6.4 Ensuring Real Hydro Power Investment and Partnerships

Problem statement

Given that this is a new endeavour and opportunity for the sector, further investigations need to be conducted to ascertain value for money attached to hydropower development. There is a need for enabling policy environment for the Department opening/encouragement of partnership for dual benefit. Terms regarding sharing of facilities, project ownership after concession, hydropower generation locations (servitudes) need to be stipulated. Furthermore, cost recovery measurers in the hydropower operation value chain need to be defined to ascertain sustainability of the hydropower operation and the DWS infrastructure.

Policy Principle

In order to enhance and encourage hydropower generation, DWS will support the following:

The Independent Power Producers (IPP) Procurement Programme: designed so as to contribute towards the target of 3 725 megawatts and towards socio-economic and environmentally sustainable growth, and to start and stimulate the renewable industry in South Africa. This will be achieved by maximising the existing opportunity of hydropower opportunities within DWS infrastructures.

Investment guaranteed as per National treasury guidelines: Preferential Procurement Process (PPP) etc,

Memorandum of Understanding on key issues: Ownership, Concession period, Leasing agreements, Risk plan, Liabilities, Insurance

Reflective cost recovery mechanisms: Operation cost, refurbishing cost or replacing obsolete and disposing infrastructure.

Water Charge/Tariff and related investment issues will be dealt with as per DWS pricing strategy in consultation with National Treasury and relevant institutions. Real Hydropower investment is a great way to afford DWS certainty on hydropower generation future sustainability and secure the investor's financial future. At the same time it ensures that DWS will not have to carry the cost if the infrastructure or resource is compromised as a result of hydropower generation by IPPs.
This policy position further encourages exploration of different, sustainable and effective investment models.

6.5 Compulsory compliance with dam safety standards and other necessary safety requirements

Problem Statement
DWS has existing Dam safety standard requirements and a plan for monitoring dam construction and operation called the Dam Safety. This plan is underpinned by National Water Act which outlines dam's safety requirements. But there is no explicit direction on how to deal with Dams with Hydropower facilities.

Policy Principle
Compulsory compliance and Non-Negotiable adherence to all DWS dam safety standards requirements. The vigilant compulsory plan will include data collection on the operation vs. safety to afford proactive efforts to deal with any unforeseen circumstances that will compromise water security.The inspection process will amongst others look at instrumentation, equipment maintenance, reading frequency and procedures, action levels, procedures should a failure occur and how reports sent to DWS must be formatted. The reports include photographs, diagrams and data taken at the dam.

6.6 Use and promotion of appropriate sustainable technology

Problem statement
Based on international experience, the development of Hydropower has not been driven solely by concern for human progress and quality of life but is also frequently used to advance nationalist or ideological agendas. Challenges with Hydropower technology include: dependence on rainfall (no control over amount of water available); changes in stream regimens (can affect fish, plants, and wildlife by changing stream levels, flow patterns, and temperature); flooding of land and wildlife habitat (creation of reservoir). Maintaining minimum flows of water downstream of a hydropower installation is critical for the survival of riparian habitats.

Policy Principle
Hydropower can be considered technologically acceptable if the cost of refurbishing or replacing obsolete infrastructure is taken into account, e.g. replacing obsolete dam and disposing sediments, which may have accreted behind them. While this removing process may be technically and

economically viable to smaller projects, there are yet no indications that it will be for the greater majority of very large dams owned by DWS. It is against this background that DWS require promotion of appropriate technology in the continuous environmental risk appraisal linked to appropriate actions taken throughout the hydropower generation value chain and the appropriate technology should be supported by available skills. The authorisation process will vary according to varieties of technology proposed and the processing and decision will be handled on case by case basis.

6.7 Utilisation of International Sustainable Hydropower generation protocol

Problem Statement

Hydropower incidents are usually caused by three (3) main factors: poor planning, unpredictable natural events or equipment failure. Sometimes developers of new dams don't take all geological factors into account. Dam failure can be caused by unpredictable natural causes or due to increased rainfall. Can the disaster related to hydropower be predicted? It is hard to tell because sometimes severity of water rises over prediction. The accidents in this sector are rare but when something does go wrong then the consequences are usually fatal. Planners need to take a lot of geological and environmental issues into account when they plan building new hydroelectric plants although sometimes the events can't be predicted.

Policy Principle

All Hydropower Project utilizing DWS owned Infrastructure and its water Resources will be subjected to The Hydropower Sustainability Assessment Protocol. The Hydropower Sustainability Assessment Protocol is a tool for assessing projects across a range of social, environmental, technical and economic topics. It provides an international common language on how these considerations can be addressed at all stages of a project's lifestyle: planning, preparation, implementation and operation.

7 Types of utilisation on DWS water resources and owned infrastructure

Within the context of this policy, there are four types of utilisation against DWS water resources and owned infrastructure namely:

a) Demand Management/Energy efficiency/Own use - Where the utilisation will result in the energy generated to be used in own operations e.g. DWS contract IPP to generate electricity to use in their operations. This type of own-use generation is generally considered as a load reduction intervention, in contrast to contributing to the electricity generation function.
b) Islanded Use Where the utilisation will result in the energy generated to be used directly to households electrification e.g. Rural Electrification Programme

c) Municipal Grid - Where the utilisation will result in the energy generated to be sold to Municipality for distribution to Municipal operations
d) Eskom Grid - Where the utilisation will result in the energy generated to be sold to Eskom national grids to support national energy requirements. This can be done through either the REIPPPP or another electricity procurement programme determined by the Minister of Energy.

The four types of utilisation are depicted below in Table 1 below.

Table 1: Types of Approved utilisation on DWS water resources and owned infrastructure

Types of Utilisation	DWS Owned Infrastructures				Water Resources	
	Exploitation opportunity				Exploitation opportunity	
	Dams	**Canals**	**Pipelines**	**Other**	**Run-of-River**	**Other (*include international rivers basin)***
	Retrofit	*Conduit*	*Conduit*	*other*	*Run-of-River*	*Other*
Demand Management/Energy Efficiency/Own Use	√	√	√	√	√	√
Islanded use	√	√	√	√	√	√
Municipal grid	√	√	√	√	√	√
Eskom Grid	√	√	√	√	√	√

8 Exclusions

The DWS may implement hydropower projects outside these policy principles through any other models as deem necessary in order to achieve and support the strategic objectives of the country and for purpose of Research and Development (piloting).

9 Conclusion

South Africa has an extremely energy-intensive economy in relation to the rest of the world. The current energy challenges have opened up a window for investors to look into independent power production. There is a potential to move towards renewable forms of energy, with hydropower being a key focus.

There is significant and identified potential for the development of hydropower in South African Water Resources infrastructure which may include large dams and the perennial streams and within existing water supply (i.e. urban and agricultural scheme) and wastewater treatment infrastructure. This potential is not necessarily significant with regard to the contribution to the Eskom's national grid, but is significant with regard to the potential reduction in electricity demand on the overloaded national power generation capacity.

Beyond the licensing procedures, the DWS is also responsible for overall management of water resources and all its activities and other water resources management aspects of any riverside hydropower development. DWS have a duty to protect the water resources from any harm that can arise from hydropower development and to ensure sustainable provisions of water.

The DWS shall work closely with the Department of Energy to embrace and advance the development of Hydropower for greater contribution in the energy needs of the country. To provide enabling environments in hydropower generation development to promote sustainable power generation and maximize protection of water resources and its infrastructure against any possible risks that may arise during Power generation processes within DWS water resources infrastructure.

10 Approval

This policy position is approved by:

MRS N P MOKONYANE: MINISTER OF WATER AND SANITATION
DATE:

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Contents