COMPILATION OF A HYDROPOWER DEVELOPMENT ASSISTANCE TOOL FOR EVALUATING HYDROPOWER RESOURCES IN SOUTH AFRICA

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COMPILATION OF A HYDROPOWER DEVELOPMENT ASSISTANCE TOOL FOR EVALUATING HYDROPOWER RESOURCES IN SOUTH AFRICA

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

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DISSERTATION SUMMARY

COMPILATION OF A HYDROPOWER DEVELOPMENT ASSISTANCE TOOL FOR EVALUATING HYDROPOWER RESOURCES IN SOUTH AFRICA

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Degree: Master of Engineering (Water Resource Engineering)

A nation's industrial growth as well as the quality of life is dependent on energy supply and demand. With the current situation of the supply of energy not matching the growing demand, small-scale hydropower projects could play an important role, especially in providing electricity to remote areas. Even though the experts classify South Africa as a water-scarce country, there is still abundant water for small-scale hydropower schemes which could help with the sustainable energy supply for the future (Banks & Schäffler, 2006).

There are numerous small-scale hydropower plants which played an important role in providing both urban and rural areas of South Africa with energy, even though not well documented. Both Pretoria's and Cape Town's initial electricity was provided by small scale hydropower stations, however these stations were decommissioned due to the national electricity grid expansions (Jonker Klunne, 2009). Approximately 188 hydropower sites are currently in South Africa, which are either potential (54 sites), under construction (21 sites), operational (91 sites) or have been decommissioned (22 sites), excluding privately owned sites (Jonker Klunne, 2016).

It was hypothesised that a user-friendly framework in conjunction with a Hydropower Development Assistance Tool (HDAT) could be compiled. The designed framework and the HDAT could guide the potential power producers through the process of developing new or upgrading existing hydropower facilities in South Africa.

The objective of this study was to develop a framework which is designed to guide users through a decision analysis procedure regarding the refurbishment, renewal or replacement of existing hydropower sites in South Africa, as well as providing guidance for the development of these identified sites. Using a visual representation with the necessary economic evaluation to determine feasibility using an Excel-based assistance tool.

The Hydropower Development Assistance Tool was tested on the Aliwal North decommissioned hydropower site. This site was chosen by the Water Research Commission (WRC) to be recommissioned. The result was a practical decision support system for the evaluation of existing or decommissioned hydropower sites in South Africa.

DECLARATION

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- I understand what plagiarism is and I am aware of the University's policy in this regard;
- The work contained in this project is my own original work;
- I did not refer to work of current or previous students, lecture notes, handbooks or any other study material without proper referencing;
- Where another person's work has been used this has been properly acknowledged and referenced;
- I have not allowed anyone to copy any part of my project;
- I have not previously in its entirety or in part submitted this project at any university for a degree.

DISCLAIMER:

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Student Number: 10053141

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LIST OF ABBREVIATIONS

B/C = Benefit/Cost Ratio
BHA = British Hydropower Association
CPI = Consumer Price Index
DME = Department of Minerals and Energy
DOE = Department of Energy
DWS = Department of Water and Sanitation
EIA = Environmental Impact Assessment
ESHA = European Small Hydropower Association
EUL = Expected Useful Life
FC = Fixed Costs
HDAT = Hydropower Development Assistance Tool
IPP = Independent Power Producers
IRP = Integrated Resource Plan
IRR = Internal Rate of Return
LCC = Life Cycle Cost
NEMA = National Environmental Management Act
NERSA = National Energy Regulator of South Africa
NPV = Net Present Value
O&M = Operation and Maintenance
PAT = Pump as Turbine
PRV = Pressure Reducing Valve
REIPPP = Renewable Energy Independent Power Procurement Program
RETs = Renewable-energy and Energy-efficient Technologies
ROI = Return on Investment
RUL = Remaining Useful Life
RR = Run-off-River
SANRAL = South African National Roads Agency Limited
SHP = Small Hydropower
SSHP = Small-scale Hydropower
WTW = Water Treatment Works
WWTW = Waste Water Treatment Works

LIST OF SYMBOLS

A = Area of the river or channel (m^2)
C_p = Power Coefficient (C_p = 0.25 for small scale turbines)
d_r = Discount or Escalation Rate (%)
g = Gravitational Acceleration (9.81 m/s^2)
H = Effective Pressure Head (m)
H_{atm} = Atmospheric Pressure Head (m)
H_b = Barometric Pressure Head (m)
H_s = Suction Pressure at the outlet of the runner (m)
H_v = Vapour Pressure Head (m)
hf = Friction Losses (m)
hl = Secondary Losses (m)
I = Electric Current (A)
K = Secondary Loss Coefficient
L = Length of Penstock (m)
$\mathbf{n}$ = Number of years
n_t = Turbine speed (rpm)
$\mathbf{N}$ = Number of turbines
Ns = Turbine specific speed
P = Mechanical Power Produced at the turbine shaft (Watts)
P_a = Available Power (watts)
Q = Flow (m^3/s)
V = Potential difference (V)
v = Velocity (m/s)
Z_1 = Elevation of the water above the datum line at Station 1 (m)
Z_2 = Elevation of the water above the datum line at Station 2 (m)
η_t = Hydraulic Efficiency of the turbine (%)
ρ = Density of Water (1000 kg/m^3)
σ = Cavitation Factor

1 INTRODUCTION

1.1 BACKGROUND

Hydropower is not a new concept. Both the Greeks and the Romans have been using it for over 2000 years in the form of water wheels for irrigation and flour milling. These water wheels were the primary source of mechanical power until 1712 when the steam engines were developed (Leyland, 2014). In 1909 electrical power plants were developed for the onsite mining generators in South Africa. Eskom then further developed this form of electrical power to provide electricity for both the railway and non-mining industries in 1923. The company expanded in 1948 to supply most of the country with electricity (Coutsoukis, 2004).

Since 2008 the national electricity grid of South Africa, which is managed by Eskom, are experiencing numerous difficulties (Lloyd & Subbarao, 2009). The supply not matching the demand, as well as the escalation in energy costs, are two of the main problems encountered by Eskom. Thus, the primary source of electricity (i.e. coal-fired power stations) is reducing and cannot sustain a constant and reliable supply against the demand of existing as well as future electricity users connected to the national grid.

Eskom has been expanding their coal-fired power stations with the construction of two stations, Kusile and Medupi (4800 MW and 4764 MW respectively) to improve their supply capacity. Similarly, the Ingula Pumped Storage Scheme with a total capacity of 1332 MW was built to improve the capacity during peak demand periods. However, sustainability and diversity in electricity sources is still lacking in South Africa and thus it is vital that alternate energy sources are being investigated. In 2011 the South African Government opened the Renewable Energy Independent Power Producers Procurement (REIPPP) program, which allows private developers to install up to 3725 MW renewable energy generation capacity. This includes renewable energy resources such as biogas, biomass, solar radiation, wind power and small hydropower schemes (Department of Energy, 2017).

A nation’s industrial growth as well as the quality of life is dependent on energy supply and demand. The industrial growth contributes to the economic growth which leads to a better quality of life. With the current situation of the supply of energy and a growing demand, small-scale hydropower projects could play an important role, especially in providing electricity to remote areas. There are also numerous opportunities to utilize existing water infrastructure in South

Africa. These hydropower projects could be stand-alone isolated mini grids or could be linked to the national electricity grid.

Even though the experts classified South Africa as a water-scarce country, there is still abundant water for small scale hydropower schemes which could help with the sustainable energy supply for the future (Banks & Schäffler, 2006). Even though not well documented, there are numerous small-scale hydropower plants which played an important role in providing both urban and rural areas of South Africa with energy. Both Pretoria's and Cape Town's initial electricity was provided by small scale hydropower stations, however these stations were decommissioned due to the national electricity grid expansions (Jonker Klunne, 2009).

Currently there are approximately 188 hydropower sites in South Africa, which are either potential (54 sites), under construction (21 sites), operational (91 sites) or have been decommissioned (22 sites) as can be seen in Figure 1-1 (Jonker Klunne, 2016). There are several additional sites that have not been included in this database as they have not been identified or are owned and managed by farmers on privately owned land.

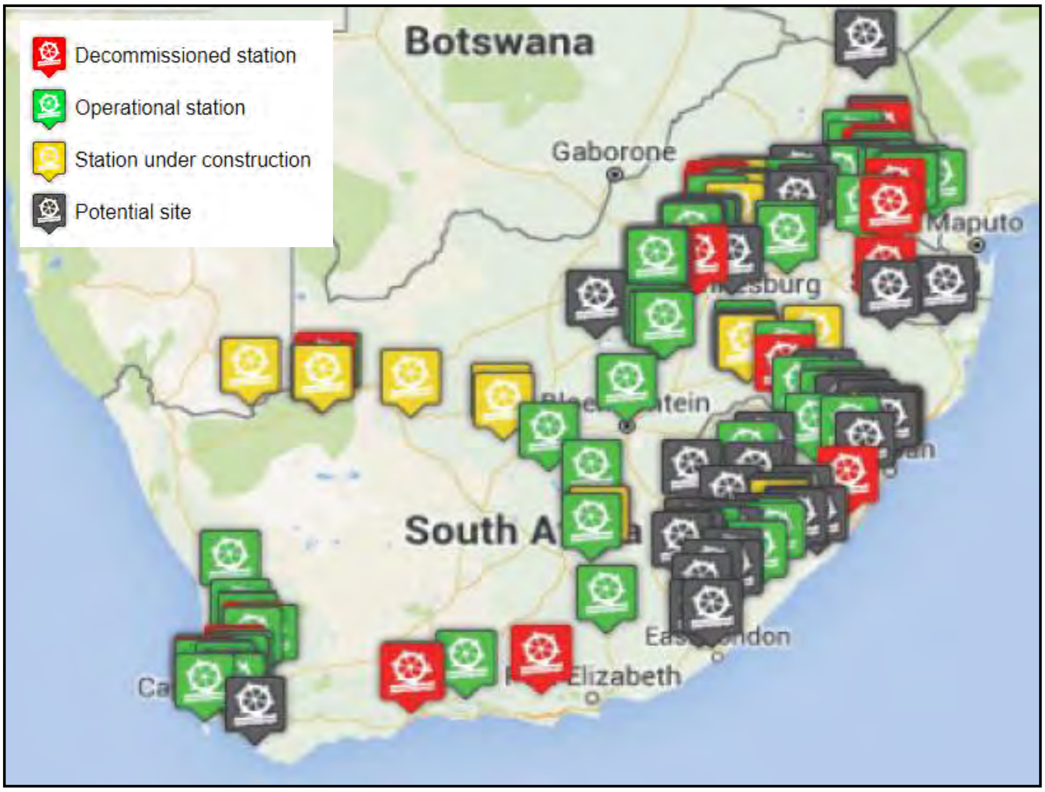


Figure 1-1: Recorded Hydropower Stations in South Africa (Jonker Klunne, 2016).

1.2 PROBLEM STATEMENT

Currently there are several hydropower plants that have been decommissioned in South Africa. A lack of both technical understanding and knowledge regarding the reinstatement of these hydropower plants has led to the major potential losses. A number of potential sites are also linked to water infrastructure such as dams or weirs and the legislative process in South Africa is not conclusive to reinstate or develop these sites. There is no clear process which can be followed to guide electricity utilities and private power producers through the process of determining whether to refurbish, renew or replace an existing hydropower scheme.

1.3 HYPOTHESIS

It was hypothesised that a user-friendly framework in conjunction with a Hydropower Development Assistance Tool (HDAT) could be compiled. The designed framework and the HDAT could guide potential power producers through the process of developing new or upgrading existing hydropower facilities in South Africa.

1.4 OBJECTIVES OF THE STUDY

The objective of this study was to develop a framework which is designed to guide users through a decision analysis procedure regarding the refurbishment, renewal or replacement of existing hydropower sites in South Africa, as well as providing guidance for the development of these identified sites. The objectives include the following:

- Understanding the intricacies of the old existing hydropower sites;
- Developing a flow diagram to include all the necessary elements that need to be evaluated with respect to an existing hydropower site;
- Designing a Microsoft excel-based assistance tool for the economic evaluation and feasibility study;
- Developing costing elements for South African context.

1.5 SCOPE OF THE STUDY

The scope of this study will entail the development of an Excel-based HDAT for the evaluation of existing hydropower plants in South Africa. Developmental procedures (pre-feasibility, feasibility, and detailed design) for the refurbishment, replacement or renewing an existing hydropower plant were included in the HDAT. The two financial evaluations, the net present value (NPV) and internal rate of return (IRR) were utilised in the study as they constitute the main evaluation measures of a basic financial cost-benefit analysis. The other financial evaluation methods fell beyond the scope of this dissertation. The HDAT was then tested on a decommissioned Hydropower Plant at Aliwal Norths which was considered by the Water Research Commission (WRC) to be recommissioned.

1.6 METHODOLOGY

The following procedures were followed to compile this report:

- A comprehensive literature review was done to gain insight and background on hydropower and all its components, as well as published literature and research.
- A hypothesis was then synthesised. The different limitations were taken into consideration and were dealt with appropriately.
- A framework was set up incorporating all the different aspects required in a hydropower plant. This framework formed the basis of the Excel-based HDAT.
- The developed framework and HDAT was applied to a case study, necessary changes were incorporated and the tool was updated.
- Finally, conclusions and recommendations were formalised.

1.7 ORGANISATION OF THE REPORT

This report consists of the following sections and appendices:

- Chapter 1 serves as the introduction to the report. It encompasses the background information, the problem statement, the objectives and the scope of the study.
- Chapter 2 comprises of the literature review which entails a detailed study of small-scale hydropower. The different aspects discussed in the literature review include: the fundamentals regarding hydropower development and evaluation; the economic analysis methods; evaluation criteria of existing hydropower sites and case studies. Background information regarding the electricity situation in South Africa is also included in this chapter.
- Chapter 3 explains the procedural approach to the development of the Hydropower Development Assistance Tool (HDAT), using flow diagrams, focusing on the Renew, Refurbishing and Replacement of Existing hydropower sites.
- Chapter 4 describes all the aspects of the Microsoft-Excell-based HDAT and how it could be used.
- Chapter 5 provides the case study of an existing hydropower site at Aliwal North, using the HDAT.

- Conclusions and recommendations are included in Chapter 6.
- Chapter 7 provides the references used in the study.
- The formulas used in HDAT are attached in Appendix A.
- Appendix B contains the drawings of the original Hydropower station constructed in the early 1900's.
- The drawings of the modified kinetic turbines are attached in Appendix C.
- Photos taken during the construction and installation of the kinetic turbines are included in Appendix D.
- Finally Appendix E contains the links to the relevant forms of Eskom and NERSA.

2 LITERATURE REVIEW

2.1 INTRODUCTION

In the Literature Review numerous topics have been covered, these have been summarised in Figure 2-1.

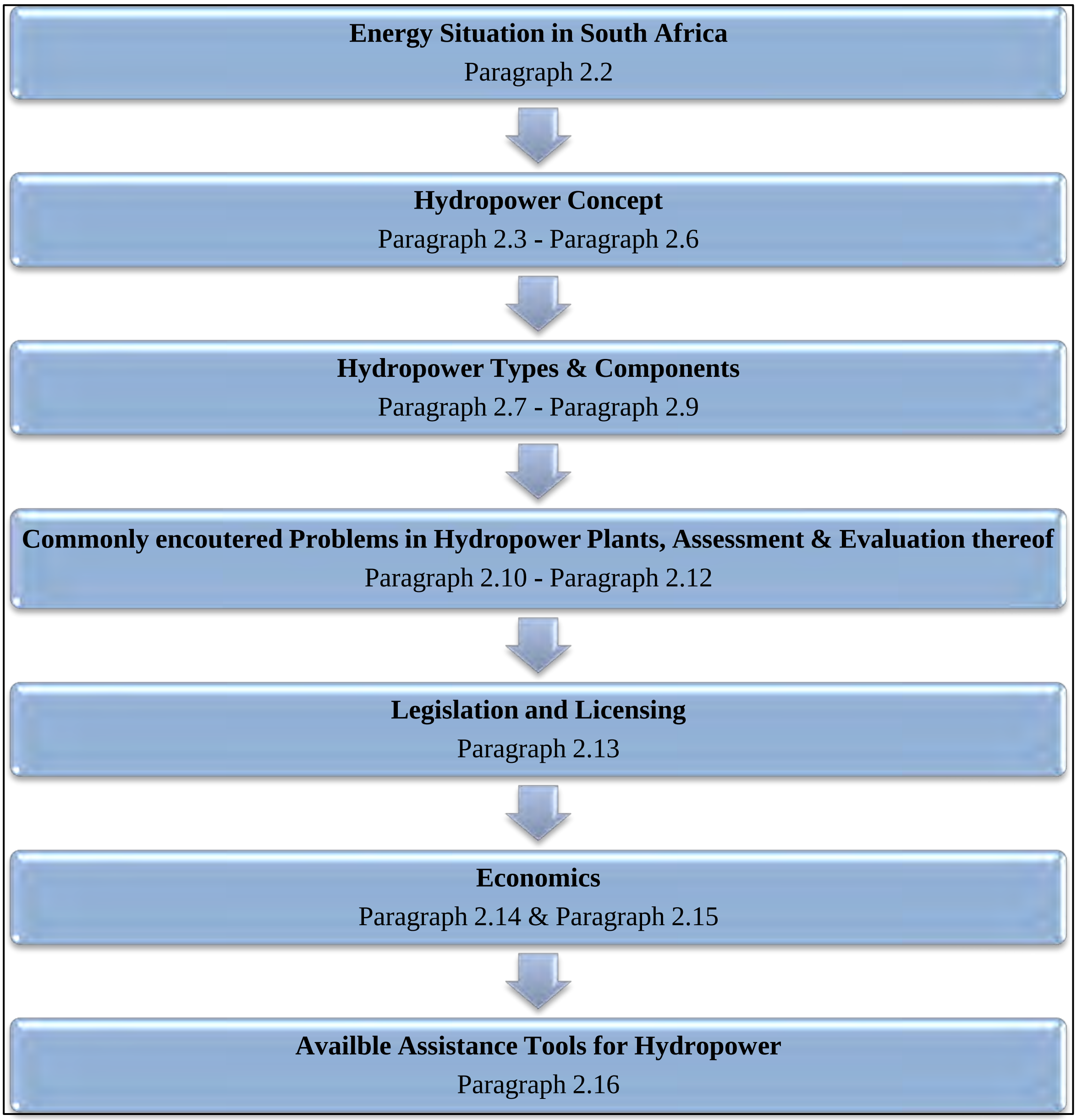


Figure 2-1: Flow Diagram of the Literature Review

2.2 SOUTH AFRICA'S ENERGY SITUATION

2.2.1 BACKGROUND

The affordability of energy forms the back bone of most of the South African economy as electronics, transportation and communications require energy to function. The energy demand is increasing both locally and globally and thus the focus is on providing sustainable energy from renewable sources which are more environmentally friendly (Renewable Projects, 2017).

The percentage of electrified households in South Africa grew from 35% in the early 1990 to around 75% in 2015. Primarily the residential sector was provided with electricity but a backlog of about 3.4 million households is still present, half of them in rural areas. The South African government planned to provide 97% of formal households with electricity by 2025, with 90% grid connected and 7% off-grid. Some areas in South Africa are so rural and difficult to get to for grid connections, thus the renewable energy sources are being investigated for off-grid connections. In the case of developing countries, mini-grids could improve the security, quality and the reliability of electricity (Jamal, 2015).

2.2.2 CURRENT SOURCES OF ENERGY IN SOUTH AFRICA

South Africa is known as a high coal-dependent country with 85% of its electricity produced from coal (Pollet *et al.*, 2015). The local utility, Eskom, produces 95% of the electricity in South Africa and the remaining 5% of the electricity is produced for personal use by private individuals (Statistics South Africa, 2015). Eskom owns and manages 13 coal-fired power stations, one nuclear power station, four gas/liquid fuel turbine stations, three pump storage schemes, six hydroelectric stations and two wind farms. These power stations have a collective nominal capacity of 42 810 MW (Eskom, 2016). The different technologies with their maximum generating capacity can be seen in Figure 2-2, and the distribution of these power stations in South Africa can be seen in Figure 2-3.

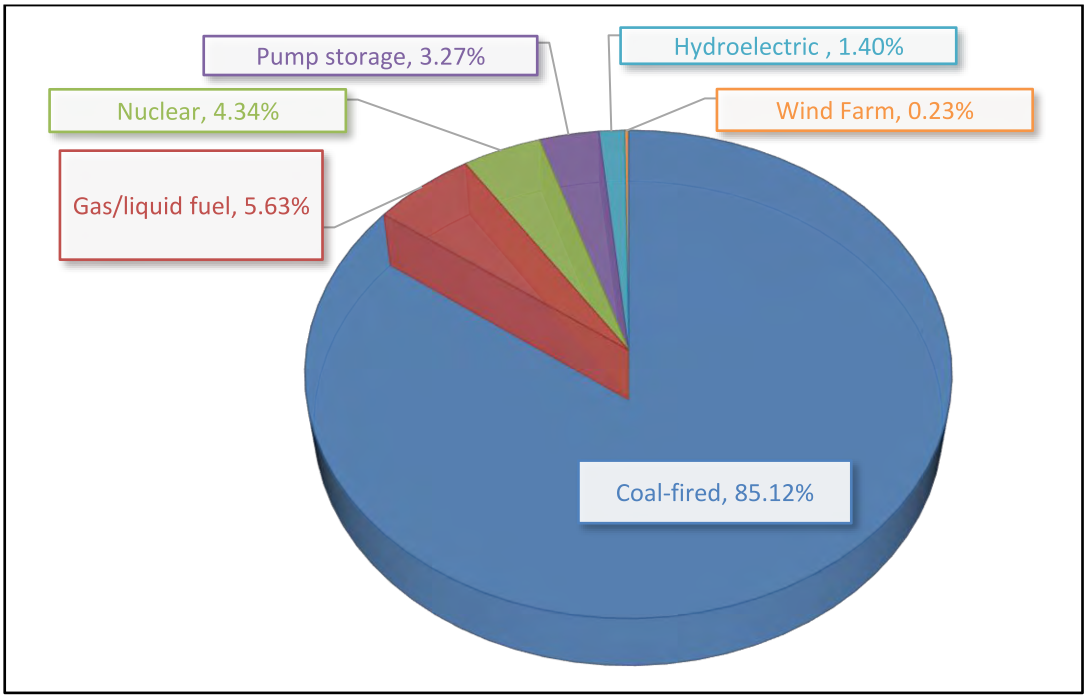


Figure 2-2: Maximum Generating Capacity Mix of Eskom’s Power Stations (Eskom, 2016).

Figure 2-3: Distribution of Eskom's Power Stations in South Africa (Eskom, 2017a).

2.2.3 ELECTRICITY PRICE ESCALATION

For many years the increase in electricity prices has been below the inflation rates but this changed in 2003, as seen in Figure 2-4. This was due to a booming economy and the depletion of the energy capacity. Eskom soon realised that additional generation capacity is required but delays in the planning and decision-making process as well as unforeseen maintenance in 2008 caused reserve margins to reach a critical point and thus Eskom was forced to introduce load shedding. This load shedding negatively impacted the local economy and the effects of the global financial crisis was noticeable (Renewable Projects, 2017; Pollet *et al.*, 2015).

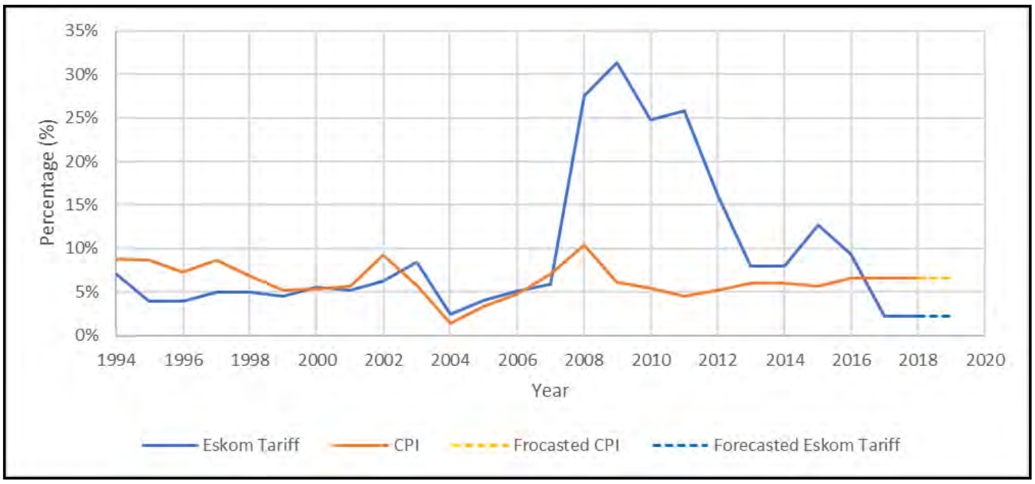


Figure 2-4: Actual Increase in Electricity Tariff Compared to the CPI (Eskom, 2017b).

Over the last 20 years (1997 to 2017) the price of electricity in South Africa increased by nearly 220%, where the inflation over the same period only increased by 120% (Figure 2-5).

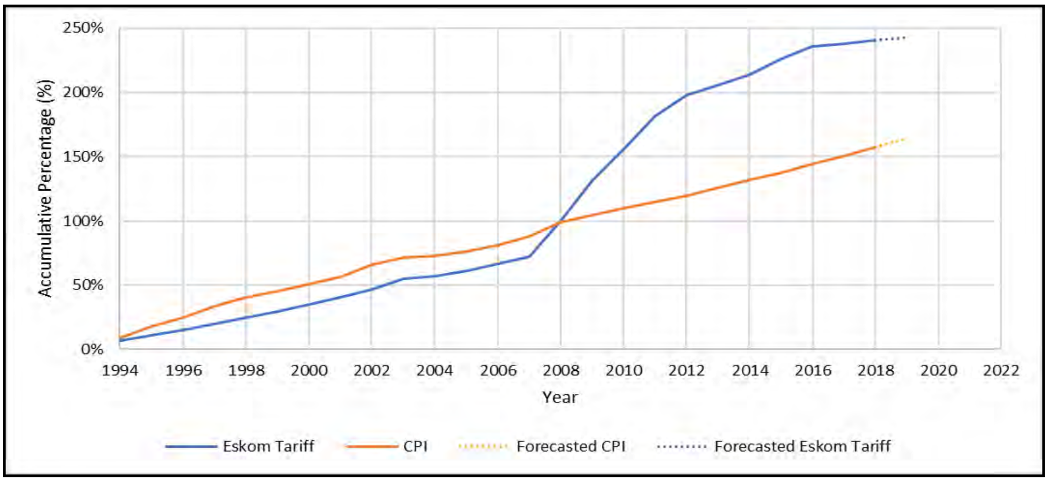


Figure 2-5: The Accumulative Electricity Increases versus the CPI (Eskom, 2017b).

In recent years, South Africa became the largest centre for the development of renewable energy resources in the world (Pollet *et al.*, 2015). After the 2008 crisis Eskom introduced the New Build Program which resulted in a more comprehensive Integrated Resource Plan (IRP), looking at both the power requirement and the infrastructure at a national level, which was established by the Department of Energy in conjunction with various stakeholders. This resulted in a successful implementation of the Renewable Energy Independent Power Procurement Program (REIPPP), allowing Independent Power Producers (IPP) to connect renewable resources to the national grid. Under the REIPPP a total of 6422 MW of power has been produced, of which 3272 MW is operational and available to the grid (Department of Energy, 2018). The development of power stations utilising fossil fuel is still incorporated into South Africa's energy build plan as the Department of Energy agreed to transition into a low-carbon economy and that clean alternatives would be given preference. The REIPPP has helped stabilise the country's power supply as well as reduce the dependence on fossil fuels. Due to the abundance and relatively low costs, coal will remain the primary source of energy (Renewable Projects, 2017). According to Pollet *et al.*, (2015) the country's 20-year plan is that 42% of the total generated capacity should originate from renewable resources. This should increase to 70% by 2040 and to more than 80% by 2050 (Department of Energy, 2018).

2.2.3.1 South African current electricity price

The local electricity utility, Eskom, has different tariff structures for the different users, which are as follows (Eskom, 2017b):

- Nightsave, Megaflex, Miniflex, Business Rate and Public Lighting for the urban applications;
- Homepower and Homelight for the residential applications;
- Nightsave, Ruraflex, Landrate and Landlight for the rural applications.

Using the Megaflex rates for the local authorities as an example, firstly the rates are depended on whether the electricity is used during peak, standard or off-peak hours. The peak, standard and off-peak periods differ for the seasons (Figure 2-6), the low demand season is associated with the summer months, from September to May, and the high demand season covers the winter months which are from June to August. Figure 2-7 shows the actual tariffs that apply to the Megaflex local authority users (Eskom, 2017b).

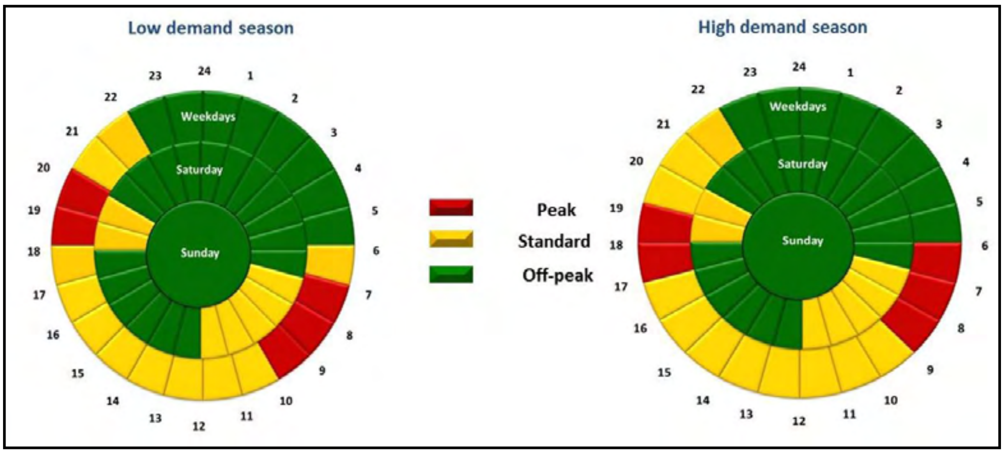
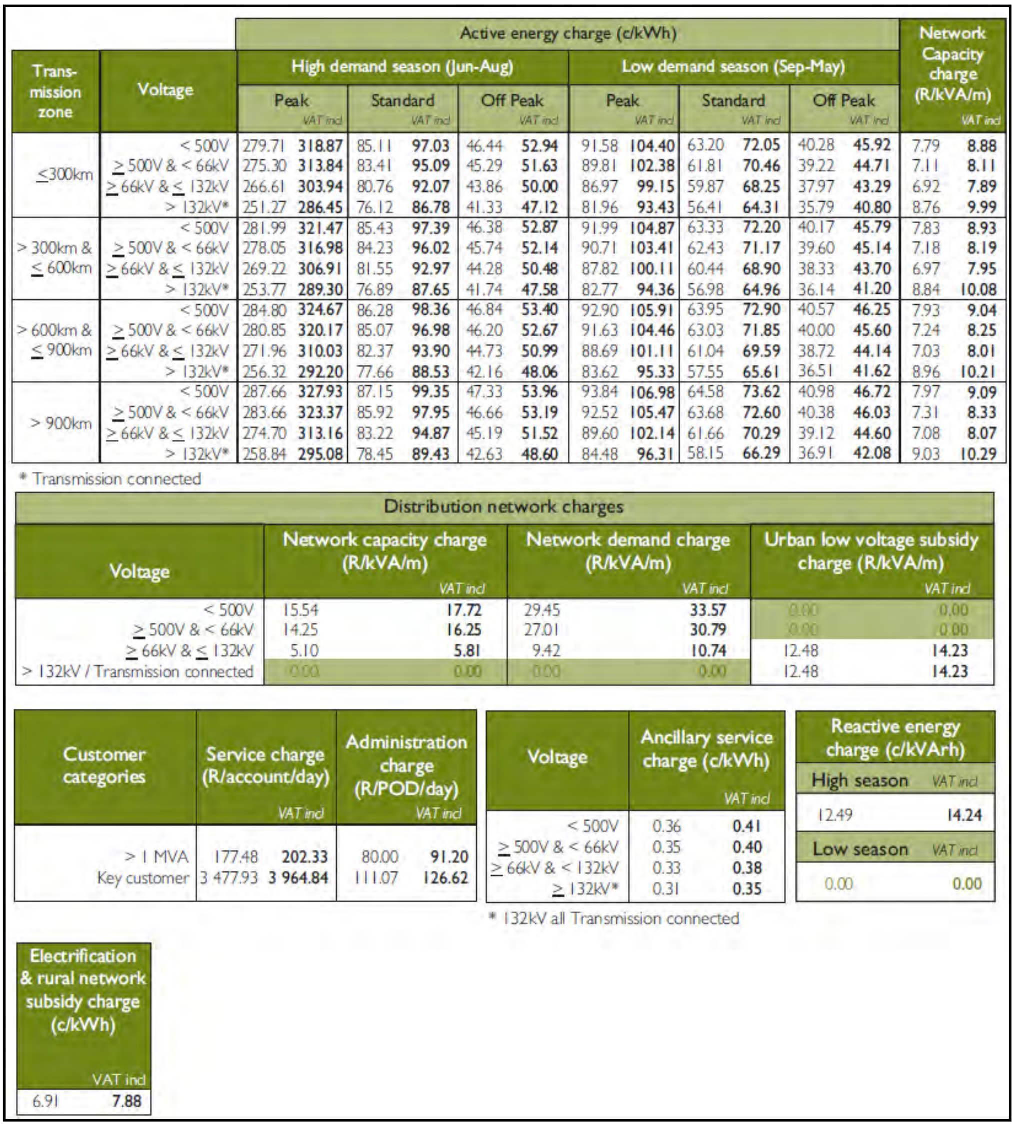


Figure 2-6: Peak and Off-Peak Periods for the Megaflex Rates (Eskom, 2017b).



		Active energy charge (c/kWh)												Network Capacity charge (R/kVA/m)	
Trans-mission zone	Voltage	High demand season (Jun-Aug)						Low demand season (Sep-May)							
		Peak	VAT incl	Standard	VAT incl	Off Peak	VAT incl	Peak	VAT incl	Standard	VAT incl	Off Peak	VAT incl		VAT incl
≤300km	< 500V	279.71	**318.87**	85.11	**97.03**	46.44	**52.94**	91.58	**104.40**	63.20	**72.05**	40.28	**45.92**	7.79	**8.88**
	≥ 500V & < 66kV	275.30	**313.84**	83.41	**95.09**	45.29	**51.63**	89.81	**102.38**	61.81	**70.46**	39.22	**44.71**	7.11	**8.11**
	≥ 66kV & ≤ 132kV	266.61	**303.94**	80.76	**92.07**	43.86	**50.00**	86.97	**99.15**	59.87	**68.25**	37.97	**43.29**	6.92	**7.89**
	> 132kV*	251.27	**286.45**	76.12	**86.78**	41.33	**47.12**	81.96	**93.43**	56.41	**64.31**	35.79	**40.80**	8.76	**9.99**
> 300km & ≤ 600km	< 500V	281.99	**321.47**	85.43	**97.39**	46.38	**52.87**	91.99	**104.87**	63.33	**72.20**	40.17	**45.79**	7.83	**8.93**
	≥ 500V & < 66kV	278.05	**316.98**	84.23	**96.02**	45.74	**52.14**	90.71	**103.41**	62.43	**71.17**	39.60	**45.14**	7.18	**8.19**
	≥ 66kV & ≤ 132kV	269.22	**306.91**	81.55	**92.97**	44.28	**50.48**	87.82	**100.11**	60.44	**68.90**	38.33	**43.70**	6.97	**7.95**
	> 132kV*	253.77	**289.30**	76.89	**87.65**	41.74	**47.58**	82.77	**94.36**	56.98	**64.96**	36.14	**41.20**	8.84	**10.08**
> 600km & ≤ 900km	< 500V	284.80	**324.67**	86.28	**98.36**	46.84	**53.40**	92.90	**105.91**	63.95	**72.90**	40.57	**46.25**	7.93	**9.04**
	≥ 500V & < 66kV	280.85	**320.17**	85.07	**96.98**	46.20	**52.67**	91.63	**104.46**	63.03	**71.85**	40.00	**45.60**	7.24	**8.25**
	≥ 66kV & ≤ 132kV	271.96	**310.03**	82.37	**93.90**	44.73	**50.99**	88.69	**101.11**	61.04	**69.59**	38.72	**44.14**	7.03	**8.01**
	> 132kV*	256.32	**292.20**	77.66	**88.53**	42.16	**48.06**	83.62	**95.33**	57.55	**65.61**	36.51	**41.62**	8.96	**10.21**
> 900km	< 500V	287.66	**327.93**	87.15	**99.35**	47.33	**53.96**	93.84	**106.98**	64.58	**73.62**	40.98	**46.72**	7.97	**9.09**
	≥ 500V & < 66kV	283.66	**323.37**	85.92	**97.95**	46.66	**53.19**	92.52	**105.47**	63.68	**72.60**	40.38	**46.03**	7.31	**8.33**
	≥ 66kV & ≤ 132kV	274.70	**313.16**	83.22	**94.87**	45.19	**51.52**	89.60	**102.14**	61.66	**70.29**	39.12	**44.60**	7.08	**8.07**
	> 132kV*	258.84	**295.08**	78.45	**89.43**	42.63	**48.60**	84.48	**96.31**	58.15	**66.29**	36.91	**42.08**	9.03	**10.29**

* Transmission connected

Distribution network charges						
Voltage	Network capacity charge (R/kVA/m)	VAT incl	Network demand charge (R/kVA/m)	VAT incl	Urban low voltage subsidy charge (R/kVA/m)	VAT incl
< 500V	15.54	**17.72**	29.45	**33.57**	0.00	0.00
≥ 500V & < 66kV	14.25	**16.25**	27.01	**30.79**	0.00	0.00
≥ 66kV & ≤ 132kV	5.10	**5.81**	9.42	**10.74**	12.48	**14.23**
> 132kV / Transmission connected	0.00	0.00	0.00	0.00	12.48	**14.23**

Customer categories	Service charge (R/account/day)	VAT incl	Administration charge (R/POD/day)	VAT incl
> 1 MVA	177.48	**202.33**	80.00	**91.20**
Key customer	3 477.93	**3 964.84**	111.07	**126.62**

Voltage	Ancillary service charge (c/kWh)	VAT incl
< 500V	0.36	**0.41**
≥ 500V & < 66kV	0.35	**0.40**
≥ 66kV & < 132kV	0.33	**0.38**
≥ 132kV*	0.31	**0.35**

* 132kV all Transmission connected

Reactive energy charge (c/kVArh)	
High season	VAT incl
12.49	**14.24**
Low season	VAT incl
0.00	**0.00**

Electrification & rural network subsidy charge (c/kWh)	VAT incl
6.91	**7.88**

Figure 2-7: Megaflex Rates for the Local Authority 2017-2018 (Eskom, 2017b).

2.2.4 RENEWABLE ENERGY RESOURCES

The four main renewable energy resources are solar, wind, biomass and hydro. For both solar and wind energy the generation of power is restricted to availability of the sun shining and the wind blowing respectively. In South Africa biomass electricity is generated from the bagasse in sugar refineries and from the bark and black liquor in the pulp mills. The greatest downside for biomass power is the low convergence of the deposits as it is spread out over vast regions in South Africa. Hydropower, on the other hand, is a renewable source that has a high load factor (Renewable Projects, 2017).

Hydropower is known as the most important renewable resource, as its technically feasible potential worldwide equates to the total global energy demand, of which only 16.2 % of this potential has been developed (Scherer & Pfister, 2016). Thus, there is still a large portion of potential still available for exploitation.

2.3 HYDROPOWER CONCEPT

Hydropower, commonly also referred to as waterpower, could be defined as the power attained from flowing water (Leyland, 2014). The power gets generated by converting the flowing water's pressure/energy into mechanical power as it flows through a water wheel or turbine. This mechanical energy is then converted into electricity by means of an electrical generator (Natural Resources Canada, 2004; IRENA, 2012), as seen in Figure 2-8.

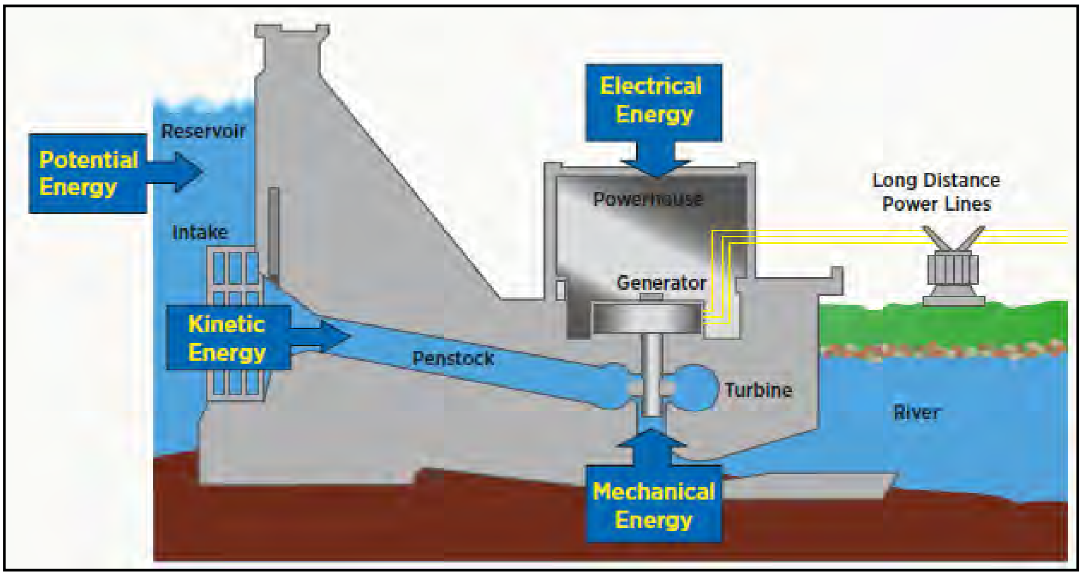


Figure 2-8: Typical Layout of a Hydropower Plant (IRENA, 2012).

For the conventional types, energy generation is primarily dependent on the available pressure head and the flow rate of the water itself. The geography and climate of the site needs to be investigated as the geography depicts the catchment size as well as the head and storage possibilities. Climate on the other hand predicts the seasonality of the rainfall over the catchment, which influences the required storage capacity for the dry seasons as well as the available flow rate of the water (Leyland, 2014).

2.3.1 PRESSURE HEAD AND FLOW

The British Hydropower Association (BHA) defined the head or the pressure head as the vertical distance that the falling water covers, which is the key to hydropower generation. As there is a direct correlation between the head and the power generation, the higher the head the more power could be generated. The maximum head that is available for the water to cover from the source to the turbine is known as the gross head (H). This head is reduced due to losses occurring during the transfer of the water into the turbine and is known as the Net Head as shown in a typical schematic view, in Figure 2-9 (BHA , 2012).

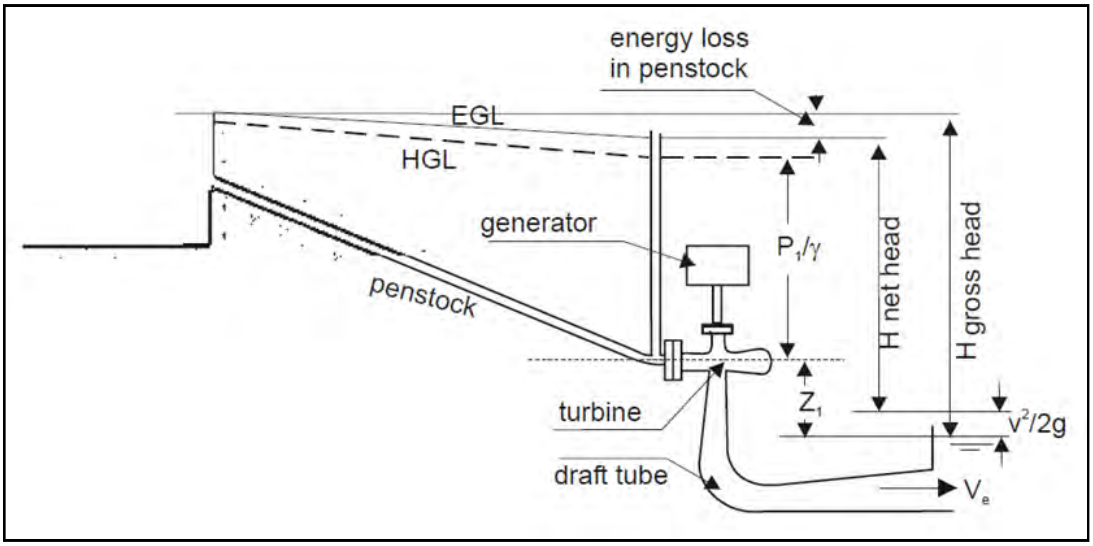


Figure 2-9: Schematic View of the Net and Gross Head of a System (ESHA, 2004).

The flow rate could be defined as the volume of water passing a specific point per second and is usually measured in cubic meters a second (m^3/s) (Paish, 2002a). This flow is commonly determined using flow duration curves, where generally the 95 % flow occurrence is taken as the available flow rate in the river (BHA, 2012).

According to Leyland (2014) as well as the BHA (2012) the ideal situation for a hydropower scheme are sites with high heads and with low flow rates as this keeps the equipment smaller. They also noted that sites with low heads and high flow rates are commonly not economically viable due to the larger turbines and civil works required for the handling of these large flow rates.

2.3.2 ENERGY AND POWER

BHA (2012), defines energy as the amount of work being done and power as the rate in which the energy is being converted. Energy is usually measured in joules and power in watts (where 1 watt is equal to 1 joule/sec).

For conventional hydropower schemes the output power is proportional to the available flow rate and head difference and could be calculated using Equation 2-1 (BHA, 2012):

$$\boldsymbol{P = \eta_t \times \rho \times g \times Q \times H} \tag{2-1}$$

Where:

$\boldsymbol{P}$ = Mechanical power produced at the turbine shaft (Watts),

$\boldsymbol{\eta_t}$ = Hydraulic efficiency of the turbine (%),

$\boldsymbol{\rho}$ = Density of water (kg/m^3),

$\boldsymbol{g}$ = Acceleration due to gravity (9.81 m/s^2),

$\boldsymbol{Q}$ = Volume flow rate passing through the turbine (m^3/s),

$\boldsymbol{H}$ = Effective pressure head of water across the turbine (m).

In cases where there is no pressure head difference such as in channels or rivers, the available power generation is dependent on the velocity of the water. In this case a hydrokinetic turbine would be used and the available power could be calculated with Equation 2-2 (Kusakana & Vermaak, 2013):

$$\boldsymbol{P_a = \frac{1}{2} \times A \times \rho \times v^3 \times C_{power}} \tag{2-2}$$

Where:

$\boldsymbol{P_a}$ = Available power (watts),

$\boldsymbol{A}$ = Area of the river or channel (m^2),

$\boldsymbol{\rho}$ = The density of water (kg/m^3),

$\boldsymbol{v}$ = Velocity of the water (m/s),

$\boldsymbol{C_p}$ = Power coefficient (C_p = 0.59 generally and 0.25 for small scale turbines).

2.4 ADVANTAGES AND DISADVANTAGES OF HYDROPOWER

Hydropower classifies as a clean renewable source of energy as the water is used to produce energy without consuming it (Frey & Linke, 2002). As noted by Paish (2002b) and BHA (2012), small-scale hydropower schemes have a higher energy concentration as well as energy conversion compared to that of wind and solar energy. Hydropower is relatively predictable and available on demand. Long-lasting technology and minimal annual operational and maintenance costs which are in order of 1 % of the initial investment costs, make small-scale hydropower plants very attractive (Oud, 2002). These schemes are also known to have minimal environmental impacts and in most cases they could be mitigated all together. In cases where large dams are required for hydropower schemes they could be used as multi-purpose dams, which could be used for flood control, irrigation or consumption, or even as recreational areas (Frey & Linke, 2002).

On the other hand, some shortcomings of these small-scale hydropower schemes is that the technologies are site-specific and that the power output is limited to the available river’s flow, which could be highly variant during the seasons. Conflict arises with fisheries especially concerning the low-head schemes and high-head schemes might influence the irrigation needs (Paish, 2002a). BHA (2012) also noted that large-scale hydropower schemes which involve dams, potentially induce changes in the flow patterns downstream.

2.5 HYDROPOWER GLOBALLY

Hydropower has played an important role globally especially in terms of economic growth. The world’s first factory system was set up in 1771 in England, utilising hydropower for the spinning of cotton. However, it is believed that hydropower was used even earlier, 202 B.C. to 9 A.D. by the Chinese for the pounding and hulling of grain, breaking of ore and in early paper making. Over the years hydropower has been replaced by coal-fired power stations but with the large carbon footprint alternatives have been implemented worldwide to reduce the footprint (IHA, 2016).

Currently 16.2% of the global electricity is produced by hydropower, which increased from 2.4% in 2012, making hydropower the largest source of renewable electricity currently. A total of 50% of this electricity is produced by United States of America, Canada, Brazil and China alone. The total of 75% of the European capacity is already exploited but in Africa and Asia there is still a great potential to be exploited. Thus it is estimated that the capacity world-wide could be tripled or even quadrupled (Scherer & Pfister, 2016).

2.6 HYDROPOWER IN SOUTH AFRICA

Hydropower schemes have been present in South Africa for several years, supplying both rural and urban areas even though they have not been well documented. Small hydropower stations were the first electricity source for both Cape Town and Pretoria (Jonker Klunne, 2013). Since South Africa is known as a water-scarce country, the viability of hydropower as source of renewable energy was threatened and thus only a small portion of potential sites where exploited (Renewable Projects, 2017). Over the years some of these hydropower stations were abandoned and decommissioned due to the “cheaper” coal power supply (Jonker Klunne, 2013), resulting in no significant hydropower development from 1980 to about 2013. Thus the total installed capacity resulted in about 5% of the total 45 500 MW potential being developed (Kusakana & Vermaak, 2013). A summary of the estimated hydropower potential in South Africa is given in Table 2-1.

Table 2-1: South African Hydropower Potential (Kusakana & Vermaak, 2013).

Size	**Type**	**Installed capacity (MW)**	**Estimated potential (MW)**
Macro hydropower (larger than 10MW)	(i) Imported	1450	36400
	(ii) Pumped storage for peak supply	1580	10400
	(iii) Diversion fed	-	5200
	(iv) Dam storage regulated head	662	1520
	(v) Run of river	-	270
Small hydropower (from a few kW to 10MW)	Dam storage and Run-of-River	29.4	113
	Water transfer	0.6	38
	Refurbishment of existing plants	8	16
	Gravity water carrier	0.3	80
Sub-total for all types		3730.3	54037
Excluding imported from abroad		2280.3	17437
Excluding pump storages using coal-based energy		700.3	7237
Total "green" hydro energy potential available within South African borders			**7237**

Most of this hydropower potential is in the eastern part of the county and is primarily in the three provinces Eastern Cape, KwaZulu-Natal and Mpumalanga. These provinces have sufficient water resources as well as the topography (Kusakana & Vermaak, 2013).

According to Jonker Klunne (2016), currently in South Africa there are about 22 decommissioned, 91 operational and 21 hydropower sites under construction (Table 2-2 and Figure 2-10), which exclude the few sites owned and operated by farmers. It is important to note that almost 60 % of the existing sites have been operational for more than 30 years (Jonker Klunne, 2016), and thus require maintenance or a refurbishment in some form or another to ensure an extension of its lifespan.

Table 2-2: Current Sites in South Africa (Jonker Klunne, 2016).

Types	**No of Sites**	**Percentage of total**
Decommissioned sites	**22 #**	**-**
Existing sites	**91**	**-**
* Between 0 and 30 years old	52	57.14 %
* Between 30 and 50 years old	30	32.97 %
* Between 50 and 75 years old	3	3.30 %
* Between 75 and 100 years old	4	4.40 %
* Older than 100 years	2	2.20 %
Under construction sites	**21**	**-**

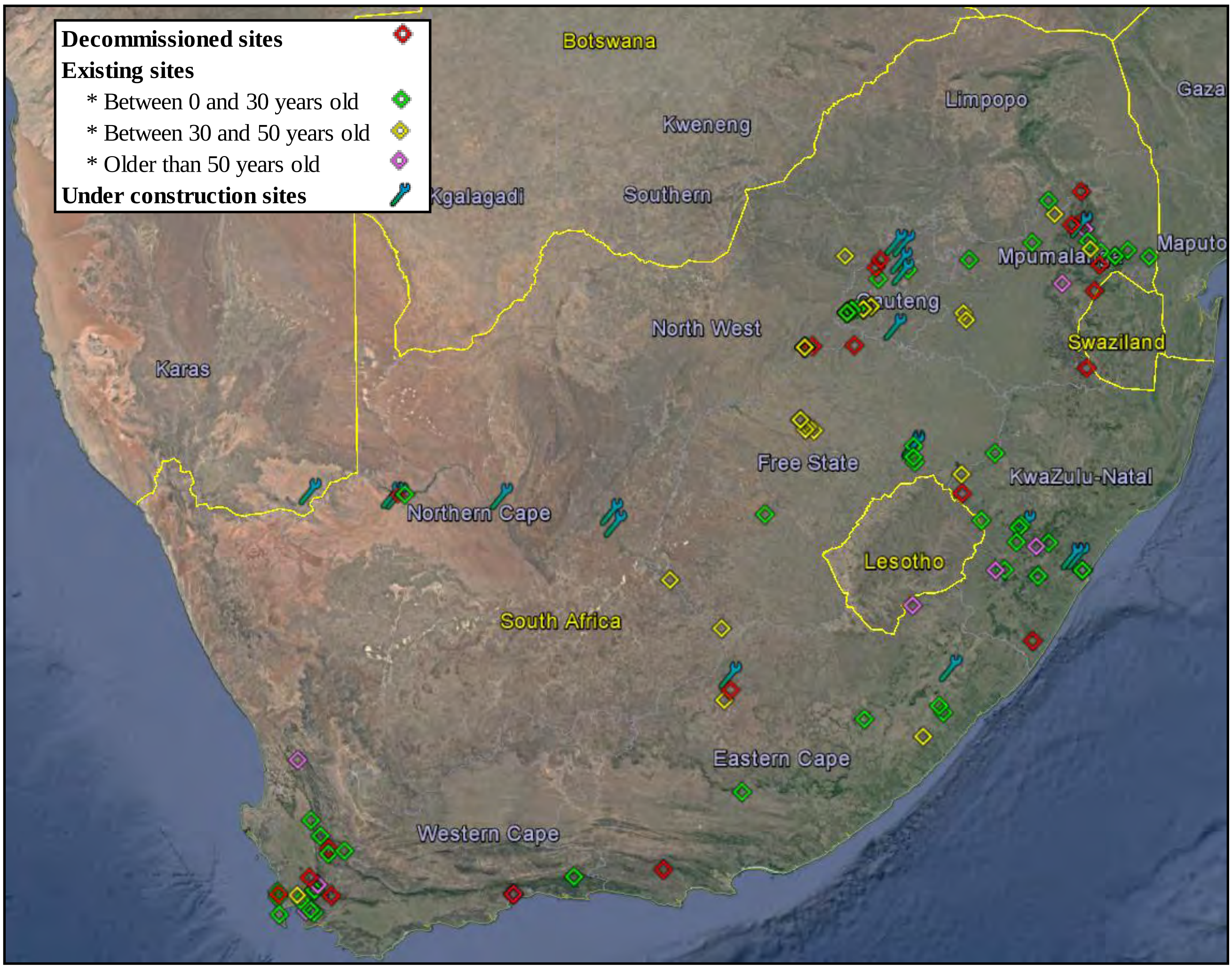


Figure 2-10: Current Sites in South Africa (Jonker Klunne, 2016).

2.7 TYPES OF HYDROPOWER

Hydropower schemes can be classified in three different ways, which are not necessarily mutually exclusive, namely:

- according to their layout or purpose (conventional or non-conventional),
- according to their power output (large, small, micro, etc.),
- or according to their available head (high or low).

2.7.1 CONVENTIONAL SITES

Conventional sites are the usual sites where hydropower generation is known to occur, such as storage and pump storage schemes, run-of-river scheme and tidal hydropower schemes (Loots, 2013).

2.7.1.1 Storage Schemes

Large dams are commonly associated with hydropower generation, where the turbines are located at the bottom of the dams or reservoirs, which can be seen in Figure 2-11. The building of these large dams is in most cases not financially viable and is usually associated with major environmental impacts. Thus the smaller dams built for water abstraction, flood control, irrigation or recreational sites were retrofitted for electricity generation in terms of small hydropower schemes (ESHA, 2004).

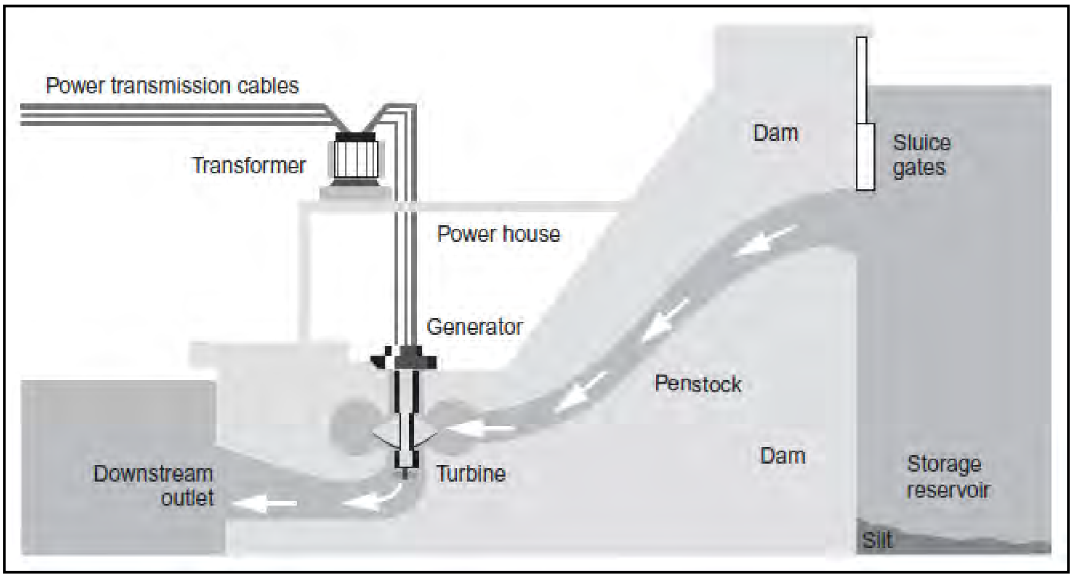


Figure 2-11: Example of a Storage Scheme (Breeze, 2014).

2.7.1.2 Pump Storage schemes

In a pump storage scheme (Figure 2-12), water gets transported between a lower and an upper reservoir through a pump-turbine. Water gets released from an upper reservoir to gravitate towards the lower reservoir through a turbine which induces electricity generation during peak energy-demand periods. The water is then pumped back from the lower to the upper reservoir during low or off-peak periods of electricity usage (Eskom, 2015). The generation phase covers 65% to 75% of the required electricity for the pumping phase (Egré & Milewski, 2002), thus making this scheme a net consumer of electricity. However this could be overcome by using wind or solar power for the pumping phase, making it a hybrid system (Bonthuys, 2016). The pumped storage scheme has the advantage that they provide frequency and voltage stabilisation for the network, as well as reserve power for peak demand periods (Bonthuys, 2016).

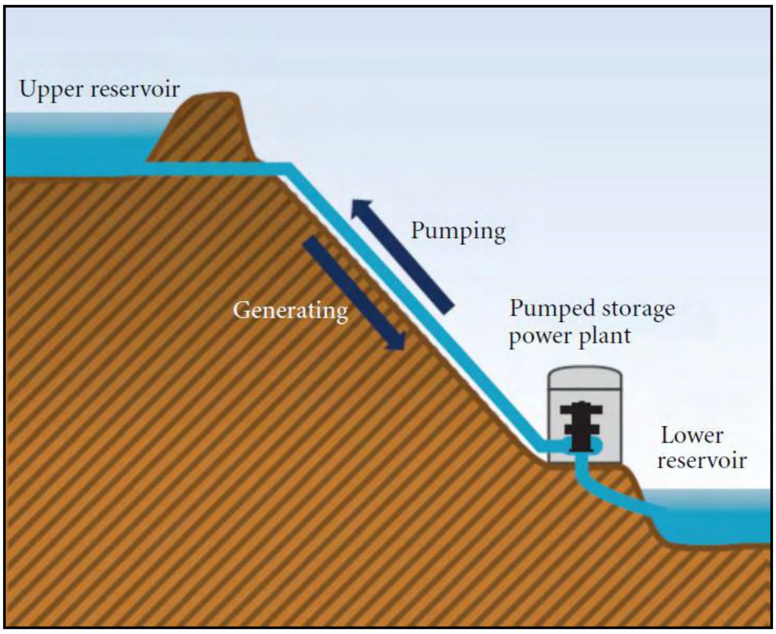


Figure 2-12: A Typical Schematic for a Pump Storage Scheme (Kaunda, et al., 2012).

2.7.1.3 Run-of-River schemes

One of the simplest and cheapest forms of hydropower generation is a run-of-river scheme since in many cases no major civil construction needs to be provided. The water gets abstracted from the river and diverted to the turbines via a penstock or tunnel. In some cases a simple diversion structure such as a weir is constructed to provide a constant head and flow, as seen in Figure 2-13. Run-of-river schemes generally rely on the flow rather than the head, which implies that any fluctuation in the flow rate will cause fluctuation in the power generation (Breeze, 2014). The power potential is determined by taking an average monthly flow rate. For a constant electricity generation a fraction of the total flow should be taken. Run-of-river schemes are known to limit both environmental and social impacts as the flow patterns as well as the river's terrain itself is somewhat unchanged (Egré & Milewski, 2002).

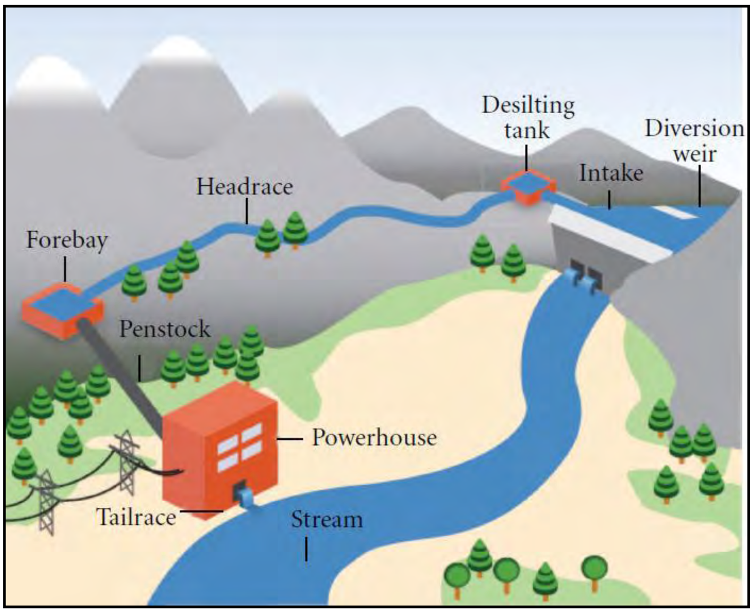


Figure 2-13: Typical Layout of a Run-Of-River Scheme (Kaunda, et al., 2012).

2.7.1.4 Tidal hydropower schemes

Tidal power refers to the power generation by the rise and fall of the water along the coastlines. A barrage is built in the mouth of the estuary which houses the turbines and controls the sluice gates during the different tidal stages. Through the rising and falling of the tides water flows in and out of the estuaries through the turbine and generating electricity, as seen in Figure 2-14 (Breeze, 2014).

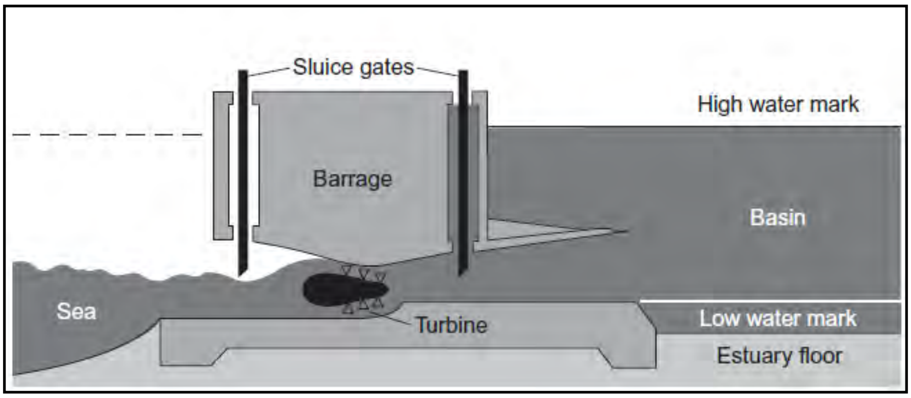


Figure 2-14: Typical Cross-Section of Tidal Hydropower Station (Breeze, 2014).

2.7.2 NON-CONVENTIONAL SITES

Non-conventional sites include: Water Treatment Works (WTW) and Waste Water Treatment Works (WWTW), Conduit hydropower, Irrigation canals and measuring weirs, where an energy generation potential exists at these sites (Loots, 2013).

2.7.2.1 Waste Water Treatment Works (WWTW)

At WWTW a constant volume of water enters and leaves via the inlet and outlet respectively. As the water enters the WWTW a forebay with trash racks would be provided for the water to accumulate before entering a penstock. The penstock then transports the water to the WWTW and in some cases could be conveyed through a turbine. The second opportunity for power generation is when the treated water leaves the system. In this case a turbine is installed between the WWTW and the natural stream or river (ESHA, 2011). When designing these schemes one should note that there is a higher corrosion risk compared to the other sources (Loots *et al.*, 2015).

2.7.2.2 Water treatment works (WTW)

In many cases the pipeline linking the feeding reservoir with the water treatment works are pressurised due to the levels in the reservoir itself. This excess pressure needs to be dissipated before entering the water works, which could be done by hydropower turbine. The power generated by these turbines could be used on site by the treatment works (Loots *et al.*, 2015).

2.7.2.3 Conduit hydropower

According to Loots *et al.* (2015) conduit hydropower is a commonly overlooked source of energy generating potential. In some pipelines pressure-reducing valves dissipate excess pressures, thus at these locations a turbine could be installed to dissipate the extra pressure and generate electricity at the same time. Similarly, in cases where pipelines link to canals or dams, turbines could be installed to dissipate any unnecessary extra pressure (Van Vuuren, 2010).

2.7.2.4 Measuring Weirs

Approximately 3000 gauging structures were constructed in many South African rivers for the determination of flood records. These gauging structures could potentially be utilised for hydropower installation. Typically, the hydropower plants would be constructed next to the weir with a short diversion structure and keeping the accuracy of the measuring station in mind. The weir could be retrofitted using either hydrodynamic screws or siphon turbines. With new installations Kaplan, propeller or bulb turbines could be installed during weir construction (Loots *et al*., 2015).

2.7.2.5 Irrigation systems

A potential for hydropower generation exists in irrigation canal systems. These systems have a relatively high flow rate but a low head. According to Loots *et al.* (2015) the different possible installation opportunities exist at:

- **The diversion structures from river to canal –** the existing diversion infrastructure can be utilised to attach the turbine for power generation. These diversion structures usually extend over the whole river, thus the total flow could be used for power generation.
- **The drop structures and concrete lined chutes -** these structures are constructed to transport water downhill and prevent in-situ material being eroded. Use of pipes and conventional turbines could bypass these chutes. Drop-structures are normally provided at very steep gradients.
- **At the Bridges –** as hydrokinetic turbines could easily be attached. The power generation at these bridges is primarily based on the velocity of the water and not on the pressure head or flow of the water.
- **Flow gauging stations –** which are commonly encountered on irrigation canals. These flow gauging stations provide a prospect for hydropower generation.
- **Open lengths of the irrigation channel –** hydrokinetic and waterwheels could be installed along the canals as there is a high reliability in the volume and velocities of the flowing water.

2.7.3 HYDROPOWER SIZE CLASSIFICATION

The above mentioned conventional and non-conventional types of hydropower schemes could further be classified into categories depending on their pressure head or power output, as seen in Table 2-3 and Table 2-4 respectively (Loots, 2013).

Table 2-3: Hydropower Classification with Respect to Available Head (ESHA, 2004).

Classification	Head (m)
High head	>100
Medium head	30 - 100
Low head	2 - 30

Table 2-4: Hydropower Categories (Jonker Klunne, 2016).

Category	Power Output
Large	> 10 MW
Small	1 MW to 10 MW
Mini	100 kW to 1 MW
Micro	20 kW to 100 kW
Pico	< 20 kW

This would typically be the classification used in South Africa to describe the type of hydropower. These hydropower classifications are not universal. As per the BHA (2012) a low head scheme includes sites up to 10m head. Any site with heads higher than 50 m are classified as high head scheme and the heads ranging from 10-50 m are classified as a medium head scheme.

2.8 ENVIRONMENTAL AND SOCIAL IMPACTS

According to the National Environmental Management Act of 1998 all the construction projects undertaken in South Africa are subjected to the environmental regulations. Under this Act it is specified that energy generation at a specific site of more than 20 MW and sites exceeding one hectare (1 ha) in size, require a full environmental impact assessment (EIA). For smaller sites only a basic assessment report (BAR) needs to be obtained (Van Vuuren *et al.*, 2011). The aim of these environmental assessments is to obtain a balance among the environment and the development. Possible environmental effects should be mitigated if possible. If not possible they should be minimised in a cost-effective manner. The EIA process should be done in the planning phase to minimise economic implications later in the project (Leyland, 2014).

2.8.1 ENVIRONMENTAL IMPACTS

There are several possible environmental impacts induced during the construction and operational phase of a hydropower scheme. Some of the major impacts are listed below (BHA 2012; van Vuuren *et al.*, 2011):

- One of the biggest concerns regarding fauna and flora are the migrating fish (salmon and sea trout) as they need to be able to follow their natural migrating flow paths. Commonly fish-passes could be provided for the fish to swim up- and downstream. To prevent the fish from entering the turbines, fine enough meshes or screens should be provided upstream of the turbine, preventing the fish from entering the penstock. Loss of biodiversity is also experienced during the construction of a hydropower scheme as the land is inundated and changed.

- Noise level increases especially during the construction phase, affecting the ecosystem. The induced traffic during the construction phase is one of the causes of the noise level increase. Others include excavations, construction, etc.
- Changes in land-use and aesthetics of the landscape of the site.
- The possible diversion of the rivers, both temporarily and permanently, as well as the changes in the flow-patterns downstream of the scheme, affecting both the ecosystem as well as the local inhabitants dependent on the river and its resources.
- Possible soil erosion where the water is released back into the river, as commonly the water is scoured at that point.
- Lastly, possible changes in both air and water quality may occur during the construction and operational phase.

In most of these cases the impacts could be minimised or mitigated by prior planning and finding the optimal position for the plant, keeping the environment in mind. Pollution and sediment control need to be considered during and after construction (Leyland, 2014).

Despite all these undesirable impacts the major positive consequence of hydropower installations includes the reduction of greenhouse gas emission, thus reducing the negative impacts on nature, wildlife as well as the public (Van Vuuren *et al.*, 2011; Koch, 2002).

2.8.2 SOCIAL IMPACTS OF HYDROPOWER

With the construction and operational phases of a hydropower station there are several social impacts that need to be considered as well as mitigated where possible. These social impacts include (Van Vuuren *et al.*, 2011; Kaunda *et al.*, 2012):

- A large amount of revenue could be generated by utilising this natural resource. The gained revenue is beneficial for local communities, government as well as the investors of the plant (Koch, 2002).
- Especially in the case of large schemes communities are forced to resettlements for the construction of the new scheme. This displacement of these communities becomes a major concern where cultural heritage is associated with the site.
- Hydropower schemes could induce changes in flow-patterns downstream of the hydropower schemes affecting the local inhabitants as well as agricultural activities.

- Acceptance of the scheme by the local communities could result in the reduction of vandalism on the infrastructure.
- And lastly balancing the communities' upliftment with their traditional way of living.

2.9 HYDROPOWER COMPONENTS

In general a hydropower scheme consists of two component groups namely civil works and mechanical and electrical works.

- Civil Works comprises of the structural components of a hydropower scheme. Thus it includes the dam, the intake structure, the trash racks and sediment traps, the conveying system (either a canal or penstock), the power house and the tail race.
- The turbine, generators, drivers, controls and transmission lines fall under the electrical and mechanical components of a hydropower facility.

The site will determine which of these hydropower components will be required.

2.9.1 CIVIL WORK

2.9.1.1 Storage facility – Headworks

A storage facility or headwork functions as the damming up of the water and then diverting it towards the turbine, which in fact regulates the flow. These headworks could be in the form of dams, weir, spillways and intake structures. In areas where there is a high risk of sedimentation a settling basin would be required (Leyland, 2014).

2.9.1.2 Intake and water conveyance structure

The required flow gets abstracted from the river through an intake structure into a penstock or pipeline which then transports the water towards the turbines (Leyland, 2014). When designing these intake structures both the structural and hydraulic aspects as well as the operational and maintenance requirements should be considered. The intake structure needs to be designed in such a manner to minimise the environmental impacts and trash racks or grids should be provided to prevent debris from entering the penstock and potentially damaging the turbine (Van Vuuren, et al., 2011). In some cases forebay and desilting basins are provided after the intake structure to allow settlement of suspended particles before entering the penstock (Natural Resources Canada, 2004).

2.9.1.3 Penstock

The water is conveyed from the intake structure to the power station under pressure via a penstock. Generally these penstocks are manufactured out of steel, concrete, PVC or fiberglass pipes. These penstocks generally make up a large portion of the total costs of a project, especially in the high-head applications, and thus the most economical design should be implemented (Leyland, 2014; Natural Resources Canada, 2004).

Leyland (2014) and Paish (2002a) also noted that these penstocks should be equipped with automated gate valves for penstock failures, turbine shutdowns or maintenance purposes. Air valves should be provided downstream of the gate valve to prevent collapsing of the penstock.

2.9.1.4 Powerhouse or turbine room

The turbines, generators and the control systems are housed in the powerhouse. Once the turbines have been selected, the powerhouse could be designed around it. During the design of the powerhouse the back-water effect up the tailrace from the river during floods needs to be considered. The powerhouse should be large enough for the removal of the generators or turbines during maintenance. A draft tube needs to be provided to transport the water from the turbine to the tailrace. This draft tube should consist of a 1.5 times runner diameter straight conical section downstream of the turbine and then a bend with a constant or slightly decreasing cross-section (Leyland, 2014).

2.9.1.5 Tailrace or the outlet structure

After passing through the turbine, the water flows back into the river via a tailrace or an outlet structure depending on the water's velocity. If the water's velocity is too high, typically the case for impulse turbines, a tailrace needs to be provided to minimise the possible environmental effects. If the velocities are low and the powerhouse is close to the river, the water can be directly discharged into the river with no major construction. The possible back-water effect in the tailrace needs to be determined as it could interfere with the turbine itself. For reaction turbines this level influences the cavitation onset of the turbine (van Vuuren *et al.*, 2011).

2.9.2 MECHANICAL AND ELECTRICAL WORK

2.9.2.1 Turbine

The energy from the falling water is converted into rotational shaft power by means of the turbine (Leyland, 2014). This turbine is chosen per head and flow availability at a given site. The desired running speed of the generator and other devices loading the turbine should also be considered. Furthermore, the fact that the power production is required under reduced flow conditions could also impact the turbine selection (Paish, 2002a).

There are two major turbine classifications namely impulse and reaction turbines. According to the BHA (2012) there is a third minor group namely Gravity turbines. The turbine and water interaction depict the above-mentioned classifications (Paish, 2002a; BHA 2012).

2.9.2.1.1 Turbine Classification

The six major turbine categories can be classified into three main categories based on their head: high, medium and low-head. Furthermore, the turbines could also be classified according to their operational principle: impulse, reaction and gravity turbines as seen in Table 2-5.

Table 2-5: Classification of Turbines (BHA, 2012).

Turbine Type	**Typical Pressure Head (British standards)**		
	High (> 50 m)	**Medium (10 – 50 m)**	**Low (< 10 m)**
Impulse Turbines	Pelton Turgo Multi-jet Pelton	Crossflow Turgo Multi-jet Pelton	Crossflow Undershot waterwheel
Reaction Turbines		Francis (spiral case)	Propeller Kaplan Francis (open-flume)
Gravity Turbines			Overshot waterwheel Archimedes Screw

Different turbines are utilized at various heads due to the primary reason that a 1500 rpm shaft speed is required for power generation to limit the speed change between the generator and turbine. In cases where the turbine and generator speeds do not match, expensive gearboxes are required to match these two speeds (BHA, 2012). The speed of any turbine decreases proportionally to the square-root of the pressure head. Thus, a faster turbine needs to be applied at a lower-head application under given working condition (Paish, 2002a).

The approximate correlation between the head, flow and power output for the different turbines is summarised in Figure 2-15.

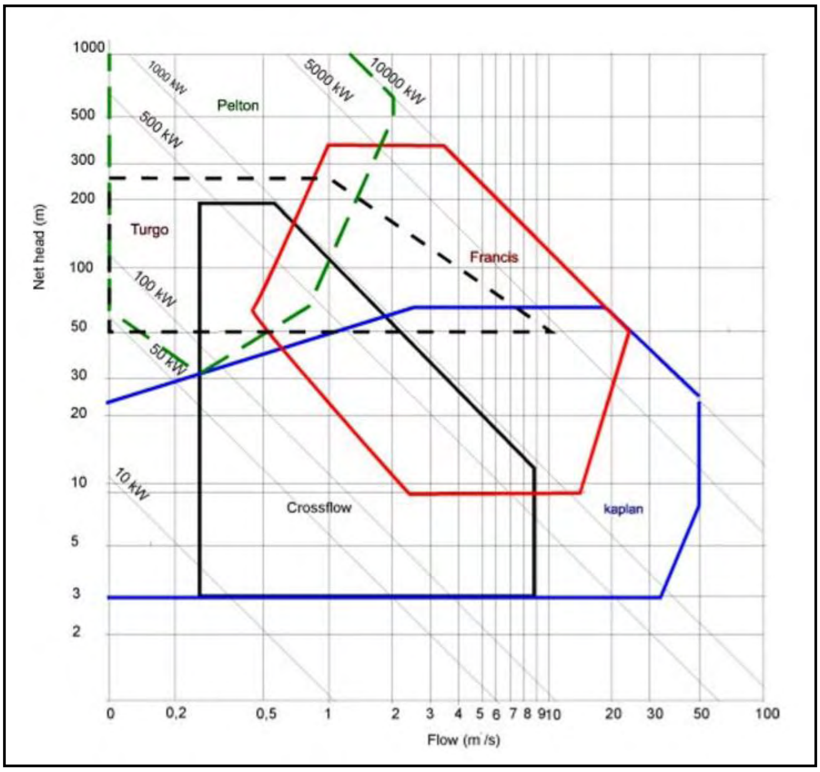


Figure 2-15: Small Hydropower Turbine Head-Flow Ranges (ESHA, 2004).

2.9.2.1.2 Impulse turbines

Impulse turbines are driven by a jet of water that is sprayed at the runners, causing the runners to rotate. For impulse turbines the water is released at atmospheric pressure and is generally used in high head applications (Loots *et al.*, 2015). Pelton, Turgo and Crossflow turbines are the three commonly encountered impulse type turbines (Paish, 2002a; BHA, 2012).

Pelton Turbine

A wheel with several split buckets around the rim makes up a Pelton turbine. The high velocity stream of water hits the buckets and splits in half while turning the rim through almost 180 °. Thereby almost all the energy is dissipated from the water into the propelling of the buckets and then the water falls into the discharge channel underneath the runners (BHA, 2012). A typical layout of a Pelton Turbine can be seen in Figure 2-16.

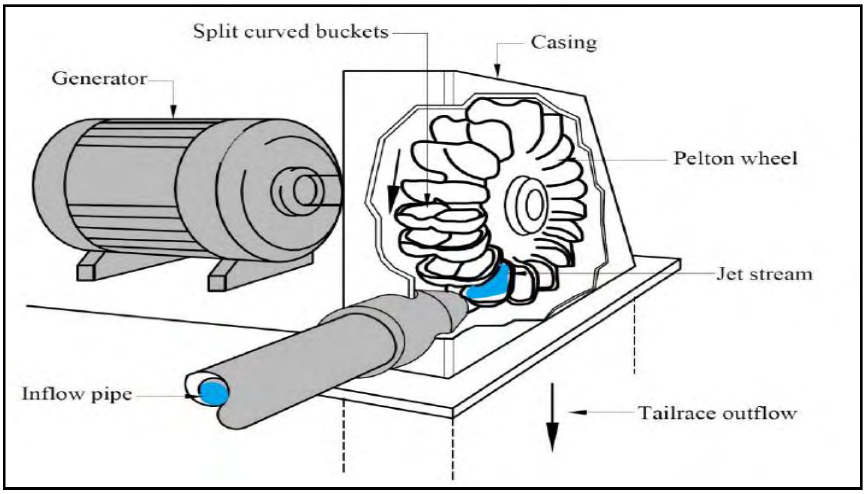


Figure 2-16: Pelton Turbine (Paish, 2002a).

Natel Energy from the USA modified the Pelton Turbine by using the Pelton buckets mounted on a belt to construct two parallel rows of buckets. A flat nozzle then projects the flow from the centre outwards to the two rows of cups, which forces the belt to rotate analogous to conventional Pelton turbines. The configuration of the Linear Pelton turbine can be seen in Figure 2-17 (Natel Energy, 2018).

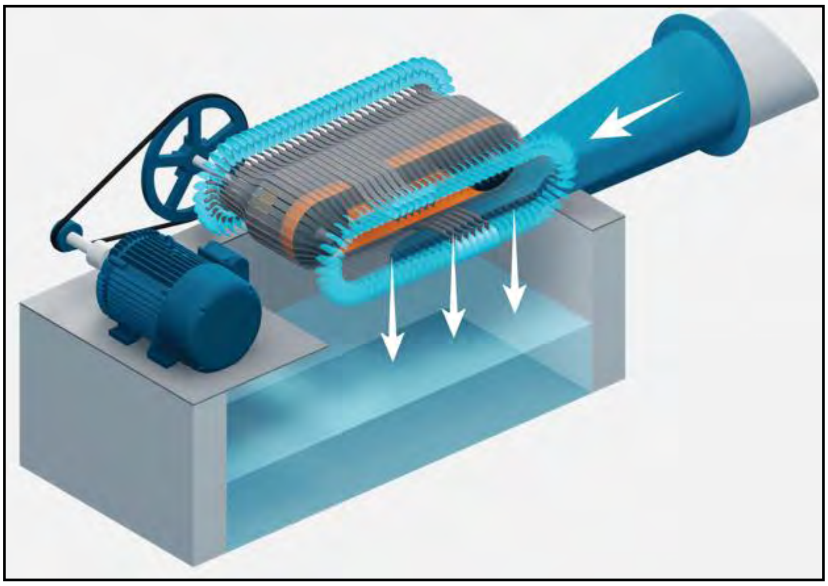


Figure 2-17: "Linear Pelton Hydroengine" from Natel Energy (2018).

Turgo Turbines

Comparable to the Pelton is a Turgo (Figure 2-18), a jet of water hits the runner, typically at an angle of 20 °. This jet of water enters the runners on the one side and exits on the opposite side, thus there is no interference between the incoming and outgoing water. This allows for a smaller diameter runner for the Turgo turbine then for the Pelton to produce equivalent amounts of energy (Paish, 2002a; BHA, 2012).

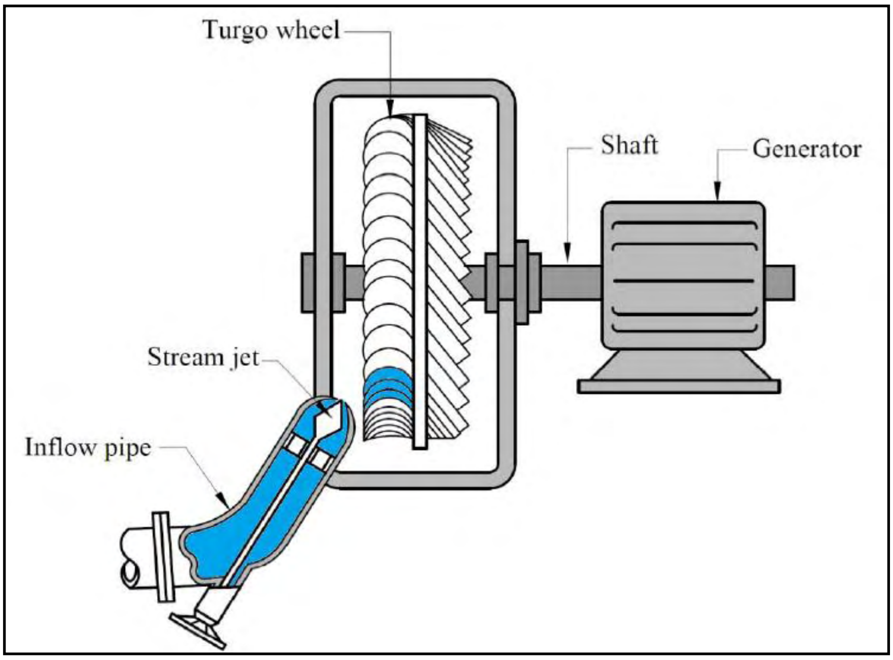


Figure 2-18: Turgo Turbine (Paish, 2002a).

Crossflow Turbines

A drum-like rotor with gutter-shaped “slats” joined by a solid disk makes up a Crossflow turbine, also called “Banki”. The stream of water enters through the curved blades at the top of the rotor and passes through the rotor while transferring the momentum of the water to the turbine and then falling out on the other side. A cross-section of the Crossflow turbine is shown in Figure 2-19 (Paish, 2002a; BHA, 2012).

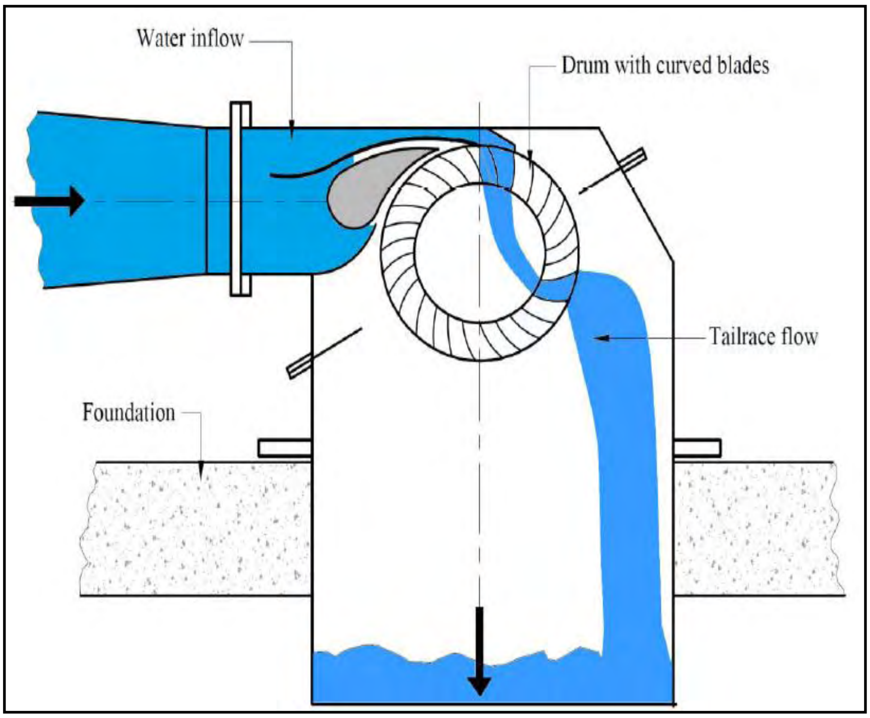


Figure 2-19: Crossflow Turbine (Paish, 2002a).

HydroEngines Turbines

Two shafts with blades attached to them, rotating in an elliptical path, makes up the HydroEngine. Similar to a Cross-flow turbine, the water flows into the HydroEngine turbine and gets directed towards the first stets of blades and then the second set of blades as seen in Figure 2-20. The HydroEngine turbines can be installed in similar circumstances as the Kaplan turbines but they have been designed to have no cavitation potential, therefore can be installed anywhere between the head- and tail-water elevation, thus simplifying the civil works (Loots *et al.*, 2015).

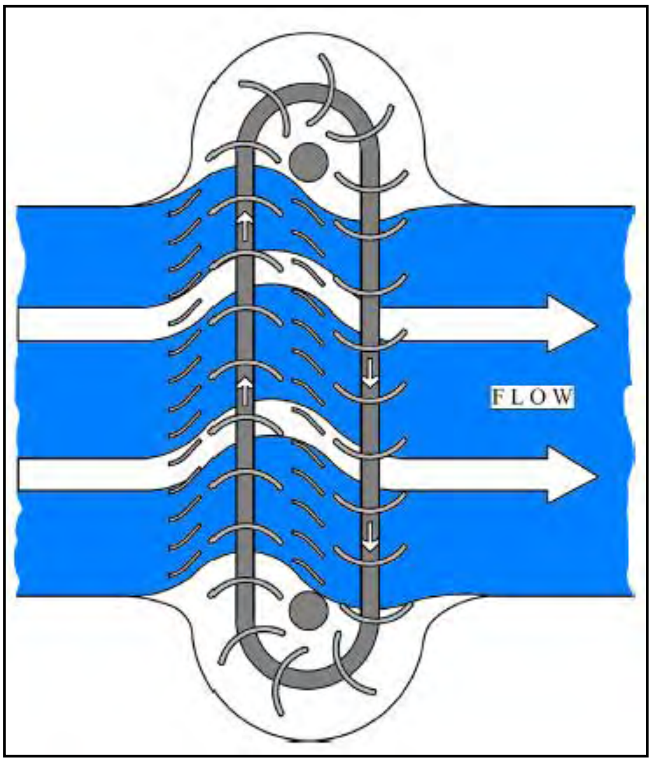


Figure 2-20: HydroEngine Turbine (Loots *et al*., 2015).

2.9.2.1.3 Reaction turbines

In a reaction turbine the runner blades are profiled in such a way that the pressure from the oncoming water causes a difference across them which induces a lift force. This lift force is like that of an aircraft wing, causing the runners to rotate and thus generates electricity. The runners of a reaction turbine are fully submerged in water and enclosed with a pressure casing. A draft tube is provided underneath the runner to discharge the water. This draft tube reduces the static pressure and thus increases the effective head. Generally reaction type turbines are used in low head applications. Francis and Kaplan turbines are the two main types of reaction turbines but there are several others as well (BHA, 2012; Loots *et al.*, 2015; Paish, 2002a).

Francis Turbine

A Francis turbine is basically a modified propeller where the water enters radially inwards onto the runner and then exits axially. Commonly the runner is mounted to a spiral casing with changeable guide vanes, as can be seen in Figure 2-21 (Paish, 2002a).

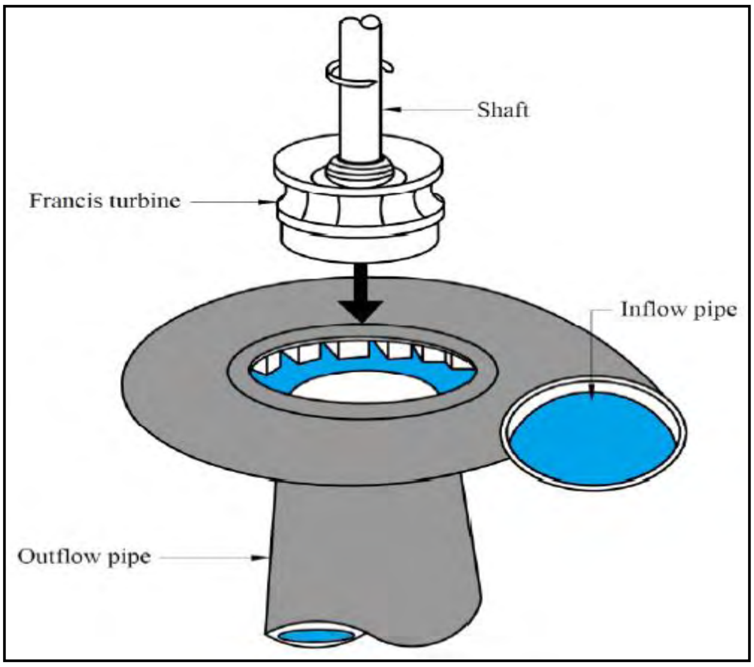


Figure 2-21: Francis Turbine (Paish, 2002a).

Francis turbines were originally designed to be used in low-head applications without a spiral casing in an open chamber. These turbines were installed all over Europe in the 1920s all through to the 1960s. A more compact turbine was then used to replace these turbines but some of them are still in place and are still appropriate for refurbishment schemes (BHA, 2012).

Kaplan Turbine

A Kaplan turbine functions like a propeller of a ship, but in reverse. An arrangement of inlet guide vanes concentrates the flow to the propeller. These guide vanes are flexible to allow control of the varying flow through the turbines. For Kaplan turbines the runners are adjustable. These adjustable guide vanes and blades can improve a system’s efficiency greatly but they come at a cost and thus they are viable in larger systems (BHA, 2012).

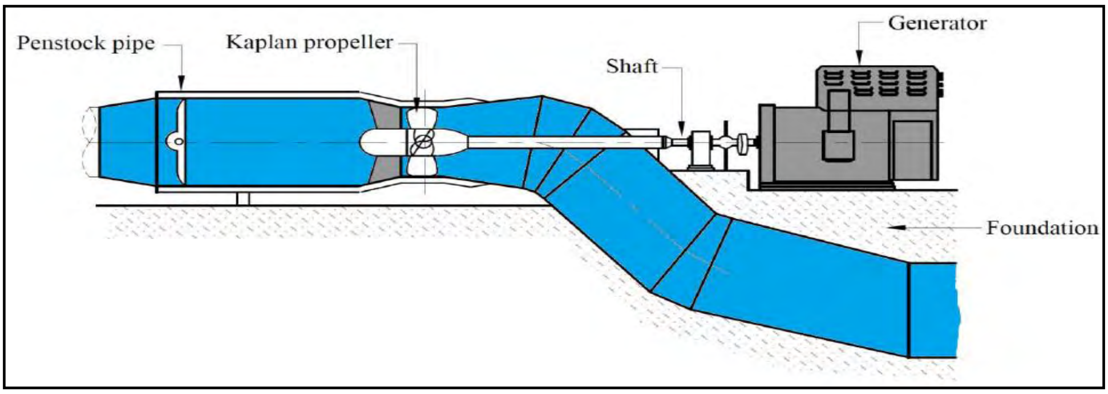


Figure 2-22: Kaplan Turbine (Paish, 2002a).

Pump-as-Turbine

A Pump-as-Turbine (PAT) is basically a conventional centrifugal pump that is reverse engineered. The cost of PAT is about 50% or less compared to the conventional turbines, since pumps are mass produced and more readily available. A constant head and flow are required for PAT to attain an adequate performance as the PAT has a low efficiency when partial flow is used. For optimum efficiency PAT should be used in pressure head ranges of 13 to 75 m (Natural Resources Canada, 2004), and a generating capacity of 1.7 - 160 kW currently operational in South Africa (Kusakana, 2014). Some of the PATs have been operating for 25 years (Kusakana, 2014). A typical layout of a PAT can be seen in Figure 2-23.

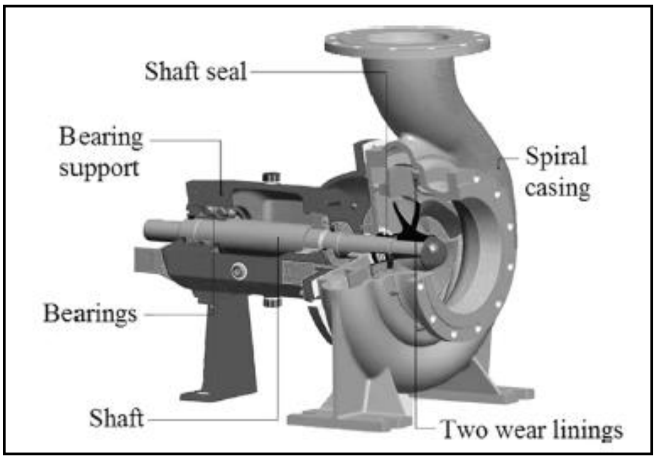


Figure 2-23: Example of a Pump-As-Turbine (Loots *et al.*, 2015).

Hydrokinetic

In low head applications, where the kinetic energy of the water is used for the power generation, hydrokinetic turbines are used. Commonly the hydrokinetic turbines consist of two rotors which can be placed vertically or horizontally. A typical example of hydrokinetic turbines can be seen in Figure 2-24, with Darrieus turbines on the left and Open Savonius rotors on the right (Loots *et al*., 2015).

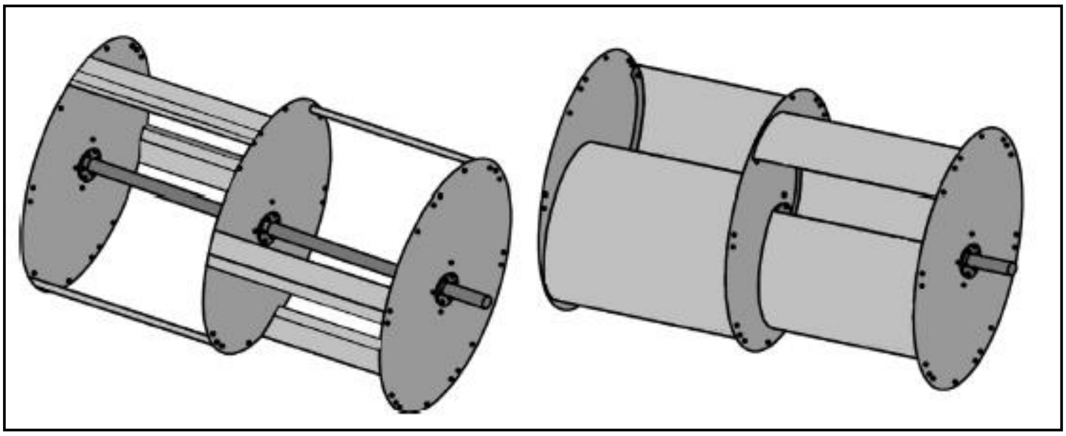


Figure 2-24: Hydrokinetic Turbine Examples (Loots *et al*., 2015).

Smart Hydro (2018) and Rickly Hydrological (2018) developed easy installable kinetic turbines for canals and river applications, Figure 2-25 and Figure 2-26 respectively (Smart Hydro Power, 2018; Rickly Hydrological, 2018).

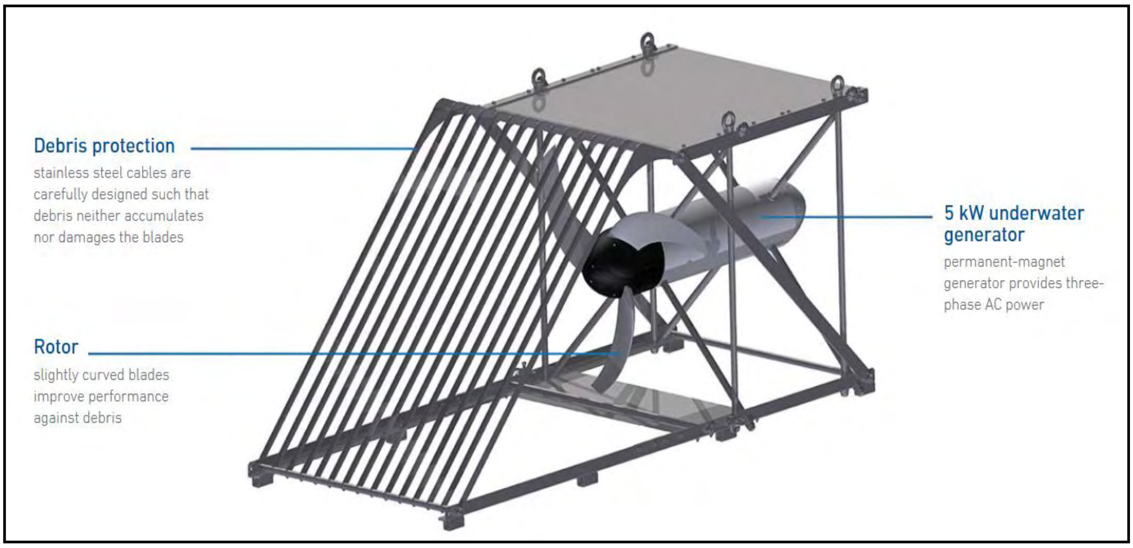


Figure 2-25: Kinetic Turbines for Canals (Smart Hydro Power, 2018).

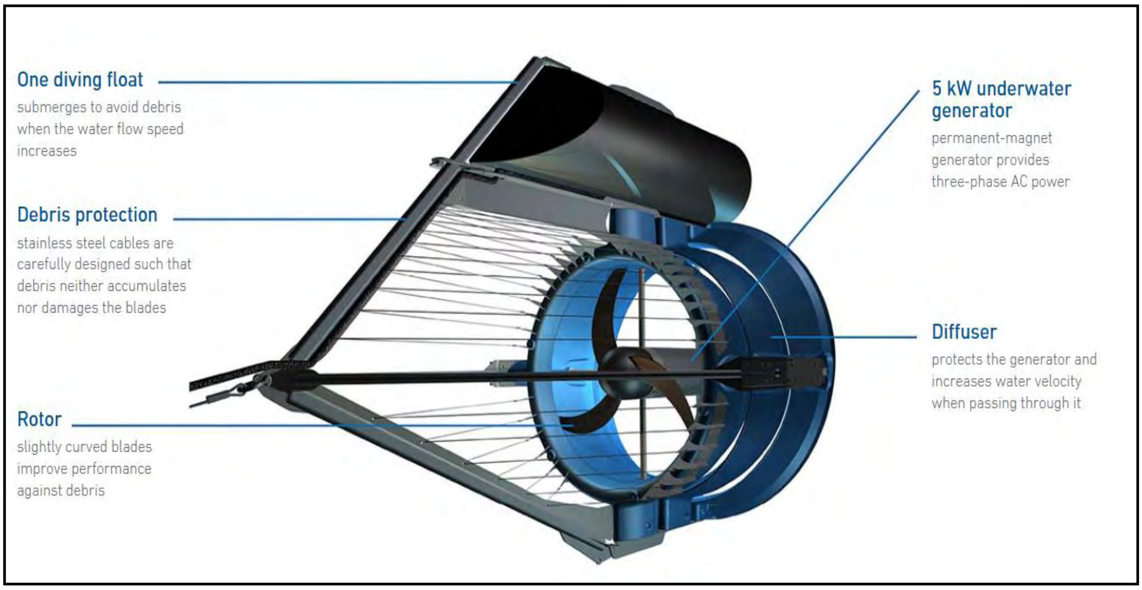


Figure 2-26: Kinetic Turbine for Rivers (Rickly Hydro, 2018).

<u>Vortex</u>

Another example for a low head application is a Vortex type turbine (Figure 2-27), which was designed with a round basin and a central drain. The central drain causes a vortex to form, which pulls down the water. A turbine is installed between the upper and lower basin to absorb the rotational energy caused by the vortex. A generator is then used to convert this rotational energy to electrical energy (Loots *et al*., 2015).

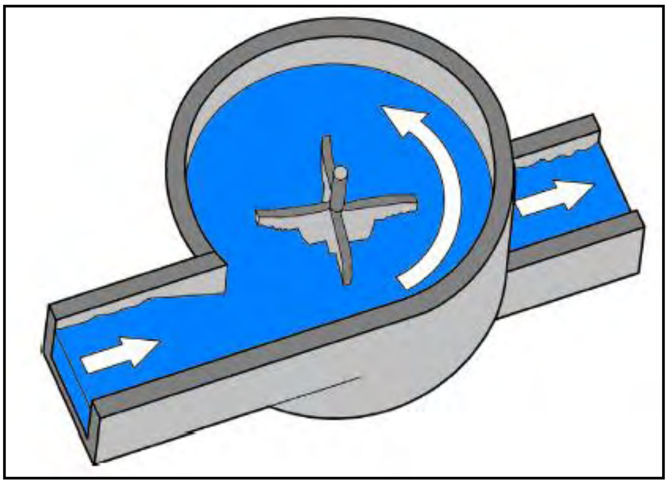


Figure 2-27: Example of a Vortex Turbine Installation (Loots *et al.*, 2015).

Inline

As of late the advancement and utilization of inline turbines has expanded. Spherical and ring turbines are two examples of inline turbines which can be installed directly into the pressurised pipelines. The generating capacities are generally between 1 kW and 100 kW and are thus applicable for Pico and micro installations (Loots *et al.*, 2015). A typical inline turbine is depicted in Figure 2-28.

Figure 2-28: Example of an Inline "Lucid Energy" Turbine (Loots *et al.*, 2015).

Siphon

The siphon type turbines (Figure 2-29) consist of blades, like those of the Kaplan turbines, which are connected via a turbine shaft to the generator. The generator functions as an electromotor during the priming phase, where after it functions like a normal generator (Loots *et al.*, 2015).

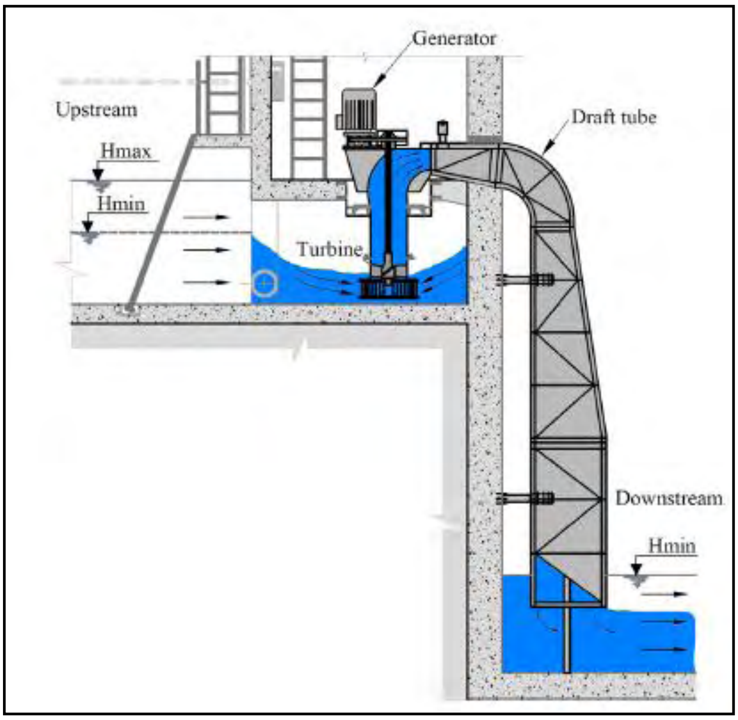


Figure 2-29: Siphon Type Turbine (Loots *et al.*, 2015).

2.9.2.1.4 Gravity Turbines

Gravity turbines fall under the impulse type turbines (Loots *et al.*, 2015). The driving mechanism for gravity turbines is the weight of the falling water. Archimedes Screw and Water Wheels are two main examples of gravity turbines (BHA, 2012).

Archimedes Screw

For centuries Archimedes Screws were used as pumps. Theses pumps were reversed recently to be used as turbines, functioning like an overshot waterwheel, but the helix shape allows the turbines to rotate faster with a higher efficiency (> 80 %). A standard generator needs to be driven by a multi-stage gearbox (BHA, 2012). Figure 2-30 shows a typical layout of an Archimedes Screw.

One of the biggest advantages of an Archimedes Screw is that there is no need for any screens, as everything can pass through with ease. The three-helix configuration is also known to be fish friendly (BHA, 2012).

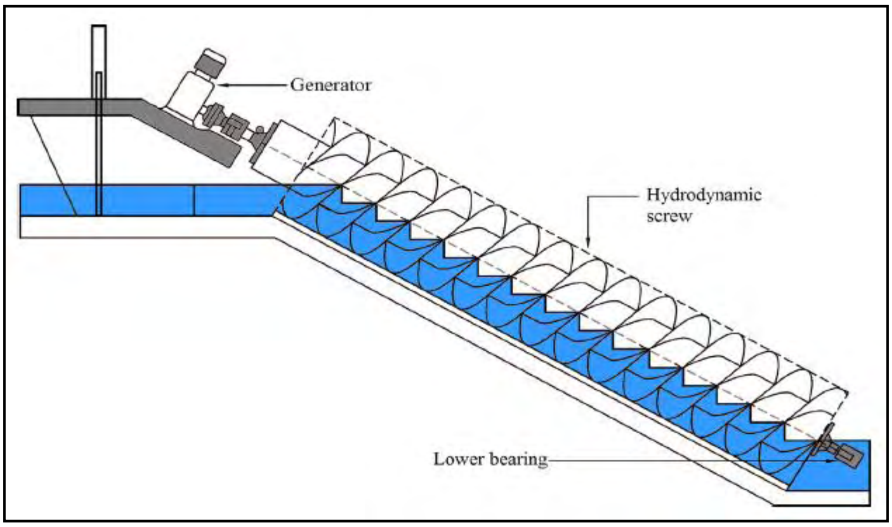


Figure 2-30: Screw Type Turbine (Loots, 2013).

Water Wheels

Traditionally water energy was converted into mechanical power by means of water wheels. Having a traditional look, being an easy installation and control friendly, they are a viable option for domestic electricity generation, even though they are not as efficient as conventional turbines. The three options of water wheels include undershot (Figure 2-31), breast-shot (Figure 2-32) and overshot (Figure 2-33), depending on the water flow onto the wheel itself (Natural Resources Canada, 2004). In the case of the undershot wheel, the water flowing underneath the wheel turns the wheel. On the other hand, in a breast-shot wheel the water hits the wheel mid height, and lastly the overshot wheel gets rotated by water hitting the blades near the top (Loots *et al.*, 2015).

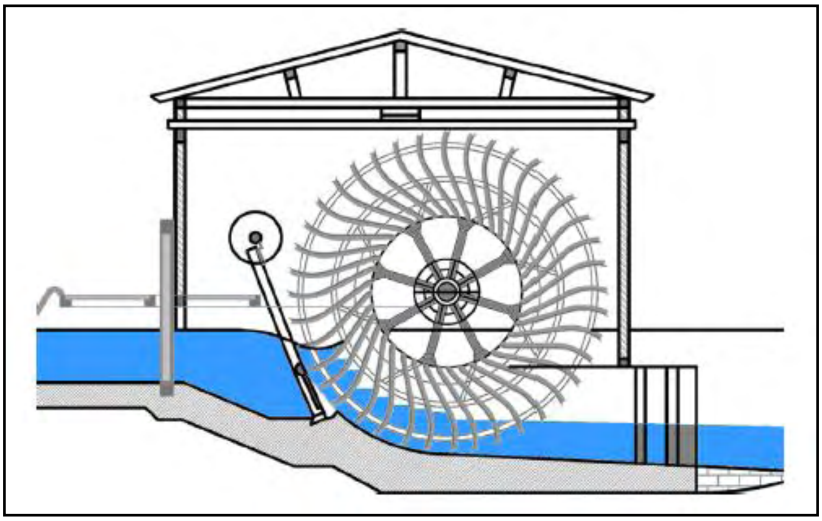


Figure 2-31: Undershot Wheel (Loots *et al.*, 2015).

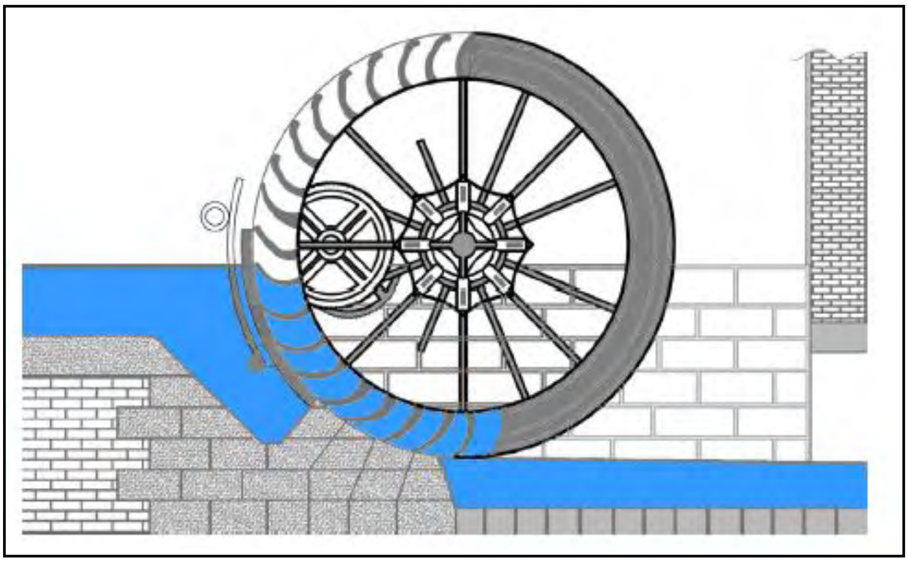


Figure 2-32: Breast-Shot Wheel (Loots *et al.*, 2015).

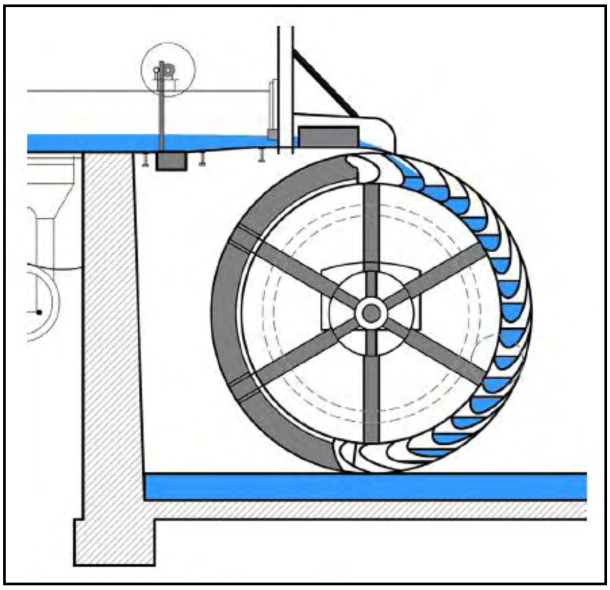


Figure 2-33: Overshot Wheel (Loots *et al.*, 2015).

2.9.2.1.5 Relative efficiencies

At a certain running speed the turbine draws the corresponding flow. If this flow decreases the turbine performance decreases, which causes the turbine to either shut down or its internal geometry needs to change. This process is commonly referred to as regulation. Turbines can adjust their inlet guide vanes and runners which in fact controls the flow intake into the system (BHA, 2012). A typical curve relating the partial flow to the efficiency of the different turbines can be seen in Figure 2-34.

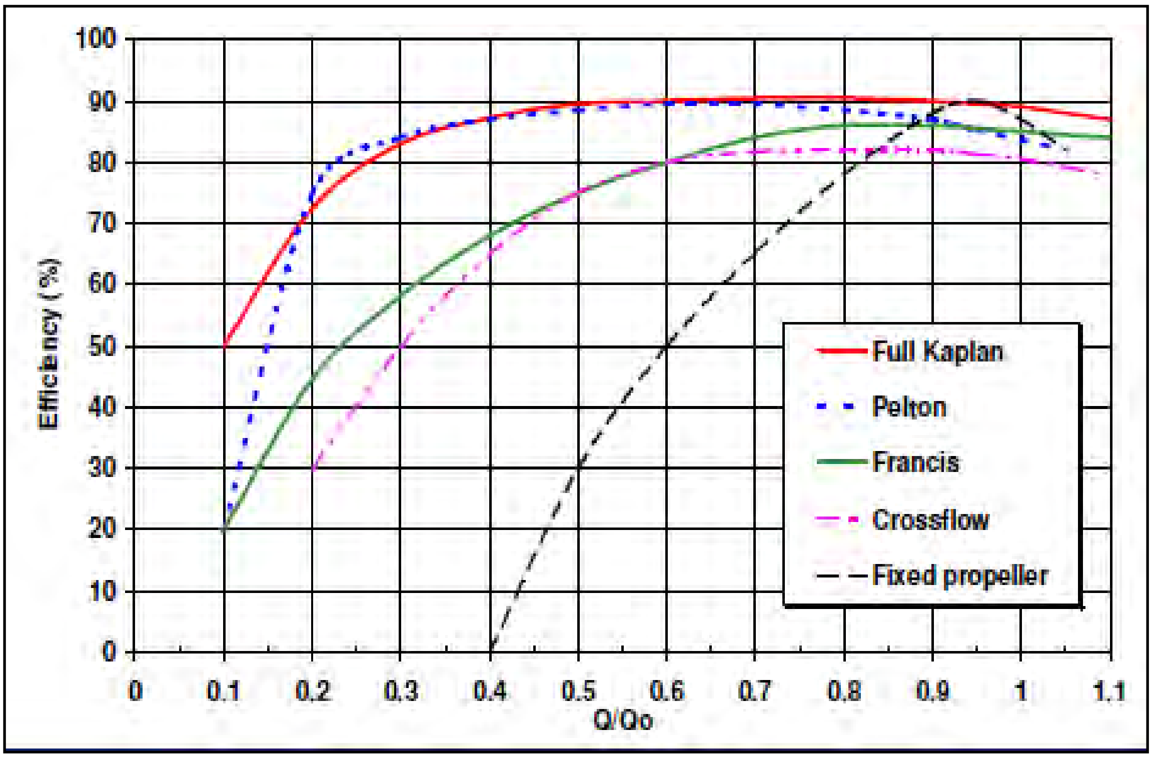


Figure 2-34: Partial-Flow Efficiency Curves (BHA, 2012).

In Figure 2-34, one could note that for the Kaplan and Pelton turbines a high efficiency is retained even when functioning below the design flow rate, whereas in case of the Crossflow and Francis turbines their efficiencies rapidly decrease when operating under their design flow rates (BHA, 2012). A poor performace is attained from the fixed pitched turbines running under 80 % of full flowing (Paish, 2002a).

A more generalised efficiency range for the different types of turbines is given in Table 2-6. These are not dependent on the flow rates. In cases where more precise efficiencies are required, the manufacturers should be contacted. The most crucial part of a micro-hydropower system design is the turbine selection which is based on the site, cost, head and flow variation, sedimentation in the water and the turbine’s overall reliability (Natural Resources Canada, 2004).

Table 2-6: Typical Turbine Efficiencies (Natural Resources Canada, 2004).

Prime Mover		Efficiency Range
Impulse Turbines	Pelton	80 – 90 %
	Turgo	80 – 95 %
	Crossflow	65 – 85 %
Reaction Turbines	Francis	80 – 90 %
	Pump-as-turbine	60 – 90 %
	Propeller	80 – 95 %
	Kaplan	80 – 90 %
Water Wheel	Undershot	25 – 45 %
	Breast-shot	35 – 65 %
	Overshot	60 – 75 %

2.9.2.1.6 *Specific Speed*

The performance characteristics of a turbine are associated with the turbine's specific speed number. The turbine's output power, the head across the turbine and the running speed of the turbine are related to the specific speed of a turbine. The following formula (Equation 2-3) can be used to determine the specific speed of a turbine (Paish, 2002b).

$$\boldsymbol{N_s = \frac{n_s P^{0.5}}{H^{1.25}}} \tag{2-3}$$

Where:

N_s = Turbine's specific speed,

n_s = Turbine's speed (rpm),

P = Shaft power (kW),

H = pressure head across the turbine (m).

The size of the turbine does not influence the specific speed of a turbine. Generally, the suppliers provide the specific speed of their turbines and using Equation 2-3 the turbine rotating speed can be determined (Paish, 2002b).

2.9.2.2 Generators

The generator is responsible for the conversion from mechanical to electrical energy. A stator and a rotor are the two main components making up a generator. The stator, being the stationary outside part consisting of a set of copper wires known as windings, and the rotor consists of electro magnets attached to the rotor which attaches to the shaft of the turbine's runners (Figure 2-35). Thus, as the water turns the turbine blades, simultaneously the rotor is turned producing an electrical current. Concurrently the magnets inside the fixed-coil generator are rotated and produce an alternating current (Breeze, 2014; International Renewable Energy Agency (IRENA), 2012).

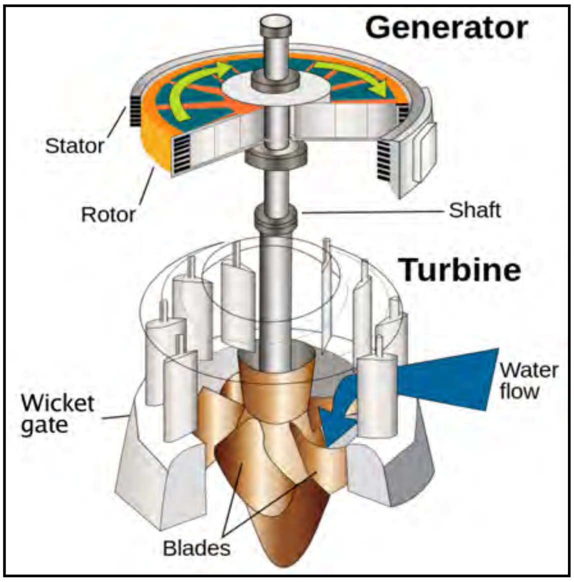


Figure 2-35: Typical Turbine-Generator Connection (Breeze, 2014).

There are two main types of generators namely: asynchronous (or induction generators) and synchronous generators, which are dependent on the network characteristics (van Vuuren *et al.*, 2011). Asynchronous generators are commonly used in smaller systems, as they are regulated by the power system, thus controlling the output voltage frequencies. These asynchronous generators have a full load efficiency of 75%, which decreases to 65% when partially loaded (Natural Resources Canada, 2004). However, in synchronous generators, the voltage is waveform and is synchronized with the rotor speeds (Daware, 2014). These synchronous generators have an efficiency of 75 to 90% when fully loaded. The larger the synchronous generator the higher the efficiency. It was also noted that a three-phase generator also has a higher efficiency compared to the single-phase ones (Natural Resources Canada, 2004). A comparative summary of the differences between Synchronous and Asynchronous generators is given in Table 2-7.

Table 2-7: Summary of Asynchronous and Synchronous Attributes (Kilimo & Kahn, n.d.).

	GENERATOR	
	Asynchronous or Induction	**Synchronous**
Efficiency	Moderately efficient	Efficient
Price	Less expensive	Expensive
Maintenance requirements	Rugged and robust, little maintenance	Requires maintenance
Reactive Power	Sink of reactive power	Reactive power flow can be controlled through excitation
Speed	Small change in speed with torque, hence more compliant	Fixed speed hence very stiff
Oscillatory response	Respond to sudden inputs in no oscillatory way	Respond in an oscillatory manner to sudden changes in torque
Connection suitability	Sustainable for weak networks only with power electronics	Suitable for connection to weak networks. Used in autonomous systems
Synchronising to mains	Can be simply synchronized to the mains	Requires special synchronization equipment to connect to mains/other generator for parallel operation

2.9.2.2.1 Speed control

In most cases the small hydropower schemes are not grid connected, which implies that effective speed regulation systems are required to maintain a constant voltage and frequency. Even if the electrical load changes the generator is required to operate at a constant 50 Hz frequency for South Africa. This requires frequency controls for both the turbine's and generator's rotational speed (Breeze, 2014).

The turbine's rotational speed is dependent on the turbine itself. A Pelton turbine's rotational speed varies between 400 to 1000 rpm, in a Francis it varies between 100 to 1500 rpm, whilst in a Propeller turbine it ranges between 60 and 300 rpm. Implying that each turbine needs a custom-fitted generator to match the turbine's speed (Breeze, 2014).

A synchronous generator operates at a few fixed speeds depending on the number of poles. Higher speeds are obtained by reducing the number of poles. For example, a two-pole generator rotating at a speed of 3000 rpm will result in a frequency of 50 Hz, whilst if the generator speed is increased to 3600 rpm a frequency of 60 Hz would be attained. Similarly, if an 8-pole generator is used, the rotational speed should be 750 rpm and 900 rpm to obtain the frequencies of 50 and 60 Hz respectively. Therefore larger numbers of poles are required by the generator for the turbines running at lower speeds (Breeze, 2014).

These synchronous generators are commonly utilised on large hydropower schemes, whilst variable-speed generators are commonly installed in the smaller schemes. As their name suggest, variable-speed generators can operate at any required speed and the efficiency is optimized later. A “solid state power electronic device” is used to convert the output frequency form the generator to the required grid frequency. These electronic devices power handling capacity depict the generator’s size (Breeze, 2014).

The variation in demand could be accommodated by installing an automated valve which adjusts the inflow. Alternatively, the inflow is kept constant but the electrical output is altered. In this circumstance an Electric Load Controller (ELC) is used to switch the excess power to and from a ballast load. In 1980 the ELCs became more reliable, which improved to the reliability of remote small-scale hydropower schemes (Paish, 2002a).

2.9.2.3 Driver system

A driver system controls or stabilises the transmission of the power from the turbine to the generator shaft. This is done by controlling the direction and speed of the generator shaft. In a micro-hydropower system, the following typical driver systems are used: Direct drivers, ‘V’ or wedge belts or pulleys, Timing belts and sprocket pulley, and lastly Gearboxes (Natural Resources Canada, 2004).

2.9.2.4 Control, protection and switchgear

The switchgear is used to control the electrical power flow and thus protects the system from overloading and short-circuiting by isolating the generating unit. In events of malfunctioning a protection system is activated to shut down the water flow into the turbines and power generation. These protection mechanisms should never be neglected as they are crucial for the people’s safety (Natural Resources Canada, 2004; Leyland, 2014).

Automated controls are commonly used in small hydropower schemes, as they operated the turbines effectively at available flow rates. Increasing reliability and reducing maintenance, automated systems are known to reduce the energy production costs (BHA, 2012).

2.9.2.5 Transformer

Transformers are used in hydropower plants to translate the generator voltage to an appropriate higher voltage, for more efficient (reduced losses) long-distance power transmission (Leyland, 2014; IRENA, 2012).

2.9.2.6 Excitation System

An excitation system creates a variable direct current (DC) for the excitation of a synchronised generator. A rotating diode and a static exciter are the two types of excitation systems. The biggest advantage of the rotating diode systems is that they are simple and reliable and prevent major damage in a winding fault event to the stator core (Leyland, 2014).

2.9.2.7 Transmission/ Distribution Network

During the inception phase of a hydropower project, both the end users and their required electricity demand need to be identified. According to the BHA (2012), onsite usage of the generated electricity is financially better compared to grid connection. In both cases transmission lines or distribution networks are required to transport the electricity from the site to the end users. Usually single-phase power lines are used for the transmission of electricity form micro-hydropower systems. In the case of the larger hydropower systems a three-phase system would be used as the voltage would be stepped up by a transformer to reduce transmission losses. For safety reasons power lines could be buried underground, but this increases the costs considerably and thus overhead transmission lines are commonly used (Natural Resources Canada, 2004; IRENA, 2012).

2.9.2.8 Lightning Protection

Some hydropower stations are in areas with high thunderstorm frequencies, exposing them to lightning strikes. These lightning strikes could affect the performance of the electrical system depending on its state of earthing. Small scale hydropower plants are commonly not connected to step-up transformers, thus exposing their generators to lightning surges harming their generator insulation windings. In these cases a surge diverter is required to protect the windings of the generator. In cases where step-up transformers are utilised, no surge diverters are required as the transformer does not transfer lightning surges (Natural Resources Canada, 2004; Leyland, 2014; Powell *et al.*, 1962).

2.10 COMMON PROBLEMS ENCOUNTERED IN EXISTING HYDROPOWER PLANTS

The condition as well as the revenue of existing hydropower plants decrease over time. As noted by Roth (2004) almost half of the installed hydropower capacity in South Africa is over 30 years old (Table 2-2) and the components are experiencing deterioration. Sand erosion and cavitation are two of the most commonly encountered deterioration factors of turbines (Kumar & Saini, 2010).

2.10.1 SAND EROSION (PARTICULATE EROSION)

Sand erosion could be defined as the "gradual removal of material caused by repeated deformation and cutting action" (Panthee *et al.*, 2015; Dorji & Ghomashchi, 2014). It commonly occurs due to sediment smaller than 0.2 mm passing through the setting basins (Panthee *et al.*, 2015). This is particularly the case in the rainy season when large quantities of sediment are present in the water. The extent of the damage is dependent on the size, hardness and concentration of the particles, the velocity of the water as well as the material properties of the component being eroded (Padhy & Saini, 2008).

Sand erosion is commonly encountered in Francis and Pelton turbines (Panthee *et al.,* 2015). According to Leyland (2014) the Pelton turbines are the most sensitive to erosion, as a relatively small amount of erosion could potentially decrease the efficiency up to 2%. The Francis turbine on the other hand is not as sensitive unless significant erosion is present. In the case of a Pelton turbine the blade profile is changed due to sand erosion, which induces an increase in vibrations leading to fatigue damage, consequentially inefficient operations and finally system failure (Padhy & Saini, 2008). Some components in the turbines are more prone to sand erosion than others. These include the following (Dorji & Ghomashchi, 2014):

- For Francis turbines – Stay vanes, guide vanes, runner vanes and turbine blades
- For Pelton turbines – buckets, nozzles, seal rings and the deflectors.

Sand erosion cannot be completely avoided. To maintain the runner's efficiency, the runner could either be replaced or repaired. The repairing of a runner entails both grinding and welding of the bucket. Grinding insures the removal of cracks and small pores, while welding builds up the runners to its original form. It is important to ensure that the runners are balanced after the buckets have been repaired. A typical example of and welding and grinding efforts on a Pelton turbine can be seen in Figure 2-36 (Panthee *et al.,* 2015).

Figure 2-36: Welding Refurbishment of an Impulse Turbine (Panthee *et al.*, 2015).

Other mitigation measures that could be implemented to reduce the effects of erosion on the turbines include: proper material selection for the turbine components, erosion resistant coatings, proper design of dams and desilting basins as well as constant monitoring of the silt concentration in the plant and implementing preventative measures where applicable (Kumar & Singal, 2015; Dorji & Ghomashchi, 2014).

2.10.2 UNBALANCED TURBINES

Turbines become unbalanced due to blow holes in the castings, eccentricity, distortions, corrosion and wear as well as deposit built-up which are non-uniformly distributed over the components (Fox, 1980). Unbalanced runners induce turbine vibrations which are detrimental to the rotor, bearings, as well as the supporting structure of the turbines. Thus it is important to balance the runners by proving additional weights at locations that allow even distribution about the axis of rotation of the turbines (Fox, 1980; Panthee *et al*., 2015).

2.10.3 OVERSPEED

In cases of sudden load losses or the malfunctioning of the governor, the turbine could be subjected to 1.8 to 3 times the normal speeds. The generators can only withstand this over-speed for about three minutes. If the turbine is subjected to this over-speed for longer periods, the bearings could overheat (Leyland, 2014).

2.10.4 CAVITATION

Cavitation occurs when the liquid inside an encasement falls below vapour pressure. Bubbles are formed and transported at this low-pressure state. As the pressure increases the bubbles implode or collapse and cavitation occurs. Cavitation is commonly referred to as pitting and is accompanied by a high impulse pressure and temperature. This cavitation damage intensifies, resulting in severe damage on the turbines or pipelines, leading up to repairment or replacement (Bansal, 2010). A typical turbine with cavitation damage can be seen in Figure 2-37.

Figure 2-37: Cavitation Damage on Francis Turbine Runner (Brennen, 1994).

Reaction turbines, such as Francis and Propeller type turbines, are most inclined to cavitation. Cavitation is commonly encountered at the outlet of the runner or at the draft tube inlet as this is where a drop in pressure is encountered. A drop in the turbine efficiency is a good indicator that cavitation has occurred. A dimensionless cavitation factor, σ (sigma), was developed by Prof Thoma which could be determined by using the following formula (Bansal, 2010):

$$\boldsymbol{\sigma = \frac{H_b - H_s}{H_{net}} = \frac{(H_{atm} - H_v) - H_s}{H_{net}}} \qquad \textbf{2-4}$$

Where:

σ = cavitation factor

H_b = Barometric pressure head of water (m),

H_{atm} = Atmospheric pressure head of water (m),

H_v = Vapour pressure head of water (m),

H_s = Suction pressure at the outlet of the runner (m),

H_{net} = Net head on the turbine (m).

This cavitation factor (σ) is then compared to the turbine's critical cavitation factor (σ_c). If the critical cavitation factor is less than the Thoma cavitation factor ($\sigma_c < \sigma$) no cavitation will occur at the turbine (Bansal, 2010).

According to literature cavitation cannot be avoided completely but it could be minimised to some extent by implementing the following measures (Kumar & Singal, 2015):

- Designing and operating the turbines with a forward whirl in the draft tubes,
- Improving the pressure sharing on the blades' back side,
- Making the blade profile a forward edge shape,
- Monitoring the vibrations online and
- Providing appropriate coatings of resistant materials.

2.10.5 FATIGUE DAMAGE

The operational conditions of turbines that have been operational for decades have changed compared to the original design conditions. These changes in operational conditions induce vibrations which typically lead to fatigue damage (Figure 2-38). There are different stages of fatigue damage starting with nucleation, crack formation, propagation and finally complete failure. The unit's operating time may be influenced by the presence of a crack as well as the risk of it propagating (Lui *et al.*, 2016).

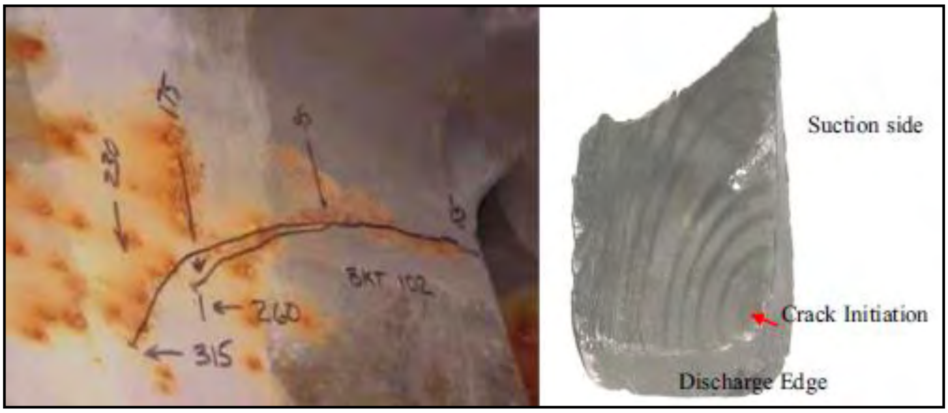


Figure 2-38: Cracking of Blade due to Fatigue Cyclic Loading (Lui *et al.*, 2016).

In Table 2-8 a summary of hydropower plants that failed due to fatigue failure is presented. It is important to note the massive economic losses due to the failure and downtime of these plants. Therefore reducing the risk of failure will not only prevent catastrophic failures but will reduce both the downtime as well as the monetary losses (Lui *et al.*, 2016).

Table 2-8: Economical Losses due to Shutdowns Resulted from Fatigue Failures (Lui *et al.*, 2016).

Plant	Country	Turbine Type	Unit Capacity (MW)	Failure Year	Downtime (months)	Loss (million $)
Er Tan	China	Francis	561	2000	1	39.71
Projus second	Sweden	Francis	240	2000	2.5	42.47
Xiao Lang Di	China	Francis	330	2001	4	93.44
Da Chao Shan	China	Francis	225	2001	4	63.71
G.M. Shrum	Canada	Francis	261	2002	14	258.67
Khimti	Nepal	Pelton	12	2003	1	0.85
Shui Kou	China	Kaplan	200	2006	1	14.16

Fatigue damage common to hydropower turbines as a constant vibration is exerted onto the turbine. The fatigue damage on the metal components of the turbines could be reduced to some extent by (Kumar & Singal, 2015):

- Periodic non-destructive inspection of component,
- Application of anticorrosive protection on the components,
- Decrease the stress levels at the critical radius of the turbine’s shaft by redesigning the transient radius,
- Keeping the start-stop cycles of a hydropower turbine to a minimum and
- If possible, trying a different material composition.

2.10.6 INGESTED BODIES

Other commonly encountered problems in turbines are ingested bodies. These include stones that get dislodged from the intake structures, damaged trash-racks allowing stones or logs to enter or even tools that have been left accidentally in the casings of turbines. The three common locations for the ingested bodies occur are at the runners, distributors or in the guide vanes.

Once these ingested bodies are lodged inside a runner (Figure 2-39), an acceleration in flow rate around the area is experienced, resulting in pressure and velocity changes, subsequently leading to a reduction in turbine efficiency. Furthermore, an increase in both mechanical and hydraulical unbalancing of the turbine runners are observed resulting in an increase in vibration levels. It was also noted that these blockages increase the likelihood of cavitation damage occurring (Egusquiza *et al.*, 2011).

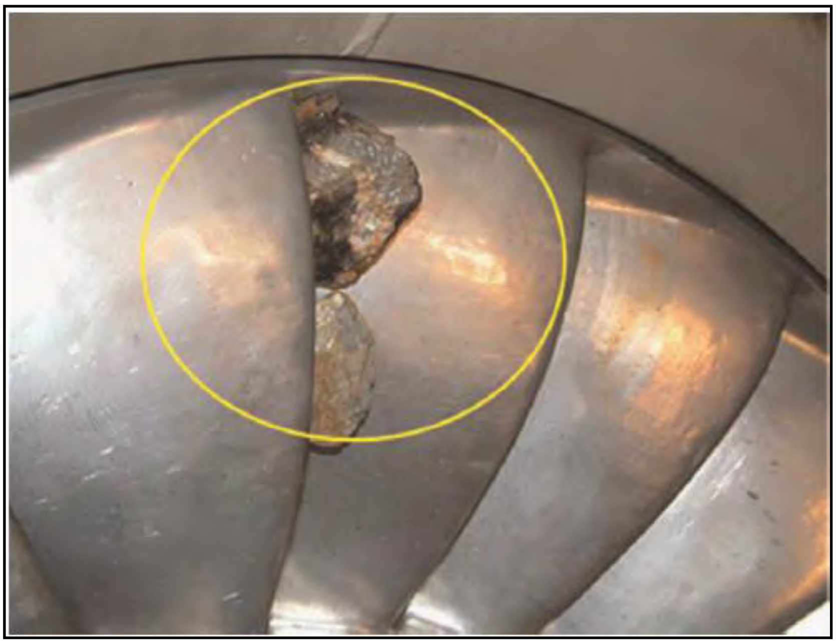


Figure 2-39: Typical Blockage on the Runners (Egusquiza *et al.*, 2011).

These types of blockages are not restricted to the runners alone. In some cases the blockages occur in the distributors or the guide vanes. In the case of the blockage occurring in the distributor, the pressure pulsation and the amplitude uniformity is changed resulting in vibration signature changes. Blockages at the guide vanes are also common and these lead to losses in the flow uniformity as well as induced forces on the runners and bearings. All the cases of ingested body blockages result in a reduction in efficiency and amplification in forces on runners as well as vibrations on the system, thus reducing the expected life of both bearings and seals or even substantial damages within the turbines (Egusquiza *et al.*, 2011).

2.10.7 INSULATION DEGRADATION

The hydropower plants' main function during the 1960s was to deliver power for the base load application but with other sources of electricity such as nuclear and coal stations, the hydropower plants were exposed to a high amount of stop-start cycles for a regulated power supply during the 1970s. With these stop-start cycles the temperature changes rapidly within the generator stator windings. The stator winding expands due to the sudden increase in temperature, which induces shear stresses within the coils. These shear stresses cannot be resisted by the insulation systems, resulting in fatigue cracking between the coils and the insulation and potentially leading up to delamination and subsequent major failures inside the generator. The hydropower plants were consequently shutdown until the winding have been repaired (Kokko, 2012).

2.10.8 FLOODING

Both the structure as well as the equipment of a hydropower station could be destroyed during flooding. In Russia a hydropower turbine room (Figure 2-40) got flooded and 10 generator units needed to be replaced (Hasler, 2010). Similarly the Uttarakhand floods, caused by a heavy downpour in June 2013, destroyed 19 hydropower stations in India (Subhajyoti, 2013).

Figure 2-40: Sayano-Shushenskaya Hydropower Plant Flood Damage (Hasler, 2010).

2.10.9 SYSTEM LOSSES - HYDRAULIC (HEAD) AND LEAKAGE LOSSES

2.10.9.1 Hydraulic losses

An increase in hydraulic losses have been observed over time, due to accumulation of debris on the trash-racks as well as the deterioration of the penstock. The accumulation of debris results in blockages at the intake structure thus restricting the flow (IEEE, 2006). A penstock’s capacity decreases over time due to biofilm growth or other deposits. This decrease in capacity results in an approximation of about 5% decrease in power generation. Fortunately the modern turbines can accommodate the slight variation in flow without influencing their efficiency (Alexander & Giddens, 2008).

2.10.9.2 Leakage losses

A decrease in flow availability is commonly observed due to leakage losses within the system. Even though these losses are minor, only about 0.5% of the flow, they could induce major problems within the system. At the intake gates leakage losses occur due to defective or absent seals, resulting in major difficulties during turbine shutdown for inspections and maintenance (IEEE, 2006). However, bearings and seals are designed to be rigorous and require minimum maintenance but over time they need to be replaced with no major downtime. In case they are not replaced, major damages on the system could occur (Alexander & Giddens, 2008).

False calibration of the gate sensors could also be the reason for leakage losses to occur at the intake gate. As false gate positions are given to the control system by the sensors, resulting in unsafe conditions. Secondly leakage losses occur at the flood control systems, due to deteriorating flashboards, spillway gates and spillways. Lastly, leakage losses could originate at some structural source such as the foundations of both dams and powerhouse, at the abutment structures of dams, in the penstock, canal or even in the tunnels. Resulting in deterioration of the structural components (IEEE, 2006).

2.10.10 WATER QUALITY

The dissolved oxygen content in water drops as the water goes through a turbine. This drop in dissolved oxygen content could be detrimental to the downstream aquatic life. Different aeration techniques could be implemented to obtain a constant dissolved oxygen content; however, these different techniques could negatively impact the efficiency, auxiliary power systems as well as the controls of the hydropower plant (IEEE, 2006).

2.10.11 LIGHTNING DAMAGE

The generators are susceptible to lightning strikes, resulting in mechanical damage such as discoloration and loosing of the laminations within the magnetic circuit (Gummer *et al.,* 1993).

2.11 CONDITION MONITORING, INSPECTION AND ASSESSMENT

With current technology the operation and condition of a hydropower plant can be monitored online. Vibration in the different sections of the turbine, the temperature of the bearings, the system's cooling, as well as the water pressure on the blades could be potentially monitored in this way (Kumar & Singal, 2015). These online monitoring systems give real time operational data, which provides early and precise fault diagnosis which could be utilized for optimising operations as well as prioritising maintenance tasks (Smith & Risberg, 2007).

2.12 REFURBISH, RENEW OR REPLACING A HYDROPOWER PLANT SITE

The above-mentioned problems commonly encountered in hydropower plants could have been mitigated or avoided if proper maintenance had been done on a regular basis. The reality is that most of the existing hydropower plants either have aging technology or have been completely abandoned. The existing hydropower plants in South Africa are at an age where major maintenance and refurbishment is required (Zhang *et al.*, 2012).

Due to the high increase in energy demands and the long construction periods for new hydropower plants, the refurbishment, upgrading as well as modernisation of existing hydropower plants have been favoured, as they are less capital intensive, environmentally friendly and require less time for implementation to attain an increase in energy generation with less uncertainties (Rahi & Kumar, 2016). However, the repowering of existing infrastructure involves both legal as well as technical risks, for example the relicensing of existing infrastructure (IEA-ETSAP & IRENA, 2015).

2.12.1 REFURBISHMENT OF HYDROPOWER PLANTS

Refurbishment of a hydropower plant is aimed at restoring the hydropower plant to its performance levels, which results in the plant’s life extension whilst reducing the operational as well as maintenance costs. The original performance level of a hydropower plant is achieved by restoring the efficiency of both the generator as well as the turbines. This is commonly achieved by replacing the runners of a turbine with present technology. This will result in an increase in output due to the increase in efficiency (Rahi & Kumar, 2016). Typically, generators should be refurbished after 10 years (Kokko, 2010).

2.12.2 RENEWING OR UPGRADING HYDROPOWER PLANTS

Technological advancements, including advancements in designs and materials since the last refurbishment or commissioning of a hydropower plant, have led to the plant’s upgrading or uprating, also referred to as modernization of the plant (Egré & Milewski, 2002). The renewing of a hydropower plant has resulted in an improvement in the plant’s efficiency, output and reliability, as well as the extension of the service life, whilst a reduction in system losses has been observed (Roth, 2004). These gains range between 5-10% (IEA-ETSAP & IRENA, 2015). Figure 2-41 shows a typical increase in efficiency as well as output due to the upgrading of a hydropower plant.

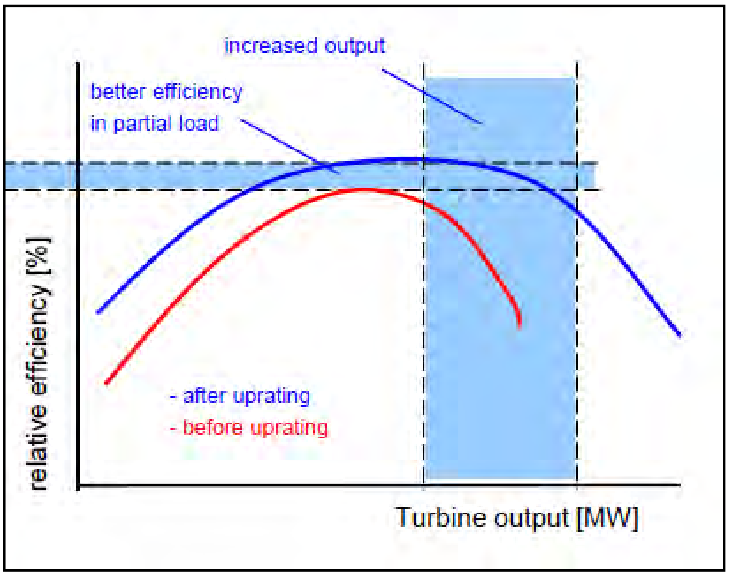


Figure 2-41: Relative Efficiency after Upgrading Turbines (Andritz Hydro, 2012).

During the uprating or renewing process an increase in capacity is commonly achieved by replacing the generator as well as the turbines. In some cases the complete unit is not replaced, rather just the windings, stator core, field poles, governor and breaks are replaced in the generator, and the runners in the turbines (Rahi & Kumar, 2016).

2.12.3 REPLACEMENT OF A HYDROPOWER PLANT

In case an existing hydropower plant is completely dilapidated or that refurbishment as well as renewing is not feasible, a new hydropower plant could be built. The same steps are followed during the replacement of a hydropower plant as for a new plant with regards to the design and construction phase. A hydropower plant is commonly replaced to improve the safety, reliability as well as the environmental impacts (BC Hydro, 2013).

2.13 LEGISLATION AND LICENSING

According to Koch (2002) the main objectives of the policy makers include:

- maintaining a secure source of electricity whilst maintaining a constant supply as well as price for it;
- protecting the lives and properties of the citizens against flooding;
- enhancing or maintaining economic equity whilst respecting the rights of the citizens during the exploration of the inundated land;
- improving air quality by reducing the amount of greenhouse gas emission;
- and lastly, protecting the environment both land and water.

In South Africa these objectives have been met by implementing the following licences or legislative assessments for the construction of a hydropower plant (website links have been attached in Appendix E):

- NERSA licensing
- Eskom
- Water-use licencing
- Environmental Impact Assessment or Basic Assessment

2.13.1 NERSA LICENSING

The regulations and procedures involved in electricity production are clearly outlined in the Energy Regulation Act (No 4 of 2006), which stipulates that an electricity licence is required for the following activities (Section 8 of Act 4, 2006):

a. ‘operate any generation, transmission or distribution facility;
b. imports or export any electricity; or
c. be involved in trading’ (of electricity).

However, exemption for the application as well as holing of the electricity licence were noted in schedule 2 of this Act. The exemptions apply to:

1. ‘Any generation plant constructed and operated for demonstration purposes only and not connected to an inter-connected power supply.
2. Any generation plant constructed and operated for own use.
3. Non-grid connected supply of electricity except for commercial use.’

Sole authority is granted to the National Energy Regulator of South Africa (NERSA) for the approval of both the energy generation and distribution licence according to the Energy Regulation Act (Act 4 of 2006).

2.13.2 ESKOM GRID CONNECTION

In the case where the generator is to be synchronised with or connect to the Eskom grid, Eskom needs to grant permission in addition to the NERSA licensing requirements. Permission is obtained from Eskom once the relevant application forms are completed and the interconnection standard of Eskom is complied with (Eskom, 2016). Small-scale hydropower however is not necessary a source which Eskom would be interested in. The application cost may also make it unfeasible.

2.13.3 WATER-USE LICENSING

As stipulated in the National Water Act (Act 36 of 1998), a water-use licence is required in several cases, however the following are relevant to hydropower generation according to Section 21 and 37:

a. ‘taking water from a water resource;
b. storing water;
c. impeding or diverting the flow of water in a watercourse;
d. disposing of waste in a manner which may detrimentally impact on a water resource;
e. disposing in any manner of water which contains waste from or which has been heated in any industrial or power generation process;
f. altering the bed, banks, course or characteristics of a watercourse;
g. a power generation activity which alters the flow regime of a water resource.’

However, in Section 22 of Act 36 (1998), water may be used without a water-use licence ‘if that water-use is permissible as a continuation of an existing lawful use’. Existing hydropower plants should have a water-use licence in place thus there is no need for a new water-use licence.

2.13.4 ENVIRONMENTAL IMPACT ASSESSMENT

As noted by the National Environmental Management Act (Act 107 of 1998), either an environmental impact assessment (EIA) and a scoping report or a basic assessment (BA) is required before any construction commences. The environmental sensitivity as well as the scale of the projects depicts the assessment required, an EIA or BA. For the larger and more environmental sensitive projects an EIA is required as it is more detailed and time consuming compared to the BA.

A summary of the possible activities in the regulations related to the refurbishment or construction of new hydropower plants are given in Table 2-9. However, additional by-laws and provincial regulations which are applicable are not listed but should be studied during the feasibility study (Loots, 2013).

Table 2-9: Extraction from the National Environmental Management Act, 1998 (Act No. 107 of 1998).

Basic Assessment activities		Scoping and EIA activities	
Activities listed in Government Notice 544 of 18 June 2010		Activities listed in Government Notice 545 of 18 June 2010	
1	The construction of facilities or infrastructure for the generation of electricity where: i. The electricity output is more than 10 megawatts but less than 20 megawatts; or ii. The output is 10 megawatts or less, but the total extent of the facility covers an area in excess of 1 hectare.	1	The construction of facilities or infrastructure for the generation of electricity where the electricity output is 20 megawatts or more
10	The construction of facilities or infrastructure for the transmission and distribution of electricity i. Outside urban areas of industrial complexes with a capacity of more than 32 but less than 275 kilovolts; or ii. Inside urban areas or industrial complexes with a capacity of 275 kilovolts or more.	8	The construction of facilities or infrastructure for the transmission and distribution of electricity with a capacity of 275 kilovolts or more, outside an urban area or industrial complex.
52	The expansion of facilities or infrastructure for the transfer of water from and to or between any combination of the following: i. Water catchment; ii. Water treatment works; or iii. Impoundments; Where the capacity will be increased by 50 000 cubic metres or more per day but excluding water treatment works where water is treated for drinking purposes.	10	The construction of facilities or infrastructure for the transfer of 50 000 cubic metres or more water per day, from and to or between any combination of the following: i. Water catchment; ii. Water treatment works; or iii. Impoundments; Excluding treatment works where water is to be treated for drinking purposes.
55	The expansion of a dam where: i. The highest part of the dam wall, as measured from the outside toe of the wall to the highest part of the wall, was originally 5 metres or higher and where the height of the wall is increased by 2.5 metres or more; or ii. Where the high-water mark of the dam will be increased with 10 hectares or more.	19	The construction of a dam, where the highest part of the dam wall, as measured from the outside toe of the wall to the highest part of the wall, is 5 metres or higher or where the high-water mark of the dam covers an area of 10 hectares or more.

2.13.4.1 Public participation process

A public participation process forms part of the EIA or BA according to the National Environment Management Act (Act 107 of 1998). The public participation process is explained in the Government Notice 543 of 18 June 2010.

2.13.5 SUMMARY OF THE LEGISLATIONS AND LICENCE REQUIREMENTS

A guideline regarding the applicability of the different legislation and licence requirements with respect to the given function of the hydropower installation is given in Table 2-10.

Table 2-10: Summary of the Licence Requirements (Scharfetter, 2016; Scharfetter *et al.*, 2017).

Usage	**Own Use**	**Islanded Use**	**Municipal Grid**		**Eskom Grid**
Description	For own use and from grid; but not into grid	Completely Independent	Feeds into		Feeds into
Environmental Authorisation	10 MW < output < 20 MW OR Output < 10 MW and Area > 1 ha; BA (if > 20 MW; EIA)				
Water-Use Authorisation	Applicable if a water resource is directly impacted Confirmation that water security of supply will not be impacted. No water use licence is required for small hydropower plants up to 300kW.				
Electricity Generation Licence	If < 1 MW NONE	If for non-commercial use NONE	If < 100 kW NONE	If > 100 kW YES	YES (only IPP's through REIPPP or ministerial determination)
Land use permission	YES	YES	YES		YES
Electricity Utility Approval	INFORM	YES (+ concessionaires)	YES	YES	YES

2.14 TYPICAL COSTING FUNCTIONS FOR HYDROPOWER COMPONENTS

In general hydropower plants are known to be capital-intensive power projects due to the capital intensity during the construction phase of the projects, while very little capital is required throughout the operational phase. The fact that hydropower projects have a life span of up to 40 years make these projects viable (Breeze, 2014).

2.14.1 HYDROPOWER COMPONENTS' COSTS

The costs involved in a small hydropower project could be divided into four main components namely the civil works, the turbine and generator set, the electrical components and the construction, engineering and management components. These different components contribute differently to the total costs of the hydropower plant as seen in Figure 2-42. The costs are based on suppliers in India, as South Africa has no turbine suppliers (Ogayar & Vidal, 2009).

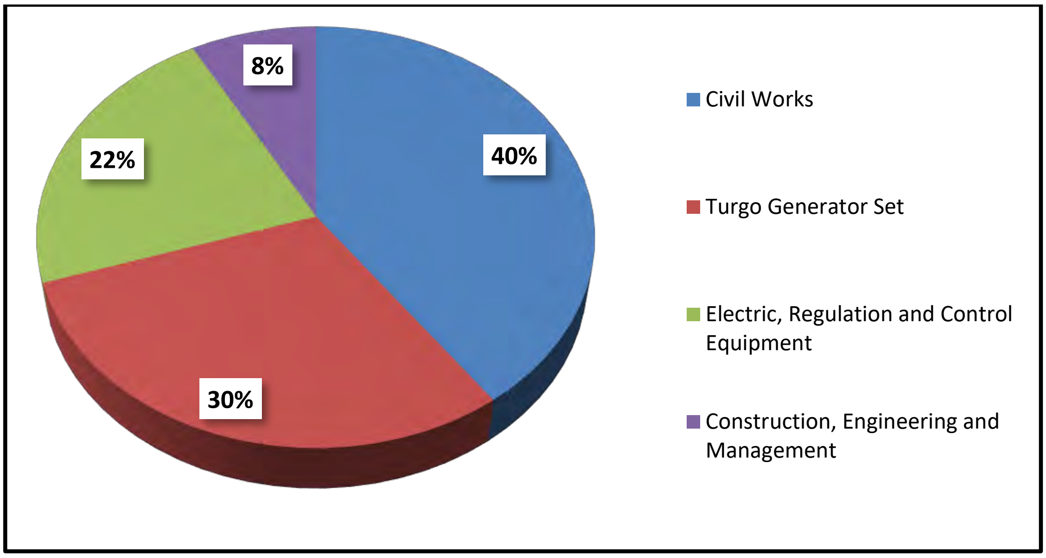


Figure 2-42: Investment Distribution of a Hydropower Plant (Ogayar & Vidal, 2009).

The contribution of these costs also differs for the size of a hydropower plant. As it is known that micro hydropower plants are costlier when compared to large scale hydropower plants, especially with regards to the electro-mechanical components. In Figure 2-43 it is noted that for a large hydropower scheme the electro-mechanical costs are around 20% whilst for a micro scheme they range from 35% to around 40%, or even up to 70% of the total costs (Binama *et al.*, 2017).

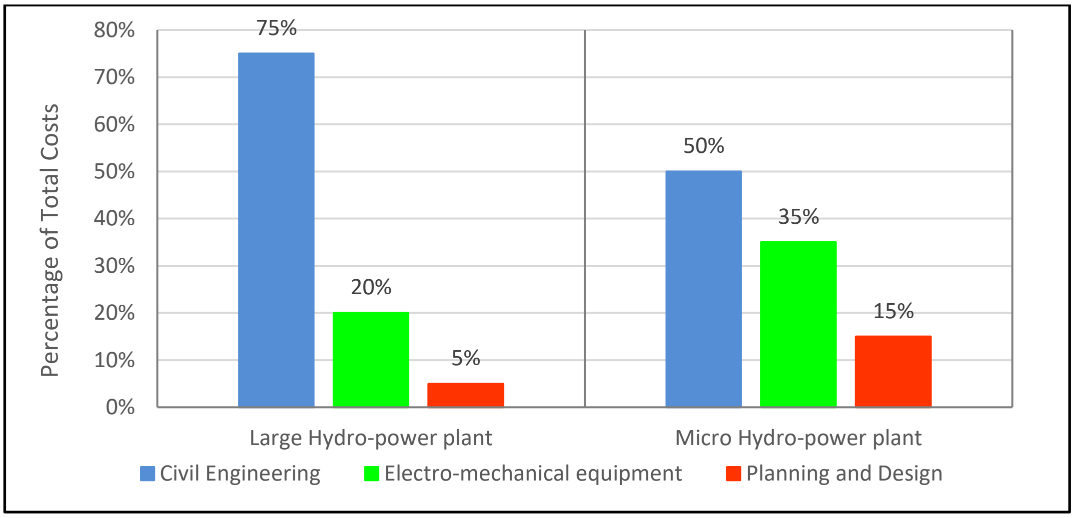


Figure 2-43: Cost Distribution for Large and Micro Hydropower Schemes (Binama *et al.*, 2017).

The cost distribution also differs when considering a new build, a hydropower addition to existing infrastructure or when refurbishing an existing hydropower station, which can be clearly noted in Figure 2-44 (Zhang *et al*., 2012).

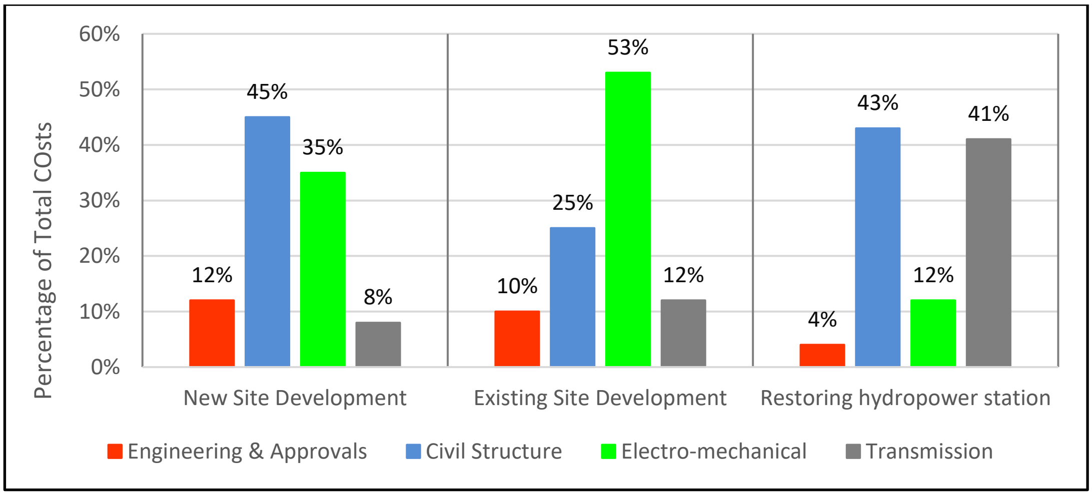


Figure 2-44: Cost Distribution for New, Existing Infrastructure or Restoring Hydropower Sites (Zhang *et al.*, 2012).

According to IEA-ETSAP & IRENA (2015) typically the total cost for a large scale hydropower plant ranges from $ 1 000/kW to $ 3 500/kW, but could be higher depending on site specifics. The costs are similar for a small-scale hydropower plant (1-10 MW) ranging from less than US$ 1 000/kW up to US$ 4 000/kW, however for micro scale hydropower schemes the total costs are higher and range between US$ 3 400/kW to US$ 10 000/kW.

2.14.1.1 Civil works costs

About 40% of the total costs consists of the civil works. These costs for the different civil components could be calculated by using the functions given by Singal and Saini (2008) which were converted to South African Rand's by Van Vuuren *et al*., (2011) and can be seen in Table 2-11. It is important to note that these given costs are the cost to retrofitting dams with hydropower plants (van Vuuren *et al*., 2011).

Table 2-11: Cost per kW for the Different Civil Components (Van Vuuren *et al*., 2011).

Component	Costs (R/kW)
Intake	$C_1 = 2792 \times (10^{-3} \times P)^{-0.2368} H^{-0.0598}$ **(2-5)**
Penstock	$C_2 = 952 \times (10^{-3} \times P)^{-0.3722} H^{-0.3866}$ **(2-6)**
Powerhouse building	$C_3 = 12\,084 \times (10^{-3} \times P)^{-0.2354} H^{-0.0587}$ **(2-7)**
Tailrace channel	$C_4 = 5\,468 \times (10^{-3} \times P)^{-0.376} H^{-0.634}$ **(2-8)**
Total	$\boldsymbol{C_{CW} = 1.13(C_1 + C_2 + C_3 + C_4)}$ **(2-9)**

Where:

$\boldsymbol{P}$ = installed capacity or power output (W),

$\boldsymbol{H}$ = effective head (m),

$\boldsymbol{C_{CW}}$ = Cost of Civil Works (R/kW).

2.14.1.2 Electromechanical equipment costs

Approximately 30 % to 40 % of the total project costs consists of the turbine costs and another 5 % consists of the generator. The equations for the determination of the turbine costs are given in Table 2-12. These functions were obtained from Ogayar & Vidal (2009) and were converted by Van Vuuren *et al*., (2011) to be applicable for South African purposes.

Table 2-12: Costs for the Different Turbines (Van Vuuren *et al*., 2011).

Turbine Type	Costs (R/kW)
Pelton	$\boldsymbol{C_{Pelt} = 201.645 \times (10^{-3} \times P)^{-0.3644725} H^{-0.281735}}$ **(2-10)**
Francis	$\boldsymbol{C_F = 292.878 \times (10^{-3} \times P)^{-0.56013} H^{-0.127242}}$ **(2-11)**
Kaplan	$\boldsymbol{C_K = 378.787 \times (10^{-3} \times P)^{-0.58338} H^{-0.1113901}}$ **(2-12)**

Where:

$\boldsymbol{C_{Pelt}}$ = Cost of a Pelton Turbine (R/kW),

$\boldsymbol{C_F}$ = Cost of a Francis Turbine (R/kW),

$\boldsymbol{C_K}$ = Cost of a Kaplan Turbine (R/kW),

$\boldsymbol{P}$ = installed capacity or power output (W),

$\boldsymbol{H}$ = effective head (m).

In 2008 Singal and Saini developed cost functions to account for the different electromechanical equipment components (Table 2-13). These cost functions where tested by Mishra *et al.*, (2012) and it was concluded that they had an accuracy of ± 10 %.

Table 2-13: Electromechanical Costs of a Hydropower Plant (Van Vuuren *et al.*, 2011).

Component	**Costs (R/kW)**	
Turbine with governing system	$\boldsymbol{C_5 = 7\,665 \times (10^{-3} \times P)^{-0.1902} H^{-0.2167}}$	**(2-13)**
Generator with excitation system	$\boldsymbol{C_6 = 9\,429 \times (10^{-3} \times P)^{-0.1807} H^{-0.209}}$	**(2-14)**
Mechanical and electrical auxiliaries	$\boldsymbol{C_7 = 6\,156 \times (10^{-3} \times P)^{-0.19} H^{-0.2122}}$	**(2-15)**
Main transformer and switchyard equipment	$\boldsymbol{C_8 = 2\,730 \times (10^{-3} \times P)^{-0.1817} H^{-0.2082}}$	**(2-16)**
Total	$\boldsymbol{C_{em} = 1.13(C_5 + C_6 + C_7 + C_8)}$	**(2-17)**

The above equations could be simplified to an equation that is applicable to all turbine types (Alardo-Ancieta, 2009), given by the Equation 2-18, which has been adapted for the application in South Africa (Van Vuuren *et al.*, 2011):

$$\boldsymbol{C_{em} = 9.742(10^{-6}P)^{0.7634}(10^{6})} \qquad \textbf{2-18}$$

Where:

$\boldsymbol{C_{em}}$ = Cost of electromechanical equipment (R/kW),

$\boldsymbol{P}$ = installed capacity or power output (W),

$\boldsymbol{H}$ = effective head (m).

2.14.1.3 Other available costing functions for electro-mechanical components

There are several other costing functions available as summarised in Table 2-14.

Table 2-14: Other Costing Functions Available for Turbines

Turbine Type	**Turbine Restriction**	**Original Cost function**	**Base currency of cost function**	**Reference**
Kaplan	0.5 m^3/s < Q < 5 m^3/s	$C_{K1} = 15000\ (Q \times H)^{0.68}$	£ (Pound Sterling)	Aggidis, et al. (2010)
		$C_{K1} = 3500\ (P)^{0.68}$		
	5 m^3/s < Q < 30 m^3/s	$C_{K2} = 46000\ (Q \times H)^{0.35}$		
		$C_{K2} = 14000\ (P)^{0.35}$		
	-	$C_K = 33\ 236 P^{-0.58338} H^{-0.113901}$	€ (Euro)/kW	Ogayar & Vidal (2009) Mishra, *et al.*, (2012)
	≤ 30 m	$C_{K1} = 909\ 000\ (\frac{P}{1000})^{0.72} \times 2.71826^{-0.0013H}$	$ (US)	USBR (2011)
	> 30 m	$C_{K2} = 5\ 240\ 000(\frac{P}{1000})^{0.72} \times H^{-0.38}$		
Semi - Kaplan	-	$C_{SK} = 19\ 498 P^{-0.58338} H^{-0.113901}$	€ (Euro)/kW	Ogayar & Vidal (2009) Mishra, *et al.*, (2012)
Francis	0.5 m^3/s < Q < 2.5 m^3/s	$C_{F1} = 142000\ (Q \times H^{0.5})^{0.07}$	£ (Pound Sterling)	Aggidis, *et al.* (2010)
		$C_{F1} = 122000\ (P/H^{0.5})^{0.07}$		
	2.5 m^3/s < Q < 10 m^3/s	$C_{F2} = 282000\ (Q/H^{0.5})^{0.11}$		
		$C_{F2} = 223000\ (P/H^{0.5})^{0.11}$		
	Q > 10 m^3/s	$C_{F3} = 50\ 000\ (Q/H^{0.5})^{0.52}$		
		$C_{F3} = 16500\ (P/H^{0.5})^{0.52}$		
	-	$C_F = 25\ 698 P^{-0.560135} H^{-0.127243}$	€ (Euro)/kW	Ogayar & Vidal (2009); Mishra, *et al.*, (2012)
	≤ 30 m	$C_{F1} = 760\ 000\ (\frac{P}{1000})^{0.71} \times 2.71828^{-0.003H}$	$ (US)	USBR (2011)
	> 30 m	$C_{F2} = 3\ 930\ 000\ (\frac{P}{1000})^{0.71} \times H^{-0.42}$		
Pelton	-	$C_P = 8300\ (Q \times H)^{0.54}$	£ (Pound Sterling)	Aggidis, et al. (2010)
		$C_P = 2600\ (P)^{0.54}$		
	-	$C_P = 17\ 693 P^{-0.3644725} H^{-0.281735}$	€ (Euro)/kW	Ogayar & Vidal (2009); Mishra, et al., (2012)
	-	$C_P = 0.8 \times 3\ 930\ 000\ (\frac{P}{1000})^{0.71} \times H^{-0.42}$	$ (US)	USBR (2011)
Other	-	$C_{OT} = 760\ 000\ (\frac{P}{1000})^{0.71} \times\ 2.71828^{-0.003H}$		

2.14.2 ENVIRONMENTAL AND SOCIAL COSTS

The environmental and social costs involve an Environment Impact Assessment (EIA) and a Basic Assessment Report (BAR) which costs about R 600 000 to R 1 000 000 and R 150 000 to R 200 000 respectively (van Vuuren *et al.*, 2011).

2.14.3 MAINTENANCE AND OPERATION COSTS

With minimal maintenance requirements and low operational costs hydropower schemes are considered favourable. Recent studies show that the total annual operation and maintenance (O&M) cost for hydropower schemes typically ranges from 1 – 4% of the total investment costs. Thus, the O&M costs are US$ 45/kW/year for large hydropower schemes, US$ 40-50/kW/year for small (1 – 10 MW) schemes and US$ 45 – 250/kW/year for micro (< 1 MW) schemes (IEA-ETSAP & IRENA, 2015). The O&M cost could also be calculated for the different components, based on a percentage of the components' costs as seen in Table 2-15 (van Vuuren *et al.*, 2011).

Table 2-15: Annual Maintenance and Operational Costs as a Percentage of Total Component Cost (van Vuuren *et al.*, 2011).

Component	Percentage of component costs
Civil works	0.25
Mechanical works	2
Electrical works	4

2.15 ECONOMIC EVALUATION

2.15.1 INTRODUCTION

Hydropower schemes are highly dependent on the identification of the technical potential. However, the economic feasibility of a project is just as important, as the cost need to be recoverable (ESHA, 2004).

Both the costs and benefits need to be compared whilst analysing the economical feasibility of the project, in order to provide an indication to the investors whether to implement or abandon the project. The costs as well as the benefits throughout the whole life of the project should be considered, which include the fixed costs (i.e. capital costs) and the variable costs (i.e. operation and maintenance (O&M) cost) (ESHA, 2004).

There are two economic analysis methods namely static and dynamic methods. The static method is somewhat easier to calculate but it does not consider the time value of money, whilst the dynamic method incorporates the time value of money in determining the economic feasibility of a project. The payback period and the return on investment are the two static methods where the net present value, internal rate of return and benefit/cost ratio are all dynamic methods (SANRAL, 2013). These different methods are discussed in more detail in Table 2-16 and Table 2-17 (Static and Dynamic methods of analysis respectively).

Table 2-16: Static Methods of Analysis (Adopted from SANRAL (2013) and ESHA (2004)).

Method	Description	Equation	Comments
Payback Period	Calculates the number of years for the benefits to cover the investment costs. Commonly revered to as the recovery or break-even period.	$Payback\ period = \frac{Investment\ cost}{Net\ annual\ revenue}$ **(2-19)**	It is important to note that payback period does not compare alternative solutions and efficiency of the investment is also not calculated, as the cash flow is only calculated up to the point of break-even and not over its entire life. For a small hydropower installation, the payback period should be less than 7 years to be considered feasible.
Return on Investment (ROI)	Calculates the total yearly benefits minus the depreciation as a percentage of the original investment costs of the project.	$ROI = \frac{Net\ annual\ revenue - Depreciation}{Investment\ costs} \times 100$ **(2-20)** Where straight line depreciation is calculated as follows: $Depreciation = \frac{Cost - Salvage\ value}{Operational\ Live}$ **(2-21)**	A quick estimate of the net profits for a given project could be determined using the ROI method, which could in fact be compared with alternatives. Unlike the payback period method, the ROI considers the entire useful life regarding its returns. Nevertheless, the ROI technique utilizes income data rather than cash flow and it overlooks the time value of money.

Table 2-17: Dynamic Methods of Analysis (Adopted from SANRAL, (2013) and ESHA (2004)).

Method	Description	Equation	Comments
Present Worth of Cost (PWOC)	Amongst mutually exclusive projects, the lowest cost alternative is selected by using the PWOC method. All costs incurred by the projects are discounted to their present worth.	$PWOC = C_A + PW(M + U)$ **(2-22)**	The alternative with the lowest PWOC is regarded as the most feasible projects.
	In the case that the null alternative is being considered.	$PWOC = PW(M + U)$ **(2-23)**	This is applicable when the replacement or upgrading of an existing facility is being considered, as well as for the comparison of the mutually exclusive alternative.
Net Present Value (NPV)	The NPV determines the difference between the total costs and the predicted future benefits. It offers an economic performance measure that is utilised for the election of the mutually exclusive alternatives as well as determines the complete financial feasibility of independent projects.	$NPV = PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A) - C_A$ **(2-24)**	
Internal Rate of Return (IRR)	In the IRR method is used to determine the discount rate for projects to break even. The calculation of future benefits and costs are determined in the same way as in the NPV and B/C methods and are then discounted to the present utilising different rates until the cost and benefits equate. That rate is then referred to as the IRR.	$IRR = r$ When $PW(M_0 + U_0) - PW(M_A + U_A) + PW(CS_A) = C_A$ **(2-25)**	The viability of independent projects is determined with the IRR and the higher the IRR the more attractive the project is. A project with a NPV lager than zero (NPV>0) is defined as an economical feasible project and the alternative with the highest positive NPV should be implemented. In the case that the NPV is less than zero, the project is defined as unfeasible as the returns are less than the cost incurred by the project.

Method	Description	Equation	Comments
Benefit Cost Ratio (B/C RATIO)	The benefit cost ratio gives a relationship between the present worth of the future returns and the present worth of the costs of a project. Annual savings relative to the null alternative, in addition to the consumer surplus increase through the utilisation of the facilities are associated with the future benefits of a project. The sum of all the discounted benefits gets divided by the sum of all the investment costs associated with the project to obtain the ratio.	$B/C = \frac{PW(M_0+U_0)-PW(M_A+U_A)+PW(CS_A)}{C_A}$ **(2-26)**	If the ratio results in a value greater than one (B/C>1), the project is viable. In the cases then mutually exclusive projects are analysed, the best alternative could be identified when using the incremental analysis method.

Where:

PWOC = present worth of cost

C_A = investment (capital) costs that is required to implement the alternative A.

PW(M+U) = present worth of all the maintenance and user costs of the facility

NPV = net present value of benefits

$PW(M_0+U_0)$ = present worth of maintenance and user costs of the null alternative.

$PW(M_A+U_A)$ = present worth of the maintenance and user costs for a proposed alternative.

$PW(CS_A)$ = consumer surplus gained through additional usage induced by the proposed alternative. This is equal to one-half of the benefit accruing to each existing journey multiplied by the number of induced trips.

IRR = Internal Rate of Return

r = rate at which the left-hand and right-hand sides of the equation are equal, resulting in a NPV of zero.

B/C = benefit/cost ratio

2.15.2 COSTS

During the life span of a hydropower plant there are several costs that are incurred which include both the fixed costs (i.e. capital costs) and the variable costs (i.e. operation and maintenance (O&M) cost) (ESHA, 2004). These costs can be split up into initial planing costs, capital costs, O&M costs and retirement/disposal costs (van Vuuren *et al.*, 2014).

2.15.2.1 Initial Planning costs

The initial planning costs comprise of the conceptual design costs, the basic site investigation costs as well as the regulatory and legal costs associated with the project. Equation 2-27 is the basic formula that could be used to determine the initial planning costs and a summary of these costs can be seen in Table 2-18.

$$\boldsymbol{IPC = C_{Invest} + C_{E\,\&\,S} + C_{L\,\&\,R}} \qquad \textbf{(2-27)}$$

Where:

IPC = Initial Planning Cost

C_{Invest} = Investigation cost

$C_{E\&S}$ = Environmental and social assessment cost

$C_{L\&R}$ = Legal and regulatory requirement cost

Table 2-18: Summary of all the Costs Related to the Initial Planning Costs (van Vuuren *et al.*, 2014).

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

2.15.2.2 Capital costs

The capital costs consist of all the costs associated with the design, the equipment, installation and commissioning of a plant (Equation 2-28). These costs arise only at the beginning of the project. A summary of all the costs that are included in the capital costs are noted in Table 2-19 (Van Vuuren, et al., 2014).

$$\boldsymbol{CEC = C_D + C_{Purch} + C_I + C_S} \qquad \textbf{(2-28)}$$

Where:

CEC = Capital Expenditure costs

C_D = System design costs

C_{Purch} = Purchase costs

C_I = Installation costs

C_S = Start-up costs

Table 2-19: Summary of the Capital Expenditure Costs (van Vuuren *et al.*, 2014).

Capital Expenditure Cost (CEC)			
Cost of design (C_D)	**Purchase Cost (C_{Purch})**	**Installation Cost (C_I)**	**Start-up cost (C_S)**
Civil Engineering Design costs (C_{CE}) - Access - Intake - Diversion - Headrace - Surge chamber - Penstock - Housing & crane - Tailrace **Mechanical & Electrical Design costs ($C_{M\&E}$)** - Turbine/generator - Valves - Controls - Transformer - Transmission - Stand-by **Project Management costs (C_{PM})** - Procurement, scheduling and controlling plans	**Manufacturing costs (C_{MC})** - Turbine/generator - Valves - Penstock - Crane or hoist **Quality control costs (C_{QC})** - Engineering supervision - Management supervision **Logistic Support and Controls (C_{SC})** - Backup & sensor systems - Operational software **Documentation costs (C_{DC})** - Equipment O&M manuals	**Construction costs (C_{CC})** - Civil engineering works - Mechanical/ electrical works **Equipment Transport costs (C_{TC})** - Road - Railway - Boat - Air **Mounting and Connecting ($C_{M\&C}$)** - Mechanical/ electrical equipment - SCADA controls - Security lighting	**Test and Evaluation cost (C_{TE})** - Training - Testing - As-build drawings **Commissioning of Plant (C_{CP})** - Technical - Administrative

The preparation works and environmental mitigations cost constitute to 5% and 7% of the total civil works respectively (Rojanamon *et al.*, 2009), whilst the engineering and design costs are around 5 – 8% of the construction costs. The supervision and administration costs are 4 – 7% of the construction costs (Forouzbakhsh *et al.*, 2007).

2.15.2.3 Operation and Maintenance costs

The operating costs for a hydropower plant consist of both direct and indirect labour, materials, expenses and establishment costs. The maintenance costs include the direct labour, materials and equipment costs. There are three types of maintenance namely, planned or preventative maintenance, intermittent maintenance (refurbishment) and lastly unplanned maintenance. A relationship between maintenance expenditure and down time exists, thus for planned maintenance the downtime is minimal but the expenditure cost might be high, where in the case of "run-to-failure" approach, the maintenance costs are reduced but the down time increases, as depicted in Figure 2-45 (Woodward, 1997).

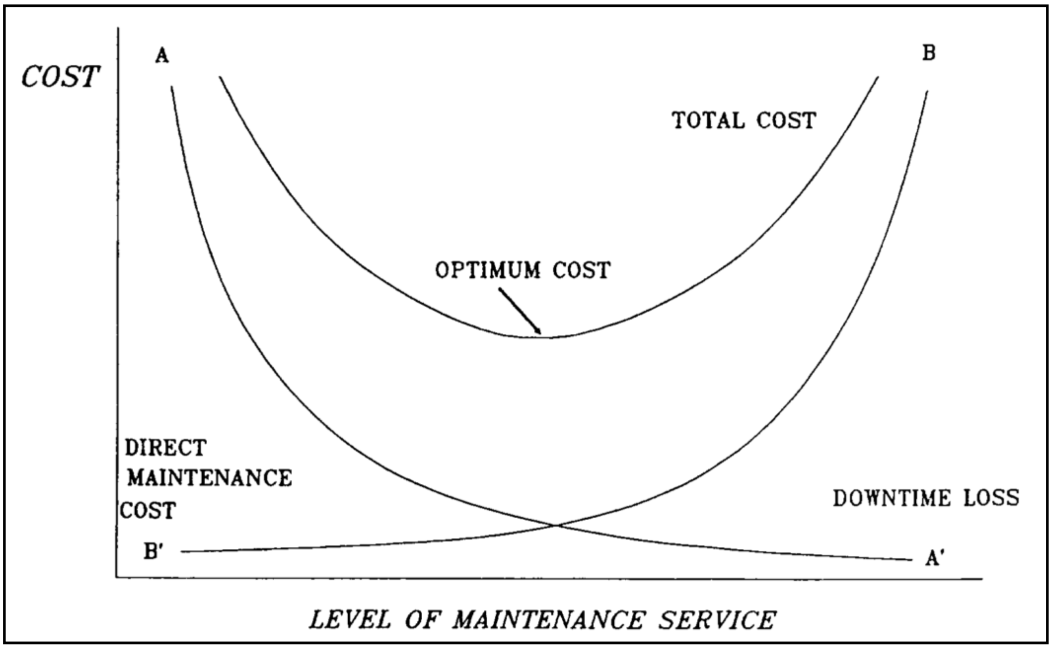


Figure 2-45: Relationship Between Maintenance and Downtime Costs (Woodward, 1997).

The O&M costs should be broken down into the different categories and at least 15 % contingencies should be allowed. In the case where a newly designed equipment is installed, the full replacement costs should be included in the O&M costs. Similarly, every three years batteries should be replaced. The prices of transportation, wages and spare parts should all allow for inflation (Harvey *et al.,* 1993). The annual O&M cost of the different components need to be at an average inflation rate of 5 % per year (Hosseini *et al.,* 2008).

2.15.2.4 Refurbishment costs

The refurbishment costs include all costs during major renovations of the hydropower plant. Typically, the electro-mechanical components need replacement 20 to 30 years earlier than the civil works. The illustration, Figure 2-46, clearly shows how the state of a hydropower plant decreases with time and how significant refurbishment is in extending the plant's life (van Vuuren *et al.,* 2014). Typically, the total cost of the equipment at the time of purchase is equal to the equipment's replacement costs (Forouzbakhsh *et al.,* 2007).

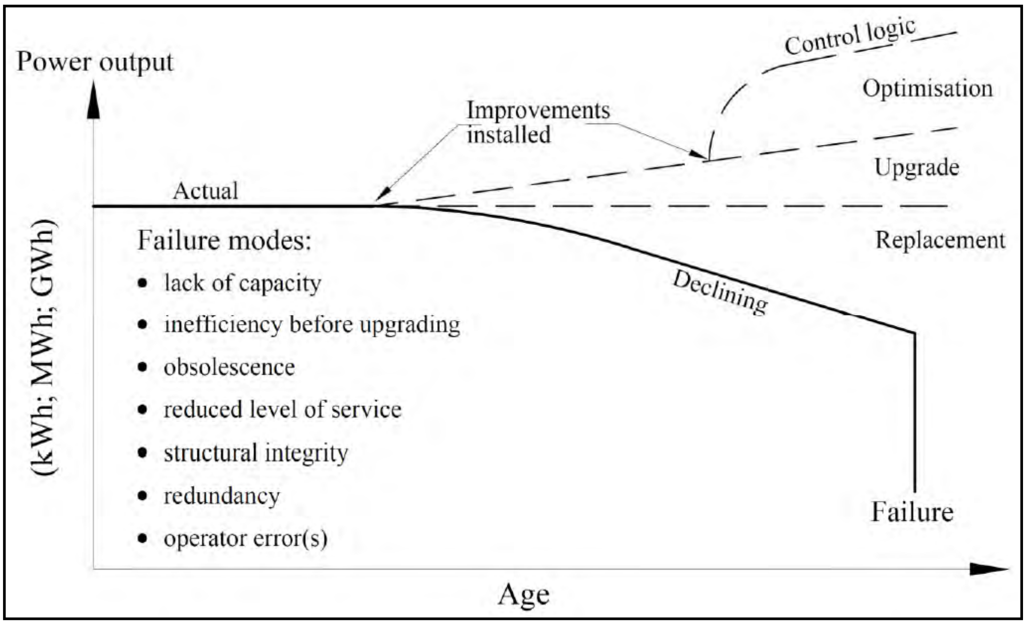


Figure 2-46: State of Hydropower Declining and the Influence of Refurbishment (van Vuuren *et al.,* 2014).

2.15.2.5 Retirement or disposal costs

The retirement, recycling and system replacement cost must be included in the costs during the planning stage to ensure a sufficient budget. These costs will have to be increased if environmental rehabilitation is required (van Vuuren *et al.,* 2014).

2.15.3 LIFE CYCLE COSTING

All the costs that occurred during the life span of a project are included in the life cycle cost (LCC) analysis, which includes the planning, construction, commissioning, ongoing maintenance and operation, replacement as well as decommissioning costs, as show in Figure 2-47 (Zhang *et al.,* 2012).

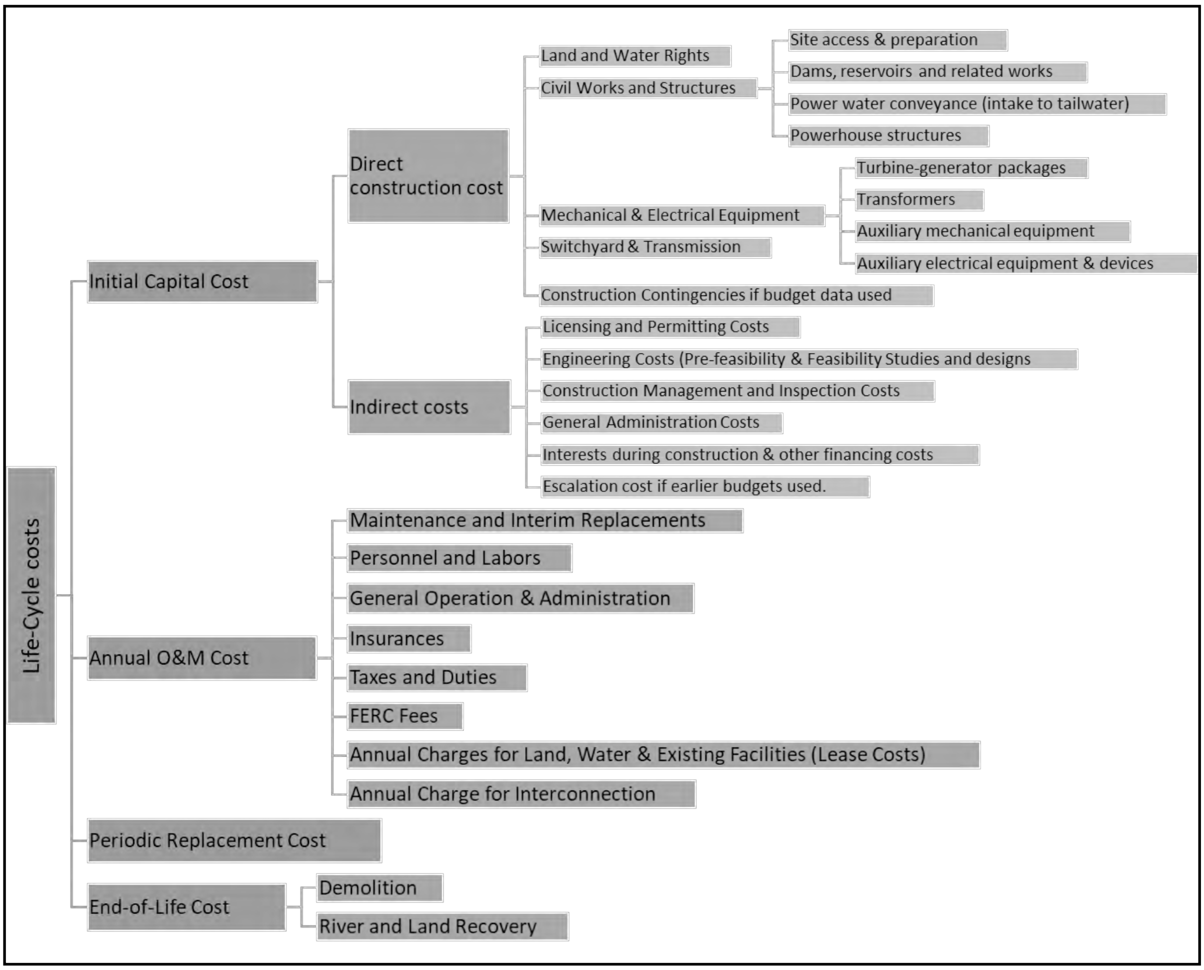


Figure 2-47: Typical Life Cycle Cost for Hydropower Projects (Zhang *et al.*, 2012).

Similarly, the actual and potential benefits should be included in a life cycle economic evaluation. A break-down of these benefits can be seen in Figure 2-48. In most cases these benefits are already deducted from the initial capital costs and thus are not represented in the formula (Zhang *et al.*, 2012).

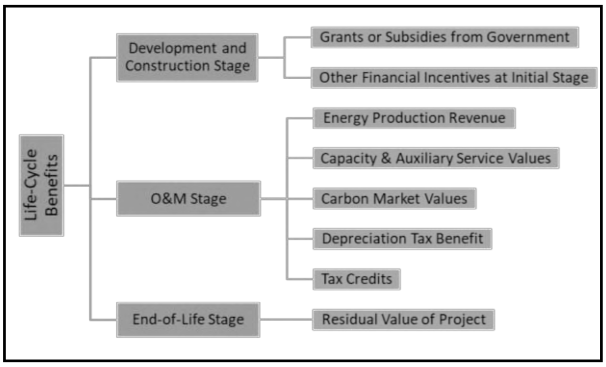


Figure 2-48: Typical Life Cycle Benefits Associated with Hydropower Projects (Zhang *et al.*, 2012).

With the LCC analysis, projects with different costing patterns can be compared, since both the time as well as the value of money is considered. Typically, the operating costs of a project should be covered by the gained revenue and the profits should cover the loan. It is important to note that the different components of a hydropower plant have different lifespans (Table 2-20), ranging from 30 to 50 years, which influences the analysis period (van Vuuren *et al.*, 2014).

Table 2-20: Expected Useful Life (EUL) of Hydropower Components (van Vuuren *et al.*, 2014).

Type of asset	Description	EUL (years)
Structures/ Road	Dams/weirs/intakes/canals	50-100
	Building/houses	50
	Access Roads (wearing surface)	20
Hydro-mechanical equipment	Turbines (small size)	25
	Valves and gates	45
	Penstocks (mainly steel)	50
Hydro-electrical equipment	Generators	20
	Transformers	20
	Transmission lines	30
Auxiliary equipment	Electrical controls	15
	Telemetry	15
	Security components	10

2.15.4 LEVELISED COST OF ENERGY (LCOE)

Levelised Cost of Energy (LCOE) is commonly used for evaluation of modelling renewable technologies. The LCOE is the cost of energy allowing the recovery of the investment costs over the lifetime of the hydropower plant. Equation 2-29 or Equation 2-30 could be used to determine the LCOE (IRENA, 2012).

$$\boldsymbol{LCOE = \frac{Lifecycle\ cost}{Lifetime\ energy\ production}} \tag{2-29}$$

$$\boldsymbol{LCOE = \sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t} \Big/ \sum_{t=1}^{n} \frac{E_t}{(1+r)^t})} \tag{2-30}$$

Where:

$\boldsymbol{LCOE}$ = Levelised cost of electricity generation (R/kW)

$\boldsymbol{I_t}$ = Investment expenditure in the year t

$\boldsymbol{M_t}$ = Operations and maintenance expenditure in year t

$\boldsymbol{F_t}$ = Fuel expenditures in the year t

$\boldsymbol{E_t}$ = Electricity generation in the year t

$\boldsymbol{R}$ = Discount rate

$\boldsymbol{n}$ = Economic life of the system or the number of years

2.16 HYDROPOWER DEVELOPMENT TOOLS

A few assistance hydropower development tools to determine the power potential and installation cost involved in the development of hydropower sites are described in Table 2-21.

Table 2-21: Available Hydropower Assessment Tools (adapted from Loots, 2013).

Tool	Description	Reference:
RETScreen	The RETScreen Clean Energy Project Analysis Software is freeware distributed by the Government of Canada as part of the country's drive to reduce pollution in an integrated manner. RETScreen can be used worldwide to determine the cost savings of various renewable energy options. 'RETScreen allows decision-makers and professionals to determine whether or not a proposed renewable energy, energy efficiency, or cogeneration project makes financial sense'. The tool is designed to analyse most clean energy projects (including solar, wind, wave, hydro, geothermal, biomass and others). The RETScreen standard analysis consists of 5 steps including, energy model, cost	• RETScreen, 2011; • Leng, 2000; • Natural Resources Canada, 2017

Tool	Description	Reference:
	analysis, emission analysis, financial analysis, and sensitivity/risk analysis. The model includes a database with hydrology and climate information for many locations around the world.	
Hydrohelp	Hydrohelp is an Excel-based tool that assists designers in choosing suitable turbines for conventional hydropower installations, as well as providing an initial cost estimate from related infrastructure. The program assesses the operating envelope of all commercially available turbines, provided by manufacturers of 28 different types of turbines from 1 MW upwards, discards unsuitable turbines and selects the most appropriate based on approximate cost and other parameters. It uses data. The program also provides details on the selected turbine, such as an efficiency curve, runner size and setting. With some added input on site conditions, it will calculate powerhouse data such as crane capacity and concrete quantity, along with the cost of ancillary equipment'.	• HydroSys Consultants, 2008 • Hydrohelp, 2010
Hydropower Evaluation Software (HES)	The Hydropower Evaluation Software (HES) is a computer software model developed by the Idaho National Engineering Laboratory for the US Department of Energy to estimate the undeveloped hydropower potential in the US. 'The software was developed and tested using hydropower information and data provided by the Southwestern Power Administration'. HES allows the user to 'assign environmental attributes to potential hydropower sites, calculate development suitability factors for each site based on the environmental attributes present, and generate reports based on these suitability factors.'	• Conner *et al.*, 1998; • Idaho National Engineering Laboratory, 2011
Leyland	Leyland included Excel-based spreadsheets in his book. These include: Hydro scheme data and cost estimate; Trash-rack (screen) losses; Dimensions of Francis, Kaplan and Pelton turbines; Cost estimated for the turbines and generators; preliminary financial analysis and economic analysis.	• Leyland, 2014
USBR Hydropower Assessment Tool	The United States Bureau of Reclamation (USBR) developed a tool for conventional hydropower assessment at its facilities. This tool can be used when evaluating a potential hydropower site that has at least the following known information: continuous flow; defined head and tail	• USBR, 2011

Tool	Description	Reference:
	water levels; and distance to a transmission line. This tool is used for preliminary hydropower-potential evaluation and has cost functions based on US prices in 2010. The program determines most suitable turbine, calculates generation potential and economic parameters such as the benefit/cost ratio and internal rate of return of a project.	
PEACH	PEACH is a preliminary analysis tool for development of hydroelectric schemes. The tool covers the different aspects of a hydropower project (assessment of the potential, dimensioning and economic and financial analysis).	• ISL, 2012
Plant Cost Estimator	This model was developed by the Idaho National Engineering and Environmental Laboratory and funded by the U.S. Department of Energy. The model uses Microsoft Excel-based tools for cost estimation of the development, operation and maintenance of various types of conventional hydropower plants in the USA. This included the development of new sites, existing dams without hydropower and the expansion of hydropower plant at dams with existing hydropower capacity.	• Hall *et al.*, 2003
IMP (Integrated Method for Power Analysis)	The integrated method for power analysis (IMP) is a convenient tool for evaluating small-scale hydroelectric power sites. By utilizing IMP (combined with the relevant meteorological and topographical data), a user can evaluate all aspects of an ungauged hydro site. IMP consists of five basic components that include: Atmospheric Model, Flood Frequency Analysis Model, Watershed Model, Hydroelectric Power Simulation Model and a Fish Habitat Analysis Model.	• Punys *et al.*, 2011
HPP-Design	HPP-Design is a simple tool for Hydro Power Plant Design to assist in the selection of the most appropriate turbine for a specific plant layout. HPP- Design will help the user in the selection, providing accurate sizing data and energy calculation for every type of turbine (Kaplan, Francis, Pelton, Cross flow). By carefully considering all the design aspects an optimal turbine and layout is designed to maximize the energy and economic performance of the plant.	• Santolin, 2017

Tool	Description	Reference:
CHDT (Conduit Hydropower Decision Tool)	A decision support System (DSS) was developed by Loots that can be used to identify the conduit hydropower potential, as well as to provide proper guidance for the development of identified sites. This Microsoft Excel based Conduit Hydropower Development Tool (CHDT) consists of several flow diagrams to identify and develop conduit hydropower sites. A systematic approach is followed when assessing hydropower potential in the water supply or distribution network to ensure that all relevant factors are considered. The DSS has been divided into three phases linked to a CHDT: • First Phase: Pre-Feasibility Investigation • Second Phase: Feasibility Study; and • Third Phase: Detailed Design.	• Loots, 2013

Several of the above-mentioned assistance tools are relevant to South Africa, however these tools have been designed for the development of mainly new hydropower plants.

As alternative energy sources are being developed, both by municipalities and private users, it was noted that there is a gap in knowledge and technical skills. For both wind and solar power, the National Renewable Energy Laboratory (NREL, 2011) has developed a tool to assist users on first order costing analysis. A similar tool is not yet available for hydropower generation in South Africa. Thus, a need for a Hydropower Development Assistance Tool was identified to guide both municipalities as well as private users through the process of developing new sites or rehabilitating/ upgrading existing hydropower stations.

2.17 LITERATURE REVIEW SUMMARY

In this chapter hydropower has been discussed focusing on the different components, different failure mechanisms of existing hydropower stations and their refurbishment. The fundamentals of hydropower potential evaluation and development, the economic evaluation, existing tools and case studies have been covered. A background to the South African energy situation as well as regulatory requirements had also been provided.

The information discussed in this chapter provides the background to the framework development and tools developed in the following chapters, focusing on existing infrastructure.

3 EVALUATION FRAMEWORK

This study's aim was to develop a user-friendly support tool for the evaluation of existing or decommissioned hydropower plants in South Africa, to either refurbish, renewing or replacing the plant.

Both a flow diagram as well as an Excel tool has been developed to guide the user through the evaluation process. This flow diagram has been applied to a decommissioned site in South Africa. Any shortcomings and variations during the analysis were addressed and a Hydropower Development Assistance Tool for South Africa was produced.

3.1 THE SCOPE OF WORK

A summary of the total scope of work in any given hydropower project is presented in Figure 3-1. However, in this study the focus will be on the identifying and evaluating existing sites (the light blue coloured blocks in Figure 3-1). The implementation as well as the ongoing operation and maintenance fall outside the scope of this study (the purple and light green blocks in Figure 3-1 respectively) however they remain very important aspects to ensure an effective hydropower plant.

Pre-feasibility study and site evaluation

- Pressure head and flow measuremenets
- Electricity-use identified
- Conceptual design of system (pipework, turbine room, transmission)
- Preliminary costing

Regulatory and Premitting

- NERSA licence application
- Environmental impact assessment
- Water-use licensing
- Public participation
- Land ownership

Detail system design

- Dynamic analysis of the system
- Selection of turbine
- Design of turbine room
- Design of pipe and valve work
- Optimisation of system

Grid integration

- Design of electric control boards
- Design of regulator system
- Design of electric transmission and grid connection

Project finance and feasibility study

- Funding strategy and sustainability
- Detailed cost estimated
- Risk assessment
- Sensitivity analysis

Equipment procurement and construction

- Tender phase
- Tender evaluation
- Equipment procurement
- Construction of facilities

Project and construction management

- Overall project management
- Site supervision
- Commissioning and testing

Operation and maintenance

- Operation and Maintenance manuals
- Routine inspections
- Maintenance plan
- Training

Monitoring and evaluation

- Recording of flow, pressure, energy, efficiency etc.
- Evaluation and optimising of plant operation

Figure 3-1: Hydropower Development Scope of Works (Adapted from Loots, 2013).

3.2 FRAMEWORK DEVELOPMENT

3.2.1 LAYOUT OF THE FRAMEWORK

The framework that is presented in Figure 3-2, was developed to evaluate existing or decommissioned hydropower sites.

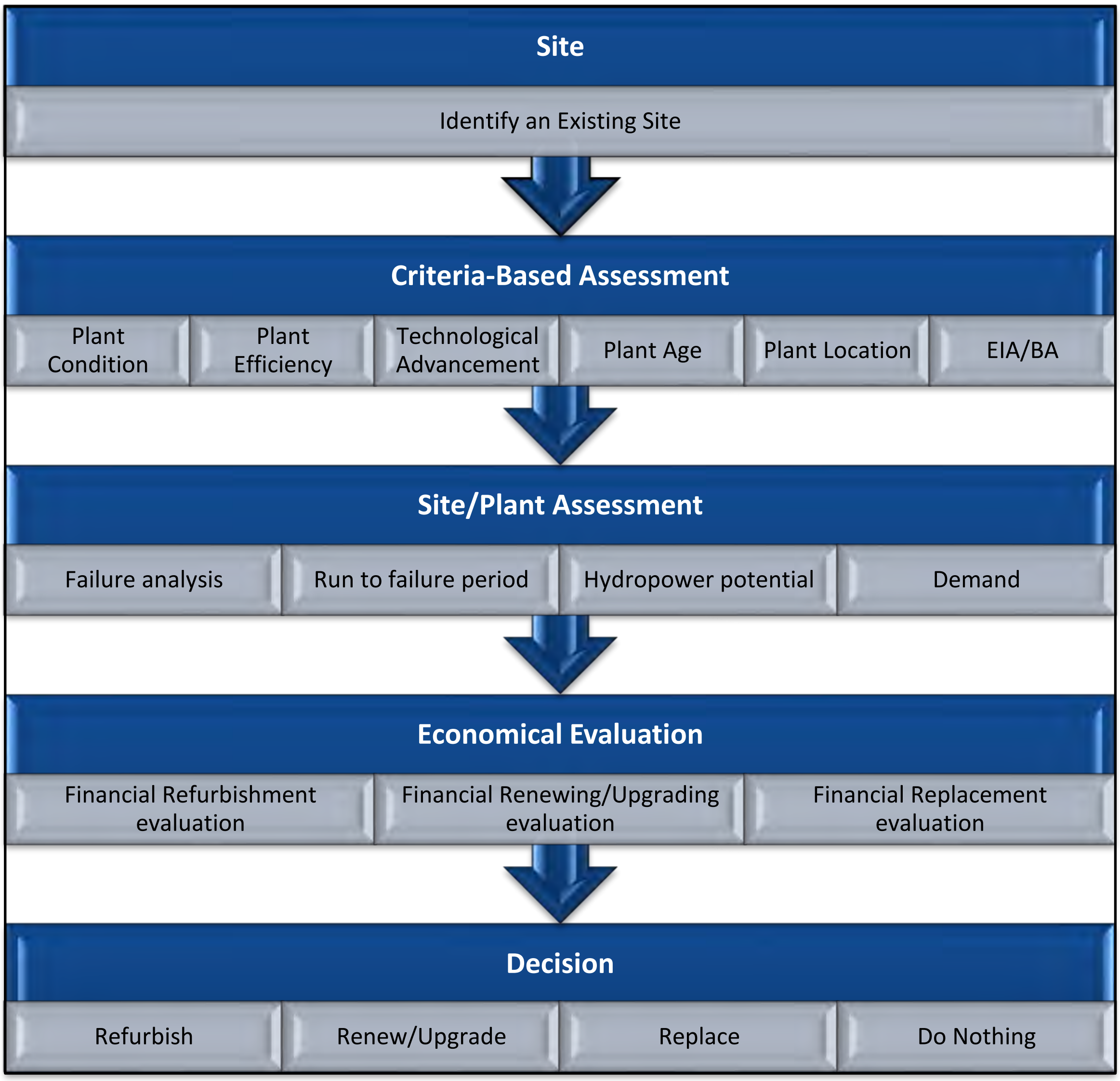
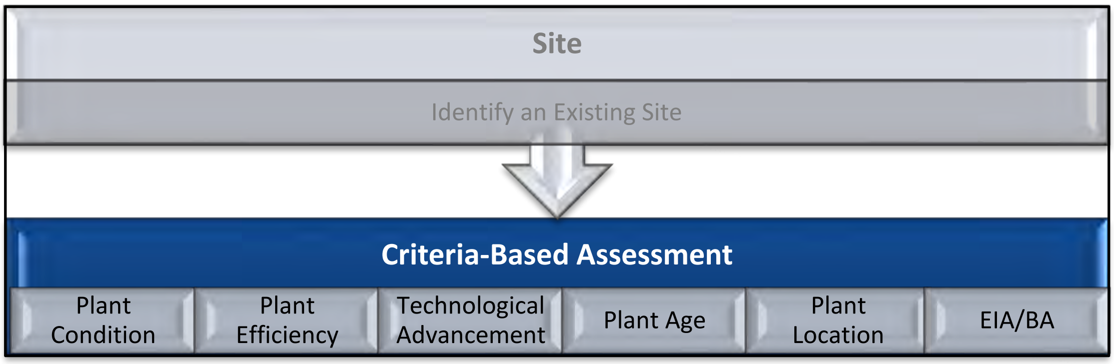


Figure 3-2: Framework for Analysing Existing Hydropower Plants

3.3 SITE IDENTIFICATION

Firstly an existing hydropower site needs to be identified, being operational or decommissioned. A complete background study regarding the site should be conducted, establishing both the owner and operator of the facility as well as the owner of the land, structure and water controller. In some cases it is the same person or company, but this is not always the case. Information regarding the commissioning, decommissioning (if applicable) as well as any maintenance, operational and major refurbishment should be gathered, as this will provide background information to the site. The existing licences should be evaluated and if necessary new licences should be obtained from the respective authorities. After the desktop study is completed, a site visit should be done for the Criteria-Based Assessment.

3.4 CRITERIA-BASED ASSESSMENT



3.4.1 SCORING OF THE CRITERIA-BASED ASSESSMENT COMPONENTS

In the Criteria-Based Assessment six different components were analysed. Each component of the criteria-based assessment was given a score of 1 to 5, with 1 being excellent and 5 being critical. Components that were not available for evaluation also received a score of 5, implying they were in critical condition. A breakdown of the scoring system used can be seen in Table 3-1. The different components within the Criteria-Based Assessments were weighted according to their importance (

Table 3-2).

Table 3-1: Scoring System for the Criteria-Based Assessments

Description	Score
Excellent	1
Good	2
Average	3
Bad	4
Critical	5
Not Available	5

Table 3-2: Weightings of the Different Decision Variables

Decision Variable	Weighting
Plant Condition	2
Plant Efficiency	1
Plant Age	1
Technological Advancements	1
Plant Location	1
Environmental Impacts	1

A plant with an overall score of 7 implies that the plant is in excellent condition, similarly if the overall score is over 35 the plant is in critical condition. The exact breakdown of the overall score can be seen in Table 3-3.

Table 3-3: Overall Scoring Description for Criteria-Based Assessment

Overall Score	Description
= 7	Excellent condition
7 - 15	Good condition
15 - 25	Average Condition
25 - 35	Bad Condition
> 35	Critical Condition

3.4.2 PLANT CONDITION ASSESSMENT

The following scoring criteria (Table 3-4) is utilised during the plant condition assessment. The turbine, generator, powerhouse crane, intake structure and the penstock are the many components evaluated during this assessment.

Table 3-4: Scoring Criteria for the Hydropower Plant Condition Assessment

Condition	Description	Score
No indication of degradation or instability.	Excellent	1
Some indication of degradation or instability occurring. The extent of degradation is noticeable.	Good	2
Some extent of degradation and instability. The degradation is obvious and requires some attention.	Average	3
Serious degradation. Condition is considerably worse than as new, and attention is required.	Bad	4
The condition is critical and serious attention is required.	Critical	5
The components are no longer available for assessment	Not available	5

3.4.2.1 The Turbine

Visual and non-destructive testing are utilised during the turbine condition assessment. Signs of cracking, cavitation and/or erosion of the blades of the turbines should be noted. Any signs of leakage occurring at the shaft seal or regulating system should be determined by inspecting the discharge ring, draft tube and regulating system.

3.4.2.2 The Generator

Both the windings and the core of a generator need to be inspected to determine the overall condition of the generator. Visual inspections as well as Polarising Index, Tan Delta and heat runs are common tests used to determine the condition of the generator windings. Signs of overheating or flashovers are indicated by discolorations, loose laminations or mechanical damage, which are determined with an “El Cid” test. In cases where the generators are in a relatively good condition, rewinding could be sufficient for the generator to operate as designed. However, in some cases the generators have not been maintained as prescribed and may result in extensive refurbishment efforts or even replacement. The generator’s foundation, support system and shaft should also be evaluated in terms of their structural integrity. In the case where the hydropower stations are being uprating, the original design torques and stress levels of these components should be established (Gummer *et al*., 1993).

3.4.2.3 The Powerhouse cranes

The powerhouse crane is primarily used during the installation and removal of the turbines. Thus, the crane is not often operational and might require some extent of refurbishment. Both the capacity and travelling speed of the powerhouse cranes should be evaluated as they are important for the refurbished or new turbine installation. Visual examination of the beam carrying the crane is required for the determination of aesthetical deterioration.

3.4.2.4 The Intake and Penstock

A visual inspection of the intake gates is required for the detection of any flow obstructions. The penstock should be visually examined along the chainage for any corrosion or leakage locations. The stability and integrity of the anchor blocks of the penstock should also be examined.

3.4.3 PLANT’S EFFICIENCY ASSESSMENT

The plant’s efficiency is dependent on the turbine’s and generator’s efficiency as well as the efficiency of the penstock. Table 3-5 indicates the scoring criteria used for the evaluation of the hydropower plant’s efficiency.

Table 3-5: Plant’s Efficiency Scoring Criteria.

Reduction in efficiency (%)	Description
0 % Reduction in efficiency	Excellent
25 % Reduction in efficiency	Average
50 % Reduction in efficiency	Bad
75 % Reduction in efficiency	Critical
Not available	N/A

3.4.3.1 The Turbine’s efficiency

Like all infrastructure, the turbine’s efficiency decreases over time, however there is an acceptable rate of efficiency reduction over time. The turbine’s efficiencies are commonly calculated by the index test which compares the rate of opening against the output, and these efficiencies are then compared to the original efficiency tests of the turbines. However, these comparisons can only be conducted if old operational records exist. Leyland (2014) also noted that the efficiency of a turbine could decrease by 2% with the slightest damage on the runners of the turbines.

3.4.3.2 The Generator's efficiency

According to Gummer *et al.* (1993) the generator's efficiency could be increased by up to 25 % due to modern insulation materials. Thus, the insulation material should be inspected to determine the efficiency of the generator.

3.4.3.3 The Penstock efficiency

A reduction in penstock efficiency could be observed due to secondary and friction loss increases, caused by cavitation or biofilm growth in the pipeline. Blockages at the intake structure cause restriction in flow towards the turbine, resulting in hydropower efficiency decreases.

3.4.4 AGE ASSESSMENT

Deterioration of infrastructure is observed over time, which is also the case with a hydropower station. Infrastructure is commonly designed for a certain design life and after that major maintenance would be required to restore the infrastructure and extend its life. Thus, all the components making up a hydropower plant have different design life's (Table 2-20) and require maintenance at different stages. Commonly a hydropower plant is known to have a design life of 30 years, after which maintenance is required to ensure that the hydropower plant is operational for another 30 years. The evaluation criteria for the age assessment is given in Table 3-6.

Table 3-6: Age Assessment Criteria

Age	Description
<< expected useful life	No attention required (Excellent)
<= expected useful life	Requires attention (Good)
> expected useful life	Requires full assessment and attention with possible replacement (Bad)
Not available	N/A

3.4.5 TECHNOLOGICAL ADVANCEMENT

Technology is constantly changing over time. The new generation of generators and turbines are improved resulting in higher efficiencies. Table 3-7 indicates the technological advancement criteria.

Table 3-7: Technological Advancement Scoring Criteria

Technology Advancement	Description
Advanced	No attention required (Excellent)
Modern	Upgrading might be required (Good)
Ancient	Critical – requires urgent attention
Not available	N/A

3.4.5.1 Turbine technology

The turbine technology has improved significantly over the years, changing from low to high oil pressure systems, and from mechanical or electro-hydraulic governors to modern electronic ones. The coating systems of the turbines and draft tubes have also been improved to counter cavitation and erosion effects, thus improving the overall efficiency and accuracy of the turbines (Gummer *et al*., 1993).

3.4.5.2 Generator technology

Improvements in efficiency and reliability have been noted in cases where new insulation materials as well as improved design and construction technologies have been used in a generator's stator coils. The state and type of generator insulation needs to be determined since ancient insulation materials could be replaced by modern technologies to improve the generator's performance level.

3.4.5.3 Excitation system technology

The excitation system is commonly replaced by modern technologies in cases where the maintenance cost of the existing excitation system is too expensive.

3.4.6 PLANT LOCATION ASSESSMENT

The location of the plant plays an important role during the determination process of whether to refurbish, renew or replace an existing hydropower plant. Both the local capacity as well as the approach roads are evaluated during this assessment. Table 3-8 indicates the assessment criteria utilised for the plant location.

Table 3-8: Plant Location Assessment Criteria

Location	Description
Optimal location with locally available skills & suppliers	Good
Location of plant & locally available skills are average	Average
No optimal location & no local skills available	Bad
Not available	N/A

3.4.6.1 Local Capacity

The situation of the hydropower station should be assessed in terms of the optimal location for the hydropower station as well as the skills required for the refurbishment, renewal or replacement of the hydropower plant. Operation and maintenance staff's competency should also be evaluated to ensure they can operate and maintain the hydropower station over its life span.

3.4.6.2 Approach Roads

The condition of the approach roads need to be assessed, as the condition is important for the planning of the transportation of both the equipment as well as the staff and construction team.

3.4.7 ENVIRONMENTAL IMPACT ASSESSMENT

Hydropower is a renewable source of energy, however if not designed properly hydropower stations could have negative impacts on the environment. These environmental impacts have been discussed in more detail below. The criteria used for the environmental impact assessment can be seen in Table 3-9.

Table 3-9: Scoring Criteria for the Environmental Impact Assessment

Environmental Effect	Description	Scoring criteria
No fish mortality, water quality is good, and no other environmental impacts are visible.	No attention required	Excellent
High fish mortality or bad water quality, and minor visible environmental impacts.	Attention required	Good
High fish mortality, bad water quality and major visible environmental impacts.	Requires full attention	Bad
Not available	Not available	N/A

3.4.7.1 Turbine environmental impacts

The fish mortality impact due to the turbine as well as the grease lubrication used within the turbine needs to be evaluated. In modern turbines self-lubrication bushes are utilised which limit the impacts on the environment.

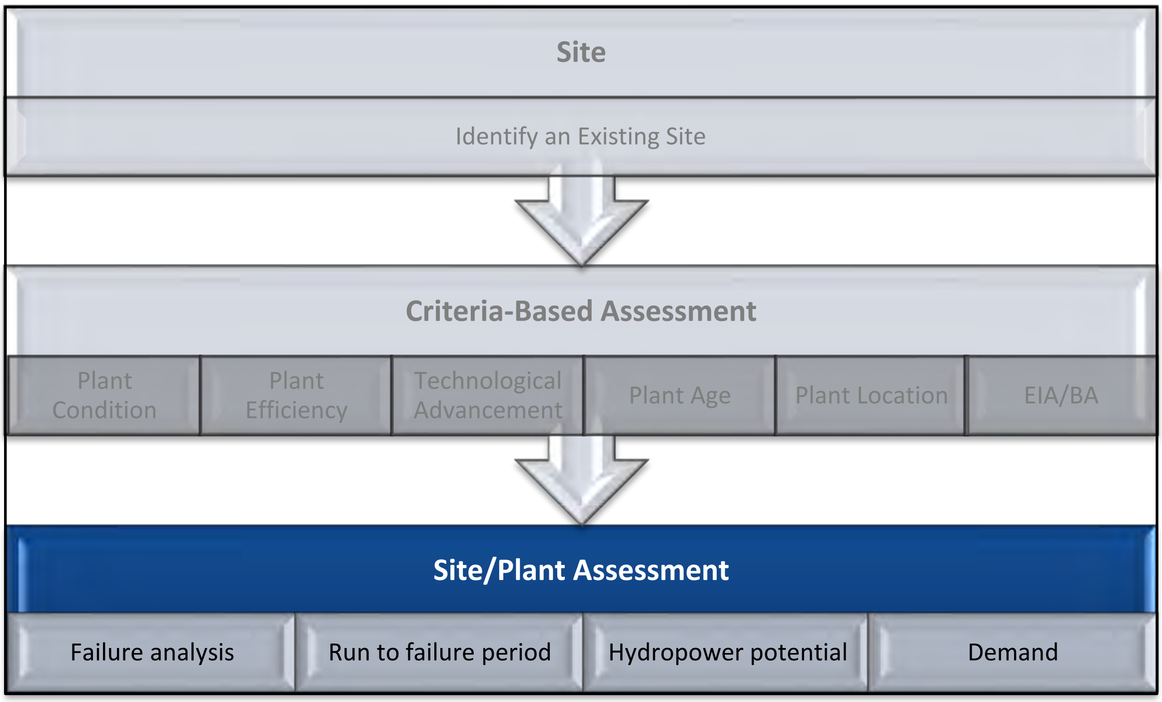
3.4.7.2 Water Quality

The water quality is an important factor for both the environment as well as the turbines. Bad water quality has a negative impact on the aquatic life which is commonly determined by the amount of dissolved oxygen content. In cases where the water contains a large amount of silt, the aquatic life decreases and abrasion occurs on the turbine blades. Thus, the water quality should be noted.

3.4.7.3 Environmental impacts at the outlet

As the water exits the turbine, there might still be some energy left in the water. The outlet structure should be designed in such a manner as to accommodate this extra energy and release the water back into the river with the least amount of environmental impacts. Thus, the environmental impacts at the outlet should be evaluated.

3.5 SITE / PLANT ASSESSMENT



A decision cannot be made once the criteria-based assessment has been completed. In some cases, expertise is required to ensure that a justifiable decision is being made by incorporating non-quantifiable criteria assessments such as automated failure analysis, run to failure periods, hydropower potential and power demands.

3.5.1 AUTOMATED FAILURE ANALYSIS

In hydropower plants the critical components are monitored for early faulty indications. These are typically indicated through graphs and/or alarm systems. The results should be evaluated and considered during the consideration on whether to refurbish, replace or renew the hydropower station.

3.5.2 RUN TO FAILURE PERIOD

In hydropower plants some components are relatively easy to be replaced and could be stored on site. These components could thus be run till they fail without major cost implications. However not all components can be stored on site and thus they cannot be run to failure and should be replaced beforehand. The period it takes for the different components to run to failure and their impacts influences the decision to refurbish the hydropower plant.

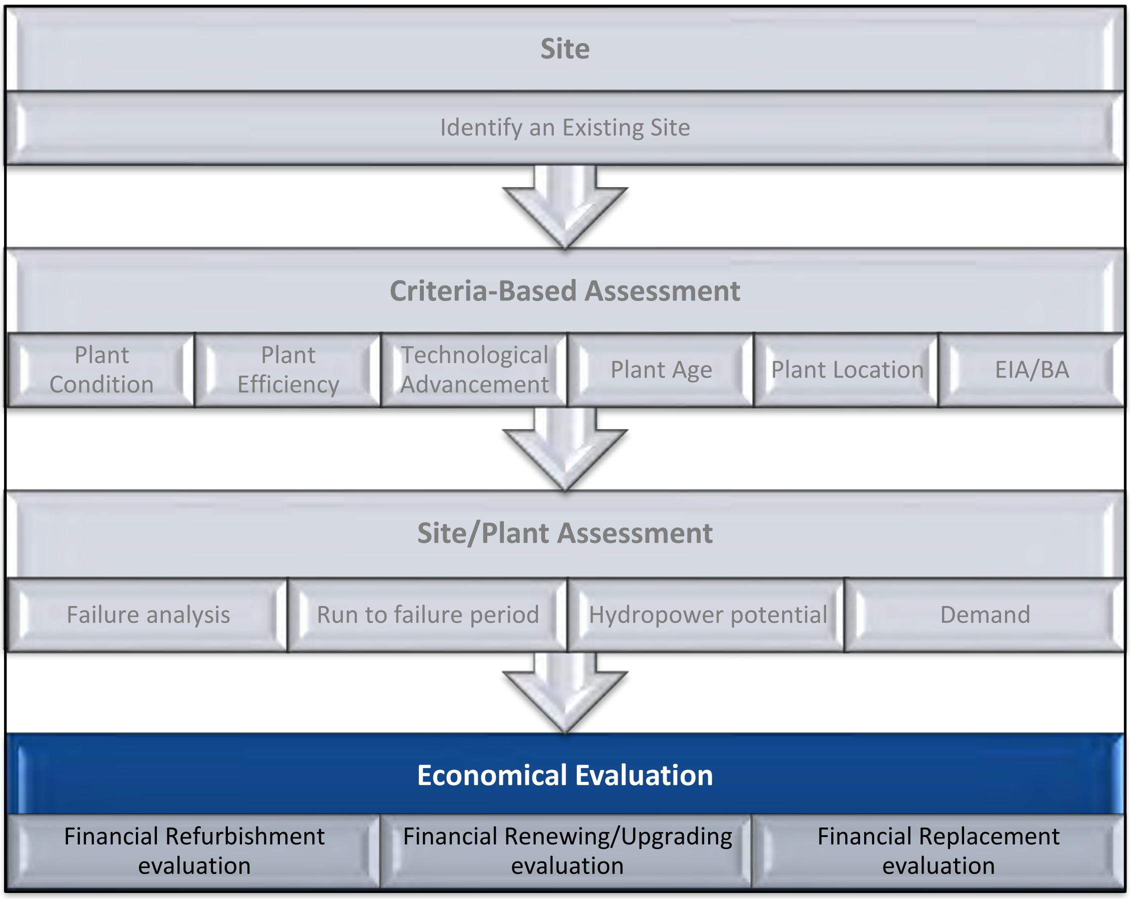
3.5.3 HYDROPOWER POTENTIAL

The hydropower potential should be evaluated by examining the head and flow records. If there is an alternative location which could result with a higher head difference, it might be feasible to replace the hydropower plant with a new one at a different location.

3.5.4 DEMAND

The supply and demand patterns for the given installation should be obtained and studied. There are three possible outcomes: either the supply and demand correlate, or the supply is higher than the demand or vice versa. In the case where the supply and demand correlate, it implies that the selected turbine is sufficient for the hydropower scheme. However, if the supply exceeds the demand, a small turbine could be implemented, or the excess power should be put back into the grid if possible. On the other hand, if the demand exceeds the current supply of the hydropower station, the hydropower plant should be uprated or replaced with a new hydropower plant to ensure that sufficient power is being generated. If this is not possible alternative energy sources should be implemented as well.

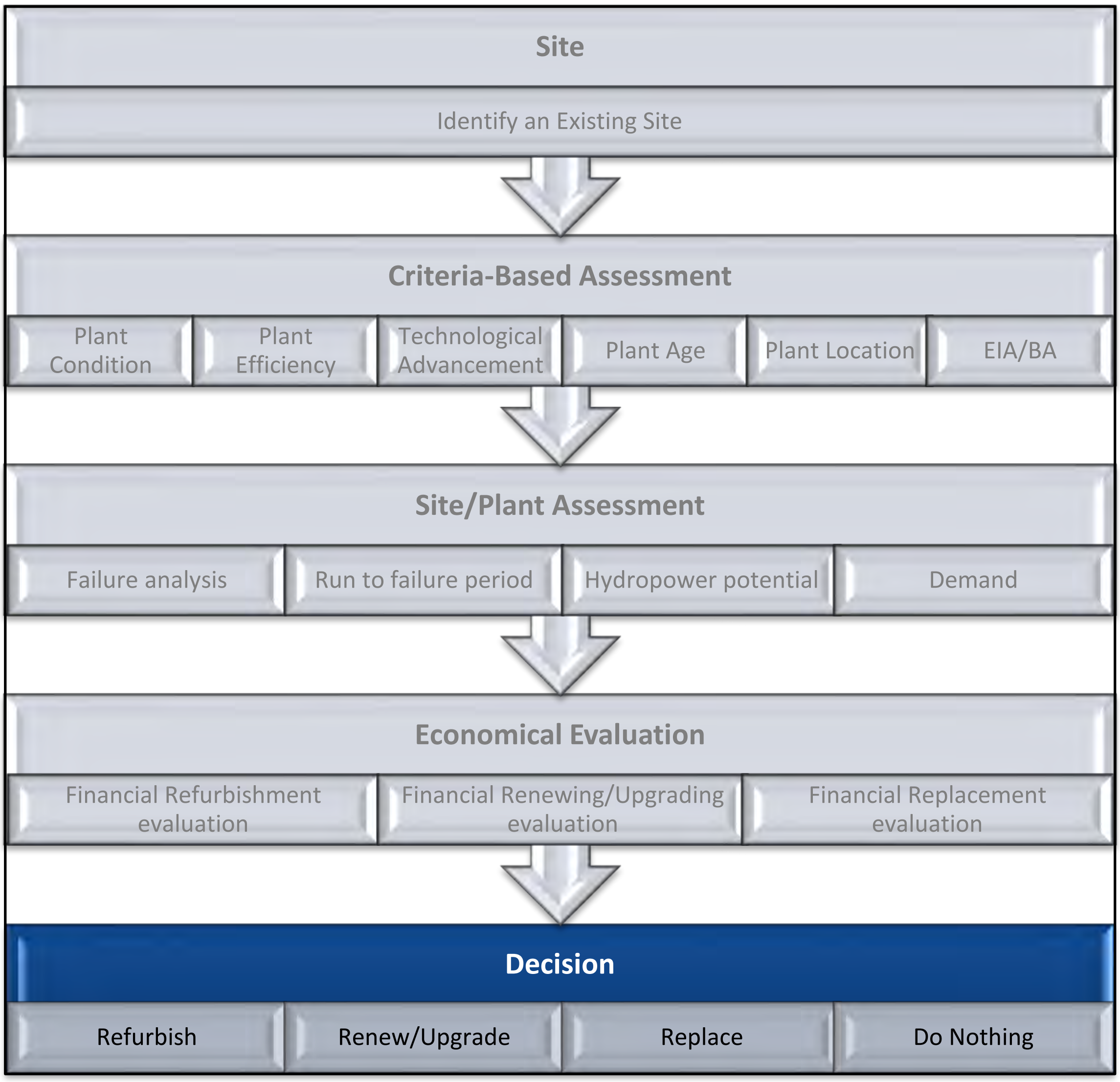
3.6 ECONOMICAL EVALUATION



Once the criteria-based assessment and the judgement and experience assessments have been completed, the economical evaluation can be conducted. Financial evaluation techniques such as the net present value, internal rate of return and benefit cost ratio have been used as financial indicators for the economical evaluation. The formulas for the different financial evaluation techniques have been indicated in Paragraph 2.15.

During the economic evaluation the payback period for the project may also be determined, however this may not be used as a deciding factor in project selection as it does not supply enough information for a decision in an evaluation tool.

3.7 DECISION



Comparing the above-mentioned criteria, commonly the alternative with the biggest benefit and the lowest cost is chosen. However, in some cases this is not that obvious and thus one has to decide what is important for the given hydropower scheme at hand.

3.7.1 SENSITIVITY ANALYSIS

Numerous assumptions are made during the evaluation process. These assumptions might change unexpectedly during the plant's life thus a sensitivity analysis needs to be conducted. The main assumption which could change unexpectedly is the inflation rates for both the income and the expenses over the years. A sensitivity analysis would have indicated whether the project would still be economically feasible under different circumstances. Both higher and lower values should be used to determine a range of possible internal rates of returns and net present values.

A given risk is associated with the different outcomes. These risks need to be assessed and the decision should be made on whether the risk is acceptable or not.

4 HYDROPOWER DEVELOPMENT ASSISTANCE TOOL (HDAT)

In this chapter the Microsoft Excel-based tool is discussed which is based on the Framework described in Chapter 3.

4.1 REFURBISHMENT, RENEWING OR REPLACING HYDROPOWER STATIONS

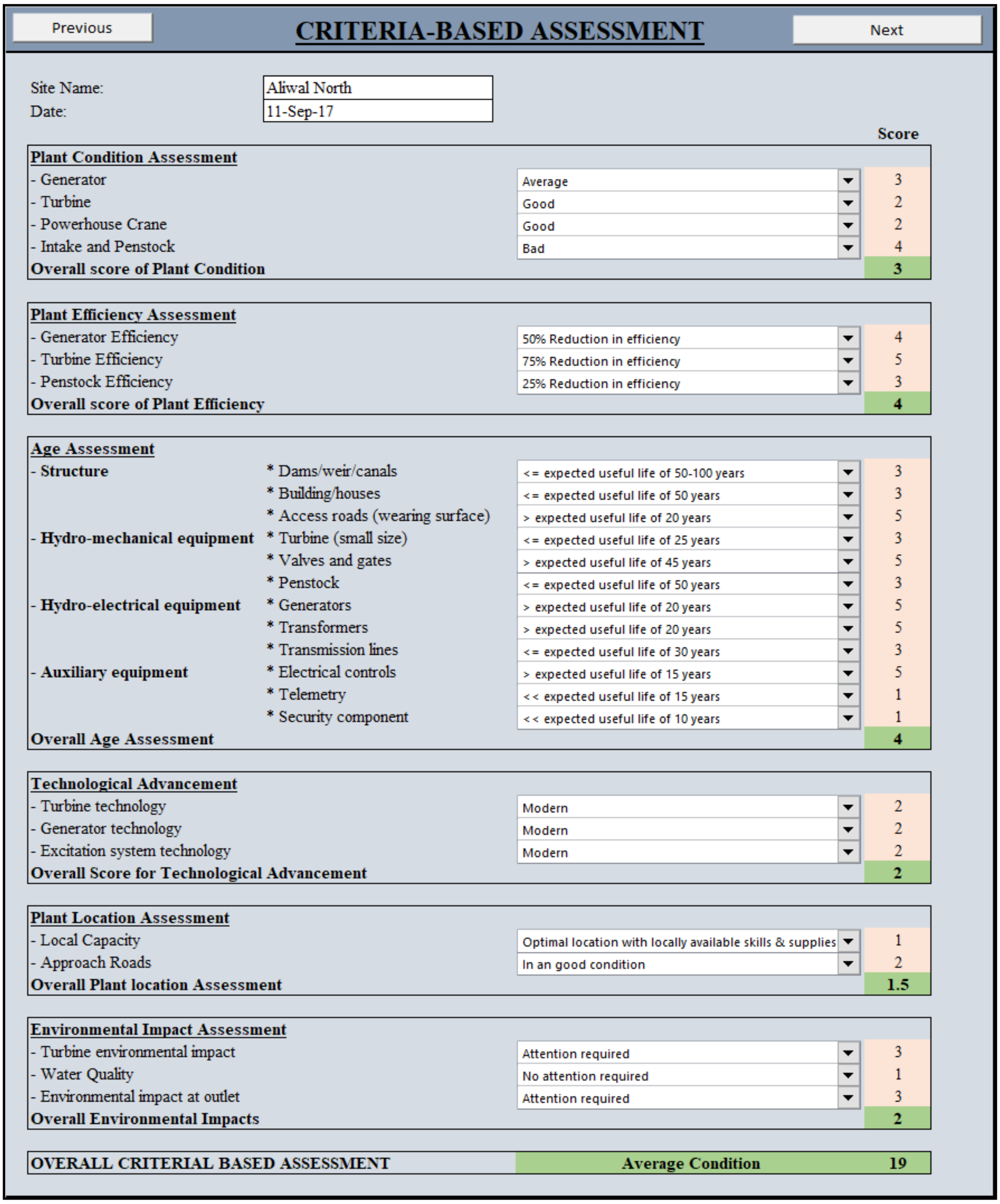
The thought process as well as the calculations are incorporated in the Hydropower Development Assistance Tool (HDAT). The HDAT is in the form of a Microsoft Excel spreadsheet which aims to guide the designers through the process of evaluating existing hydropower stations by including all the relevant calculations in a user-friendly format. The following colour coding (Table 4-1) is used to distinguish between input, output, user entered values as well as default values. The assumptions, equations as well as the derivations of the default values are summarised and discussed in Appendix A.

Table 4-1: Colour Coding Used in the HDAT

Colour coding	Description
White	User input values
Light Pink	Default values, but may be changed by user with better information
Purple	Steps to follow to get necessary information
Light green	Results or calculated output values

4.1.1 THE CRITERIA-BASED ASSESSMENT

The Criteria Based Assessment section is shown in Figure 4-1. For this section it is required to evaluate the existing hydropower station accordingly. The output of this section is the overall condition of the exiting hydropower plant as well as the critical component of the plant that requires immediate attention.



CRITERIA-BASED ASSESSMENT

Site Name: Aliwal North
Date: 11-Sep-17

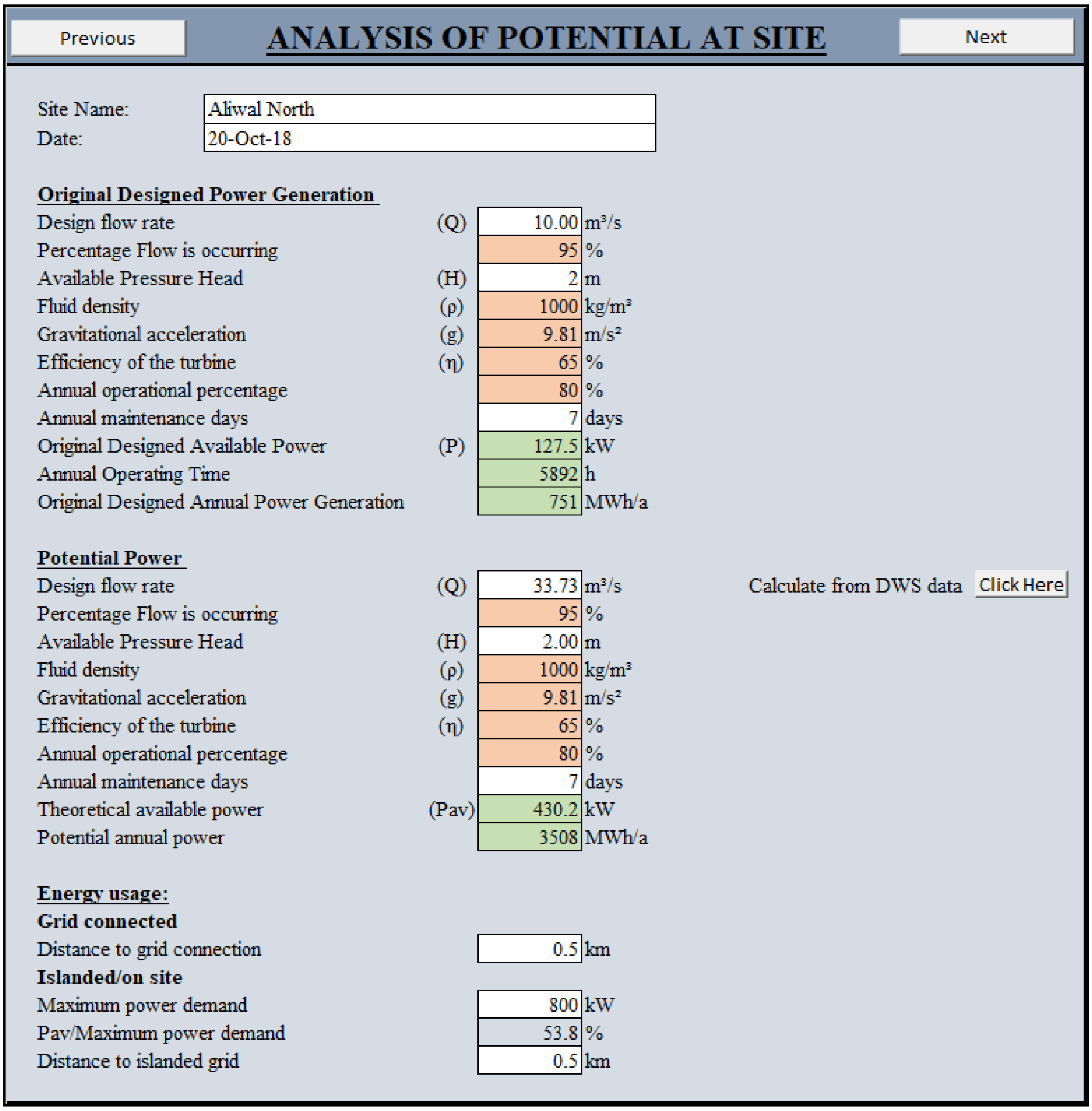
			Score
Plant Condition Assessment			
- Generator		Average	3
- Turbine		Good	2
- Powerhouse Crane		Good	2
- Intake and Penstock		Bad	4
Overall score of Plant Condition			**3**
Plant Efficiency Assessment			
- Generator Efficiency		50% Reduction in efficiency	4
- Turbine Efficiency		75% Reduction in efficiency	5
- Penstock Efficiency		25% Reduction in efficiency	3
Overall score of Plant Efficiency			**4**
Age Assessment			
- **Structure**	* Dams/weir/canals	<= expected useful life of 50-100 years	3
	* Building/houses	<= expected useful life of 50 years	3
	* Access roads (wearing surface)	> expected useful life of 20 years	5
- **Hydro-mechanical equipment**	* Turbine (small size)	<= expected useful life of 25 years	3
	* Valves and gates	> expected useful life of 45 years	5
	* Penstock	<= expected useful life of 50 years	3
- **Hydro-electrical equipment**	* Generators	> expected useful life of 20 years	5
	* Transformers	> expected useful life of 20 years	5
	* Transmission lines	<= expected useful life of 30 years	3
- **Auxiliary equipment**	* Electrical controls	> expected useful life of 15 years	5
	* Telemetry	<< expected useful life of 15 years	1
	* Security component	<< expected useful life of 10 years	1
Overall Age Assessment			**4**
Technological Advancement			
- Turbine technology		Modern	2
- Generator technology		Modern	2
- Excitation system technology		Modern	2
Overall Score for Technological Advancement			**2**
Plant Location Assessment			
- Local Capacity		Optimal location with locally available skills & supplies	1
- Approach Roads		In an good condition	2
Overall Plant location Assessment			**1.5**
Environmental Impact Assessment			
- Turbine environmental impact		Attention required	3
- Water Quality		No attention required	1
- Environmental impact at outlet		Attention required	3
Overall Environmental Impacts			**2**

OVERALL CRITERIAL BASED ASSESSMENT	**Average Condition**	**19**

Figure 4-1: Criteria-Based Assessment

4.1.2 SITE / PLANT ASSESSMENT

The site and plant should be assessed in terms of its components and its supply vs demand. The hydropower potential at a given site can be calculated by the HDAT (Figure 4-2). It is required by the user to specify the available flow rate, pressure head and annual maintenance days. The resulting output and the annual power generation will be determined automatically. The fluid density, gravitational acceleration, turbine efficiency and operational percentage are default values, however if the user has more accurate values they may be changed.



ANALYSIS OF POTENTIAL AT SITE

Site Name: Aliwal North
Date: 20-Oct-18

Original Designed Power Generation

Design flow rate	(Q)	10.00	m³/s
Percentage Flow is occurring		95	%
Available Pressure Head	(H)	2	m
Fluid density	(ρ)	1000	kg/m³
Gravitational acceleration	(g)	9.81	m/s²
Efficiency of the turbine	(η)	65	%
Annual operational percentage		80	%
Annual maintenance days		7	days
Original Designed Available Power	(P)	127.5	kW
Annual Operating Time		5892	h
Original Designed Annual Power Generation		751	MWh/a

Potential Power

Calculate from DWS data

Design flow rate	(Q)	33.73	m³/s
Percentage Flow is occurring		95	%
Available Pressure Head	(H)	2.00	m
Fluid density	(ρ)	1000	kg/m³
Gravitational acceleration	(g)	9.81	m/s²
Efficiency of the turbine	(η)	65	%
Annual operational percentage		80	%
Annual maintenance days		7	days
Theoretical available power	(Pav)	430.2	kW
Potential annual power		3508	MWh/a

Energy usage:

Grid connected

Distance to grid connection	0.5	km

Islanded/on site

Maximum power demand	800	kW
Pav/Maximum power demand	53.8	%
Distance to islanded grid	0.5	km

Figure 4-2: Analysis of Hydropower Potential at the Given Site

The available flow rate could be determined by inserting the flow records with their corresponding pressure head of the site into the HDAT (Figure 4-3). It must be noted that the data does not have to be sorted however all data gaps should be removed. A maximum of 1350 data points are accepted by the HDAT.

Four different options can be chosen for the available flow rate. These options rates are as follows:

a. Optimum flow rate is the flow rate resulting in the highest power generation;
b. Average flow rate is the average flow obtained from the raw data or flow records;
c. Chosen flow rate is the flow rate that the user can specify in terms of flow and head;
d. The assurance flow rate is the specific percentage of time when energy production is required and is commonly taken as 95 % (as mentioned in Paragraph 2.3.1).

The user can choose which flow rate should be used in the design of the hydropower plant, however most commonly the assurance flow rate of 95 % is used.

FLOW DATA AND POTENTIAL ANALYSIS

Site Name: Aliwal North
Date: 11-Sep-17

General Input

Fluid density	(ρ)	1000	kg/m^3
Gravitational accelerati	(g)	9.81	m/s^2
Efficiency	(η)	65	%
Annual maintenance days		7	days

Statistical Analysis of the Hydrological data

Gauging weir		D1H003	
Mean flow rate		486	m^3/s
Standard Deviation		699	m^3/s
Maximum flow rate		6348	m^3/s
Minimum flow rate		0	m^3/s
95%	of flow rate	33.73	m^3/s
95%	of flow rate	33.73	m^3/s

Flow rating curve	Load factor (%)	Flow (m^3/s)	Available head (m)	Time in use (h)	Power rating (kW)	Potential power (MWh/a)	Potential power for optimum use (MWh)
	100%	2.78	2	8592	35.4	304.53	106.59
	95%	33.73	2	8154	430.2	3507.70	1293.64
	90%	54.59	2	7716	696.2	5372.21	2093.74
	85%	74.73	2	7278	953.0	6936.12	2865.94
	80%	96.59	2	6840	1231.8	8425.27	3704.16
	75%	119.59	2	6402	1525.1	9763.94	4586.40
	70%	140.65	2	5964	1793.7	10697.59	5394.00
	65%	173.66	2	5526	2214.7	12238.26	6659.95
	60%	201.72	2	5088	2572.5	13088.98	7736.08
	55%	234.14	2	4650	2985.9	13884.61	8979.31
	50%	276.69	2	4212	3528.7	14862.80	10611.45
	45%	321.03	2	3774	4094.2	15451.33	12311.93
	40%	368.42	2	3336	4698.5	15674.06	14129.21
	35%	424.67	2	2898	5415.9	15695.21	16286.62
	30%	499.80	2	2460	6374.0	15680.06	16286.62
	25%	567.93	2	2022	7242.8	14644.89	16286.62
	20%	656.35	2	1584	8370.4	13258.66	16286.62
	15%	796.07	2	1146	10152.3	11634.52	16286.62
	10%	1019.30	2	708	12999.1	9203.38	16286.62
	5%	1631.80	2	270	20810.4	5618.80	16286.62
	0%	6348.28	2	0	80959.6	0.00	16286.62
Optimum Flow	35%	424.67	2	2898	5415.9	15695.2	16286.62
Average Flow		484	1.12	8592	3469.4	29809.1	
Chosen Flow		2.2	2.1	8592	29.5	253.1	
Assurance Flow	95%	33.73	2	8154	430.2	3507.7	
Design Flow	95%	33.73	2.00	8154.0	430.2	3507.7	

Open Department of water affairs website: https://www.dwa.gov.za/Hydrology/Verified/hymain.aspx
Select the drainage region
Select the Station Number
Open the monthly Flood Peak data
Copy data into here - Please remove all the empty cells

Date	Time of Peak	Level at Peak (m)	Peak Flow (cumec)	
19140124	08:00	0.165	41.2	M
19140221	08:00	0.189	47.7	$
19140325	08:00	0.342	92.2	$
19140405	08:00	0.442	124.2	$
19140501	00:00	0.13	31.9	$
19140601	00:00	0.07	16.7	$
19140701	08:00	0.037	8.7	$
19140820	08:00	0.137	33.7	$
19140918	08:00	0.113	27.5	$
19141028	08:00	0.646	196.1	$
19141128	08:00	1.18	424.7	$
19141205	08:00	1.789	750.4	$
19150127	12:00	1.994	874.1	$
19150220	08:00	2.222	1019.3	$
19150301	00:00	0.612	183.5	$
19150407	08:00	0.165	41.2	$
19150521	08:00	0.366	99.7	$
19150601	00:00	0.061	14.5	$
19150720	08:00	0.089	21.4	$
19150831	23:59	0.14	34.5	$
19150901	08:00	0.165	41.2	$
19151031	08:00	1.128	400.0	$
19151128	08:00	1.408	539.0	$
19151201	00:00	1.086	380.4	$
19160118	08:00	1.052	364.8	$
19160228	08:00	0.671	205.5	$

Figure 4-3: Flow Data and Potential Analysis

Various graphs are generated which include the flow rating curve, the instantaneous potential energy curve, the optimum percentage use curve and the flow versus head curve, as seen in Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7 respectively. A turbine selection curve is also obtained during this section as seen in Figure 4-8. The user could add more turbines as shown on Figure 4-8.

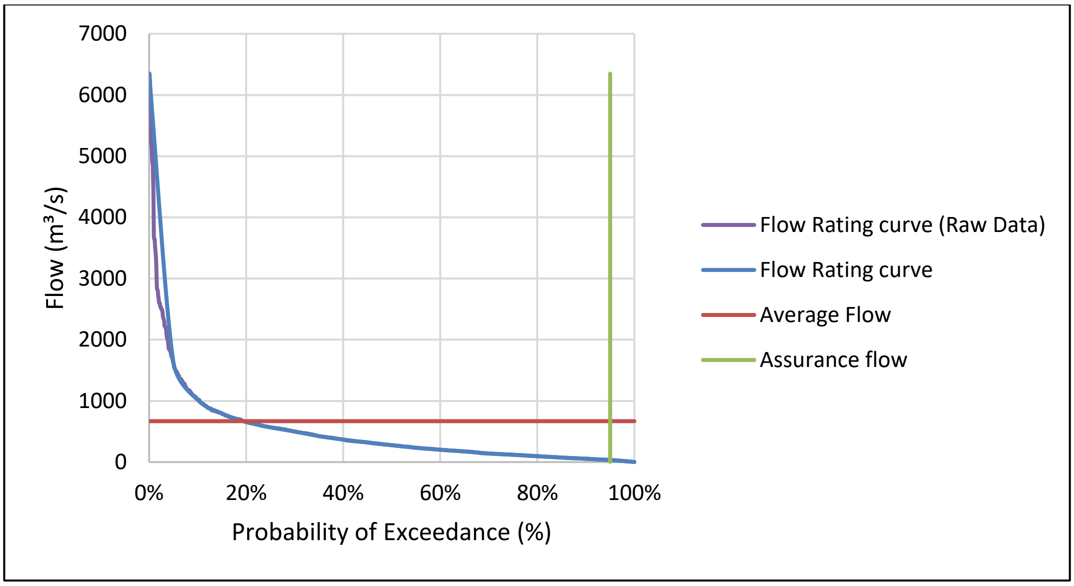


Figure 4-4: Flow Rating Curve

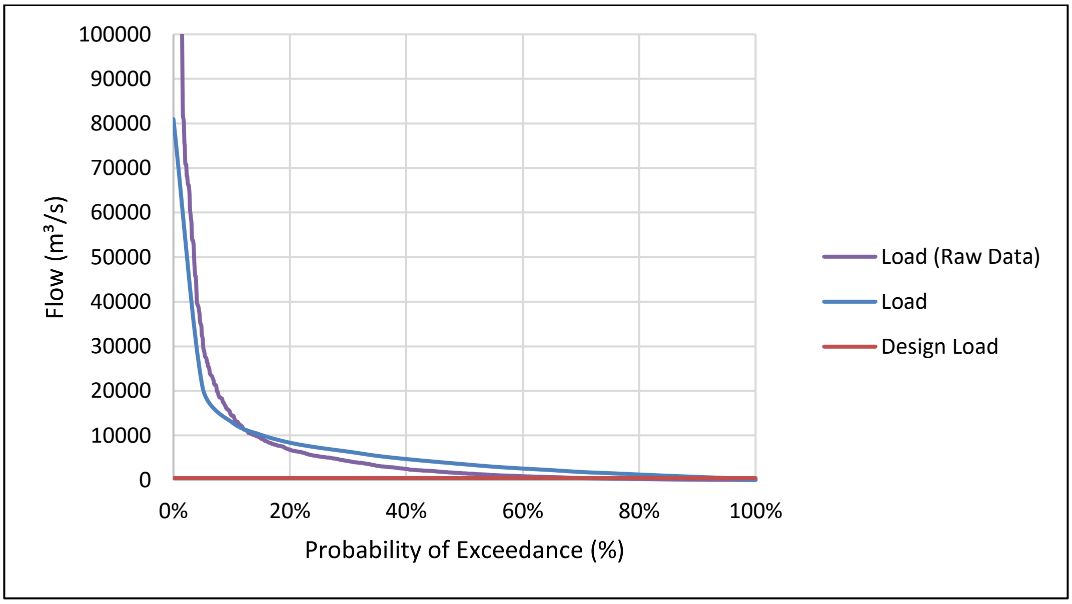


Figure 4-5: Instantaneous Potential Energy

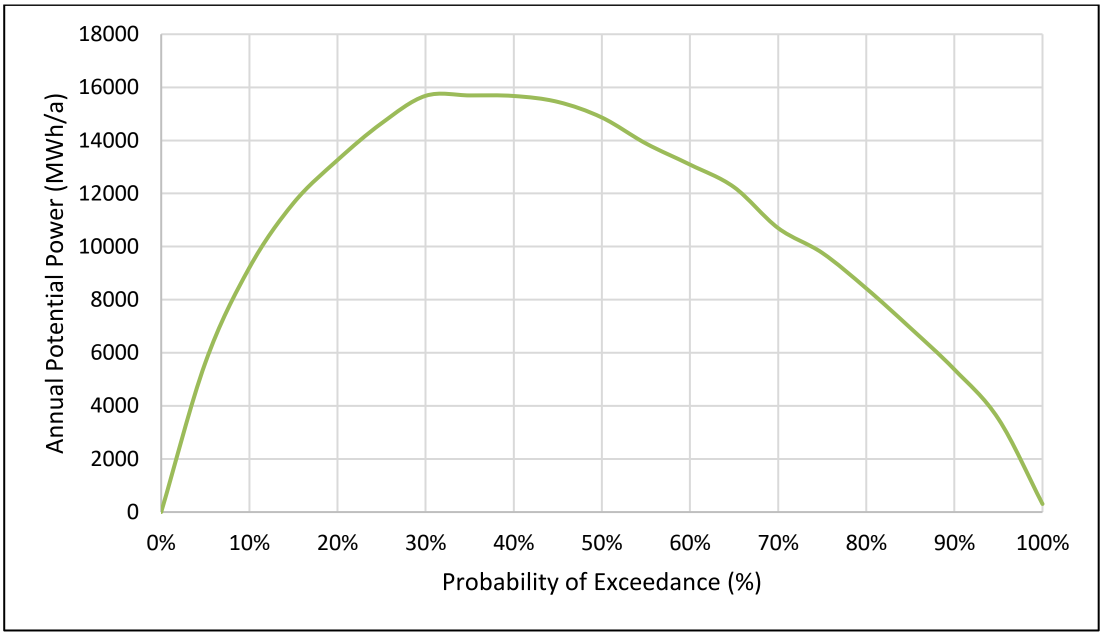


Figure 4-6: Optimum Percentage Use

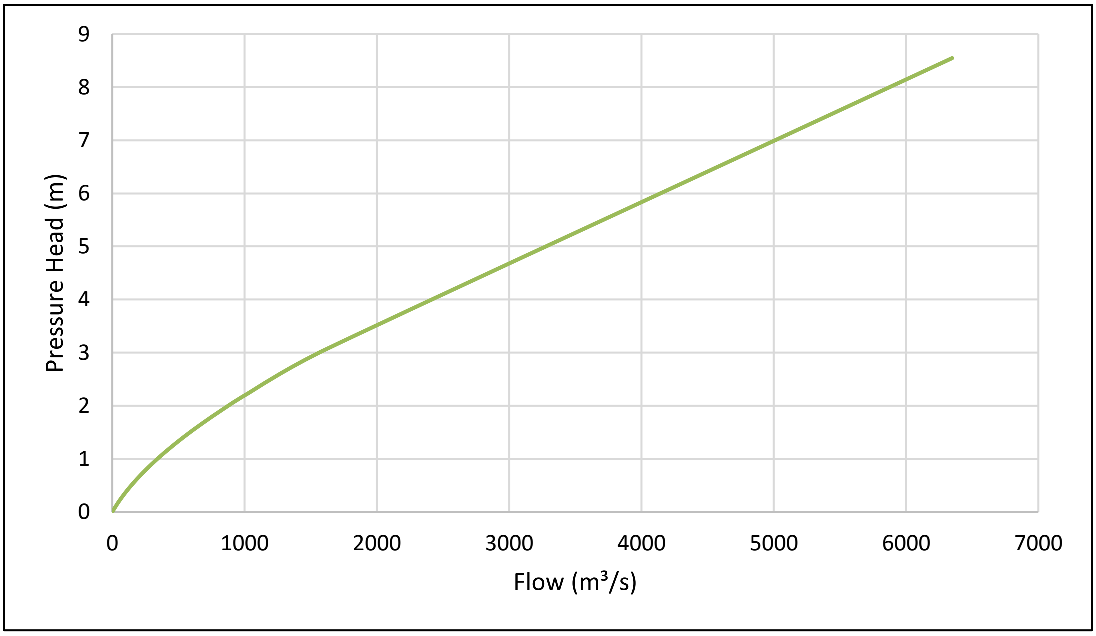


Figure 4-7: Flow versus Head

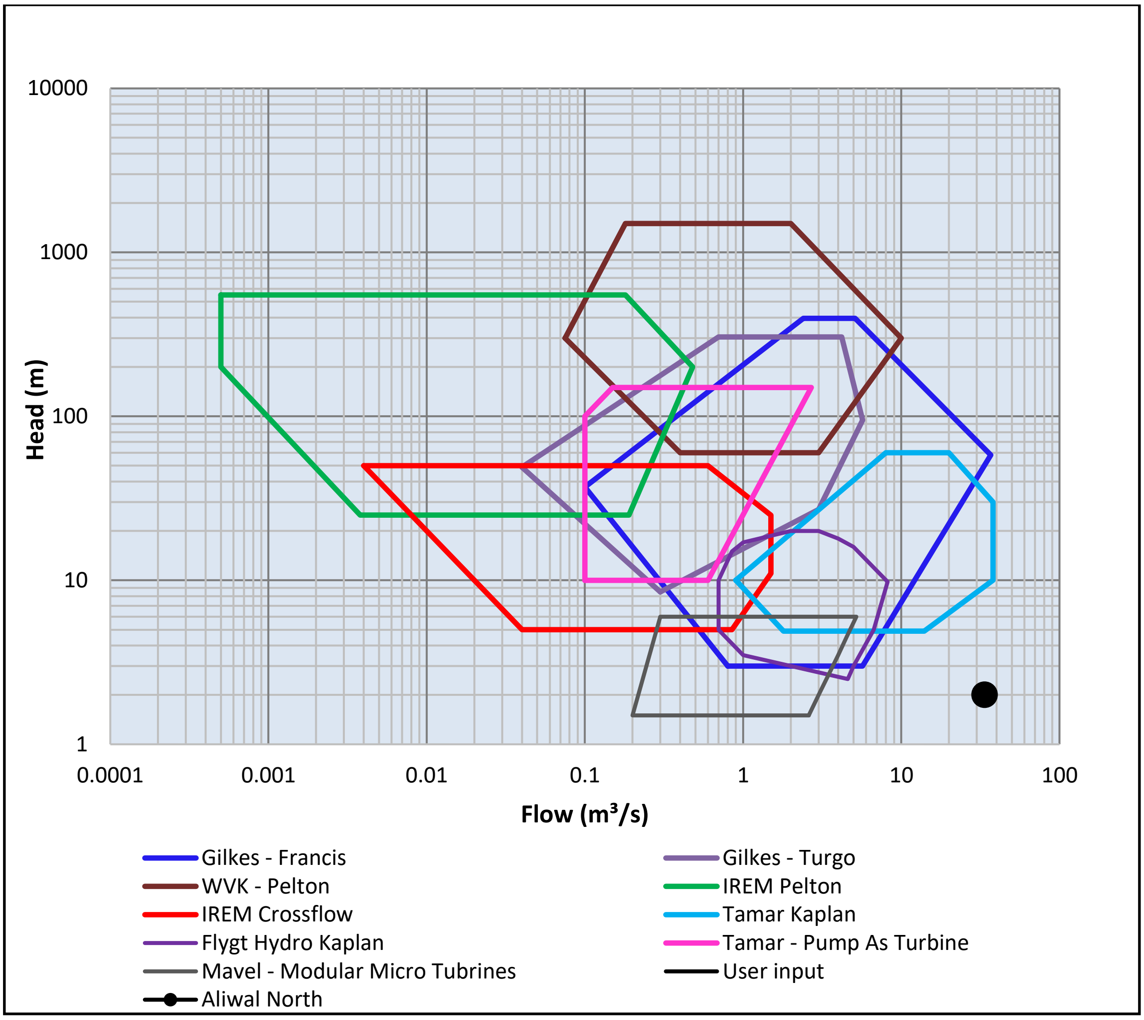
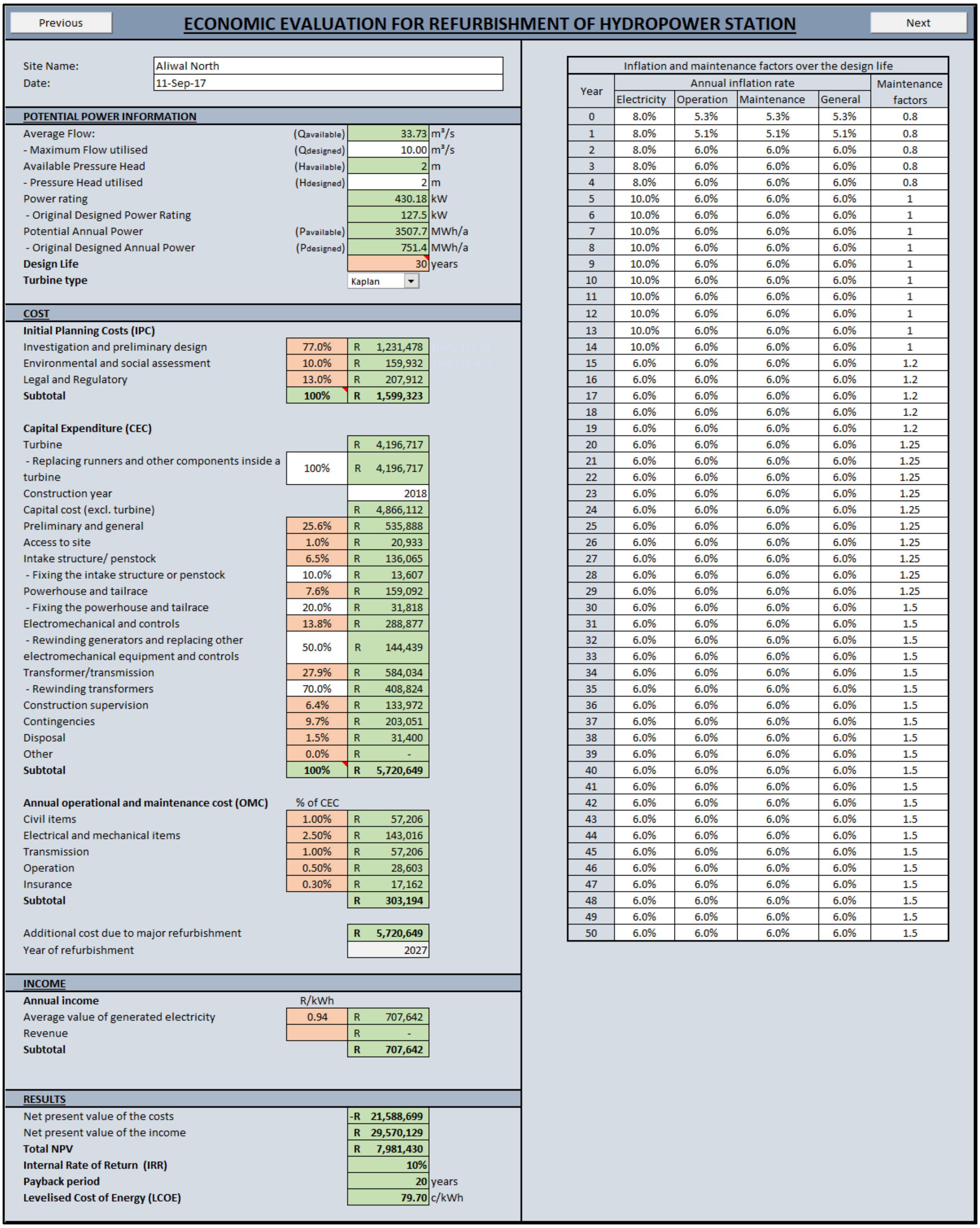


Figure 4-8: Turbine Selection

4.1.3 THE ECONOMIC EVALUATION

Default formulas were used in the Economic Evaluation Section. The formulas and their derivations are presented in Appendix A. However, information regarding the type of turbine to be installed and the design life of the hydropower plant need to be specified by the user. The given inflation rates are estimates but can be adjusted by the user accordingly. In the case of refurbishment and renewal of a hydropower plant, the user can estimate the costs of replacing components by providing the percentages with respect to the overall component costs. An example of the refurbishment section can be seen in Figure 4-9. A summary of the Refurbishment, Renewal and Replacement Economic Evaluations can be seen in Figure 4-10.



ECONOMIC EVALUATION FOR REFURBISHMENT OF HYDROPOWER STATION

Site Name:	Aliwal North
Date:	11-Sep-17

POTENTIAL POWER INFORMATION

Average Flow:	$(Q_{available})$	33.73	m^3/s
- Maximum Flow utilised	$(Q_{designed})$	10.00	m^3/s
Available Pressure Head	$(H_{available})$	2	m
- Pressure Head utilised	$(H_{designed})$	2	m
Power rating		430.18	kW
- Original Designed Power Rating		127.5	kW
Potential Annual Power	$(P_{available})$	3507.7	MWh/a
- Original Designed Annual Power	$(P_{designed})$	751.4	MWh/a
Design Life		30	years
Turbine type		Kaplan ▾	

COST

Initial Planning Costs (IPC)			
Investigation and preliminary design	77.0%	R 1,231,478	10662151.01
Environmental and social assessment	10.0%	R 159,932	1599322.652
Legal and Regulatory	13.0%	R 207,912	
Subtotal	**100%**	**R 1,599,323**	

Capital Expenditure (CEC)		
Turbine		R 4,196,717
- Replacing runners and other components inside a turbine	100%	R 4,196,717
Construction year		2018
Capital cost (excl. turbine)		R 4,866,112
Preliminary and general	25.6%	R 535,888
Access to site	1.0%	R 20,933
Intake structure/ penstock	6.5%	R 136,065
- Fixing the intake structure or penstock	10.0%	R 13,607
Powerhouse and tailrace	7.6%	R 159,092
- Fixing the powerhouse and tailrace	20.0%	R 31,818
Electromechanical and controls	13.8%	R 288,877
- Rewinding generators and replacing other electromechanical equipment and controls	50.0%	R 144,439
Transformer/transmission	27.9%	R 584,034
- Rewinding transformers	70.0%	R 408,824
Construction supervision	6.4%	R 133,972
Contingencies	9.7%	R 203,051
Disposal	1.5%	R 31,400
Other	0.0%	R -
Subtotal	**100%**	**R 5,720,649**

Annual operational and maintenance cost (OMC)	% of CEC	
Civil items	1.00%	R 57,206
Electrical and mechanical items	2.50%	R 143,016
Transmission	1.00%	R 57,206
Operation	0.50%	R 28,603
Insurance	0.30%	R 17,162
Subtotal		**R 303,194**

Additional cost due to major refurbishment	**R 5,720,649**
Year of refurbishment	2027

INCOME

Annual income	R/kWh	
Average value of generated electricity	0.94	R 707,642
Revenue		R -
Subtotal		**R 707,642**

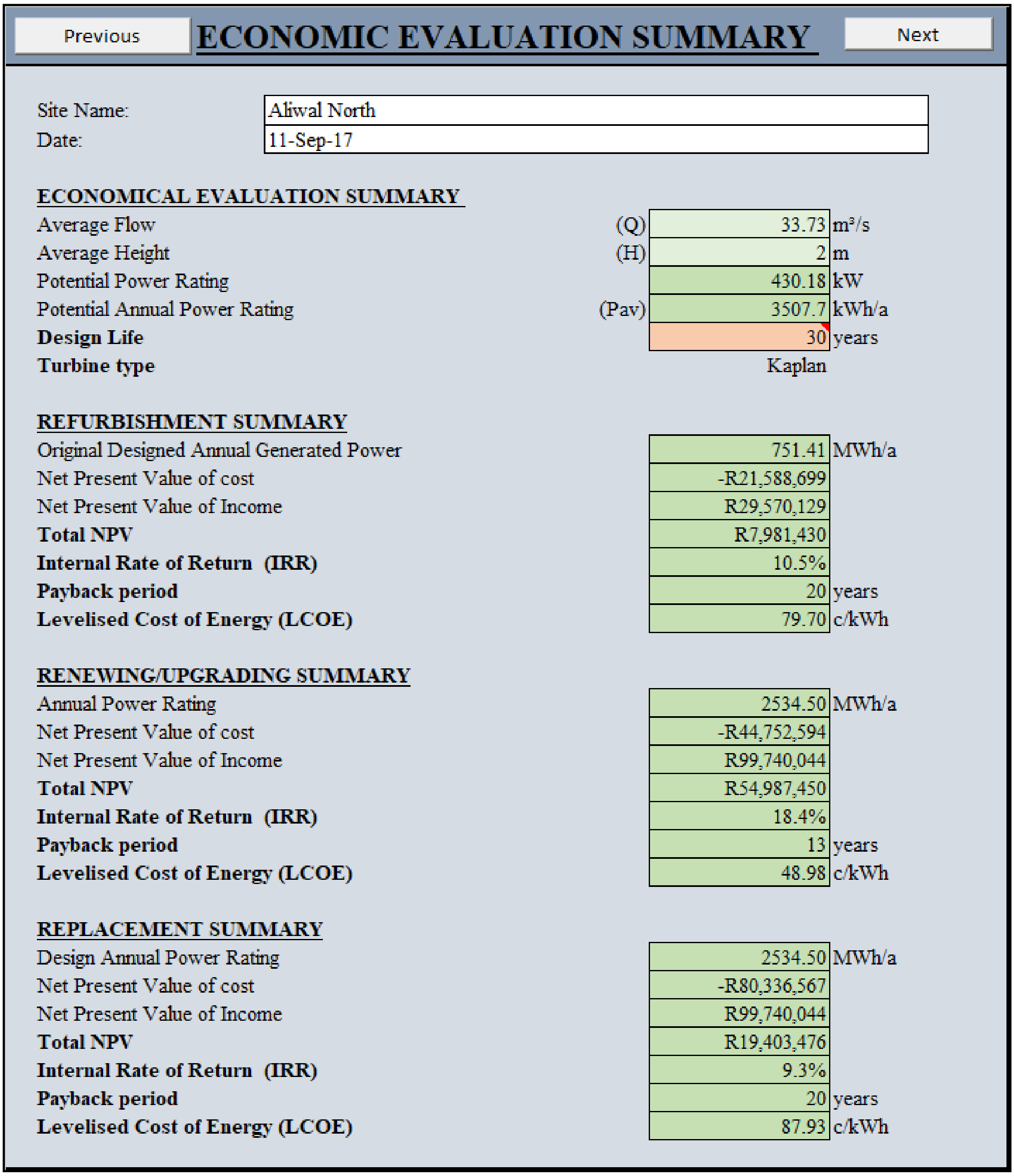
RESULTS

Net present value of the costs	**-R 21,588,699**	
Net present value of the income	**R 29,570,129**	
Total NPV	**R 7,981,430**	
Internal Rate of Return (IRR)	**10%**	
Payback period	**20**	years
Levelised Cost of Energy (LCOE)	**79.70**	c/kWh

Inflation and maintenance factors over the design life

Year	Annual inflation rate				Maintenance factors
	Electricity	Operation	Maintenance	General	
0	8.0%	5.3%	5.3%	5.3%	0.8
1	8.0%	5.1%	5.1%	5.1%	0.8
2	8.0%	6.0%	6.0%	6.0%	0.8
3	8.0%	6.0%	6.0%	6.0%	0.8
4	8.0%	6.0%	6.0%	6.0%	0.8
5	10.0%	6.0%	6.0%	6.0%	1
6	10.0%	6.0%	6.0%	6.0%	1
7	10.0%	6.0%	6.0%	6.0%	1
8	10.0%	6.0%	6.0%	6.0%	1
9	10.0%	6.0%	6.0%	6.0%	1
10	10.0%	6.0%	6.0%	6.0%	1
11	10.0%	6.0%	6.0%	6.0%	1
12	10.0%	6.0%	6.0%	6.0%	1
13	10.0%	6.0%	6.0%	6.0%	1
14	10.0%	6.0%	6.0%	6.0%	1
15	6.0%	6.0%	6.0%	6.0%	1.2
16	6.0%	6.0%	6.0%	6.0%	1.2
17	6.0%	6.0%	6.0%	6.0%	1.2
18	6.0%	6.0%	6.0%	6.0%	1.2
19	6.0%	6.0%	6.0%	6.0%	1.2
20	6.0%	6.0%	6.0%	6.0%	1.25
21	6.0%	6.0%	6.0%	6.0%	1.25
22	6.0%	6.0%	6.0%	6.0%	1.25
23	6.0%	6.0%	6.0%	6.0%	1.25
24	6.0%	6.0%	6.0%	6.0%	1.25
25	6.0%	6.0%	6.0%	6.0%	1.25
26	6.0%	6.0%	6.0%	6.0%	1.25
27	6.0%	6.0%	6.0%	6.0%	1.25
28	6.0%	6.0%	6.0%	6.0%	1.25
29	6.0%	6.0%	6.0%	6.0%	1.25
30	6.0%	6.0%	6.0%	6.0%	1.5
31	6.0%	6.0%	6.0%	6.0%	1.5
32	6.0%	6.0%	6.0%	6.0%	1.5
33	6.0%	6.0%	6.0%	6.0%	1.5
34	6.0%	6.0%	6.0%	6.0%	1.5
35	6.0%	6.0%	6.0%	6.0%	1.5
36	6.0%	6.0%	6.0%	6.0%	1.5
37	6.0%	6.0%	6.0%	6.0%	1.5
38	6.0%	6.0%	6.0%	6.0%	1.5
39	6.0%	6.0%	6.0%	6.0%	1.5
40	6.0%	6.0%	6.0%	6.0%	1.5
41	6.0%	6.0%	6.0%	6.0%	1.5
42	6.0%	6.0%	6.0%	6.0%	1.5
43	6.0%	6.0%	6.0%	6.0%	1.5
44	6.0%	6.0%	6.0%	6.0%	1.5
45	6.0%	6.0%	6.0%	6.0%	1.5
46	6.0%	6.0%	6.0%	6.0%	1.5
47	6.0%	6.0%	6.0%	6.0%	1.5
48	6.0%	6.0%	6.0%	6.0%	1.5
49	6.0%	6.0%	6.0%	6.0%	1.5
50	6.0%	6.0%	6.0%	6.0%	1.5

Figure 4-9: Economic Evaluation for the Refurbishment of the Hydropower Station



ECONOMIC EVALUATION SUMMARY

Site Name: Aliwal North
Date: 11-Sep-17

ECONOMICAL EVALUATION SUMMARY

Average Flow	(Q)	33.73	m^3/s
Average Height	(H)	2	m
Potential Power Rating		430.18	kW
Potential Annual Power Rating	(Pav)	3507.7	kWh/a
Design Life		30	years
Turbine type		Kaplan	

REFURBISHMENT SUMMARY

Original Designed Annual Generated Power	751.41	MWh/a
Net Present Value of cost	-R21,588,699	
Net Present Value of Income	R29,570,129	
Total NPV	R7,981,430	
Internal Rate of Return (IRR)	10.5%	
Payback period	20	years
Levelised Cost of Energy (LCOE)	79.70	c/kWh

RENEWING/UPGRADING SUMMARY

Annual Power Rating	2534.50	MWh/a
Net Present Value of cost	-R44,752,594	
Net Present Value of Income	R99,740,044	
Total NPV	R54,987,450	
Internal Rate of Return (IRR)	18.4%	
Payback period	13	years
Levelised Cost of Energy (LCOE)	48.98	c/kWh

REPLACEMENT SUMMARY

Design Annual Power Rating	2534.50	MWh/a
Net Present Value of cost	-R80,336,567	
Net Present Value of Income	R99,740,044	
Total NPV	R19,403,476	
Internal Rate of Return (IRR)	9.3%	
Payback period	20	years
Levelised Cost of Energy (LCOE)	87.93	c/kWh

Figure 4-10: Economic Evaluation Summary

4.1.4 DECISION

Once the economical evaluation is completed a decision can be made regarding refurbishment, renewal or replacement of a given hydropower station. In most cases this decision is based on the costs as well as the practicality of the hydropower scheme. A positive NPV indicates that the option is economically feasible. Similarly an IRR larger than 10 % is a good indication that the project will be economically successful.

4.1.4.1 Sensitivity Analysis

It is always beneficial to conduct a sensitivity analysis by changing the assumptions made during the analysis. Inflation rates are the volatile and tend to change over the lifespan of a project. Thus during the sensitivity analysis it is important to evaluate the options with increased and decreased values, to determine whether the options are still viable.

5 THE HDAT APPLICATION

In this chapter the developed HDAT is applied to a case study. A decommissioned site in Aliwal North in the Eastern Cape Province of the Republic of South Africa (RSA) has been identified as a possible site to be recommissioned. The generated electricity would be used on site by the municipality, thus reducing their electricity bill at the end of the month.

5.1 JOE GQABI DISTRICT MUNICIPALITY - ALIWAL NORTH

The Joe Gqabi District Municipality (JGDM), previously known as the Ukhahlamba District Municipality, is classified as a Category C municipality and is one of the six districts within the Eastern Cape Province. The seat of Joe Gqabi is Barkly East and there are three local municipalities included in this district: Elundini LM, Walter Sisulu LM and Senqu LM (Figure 5-1).

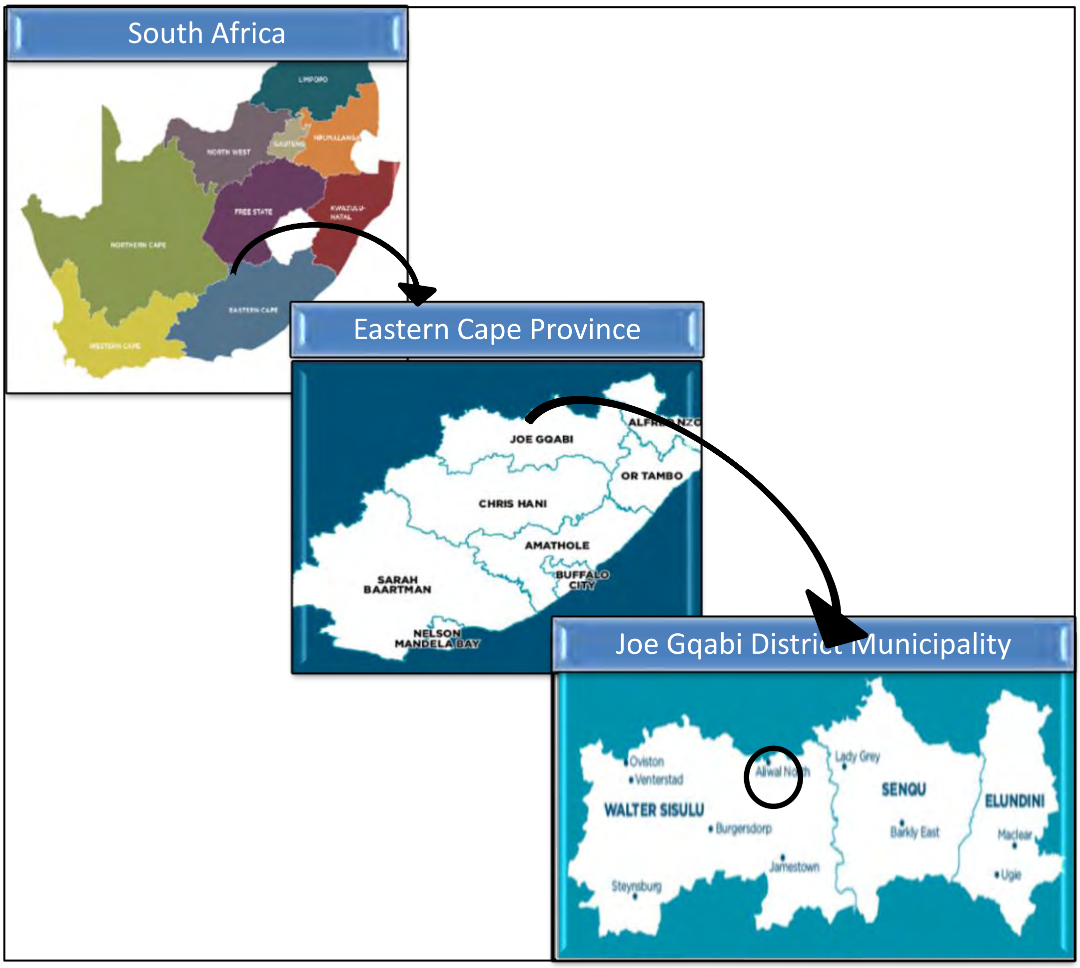


Figure 5-1: Joe Gqabi District Municipality.

Provision of electricity is not a direct function of the District Municipality as Eskom is the main provider of electricity through the District though there are some areas that are under-serviced by the local municipalities. The Census 2016 statistics show a noticeable improvement of 80 % access to the basic level of electricity from 69.1 % in 2011. Most of the backlog occur in the informal settlements.

5.1.1 EXISTING DECOMMISSIONED HYDROPOWER PLANT

Site

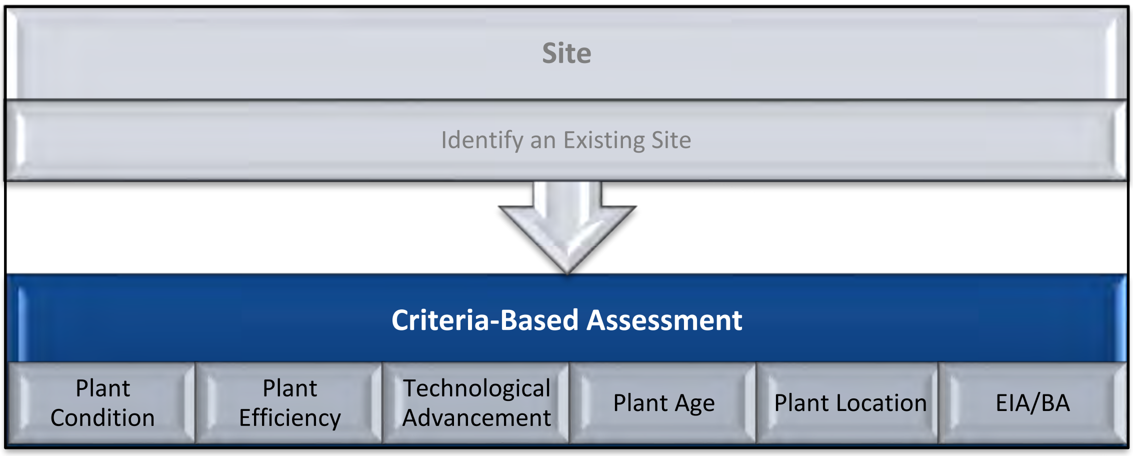
Identify an Existing Site

One of the responsibilities of the Joe Gqabi District Municipality (JGDM) is to supply the Aliwal North town with water. This is accomplished by abstracting the water from the Orange River at a weir, as seen in Figure 5-2. In the early 20th century a tunnel was built to divert the water from the river to the pump house (the old drawings are attached in Appendix B). From here the water was pumped to irrigation channels via the mechanical turbine- pumps. Over the years these mechanical turbines were replaced by electrical pumps as they were cheaper and more readily available. However, with escalating electricity costs exceeding inflation rates, the local municipality is looking at recommissioning the hydropower station.

Figure 5-2: The Decommissioned Hydropower Plant Along the Weir at Aliwal North.

Currently the JGDM is operating the system by abstracting water from the Orange River, utilizing the weir, the intake and the tunnel infrastructure. This raw water is pumped to the desiltation tanks of the water treatment works (WTW). From there the water gravitates through the WTW and the potable water is then pumped into the water distribution network of Aliwal North. A direct need for electricity exists for the WTW and pump station which are all owned and operated by the JGDM.

5.1.2 CRITERIA-BASED ASSESSMENT



Once the desktop study regarding the identified decommissioned hydropower site has been conducted, a site investigation needs to be done to evaluate the given site.

5.1.2.1 Plant Condition Assessment

A generator was not used in the original design of the hydropower turbine, as the mechanical power was not converted into electrical power it was only used to pump the water to the channels supplying the town with water. The runners of the original turbine can be seen in Figure 5-3, and it could be noted that they have been subjected to some corrosion and cavitation.

Figure 5-3: Original Decommissioned Turbine

The powerhouse, Figure 5-4, is in a good condition and is still utilised for the pump station. In the powerhouse is a 3-ton crane on a crawler beam (Figure 5-5) that is still utilised for the installation and removal of the pumps. The crawler beam is slightly rusted in places.

Figure 5-4: Powerhouse at Aliwal North

Figure 5-5: The 3-ton Crane and Crawler Beam

The intake structure is in a relatively good condition however the structure has been chipped off a bit and some of the gates are missing, as seen in Figure 5-6. Sedimentation has been noted as a problem in the Orange River, which is noticeable at the intake structure as it accumulates and potentially blocks the intake structure. Therefore, from time to time the intake structure needs to be scoured to ensure that the sedimentation is washed down the river. The penstock from the intake structure towards the turbine seems to be in a decent condition.

Figure 5-6: Intake Structure

5.1.2.2 Plant Efficiency Assessment

Since the mechanical turbine has been replaced with a pump, the efficiency of the turbines cannot be determined. Records of the old turbines were not available therefore the efficiency could not be determined. However, it was assumed that the efficiency was relatively low as ancient equipment was utilised in the hydropower plant.

5.1.2.3 Plant Age Assessment

The hydropower plant was constructed in the early 1900s. Thus, the plant and its components have exceeded its expected life span and a score of 5 was given for the plant's age assessment.

5.1.2.4 Technological Advancement

The technology used in the Aliwal North Plant is ancient. The original turbine was a mechanical turbine that had been used to pump the water into the channels to supply the town with water. These turbines were replaced with pumps and are not operational anymore.

5.1.2.5 Plant Location Assessment

Currently the hydropower plant is in a relatively good location with a decent dirt access road. However, the local capacity is inadequate with respect to the skilled laborers for both the refurbishment as well as the operation of the hydropower plant. A score of 3 was given for the plant location assessment.

5.1.2.6 Environmental Impact Assessment

The water in the Orange River is known for its siltation problem, as seen in Figure 5-7, which implies that the water is of bad quality with a high silt load. This siltation has detrimental effects on the turbine runners as seen in Figure 5-8.

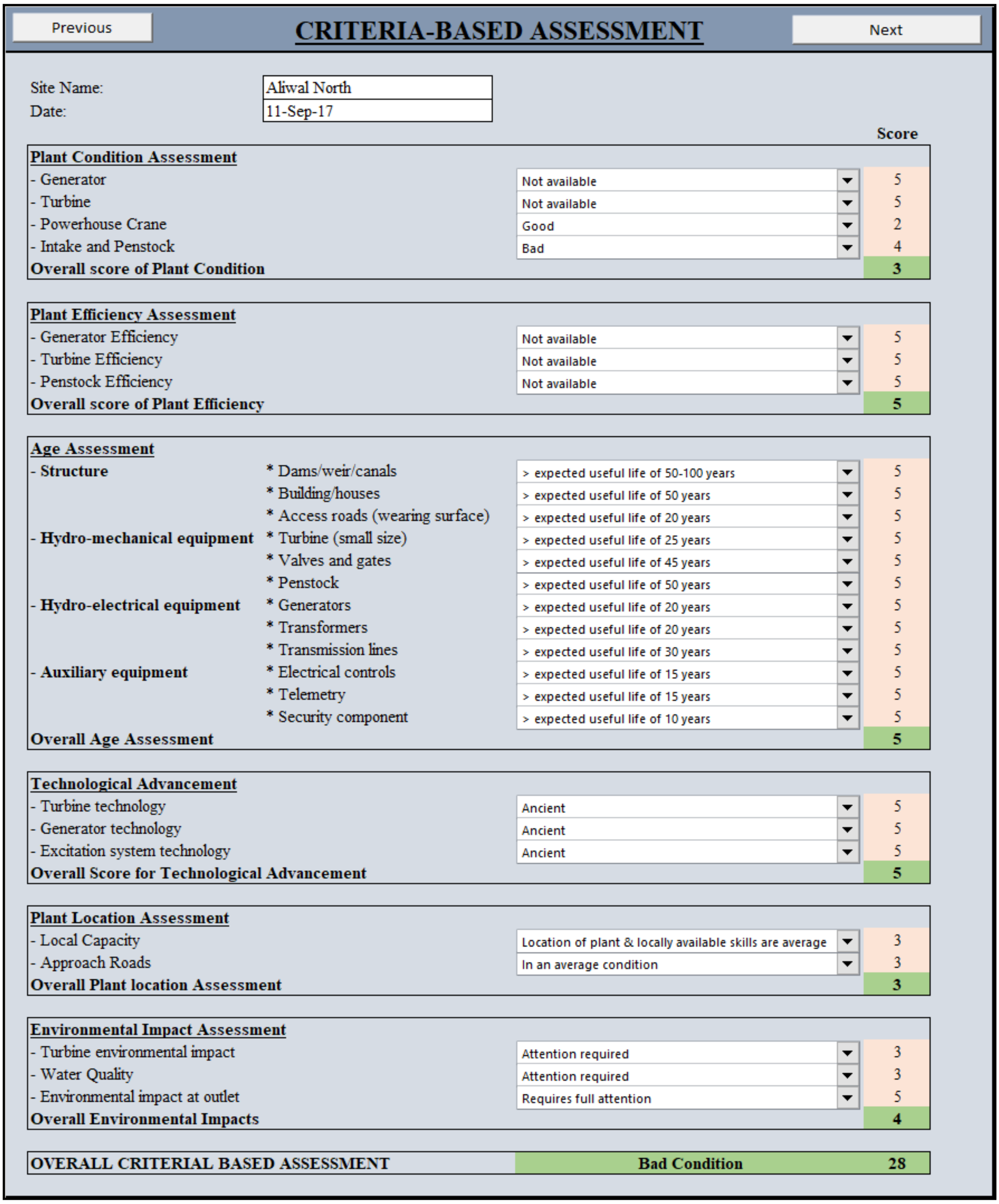
Figure 5-7: Water Quality in the Orange River

Figure 5-8: Damage on the Runners

Over the years the outlet tunnel released the water back into the river in such a way that it eroded the river bank (Figure 5-9). Therefore the overall environment impact assessment was given a score of 4, implying that some attention is required.

Figure 5-9: Erosion of the River Banks at the Outlet Structure

The overall criteria-based assessment for the Aliwal North Decommissioned site resulted in a score of 28 (Figure 5-10), implying that the decommissioned site is in bad condition, not taking into account the equipment has been removed.



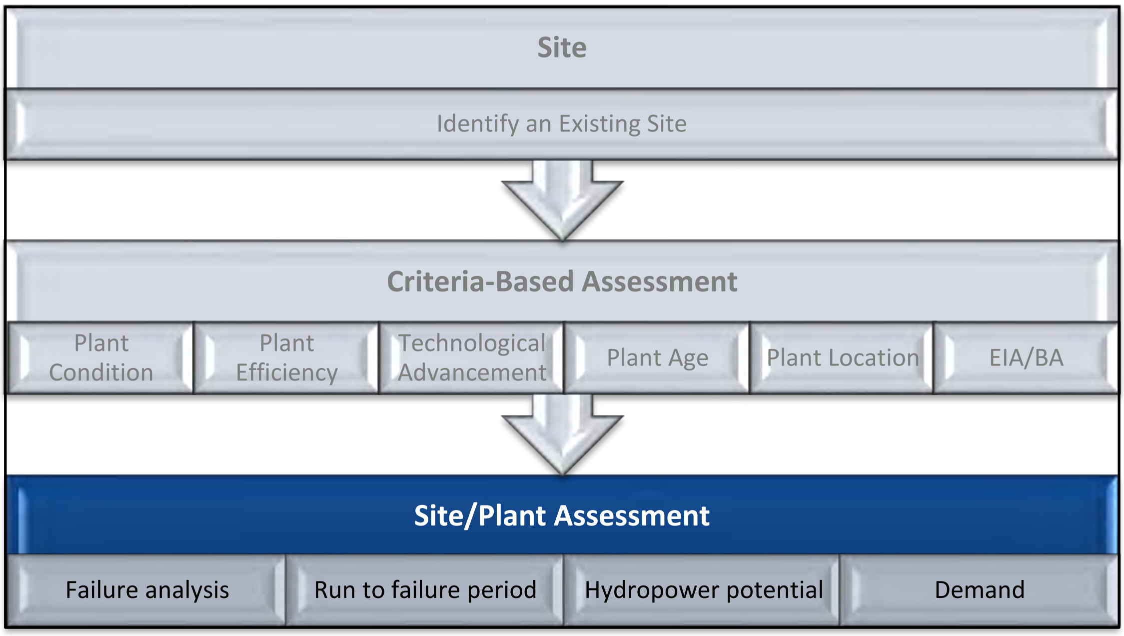
CRITERIA-BASED ASSESSMENT

Site Name: Aliwal North
Date: 11-Sep-17

			Score
Plant Condition Assessment			
- Generator		Not available	5
- Turbine		Not available	5
- Powerhouse Crane		Good	2
- Intake and Penstock		Bad	4
Overall score of Plant Condition			3
Plant Efficiency Assessment			
- Generator Efficiency		Not available	5
- Turbine Efficiency		Not available	5
- Penstock Efficiency		Not available	5
Overall score of Plant Efficiency			5
Age Assessment			
- **Structure**	* Dams/weir/canals	> expected useful life of 50-100 years	5
	* Building/houses	> expected useful life of 50 years	5
	* Access roads (wearing surface)	> expected useful life of 20 years	5
- **Hydro-mechanical equipment**	* Turbine (small size)	> expected useful life of 25 years	5
	* Valves and gates	> expected useful life of 45 years	5
	* Penstock	> expected useful life of 50 years	5
- **Hydro-electrical equipment**	* Generators	> expected useful life of 20 years	5
	* Transformers	> expected useful life of 20 years	5
	* Transmission lines	> expected useful life of 30 years	5
- **Auxiliary equipment**	* Electrical controls	> expected useful life of 15 years	5
	* Telemetry	> expected useful life of 15 years	5
	* Security component	> expected useful life of 10 years	5
Overall Age Assessment			5
Technological Advancement			
- Turbine technology		Ancient	5
- Generator technology		Ancient	5
- Excitation system technology		Ancient	5
Overall Score for Technological Advancement			5
Plant Location Assessment			
- Local Capacity		Location of plant & locally available skills are average	3
- Approach Roads		In an average condition	3
Overall Plant location Assessment			3
Environmental Impact Assessment			
- Turbine environmental impact		Attention required	3
- Water Quality		Attention required	3
- Environmental impact at outlet		Requires full attention	5
Overall Environmental Impacts			4
OVERALL CRITERIAL BASED ASSESSMENT		**Bad Condition**	**28**

Figure 5-10: Summary of the Criteria-based Assessment for Aliwal North Decommissioned Hydropower Plant.

5.1.3 SITE / PLANT ASSESSMENT



Since Aliwal North’s Hydropower plant has been decommissioned and the turbines have been removed and replaced with pumps, automated failure analysis cannot be conducted and the run to failure period cannot be determined. However, the hydropower potential and the power demand can be determined.

The Aliwal North’s WTW is located next to the gauging weir, in the Orange River (Figure 5-11). Thus, the hydrological data for this gauging station (D1H003) was obtained from the Department of Water and Sanitation (DWS) website.

Figure 5-11: D1H003 Gauging Weir Across the Orange River

From the historical flow data (Figure 5-12), a flow duration curve could be plotted indicating the flows obtainable at given time percentages, Figure 5-13. Hence it could be concluded that 95 % of the time a flow rate of 33.73 m^3/s is available.

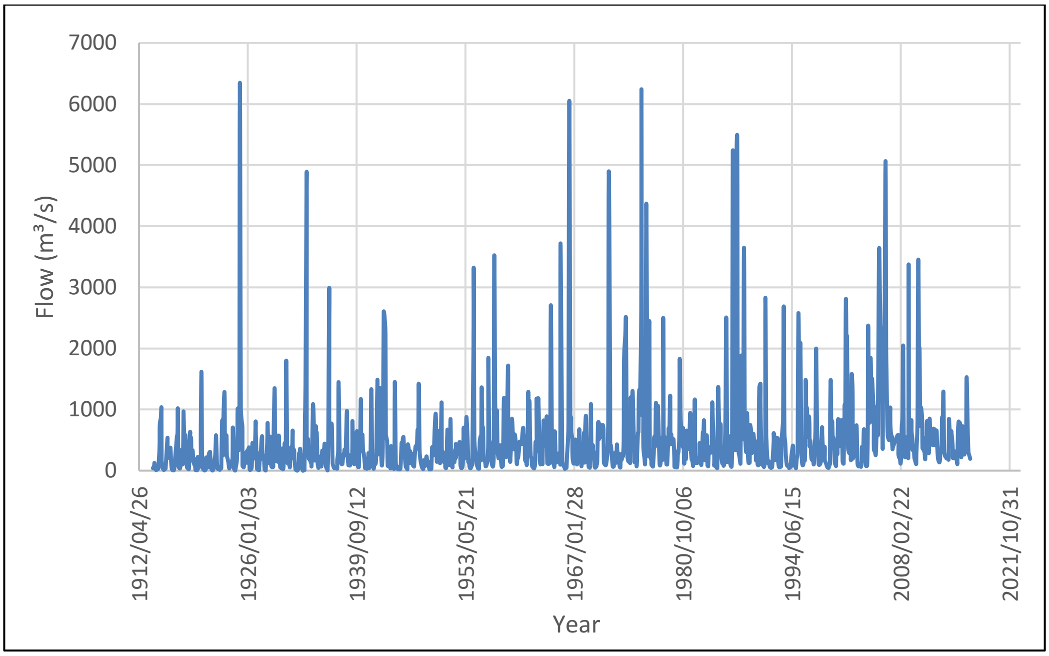


Figure 5-12: Historical Flow Data for the D1H003 Gauging Station

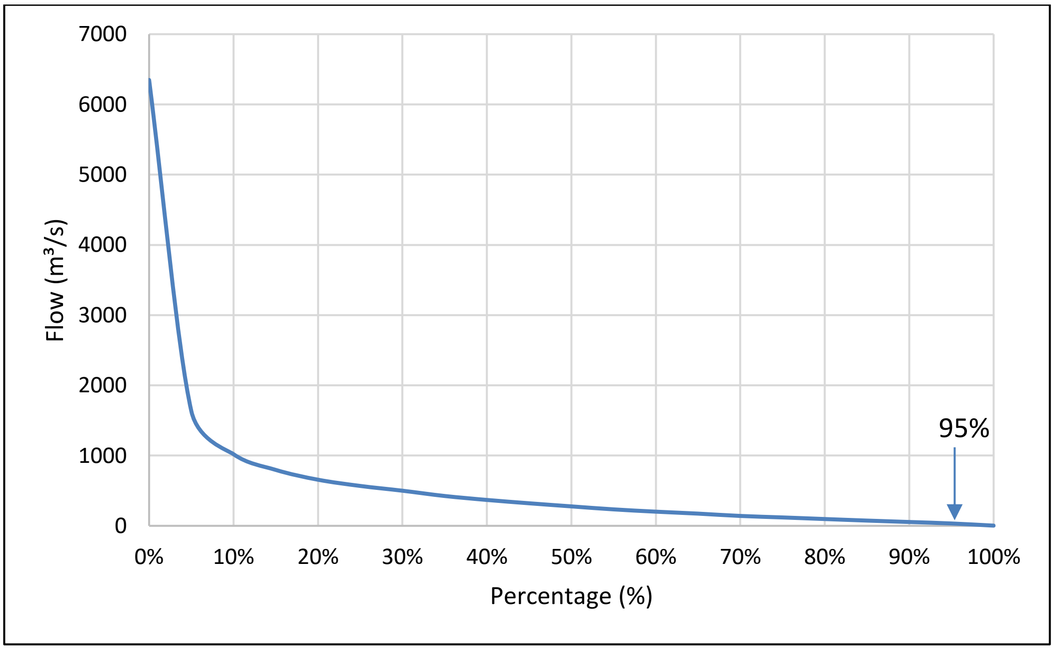
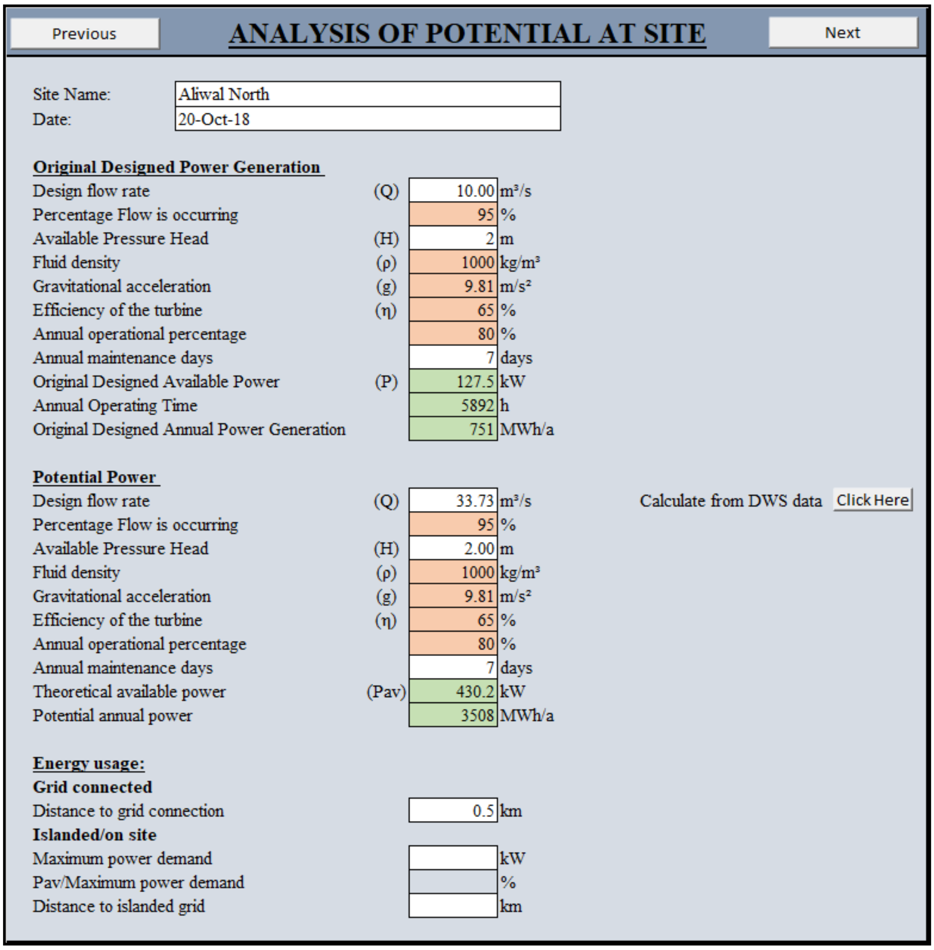


Figure 5-13: Flow Duration Curve for Gauging Station D1H003

The operators of the Aliwal North's WTW indicated that the river floods at least once a year. This flooding level dictates the water level in the turbine room. Statistical methods were used to determine the flood peaks and a flow rate of 6062 m^3/s was obtained with a corresponding height of 7.65 m above the weir. This flood height dictated the height of the measuring station as well as the level for the generator, if not submersible.

As seen in Figure 5-12, the Orange River has a high variation in flow rates, ranging from 0 to 6348 m^3/s, and a low head difference of only 2 m. During high flow rates the weir gets fully submerged causing the head difference to become insignificant. A Kaplan type turbine would therefore be suitable for the Aliwal North site as it accommodates flow rates from 3 m^3/s - 30 m^3/s as well as heads from 1.5 to 20 meters, resulting in power outputs between 75 kW to 1 MW. Figure 5-14 summarises the potential power output for this site.



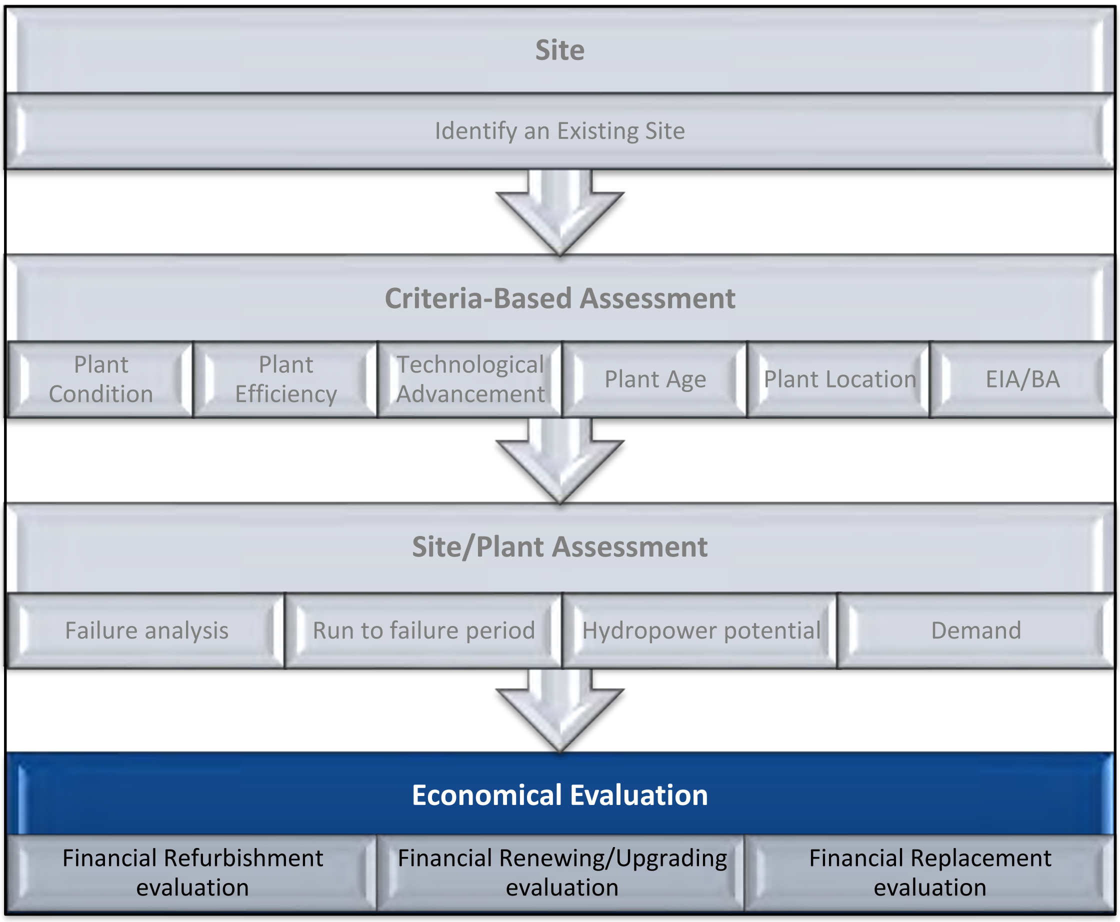
ANALYSIS OF POTENTIAL AT SITE

Site Name: Aliwal North
Date: 20-Oct-18

Original Designed Power Generation				
Design flow rate	(Q)	10.00	m³/s	
Percentage Flow is occurring		95	%	
Available Pressure Head	(H)	2	m	
Fluid density	(ρ)	1000	kg/m³	
Gravitational acceleration	(g)	9.81	m/s²	
Efficiency of the turbine	(η)	65	%	
Annual operational percentage		80	%	
Annual maintenance days		7	days	
Original Designed Available Power	(P)	127.5	kW	
Annual Operating Time		5892	h	
Original Designed Annual Power Generation		751	MWh/a	
Potential Power				
Design flow rate	(Q)	33.73	m³/s	Calculate from DWS data
Percentage Flow is occurring		95	%	
Available Pressure Head	(H)	2.00	m	
Fluid density	(ρ)	1000	kg/m³	
Gravitational acceleration	(g)	9.81	m/s²	
Efficiency of the turbine	(η)	65	%	
Annual operational percentage		80	%	
Annual maintenance days		7	days	
Theoretical available power	(Pav)	430.2	kW	
Potential annual power		3508	MWh/a	
Energy usage:				
Grid connected				
Distance to grid connection		0.5	km	
Islanded/on site				
Maximum power demand			kW	
Pav/Maximum power demand			%	
Distance to islanded grid			km	

Figure 5-14: Potential at Aliwal North

5.1.4 ECONOMICAL EVALUATION

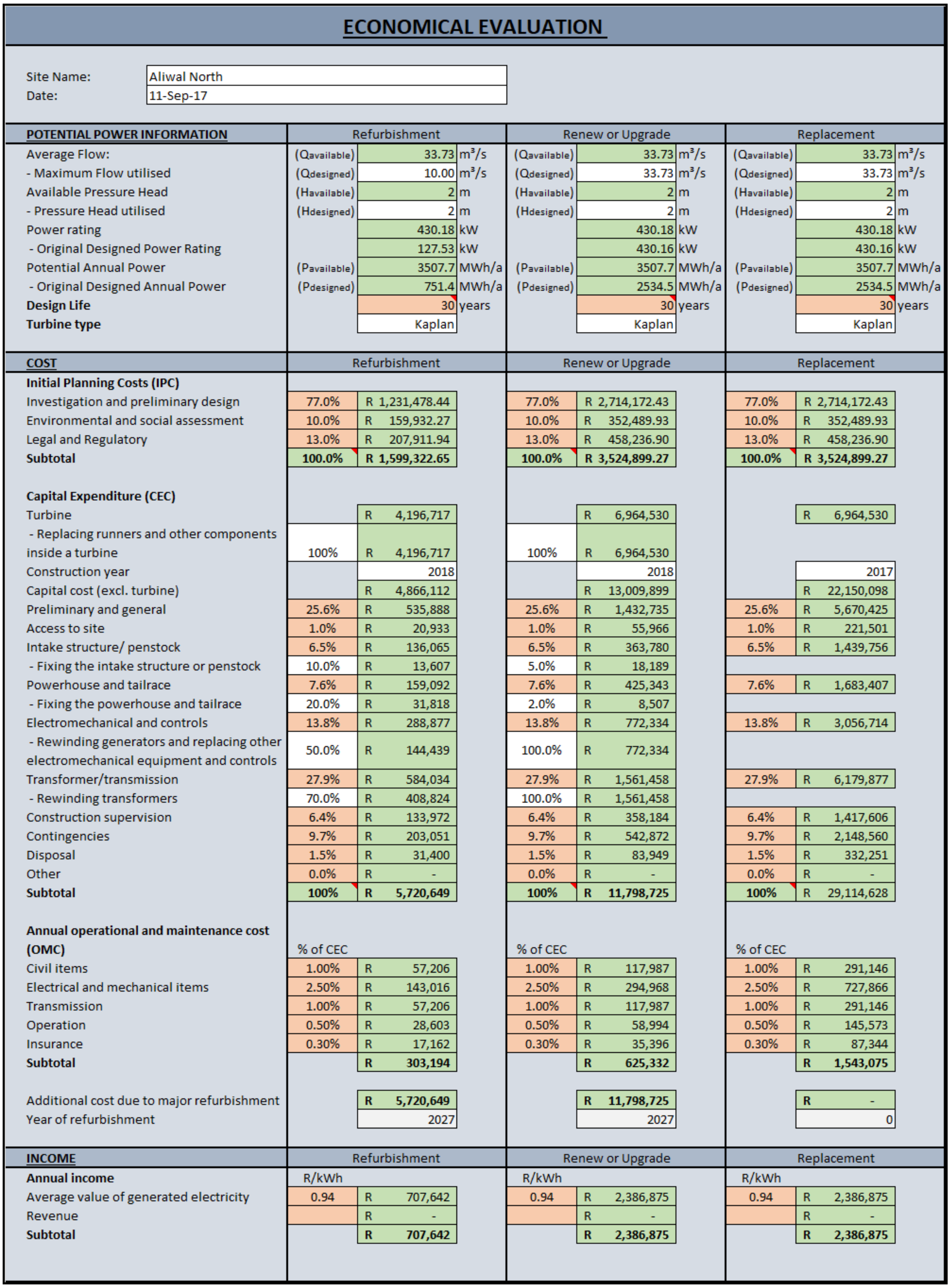


Once the potential power has been determined, the next step to look at the economic feasibility of the different options on whether to refurbish, renew or replace the existing/ decommissioned hydropower station.

5.1.4.1 Economic Evaluation for the Aliwal North's Hydropower Plant

A cost estimate can be seen in Table 5-1 for Aliwal North's Hydropower plant. It is important to note that only a portion of the available flow would be utilised for the Refurbishment of the Plant, as this is how the original plant operated. However, for both the renewal and replacement of the plant the total available flow would be utilised, as a new turbine would be installed. In the case of refurbishment and renewal, the existing infrastructure would be used as far as possible. Whereas in the case of replacement a complete new infrastructure would be considered.

Table 5-1: Economical Evaluation for Aliwal North's Hydropower Plant



ECONOMICAL EVALUATION

Site Name: Aliwal North
Date: 11-Sep-17

POTENTIAL POWER INFORMATION	Refurbishment			Renew or Upgrade			Replacement		
Average Flow:	(Qavailable)	33.73	m³/s	(Qavailable)	33.73	m³/s	(Qavailable)	33.73	m³/s
- Maximum Flow utilised	(Qdesigned)	10.00	m³/s	(Qdesigned)	33.73	m³/s	(Qdesigned)	33.73	m³/s
Available Pressure Head	(Havailable)	2	m	(Havailable)	2	m	(Havailable)	2	m
- Pressure Head utilised	(Hdesigned)	2	m	(Hdesigned)	2	m	(Hdesigned)	2	m
Power rating		430.18	kW		430.18	kW		430.18	kW
- Original Designed Power Rating		127.53	kW		430.16	kW		430.16	kW
Potential Annual Power	(Pavailable)	3507.7	MWh/a	(Pavailable)	3507.7	MWh/a	(Pavailable)	3507.7	MWh/a
- Original Designed Annual Power	(Pdesigned)	751.4	MWh/a	(Pdesigned)	2534.5	MWh/a	(Pdesigned)	2534.5	MWh/a
Design Life		30	years		30	years		30	years
Turbine type		Kaplan			Kaplan			Kaplan	
COST	Refurbishment			Renew or Upgrade			Replacement		
Initial Planning Costs (IPC)									
Investigation and preliminary design	77.0%	R 1,231,478.44		77.0%	R 2,714,172.43		77.0%	R 2,714,172.43	
Environmental and social assessment	10.0%	R 159,932.27		10.0%	R 352,489.93		10.0%	R 352,489.93	
Legal and Regulatory	13.0%	R 207,911.94		13.0%	R 458,236.90		13.0%	R 458,236.90	
Subtotal	**100.0%**	**R 1,599,322.65**		**100.0%**	**R 3,524,899.27**		**100.0%**	**R 3,524,899.27**	
Capital Expenditure (CEC)									
Turbine		R 4,196,717			R 6,964,530			R 6,964,530	
- Replacing runners and other components inside a turbine	100%	R 4,196,717		100%	R 6,964,530				
Construction year		2018			2018			2017	
Capital cost (excl. turbine)		R 4,866,112			R 13,009,899			R 22,150,098	
Preliminary and general	25.6%	R 535,888		25.6%	R 1,432,735		25.6%	R 5,670,425	
Access to site	1.0%	R 20,933		1.0%	R 55,966		1.0%	R 221,501	
Intake structure/ penstock	6.5%	R 136,065		6.5%	R 363,780		6.5%	R 1,439,756	
- Fixing the intake structure or penstock	10.0%	R 13,607		5.0%	R 18,189				
Powerhouse and tailrace	7.6%	R 159,092		7.6%	R 425,343		7.6%	R 1,683,407	
- Fixing the powerhouse and tailrace	20.0%	R 31,818		2.0%	R 8,507				
Electromechanical and controls	13.8%	R 288,877		13.8%	R 772,334		13.8%	R 3,056,714	
- Rewinding generators and replacing other electromechanical equipment and controls	50.0%	R 144,439		100.0%	R 772,334				
Transformer/transmission	27.9%	R 584,034		27.9%	R 1,561,458		27.9%	R 6,179,877	
- Rewinding transformers	70.0%	R 408,824		100.0%	R 1,561,458				
Construction supervision	6.4%	R 133,972		6.4%	R 358,184		6.4%	R 1,417,606	
Contingencies	9.7%	R 203,051		9.7%	R 542,872		9.7%	R 2,148,560	
Disposal	1.5%	R 31,400		1.5%	R 83,949		1.5%	R 332,251	
Other	0.0%	R -		0.0%	R -		0.0%	R -	
Subtotal	**100%**	**R 5,720,649**		**100%**	**R 11,798,725**		**100%**	R 29,114,628	
Annual operational and maintenance cost (OMC)	% of CEC			% of CEC			% of CEC		
Civil items	1.00%	R 57,206		1.00%	R 117,987		1.00%	R 291,146	
Electrical and mechanical items	2.50%	R 143,016		2.50%	R 294,968		2.50%	R 727,866	
Transmission	1.00%	R 57,206		1.00%	R 117,987		1.00%	R 291,146	
Operation	0.50%	R 28,603		0.50%	R 58,994		0.50%	R 145,573	
Insurance	0.30%	R 17,162		0.30%	R 35,396		0.30%	R 87,344	
Subtotal		**R 303,194**			**R 625,332**			**R 1,543,075**	
Additional cost due to major refurbishment		**R 5,720,649**			**R 11,798,725**			**R -**	
Year of refurbishment		2027			2027			0	
INCOME	Refurbishment			Renew or Upgrade			Replacement		
Annual income	R/kWh			R/kWh			R/kWh		
Average value of generated electricity	0.94	R 707,642		0.94	R 2,386,875		0.94	R 2,386,875	
Revenue		R -			R -			R -	
Subtotal		**R 707,642**			**R 2,386,875**			**R 2,386,875**	

5.1.4.2 Results of the Economic Evaluation for the Aliwal North’s Hydropower Plant

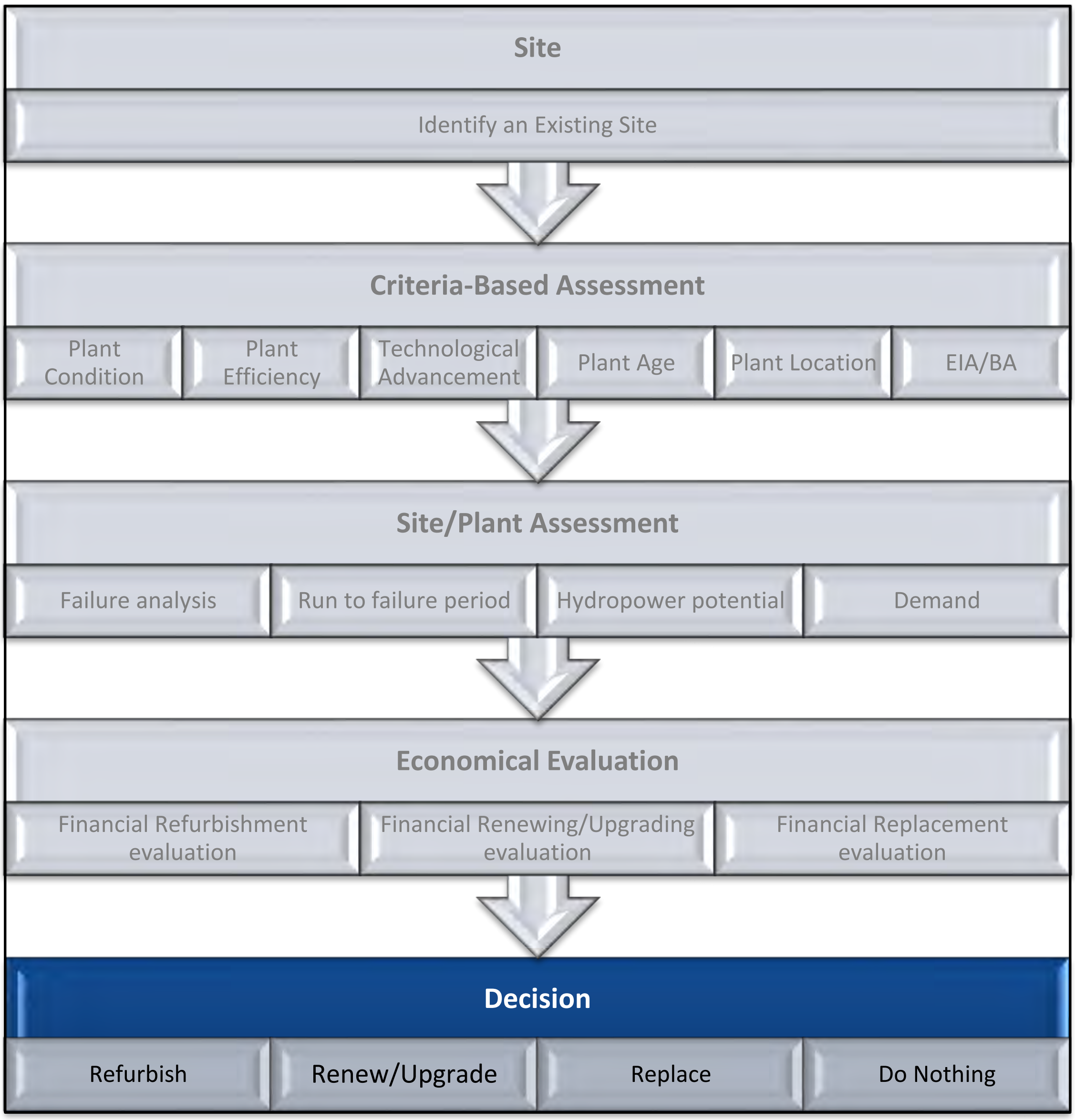
The economical evaluation of the refurbishment of the plant provides a relatively good investment with a positive IRR of 10.45 % and a development cost of around R 169 300 / kW. Similarly, the economical evaluation for the renewal of this site provides a positive IRR of 18.4 % and a development cost of around R 104 100 / kW. Lastly a positive IRR of 9.4 % and a development cost of around R 186 800 / kW was obtained for the replacement of the hydropower plant at Aliwal North.

In summary the economic evaluation for the renewal of the existing hydropower station seems the most favourable, with the highest rate of return and the lowest return on investment period with 13 years, as seen in Table 5-2.

Table 5-2: Summary of the Aliwal North's Economic Evaluation

		Refurbishment	Renew/Upgrade	Replacement
Annual Generated Power	(MWh/a)	751.41	2534.50	2534.50
Net present value of the costs	(R)	-R 21,588,699	-R 44,752,594	-R 80,336,567
Net present value of the income	(R)	R 29,570,129	R 99,740,044	R 99,740,044
Total NPV	(R)	R 7,981,430	R 54,987,450	R 19,403,476
Internal Rate of Return (IRR)	(%)	10.45 %	18.36 %	9.35 %
Payback period	(Years)	20.00	13.00	20.00
Levelised Cost of Energy (LCOE)	(c/kWh)	79.70	48.98	87.93
Development Cost	(R/kW)	169283	104037	186760

5.1.5 DECISION



After analysing the decommissioned hydropower station at Aliwal North, it seemd that all three options are feasible in terms of the economical evaluation. However, the most feasible option with respect to the environment and location remains the renewal of the hydropower station, as the civil works are in a good condition and only mechanical electrical equipment required replacements.

5.1.5.1 Sensitivity Analysis

A sensitivity analysis was done comparing the IRR for the different options by increasing and decreasing the inflation rates for the electricity, operation and maintenance costs over the analysis period. The sensitivity analysis confirms that the renewal of the hydropower station is the most feasible option, as seen in Table 5-3. With an IRR greater than 10% in all cases confirms that the Renewing of the Decommissioned Hydropower Plant is the best decision.

Table 5-3: Sensitivity Analysis for the Refurbishment, Renewing or Replacement of the Aliwal Norths Hydropower Plant

	Refurbishment	**Renewing**	**Replacement**
High electricity (12%), High Operation and Maintenance (7%)	16.2 %	**23.8 %**	14.9 %
High electricity (12%), Expected Operation and Maintenance (5%)	16.7 %	**24.1 %**	15.8 %
High electricity (12%), Low Operation and Maintenance (3%)	17.1 %	**24.5 %**	16.4 %
Expected electricity (8%), High Operation and Maintenance (7%)	8.9 %	**16.8 %**	7.2 %
Expected electricity (8%), Expected Operation and Maintenance (5%)	10.1 %	**17.5 %**	9.4 %
Expected electricity (8%), Low Operation and Maintenance (3%)	10.9 %	**18.0 %**	10.6 %
Low electricity (6%), High Operation and Maintenance (7%)	3.9 %	**12.8 %**	0 %
Low electricity (6%), Expected Operation and Maintenance (5%)	6.2 %	**13.9 %**	5.1 %
Low electricity (6%), Low Operation and Maintenance (3%)	7.4 %	**14.6 %**	7.3 %

5.2 HYDROPOWER INSTALLATION

Initially it was considered that a turbine should be installed in its original position into the shafts in the pump house. After several site visits, including a site visit with a specialist from University of Padova and a turbine supplier from Italy it was decided to avoid the tunnel or shaft in the pump house completely, as the outlet is almost completely blocked due to sedimentation build-up (Figure 5-15). The sedimentation build-up is caused by the water quality as well as the reduction in flow as the water is abstracted for the WTW in the shaft. Thus, by avoiding the shaft area altogether it results in no interference with the abstraction of water for the town of Aliwal North.

Figure 5-15: Blocked Outlet Structure

A scouring section of the intake structure seemed to be a second potential opportunity for a turbine installation (Figure 5-16). This was a better option, with little to no sedimentation build-up as the water is continuously scouring through a 300 mm diameter pipe at the bottom. The two gates on either side of the scouring pipes are also opened from time to time to clean the intake structure from any potential sedimentation build-up especially after flooding events.

Figure 5-16: Scouring Section of the Intake Structure

5.2.1 ALTERNATIVE TURBINE INSTALLATION OPTIONS

Three different turbine suppliers were considered for the scouring section of the intake structure. Each of the turbines had advantages as well as disadvantages.

5.2.1.1 Alternative 1 – Pump as Turbine from Flygt Hydro

Flygt Hydro suggested a siphon type turbine to be installed over the scouring section of the intake structure as seen in Figure 5-17.

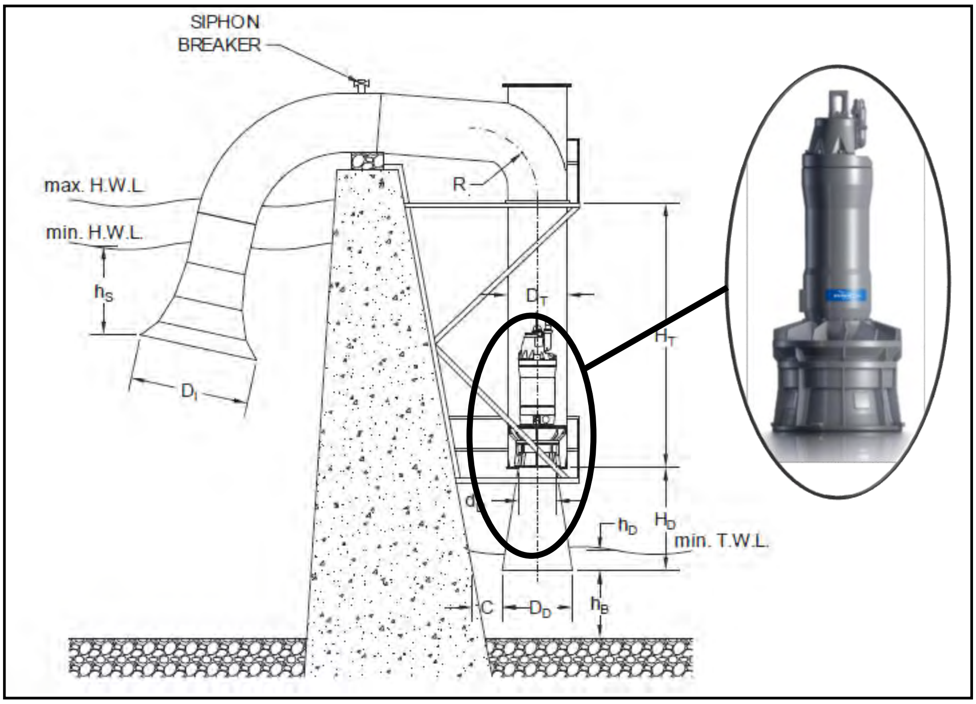


Figure 5-17: Turbine Layout Suggested by Flygt Hydro

The siphon type turbine from Flygt Hydro was designed in such a way that the turbine and generator are a single unit that could be completely submerged during flooding events. The pipe work housing the unit would be a permanent structure and only the turbine unit would be removed during maintenance. Some pros and cons of the turbine have been listed in Table 5-4.

Table 5-4: Pros and Cons of the Flygt Hydro Siphon Type Turbine

Positives	**Negatives**
- Generating capacity of 30 kW - The turbine and generator can be completely submerged - During floods the generator does not need to be removed - Easy installation and removal during maintenance	- The extension of wall is required for unit to fit. - Time to delivery is 18-20 weeks + shipping. - Output frequency is 33Hz, thus a VFD is required. - High costs – R 2.1 million just for the turbine excl. import costs, VFD and pipework (thus unviable). Estimated total cost is R 3.17 million. - Obstruction in the flow path (although minimal).

5.2.1.2 Alternative 2 – Mavel's Siphon Type Turbine

An alternative supplier, Mavel, also suggested a siphon type turbine. In this case the turbine is located on the upstream side of the chamber as seen in Figure 5-18.

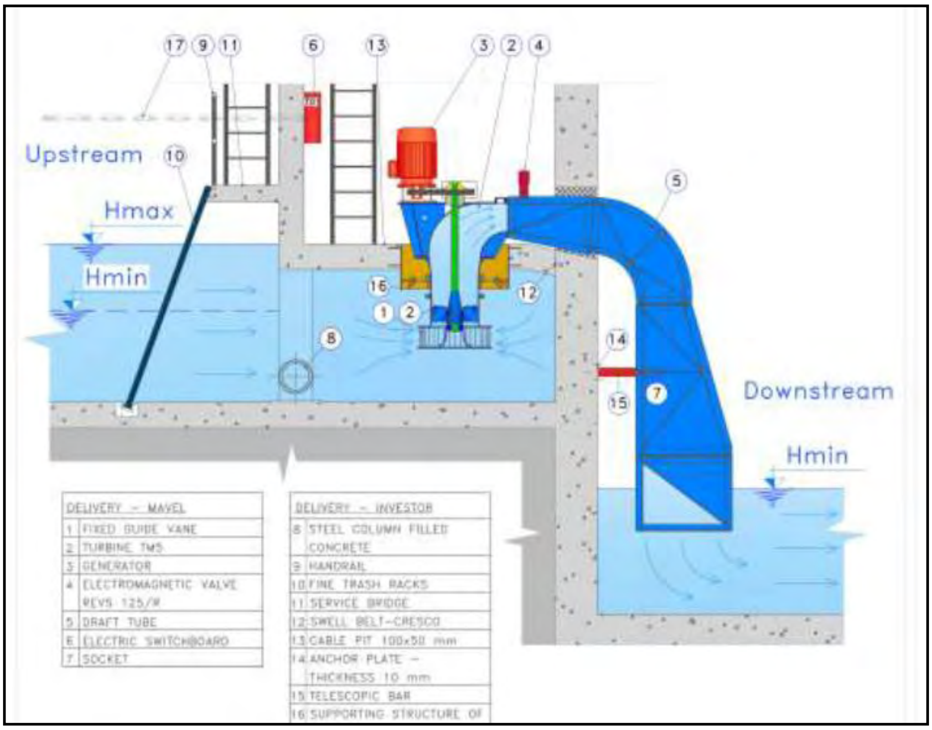


Figure 5-18: Siphon Turbine Suggested by Mavel

The turbine and generator are separate in Mavel's case. A shaft connects the submerged turbine with the generator located above the water. The Generator used by Mavel is not submergible and must therefore be removed during flooding. Pros and Cons for the Mavel turbine installation are summarised in Table 5-5.

Table 5-5: Pros and Cons of the Mavel Siphon Type Turbine

Positives	Negatives
- Generating capacity of 29.4 kW - Easy installation and removal during maintenance - No extension of the scouring wall is required. - Output Frequency is 50 Hz	- The generator is not water tight, thus must be removed during floods, greater than the 1:5 year - Cost – R 2.7 million for the complete unit including installation, which is better when compared to Alternative 1. - Time to delivery is 10 - 12 months which makes this unpractical. - Obstruction in the flow path (although minimal).

5.2.1.3 Alternative 3 – Smart Hydro's Kinetic Turbine

It is suggested to configure a set of kinetic turbines which already had been bought and delivered to South Africa. These kinetic turbines from Smart Hydro are typically installed into a canal system and can be completely submerged. In this case these will be installed into a 1 m steel pipeline, to constrict the flow and force it through the turbines. The pipe section containing the turbine will then be attached to a steel plate which will be placed at the gate openings. A bell-mouth inlet on the upstream side of the gates will be provided for a smooth intake. A typical layout of this can be seen in Figure 5-19. A steel gate will be installed at the downstream side of the scouring section to provide a dry area for both the installation period as well as the maintenance periods.

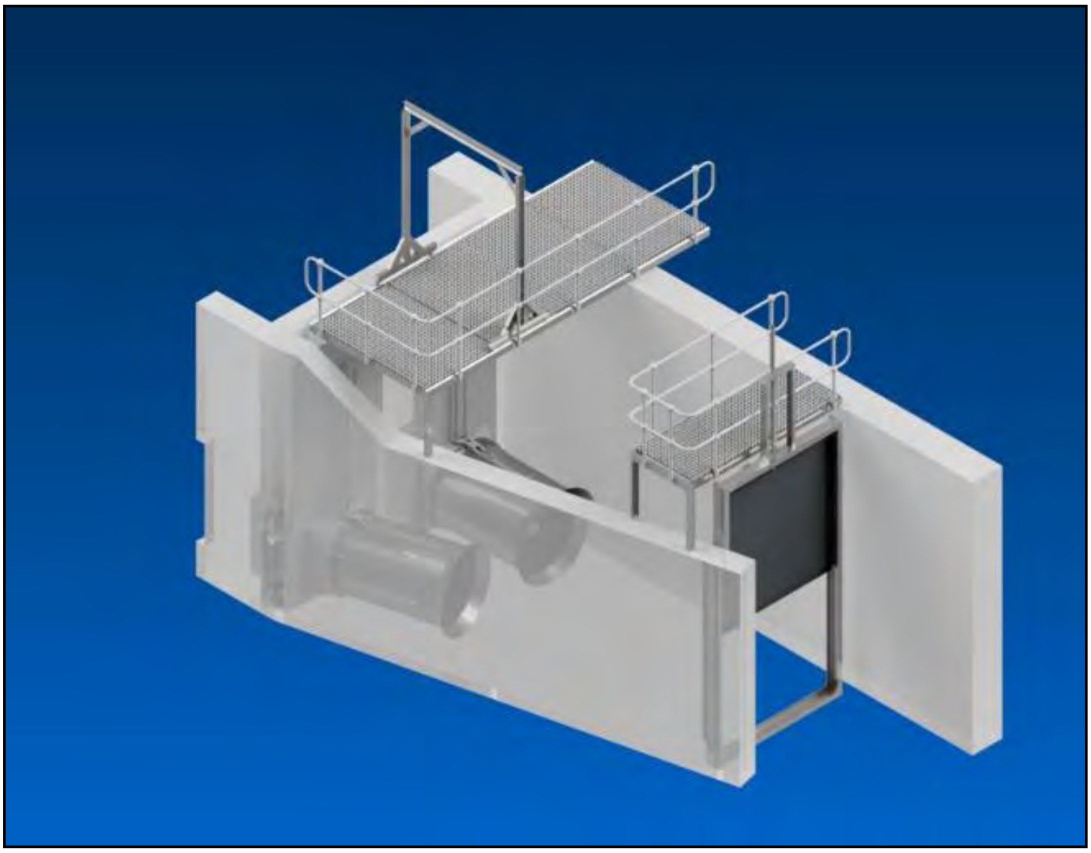


Figure 5-19: Modified Kinetic Turbines from Smart Hydro

To achieve the maximum generating capacity of 5 kW, a velocity of 3.1 m/s is required, implying that a constant flow of 2.4 m^3/s needs to go through the turbines. A summary of all the positives and negatives can be seen in Table 5-6.

Table 5-6: Pros and Cons of Modified Kinetic Turbines from Smart Hydro

Positives	Negatives
- Easy installation and removal during maintenance. - Minor amounts of civil works required. - Output Frequency is 50 Hz. - Generator and turbine completely submerged. - No need for removal during floods - Robust system. - No long delivery periods, as they are already in South Africa. - No problems with siltation. - No obstruction of the flow path. - Could possibly extended by adding more turbines in series. - Total cost would be within available budget. (Total cost would be R 815 229, excl. electrical components).	- Generating capacity is limited to 5 kW per turbine i.e. 10 kW in total. - Not as efficient as other alternatives.

5.2.2 TURBINE SELECTION AND MODIFICATION

Aliwal North has a generation potential of 430kW, however due to the low heads a massive turbine would be required to accommodate the flow for the generation of the power potential. Thus the three above mentioned turbines where considered and it was decided that the turbine from Smart Hydro should be modified and installed in Aliwal North. As these turbines are already in the country, within budget and can be fully submerged even during flooding periods.

The modification of the turbines included the construction of a shroud, face plates, flow straighteners, a walk way and gantry. WEC Project assisted with the modifications of the turbines. Drawings for the different components can be seen in Appendix C.

5.2.3 INSTALLATION OF THE TURBINES

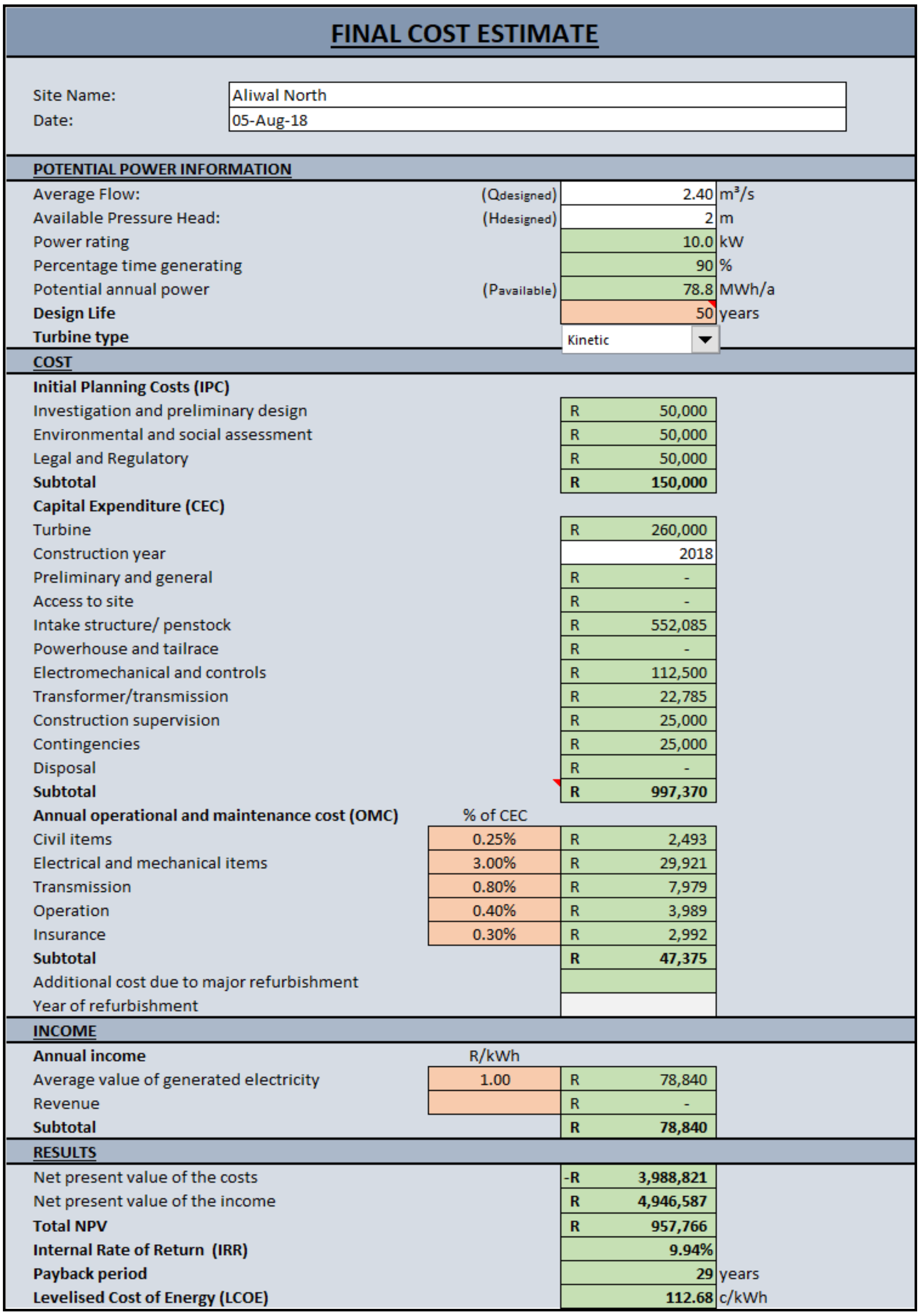
Once the modification of the turbines was completed the installation process commenced. Guide vanes for the flow straighteners were attached to the upstream side of the intake structure and then the flow straighteners were installed. Secondly the face plates were installed on the downstream side of the intake structure. These face plates were designed in such a way to guide the turbine shrouds in place. For safety a walk way was installed over the turbines. The walk way included rails for the gantry for the removal of the turbines during maintenance periods.

The electrical components such as the inverter, rectifier and distribution board were installed in the powerhouse, from where it is then connected into the electricity supply of the Water Treatment Works. Photos of the installation can be seen in Appendix D.

5.2.4 FINAL COSTS FOR THE INSTALLATION OF THE TURBINES

The final recommissioning of the Aliwal North's Hydropower station resulted in a total cost of R 1 147 370, with an NPV of R 957 766, IRR of 9.94 % and a payback period of 29 years. A summary of the final costs can be seen in Table 5-7.

Table 5-7: Final Costs for the Recommissioning of the Aliwal North's Hydropower Plant



FINAL COST ESTIMATE

Site Name: Aliwal North
Date: 05-Aug-18

POTENTIAL POWER INFORMATION				
Average Flow:	($Q_{designed}$)		2.40	m³/s
Available Pressure Head:	($H_{designed}$)		2	m
Power rating			10.0	kW
Percentage time generating			90	%
Potential annual power	($P_{available}$)		78.8	MWh/a
Design Life			50	years
Turbine type			Kinetic	
COST				
Initial Planning Costs (IPC)				
Investigation and preliminary design		R	50,000	
Environmental and social assessment		R	50,000	
Legal and Regulatory		R	50,000	
Subtotal		**R**	**150,000**	
Capital Expenditure (CEC)				
Turbine		R	260,000	
Construction year			2018	
Preliminary and general		R	-	
Access to site		R	-	
Intake structure/ penstock		R	552,085	
Powerhouse and tailrace		R	-	
Electromechanical and controls		R	112,500	
Transformer/transmission		R	22,785	
Construction supervision		R	25,000	
Contingencies		R	25,000	
Disposal		R	-	
Subtotal		**R**	**997,370**	
Annual operational and maintenance cost (OMC)	% of CEC			
Civil items	0.25%	R	2,493	
Electrical and mechanical items	3.00%	R	29,921	
Transmission	0.80%	R	7,979	
Operation	0.40%	R	3,989	
Insurance	0.30%	R	2,992	
Subtotal		**R**	**47,375**	
Additional cost due to major refurbishment				
Year of refurbishment				
INCOME				
Annual income	R/kWh			
Average value of generated electricity	1.00	R	78,840	
Revenue		R	-	
Subtotal		**R**	**78,840**	
RESULTS				
Net present value of the costs		**-R**	**3,988,821**	
Net present value of the income		**R**	**4,946,587**	
Total NPV		**R**	**957,766**	
Internal Rate of Return (IRR)			**9.94%**	
Payback period			**29**	years
Levelised Cost of Energy (LCOE)			**112.68**	c/kWh

It is important to note that the final costs and the cost given by the HDAT differ. This is because a different turbine was used and modified for this specific site and less power was generated than available.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

Hydropower generation is proportional to the flow rate of the water, available pressure head and efficiency of the turbines. The available flow rate and pressure head dictates the different hydropower classification categories namely pico, micro, mini, small and large. Hydropower stations are complex systems consisting of the intake structure, penstock, turbine, generator, and power house.

Like all infrastructures, hydropower stations deteriorate over time, however there are some key components that increase the deterioration rate of a hydropower plant drastically. These include the following: sand erosion on the runners of the turbines; unbalanced turbines inducing excessive vibrations; turbine over-speeding; cavitation damage on the turbine runners or blades; fatigue damage on the turbines; ingested bodies in the runners causing obstructions and unbalancing; insulation degradation; flooding in the powerhouse; system losses, both hydraulic and leakage losses in the system; poor water quality and lightning damage on the electrical components of the turbine.

This dissertation entails development of a framework for the evaluation of existing or decommissioned hydropower plants. Key factors affecting the decision whether to refurbish, renewing or replacing an existing hydropower station consist of the condition of the plant, the efficiency, the age of the plant as well as the age of the equipment, the technological advancements of components, the environmental impacts, automated failure, run to failure periods, hydropower potential, demand, risks and costs. These factors were incorporated into the framework and were assessed accordingly.

The developed framework was incorporated into a Hydropower Development Assistance Tool (HDAT), which is a Microsoft Excel-based tool, to facilitate the necessary calculations for the evaluation of existing or decommissioned hydropower sites.

The framework was tested on a decommission hydropower plant in Aliwal North, Eastern Cape Province, with a hydropower potential of 125 kW. However due to financial reasons and long waiting periods, two kinetic turbines have been modified and installed at Aliwal North site, with a total power potential of 10 kW.

This study addressed the necessity for a system that can be used to evaluate existing or decommissioned hydropower plants in South Africa. A user-friendly HDAT was developed, to guide potential users through the evaluation and decision process of an existing or decommissioned hydropower station. However the final decision cannot be based on the framework only, nevertheless it aids in the decision whether to refurbish, replace or renew the hydropower plant.

6.2 LIMITATIONS AND RECOMMENDATIONS

During the study some limitations were present. These include the following:

- There were no records regarding the operation and maintenance of the decommissioned hydropower plant. Hence numerous assumptions were based on the old drawings of the initial hydropower plant, which was built in the early 1900s.
- The formulas used during the study where applicable to European and US hydropower plant developments, however they were adjusted with respect to inflation as well as the exchange rate for applications in South Africa. However, the absence of more recent formulas for the prediction of theoretical costs resulted in imprecise financial forecasting.
- Flow records obtained from the DWS had some missing data and are not up to date.
- The decommissioned hydropower plant had missing components. Subsequently it was challenging to determine additional components to be integrated into the framework.
- With no local turbine suppliers, high exchange rates and long importation periods makes it extremely difficult to develop a hydropower site in South Africa to their full potential.

It is recommended that the HDAT should be used by engineers, municipalities as well as private owners of hydropower stations for a first order evaluation of their existing hydropower station. With regards to future studies it is recommended that:

- Operation and maintenance guidelines for all types of hydropower schemes, especially for existing hydropower stations, should be compiled and implemented where applicable.
- Updating and developing cost functions relevant for South African terms, with respect to the total costs a new hydropower station. Similarly cost functions should be developed for the refurbishment of different components of an existing hydropower station.
- Incorporating other engineering disciplines and expertise with respect to the mechanical and electrical components during the site assessment stage.
- A similar tool should be developed for new hydropower stations in South Africa.

- There is also a need for a hydropower atlas to incorporate and monitor all the existing hydropower plants world-wide. Location, as-builts and any operational and maintenance records of all the hydropower sites should be included in the Atlas.

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APPENDIX A

FUNCTIONS USED IN HDAT

A. APPENDIX A

This appendix contains all the derivations and assumptions used by the HDAT. These functions may be modified in cases where more recent information is available. The origin of the functions and default values are also given in this appendix.

A.1 DEFAULT VALUES

The following default values have been used in the HDAT for the evaluation of the hydropower potential, Table A-1.

Table A-1: Default values used in HDAT to determine the hydropower potential

Component	Symbol	Default value	Units	Reference / Motivation
Fluid density	(ρ)	1000	kg/m³	Value accepted by industry. (Chadwick *et al.*, 2004; Ojha *et al.*, 2010).
Gravitational acceleration	(g)	9.81	m/s²	Value accepted by industry. (Chadwick *et al.*, 2004; Ojha *et al.*, 2010).
Efficiency	(η)	60	%	Typical efficiency for micro-hydropower systems (BHA, 2012; Loots, 2013)
Annual operational percentage		60	%	Conservative value (Loots, 2013)
Annual maintenance days		7	days	Conservative value (Loots, 2013)
Percentage of peak flow used		95	%	Conservative value

A.2 ECONOMICAL ANALYSIS FUNCTION

Numerous sources were studied and evaluated to find realistic and appropriate cost functions for the HDAT. The functions used during the economical evaluation are presented in Table A-2 andTable A-3.

Table A-2: Overall Project Costs

Cost Function for Component:	Overall cost of Project (for heads of 2-30m)	Overall cost of Project (for heads of 30-200m)
Original Costing Function:	$C = 25000 \times (\frac{kW}{H^{0.35}})^{0.65}$	$C = 45500 \times (\frac{kW}{H^{0.3}})^{0.6}$
Base Currency:	£	£
Exchange Rate:	R17.26/£	R17.26/£
Base Year:	2008	2008
Average Inflation Rate:	2.40%	2.40%
Modified Cost Function:	$C = 534\ 172 \times (\frac{kW}{H^{0.35}})^{0.65}$	$C = 972\ 192 \times (\frac{kW}{H^{0.3}})^{0.6}$
Source:	Aggidis, *et al.* (2010)	Aggidis, *et al.* (2010)
Motivation:	The given cost function was obtained from a peer reviewed journal. This cost function was adapted for both the inflation and the exchange rate.	The given cost function was obtained from a peer reviewed journal. This cost function was adapted for both the inflation and the exchange rate.

Table A-3: Turbine cost functions

Cost Function for Component	Original Costing Function:	Base Currency of Cost Function:	Exchange Rate (14/09/2017):	Base Year of Function:	Average Inflation Rate:	Modified Cost Function:	Source:	Motivation:
Kaplan Turbine	$C_K = 33\,236P^{-0.58338}H^{-0.113901}$	€/kW	R15.62/€	2007	1.50%	$C_K = 602\,500P^{-0.58338}H^{-0.113901}$	Ogayar & Vidal (2009)	The given cost functions were obtained from a peer reviewed journal. These cost functions were adapted for both the inflation and exchange rate.
Francis Turbine	$C_F = 25\,698P^{-0.560135}H^{-0.127243}$	€/kW	R15.62/€	2007	1.50%	$C_F = 465\,900P^{-0.560135}H^{-0.127243}$	Ogayar & Vidal (2009)	
Pelton Turbine	$C_P = 17\,693P^{-0.3644725}H^{-0.281735}$	€/kW	R15.62/€	2007	1.50%	$C_P = 320\,750P^{-0.3644725}H^{-0.281735}$	Ogayar & Vidal (2009)	
Other Turbine Types	$C_{OT} = 760\,000(\frac{P}{1000})^{0.71} \times 2.71828^{-0.003H}$	$	R13.12/$	2010	1.50%	$C_{OT} = 8\,926\,717(\frac{P}{1000})^{0.71} \times 2.71828^{-0.003H}$	USBR (2011a)	

The additional costs for a hydropower project could be broken down further into the following categories as summarised in Table A-4 to Table A-6.

Table A-4: Initial Planning Costs distribution

Initial Planning Costs (IPC)			
Component	**Percentage of IPC for Component**	**Source**	**Motivation**
Investigation and preliminary design	77%	Bonthuys (2016)	The information was obtained from a recent study done on hydropower installations in South Africa.
Environmental and social assessment	10%		
Legal and Regulatory	13%		

Table A-5: Capital Expenditure Costs distribution

Capital Expenditure Costs (CEC)			
Component	**Percentage of CEC (excl. turbine)**	**Source**	**Motivation**
Preliminary and general	25.6%	Bonthuys (2016) and Loots (2013)	The information has been obtained from two sources based on South African hydropower studies. These percentages obtained also correlate to those given in other sources such as USBR (2011a) and Aggidis (2010).
Access to site	1.0%		
Intake structure/penstock	6.5%		
Powerhouse and tailrace	7.6%		
Electromechanical and controls	13.8%		
Transformer/transmission	27.9%		
Construction supervision	6.4%		
Contingencies	9.7%		
Disposal	1.5%		

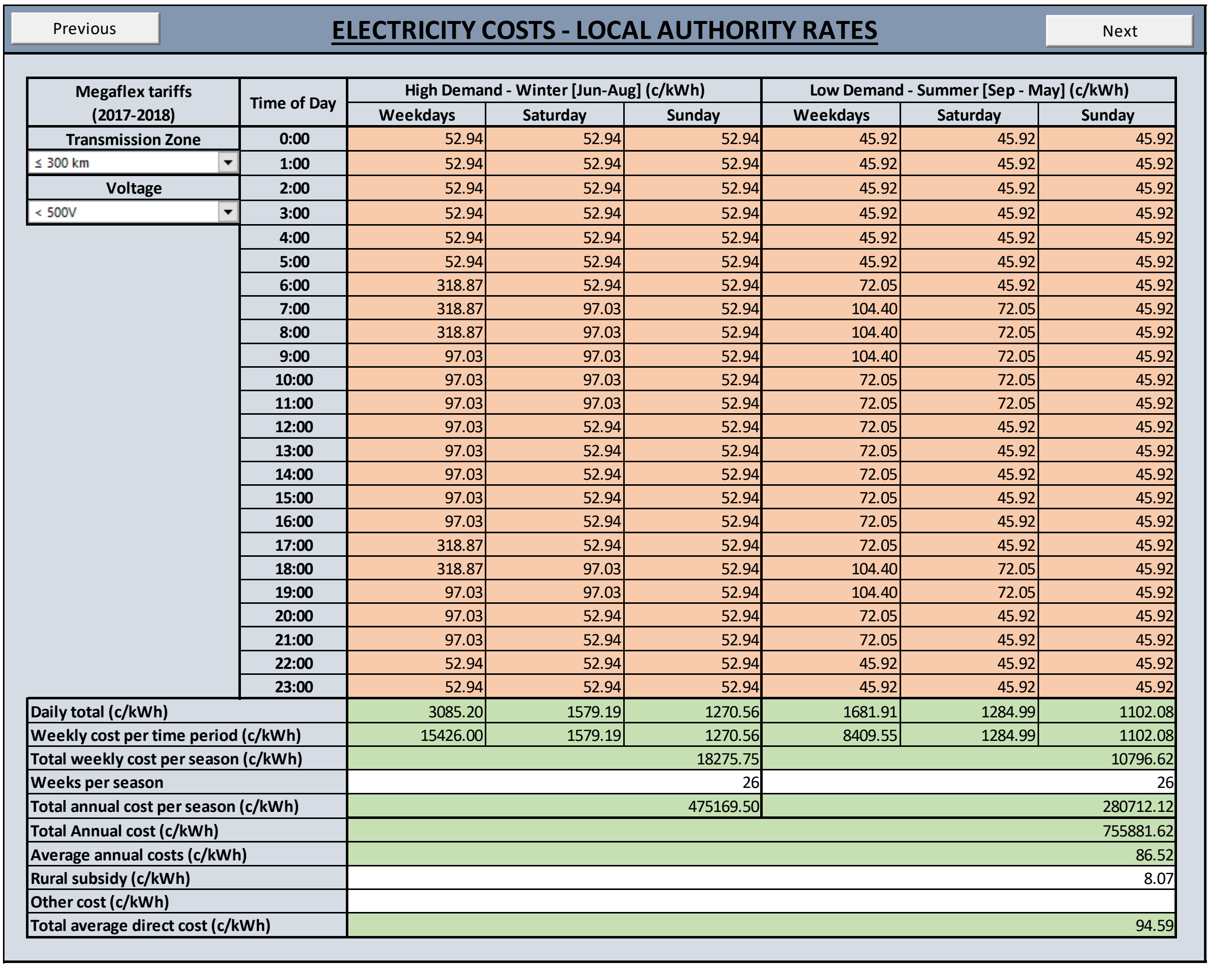
Table A-6: Annual Operational and Maintenance Costs

Annual operation and maintenance costs (O&M Costs)			
Component	**Percentage of CEC for component**	**Source**	**Motivation**
Civil	0.3%	Loots (2013) and Van Vuuren *et al.* (2014)	The information was obtained during a recent study on Hydropower stations in South Africa, and these percentages also correlate with USBR (2011a).
Electrical and mechanical	2.0%		
Transmission	0.8%		
Operation	0.4%		
Insurance	0.3%		
Overall	1.0%		

A.3 ELECTRICITY TARIFFS

For the HDAT the electricity tariffs were based on Megaflex 2017-2018 tariffs from Eskom, as they are generally used by the municipalities. However, the HDAT was designed to allow changing the tariffs if required by the user between local and non-local authorities (Table A-7 and Table A-8).

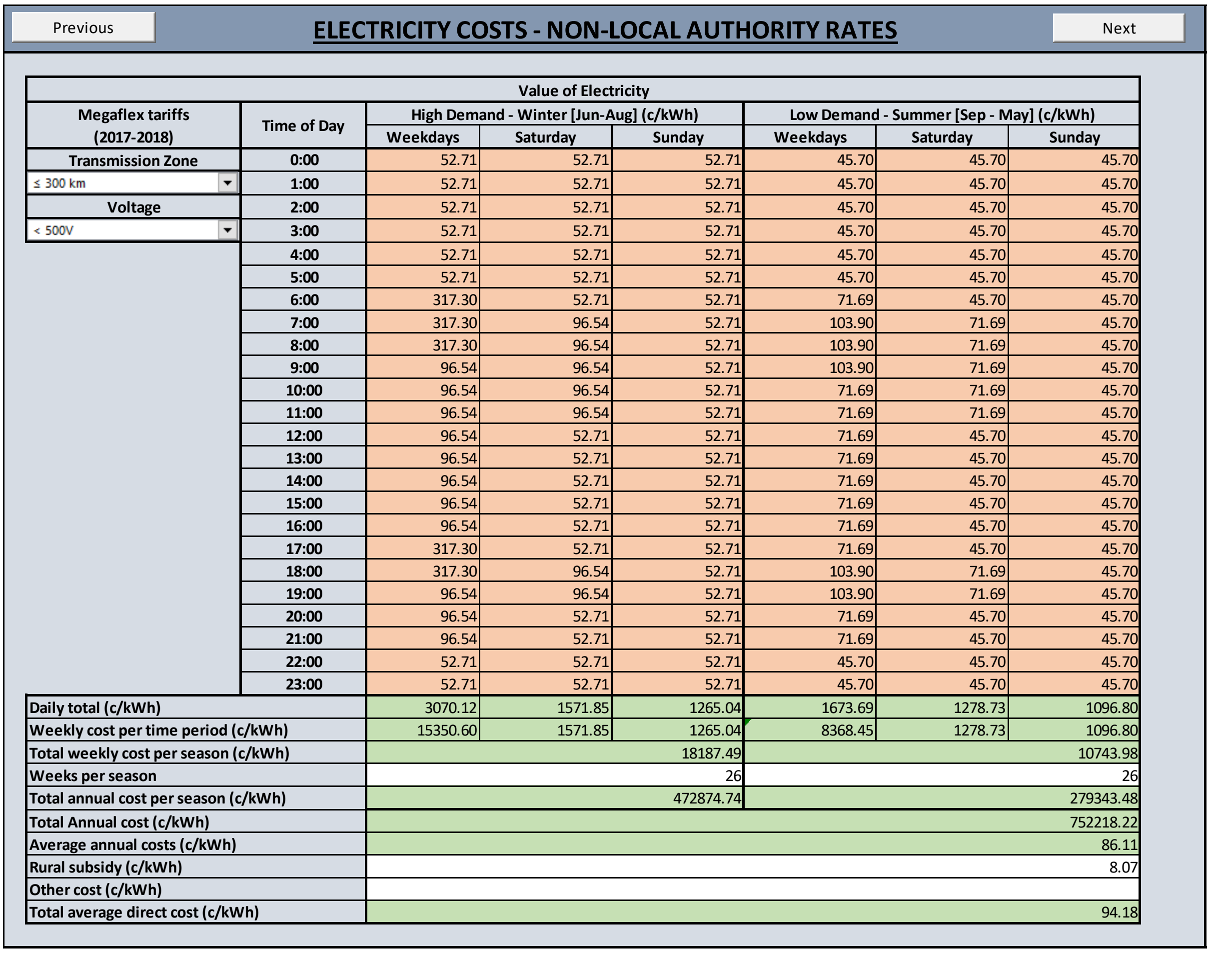
Table A-7: Megaflex Local Authority Rates (Eskom, 2017b).



ELECTRICITY COSTS - LOCAL AUTHORITY RATES

Megaflex tariffs (2017-2018)	Time of Day	High Demand - Winter [Jun-Aug] (c/kWh)			Low Demand - Summer [Sep - May] (c/kWh)		
		Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday
Transmission Zone	0:00	52.94	52.94	52.94	45.92	45.92	45.92
≤ 300 km	1:00	52.94	52.94	52.94	45.92	45.92	45.92
Voltage	2:00	52.94	52.94	52.94	45.92	45.92	45.92
< 500V	3:00	52.94	52.94	52.94	45.92	45.92	45.92
	4:00	52.94	52.94	52.94	45.92	45.92	45.92
	5:00	52.94	52.94	52.94	45.92	45.92	45.92
	6:00	318.87	52.94	52.94	72.05	45.92	45.92
	7:00	318.87	97.03	52.94	104.40	72.05	45.92
	8:00	318.87	97.03	52.94	104.40	72.05	45.92
	9:00	97.03	97.03	52.94	104.40	72.05	45.92
	10:00	97.03	97.03	52.94	72.05	72.05	45.92
	11:00	97.03	97.03	52.94	72.05	72.05	45.92
	12:00	97.03	52.94	52.94	72.05	45.92	45.92
	13:00	97.03	52.94	52.94	72.05	45.92	45.92
	14:00	97.03	52.94	52.94	72.05	45.92	45.92
	15:00	97.03	52.94	52.94	72.05	45.92	45.92
	16:00	97.03	52.94	52.94	72.05	45.92	45.92
	17:00	318.87	52.94	52.94	72.05	45.92	45.92
	18:00	318.87	97.03	52.94	104.40	72.05	45.92
	19:00	97.03	97.03	52.94	104.40	72.05	45.92
	20:00	97.03	52.94	52.94	72.05	45.92	45.92
	21:00	97.03	52.94	52.94	72.05	45.92	45.92
	22:00	52.94	52.94	52.94	45.92	45.92	45.92
	23:00	52.94	52.94	52.94	45.92	45.92	45.92
Daily total (c/kWh)		3085.20	1579.19	1270.56	1681.91	1284.99	1102.08
Weekly cost per time period (c/kWh)		15426.00	1579.19	1270.56	8409.55	1284.99	1102.08
Total weekly cost per season (c/kWh)				18275.75			10796.62
Weeks per season				26			26
Total annual cost per season (c/kWh)				475169.50			280712.12
Total Annual cost (c/kWh)							755881.62
Average annual costs (c/kWh)							86.52
Rural subsidy (c/kWh)							8.07
Other cost (c/kWh)							
Total average direct cost (c/kWh)							94.59

Table A-8: Megaflex, Non-local Authority Rates (Eskom, 2017b).



ELECTRICITY COSTS - NON-LOCAL AUTHORITY RATES

Value of Electricity							
Megaflex tariffs (2017-2018)	Time of Day	High Demand - Winter [Jun-Aug] (c/kWh)			Low Demand - Summer [Sep - May] (c/kWh)		
		Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday
Transmission Zone	0:00	52.71	52.71	52.71	45.70	45.70	45.70
≤ 300 km	1:00	52.71	52.71	52.71	45.70	45.70	45.70
Voltage	2:00	52.71	52.71	52.71	45.70	45.70	45.70
< 500V	3:00	52.71	52.71	52.71	45.70	45.70	45.70
	4:00	52.71	52.71	52.71	45.70	45.70	45.70
	5:00	52.71	52.71	52.71	45.70	45.70	45.70
	6:00	317.30	52.71	52.71	71.69	45.70	45.70
	7:00	317.30	96.54	52.71	103.90	71.69	45.70
	8:00	317.30	96.54	52.71	103.90	71.69	45.70
	9:00	96.54	96.54	52.71	103.90	71.69	45.70
	10:00	96.54	96.54	52.71	71.69	71.69	45.70
	11:00	96.54	96.54	52.71	71.69	71.69	45.70
	12:00	96.54	52.71	52.71	71.69	45.70	45.70
	13:00	96.54	52.71	52.71	71.69	45.70	45.70
	14:00	96.54	52.71	52.71	71.69	45.70	45.70
	15:00	96.54	52.71	52.71	71.69	45.70	45.70
	16:00	96.54	52.71	52.71	71.69	45.70	45.70
	17:00	317.30	52.71	52.71	71.69	45.70	45.70
	18:00	317.30	96.54	52.71	103.90	71.69	45.70
	19:00	96.54	96.54	52.71	103.90	71.69	45.70
	20:00	96.54	52.71	52.71	71.69	45.70	45.70
	21:00	96.54	52.71	52.71	71.69	45.70	45.70
	22:00	52.71	52.71	52.71	45.70	45.70	45.70
	23:00	52.71	52.71	52.71	45.70	45.70	45.70
Daily total (c/kWh)		3070.12	1571.85	1265.04	1673.69	1278.73	1096.80
Weekly cost per time period (c/kWh)		15350.60	1571.85	1265.04	8368.45	1278.73	1096.80
Total weekly cost per season (c/kWh)		18187.49			10743.98		
Weeks per season		26			26		
Total annual cost per season (c/kWh)		472874.74			279343.48		
Total Annual cost (c/kWh)		752218.22					
Average annual costs (c/kWh)		86.11					
Rural subsidy (c/kWh)		8.07					
Other cost (c/kWh)							
Total average direct cost (c/kWh)		94.18					

A.4 INFLATION RATES

The inflation rates for the HDAT were taken from an average general inflation rate in the country, which correlates to the values utilised by Loots (2013). These inflation rates were used for the general, operation and maintenance inflation rates. Similarly, the maintenance factor assumed that little maintenance is required during the first five years of operation. However thereafter the equipment ages and more maintenance would be required. Table A-9 summarised the inflation rates as well as the maintenance factor used by the HDAT.

Table A-9: Inflation and maintenance factors used as default values in HDAT

Inflation and maintenance factors over the design life					
Year	**Annual inflation rate**				**Maintenance factors**
	Electricity	**Operation**	**Maintenance**	**General**	
0	8.0%	5.3%	5.3%	5.3%	0.8
1	8.0%	5.1%	5.1%	5.1%	0.8
2	8.0%	6.0%	6.0%	6.0%	0.8
3	8.0%	6.0%	6.0%	6.0%	0.8
4	8.0%	6.0%	6.0%	6.0%	0.8
5	10.0%	6.0%	6.0%	6.0%	1.0
6	10.0%	6.0%	6.0%	6.0%	1.0
7	10.0%	6.0%	6.0%	6.0%	1.0
8	10.0%	6.0%	6.0%	6.0%	1.0
9	10.0%	6.0%	6.0%	6.0%	1.0
10	10.0%	6.0%	6.0%	6.0%	1.0
11	10.0%	6.0%	6.0%	6.0%	1.0
12	10.0%	6.0%	6.0%	6.0%	1.0
13	10.0%	6.0%	6.0%	6.0%	1.0
14	10.0%	6.0%	6.0%	6.0%	1.0
15	6.0%	6.0%	6.0%	6.0%	1.2
16	6.0%	6.0%	6.0%	6.0%	1.2
17	6.0%	6.0%	6.0%	6.0%	1.2
18	6.0%	6.0%	6.0%	6.0%	1.2
19	6.0%	6.0%	6.0%	6.0%	1.2
20	6.0%	6.0%	6.0%	6.0%	1.25
21	6.0%	6.0%	6.0%	6.0%	1.25
22	6.0%	6.0%	6.0%	6.0%	1.25
23	6.0%	6.0%	6.0%	6.0%	1.25
24	6.0%	6.0%	6.0%	6.0%	1.25
25	6.0%	6.0%	6.0%	6.0%	1.25
26	6.0%	6.0%	6.0%	6.0%	1.25
27	6.0%	6.0%	6.0%	6.0%	1.25
28	6.0%	6.0%	6.0%	6.0%	1.25
29	6.0%	6.0%	6.0%	6.0%	1.25
30	6.0%	6.0%	6.0%	6.0%	1.5

APPENDIX B

DRAWINGS OF THE ORIGINAL ALIWAL NORTH HYDROPOWER STATION IN EARLY 1900’s

B. APPENDIX B

This appendix contains all the old drawings of the decommissioned hydropower plant at Aliwal North.

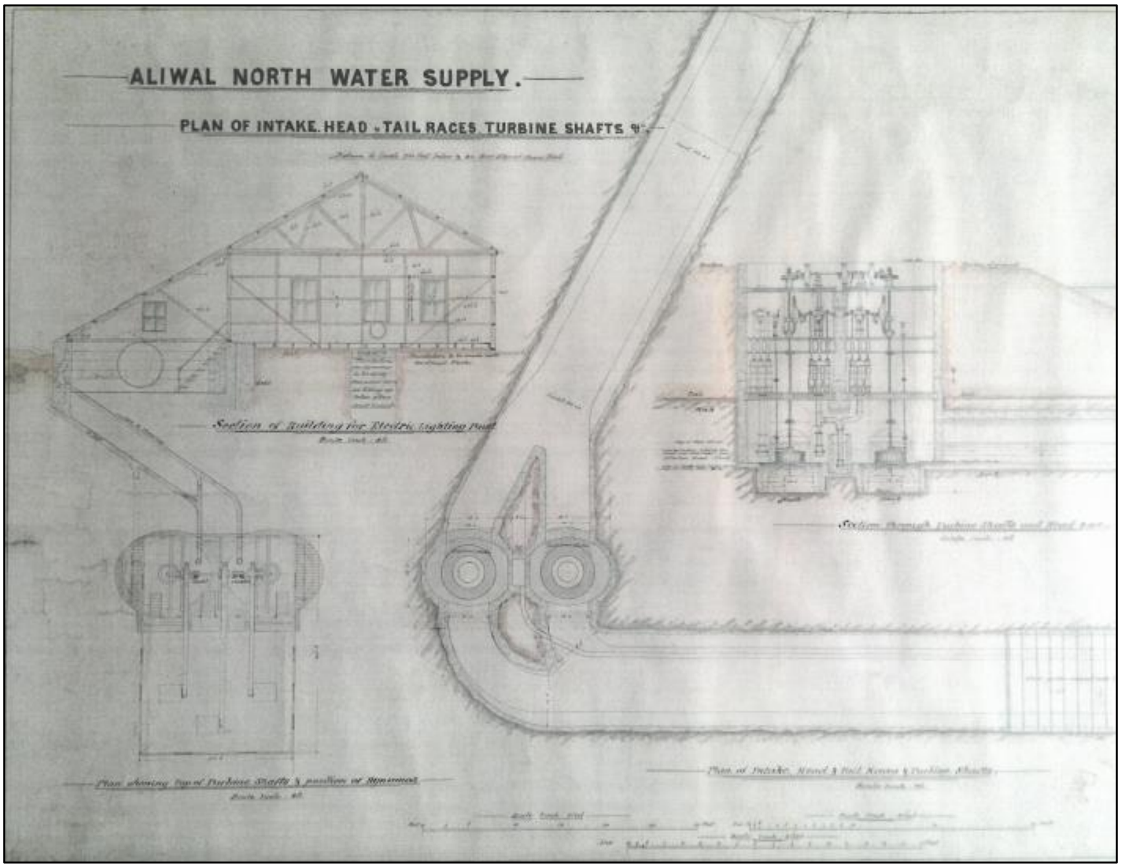


Figure B-1: Plan of intake structure, head and tailraces, pump house and turbine shafts

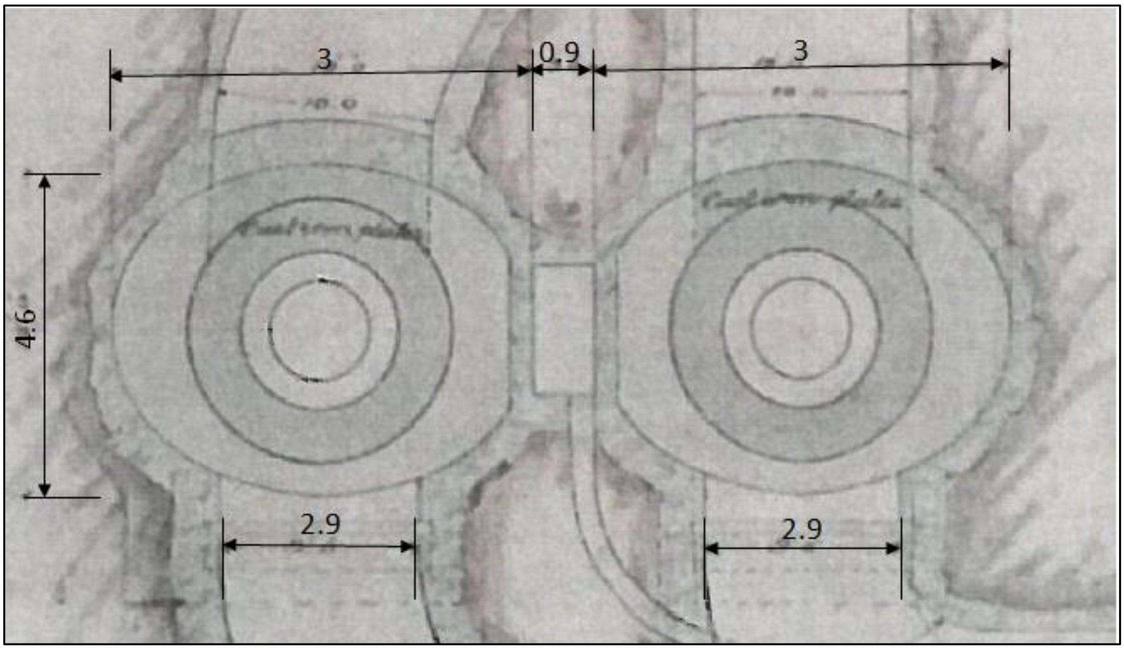


Figure B-2: Hydropower Shaft Plan

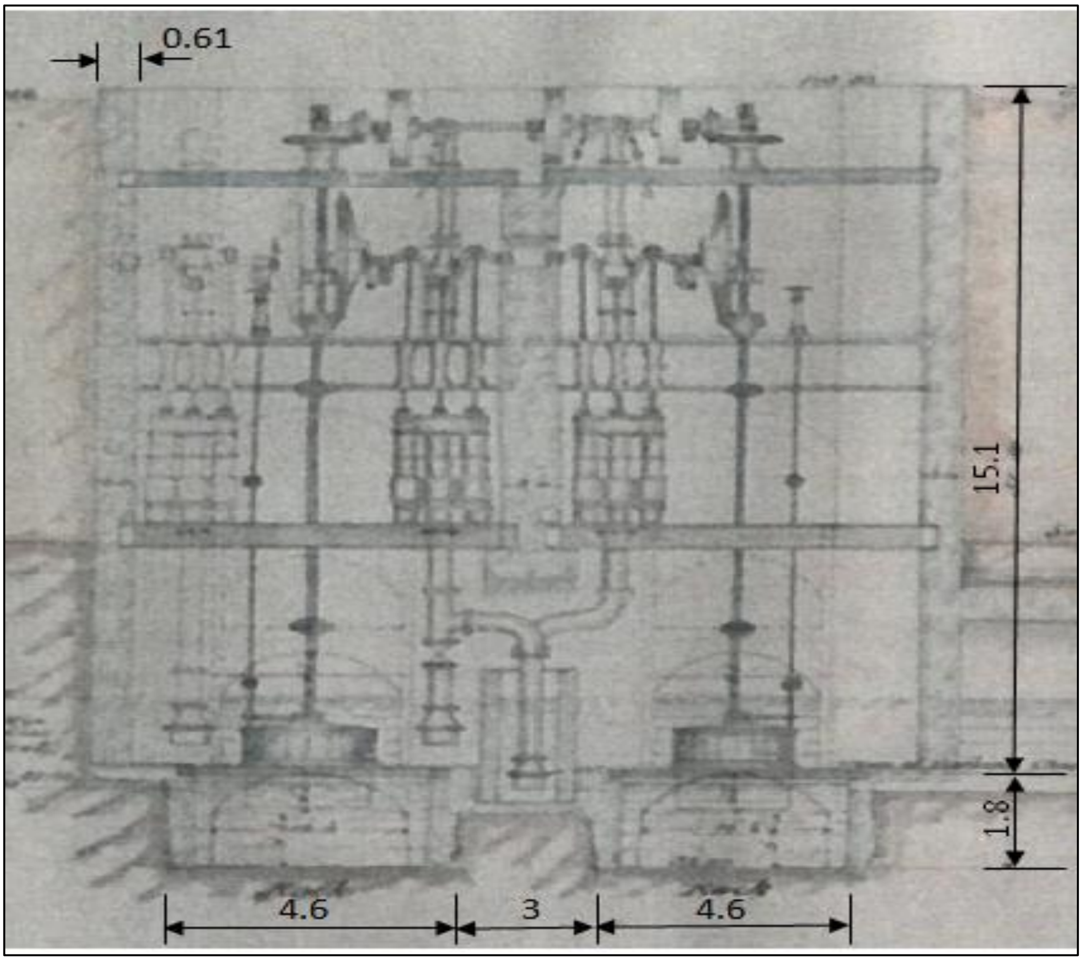


Figure B-3: Hydropower Shaft Section

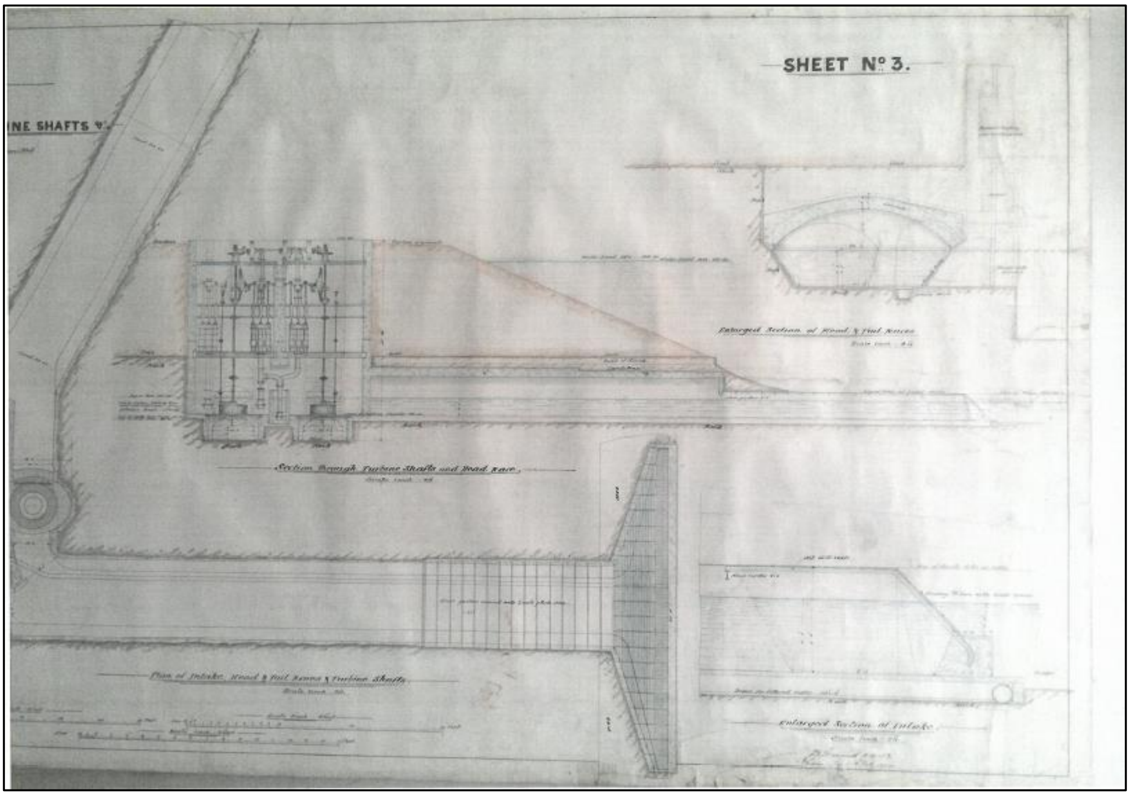


Figure B-4: Plan of intake, headrace, tailraces and turbine shafts and section through turbine shafts

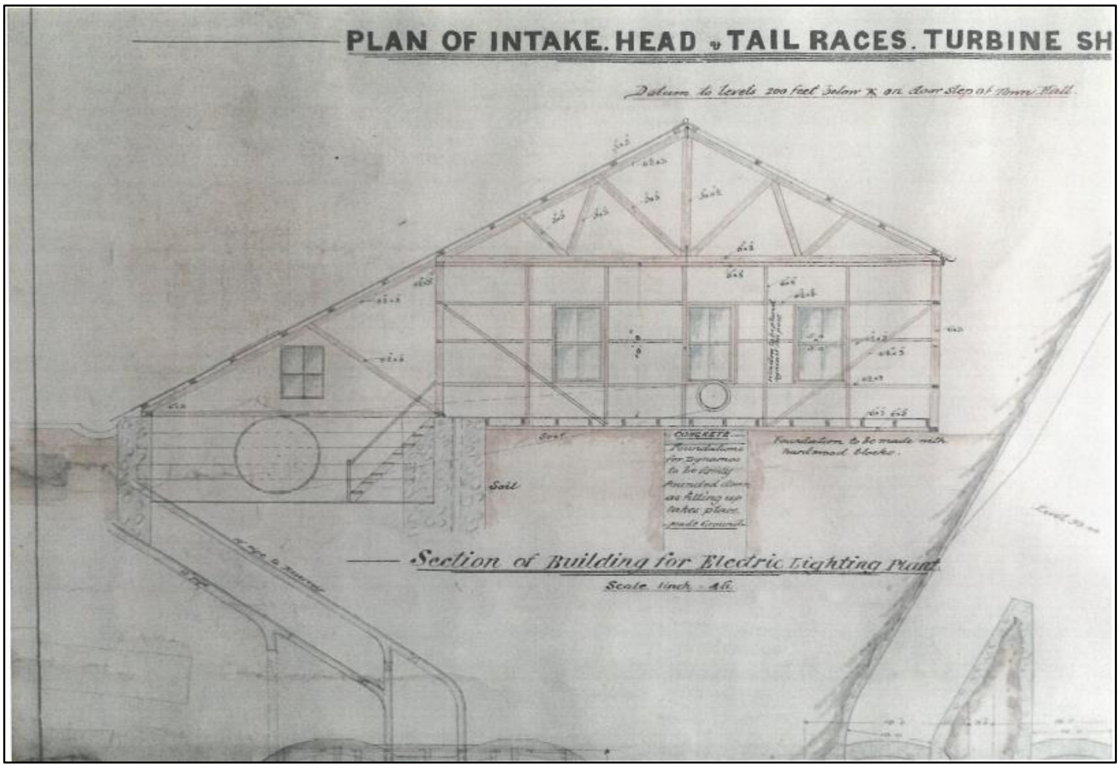


Figure B-5: Section of pump house

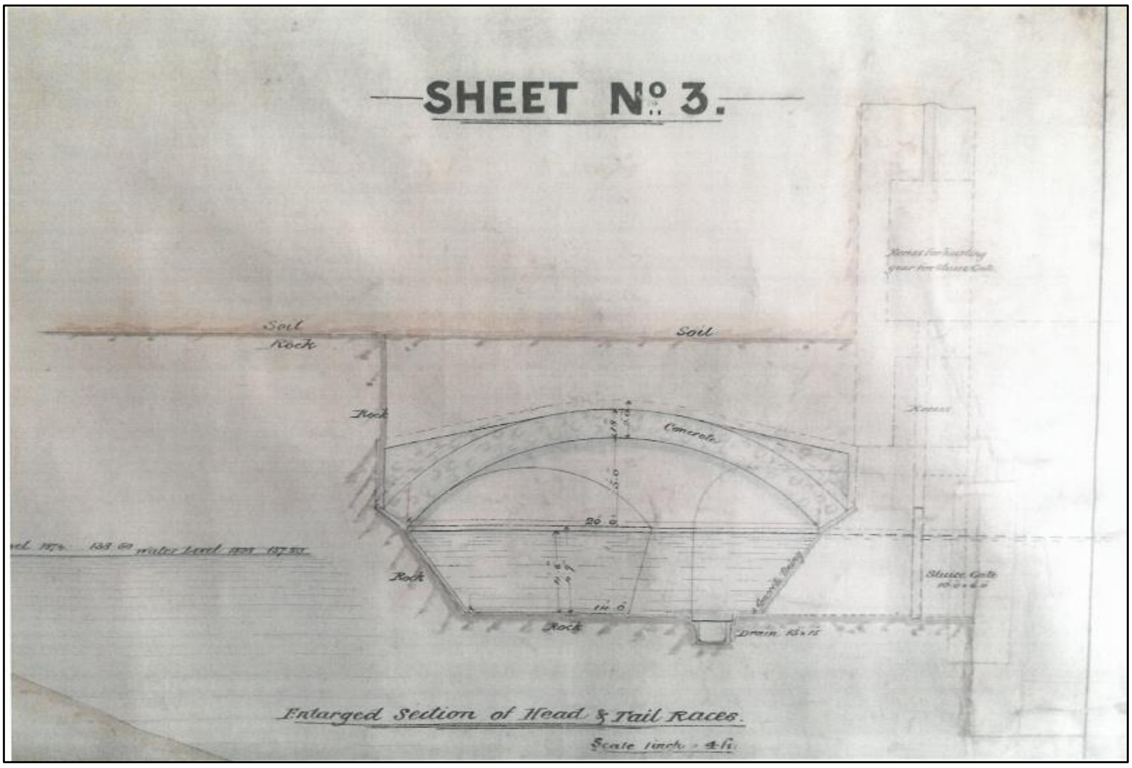


Figure B-6: Enlarged section of head and tailrace

APPENDIX C

DRAWINGS OF THE MODIFIED TURBINES

C. APPENDIX C

List of Drawings included in this appendix:

- General Arrangement 1
- General Arrangement 2
- General Arrangement Civil Details
- Turbine Shroud Detail
- Face Plates
- Flow Straightener
- Walkway
- Gantry

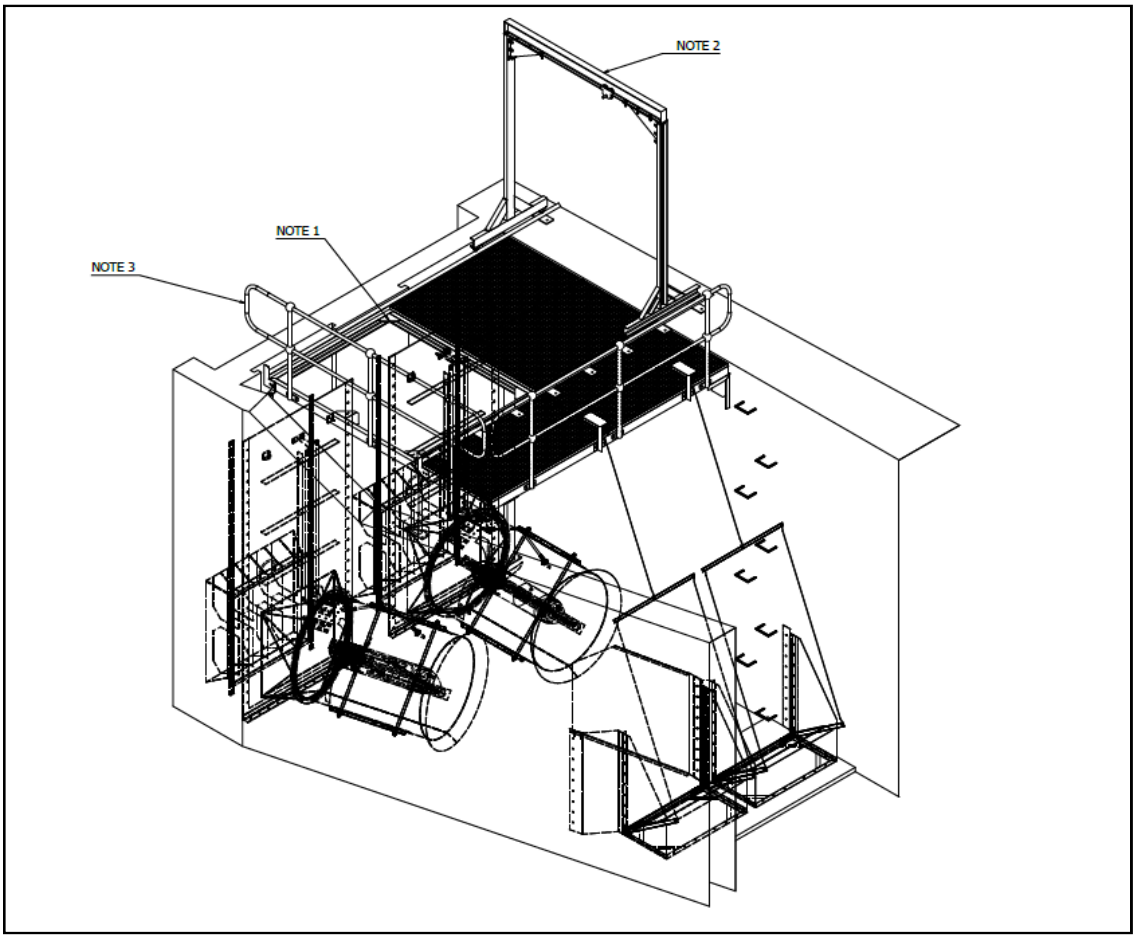


Figure C-1: General Arrangement 1

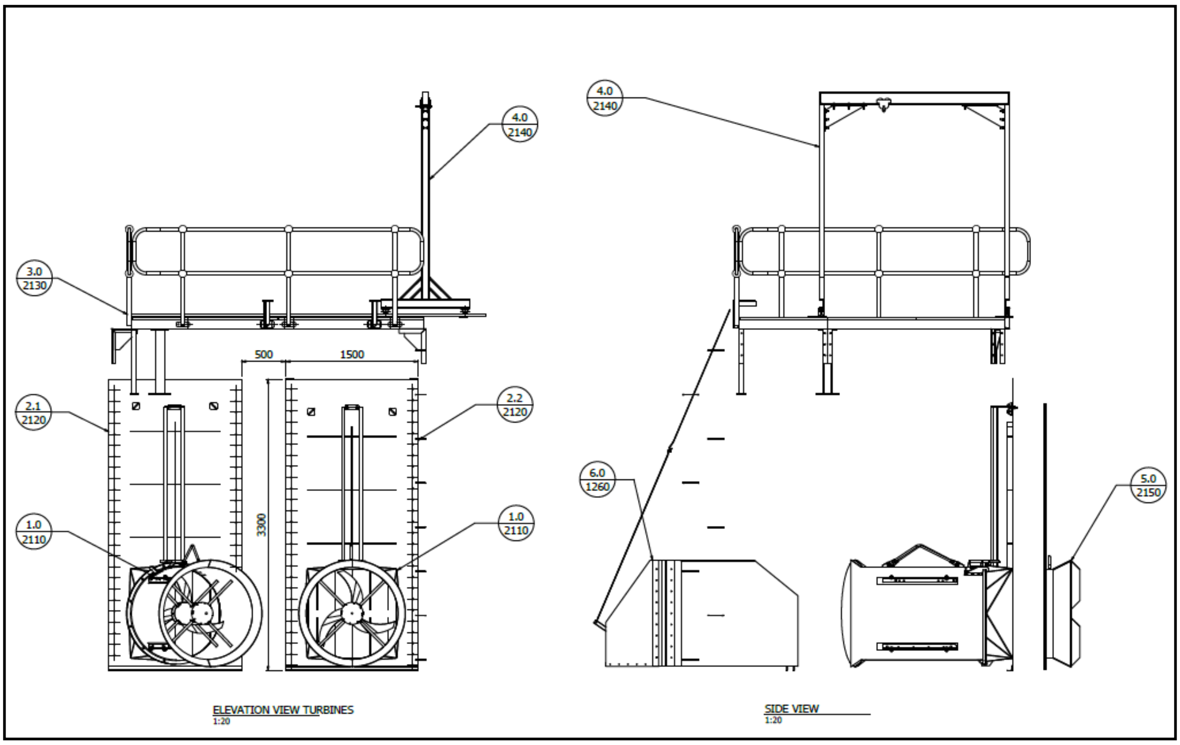


Figure C-2: General Arrangement 2

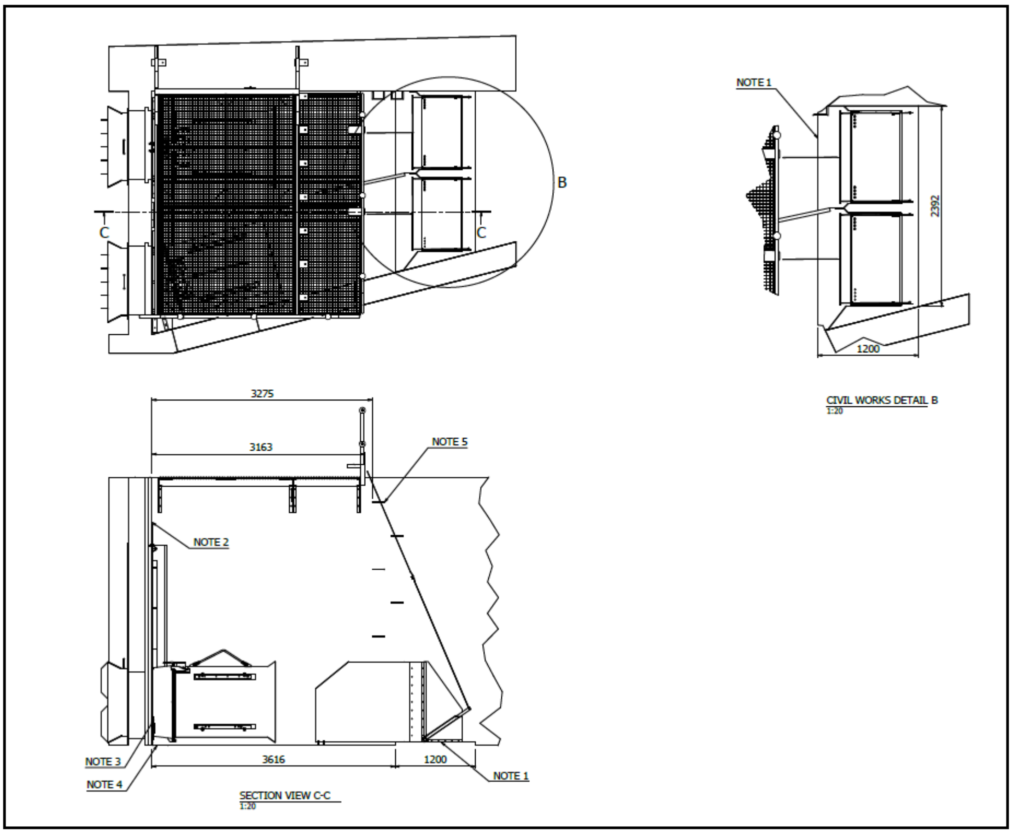


Figure C-3: General Arrangement and Civil Details

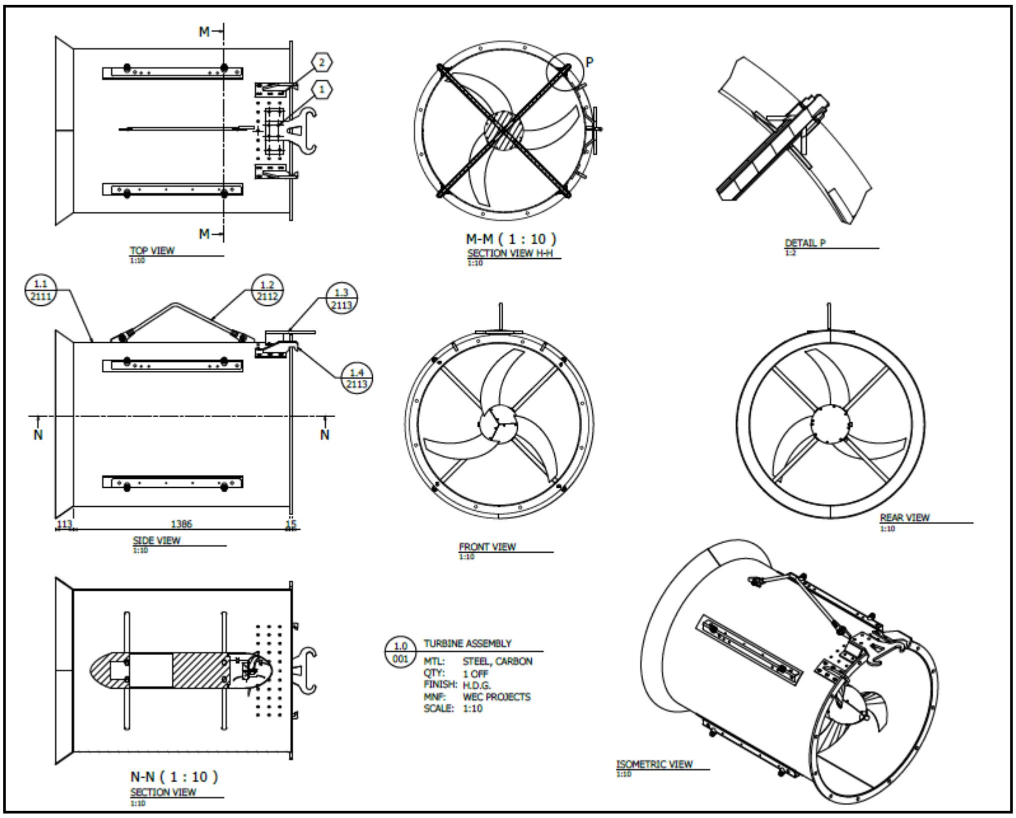


Figure C-4: Turbine Shroud Details

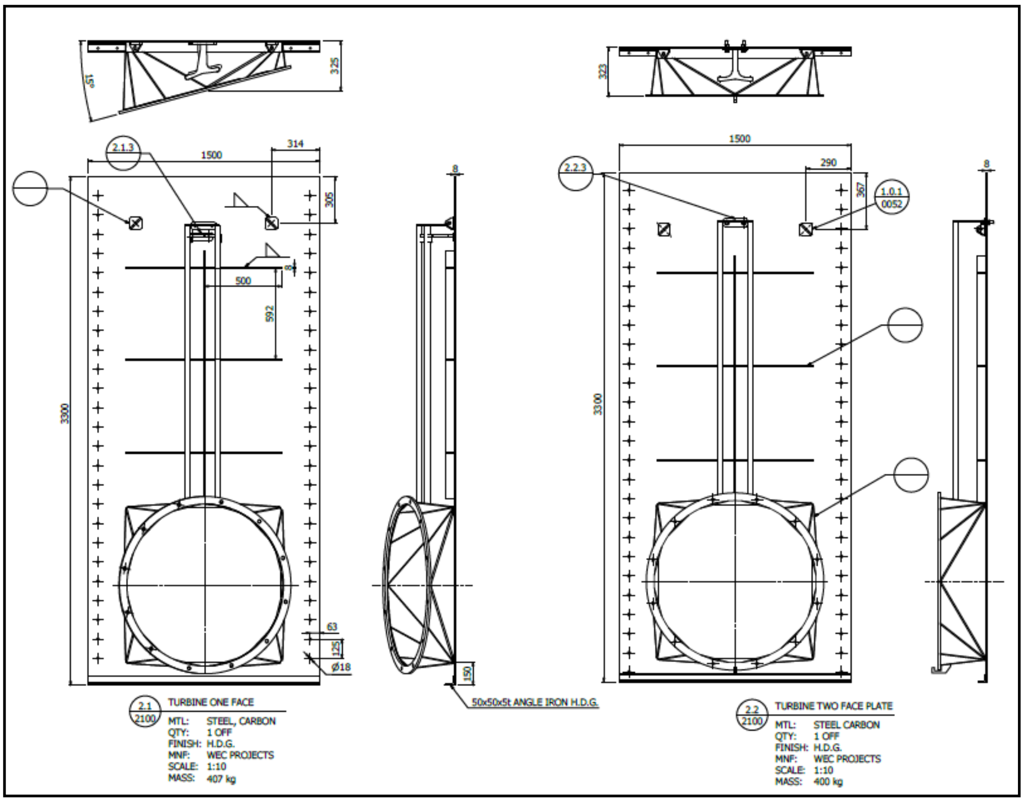


Figure C-5: Face Plates

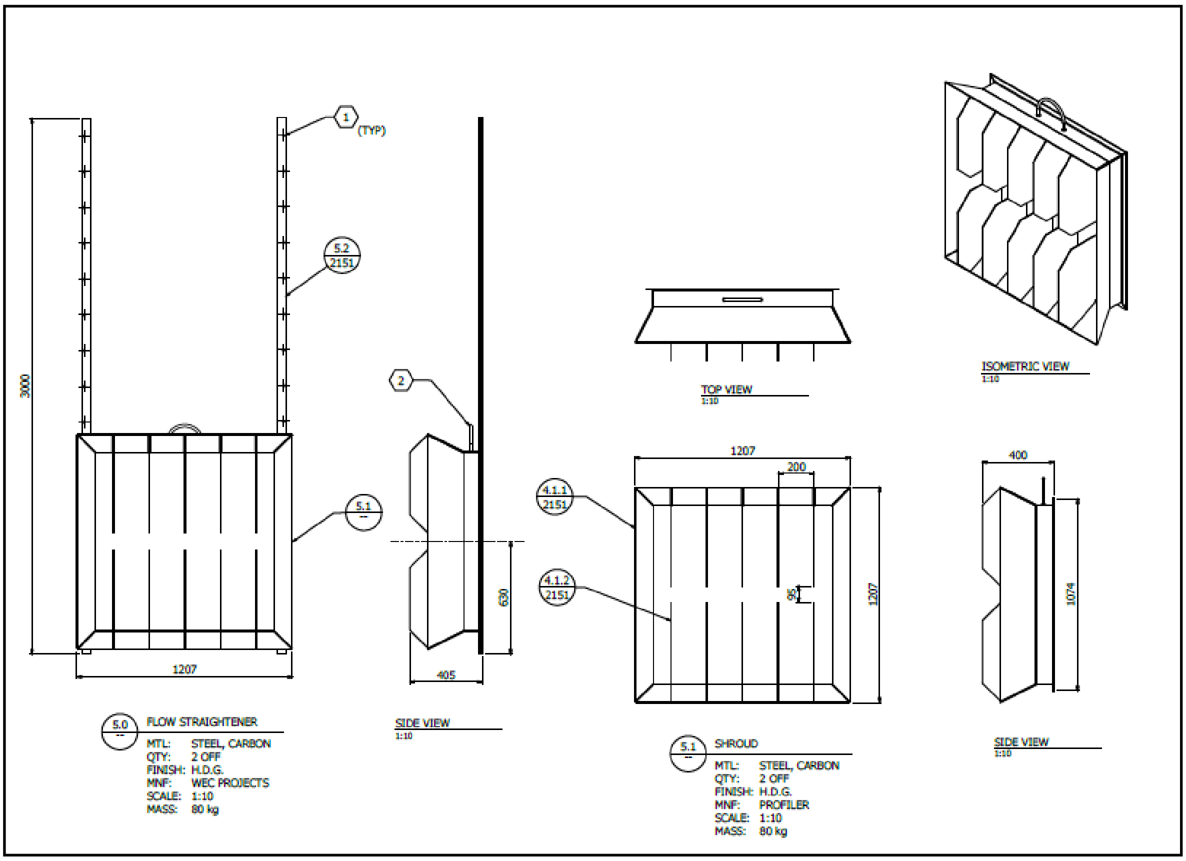


Figure C-6: Flow Straightener

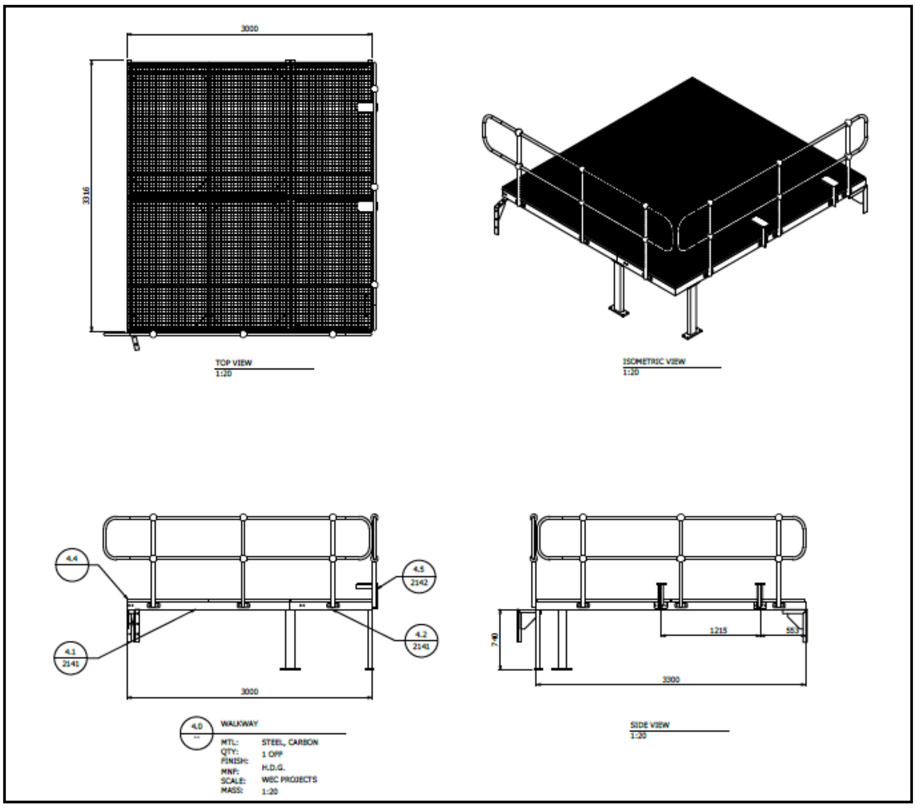


Figure C-7: Walkway

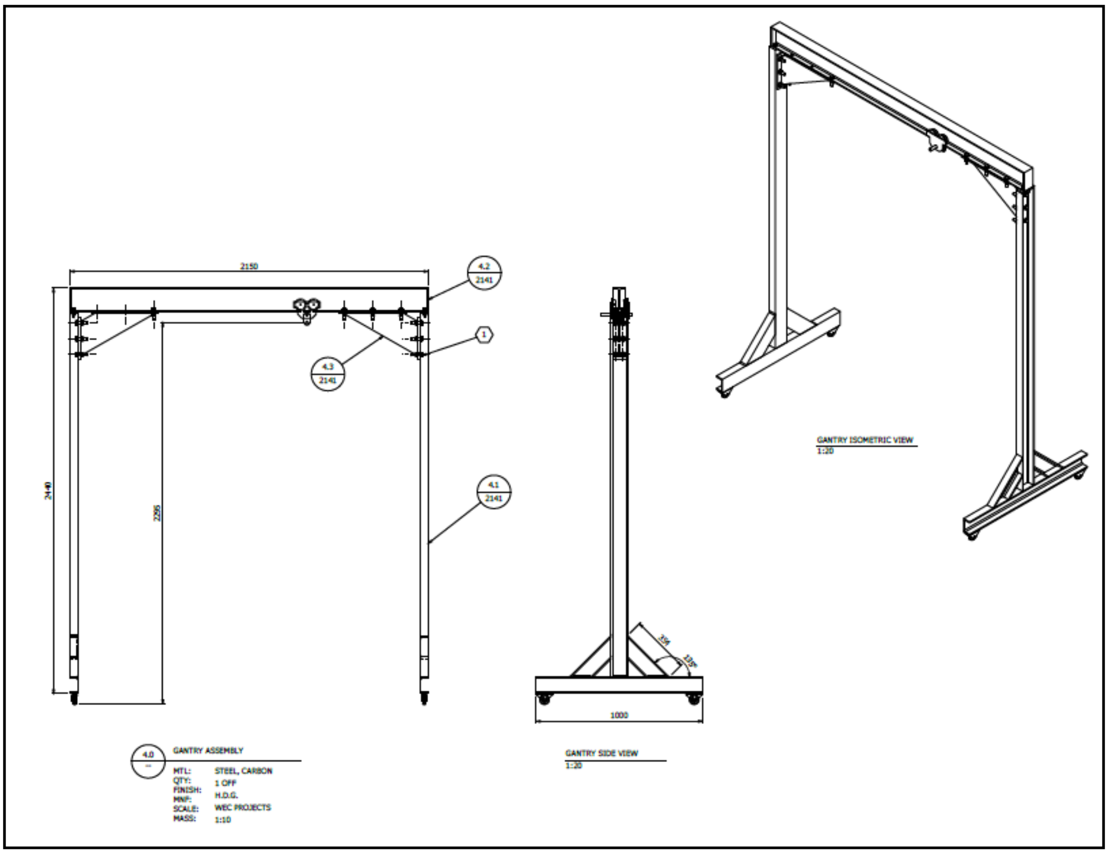


Figure C-8: Gantry

APPENDIX D

PHOTOS TAKEN DURING INSTALLATION

D. APPENDIX D

Appendix D contains the pictures taken on site during the different stages of the installation of the kinetic hydropower turbines at Aliwal North's Water Treatment Works.

Figure D-1: Scouring section of the Intake structure where the new turbine will be installed

Figure D-2: Assembly of the new walkway

Figure D-3: New walkway frame in place

Figure D-4: New walkway in place with head rails for safety

Figure D-5: Inlet shrouds in place (upstream side of the scouring section of the intake structure)

Figure D-6: Face plates in position

Figure D-7: Modified kinetic turbine

Figure D-8: Kinetic turbines connected onto face plates

Figure D-9: Covering of the exposed turbine wiring

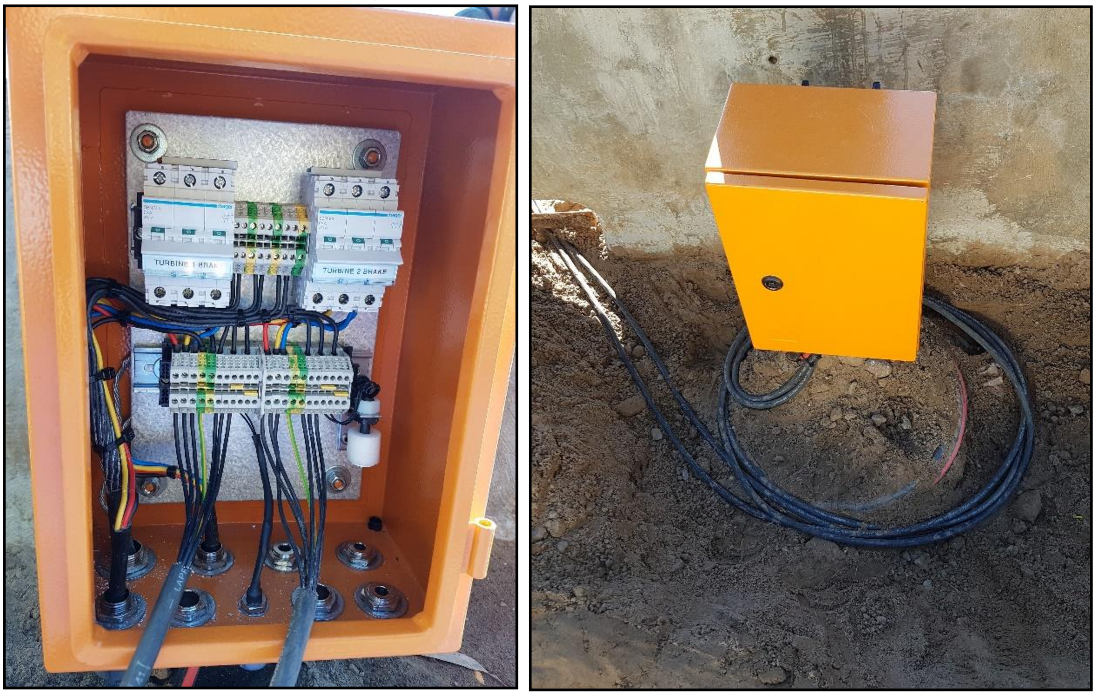


Figure D-10: Electricity box connecting the turbines and the powerhouse, located next to the intake structure.

Figure D-11: Powerhouse containing the new control panel as well as the existing control panels for the pumps

Figure D-12: Control Panel housing the Inverter, Rectifier and Dump Loads

Figure D-13: Inverter

Figure D-14: Initial power output of one turbine once installation was complete

APPENDIX E

LINKS TO RELEVANT APPLICATION FORMS AND INFORMATION

E. APPENDIX E

List of relevant links:

NERSA

- NERSA website:
  http://www.nersa.org.za
- General Information required by NERSA in terms of electricity regulation Act, 2006 (Act No. 4 of 2006):
  http://www.nersa.org.za/Admin/Document/Editor/file/Electricity/Forms/Distribution%20Forms/NERSA%202016%20G-Forms%20Cover%20Letter-%20Submission%20of%20generation%20information%20required%20by%20NERSA%20in%20Terms%20of%20The%20Electricity%20Regulation%20Act,%202006%20%20ACT%20NO%204%20OF%202006.pdf
- Electricity Generation Licence Application Form:
  http://www.nersa.org.za/ContentPage.aspx?PageId=628&PageName=Generation Form
- Electricity Distribution Licencing Form:
  http://www.nersa.org.za/ContentPage.aspx?PageId=626&PageName=Distribution Forms

ESKOM

- Eskom website:
  http://www.eskom.co.za/Pages/Landing.aspx
- Guide for IPP Process (2011):
  http://www.eskom.co.za/Whatweredoing/Pages/GuideIPP.aspx
- Grid Connection Application Form:
  http://www.eskom.co.za/Whatweredoing/GAU/Documents/GridConnecApplRev10-Jul2016.pdf
- Eskom Electricity Tariffs and charges:
  http://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariffs_And_Charges.aspx
- Eskom Standard Offer Program:
  http://www.eskom.co.za/IDM/MeasurementVerification/Documents/Standard_Offer_General_M_and_V_Guideline_v1r0_-_2010117.pdf