THE SOUTH AFRICAN HYDROPOWER ATLAS

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THE SOUTH AFRICAN HYDROPOWER ATLAS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

The electrification of urban areas in South Africa, including many informal settlements, reached its culmination during recent years. However the electrification of rural areas has still a long way to go before most of the rural communities will be provided with reliable and sustainable electricity supply. The national electricity grid managed by the parastatal ESKOM has been experiencing problems due to various reasons, particularly since 2008. The further development of rural electrification presently is in the doldrums mainly due to the shortage in the generation capacity available to ESKOM which need to be made available to the users already connected to the national grid. The increases in the price of electricity are starting to be felt by the urban- as well as the rural communities. The primary electricity infrastructure (i.e. coal-fired power stations, major supply lines and distribution of electricity within urban areas) is becoming rapidly insufficient and cannot sustain a supply against the demand for electricity from the existing and future users connected to the national grid.

The research project's aim is to enhance the uptake of micro-hydro technology, making local stakeholders (private sector, financial sector, government entities, etc.) aware of the opportunities that this technology brings, and the efforts required to get this technology successfully implemented in SA. The project provides general information regarding the assessment of hydropower potentials and provides the information required regarding the feasibility of such projects.

Potential for hydropower in South Africa

South Africa is acknowledged to be not particularly endowed with the best hydropower conditions as it might be elsewhere in Africa and the rest of the world. However, large quantities of raw and potable water are conveyed daily under either pressurised or gravity conditions over large distances and elevations.

An initial WRC scoping study highlighted the potential hydropower generation at the inlets to storage reservoirs. In South Africa there are 284 municipalities, several water supply utilities and mines, all owning and operating gravity water supply distribution systems which could be considered for small-, mini-, micro- and pico scale hydropower installations.

Most of these water supply/distribution systems could be equipped with turbines or pumps as turbines, supplementing and reducing the requirements for pressure control valves. The hydro energy may be used on-site and supplied to the national electricity grid or feeding an isolated electricity demand cluster.

There are also numerous storage dams in SA which release environmental releases or releases water for irrigation purposes which could be retrofitted with turbines to harness the available flow and pressure.

Hydropower, which utilises the flow of water from existing water infrastructure and rivers to generate electricity, is considered a good renewable energy source and an alternative to fossil fuels. The different locations where hydropower can be considered are illustrated in Figure i.

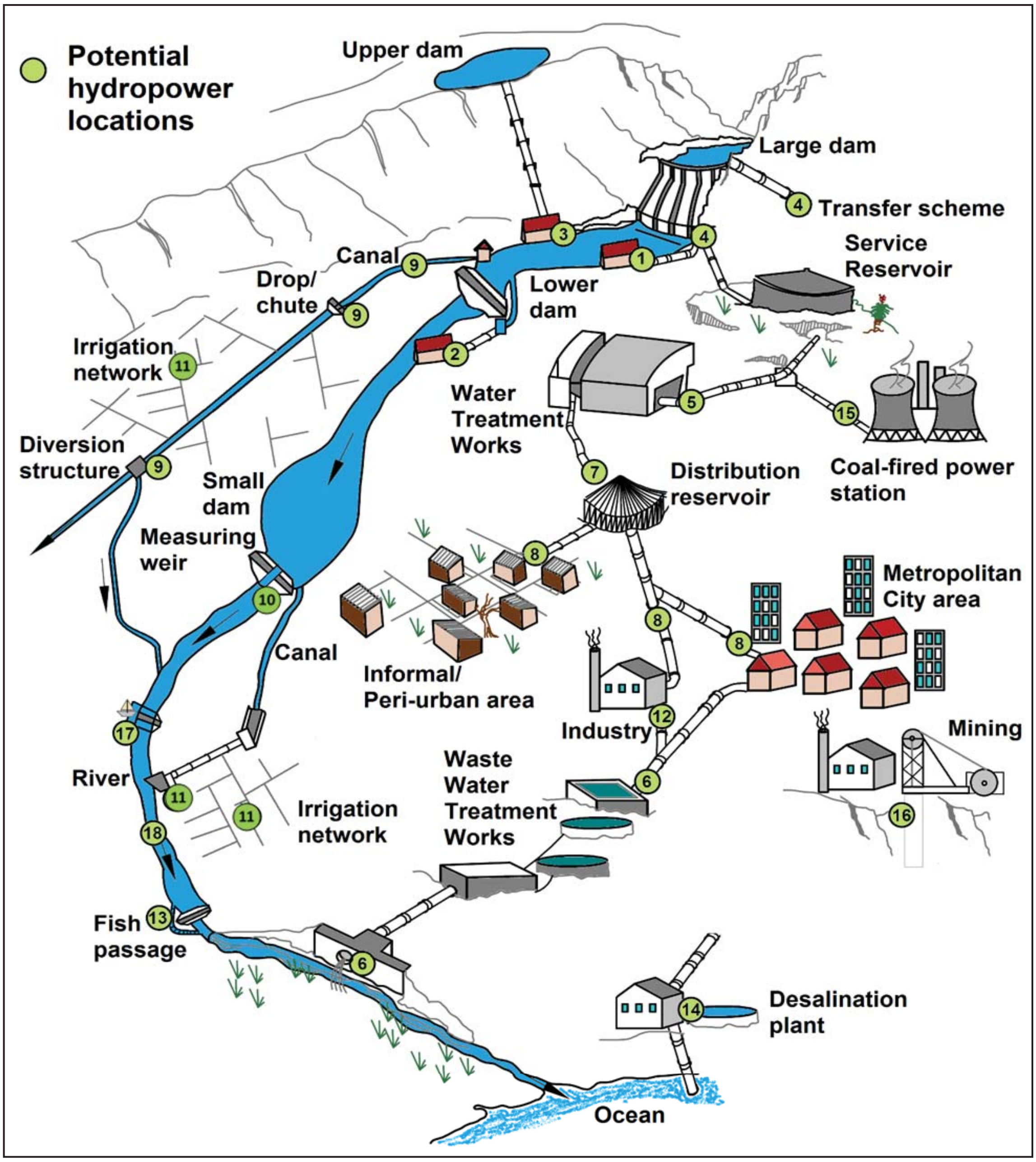

Figure i: Locations of electricity generation potential (Adapted from Loots *et al.* (2015))

Development of generic evaluation methods

The aim of this project was to create a web-based atlas to showcase the hydropower potential available in South Africa, thereby encouraging owners of South African water infrastructure and rivers to invest in renewable and sustainable energy generation sources. Various water infrastructure and river data sources were identified and incorporated in the development of evaluation frameworks for all hydropower types (run-of-river, conduit, hydrokinetic, weirs, WWTW, WTW, pumped storage and storage schemes) considered in the initial assessment. The identified sources were incorporated in the development of evaluation frameworks which assisted in the evaluation of hydropower potential in South African rivers and water infrastructure.

A summary of the data sources and criteria included in each framework is shown in Figure ii.

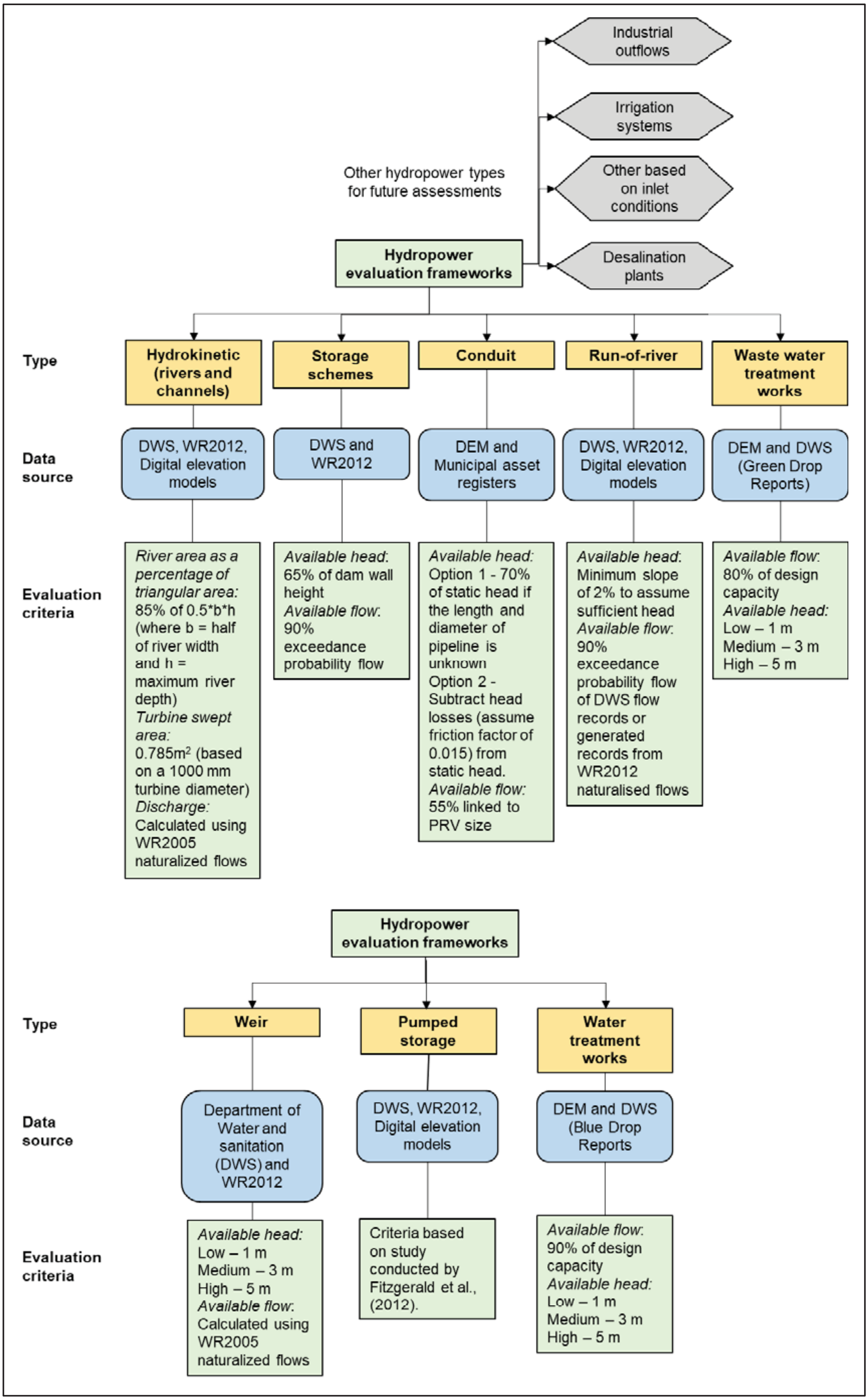

Figure ii: Summary of identified data sources and selected criteria for hydropower evaluation

Selection of suitable platform to host web-based atlas

The conceptual layout for the web-based South African hydropower atlas was completed with the inclusion of different base layers. Various platforms were considered, and the functionality compared to eventually select the most suitable online platform (ArcGIS Online) to host the South African Hydropower Atlas. Using this online platform, the graphical user interface could be developed based on the conceptual layout.

Assessment tools

To assist in developing hydropower opportunities various assessment tools have been developed, which assisted in the evaluation of potential sites and assessment of feasibilities.

The South African Hydropower Atlas

The development evaluation framework with the identified data sources were used to assess the available hydropower potential in SA. Figure iii shows the developed atlas. The South African hydropower atlas will aid in the enhanced the uptake of hydropower technologies in SA and will assist in the development of a database capturing all hydropower opportunities in SA.

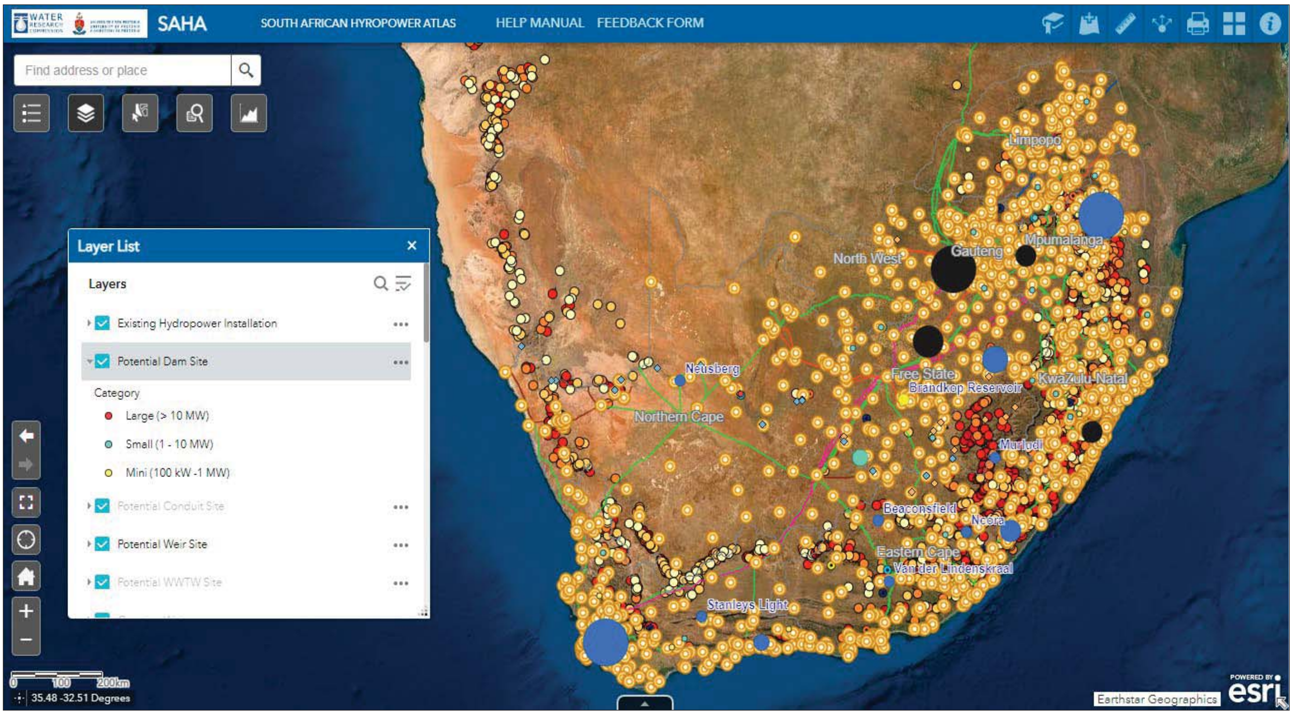

Figure iii: Summary of identified data sources and selected criteria for hydropower evaluation

Link to South African Hydropower Atlas: https://uparcgis.maps.arcgis.com/apps/webappviewer/index.html?id=9618bcec00ad4f5398f4cc0cd1a447b8&utm_source=web+map&utm_medium=res&utm_campaign=hydropower

Using the identified data sources and developed frameworks the following potential was identified:

- Total conduit hydropower potential of approximately 83 MW from 919 assessed sites;
- Total run-of-river potential between 760 and 882 MW (1.04 MW/km determined in rivers with numerous specific assessed sites);
- Total hydropower of 1102 MW from 654 storage schemes;
- Total hydropower potential of 0.73-3.7 MW from 124 WWTWs;
- Total hydropower potential of 0.67-3.3 MW from 122 WTWs;
- Total hydropower potential of 10.6-50.3 MW from 424 gauging weirs; and
- Total pumped storage potential of approximately 31 000 MW (from overlapping sites).
- Total of more than 22 MW hydropower potential in the primary transfer schemes.

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ACRONYMS & ABBREVIATIONS

AADD	average annual daily demand
BA	basic assessment
B/C	benefit/cost ratio
CO_2	carbon dioxide
D	diameter of penstock or pipe (m)
DEA	Department of Environmental Affairs
Dem	system's daily demand (kWh or MWh)
DME	Department of Minerals and Energy (now DoE)
DoE	Department of Energy
DSS	decision support system
EIA	environmental impact assessment
ESHA	European Small Hydropower Association
g	gravitational acceleration (m/s^2) (typically 9.81 m/s^2)
H	effective pressure head (m)
h_f	friction loss (m)
h_l	secondary losses (m)
I	electrical current (A)
IHA	International Hydropower Association
IPP	independent power producer
IRR	internal rate of return
K	secondary loss coefficient
L	length of penstock (m)
LCC	life cycle cost
n	number of years
NERSA	National Energy Regulator of South Africa
NPV	net present value of benefits
O&M	operation and maintenance
P	mechanical power output (W)
P_{actual}	actual power output of turbine (W)
$P_{theoretical}$	theoretical output at 100% efficiency (W)
PW	present worth
Q	flow rate through the turbine (m^3/s)
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
ROI	return on investment
ROD	Record of decision
SABS	South African Bureau of Standards
SANEDI	South African National Energy Development Institute
USBR	United States Bureau of Reclamation
V	potential difference (V)
v	velocity of water in penstock or pipe (m/s)
η	Hydraulic efficiency of the turbine (%)
λ	friction coefficient of penstock or pipe (m)
ρ	Hydraulic efficiency of the turbine (%)

CHAPTER 1: INTRODUCTION

Since 2008 the South African energy suppliers, ESKOM, has been experiencing numerous generation and supply problems. These included the supply not matching the demand as well as the escalation of the electricity costs (Steyn, 2006). Thus, the primary electricity infrastructure (i.e. the coal-fired power stations, the major supply lines and the distribution of the electricity within the urban areas) is rapidly becoming insufficient and cannot sustain a supply against the demand of existing as well as future electricity users connected to the national grid.

ESKOM is currently improving their supply capacity by constructing two new coal-fired power stations, Kusile and Medupi (4800 MW and 4764 MW respectively). The Ingula Pumped Storage Scheme with a capacity of 1332 MW was also built to improve the capacity during peak demand periods. But this is still not sufficient electricity for South Africa. Thus, alternative energy sources need to be considered. The Renewable Energy Independent Power Producers Procurement (REIPPP) program which was opened by the South African Government in 2011, enables private developers to install up to 3725 MW renewable energy generation capacity. These renewable energy resources include biomass, biogas, solar radiation, wind power and small hydropower schemes (Department of Energy, 2017).

A nation’s industrial growth as well as the quality of life are 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 and utilizing existing water infrastructure in South Africa. These hydropower projects could be stand-alone isolated mini grids or could be linked to the national electricity grids.

Over the last few years several new water supply infrastructures were constructed in the rural areas for the upliftment of the rural communities. These different infrastructures should urgently be re-evaluated for their possible opportunities in power generation as well as their efficiencies if power is being generated already. On the more constant rivers, small dams and water intakes were built and pipelines were installed to transport the water to water treatment works as well as communities. At all of these different locations, a possible hidden potential of hydropower ranging from a pico (<20kW), a micro (up to 100kW), or even mini (up to 1MW) scheme, to possibly supply a school or clinic, a cultural village centre or even a whole community (Jonker Klunne, 2009). Municipalities, water utilities and government entities (DWS, ESKOM, etc.) also own and operate water infrastructure which could be modified to provide a multipurpose function.

Although not very well documented, small scale hydropower used to play an important role in the provision of energy to urban and rural areas of South Africa. The first provision of electricity to cities like Cape Town and Pretoria was based on small scale hydro, while smaller towns also started local distribution of electricity through isolated grids powered by small hydro stations (Jonker Klunne, 2009). However, with the expansion of the national electricity grid and the cheap, coal generated power supplied through this grid, large numbers of systems were decommissioned.

Small hydropower is a proven, mature technology with a long track record, including in Africa. The gold mines at Pilgrims' Rest (South Africa), for example, were powered by two 6 kW hydro turbines as early as 1892, complemented by a 45 kW turbine in 1894 to power the first electrical railway (Eskom (2009) in Jonker Klunne, 2012). Many countries in Africa do have a rich history of small scale hydropower, but over time large numbers of these stations have fallen into disrepair. Some because the national grid reached their location, some because a lack of maintenance or even pure neglect.

Recently initiatives have seen the light in a number of countries in Africa to revive the small hydro sector, either through international development agencies or through private sector led initiatives. Particular in Central Africa (Rwanda), East Africa (Kenya, Tanzania and Uganda) as well as Southern Africa (Malawi, Mozambique and Zimbabwe) new initiatives are focusing on implementing small hydropower projects, while in South Africa the first new small hydro station in 20 years was opened in 2009, with more under development.

Even though South Africa is classified as a water scares country by the experts, there is still enough water for small scale hydropower schemes, which could help with the sustainable energy supply for the future (Banks & Schäffler, 2006).

During the launch of the BioEnergy Atlas the Minister of Science and Technology indicated that the lack of capacity and limited access to data at different spheres of government contributed to the delayed uptake of bioenergy in South Africa. This can also be said for the development of hydropower, although the WRC in particular have aimed to showcase hydropower technologies in SA. This research project makes the data required for evaluating the hydropower potential more well-known and accessible and outline the necessary steps that need to be followed when considering development of a hydropower site (decommissioned, existing, or new site) in SA. The Hydropower Atlas will provide policy makers with a way to address the lack of development and facilitate local, provincial and national government plans to exploit hydropower resource opportunities.

The research project's aim is to enhance the uptake of micro-hydro technology, making local stakeholders (private sector, financial sector, government entities, etc.) aware of the opportunities that this technology brings and the efforts required to get this technology successful implemented in SA. The project provides general information regarding the assessing of hydropower potentials and provides the information required regarding the feasibility of such projects.

Most of the other renewable sectors have already developed atlases depicting the opportunities for development in South Africa.

CHAPTER 2: POTENTIAL FOR HYDROPOWER IN SOUTH AFRICA

2.1 BACKGROUND

Hydropower, which utilises the flow of water from existing water infrastructure and rivers to generate electricity, is considered a good renewable energy source and an alternative to fossil fuels. The different locations where hydropower can be considered are illustrated in Figure 2-1.

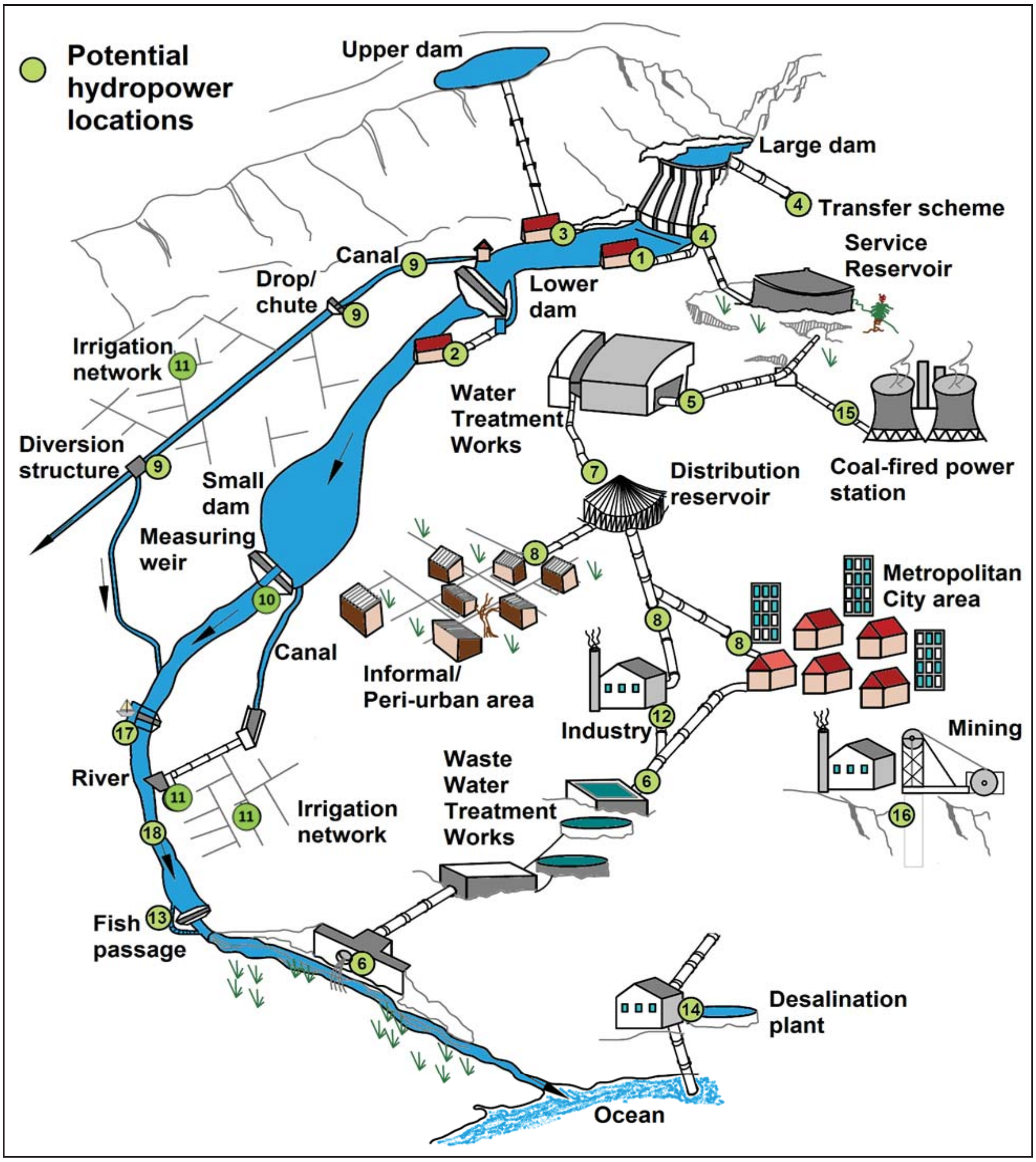


Figure 2-1: Locations of electricity generation potential (Adapted from Loots *et al.* (2015))

The water-energy nexus principle describes the directly proportional relationship between water supply and energy demand, which states that the increase in energy use causes an increase in the demand of water and an increased demand in clean, potable water, increases the energy demand. It is, therefore, recommended to explore technologies that can couple water and energy supply, especially in areas with high population densities (Gilron, 2014).

Research conducted by (Spänhoff, 2014), shows that hydropower is the greatest renewable energy contributor to the world's electricity generation, with a 16.5% contribution in 2012. The installed hydropower capacity is forecasted to exceed 1400 GW by 2035, which will be the largest renewable energy source in terms of installed capacity. The top ranked countries with regards to installed hydropower capacity are the United States, Brazil, Canada and China, with the latter having an installed capacity (249 GW in 2012) exceeding the cumulative capacity of the three former countries (Hennig *et al.*, 2013). Furthermore, the global hydropower potential as reported in the World Hydropower Atlas, published by the International Journal of Hydropower and Dams is approximately 14 400 TWh/year (International Journal of Hydropower and Dams, 2000). According to (Paish, 2002), only 18% of the total amount of hydropower potential was exploited in 1999, which is approximately half the installed hydropower capacity of today (IHA, 2019). The literature, therefore, indicates that even though the world's installed hydropower capacity has almost doubled in the last 30 years, there is still a significant amount of hydropower potential to be exploited as shown in Figure 2-2.

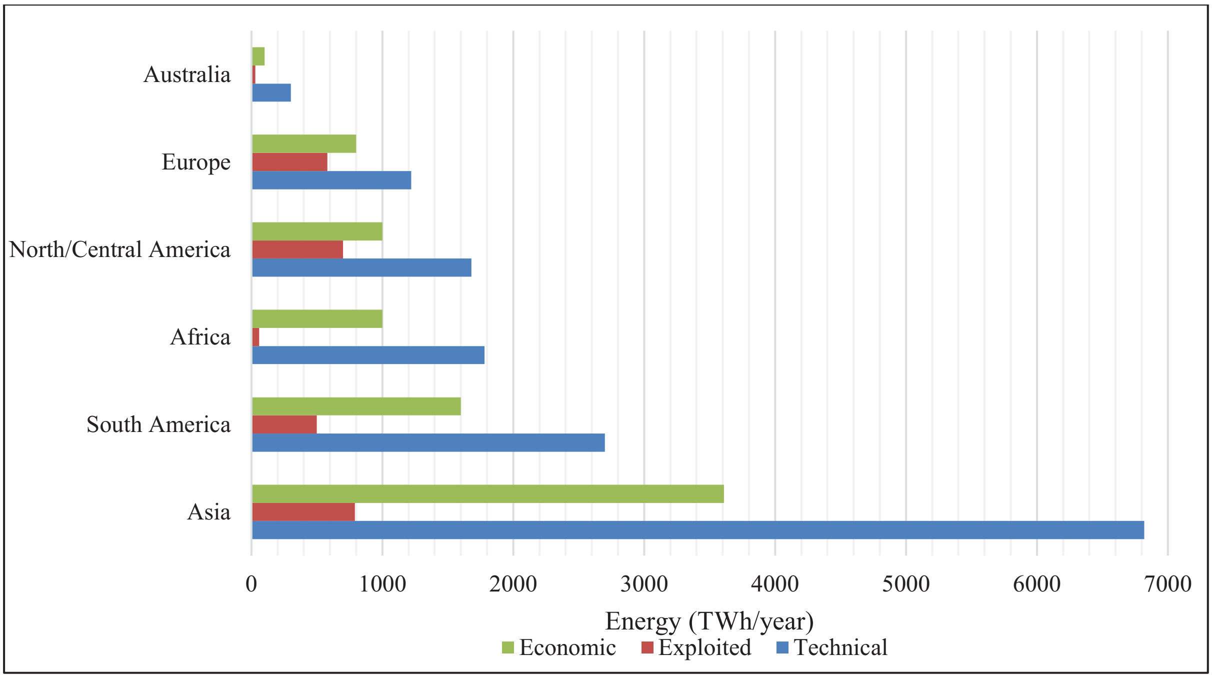


Figure 2-2: World hydropower potential (adapted from Pérez-Sánchez *et al.* (2017))

2.1.1 Large hydropower

Although there is no internationally agreed definition of different hydropower sizes (Paish, 2002), the distinction between large and small hydropower is whether the installed capacity is larger than 10 MW. Mini hydropower plants refer to installations with an installed capacity between 100 kW and 1 MW. Furthermore, Micro hydropower plants usually have an installed capacity between 20 kW to 100 kW where hydropower plants with an installed capacity below 20 kW is usually referred to as pico hydropower (Loots *et al.*, 2014; Pérez-Sánchez *et al.*, 2017).

The international standards defines all dams with a wall height greater than 15 m as large (Nilsson *et al.*, 2005). Using this criterion, (Ansar *et al.*, 2014) identified 245 of the largest hydropower sites in the world, constructed between 1934 and 2007. These sites (with the distribution according to the different continents as shown below) includes 97 dams devoted to energy generation, 89 dams for multipurpose use and 59 dams devoted to irrigation and other uses.

- 25 dams are located in South Asia;
- 29 dams in Europe;
- 29 dams in Africa;
- 40 dams in North America;
- 50 dams in Latin America; and
- 72 dams in East Asia

2.1.2 Small hydropower

The increase in small hydropower development can largely be attributed to the development of the Francis turbine. This development contributed to the establishment of electrical services in either remote areas or areas located a relative distance from the supply points (Mataix, 2009).

Countries with the largest installed small hydropower capacity are China, Brazil, India, Canada and some European countries (Pérez-Sánchez *et al.*, 2017). A summary of the installed small hydropower capacity of selected countries or continents is provided in Table 2-1.

Table 2-1: Installed small hydropower capacity of selected countries or continents (adapted from (Pérez-Sánchez *et al.*, 2017))

Country/Continent	Small hydropower capacity
China	China has an installed small hydropower capacity equal to 80 GW supplying approximately 650 rural areas (Hennig *et al.*, 2013)
Brazil	There are currently 397 small hydropower plants in operation with an installed capacity of 3.5 GW (in comparison to the 25.9 GW potential available) (Pereira *et al.*, 2013)
United States	Approximately half a million sites were identified with an installed capacity of 100 GW (Kosnik, 2010).
Australia	There are currently 60 existing small hydropower plants with an installed capacity of 0.15 GW (Bahadori *et al.*, 2013).
India	The potential capacity was quantified as 15 GW of which 2.4 GW is currently installed in 674 plants (Nautiyal *et al.*, 2011).
Japan	In 2010 the installed hydropower capacity of Japan was non-existent, but with a hydropower installation rate of 300 MW per year, the installed hydropower capacity is forecast to reach 3.5 GW soon (Liu *et al.*, 2013; Ushiyama, 1999)
Europe	The installed small hydropower capacity in 2005 was 12.4 GW of which Italy, Spain, Germany, Austria, France, Sweden, Switzerland and Norway contributed more than 90% of the capacity (ESHA, 2012).
Africa	Small hydropower, with a capacity lower than 300 kW, is developed in rural areas across the continent (Miller *et al.*, 2015).

Over the last decades the development of mini hydropower plants (100 kW – 1 MW) has been considered an effective means of providing electricity to isolated communities and it is predicted that hydropower will expand in developing countries such as India and Pakistan, as the demand for rural electrification is increased (Bhutto *et al.*, 2012).

Spänhoff (2014) supports the statement by arguing that countries with increased demand for rural electrification will benefit economically from small hydropower and will, therefore, have the highest contribution to the expansion of small hydropower sites. According to (Miller *et al.*, 2015), an increased trend in the development of hydropower plants with an installed capacity less than 300 kW is being observed in Africa as the social benefit associated with these smaller installations are significant. Mini, micro and pico hydropower can, therefore, be utilised as part of the solution to provide electrification to the approximately 2.5 million households without power in SA (Statistics SA, 2017).

2.1.3 Hydropower working principles

Conventional hydropower generation at storage schemes utilises the head available as well as the discharge from the dam. The equation used for to calculate the power output of hydropower schemes (Equation 2-1) describes the relationship between power outputs, flow through the turbine and the available pressure head.

$$\boldsymbol{P = \eta \rho g Q H} \qquad \textbf{[2-1]}$$

Where:

P	=	mechanical power output (W)
η	=	hydraulic efficiency of the turbine (%)
ρ	=	density of water (1000 kg/m^3)
g	=	gravitational acceleration (9.81 m/s^2)
H	=	effective pressure head across the turbine (m)
Q	=	discharge (m^3/s)

The amount of energy that hydrokinetic devices extract from flow flowing water is dependent on the kinetic energy or velocity of the water. According to Kartezhnikova & Ravens, (2014) the power available from hydrokinetic devices per unit swept area is dependent on the efficiency of the turbine unit as well as the fluid density and flow velocity in the channel or river as shown in Equation 2-2.

$$\boldsymbol{PD = \xi \frac{\rho}{2} V^3} \qquad \textbf{[2-2]}$$

Where:

PD	=	Power density (W/m^2)
ξ	=	Device efficiency (%)
ρ	=	Fluid density (kg/m^3)
V	=	Fluid velocity (m/s)

Equation 2-3 provides a similar method to calculate the power generated through hydrokinetic turbines (Behrouzi *et al.*, 2016).

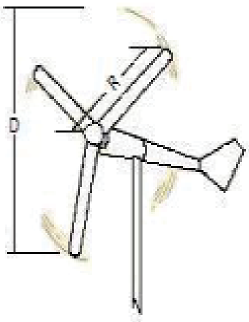
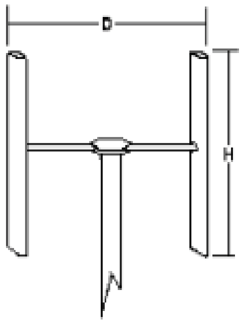
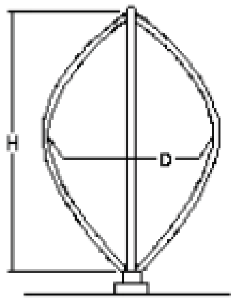
$$\boldsymbol{P = 0.5 {V_0}^3 \rho A_{ref} \eta_t} \qquad \textbf{[2-3]}$$

Where:

P	=	Power (W)
η_t	=	Total turbine efficiency
V_0	=	Fluid velocity (m/s)
ρ	=	Fluid density (kg/m^3)
A_{ref}	=	Hydrokinetic turbine swept area (m^2)

The swept area in the aforementioned equations is dependent of the rotor blade configuration and can be calculated as shown in Table 2-2.

Table 2-2: Swept area calculation based in blade configurations (Koko, 2014)

Rotor blade	Conventional rotor	H-Darrieus Rotor	Darrieus Rotor
Blade arrangement			
Swept area	$A = \pi R^2$	$A = DH$	$A = 0.65DH$

~D = Turbine diameter (m)
~H = Turbine height (m)
~R = Turbine radius (m)

2.1.4 Advantages of hydropower

Retrofitted hydropower utilises existing infrastructure and harnesses the energy already available for electricity generation. The advantage of retrofitted hydropower is that no new infrastructure is required for energy generation (Van Vuuren *et al.*, 2011). This explains the stamen by Pérez-Sánchez *et al.* (2017) that hydropower plants are considered the most feasible renewable energy type, when being compared to solar, wind, tidal and photovoltaic energy types. There are several benefits of using hydropower as a renewable energy source:

- Hydropower is a clean and renewable form of energy as it is generated by using the energy in the water due to the flow and the head without using the water itself (Frey & Linke, 2002);
- Hydropower does not result in any pollution (carbon dioxide, sulphurous oxides, nitrous oxides or ash), release of heat or toxic gasses (Frey & Linke, 2002);
- Hydropower has a low operation (as low as 1% of the initial investment due to high efficiency levels) and maintenance cost and is not subjected to inflation (Oud, 2002) (Loots, Van Dijk, Van Vuuren, & Bhagwan, 2014);
- Reliable and flexible operation is ensured with hydropower technology;
- Hydropower stations have a long operating lifetime (Frey & Linke, 2002); and
- Hydropower systems can easily respond to a change in load demand (Loots, Van Dijk, Van Vuuren, & Bhagwan, 2014) This flexibility in energy supply makes hydropower ideal for either base load or peak load generation (or in some cases both) (Egre & Milewski, 2002).

2.2 HYDROPOWER IN SOUTH AFRICA

According to the Hydro4Africa database (Jonker-Klunne, 2012), South Africa has an installed hydropower capacity of approximately 2 400 MW, which includes the capacity from the hydropower peaking stations. The existing hydropower mix of SA consists primarily of run-of-river, pumped storage and storage schemes with the top nine contributors of the installed hydropower capacity summarised in Table 2-3.

Table 2-3: Nine largest hydropower sites in South Africa (Adapted from Jonker Klunne, (2007))

Name	Installed Capacity (MW)	Type
Drakensberg Pumped Storage	1 000	Pumped storage
Palmiet pumped storage	400	Pumped storage
Gariep	360	Storage
Van der Kloof	240	Storage
Steenbras pumped storage	180	Pumped storage
Collywobbles / Mbashe	42.0	Run-of-river
Neusberg	12.6	Run-of-river
Second Falls	11.0	Run-of-river
First Falls	6.00	Run-of-river

The locations and sizes of the existing hydropower plants in SA is displayed in Figure 2-3 and shows the 19 pico-hydropower sites, 18 micro-hydropower sites, 47 mini-hydropower sites and 8 large-hydropower sites.

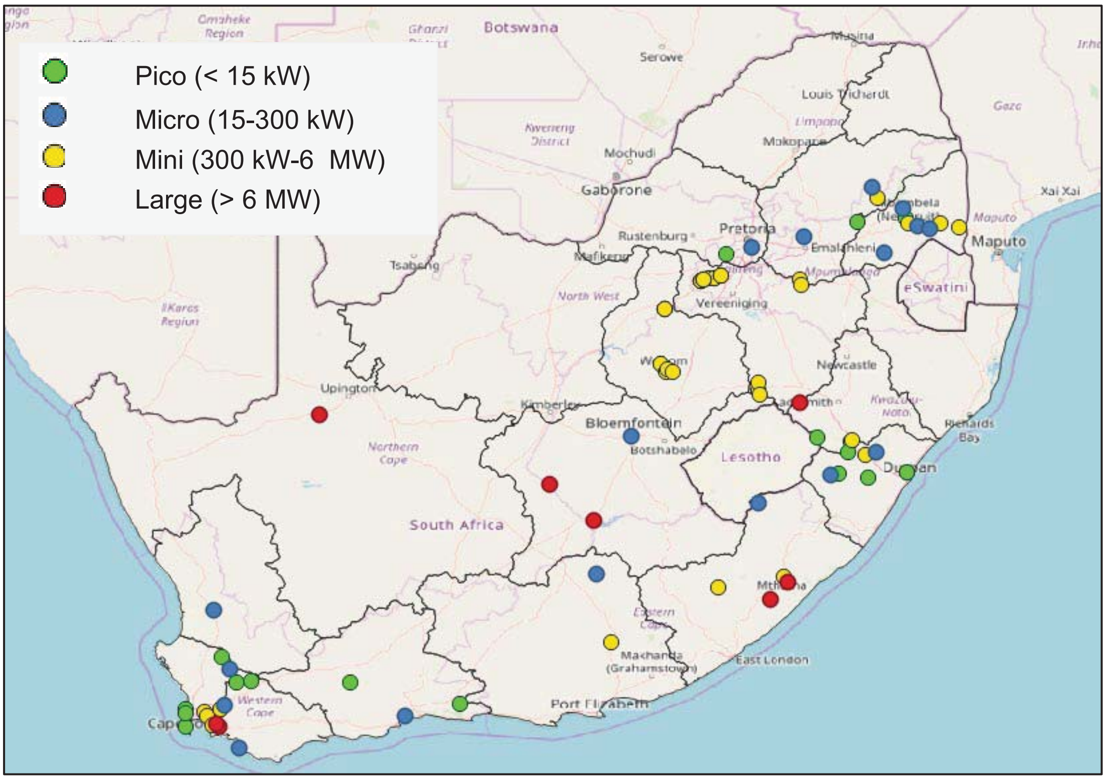


Figure 2-3: Existing hydropower installations in South Africa (Adapted from Klunne, (2012))

2.3 HYDROPOWER TYPES TO BE INCLUDED IN ATLAS

The different hydropower types that are (initially) included in the atlas are shown in Figure 2-4. A brief discussion of each hydropower type is provided in Table 2-4.

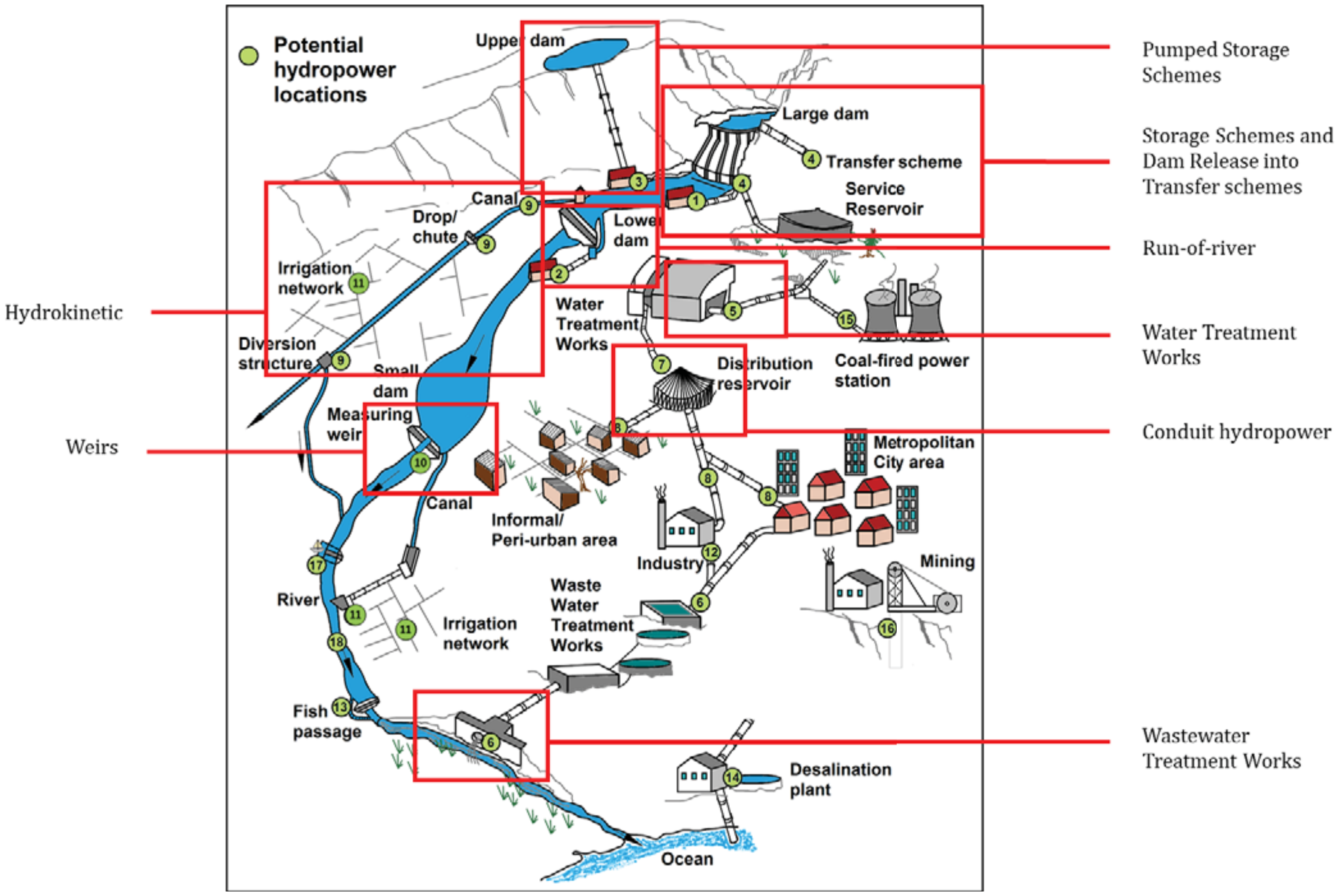
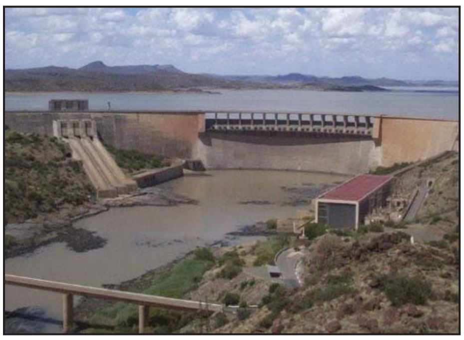
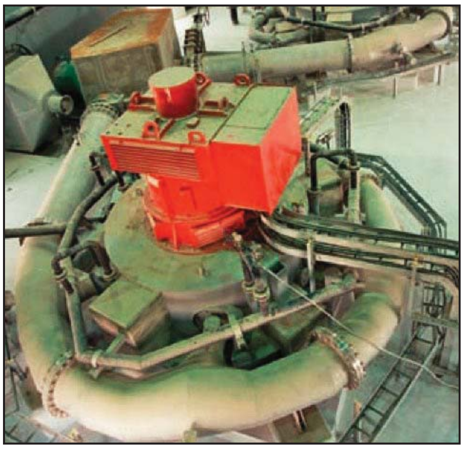
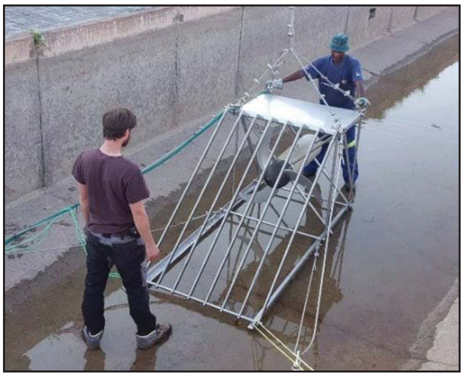


Figure 2-4: Hydropower types included in SAHA

Table 2-4: Description of SAHA hydropower types

Hydropower Type	Description
① Storage schemes 	Conventional type of hydropower can be generated at dams by utilizing the available pressure (water level) and the discharge from the dam associated with the dam's fundamental use. This type of hydropower is normally associated with large environmental impacts, but small hydropower schemes can be retrofitted on existing dams.

Hydropower Type	Description
② Run-of-river schemes 	Hydropower is generated from these types of schemes through the diversion of either all or a portion of the flow from the river combined with the head difference between the inlet to the diversion structure and the turbine unit(s). Rivers or streams that can sustain a minimum flow are usually ideal locations for run-of-river plants.
③ Pumped storages schemes 	Pumped storage schemes generate power based on the principle of pumping water to an upper dam during off-peak periods and releasing the water under gravity conditions to a lower dam during peak time to generate electricity.
④ Dam release into transfer schemes 	Excess pressure available when water is released from storage dams for industrial or irrigation purposes can be dissipated by installing a turbine to generate hydropower before the water enters the conveyance system or exiting it.
⑤ Water Treatments Works 	Hydropower can be generated at WTW if the water source of the WTW is located at a higher elevation compared to the plant. The potential for hydropower exists in the conveyance system, usually at the end of the conduit where the water enters the WTW.

Hydropower Type	Description
⑥ Wastewater Treatment Works 	The constant head and the outflows at WWTW make this an ideal location for hydropower development. The opportunity for energy recovery could exist at the inlet or at the outflow from the WWTW into the natural river system.
⑦⑧ Water supply and distribution systems 	Pressure reducing stations (PRS) are constructed on gravity fed bulk water supply lines to dissipate excess pressures that might exist by means of a pressure reducing valve (PRV). The opportunity for energy recovery exists at the PRV, where the hydropower installation bypasses the PRV and uses the excess pressure for energy generation.
⑨ Irrigation canals and rivers 	Hydrokinetic turbines in rivers and canals are referred to as zero head installations as energy is generated from kinetic energy in the flowing water. Some irrigation canal systems have potential for low-head hydropower installations either through a diversion channel or chute or in the canal itself.
⑩ Weirs 	Measuring weirs provide an example where hydropower installations can be considered. The potential available at this type of location can be attributed to the large flow and elevation difference created by the weir. The challenge, however, would be to install a hydropower plant without affecting the accuracy of the measuring weir.

CHAPTER 3: FRAMEWORKS FOR HYDROPOTENTIAL MAPPING IN SOUTH AFRICA

3.1 INTRODUCTION

The initial development of the SAHA includes storage schemes, run-of-river, pumped storage, water treatment works (WTW), wastewater treatment works (WWTW), water distribution systems (WDS), irrigation canals and weirs. Evaluation frameworks were developed for all the hydropower types (hydrokinetic, pumped storage conduit, storage schemes, WTW, WWTW and weirs) to assess the hydropower potential in SA and provide a first order estimate of the potential available, as well as to provide the number of hydropower sites to be included in the SAHA.

This chapter describes the development of the initial evaluation criteria, which entailed reviewing case studies of existing hydropower atlases, identifying available water infrastructure and river data sources and validating the criteria using case studies.

3.2 UTILISED DATA SOURCES

Various data sources have been identified from which the attribute information for each hydropower site (potential and existing) could be obtained. It should be noted that the data sources available to obtain South African water infrastructure and river data are not limited to the sources identified in this study.

3.2.1 Department of Water and Sanitation Verified Data

The Department of Water and Sanitation (DWS) website provides information on water infrastructure and rivers in South Africa that are easily accessible and free to the public. The verified data provided on the DWS website that are included in the evaluation criteria are summarised in Table 3-1. Additionally, the locations of all the stream gauges and dams and a map of the quaternary catchment, primary and secondary rivers are obtainable from the website and is downloadable in a format that is compatible with any GIS program.

Table 3-1: Summary of data provided for DWS water infrastructure and rivers

Type	Data provided
River	Monthly volume (m^3), daily average and primary flow data (m^3/s) with the corresponding water level (m)).
Reservoir and component	Monthly spill volume (m^3), daily average spill (m^3/s) and primary data (flow (m^3/s) and corresponding level above spillway (m)).
Reservoir downstream component	Monthly volume (m^3), daily average flow and primary data (flow (m^3/s) and corresponding water level (m)).
Canals	Monthly volume (m^3), daily average flow and primary data (flow (m^3/s) and corresponding water level (m)).
Closed conduit	Monthly volume (m^3), daily average flow (m^3/s) and primary data (flow (l/s)).

3.2.2 WR2005 and WR2012

The Surface Water Resources of South Africa studies (1952-2012) have played a major role in providing access to hydrological data for national water resource planning. The WR2005 study included the reassessment and updating of rainfall, observed streamflow and water data up to September 2006 whereas the WR2012 study focussed on re-evaluating, improving and producing new data and tools. Data is provided at quaternary catchment level for the entire South Africa, Lesotho and Eswatini (WRC, November 2015).

The relevant data provided by WR2005 and WR2012 studies includes:

- GIS River information (location, name, stream order);
- GIS Stream gauge information (location, name);
- GIS Quaternary catchment information;
- Mean annual precipitation and mean annual runoff per quaternary catchment;
- GIS Dams and lakes information
- GIS Water Management Areas (WMA) information; and
- Historical runoff data for every WMA.

3.2.3 SANCOLD Registry for Large Dams and DWS List of Registered Dams

South African Notional Committee on Large Dams (SANCOLD) complied a register containing data (dam capacity, spillway capacity, dam wall height, owner, etc.) of all ‘Large’ dams in SA. A dam is classified as ‘Large’ if the following criteria are met:

- Height of the dam must be at least 15 m, measured from the lowest point of the foundation; and
- Dams with at least 3 million m^3 capacity (this includes dams with a height between 5m and 15m).

Additionally, a list of all the registered dams in SA is available from the DWS website. The list contains the data of 323 DWS-owned dams and 4907 dams owned by entities other than DWS. Data provided in the registry includes:

- Gauging station name (for DWS-owned dams);
- Quaternary drainage area;
- Spillway type;
- Capacity;
- Catchment area;
- Surface area;
- Purpose of dam; and
- Dam owner.

3.2.4 Green Drop Reports

Green drop reports as published by the Department of Water and Sanitation aim to measure and compare the results of the performance of WSA and WSP. The Green Drop also aims to focus on the wastewater treatment function (DWS, 2011).

The reports consist of 9 separate reports for each province, with each report containing a list of the WWTWs in each municipality within the specific province, the design capacity (ML/day) and operational capacity of each WWTW expressed as a percentage of the design capacity, as well as a cumulative risk rating for each WWTW.

3.2.5 Blue Drop Reports

Blue drop reports as published by the Department of Water and Sanitation aim to measure and compare the results of the performance of WSA and WSP. The Green Drop also aims to encourage progress in the drinking water services management (DWS & WRC, 2015). There are 9 individual reports each province, with each report containing a list of the WTWs in each municipality within the specific province, the design capacity (ML/day) and operational capacity of each WTW expressed as a percentage of the design capacity, as well as the overall Blue Drop score of each WTW.

3.2.6 Municipal Asset Registers

Asset Registers (AR) are databases that contain the data on all the significant infrastructure owned by the organization and supports the Asset Management Plan (AMP). According to the Water Services Act, every municipality in SA is required to have an AMP for their water infrastructure and sanitation (Bonthuys *et al.*, 2018).

Permission by the responsible municipality must be granted for the necessary access to the AR.

3.2.7 Municipal water services development plans (WSDP)

The WSDP web-based database (hosted by the DWS) contains all the WSDPs for all Water Service Authorities (WSA) (consisting of metropolitan municipalities, some district municipalities and authorised local municipalities) in SA.

The (approved) WSDP, which is available to the public, contains Information pertaining to water and sanitation infrastructure of each municipality.

3.2.8 USGS Earth Explorer (DEM)

Digital evaluation models (DEMs) with a 30 m resolution can be freely downloaded for any area in the world from the Unites States Geological Survey (USGS) website. Other sources exist where DEMs can be downloaded and utilized for the same purpose.

3.2.9 Other data sources

Table 3-2 provides additional data sources which were utilized in the formation of the atlas.

Table 3-2: Other data sources that were utilized

Variable	Source	Resolution	Comments
Precipitation	TRMM 3B43	0.25 deg raster	Monthly averages, period:1998-2010
	GPCP V2.3	2.5 deg raster	Monthly averages, Period: 1979/01 to 2020/01
	Global Precipitation Measurement (GPM)	0.1° – 30 minute	June 2000 to present
	FAO Water Productivity	5 km	Daily, 1983 to 2013
	CliMond	10' or 30'	Monthly
Evaporation	FAO Water Productivity	200 m	2009-2017
Runoff	Global Runoff Data Centre	Flow gauge records	Varies
Digital Elevation Model (DEM)	SRTM v4.1 CGIAR	90 m	Elevation interpolated DEM with corrections based on new algorithms
	HydroSHEDS	3 arc sec (~90 m)	Hydrologically corrected DEM based on the SRTM data. 15 and 30 arc sec data are also available
	ALOS World 3D – 30 m (AW3D30) Version 3.1	1 arc sec (~30 m)	Uncorrected DEM last updated in 2020
Land cover	Modis		
	CCI	20 m	
	ESA	300 m	2017
	Geoterra Image	30 m	2015
Soil characteristics	quick	quick	

3.3 CASE STUDIES OF EXISTING HYDROPOWER ATLASES AND EVALUATION METHODS

The selection of the initial evaluation criteria entailed an investigation into existing studies on the evaluation of hydropower potential at various locations as described in Chapter 2. After the revision of several case studies the following conclusions were made:

- Multiple studies have been conducted on hydropower potential evaluation, specifically focussing on the identification of hydropower sites or hydropower "spotting" using GIS tools. The development of the GIS tools for hydropower evaluation requires complex programming and various input data layers and the development of such tools fall outside the scope of this research project;
- Of the studies reviewed, either very little information was provided on the evaluation criteria used to identify potential hydropower sites or the evaluation criteria provided were not applicable to this project; and
- The largest majority of the case studies entailed the evaluation of run-of-river hydropower, with the minority of the case studies available describing the evaluation of hydrokinetic type hydropower.

3.4 INITIAL EVALUATION FRAMEWORKS

Initial criteria included in this evaluation framework were assumed for many of the hydropower types as the topic of hydropower potential estimation methods using limited data is a somewhat unexplored area within the hydropower research field. The criteria, governing the inclusion or exclusion of a specific water infrastructure or river in the SAHA, were validated using data obtained from a collection of available data sources including, studies conducted by Loots *et al.* (2014), Pakenas, (1995) and Van Dijk *et al.* (2016). The validation process is illustrated in Figure 3-1.

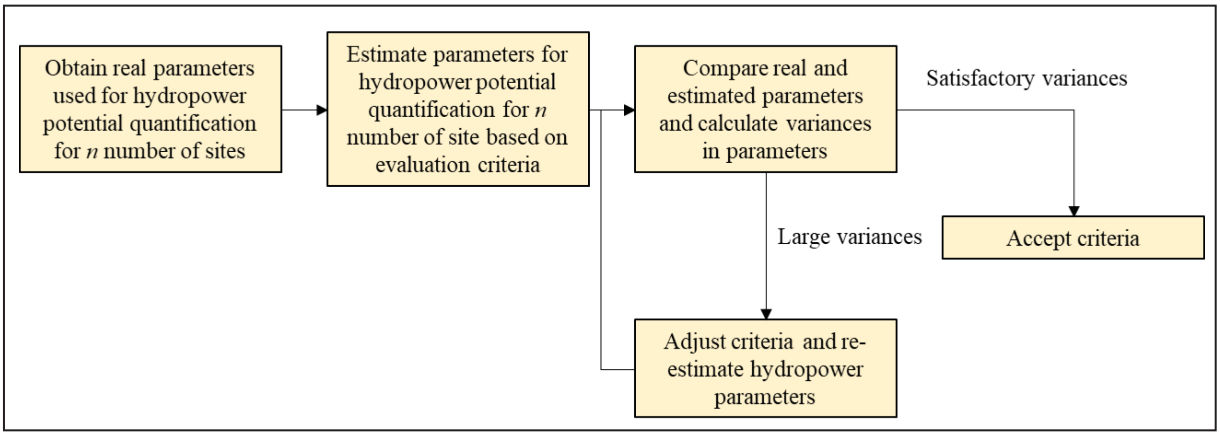


Figure 3-1: Explanation of validation of evaluation criteria

3.4.1 Conduit Hydropower

The evaluation of conduit hydropower potential in a water distribution is based on the available flow in the system and the amount of pressure being dissipated by the pressure reducing valves placed at either the inlet to a reservoir or within the water distribution system itself. The parameters that need to be quantified to enable hydropower evaluation are pressure head and flow.

The reliability of the criteria included in the final framework is subject to the amount of data used during the validation process. As more sites are evaluated in feasibility studies, the reliability of the criteria used in the assessments increase. The final conduit hydropower framework is shown in Figure 3-2.

3.4.2 Hydrokinetic Energy

The evaluation criteria selected in this sub-section evaluates the hydrokinetic energy in both rivers and channels (natural and manmade). The velocity in the river or channel as well as the turbine swept area are the primary factors influencing the hydrokinetic potential available in a river or channel.

The reliability of the criteria would be further improved during future assessments and the reliability enhanced (such as the large variance between estimated and real flows). The challenge, however, is the lack of hydrokinetic case studies in South Africa that limits the process of validation. It is, therefore, recommended to include hydrokinetic case studies of other countries in future assessments to improve the reliability of the criteria.

The final hydrokinetic evaluation diagrams are shown in Figure 3-11 to Figure 3-5.

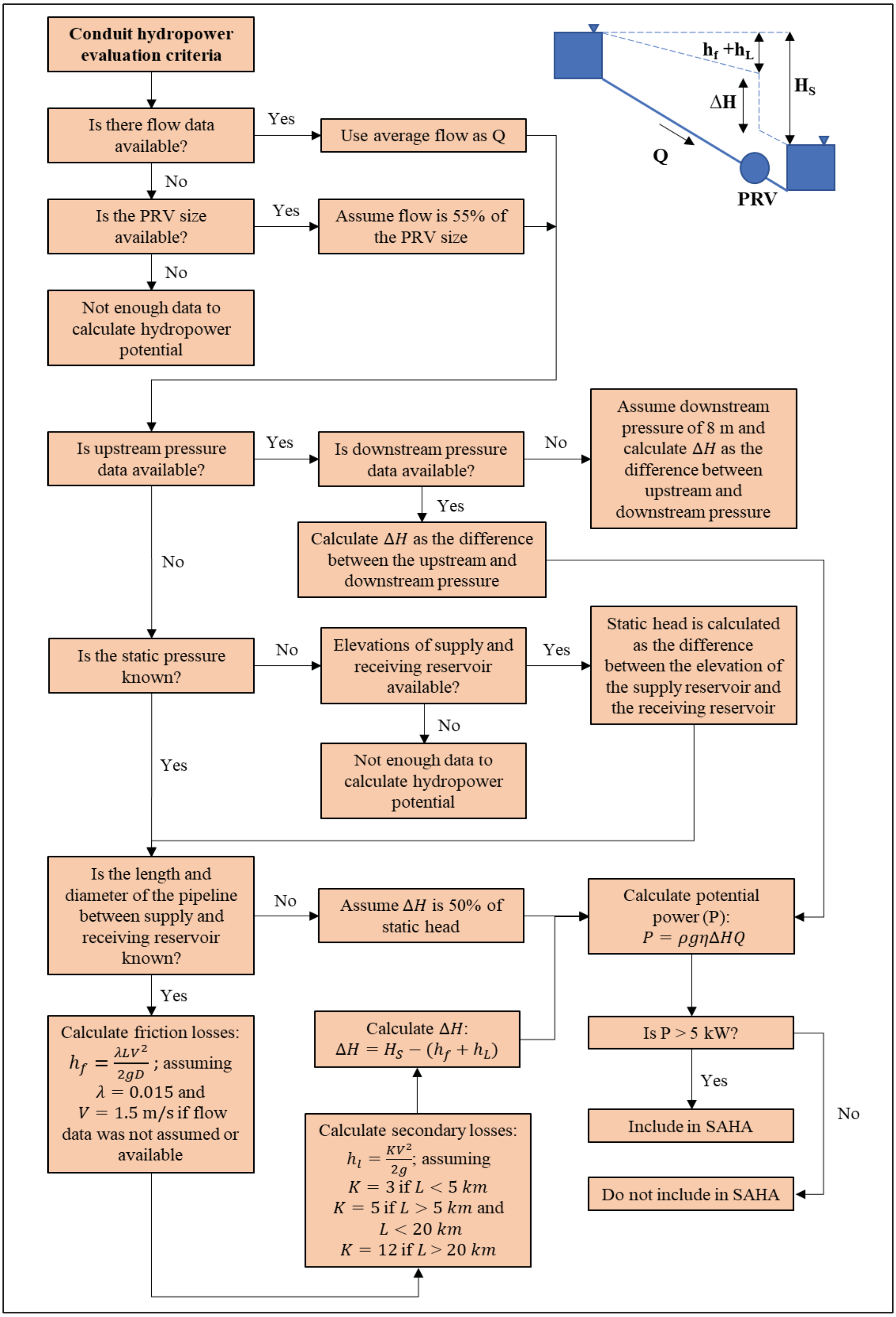


Figure 3-2: Conduit hydropower evaluation framework

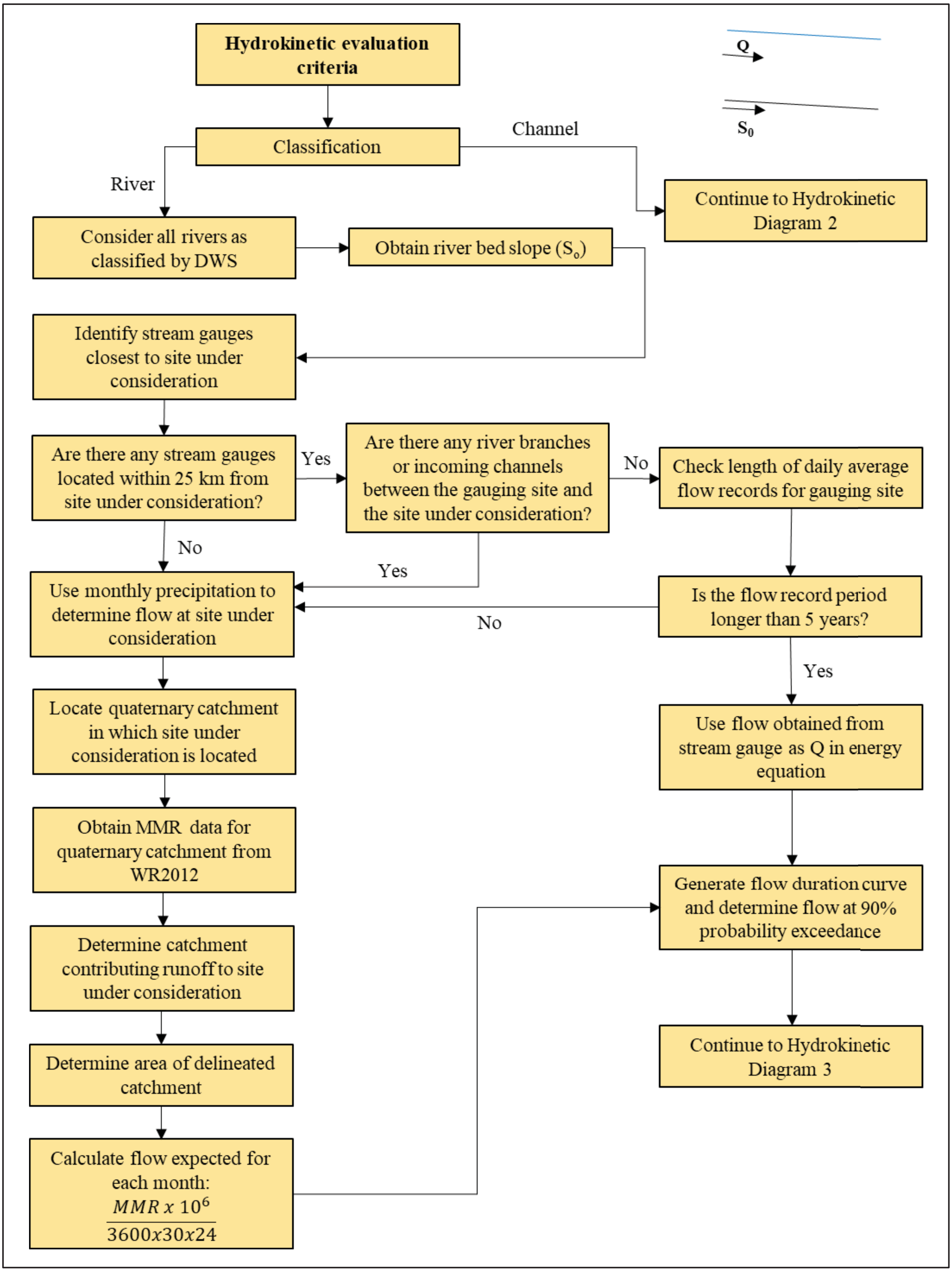


Figure 3-3: Hydrokinetic evaluation diagram 1

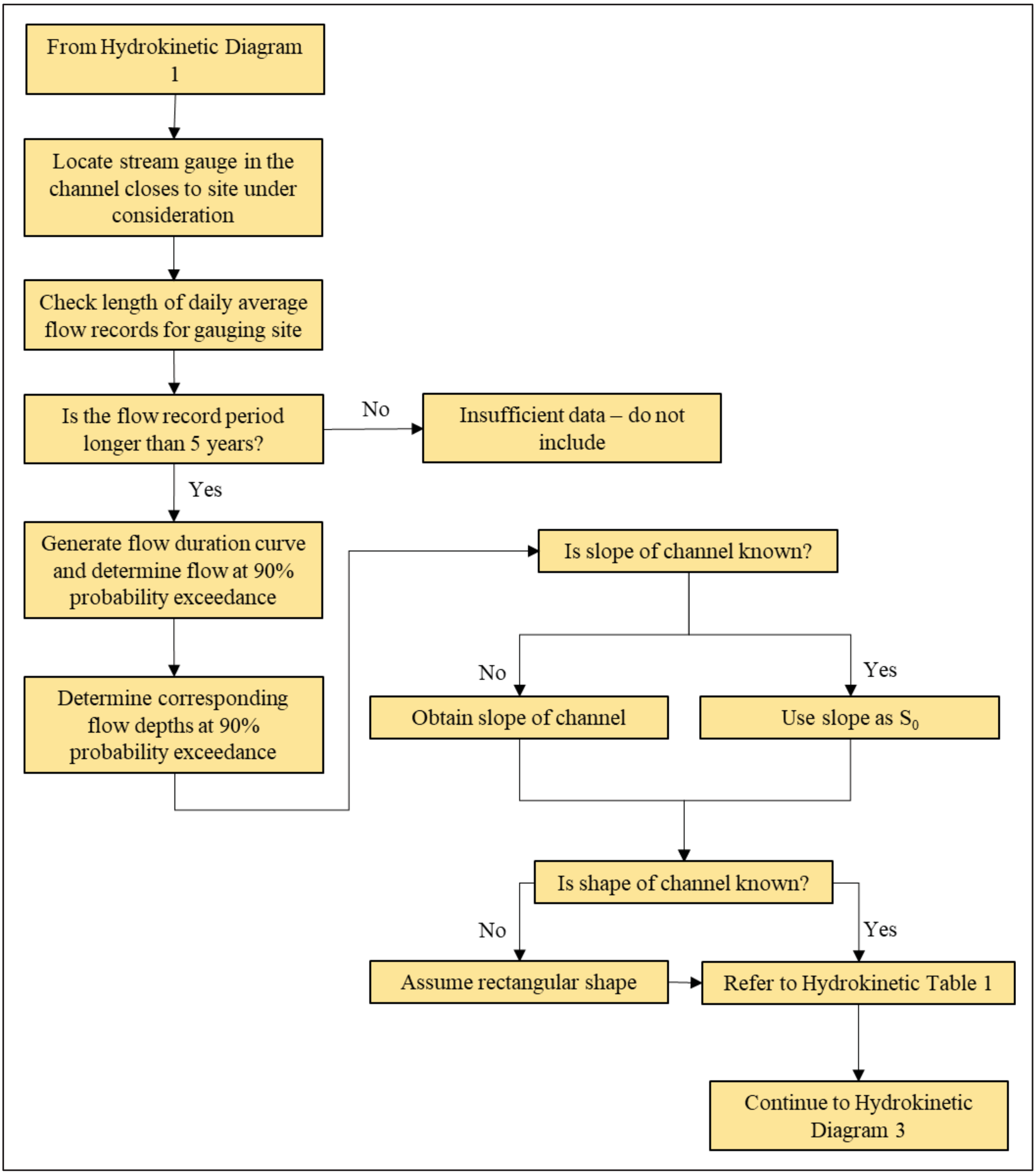


Figure 3-4: Hydrokinetic evaluation diagram 2

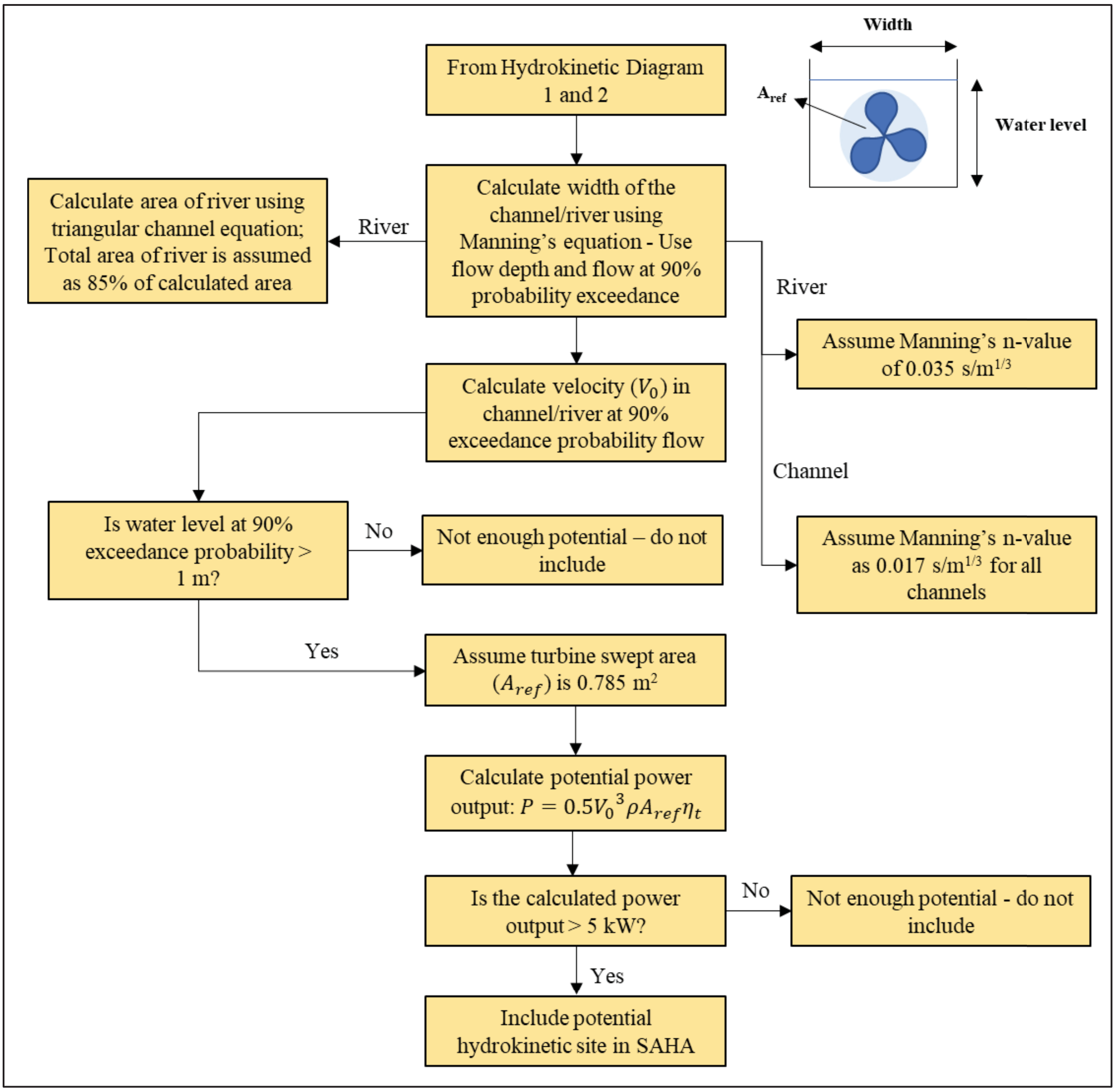


Figure 3-5: Hydrokinetic evaluation diagram 3

3.4.3 Run-of-River

The evaluation of the potential for a run-of-river site was based on the available head and the flow in the river. Certain criteria were selected in order to quantify the parameters necessary when using data sets with limited data for hydropower evaluation.

<u>Run-of-river evaluation option 1</u>

The final run-of-river evaluation diagrams are shown in Figure 3-6 and Figure 3-7.

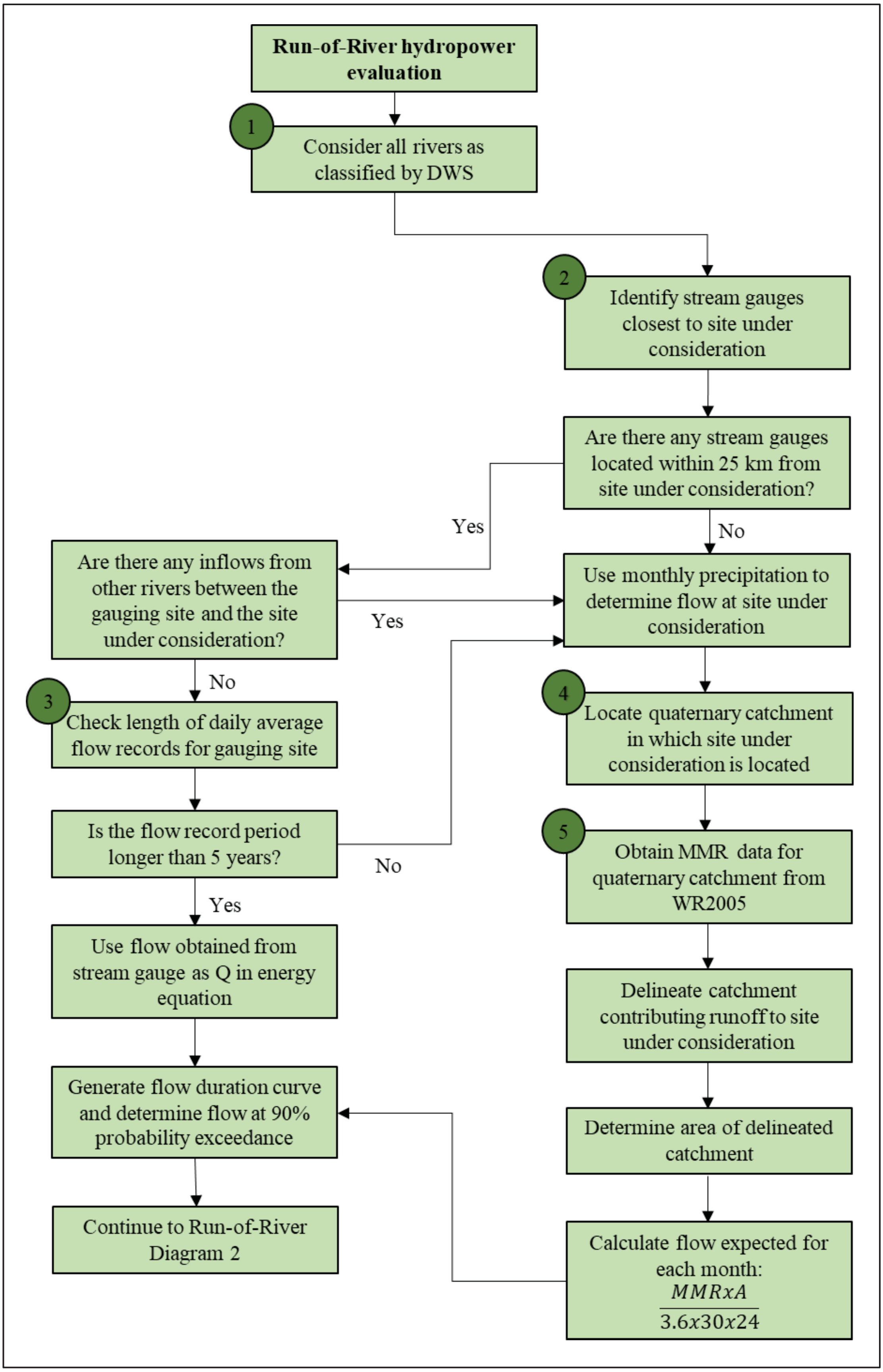


Figure 3-6: Run-of-river evaluation diagram 1

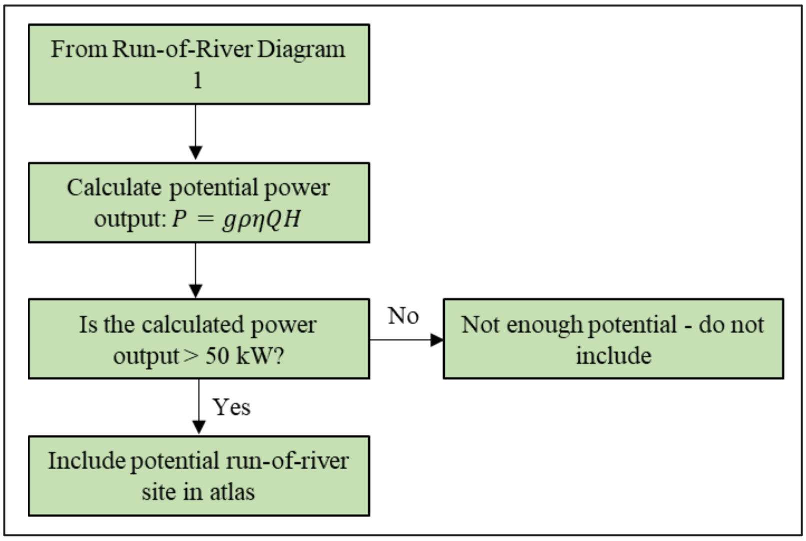


Figure 3-7: Run-of-river evaluation diagram 2

<u>Run-of-river evaluation option 2</u>

Run-of-river evaluation Option 2 was another approach that was followed where river systems were analysed which does not have any DWS flow records available.

The considerations for the selection of data to be used in the modelling approach for these potential sites are discussed in the paragraphs below.

Hydrological Study

- Data Collection (climate, topography, channel geometry, land cover and soil characteristics)
- Delineation of catchments, sub-catchments and sub areas
- Derivation of river network
- Runoff and discharge calculation

Hydroelectric potential calculation (with the reported output per river reach in kW/Km):

The algorithm depicted in Figure 3-8 describes the steps to calculate the hydroelectric potential.

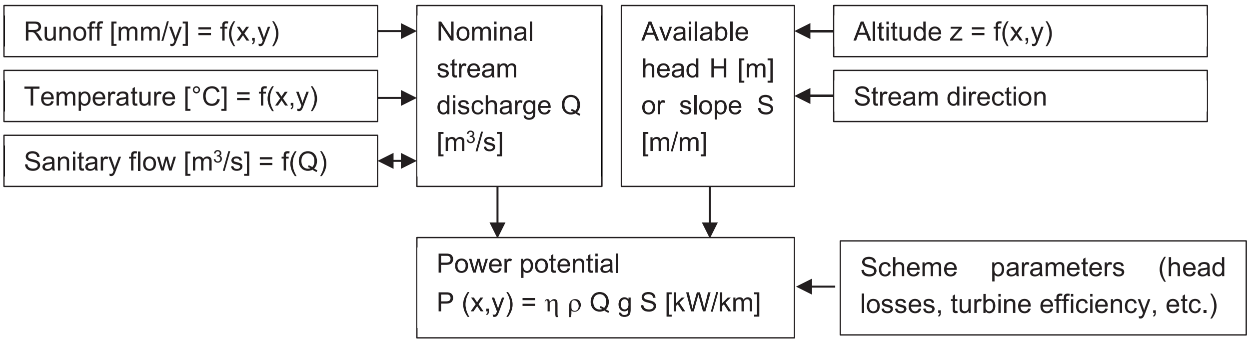


Figure 3-8: Proposed calculation algorithm

3.4.4 Storage Schemes

Power can be generated at large reservoirs or dams by utilising the available head combined with the discharge from the reservoir that corresponds with the normal operating conditions of the reservoir. Large hydropower dams have major environmental impacts, but for small hydropower schemes where large dams are retrofitted for hydropower, the environmental impacts are minimised. Existing dams that are utilised for flood control, irrigation, recreation or water abstraction can be retrofitted as hydropower dams in the case where the discharge from the dam is constant. The final storage scheme evaluation diagram is shown in Figure 3-9.

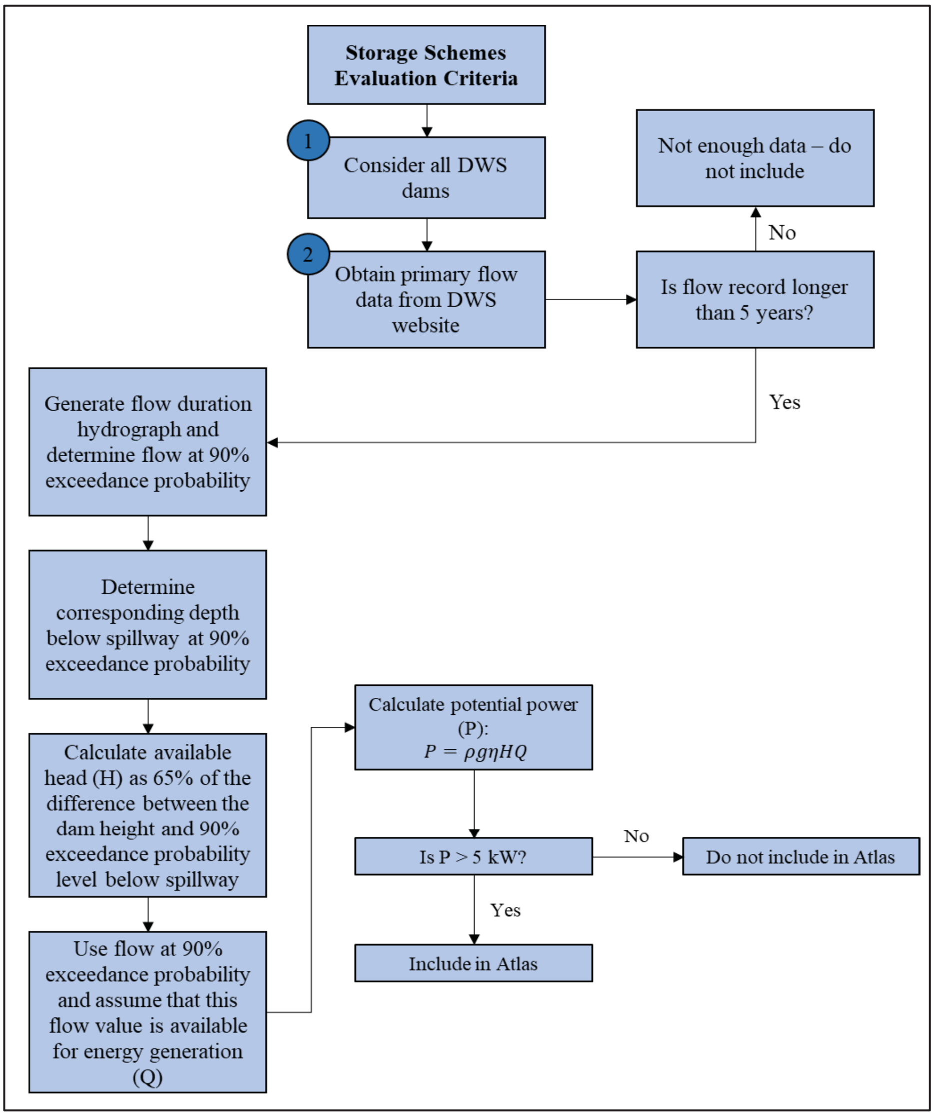


Figure 3-9: Storage scheme evaluation diagram

3.4.5 Pumped Storage

Existing reservoirs can be converted into pumped storage schemes with the addition of a second reservoir and ensuring a sufficient elevation difference between the two reservoirs for energy generation. The criteria described in this sub-section entails the analysis of the surrounding area of existing reservoirs to find a suitable site for a new reservoir in order to transform the existing reservoirs or dams to pumped storage schemes.

The criteria selected for this hydropower type was primarily based on the criteria selected for the study conducted by Fitzgerald *et al.* (2012), where a methodology was developed to identify the potential for transforming existing hydropower and non-hydropower dams into pumped storage schemes. The final pumped storage evaluation framework is shown in Figure 3-10.

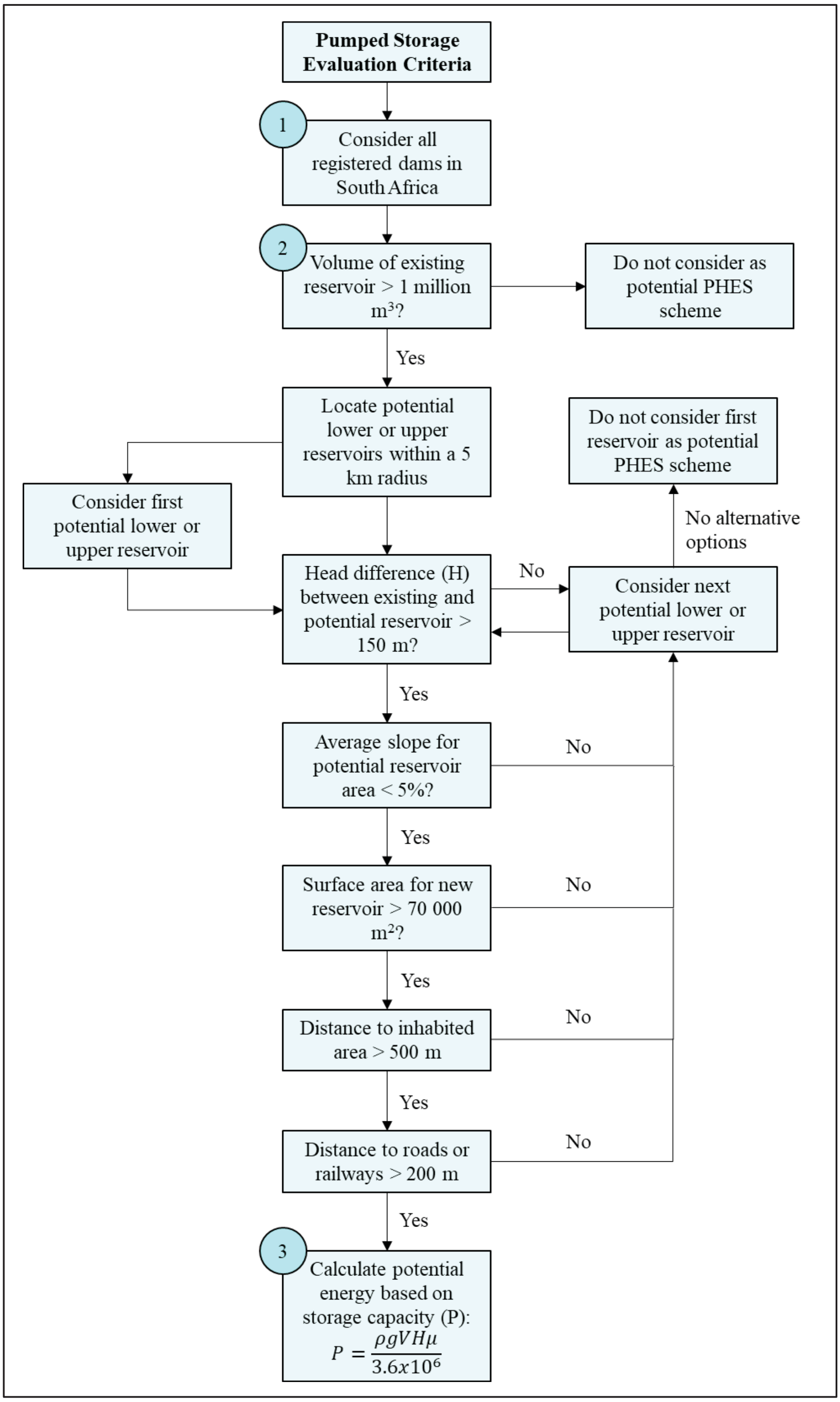


Figure 3-10: Pumped storage evaluation diagram

The hydropower potential of a pumped storage site is based on the available head between the upper and lower reservoir and the available storage capacity (taken as the storage capacity of the reservoir with the lowest storage capacity). The selection of the pumped storage evaluation criteria required certain assumptions to be made with regards to the existing reservoir and potential new reservoir parameters.

3.4.6 WWTW

The topic of potential estimation methods at the outflows of WWTW, especially when limited data might pose a challenge, is somewhat an unexplored area within the hydropower research field. It was, therefore, necessary to make some assumptions regarding initial criteria included in the framework. The WWTW evaluation framework in shown in Figure 3-11.

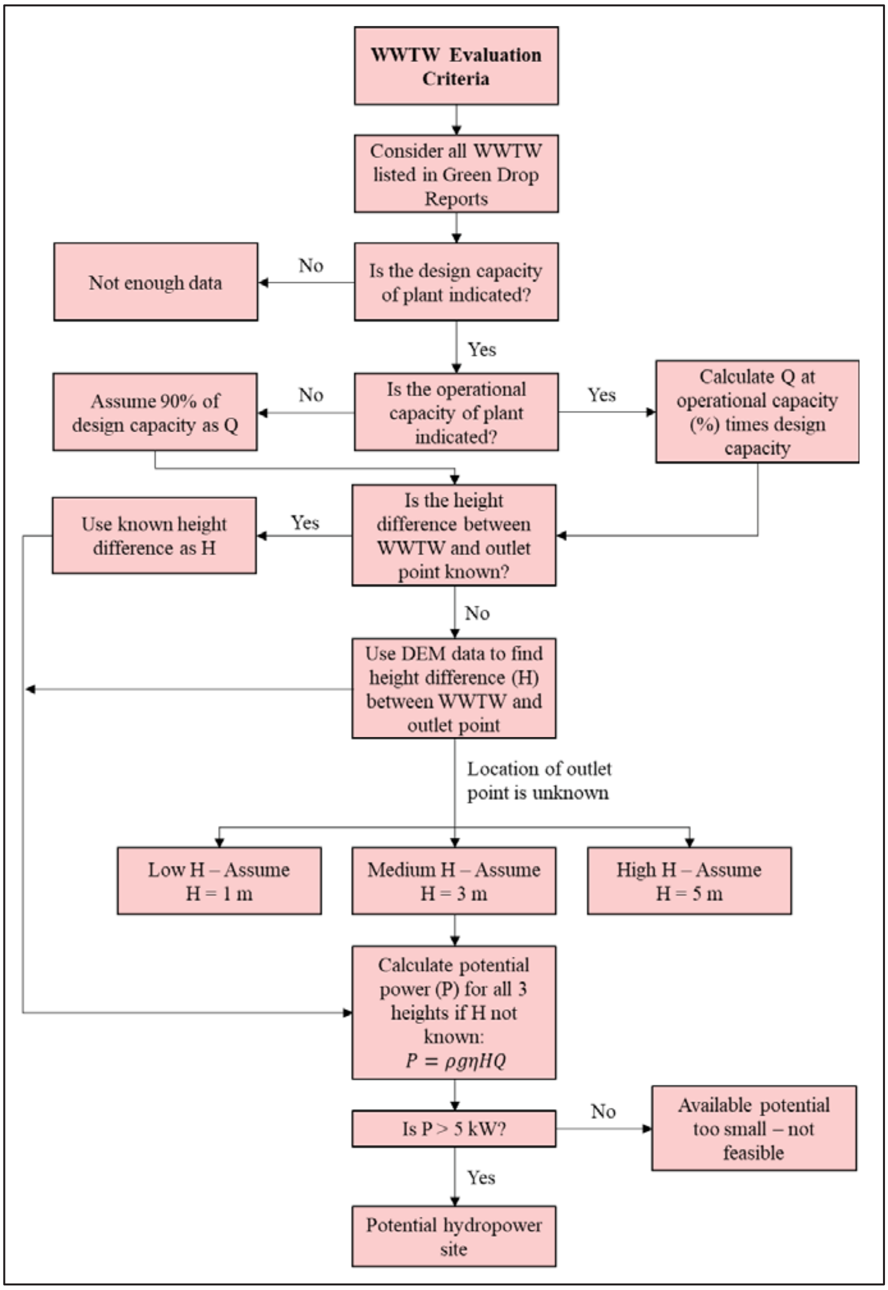


Figure 3-11: Diagrammatic depiction of WWTW evaluation framework

3.4.7 WTW

The topic of potential estimation methods at the outflows of WTW, especially when limited data might pose a challenge, is somewhat an unexplored area within the hydropower research field. It was, therefore, necessary to make some assumptions regarding initial criteria included in the framework.

The WTW evaluation framework in shown in Figure 3-12.

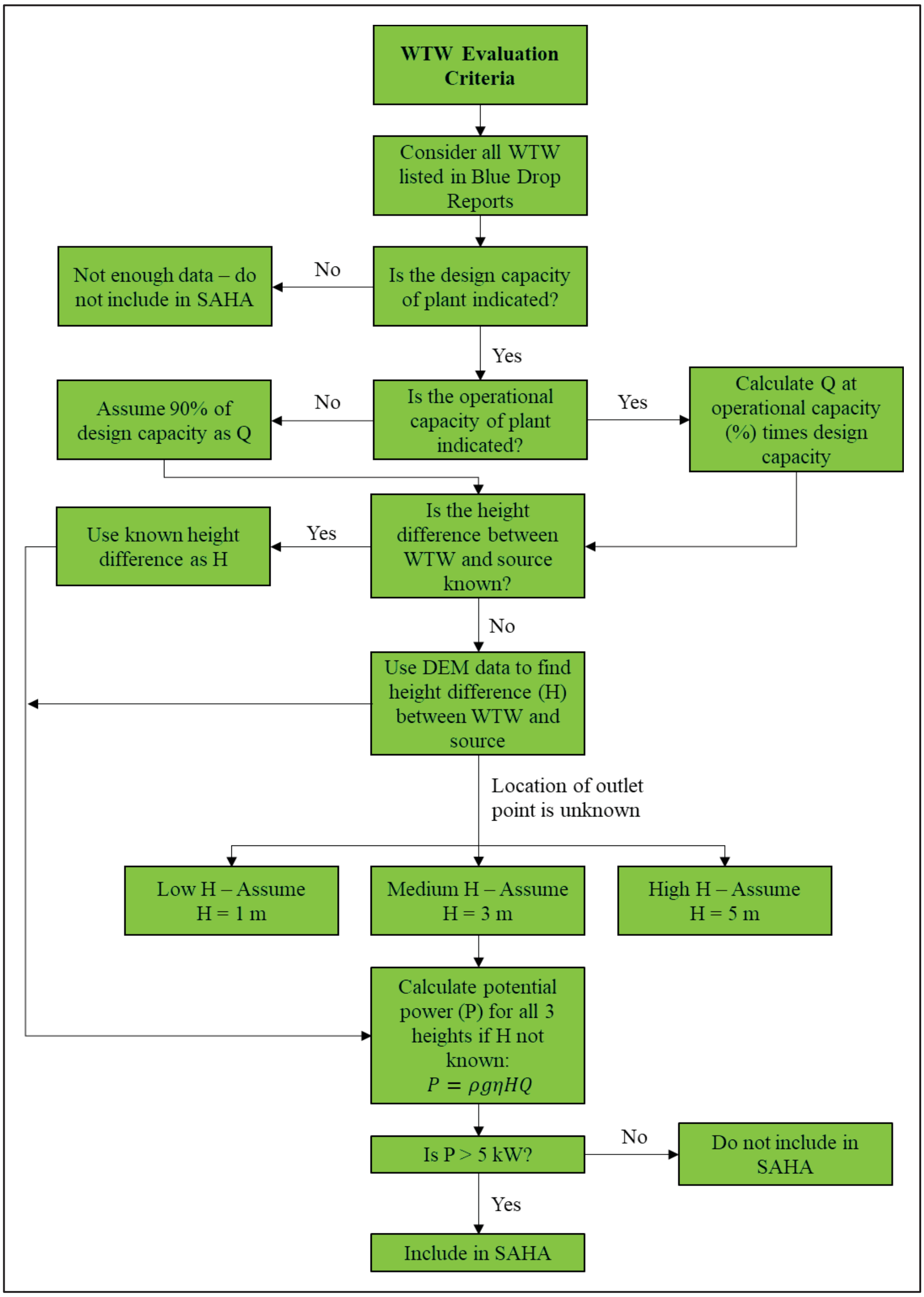


Figure 3-12: WTW evaluation diagram

3.4.8 Weirs

The evaluation criteria selected in this sub-section evaluates the potential at weirs. The flow over the weir (in the river) and upstream-downstream head difference over the weir are the primary factors influencing the hydropower potential available at a weir.

The baseline evaluation frameworks for hydropower evaluation at weirs are shown in Figure 3-13 and Figure 3-14.

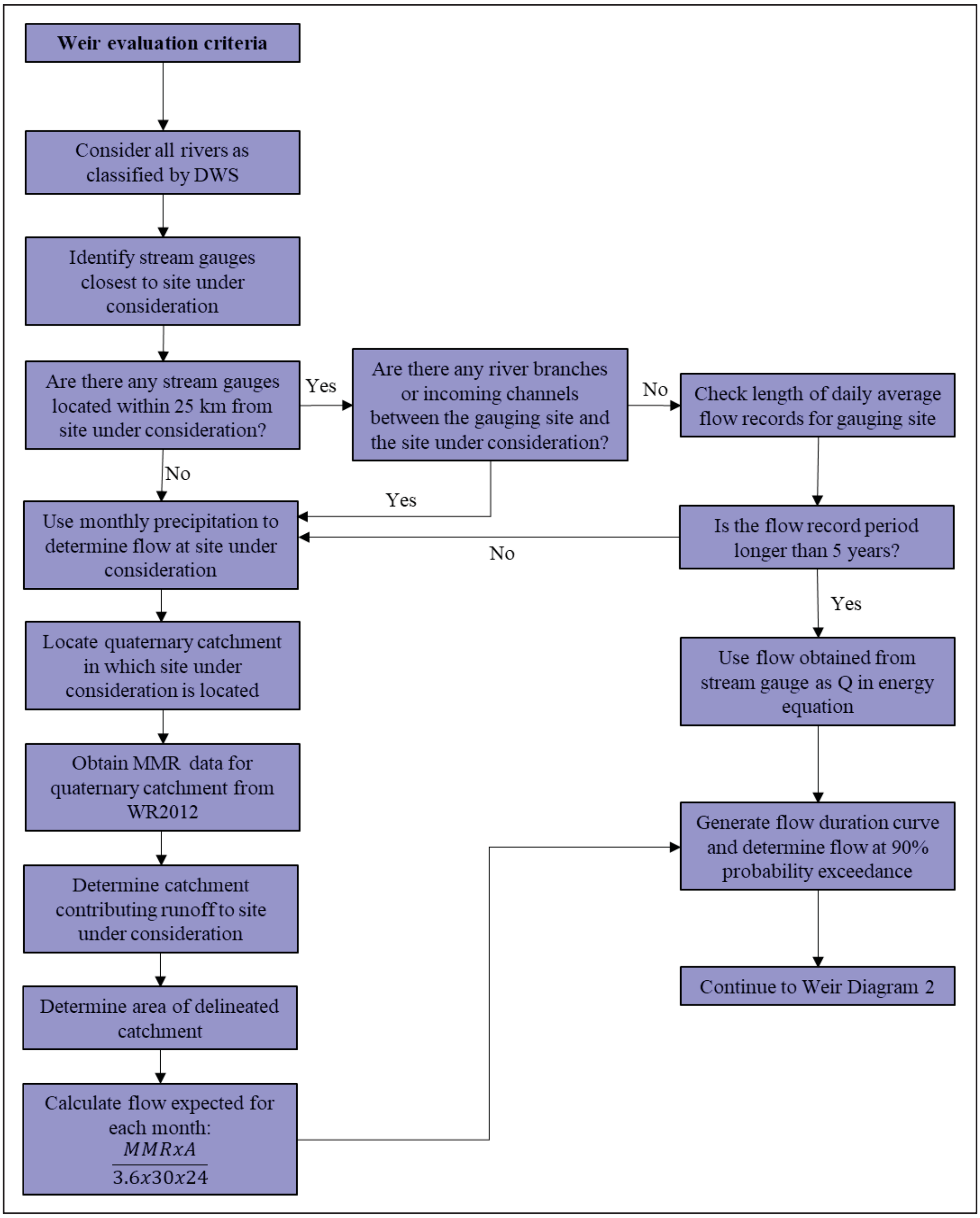


Figure 3-13: Weir evaluation diagram 1

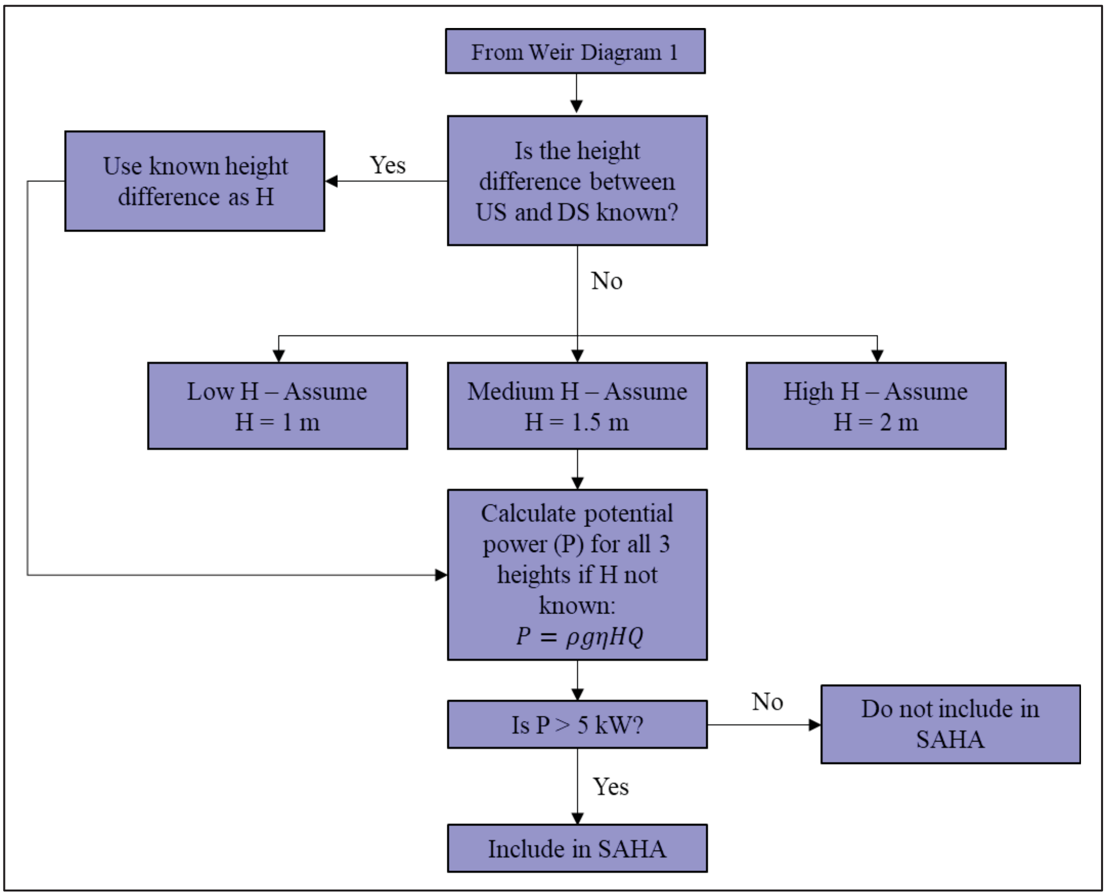


Figure 3-14: Weir evaluation diagram 2

CHAPTER 4: ATLAS PLATFORM AND GRAPHICAL USER INTERFACE DESIGN

4.1 SELECTION OF A SUITABLE PLATFORM

Information regarding aspects such as security, stability, server requirements, data handling, user friendliness, and accessibility were not available for some of the platforms. Therefore, the decision regarding which platform is suitable for hosting the Hydropower Atlas for South Africa was made based on the available information with a specific focus on features, functionality, ease of use and suitability of the platform. Thus, the two most suitable platforms that were identified are QGIS Cloud, which is a free and open source software, and ArcGIS online, which is the proprietary software. Although, these two platforms have similar functionalities, ArcGIS online comes across as the most secure, reliable and trusted platform for hosting web maps. According to Esri (n.d.), ArcGIS Online continually earns security and privacy certifications, software updates and maintenance is done by Esri meaning the user does not have to worry about this. The platform also handles multiple data layers and users well. This is an important aspect since the chosen platform must be able to handle multiple users and function without any disturbances (crashing). For the above reasons, ArcGIS Online has been chosen as a suitable platform for hosting the Hydropower Atlas for South Africa.

4.1.1 ArcGIS Online

ArcGIS Online is a well-known and widely used web-based Geographic Information System platform that allows users to create, use, share maps, scenes, layers, analytics and data (Esri, n.d.). The platform allows users to access workflow-specific apps, maps and data from around the world. It also provides a secure and private infrastructure to store data and maps. Since the Web AppBuilder for ArcGIS is developed on ArcGIS (API) for JavaScript and HTML5, project developers can develop GIS web applications that can be run on any device (Esri, n.d.).

The following points refer to the features of the ArcGIS Online platform:

- 2D and 3D data can be visualised;
- Web maps can be shared with anyone, anywhere or kept private;
- Project developers can access analysis tools that help provide insights into the data being used;
- Supports the ESRI shapefile data format;
- Offers interactivity and 3D scenes;
- Provides analysis tools, measurement tools and many more other tools;
- IT requirements such as security, authentication, and privacy are met;
- Authors can manage who has access to the app and the activities that can be performed on the app;
- It provides logging and other advanced reports;
- Authors can add valuable context to their data by combining it with Esri's demographic and lifestyle data;
- Data can be updated and added without disrupting the maps and apps that use the data;
- Web maps can be scaled to allow hundreds or even millions of users at the same time; and
- Supports most web browsers including Google chrome, Microsoft Edge, Microsoft Internet Explorer 11, Mozilla Firefox and Safari.

The following points refer to the ease of use of the ArcGIS Online platform as well as the suitability to the project of developing a hydropower atlas:

- ArcGIS Server web services can be added to ArcGIS Online;
- ArcGIS Server supports 64-bit Microsoft Windows operating systems, however, machines with an underscore (_) in their names are not supported;
- ArcGIS Server is not supported on domain controllers;
- ArcGIS Online offers a wide range of functionality that is readily available on the platform, without having to write a single line of code;
- The platform is proven to be secure and has been trusted by even the most regulated industries; and
- This platform is, therefore, able to provide most, if not all, the functionality that is required for the Hydropower Atlas and ensure that uploaded data are secure; and

The visualisation of the platform using an example application can be seen in Figure 4-1.

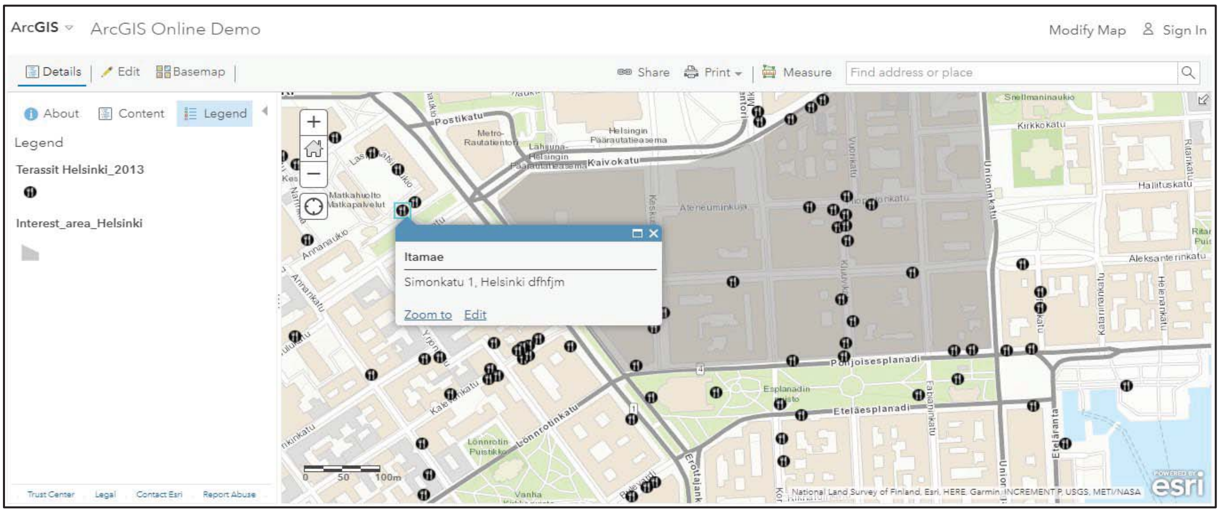


Figure 4-1: Example application of ArcGIS Online

4.2 GRAPHICAL USER INTERFACE

The layout of the atlas requires the user to read through and agree to a copyright disclaimer (Figure 4-2) before the atlas can be accessed. This prevents possible copyright infringements and sharing of data without the necessary referencing.

The layout of the web-based atlas, which is based on a generic layout of existing renewable energy atlases is shown in Figure 4-3. The specified layout enables the user to easily access all the functionality options of the atlas. Furthermore, widely recognised icons (pan, zoom in, zoom out, etc. – examples provided on layout) are used to display the functionality options on the screen of the atlas. A detailed illustration of the atlas functionality is shown in Figure 4-4 to Figure 4-12.

Figure 4-2: Atlas copyright disclaimer

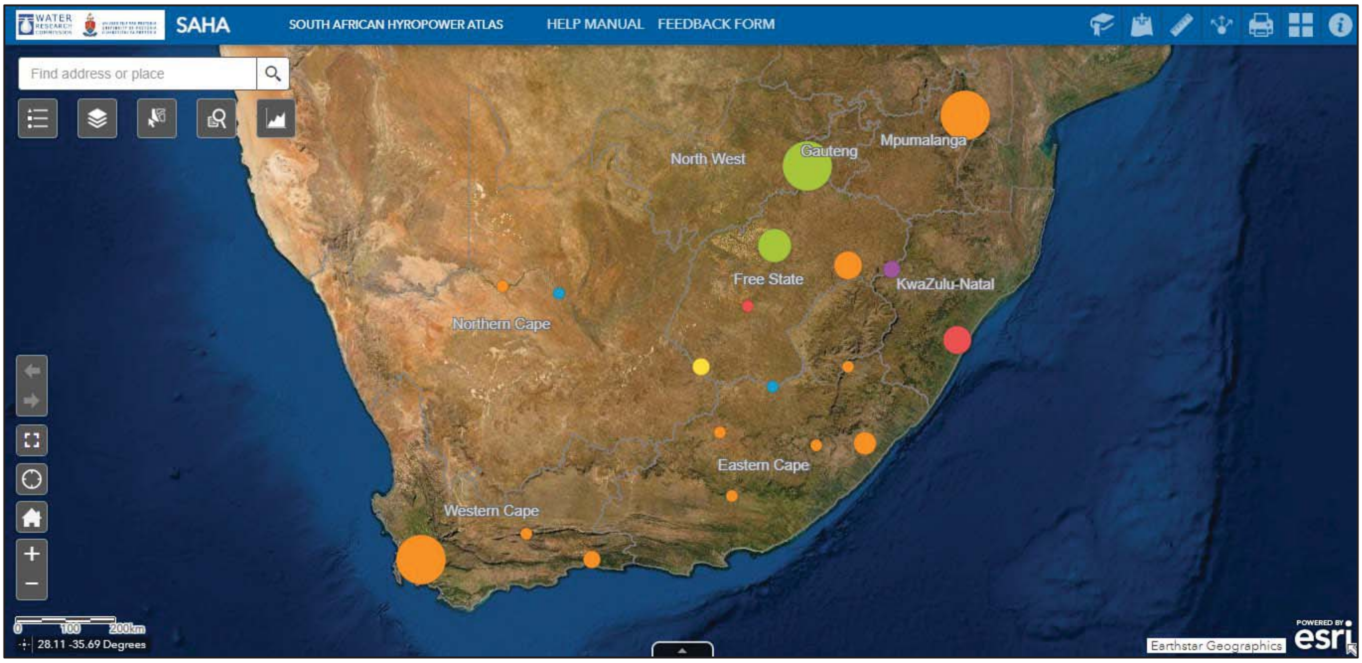


Figure 4-3: SAHA home screen

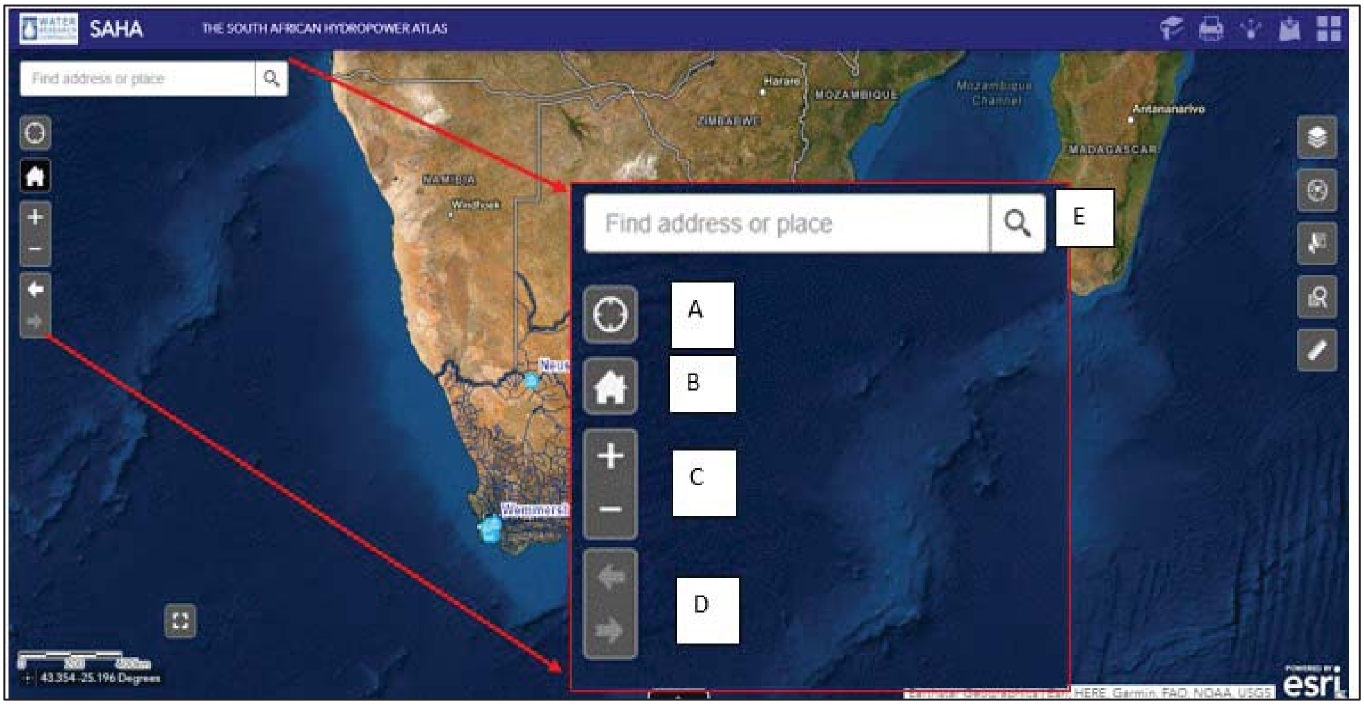


Figure 4-4: My location (A), Default extent (B), Zoom in or out (c), Previous or next extent (D), Search tab (E)

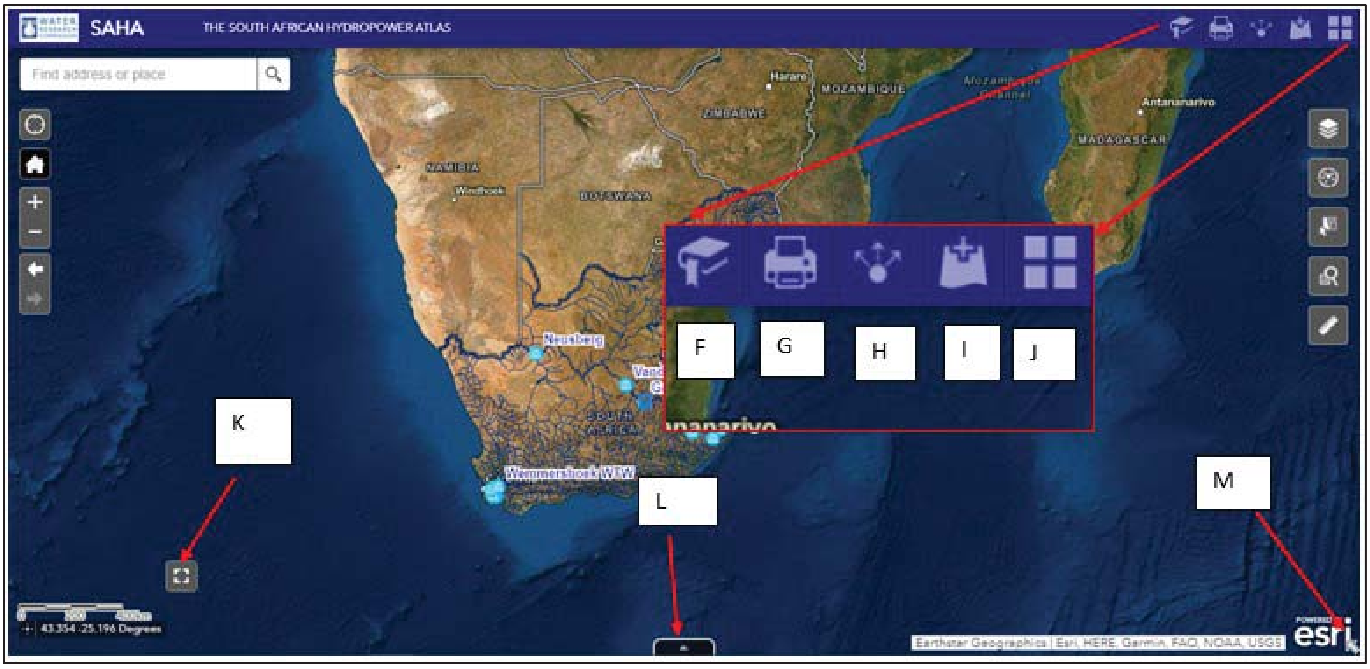


Figure 4-5: Bookmark (F), Print (G), Share (H), Add data (I), Basemap Gallery (J), Switch to full screen (k), Attribute table for data layers (L), Show Map Overview function(M)

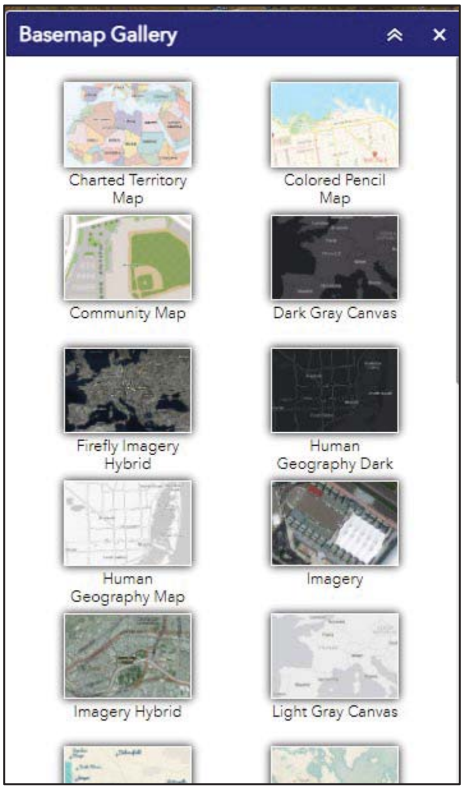


Figure 4-6: Basemap Gallery showing different base maps

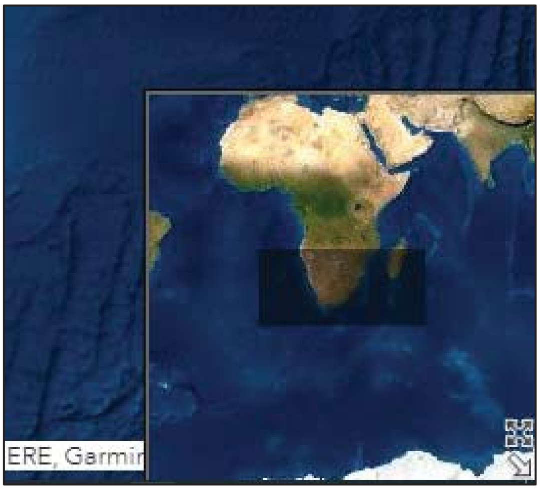


Figure 4-7: Map Overview function

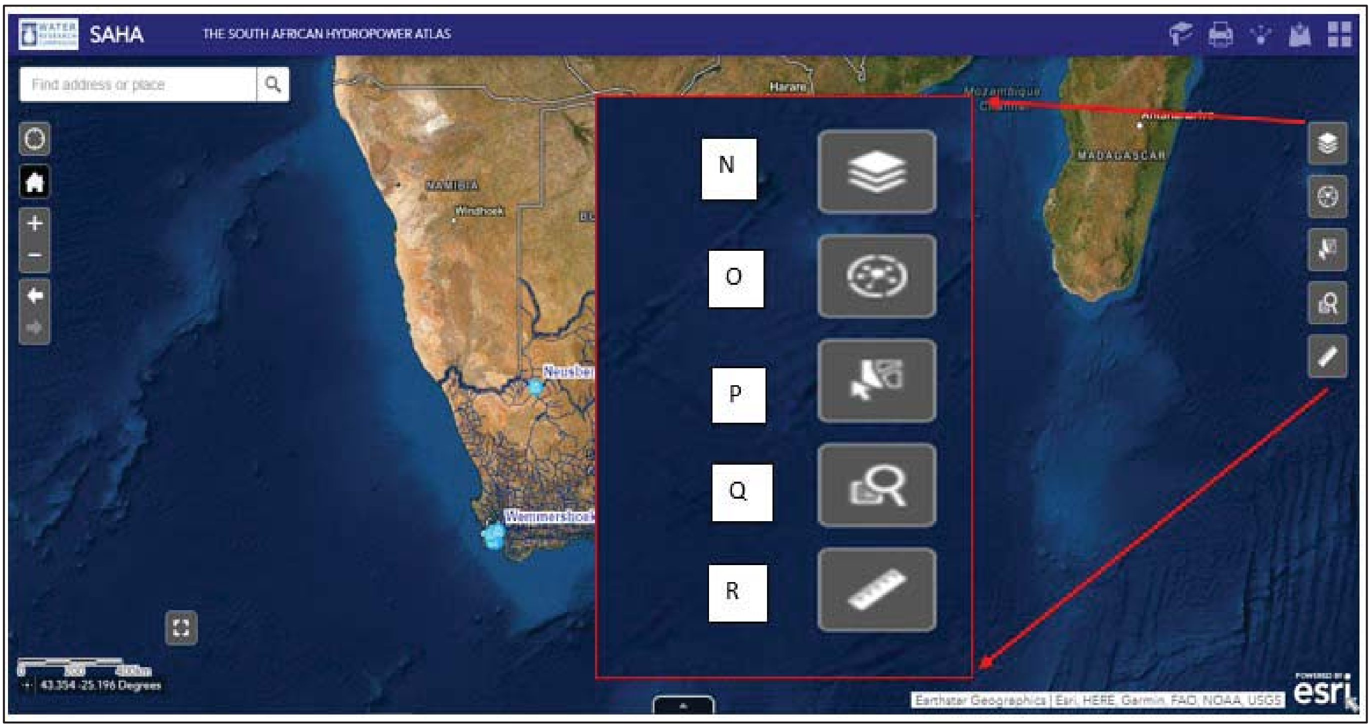


Figure 4-8: Data Layer list (N), The Analysis (O), Select (P), Query (Q), Measurement tool (R)

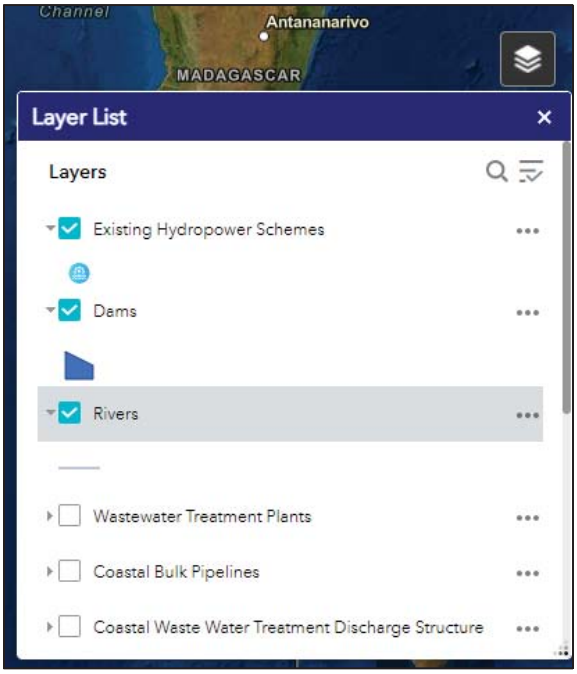


Figure 4-9: Layer list showing selected data layers and associated legend of each layer

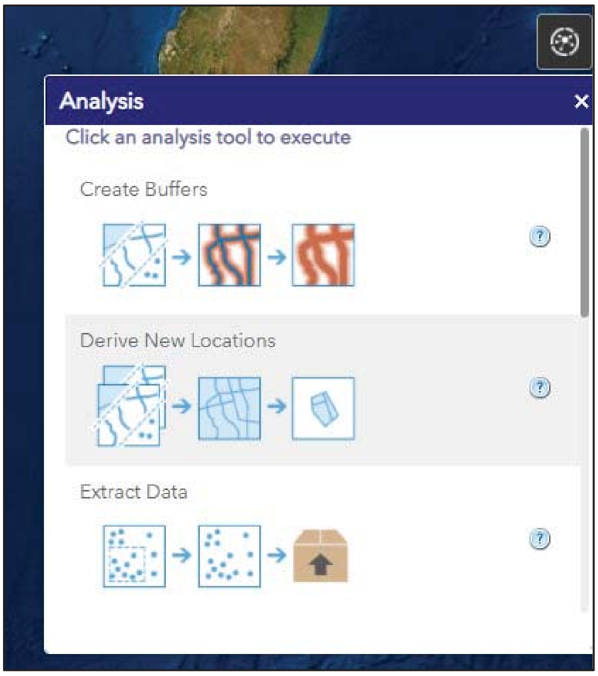


Figure 4-10: The Analysis function containing several tools

Figure 4-11: The Query function storing predefined queries

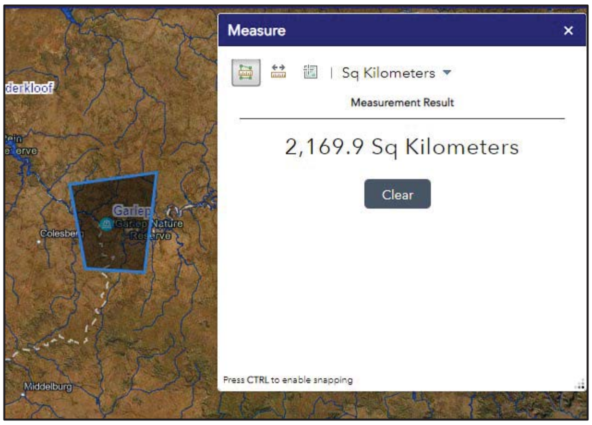


Figure 4-12: Illustration of the Measurement tool

CHAPTER 5: ASSESSMENT TOOLS

5.1 UNIVERSITY OF PRETORIA RETROFIT HYDROPOWER EVALUATION SOFTWARE

This chapter details how to obtain and use the UP-RHES. Specific detail is given for each of the five tools that comprise the UP-RHES, and a general introduction covers how to download and install Python, which is required to run the UP-RHES. This chapter does not cover the methodology used to develop the tools, as this was presented in Chapter 3.
The UP-RHES is a set of five Python programs that, when used together, are capable of rapidly and accurately estimating the retrofit hydropower potential and viability of South African dams. The programs that comprise the UP-RHES are as follows:

- Initial screening tool,
- Dataset downloader,
- Rapid assessment tool,
- Scenario assessment tool, and
- Life cycle cost analysis tool,

The tools are available from a Google drive accessible from the following link: https://tinyurl.com/UPRHES

Alternatively, the source code, presented in Appendix A, can be run using a Python compiler. Once the tools have been obtained, they can be run by double clicking on the respective '.pyw' programs. This action requires Python 3, the latest version of the language, to be installed on the user's Windows, Linux or macOS device. This can be done by simply downloading the installer from the Python website, available at: https://www.Python.org/downloads/

5.1.1 INITIAL SCREENING TOOL

The initial screening tool is a basic tool and the first of the tools in UP-RHES. The initial screening tool is a series of questions that rapidly evaluate whether a site warrants further investigation.

The questions include general questions about the site, including the proposed use of electricity, and environmental and social considerations that may jeopardise the feasibility of the site.

The tool begins with simple yes and no questions as shown in Figure 5-1 and proceeds to checklists wherein the user should select all options that apply to the given site, an example of which is given in Figure 5-2.

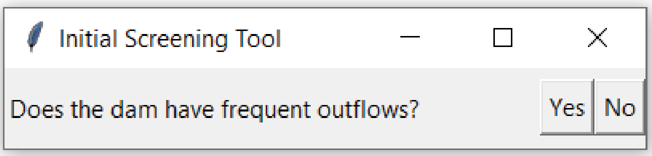


Figure 5-1: Initial screening tool (Yes/No Example)

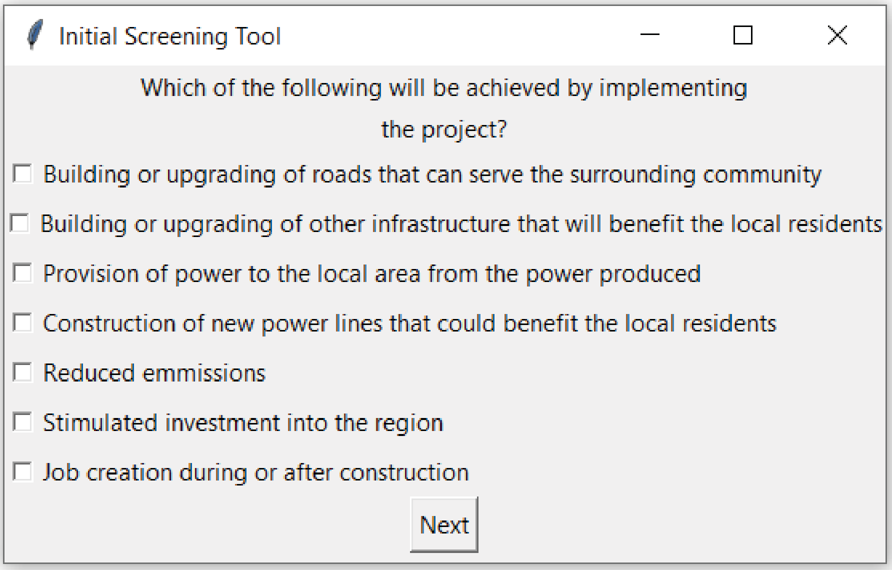


Figure 5-2: Initial screening tool (Checkbox Example)

Should the initial screening be successful the user will be greeted with the message “Proceed to analysis”, however upon failure the message, “Abandon project”, will be displayed, as shown in Figure 5-3 and Figure 5-4 respectively.

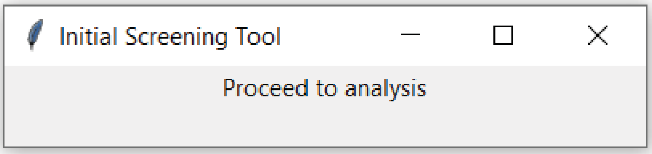


Figure 5-3: Initial screening tool (Success)

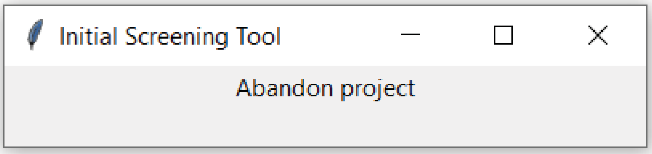


Figure 5-4: Initial screening tool (Failure)

5.1.2 DATASET DOWNLOADER

The UP-RHES relies upon data available from the DWS, however acquiring the data can be a tedious task. As such, a dataset downloader was developed that automates the process of downloading verified data from the DWS website. A layout of the dataset downloader’s user interface is provided in Figure 5-5.

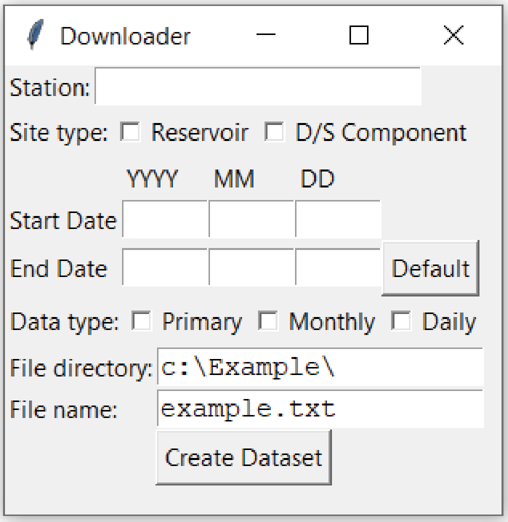


Figure 5-5: Dataset downloader UI

5.1.3 IMPORTING NON DWS DATASETS

The UP-RHES was designed to function according to the formats of DWS datasets, however any dataset from any country can be used as an input for both the rapid assessment tool and the scenario assessment tool.

This is done by formatting the desired dataset to a '.txt' file with a layout that matches those of the applicable DWS dataset. In all cases the UP-RHES requires the dataset to exclude any headers.

5.1.4 RAPID ASSESSMENT TOOL

The rapid assessment tool is the initial hydraulic assessment tool of the UP-RHES and can quickly and accurately estimate the hydropower potential of a dam. The rapid assessment tool performs monthly power computations, as proposed by Chadderton & Niece (1983). The rapid assessment tool requires the inputs as shown in Figure 4-9.

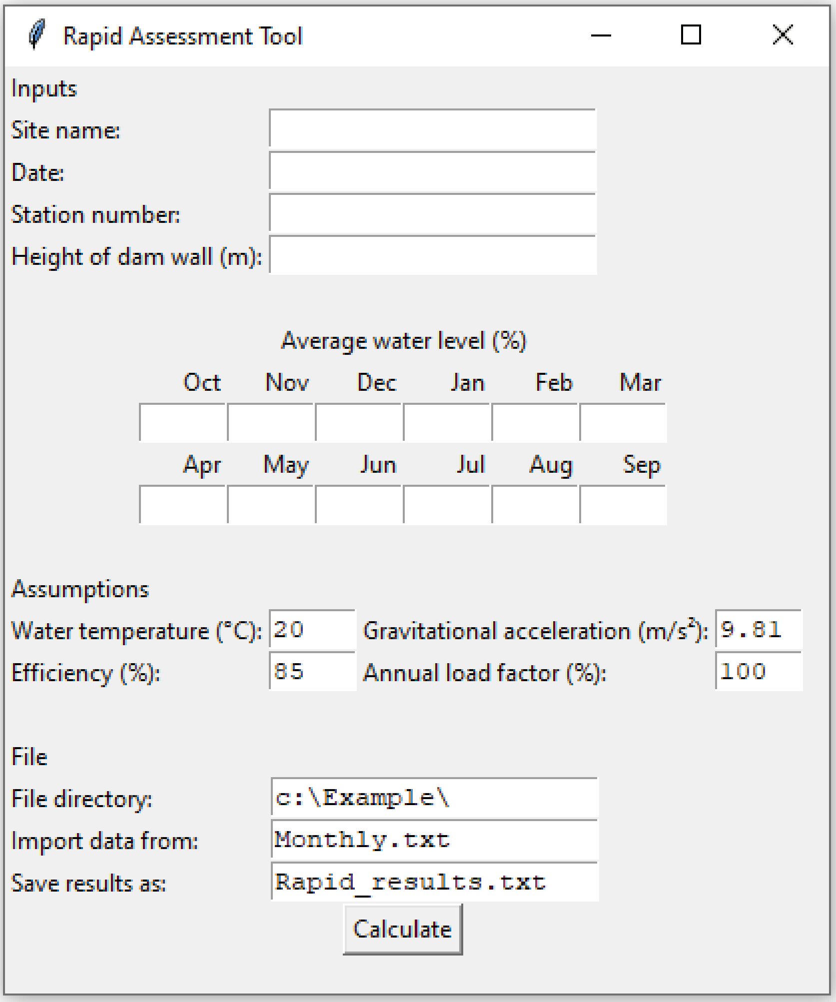


Figure 5-6: Rapid assessment tool UI

5.1.5 SCENARIO ASSESSMENT TOOL

The scenario assessment tool is the second of the hydraulic assessment tools in the UP-RHES, it generates a power duration curve, a modification of the conventional flow duration curves used in hydropower evaluation. The scenario assessment tool estimates the annual energy output available at a site for a given installation scenario, based on the historic power available. The tool should be used in conjunction with both the rapid assessment tool and the LCCA tool to estimate the maximum energy output of a dam. The scenario assessment tool requires the inputs as shown in Figure 5-7.

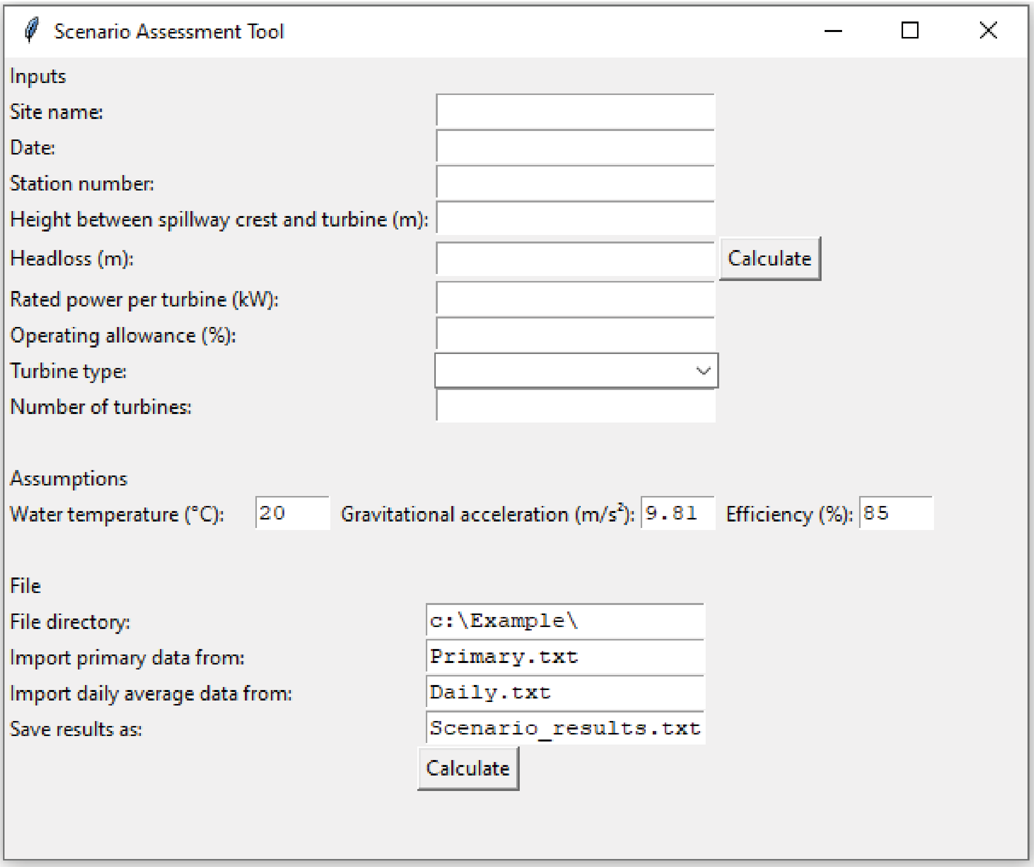


Figure 5-7: Scenario assessment tool UI

The expected headloss can either be entered directly or it can be calculated by the programme using Darcy-Weisbach with von Kármán & Prandtl, by selecting the calculate button shown in Figure 5-7. This will open a separate user interface, shown in Figure 5-8.

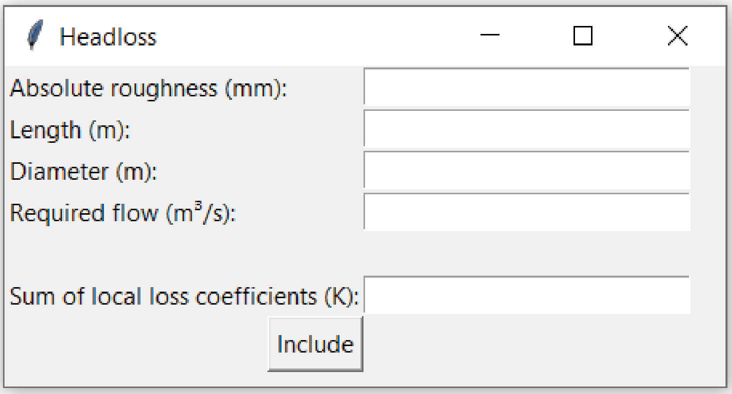


Figure 5-8: Headloss calculation UI

5.1.6 LIFE CYCLE COST ANALYSIS TOOL

The Life Cycle Cost Analysis (LCCA) tool determines the feasibility of the project based on a financial analysis using the results generated by either the rapid or scenario assessment tools. Although specific focus should be given to analyse the results of the scenario assessment and adjusting accordingly, until an optimal solution is reached.

The LCCA tool estimates the costs and benefits expected from the project over its design life, from which the financial feasibility of the project can be determined. Although this tool requires inputs that can be determined using the UP-RHES, a hydraulic analysis is not required to run the tool, should the values be known.

The LCCA tool requires the inputs as shown in Figure 5-9.

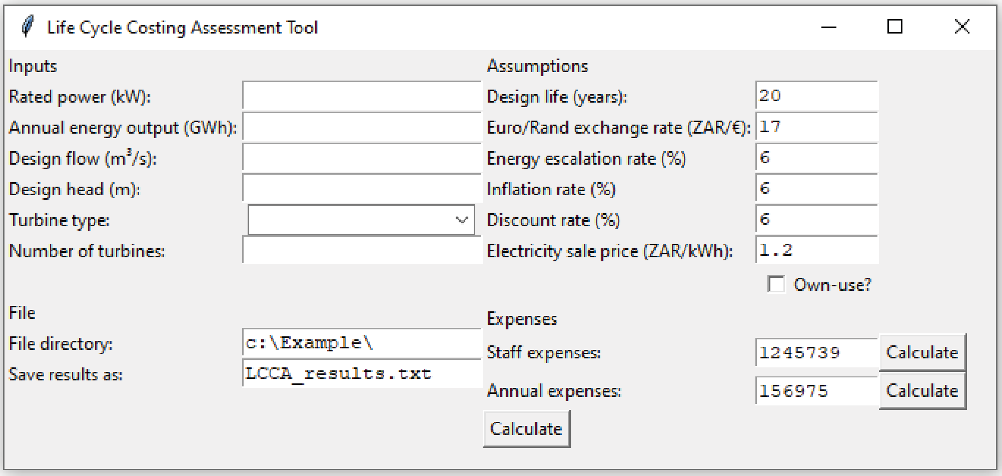


Figure 5-9: LCCA tool UI

Additionally, the LCCA tool assumes the values for the staff and operating expenses. These can be changed directly. Alternatively, by pressing their respective calculate button, a separate user interface will be launched allowing for modification of the specific components, as shown in Figure 5-10 and Figure 5-11.

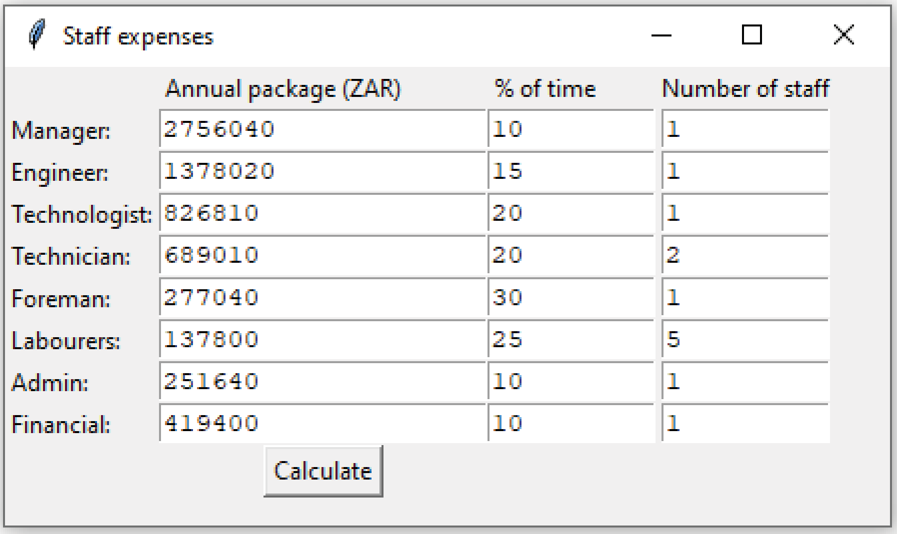


Figure 5-10: Staff expenses UI

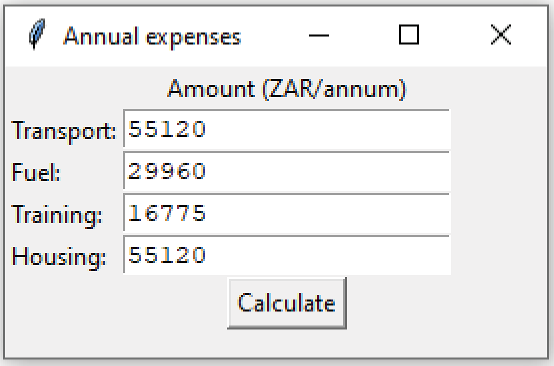


Figure 5-11: Annual expenses UI

5.2 CONDUIT HYDROPOWER ASSESSMENT TOOL – PROCDEURAL METHOD DESCRIPTION

The aim of this section was to develop a decision support system that can be used to identify conduit hydropower potential in South Africa, as well as to provide proper guidance for the development of identified sites.

A system of flow diagrams and tools has been compiled to identify and develop conduit hydropower sites. These diagrams and tools were tested at three sites in the City of Tshwane Metropolitan Municipality. During the analysis, shortcomings and variances in the system were identified and addressed, and a practical decision support system for conduit hydropower development in South Africa was produced.

5.2.1 SYSTEMATIC APPROACH

A systematic approach must be followed when assessing hydropower potential in a distribution network to ensure that all relevant factors are considered. The procedure for determining hydropower potential is illustrated through a series of flow diagrams, whilst a tool developed in Microsoft Excel facilitates calculation of all the factors that need consideration. The development procedure has been divided into three phases:

- First Phase: Pre-Feasibility Investigation
- Second Phase: Feasibility Study
- Third Phase: Detailed Design

Each phase has its own process flow diagram linked to the Conduit Hydropower Development Tool (CHD Tool). Each item in the flow diagrams is also numbered and discussed in more detail in *The Conduit Hydropower Development Guide* (Van Vuuren *et al.*, 2014). Some of the aspects of the study will be required in two or more of the phases, but will be dealt with in increasing detail as the project progresses.

A fourth phase, dealing with operation and maintenance aspects, falls outside the scope of this document, but is also an important phase to consider when designing a conduit hydropower facility.

5.2.2 FLOW DIAGRAMS

5.2.2.1 Phase 1 flow diagram

Phase 1 represents a pre-feasibility study and comprises various first-order analyses and studies. The purpose of this phase is to rapidly determine whether more in-depth studies will be worthwhile. Figure 5-12 and Figure 5-13 indicate the decision flow process for this phase.

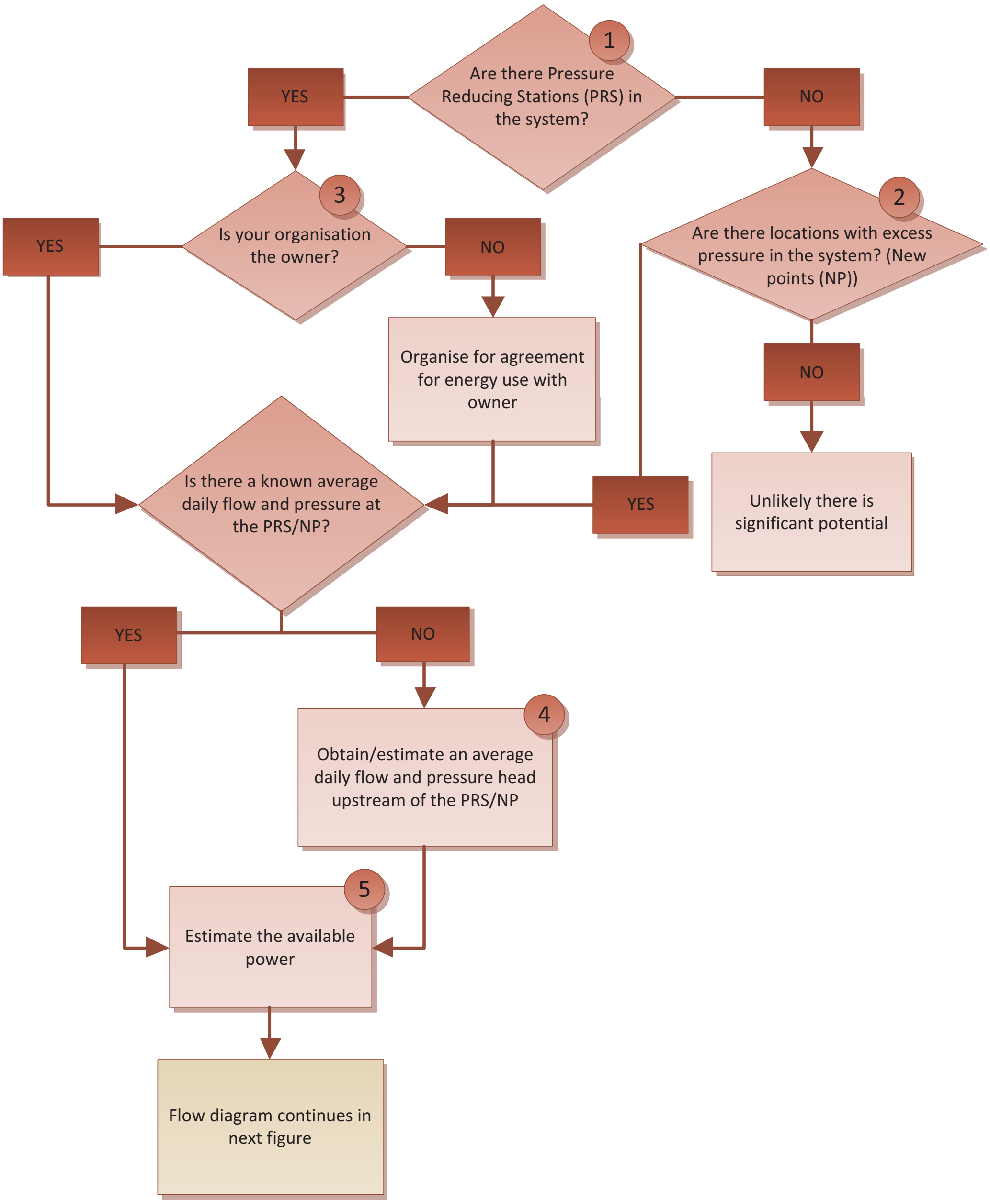


Figure 5-12: Phase 1 flow diagram Part A

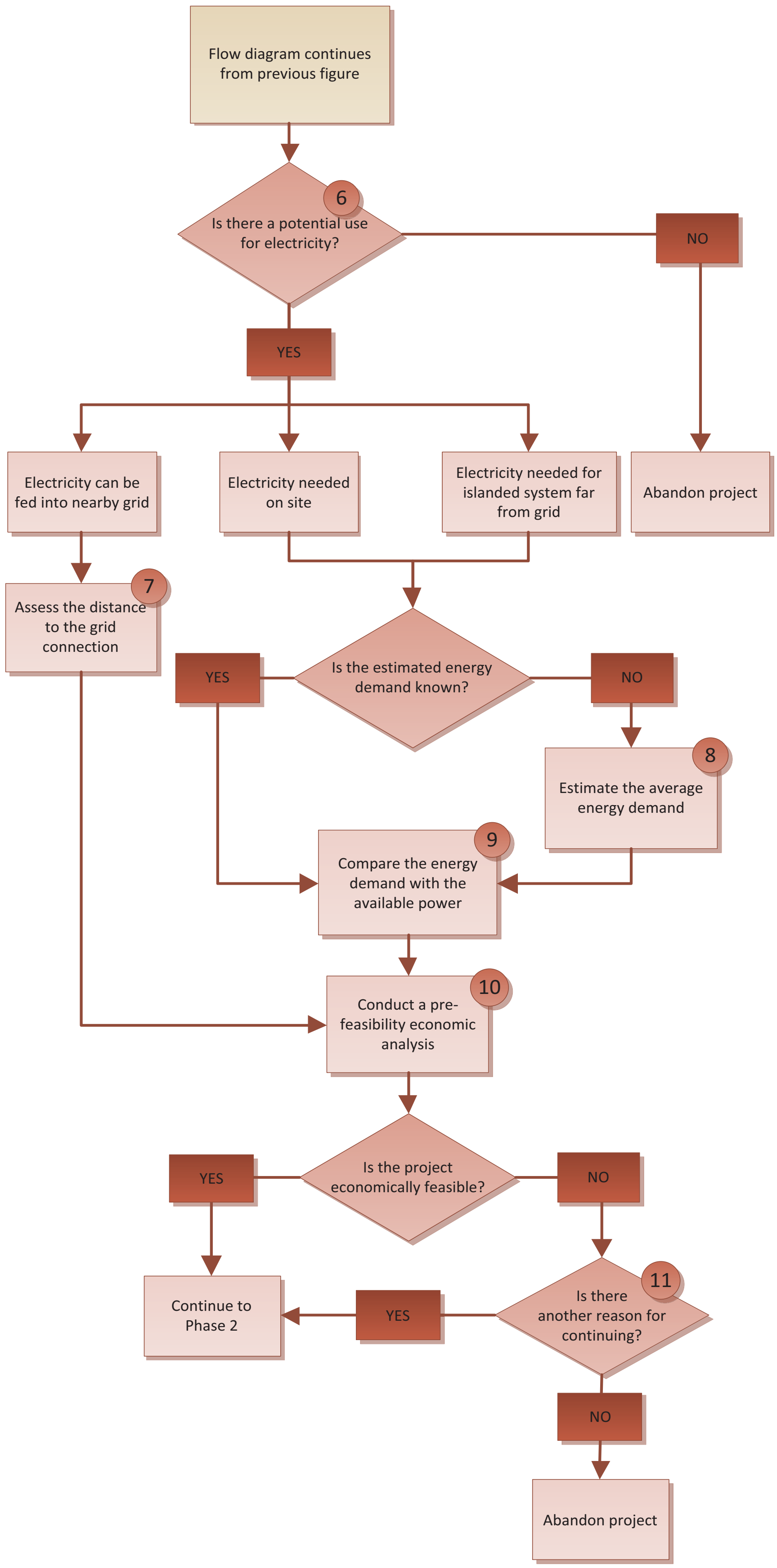


Figure 5-13: Phase 1 flow diagram Part B

5.2.2.2 *Phase 2 flow diagram*

If Phase 1 indicates project viability, a more in-depth investigation can be done during the feasibility study of Phase 2. Figure 5-14 and Figure 5-15 illustrate the process to be followed during this stage.

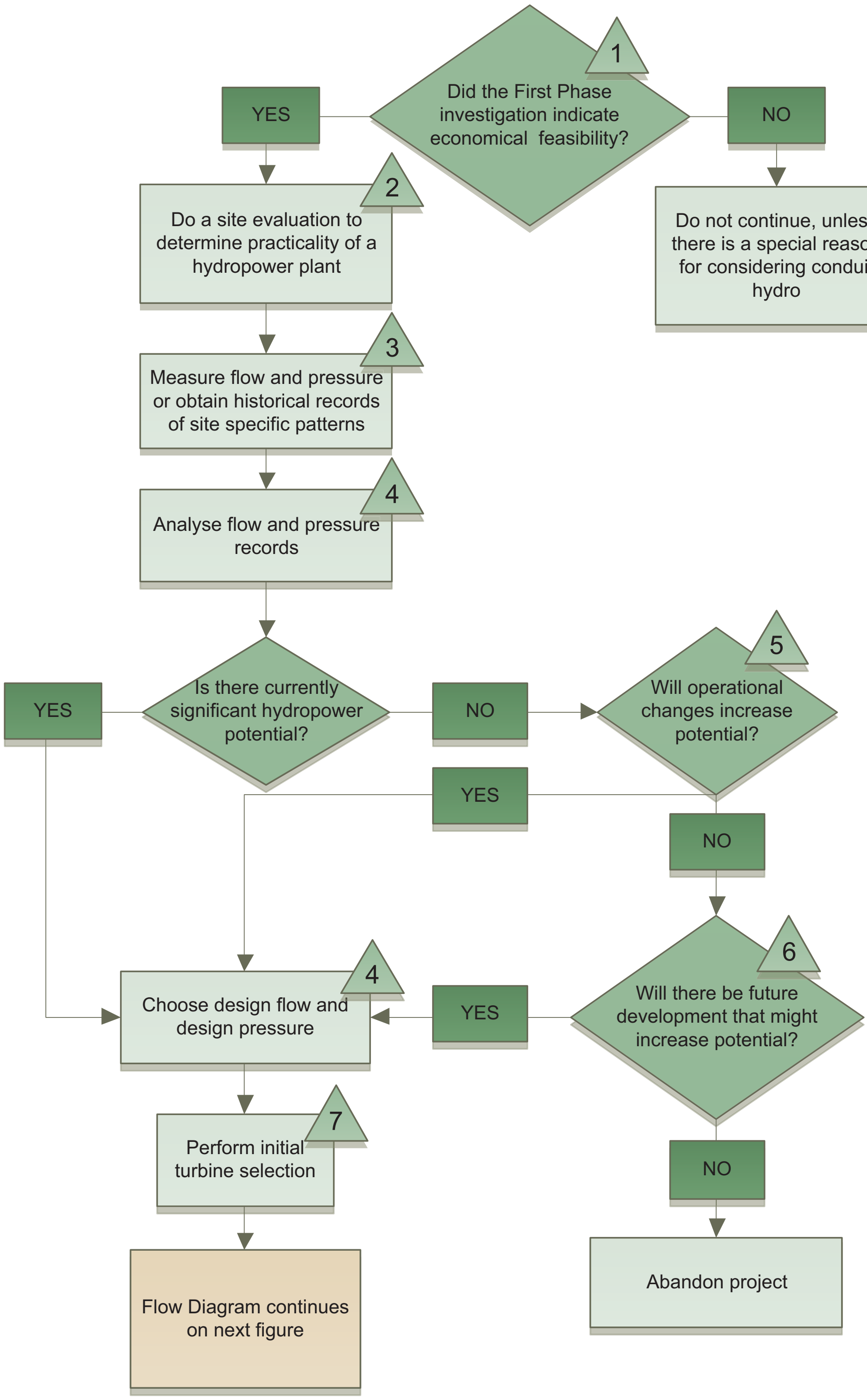


Figure 5-14: Phase 2 flow diagram Part A

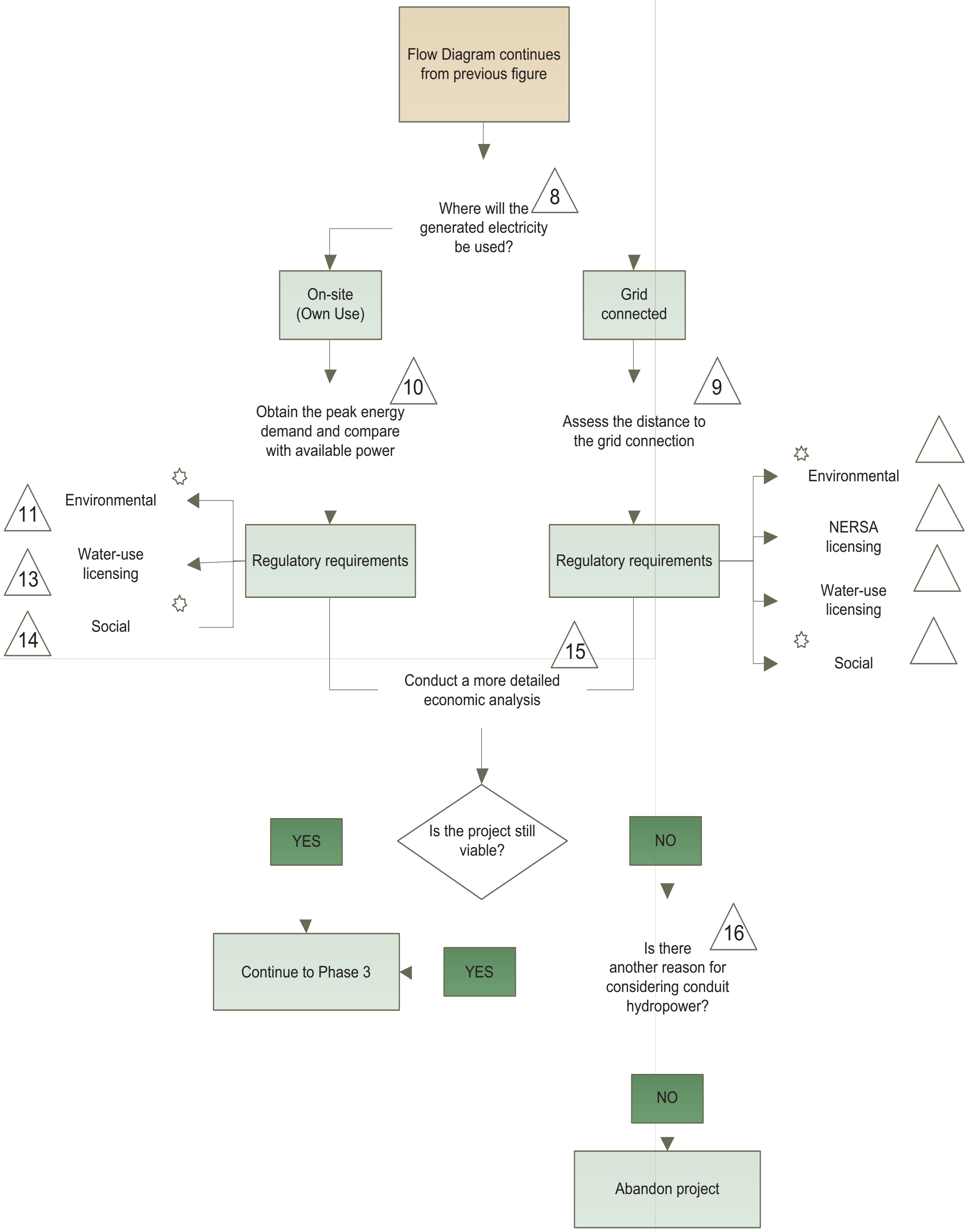


Figure 5-15: Phase 2 flow diagram Part B (✩ depicts specialist consultant input)

5.2.2.3 Phase 3 flow diagram

If Phase 2 indicates project viability, a detailed design for the hydropower plant can be done during Phase 3. Figure 5-16, Figure 5-17 and
Figure **5-18** depict the decision support process to be followed in developing the hydropower potential.

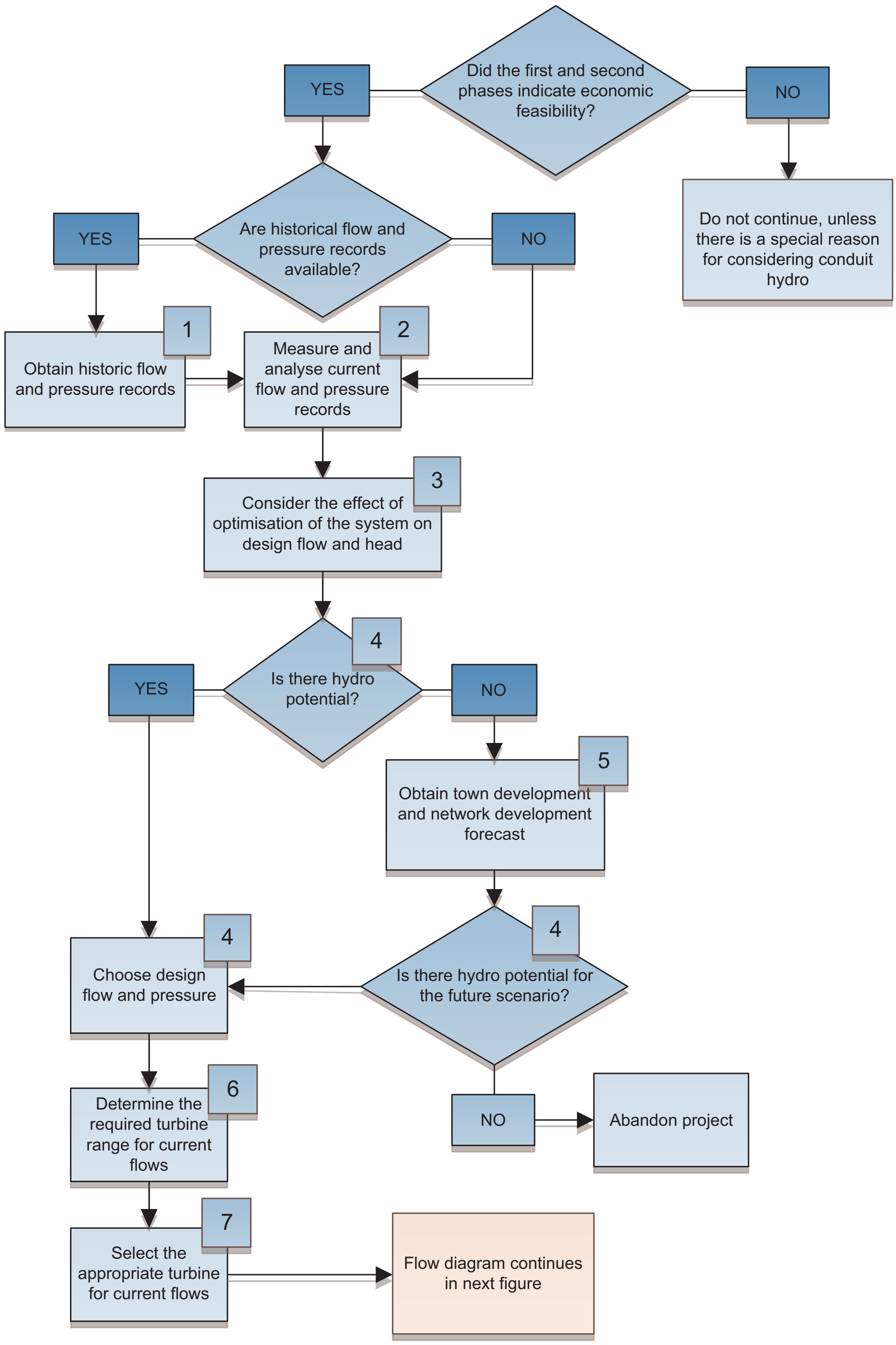


Figure 5-16: Phase 3 flow diagram Part A

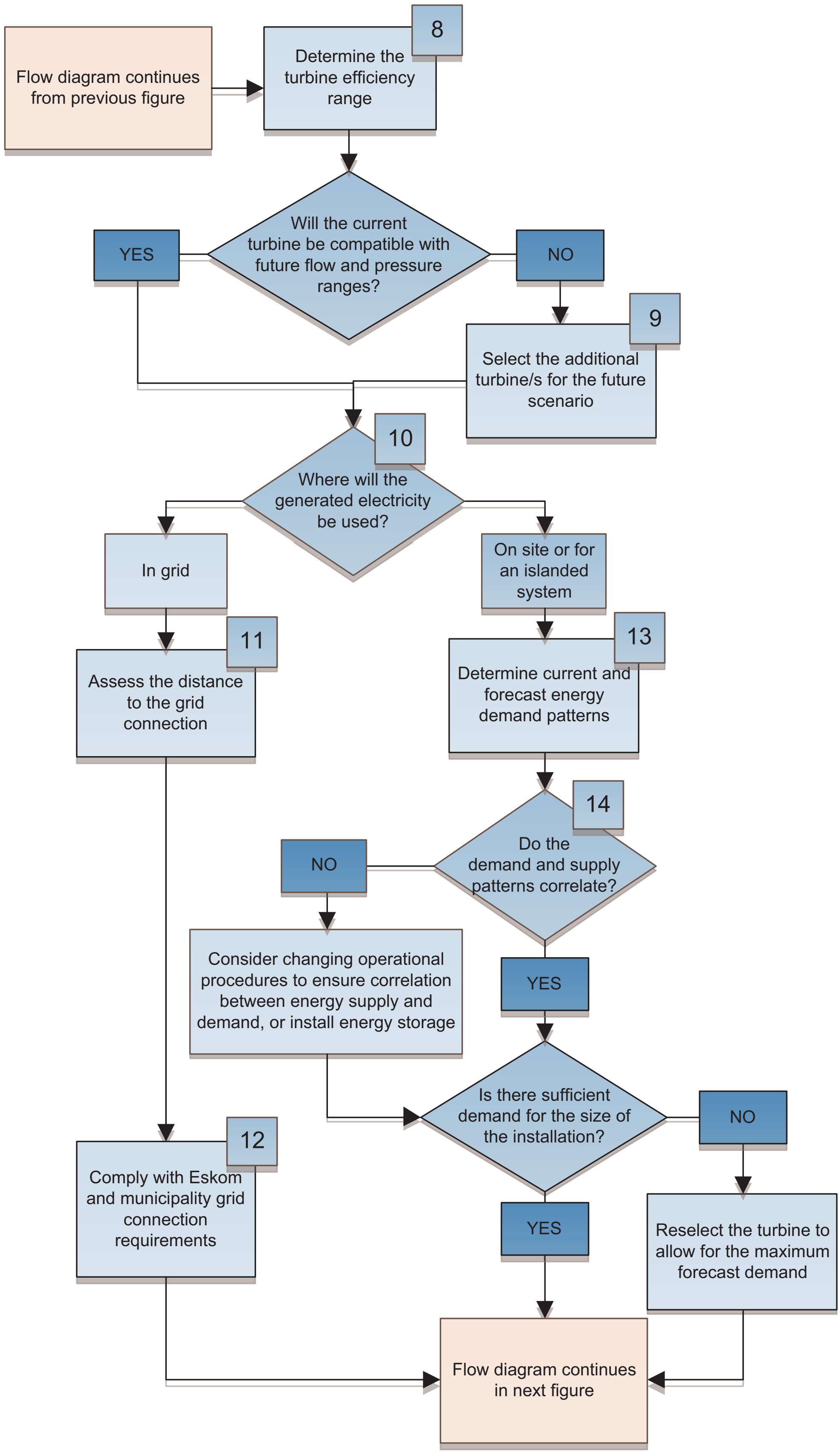


Figure 5-17: Phase 3 flow diagram Part B

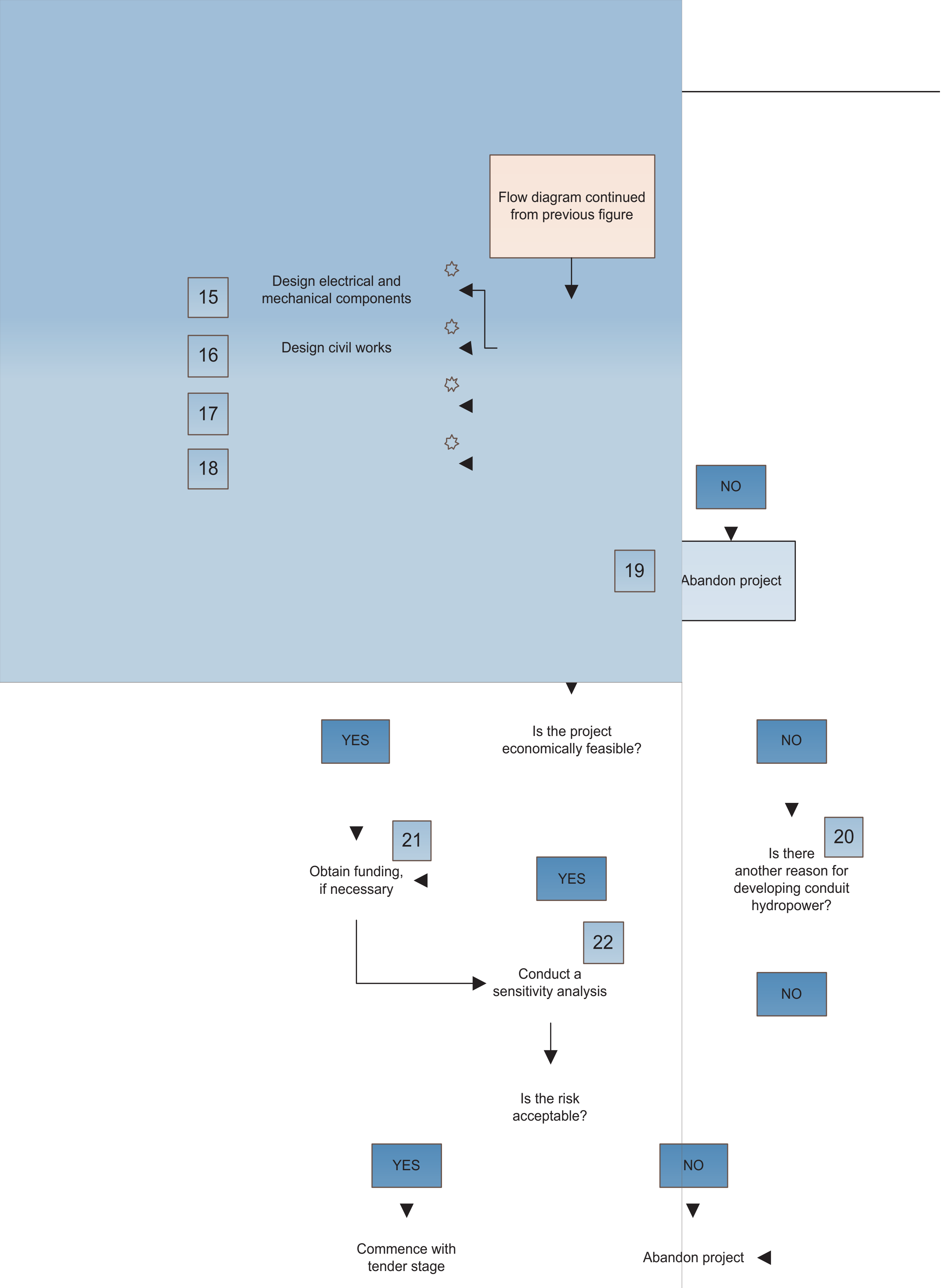


Figure 5-18: Phase 3 flow diagram Part C (✩ depicts specialist consultant input)

CHAPTER 6: HYDROPOWER ATLAS OF SOUTH AFRICA

The final product of the South African Hydropower Atlas visually illustrates the hydropower potential that exists in the various water infrastructure and rivers. This section showcases this by providing examples of selected layers displayed in the SAHA platform.

The very simplified process of finally obtaining the hydropower layers using the information discussed in the previous sections is illustrated in Figure 6-1.

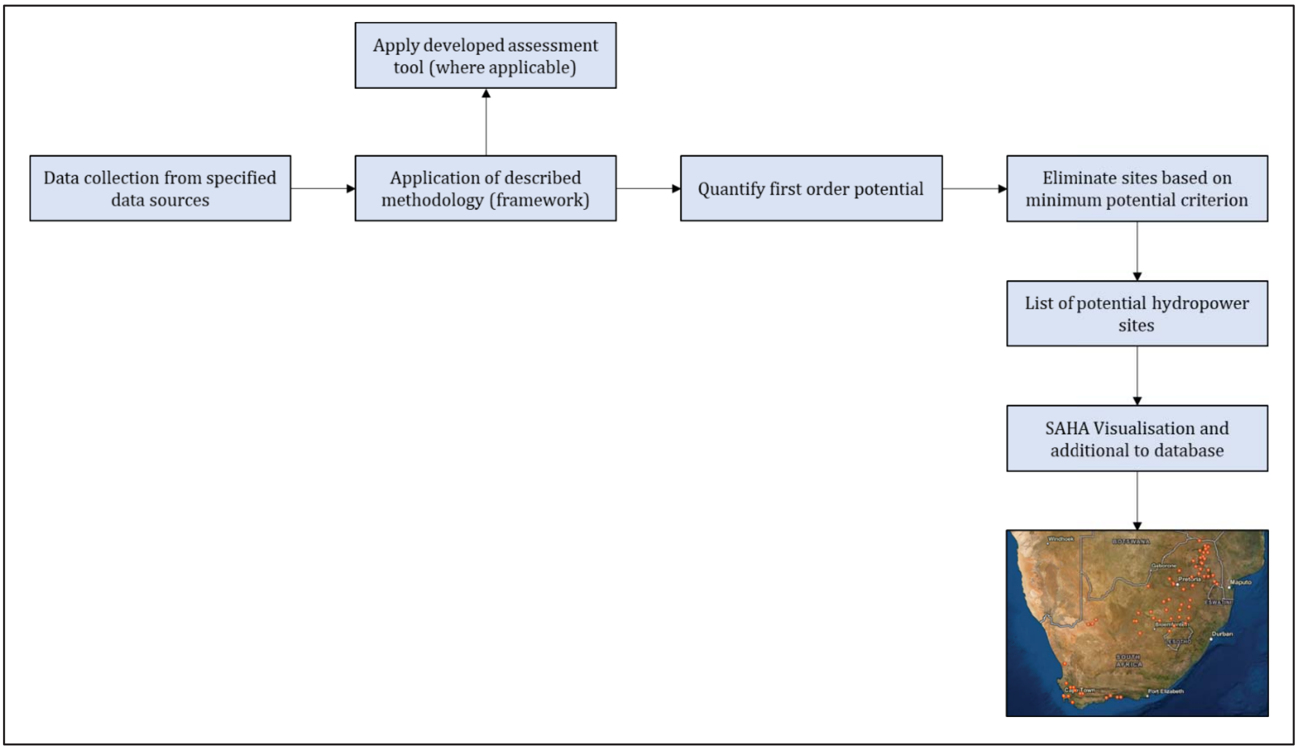


Figure 6-1: Simplified process of creating layers for SAHA

The layer for conduit hydropower is shown in Figure 6-2 and Figure 6-3. This layer contains the sites that have been evaluated based on the information that was available. The number of potential sites will increase as more access is granted to available data.

Link to South African Hydropower Atlas:
https://uparcgis.maps.arcgis.com/apps/webappviewer/index.html?id=9618bcec00ad4f5398f4cc0cd1a447b8&utm_source=web+map&utm_medium=res&utm_campaign=hydropower

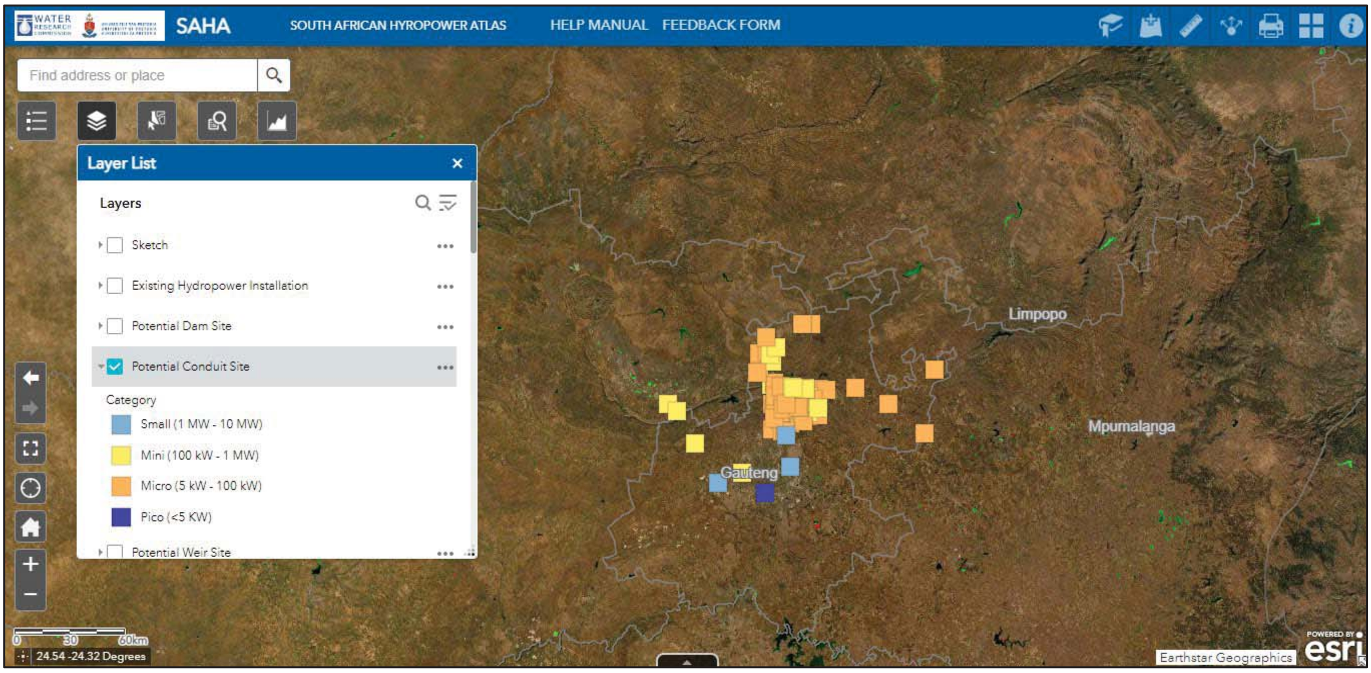


Figure 6-2: Conduit hydropower potential layer

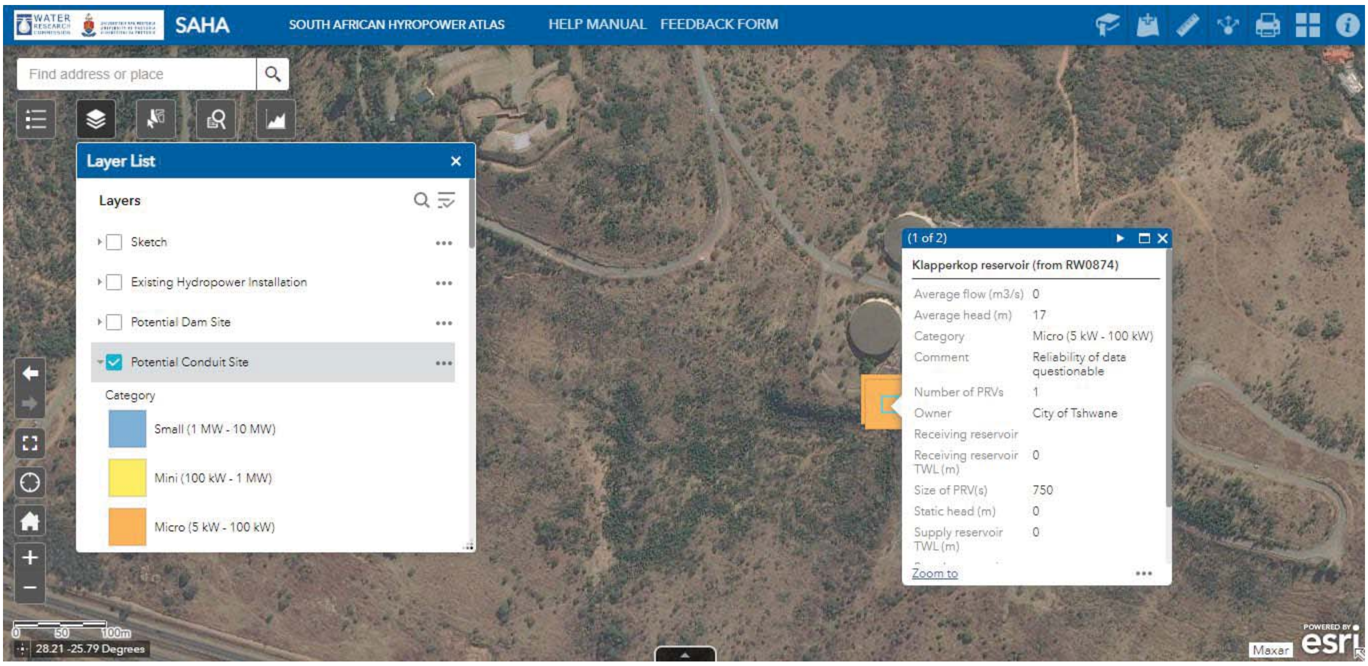


Figure 6-3: Conduit hydropower potential layer – zoomed in with attributes

The layer for the potential storage schemes that can be retrofitted for hydropower generation is shown in Figure 6-4 and Figure 6-5. As with the other layer continuous evaluation and updating of the layer will be required as more data becomes available.

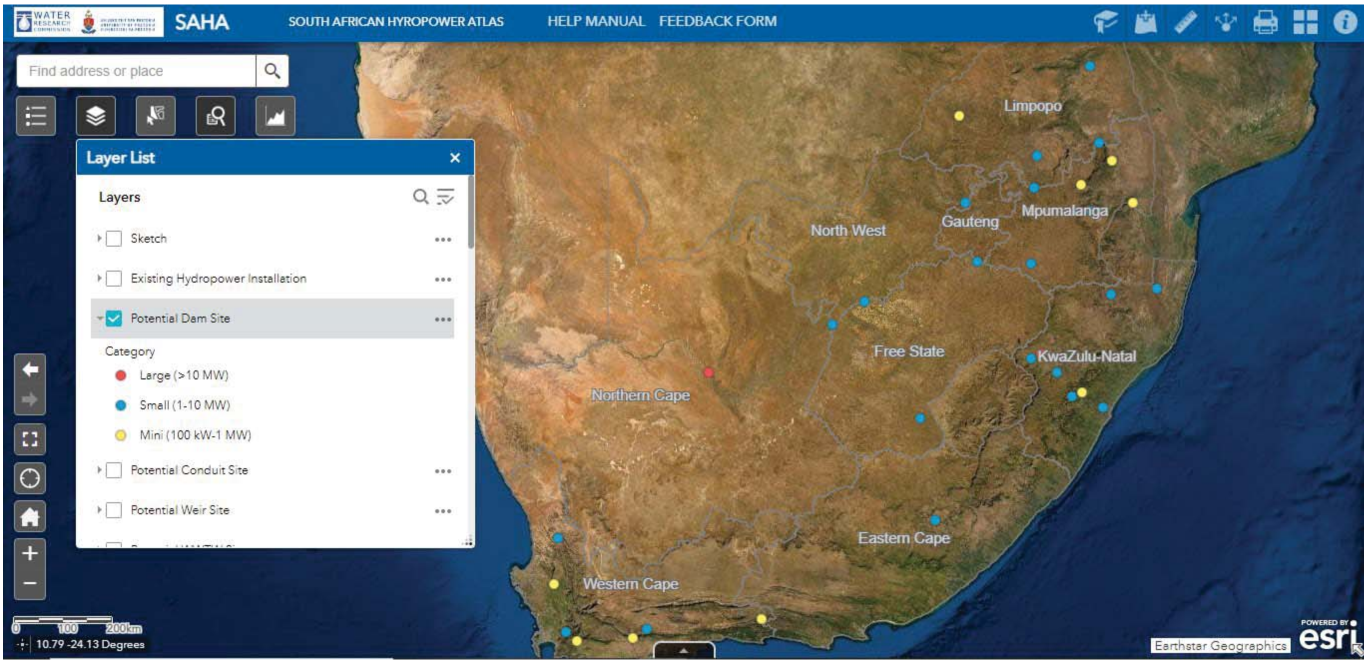


Figure 6-4: Storage schemes potential layer

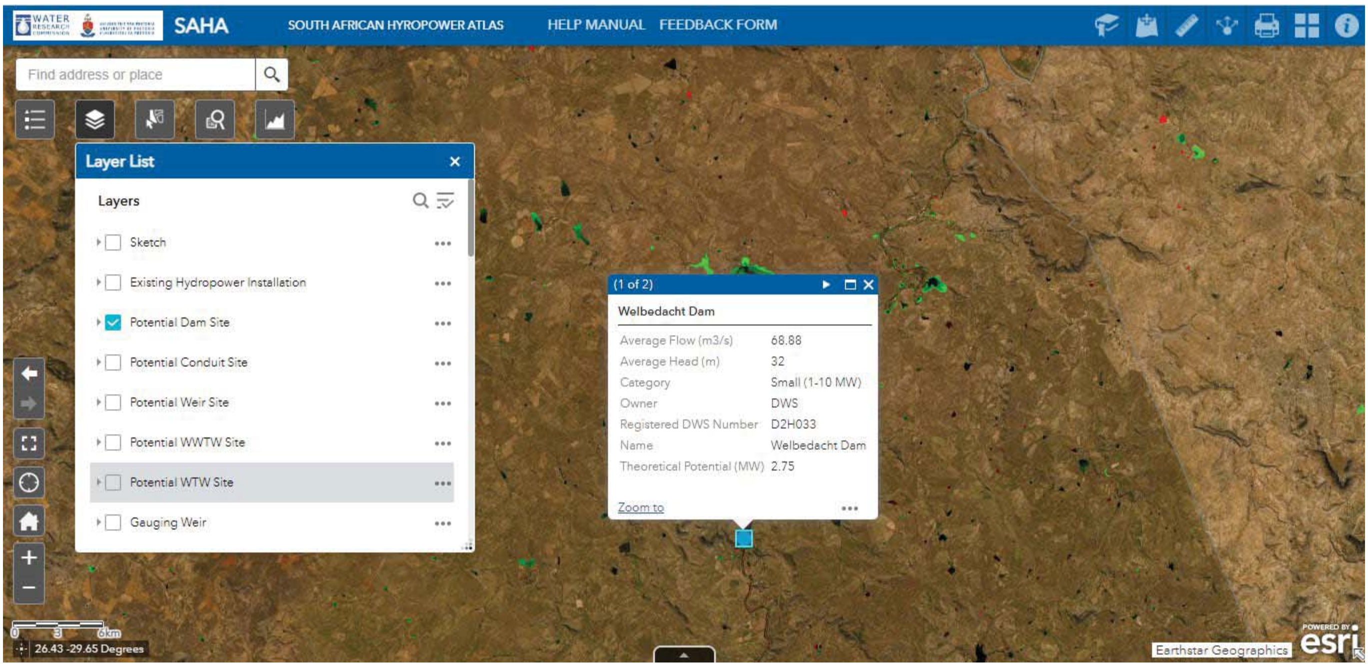


Figure 6-5: Storage schemes potential layer – zoomed in with attributes

The layer containing all gauging weirs with hydropower potential greater than 5 kW is shown in Figure 6-6 and Figure 6-7. It should be noted that the sites included in this layer is limited to DWS owned gauging sites. Further evaluations will include obtaining access to the data of and identifying additional weirs sites that are not DWS owned (such as weirs owned and utilised by farmers).

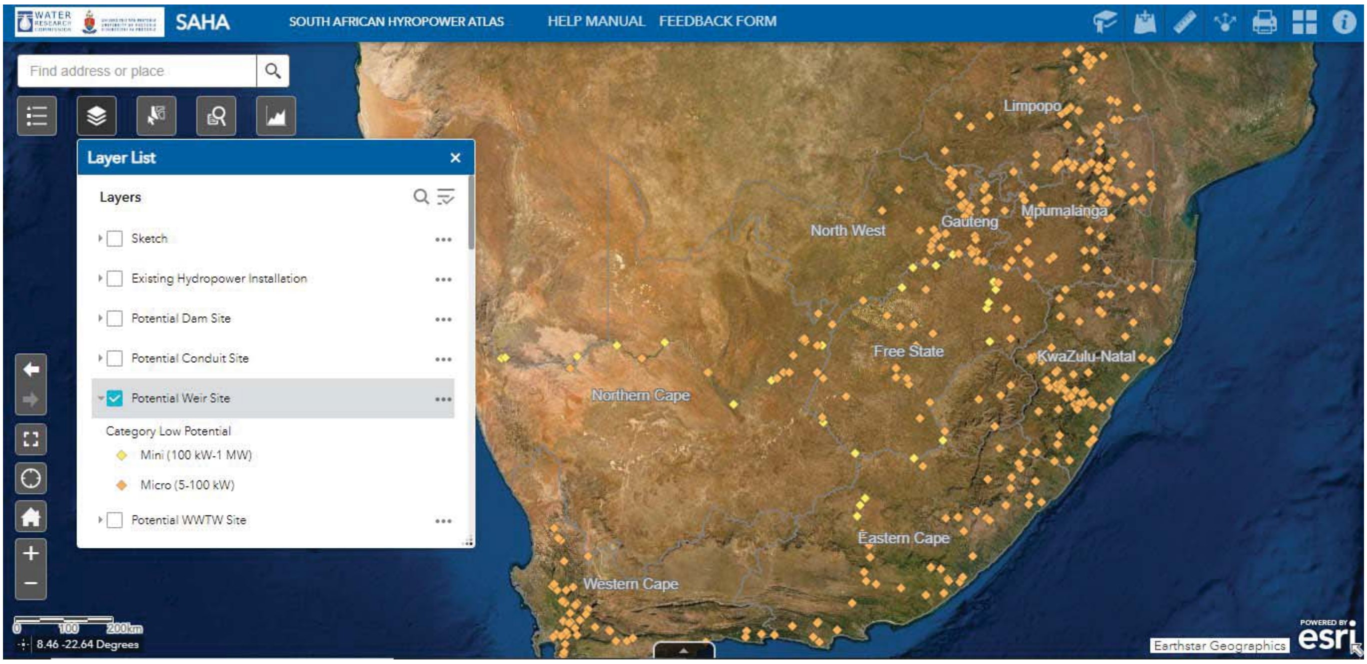


Figure 6-6: Weirs potential layer

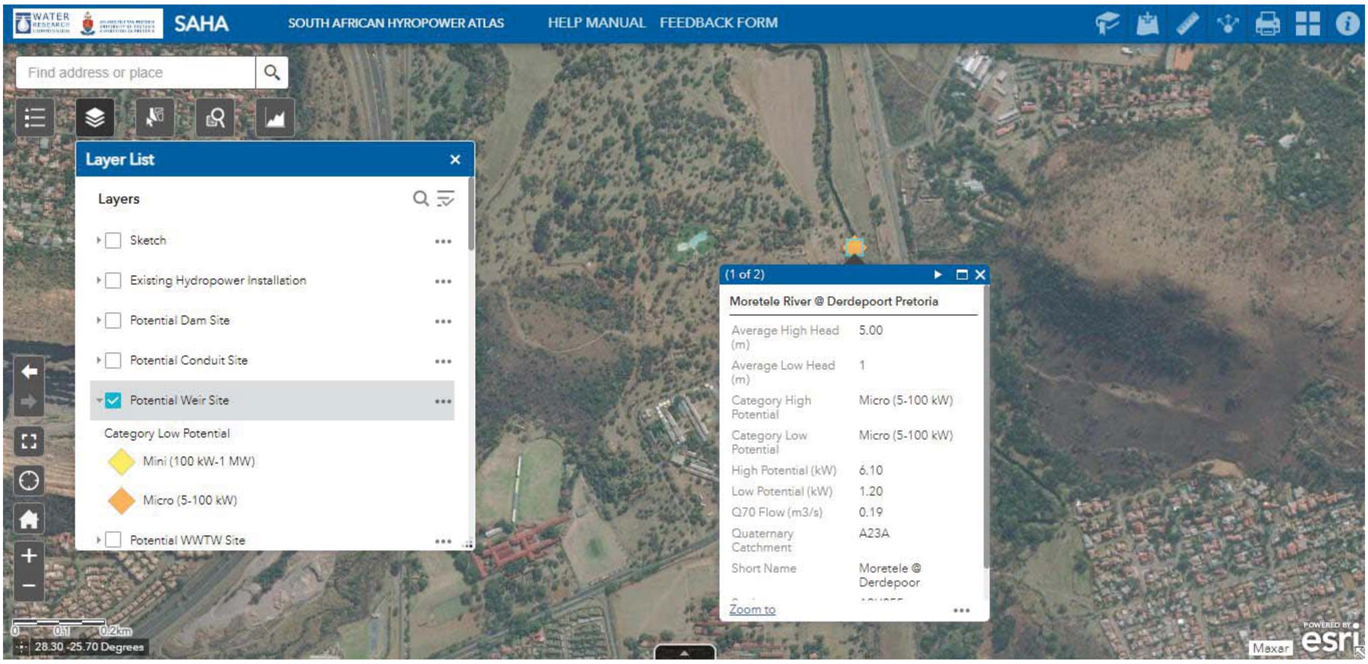


Figure 6-7: Weirs potential layer – zoomed in with attributes

The layer containing all identified (potential) hydropower sites at WWTW are shown in Figure 6-8 and Figure 6-9. The sites included in this layer are limited to sites with a generating potential greater than 5 kW and only those sites that are listed in the DWS Green Drop Report. It should also be noted that due to limited data it was assumed for all sites that the available head for energy generation is between 1 m to 5 m.

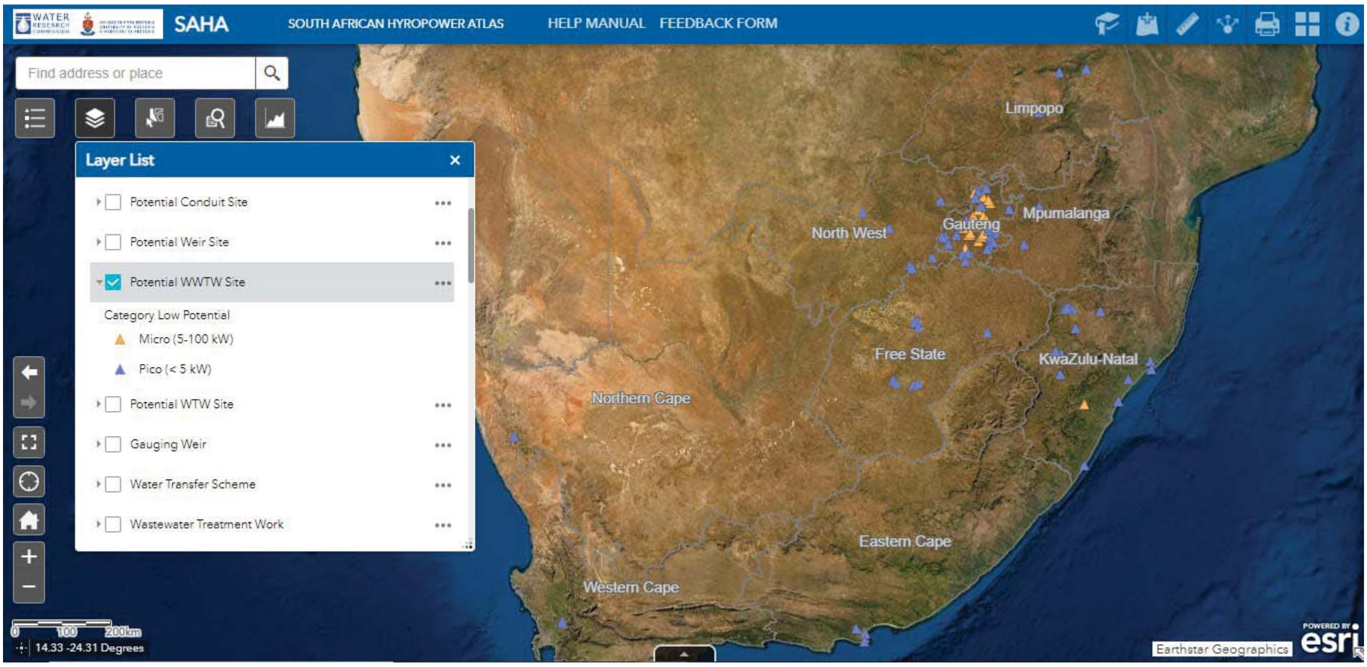


Figure 6-8: WWTW potential layer

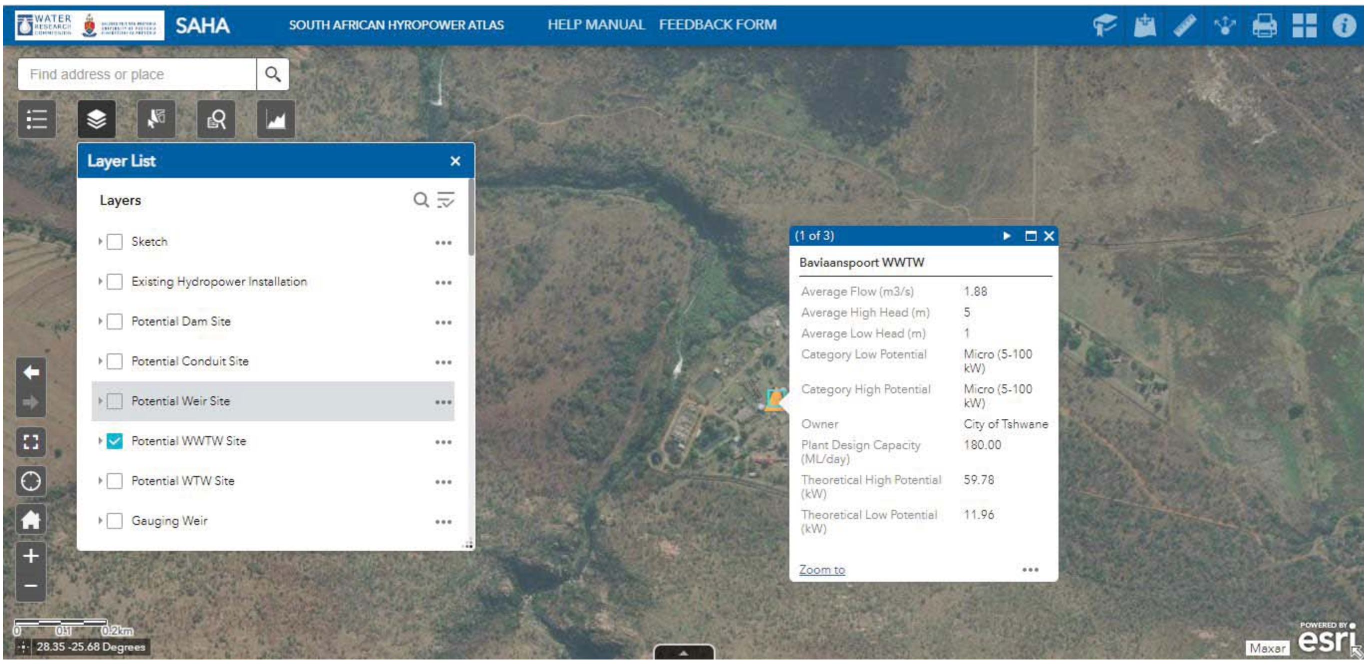


Figure 6-9: WWTW potential layer – zoomed in with attributes

The layer containing all identified (potential) hydropower sites at WTW are shown in Figure 6-10 and Figure 6-11. The sites included in this layer are limited to sites with a generating potential greater than 5 kW and only those sites that are listed in the DWS Blue Drop Report. It should also be noted that due to limited data it was assumed for all sites that the available head for energy generation is between 1 m to 5 m.

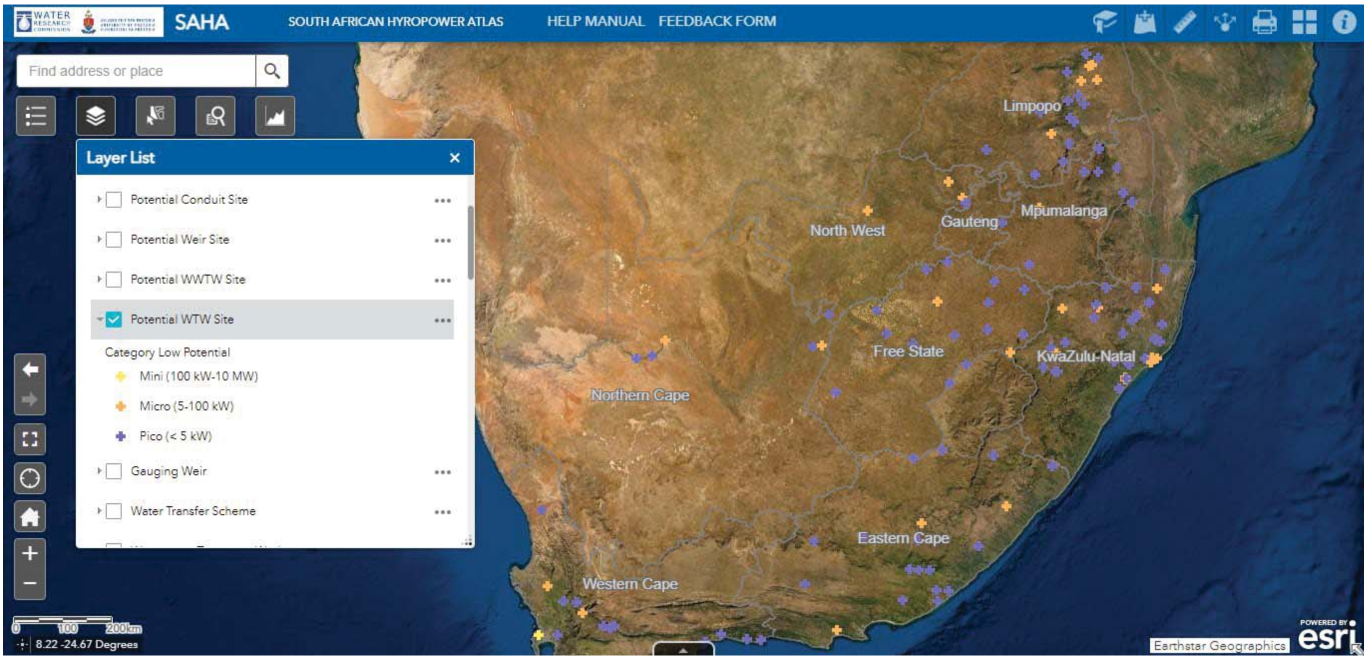


Figure 6-10: WTW potential layer

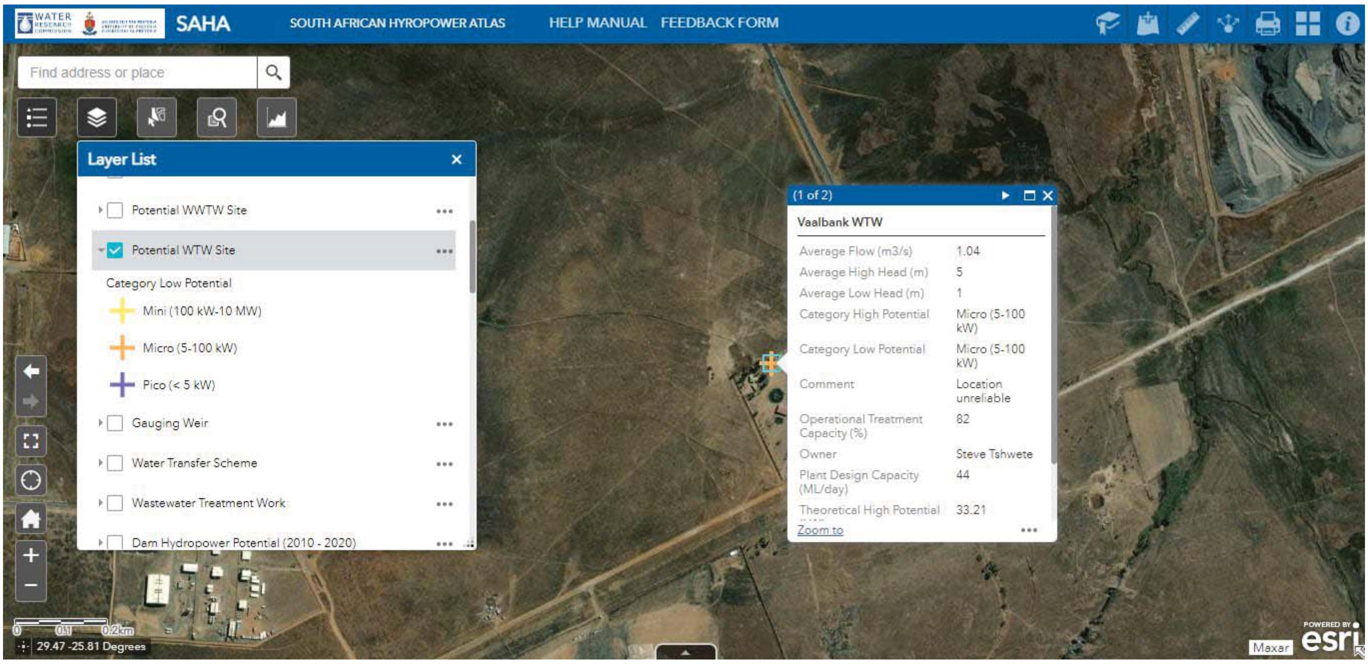


Figure 6-11: WTW potential layer – zoomed in with attributes

The layer containing the potential sites for pumped storage hydropower generation is shown in Figure 6-12 and Figure 6-13. From this layer it can be seen that for one specific location, more than one potential reservoir (upper or lower) size is indicated – Figure 6-13 shows an example of this. This is because evaluations were conducted for the following scenarios where an increase in generating capacity is usually also indicative of a larger reservoir size.

- 2 GWh for a generation period of 6 hours;
- 5 GWh for a generation period of 6 hours;
- 5 GWh for a generation period of 18 hours;
- 15 GWh for a generation period of 6 hours;
- 15 GWh for a generation period of 18 hours;
- 50 GWh for a generation period of 6 hours;
- 50 GWh for a generation period of 18 hours; and
- 150 GWh for a generation period of 18 hours.

This implies that the total pumped storage potential based on this layer is significantly lower than indicated due to overlapping potential sites.

Lastly, it should be noted that the identified sites included in the layer was not evaluated using geological, hydrological or environmental data. This implies that some identified sites might still be deemed unsuitable upon a more detailed investigation (Australian Government, 2014).

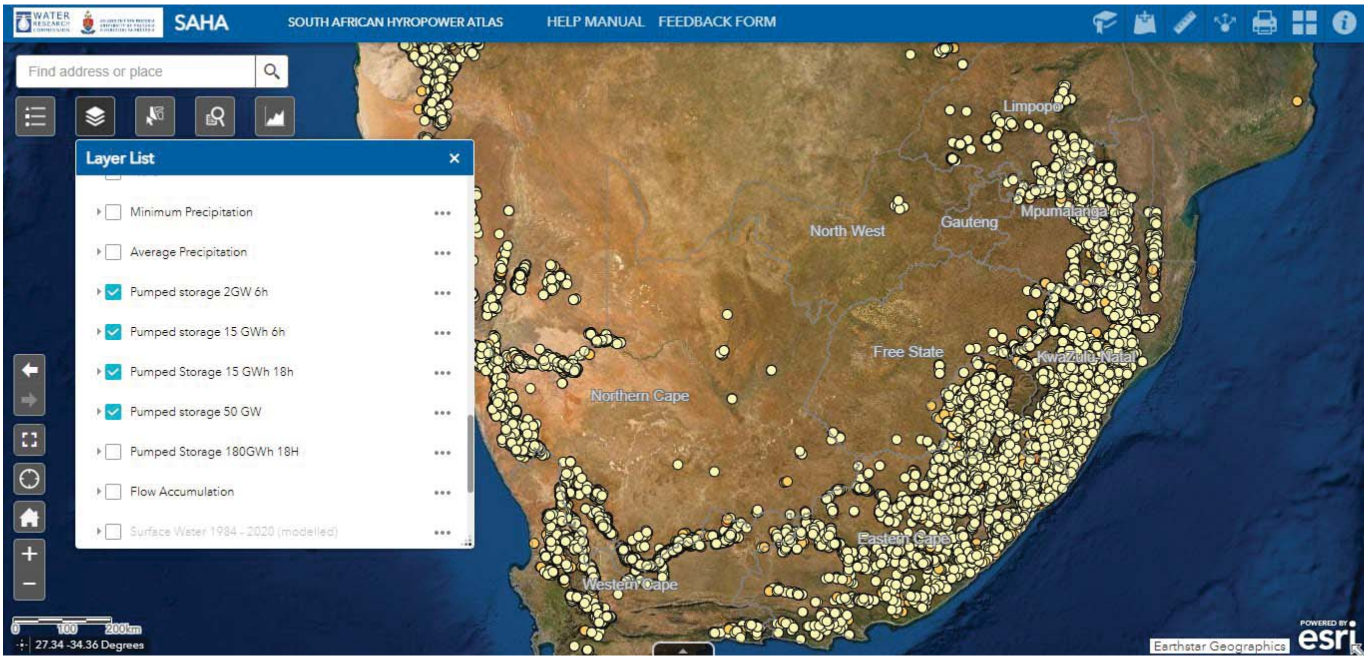


Figure 6-12: Pumped storage potential layer

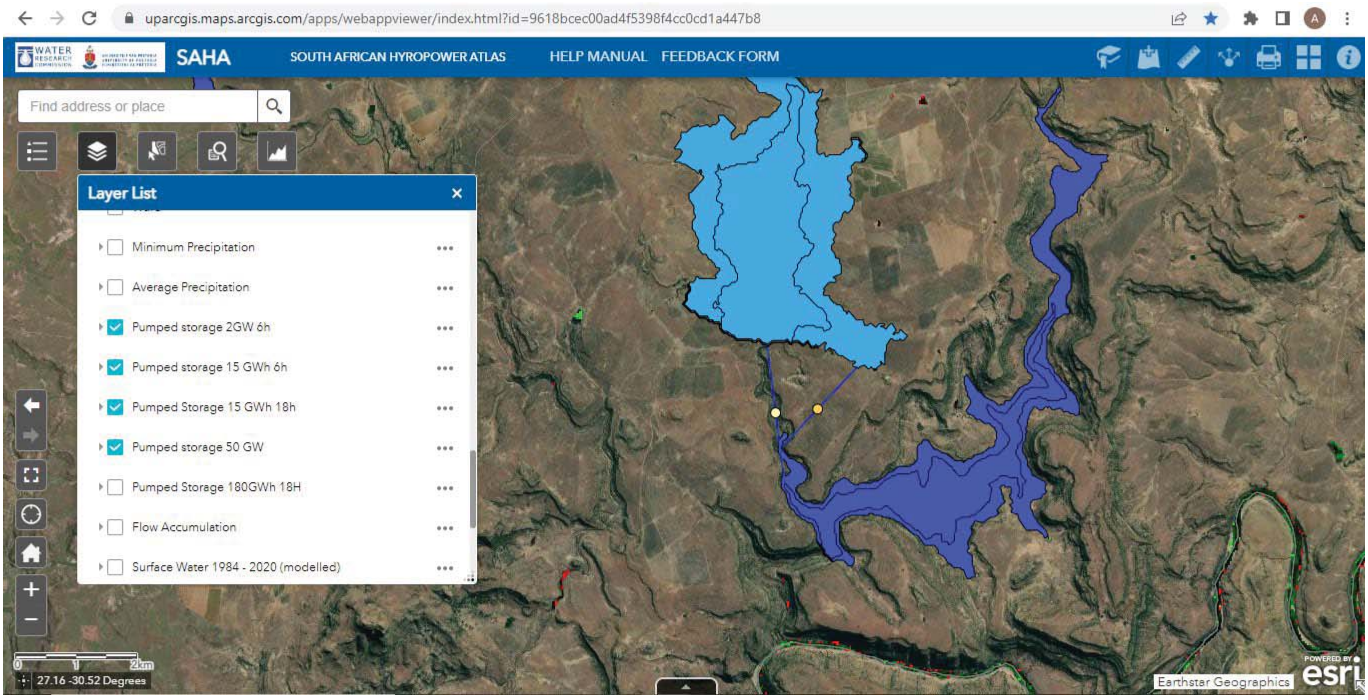


Figure 6-13: Pumped storage potential layer – zoomed in with attributes

CHAPTER 7: SUMMARY OF HYDROPOWER POTENTIAL IN SOUTH AFRICA

The primary aim of developing a hydropower atlas for SA was to realise the potential for hydropower that exists within the water infrastructure and rivers. The atlas visually illustrates the potential available and serves as a platform to share available data continuously and freely. Additionally, the development of the atlas also provides an update of the potential that exists. Very limited studies (Ballance *et al.*, 2000) have been dedicated to evaluating the total potential for hydropower in South Africa. This atlas is therefore the first in-depth evaluation of the hydropower potential in SA. Additionally, the SAHA is also the first hydropower atlas to include small scale hydropower opportunities such as hydropower at WWTW, WTW and in water supply and distribution systems.

A summary of the total identified hydropower potential in SA (according to hydropower type) is provided in Table 7-1.

Table 7-1: Summary of total hydropower potential in SA

Hydropower type	Total potential sites					Total potential (MW)
	Large	Small	Mini	Micro	Pico	
Conduit	0	3	148	501	272	> 83
Run-of-river						760 to 882[a]
Storage schemes	4	310	340	N/A	N/A	1 102
Hydrokinetic[b]						>16
WWTW	0	0	8	36	80	0.73-3.7
WTW	0	0	4	30	88	0.67-3.3
Weirs (gauge)	0	9	84	152	179	10.6-50.3
Pumped storage						31 000[c]
Transfer schemes [b]		6	12	5	6	>22

Values based on current available data will be continuously updated as database matures

[a] Potential for run-of-river provided as kW/km (1.04). Total for SA still being determined

[b] To be assessed in detail

[c] Value based on an assumption of a generating capacity of 12 hours per day. Value is also based on overlapping sites (based on reservoir size). Actual value of potential is significantly lower.

It should be noted that the table provided above will be continuously updated as more data becomes available and more sites are identified. This is especially the case for the small scale hydropower opportunities as available data remains a challenge. The evaluation methods for the identification of hydropower as discussed in Section 3 aided in the identification of sites with limited access to data that would otherwise not have been included in the atlas. But is should still be pointed that the limited access to data remains a challenge and did result in some small scale hydropower sites to not be evaluated and therefore not yet included in the atlas (especially conduit hydropower).

CHAPTER 8: CONCLUSIONS

Due to the low cost and high availability of coal, electricity generation in South Africa is heavily dependent on this fossil fuel, with the majority of the country's electricity generated in coal fired power stations. With a global shift towards greater concern for the environment, the use of fossil fuels in generating electricity is becoming increasingly unfavourable, because of its production of greenhouse gases and their contribution to global warming. Worldwide, alternative methods involving the use of inexhaustible natural flows of energy to generate electricity are being investigated to determine the feasibility of using renewable energy technologies to generate electricity.

The aim of this project was to create a web-based atlas to showcase the hydropower potential available in South Africa, thereby encouraging owners of South African water infrastructure and rivers to invest in renewable and sustainable energy generation sources. Data sources have been identified from which parameters necessary for hydropower evaluation could be quantified. The identified sources were incorporated in the development of evaluation frameworks which assisted in the evaluation of hydropower potential in South African rivers and water infrastructure.

Additionally, various platforms were considered, and the functionality compared to eventually select the most suitable online platform (ArcGIS Online) to host the South African Hydropower Atlas. Using this online platform, the graphical user interface could be developed based on the conceptual layout discussed in previous reports.

Lastly, using the information discussed in the previous deliverables allowed for the collection of data and creation of layers to be included in the atlas. Using the identified data sources and developed frameworks the following potential was identified:

- Total conduit hydropower potential of 83 MW from 919 assessed sites:
- Total run-of-river potential between 760 and 882 MW (1.04 MW/km determined in rivers with numerous specific assessed sites);
- Total hydropower of 1102 MW from 654 storage schemes;
- Total hydropower potential of 0.73-3.7 MW from 124 WWTWs;
- Total hydropower potential of 0.67-3.3 MW from 122 WTWs;
- Total hydropower potential of 10.6-50.3 MW from 424 gauging weirs; and
- Total pumped storage potential of approximately 31 000 MW (from overlapping sites).
- Total of more than 22 MW hydropower potential in the primary transfer schemes.

The South African hydropower atlas will aid in the enhanced the uptake of hydropower technologies in SA and will be the start in the compilation of a database capturing all hydropower opportunities in SA.

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