National University of Lesotho

Energy Research Centre

Estimating hydropower generation potential of the Metolong dam.

Mokhothu Emmanuel Moerane

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

Master of Science in Sustainable Energy

Offered by the

Energy Research Centre
Faculty of Science & Technology

October 2022

Abstract

Metolong dam is located 30 km east of Maseru town, with the dam retaining wall built inside the Phuthiatsana River. The purpose of the dam is to supply portable water to Maseru, Roma Mazenod, Morija and Teyateyaneng. The Instream Flow Requirement (IFR) given post Metolong dam construction and meant to sustain life downstream of the dam was used to estimate how much hydropower can be generated from IFR. Even though the study is aimed at assessing the hydropower generation potential of the dam, it did not address the sedimentation rate occurring inside the dam per year and how much storage capacity is lost due to sedimentation. Microsoft excel spreadsheet is used to estimate how much electricity can be generated from IFR and to examine how the water temperature affects the electricity projections.

The results show that the dam has the capacity to produce 65kW from In-stream flow requirement (IFR) in April, as a month with the highest IFR and 7 kW in September, as a month with the lowest IFR. These power production figures are studied together with the water temperature in three scenarios to observe the effects of water temperature on power production. The outcome is that they seem to have no significant effect. The power production is based on when a Radial flow PAT (Pump As Turbine) of 0.6 efficiency and generator of 0.955 efficiency are attached at IFR release point. The dam head ranges between 23 m – 44 m for IFR, with water releases of 0.01 m^3/s – 0.3 m^3/s. This power can be used for distributed generation or net metering by the Water and Sewage Company (WASCO). The financing of the project is not expected to exceed $50 000 given the condition of the already installed penstock at the recovery period of less than 4 years factoring in fluctuations of power brought by those of IFR for environmental purposes downstream of Metolong dam.

Table of Contents

List of Figures

List of tables

List of equations

List of Abbreviations and Acronyms

IFR – In-stream Flow Requirement

PAT – Pump As Turbine

SDGs – Sustainable Development Goals

MDGs – Millennium Development Goals

SADC – Southern African Development Community

MoE – Ministry of Energy

LEWA – Lesotho Electricity and Water Authority

MEM – Ministry of Energy Meteorology

DoE – Department of Energy

REU – Rural Electrification Unit

LHWC – Lesotho Highlands Water Commission

COW – Commission Of Water

LEC – Lesotho Electricity Company

LHDA – Lesotho Highlands Development Authority

WASCO – Water and Sewage Company

PMF – Probable Maximum Flood

SEF – Spillway Elevation Flood

LCOE – Levelized Cost of Electricity

EU – European Union

SHP – Small Hydropower Plant

DEM – Digital Elevation Map

LRWSS – Lowlands Rural Water Supply and Sanitation

ADF – African Development Bank

RWSS-TF - Rural Water Supply and Sanitation

GoL – Government of Lesotho

IPP – Independent Power Producer

EIA – Environmental Impact Assessment

Chapter 1.0 – Introduction

1.1 Water and Energy nexus for hydropower.

Water is a very abundant resource, with 2.5 % of global water made of freshwater and only less than 1 % available for human consumption [1]. In 2014, the energy sector, comprised of power generation and primary energy production, accounted for 10 % of the total worldwide withdrawals and 3 % of the total water consumption [1]. The European Union set a goal to achieve 20 % share of energy from renewable sources until 2020. Developing countries are striving to achieve this goal as there is huge stress on water resources thus making wind, solar and biomass the other available sources [2].

Most countries have access to enormous amounts of water through rivers and canals which can be used to generate electricity without polluting the environment. Thus, it would be possible to plan development through a mix of energy and to implement measures that control the development of the electricity market through the use of sustainable small hydropower projects [3]. Predictions indicate that 60 % of new energy investments in the next 20 years will be in renewables with 25 % estimated on hydropower production of all renewables due to the potential in Africa, China South East Asia and Latin America [4].

Unsustainable electricity generation can lead to environmental degradation and climate change; the energy sector contributes 26 % of global greenhouse gas emissions [5]. But energy remains important for social and economic growth with the water-energy nexus proving that water is used for multiple energy generation processes (Hydroelectric and thermoelectric). Similarly, energy is used for various processes in water treatment and distribution [6]. Hydropower remains a vital sustainable generation method with high efficiency application and low to no greenhouse gas emissions [7]. Micro hydropower plants are an important means of producing energy and have a high prestige in the carbon trade market [8].

Sustainable development is faced with a major risk in the coming decades because of indispensable water and energy which are inputs in modern economies [9]. This has resulted in the increasing demand for water and energy resources and the growing impact of climate change on humanity. Hence, simultaneously solving the problem of using water and energy resources sustainably and limiting carbon emissions has gained world-wide recognition [10]. Water supply solely brings challenges to most economic sectors like energy, agriculture and forestry [11].

Climate change adaptation and mitigation could be achieved by efficient resources management of water and energy; although predictions for water and energy demand are forever increasing together with food security issues [12]. However, there are serious environmental problems like the green-house effect, air pollution and scarce water resources which increase the request for cleaner application of energy technologies especially in urban energy supply systems [13]. The Sustainable Development Goals (SDG) Center reports indicate that Africa has achieved SDG 13 on climate action and SDG 15 on life on earth but 60 % of poor people in the Southern African Development Community (SADC) region have scarce access to water, energy and food resources [13].

1.2 Background of Lesotho.

Lesotho is a country located in Southern Africa and is landlocked by South Africa in the Karoo basin [14]. The country is therefore under a subtropical high pressure zone, also influenced by its altitude, which gives it an alpine characteristic with distinct seasons (Summer and Winter) and two transition seasons (Autumn and Spring) [14]. Precipitation is highly variable, both temporally and spatially ranging from 500 mm in the Senqu River Valley to 1200 mm annually in the northern and eastern escarpment in the Southern African sub-region (Senqu, Lekoa and Tugela) [14].

Lesotho has a peak rainfall season from December to February, a monthly evaporation of 60 mm to 70 mm between June and July, 175 mm and 225 mm between December and January [14]. The mean lowest annual temperature ranges from 15.2^{o} C in the Lowlands to 7^{o} C in the Highlands, whereas it has the highest mean annual temperature ranging from 20^{o} C to 32^{o} C in the Lowlands and Highlands respectively [14]. The country enjoys over 300 days of sunshine; that is, 3 211 hours with annual solar radiation estimated to be between 5 700 MJ/m^{2} and 7 700 MJ/m^{2} making it very resourceful for solar energy [14]. The lowest temperature recording in the lowlands ranges between -3^{o} C and -1^{o} C and -8.5^{o} C to -6^{o} C in the highlands [14].

According to Lesotho's Bureau of Statistics, the country's population is 2.2 million as of 2018 and the life expectancy is 56 years, with 80 % of the population residing in the rural areas [14]. This renders most people in the rural areas energy deficient, hence having to rely on biomass for cooking, heating, lighting and ironing [15]. With the utilization of electricity, people's productivity improves through better use of time and so does their income; this enables them to move out of poverty [16]. LEC data proves that the average electricity consumption between 2001 and 2016 in urban households has decreased by 60 %; it may be the worse for rural households since only 5.5 % are grid connected [17].

Rural populations in Lesotho face insufficient energy resources; for instance, to play a radio to link to the outside world, one must recharge batteries [15]. On the other hand, rural people travel long distances for paraffin which they use for cooking and lighting if they are not using fire-wood [15]. Sub-Saharan countries have been characterized by dependency on paraffin which in many cases has been associated with health issues and has a high safety risk. Paraffin is additionally used for lighting though it provides vivid and insufficient light [16]. It is quite expensive and demands a substantial portion of the rural households' monthly income [16].

Lesotho has a 72 MW 'Muela hydropower plant and four mini hydropower plants commissioned between 1983 and 1993 namely: Mantšonyane with 2 MW capacity and the plant is grid connected; Semonkong with 180 kW hydro generator and 120 kVA diesel generator; Tlokoeng with 460 kW and 210 kW hydro generators and 200 kVA diesel generator with 33 kV distribution line to Mokhotlong; Tsoelike with 275 kW and 125 kW hydro generators and 200 and 320 kVA diesel generators and 33 kV distribution line to Qacha's Nek [18]. These mini-hydropower plants have not been in operation for a while now because of siltation since they rely on run-off water from rivers and use diesel generators for backup which is costly to run [18]. There are concerns regarding fossil fuels and how they deplete the ozone layer; but energy demand and utilization investigations need to be conducted on a large number of abandoned small hydropower plants so that ways to desist from the use of energy derived from fossil fuels may be found [19]. The four mini-hydropower plants have been abandoned due to siltation problem [20].

As shown in Figure 1, the small hydropower plants comprise 1 % of Lesotho's electricity when operational and exploring the remaining untapped hydro potential would benefit the country through exporting electricity as the peak demand is only 160 MW [14]. This untapped hydropower potential is divided into Lesotho's four geographical zones which are;

- Mountain region catchment area of 18 037 km^2 making 59 % of the country's total area, comprising the Maluti range and deep river valleys at an elevation of about 2000 m above sea level (a.s.l.).
- Foothills catchment area of 4 529 km^2 making 15 % of the country's total area, located between the Mountain region and the Lowlands at an elevation range of 1800 m – 2000 m a. s. l.
- Lowlands catchment area of 5 094 km^2 which makes 17 % of the country's total area with elevation around 1800 m a. s. l.
- Senqu valley catchment area of 2 690 km^2 which makes 9 % of the country's total area at an elevation varying from deep Maluti mountains to Lowlands along the Senqu Orange river banks [18].

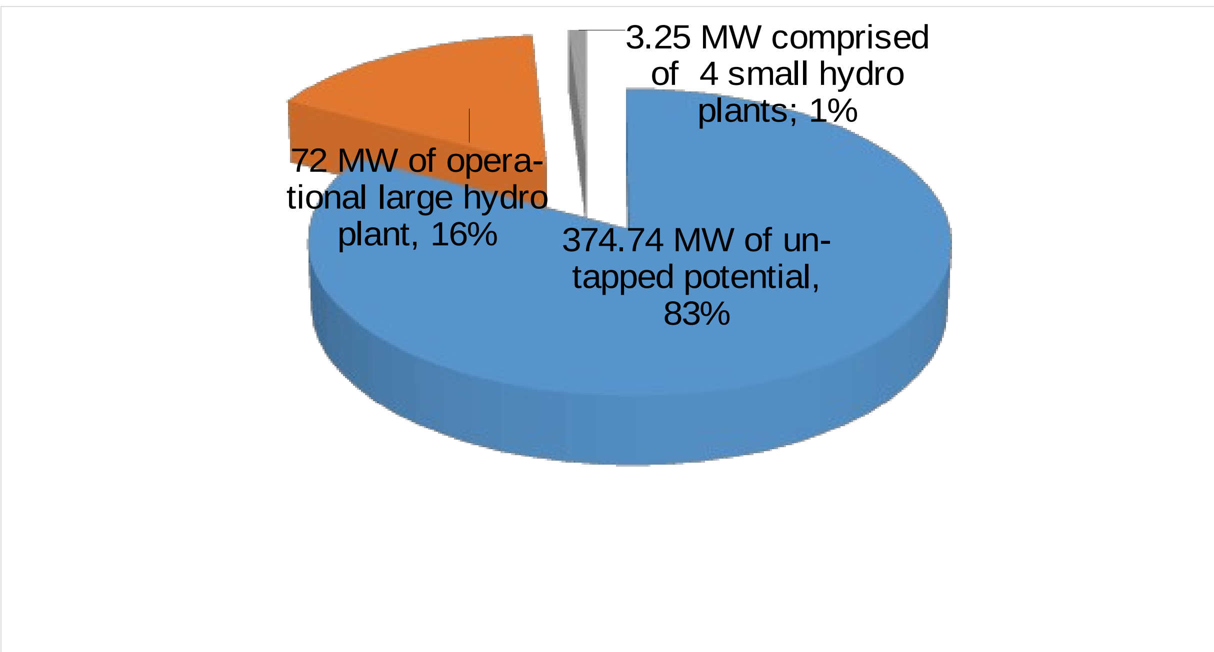

Figure 1: Lesotho's potential hydropower without pumped storage [18].

To explore the untapped potential as shown in Figure 1, Lesotho needs huge capital investments in order to own and operate these relatively large hydroelectric plants [18] or even rehabilitate the four existing ones abandoned due to siltation, and supplement the operational large 'Muela hydropower plant [21].

Lesotho has the following organizations which are related by their roles in the power sector as shown in Figure 2. The water organizations are shown because they are delegated and regulated by the Ministry of Water (MoW) or the Lesotho Electricity and Water Authority (LEWA) [22].

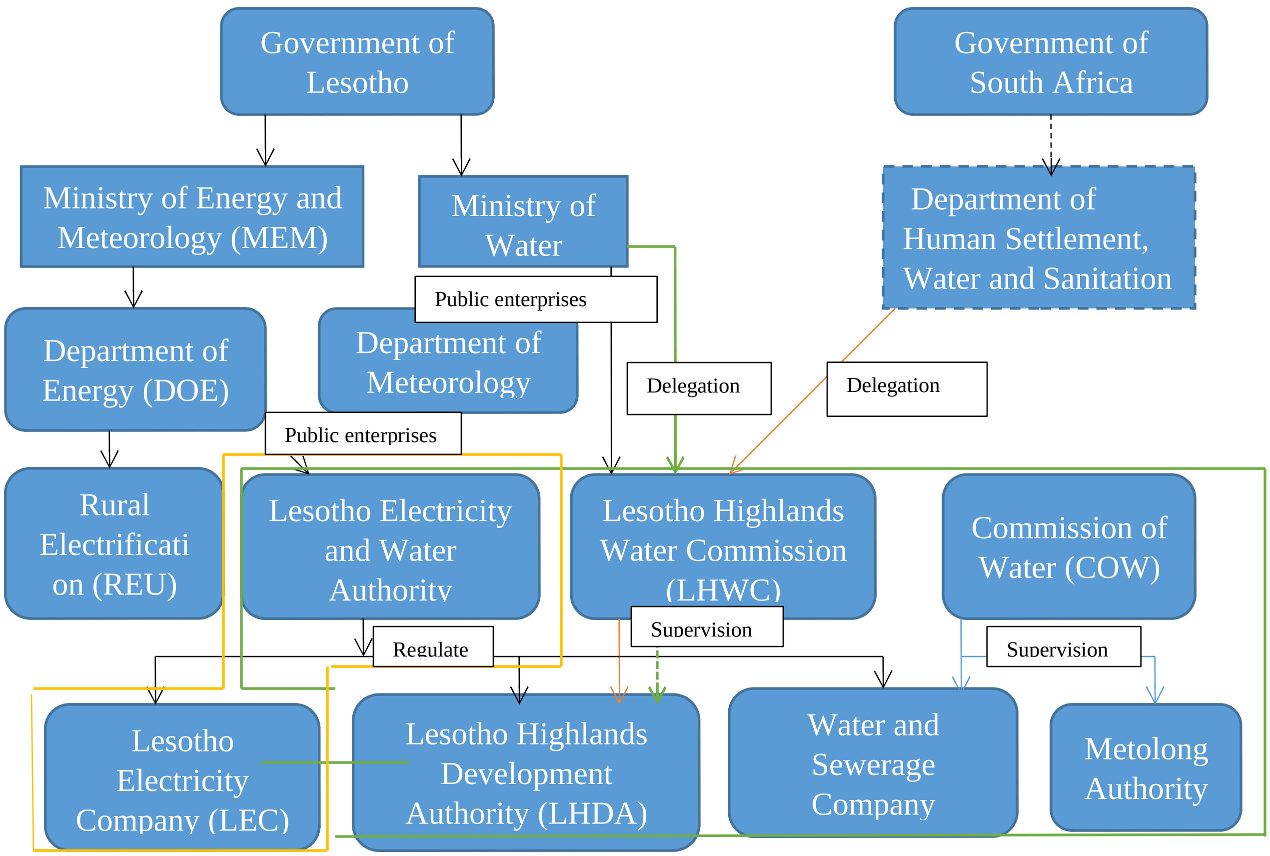

Figure 2: Lesotho power sector related organizations.[22].

The following organizations play different roles in electricity generation in Lesotho: Ministry of Energy and Meteorology (MEM), Department of Energy (DOE), Lesotho Electricity and Water Authority (LEWA), Lesotho Electricity Company (LEC), the Lesotho Highlands Development Authority (LHDA), and the Rural Electrification Unit (REU). LEWA regulates both the electricity and water service in the urban water and sewage sector provided by LEC and WASCO respectively [22]. The Ministry of Water has LHWC which monitors the activities of LHDA and Trans-Caledon Tunnel Authority against milestone and performance indicators agreed with the relevant boards. REU is responsible for off-grid electricity supply and distribution [22].

1.3 Problem statement

This water can be used to generate electricity. However, it is not known as to how much power can be generated from this water. Different studies have evaluated the potential for power generation through water IFR but not for dams used for water consumption. Literature is limited on the instance where hydropower is generated using water delivery pipes to different destinations in low-income countries. Thus, the contribution for the study is also on the literature of the dam used for water consumption.

1.4 Objective of the study

The objective of this study is to estimate how much hydro-electricity the Metolong dam can generate. The forecasting of hydropower generation will rely on the In-stream Flow Requirement (IFR), head and temperature as a water quality parameter using Microsoft Excel's spread sheet software. Power projections were based on the IFR data provided by the Metolong dam safety department.

1.5 Research questions

This study tries to address the following research questions:

- How much storage capacity is lost through sedimentation per year?
- How much water is released as IFR per day and how much electricity can it produce?

1.6 Justification / Motivation of the study

Lesotho has water as its huge asset and is defined as a water tower for Africa, with accelerated rates of soil erosion and high sediment deposition resulting in reservoir storage capacity loss [23]. Reservoir sedimentation is classified as a world problem which results in loss of storage capacity and other negative impacts associated with the environment, including the loss of flood carrying capacity and decrease in water [24].

Lesotho generates electricity through the 'Muela hydro-electric power station at 72 MW capacity; it has a domestic peak demand of 160 MW [25]. The 88 MW remainder is imported from Mozambique to meet domestic peak demand [25]. This implies that there is a need to explore other generation means; hence the Metolong dam can be used to compliment the domestic supply deficit. This study is also important because it tries to evaluate how much electricity can be generated to supply Maseru and other neighbouring towns. Additionally, the Water and Sewage Company (WASCO) is one of the highest industrial electricity consumers which can use the results of this study for self-generation or for Lesotho to take advantage and decrease spending on expensive electricity imports.

1.7 Limitations / Scope of the study

This is a desktop study and most of the data used is subject to human error interaction; some temperature data is acquired from satellite which may not be as accurate as physically collected data. The Microsoft Excel Spreadsheet used relies on input data and formulas computed by the user and if there are mistakes, the results are likely to be wrong.

1.8 Summary of methodology adopted.

This study gives an overview of how much hydropower electricity can be produced from Instream Flow Requirement (IFR) of Metolong dam using data of dam head and IFR provided over a period between September 2016 and August 2019. Using Microsoft excel spreadsheet, it also examines how water temperatures on site affect hydropower electricity projections from three scenarios.

1.9 Dissertation outline

In chapter one, a general review of hydropower status of Lesotho is given, entailing water and energy nexus. The problem statement of the research is provided together with its objectives and research questions. Then, the justification of the study and its limitations are outlined, followed by the organization of chapters. In chapter two, a trace of how water moves in different forms in the hydrological cycle, is highlighted. The history of hydropower, classification and global installation trends as reviewed by various researchers are then detailed. Reservoirs, sedimentation challenges and the impacts of dams on sustainability are outlined. The summary of how the penstock material and turbines are selected, followed by the barriers of hydropower dissemination are then given.

In chapter three, the methodology is presented, starting with the description of the area of study and how the study is carried out. The adopted approach in the process of assessing the hydropower potential is detailed. In chapter four, results of the study are presented entailing how head and flow rate vary over the specified period leading to the determination of water velocity, Reynold's number, friction factor and head loss. Hydropower estimates, which are dependent on the three scenarios and how the power varies seasonally are discussed. The study is then compared with other studies and goes further to elaborate on how the project can be financed. Chapter five, presents major findings of the study and recommendations for further work.

1.10 Organization of chapters

This study is divided into five chapters. Chapter 1 is the introduction, and this is followed by the literature review which gives the background information (Chapter 2). Chapter 3 is the methodology which details the general approach and design. This is followed by Chapter 4 which focuses on the results and discussion. The conclusion and recommendations are made in the final chapter.

Chapter 2.0 - Literature Review

2.1 Hydrological cycle

Water is a very vital natural resource that supports life, ecosystems and the human society; hence the water cycle is important for sustainable development [26]. The water cycle is very sensitive to climate change as a result of human activities on earth and that affects the water balance [27]. Climate model projections mostly used for hydrological models predict the future of water and severe events over large temporal and spatial scales [28]. There is an expectation of an accelerated hydrological cycle under a warming climate, with increased drought and flooding bringing challenges for agriculture, food security and hydro energy [29].

There are studies focused on the impact of anthropogenic scales, for instance, precipitation and evapotranspiration [30]. These studies also predict changes in river basins which are also driven by anthropogenic forces and other multi-drivers that negatively affect hydrological cycles [31]. In Figure 3, the water hydrological cycle is shown with illustrations of water movement, oceans and lakes that store water or as underground water. The sun heats water in lakes and oceans to form water vapour which condenses and precipitates in the form of rain or snow back to the earth's surface as run-off and added to the river networks for human activities [32].

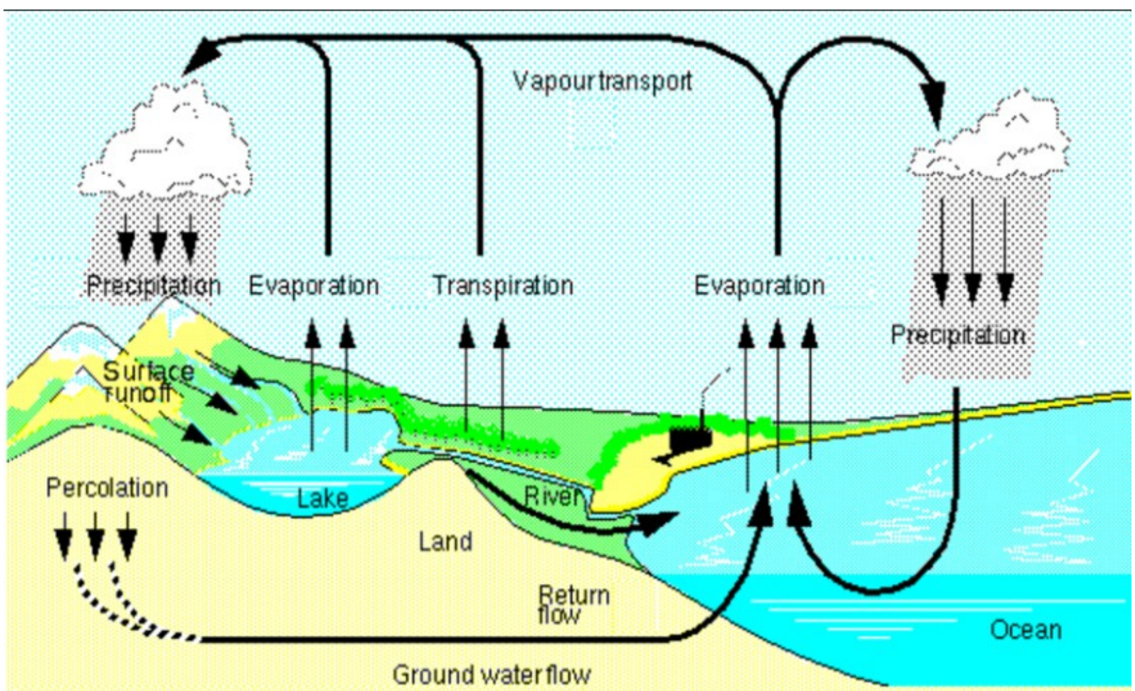

Figure 3 *:* Hydrological cycle displaying water moving system [32].

2.2 Hydropower history, classification and global installation trends.

In history, hydropower is known to provide low cost electricity in a number of significant countries world-wide and is mostly the cheapest way to generate electricity where the resource is good and unexploited [33]. Hydropower is the energy harvested from flowing water which is known to have been in use since 2000 years ago when ancient Greeks used it for grinding grain [34]. It is known to be the most cost-effective means of generating electricity [33]. Norway is, for instance, one country which is producing 99 % of its electricity from hydropower [34].

The levelized cost of energy (LCOE) for large scale hydropower projects at high performing plants is USD 0.02 /kWh [33]. But on average, after the addition of some capacity in 2019, it was slightly less than 0.05 /kWh [33]. The majority of hydropower projects commissioned between 2010 and 2019 are in the range of USD 600 /kWh – 4500 / kWh, but it is highly possible to find hydropower installation outside this range, especially from dams built for other purposes which may cost USD 450 /kWh [33]. The world's largest hydropower is that of China; Three Gorges producing 22.5 terawatt equivalent to 80 – 100 terawatt-hours, enough to supply 70 – 80 million households [34]. In terms of global electricity production, hydropower is the main renewable source of energy, it has over the last decade provided an alternative to fossil fuels due to accelerated use and need for renewable energy [35].

Hydropower has a potential to produce 31 000 GWh per year of renewable energy but only 10 000 GWh per year has been exploited for possibilities to complete utilization through construction of small hydropower plants [36]. Hydropower, regardless of size (large or small) up to this far, remains the most important of the "renewable energy" for electrical power production world-wide and it provides 19% of the planet's electricity, for less developed countries [36]. Hydropower with no dam or water storage is a very cost effective and environmentally benign energy technology to be considered for rural electrification because it only needs "run-off rivers [37].

Hydropower installed capacities have increased from 5 900 MW (European Union (EU)) and 19 000 MW (World) in 1980 to 10 300 MW (EU) and 46 000 MW (World) in 2005 [38]. Hydropower schemes are classified according to their type and capacity of the station; Pico produces less than 50 kW, Micro produces below 100 kW, Mini produces in the range of 101 – 2000 kW and Small produces in the range of 2001 – 25 000 kW [39]. Hydropower capacity factor is above 50 % which is greater than wind (30 %) and solar (10%) and can last up to 50 years [40]. Hydropower annual investment has been declining with the upsurge in solar photovoltaics and wind [40]. However, in order to meet climate change targets, widely accepted scenarios still include increase in hydropower development by 2050 from 50% to about 100 % in relation to the current capacity [41].

2.3 Reservoirs and sedimentation

Human beings build dams and construct reservoirs with the purpose of alleviating water shortage and hydropower generation but pay little attention on sediment transport into the dam or reservoir [42]. Apart from these dams having a sedimentation problem, they are also attributed to have negative impacts on water quality, habitat, landscape and biodiversity which leaves decision makers to integrate and practice the cost and benefit beyond the market approach [43]. The increase in sediment loading to rivers results in excessive sedimentation in dams and reservoirs which threaten aquatic biota and hydropower generation [44]. Retrogressive erosion is also another cause of sediment transport in reservoirs which impact both the reservoir capacity and sedimentation in downstream river channels [45]. In Kenya, the Masinga reservoir losses 23 million m^3 of water storage volume due to high sediment transport rates of 86.5 % on average [46].

In hydropower generation, the available net head and flow rate play a crucial role. Turbidity currents also play a significant role and should be included in the designing and planning phase of any reservoir, dam or lake which is likely to be used for hydropower generation [46]. On average, the loss of storage capacity in the ‘Muela reservoir between 1985 and 2015 is 15 400 m^3 /year based on Kriging [23]. In the Liuxihe reservoir in China, facts about turbidity currents involvement and flooding season are influenced by run-off events which affect hydraulic structures and nutrient circulation in the reservoir [47]. Reservoir and downstream ecosystems located in the climate region of monsoon in Korea are under long-term negative effects of high turbidity run-off [48]. In Switzerland, dams were constructed for the purpose of water storage in reservoirs to supply water for human consumption, irrigation, energy production. The byproducts included recreation, navigation and provision of safety against flood events and drought in downstream valleys [49].

Recently, in an experimental investigation at Stellenbosch University in South Africa, it was established that sedimentation has a great effect on flood levels, drainage for agriculture, pump station and hydropower operations as well as navigation [50]. Turbidity currents are a result of flows driven by floods from turbid river water that has excess density of suspended sediment; thus these currents are responsible for sedimentation through transportation of fine particles over long distances, hence the majority of deposition that in turn reduces storage capacity [51]. The inflows containing suspended sediments to the water systems of hydropower plants cause hydro-abrasive erosion of the hydraulic turbines and structures [52]. Consequently, maintenance costs are increased, efficiency is reduced and downtimes occur frequently [52].

It is important to manage and minimize sediment accumulation from watersheds [52]. For this reason, in 1953, Brune proposed a trap efficiency method to help estimate the quantity of sediment accumulating in a reservoir [53]. Sediment management strategies include; reforestation of wetlands, vegetative filter strip and construction of stone bunds that effectively reduce sedimentation on major tributaries (zones) by 65.6 %, 63.4 % and 12 % respectively [54].

2.4 Hydropower dams and their impacts.

Despite the physical, economic and social requirements being vital for micro-hydropower schemes to meet energy demands and being beneficial in most remote mountainous communities with good water supply, environmental and political factors also affect the performance and longevity of the scheme after installation [55]. Hydropower benefits its developers and bears negative social and environmental consequences to those who must be resettled since there is disruption in their livelihoods [56]. This effect can be rationalized by developing compensation for resettlement, community development funds and payments for ecosystem services [56]. In the case of Metolong dam post construction, the mainstreamed Health Impact Statement recommended in the Environmental Impact Assessment prior to construction was low as the local community’s perception was that they were not benefiting from the dam project [57].

Large hydropower plants are associated with negative environmental impacts and this has shifted the attention to small-scale plants which reduce these impacts considerably [58]. The operation of hydropower plants may change river flows which may degrade the stability of the river ecosystems [59]. Energy security is very vital especially when green energy choice is urgently needed; however, hydropower has many obstacles hindering its development which include accommodation and consumption problem, environmental pollution and climate change problem, immigration issues etc.[60]. There is water exploitation due to energy production from small hydropower plants and this seems to be increasing despite human pressure on fresh water already being very intense in most countries [61].

Key global energy, environmental and sustainability targets are closely related to the developments of renewable energy sources; they include the reduction of greenhouse gas emissions and safe energy provision in a sustainable manner [62]. Small hydropower plants built on run-off rivers are important due to the economic, environmental and social benefits which they have over large hydropower plants which have large capital costs. SHP plants are cheap to construct, have lower capital costs and do not have to store water; but they run a risk of siltation [35]. Regional climate and hydrology are also affected when water management strategies are implemented on hydropower dams which may reduce or increase the river flow downstream depending on the rate of evaporation and weather conditions around the dam [63].

Hydropower dams often have undesirable societal and ecological impacts including community resettlement in low fertility agricultural lands, declines in fisheries, flood plain recession agriculture, sediment and nutrient transport and safety hazard brought by changing flows; these occur continuously and uncertainly [64]. Despite hydropower being the most reliable and efficient renewable energy technology, it is a threat to freshwater fishes [65]. There are also a range of socio-ecological impacts associated with hydropower dams where implemented compensation programs meant to redress the damages done by government overseeing the hydropower projects are still under critique regarding change in the economies of rural communities [66].

Exploiting water for energy production from small hydropower plant is escalating despite the pressure imposed by humans on fresh water [67]. For countries with large amounts of water resources, electricity generation can occur without polluting the environment; this is because the electricity demand is increasing and this triggers an increase the in energy mix through cleaner energy from sustainable small hydropower projects in the electricity market [7].

Among the components of hydropower development, there exists; river section selection, the conception of general development scheme together with detailed technical solution, the applied performance technology, the quality of operation tests and the structure of the operation management [68]. These represent the main steps that need to be carefully controlled [68]. Material selection in small hydropower projects is vital, especially the selection of penstock which is the most challenging task for civil work as it contributes largely to the overall cost of the project [69].

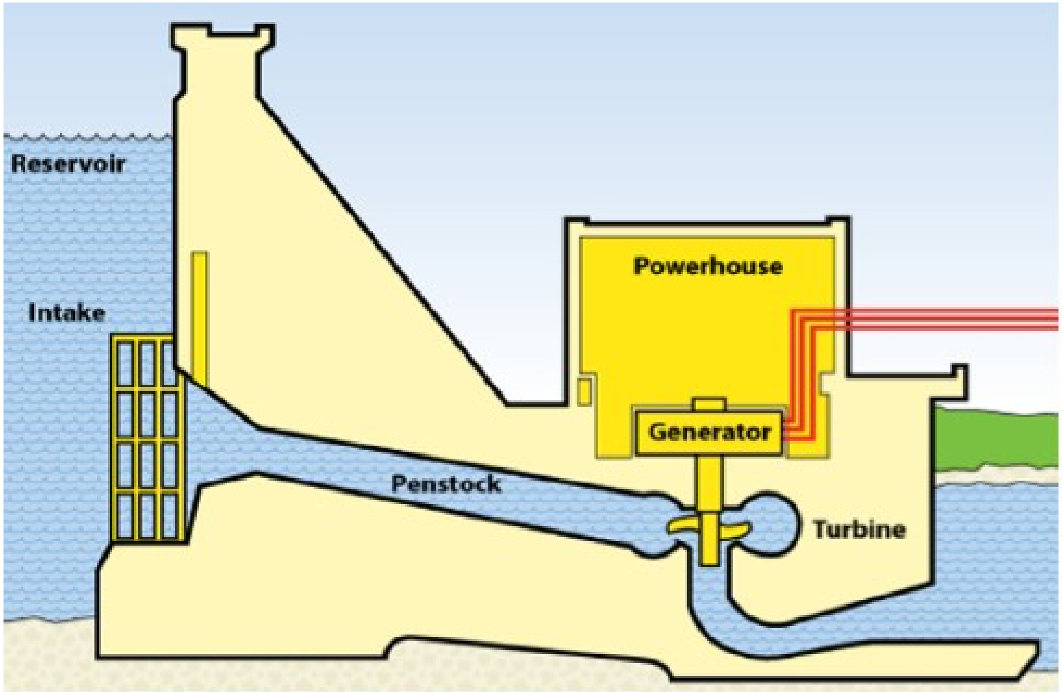

Figure 4 : Penstock integral with dam structure *[69]*

Figure 4 shows penstock in a reservoir intake tower going down to the power house. This is an illustration of how a micro hydropower station constructed on an artificial reservoir will look like.

Micro hydropower stations are growing in an accelerated manner to answer to the energy demand in decentralised areas [70], especially those with mountainous regions in developing countries [71]. For a hydropower station to work, hydrokinetic turbines capture power from the energy retained in flowing water into the turbines as illustrated in Figure 5. As depicted in Figure 5, a cut-away view of hydro-electric turbine shows water flowing through the turbine blades and turning the turbine generator shaft, thereby inducing current in the solenoid as it cuts through the magnetic field of the generator.

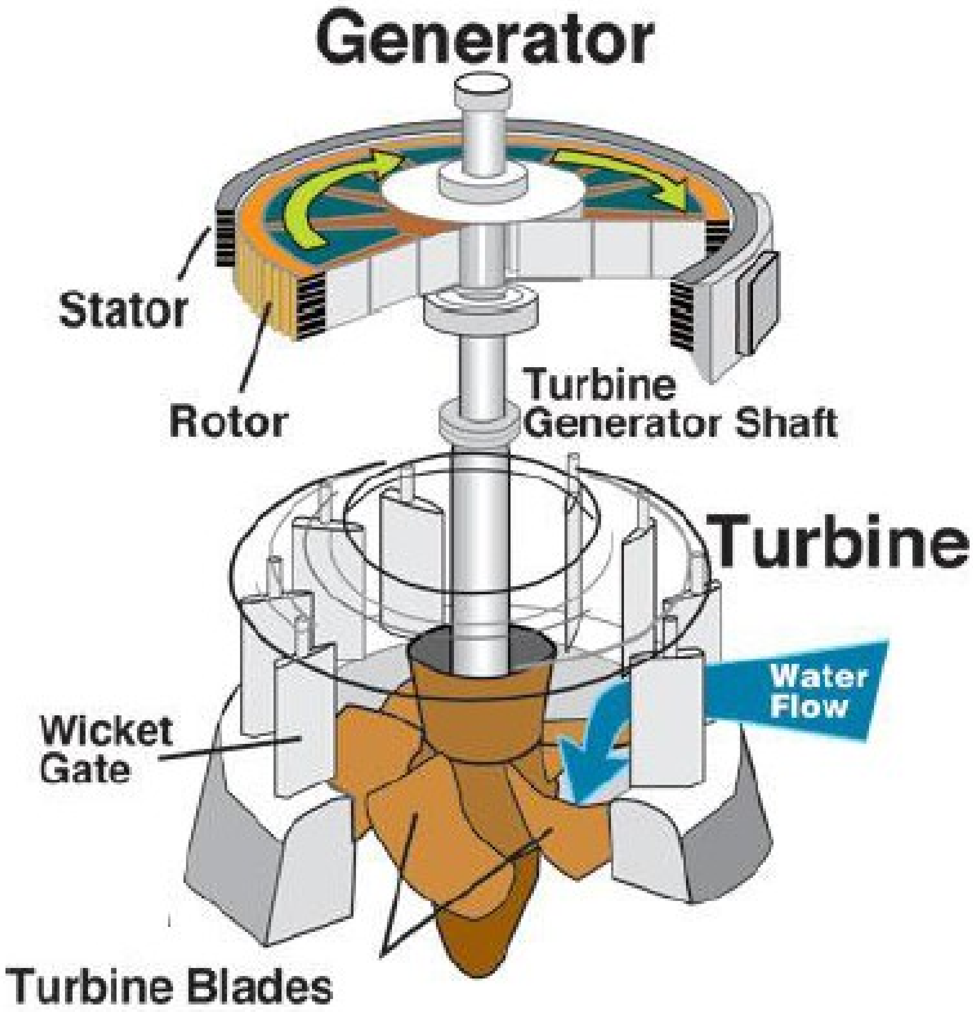

Figure 5 : Cut-away view of hydro-electric turbine.

2.5 Incorporation of hydropower equations.

The equations used for hydropower generations discussed subsequently are adapted from Kaunda et al 2012 [5]. Water velocity is a measure of how much water passes a particular cross-sectional area per unit time and is given by:

$$v_x = \frac{Q}{\pi r^2}$$ Error: Reference source not found

Where v_x = Water velocity (m/s), Q = Flow rate (m^3/s), π = 3.14159265, r = Radius.

Measuring flow rate depends on accuracy and whether the method used is advanced, conventional or indirect flow rate method. Conventional methods have more frequency of usage but have low accuracy. They include bucket, float, dilution and velocity-area methods; while advanced methods include hydraulic structure (gauging weir), Slope-area Manning, Price AA and Pygmy current meters, electromagnetic flow meters and ultrasonic device [43].

Kinematic viscosity (μ), which can be obtained from Error: Reference source not found relies on the monthly average water temperature and can be used to calculate Reynolds's number (R_e). Low R_e indicates that the fluid will exhibit a laminar flow while high R_e indicates that a fluid will exhibit a turbulent flow [82]. R_e is the ratio explaining the relationship between forces of inertia to viscous forces of the fluid; it is also helpful in determining the point at which the flow might change between laminar and turbulent [82]. Frictional drag and turbulence are caused by the material used for the pipe which relies on Reynolds number (R_e) and is calculated as:

$$R_e = \frac{v_x D}{\mu}$$ Error: Reference source not found

Where R_e = Reynolds number, v_x = Water velocity (m/s), D = Diameter of pipe (m), μ = kinematic viscosity of fluid (mm^2 /s).

Table 1: Kinematic viscosity table, *adapted from Otuagoma et.al (2015) [81]*.

Temp. [°C]	**Kin. Viscosity [mm²/s]**	**Density [g/cm³]**
2	1.6736	0.9999
3	1.6191	1
4	1.5674	1
5	1.5182	1
6	1.4716	0.9999
7	1.4272	0.9999

8	1.3849	0.9999
9	1.3447	0.9998
10	1.3063	0.9997
11	1.2696	0.9996
12	1.2347	0.9995
13	1.2012	0.9994
14	1.1692	0.9992
15	1.1386	0.9991
16	1.1092	0.9989
17	1.0811	0.9988
18	1.0541	0.9986
19	1.0282	0.9984
20	1.0034	0.9982
21	0.9795	0.998
22	0.9565	0.9978
23	0.9344	0.9975
24	0.9131	0.9973
25	0.8926	0.997
26	0.8729	0.9968
27	0.8539	0.9965
28	0.8355	0.9962
29	0.8178	0.9959
30	0.8007	0.9956
31	0.7842	0.9953
32	0.7682	0.995
33	0.7528	0.9947
34	0.7379	0.9944
35	0.7234	0.994
36	0.7095	0.9937
37	0.6959	0.9933
38	0.6828	0.993
39	0.6702	0.9926
40	0.6579	0.9922
45	0.6017	0.9902
50	0.5531	0.988

55	0.5109	0.9857
60	0.474	0.9832
65	0.4415	0.9806
70	0.4127	0.9778
75	0.3872	0.9748
80	0.3643	0.9718

A Moody diagram, illustrated in **Figure 6**, is used to relate R_e and frictional factor (*f*).

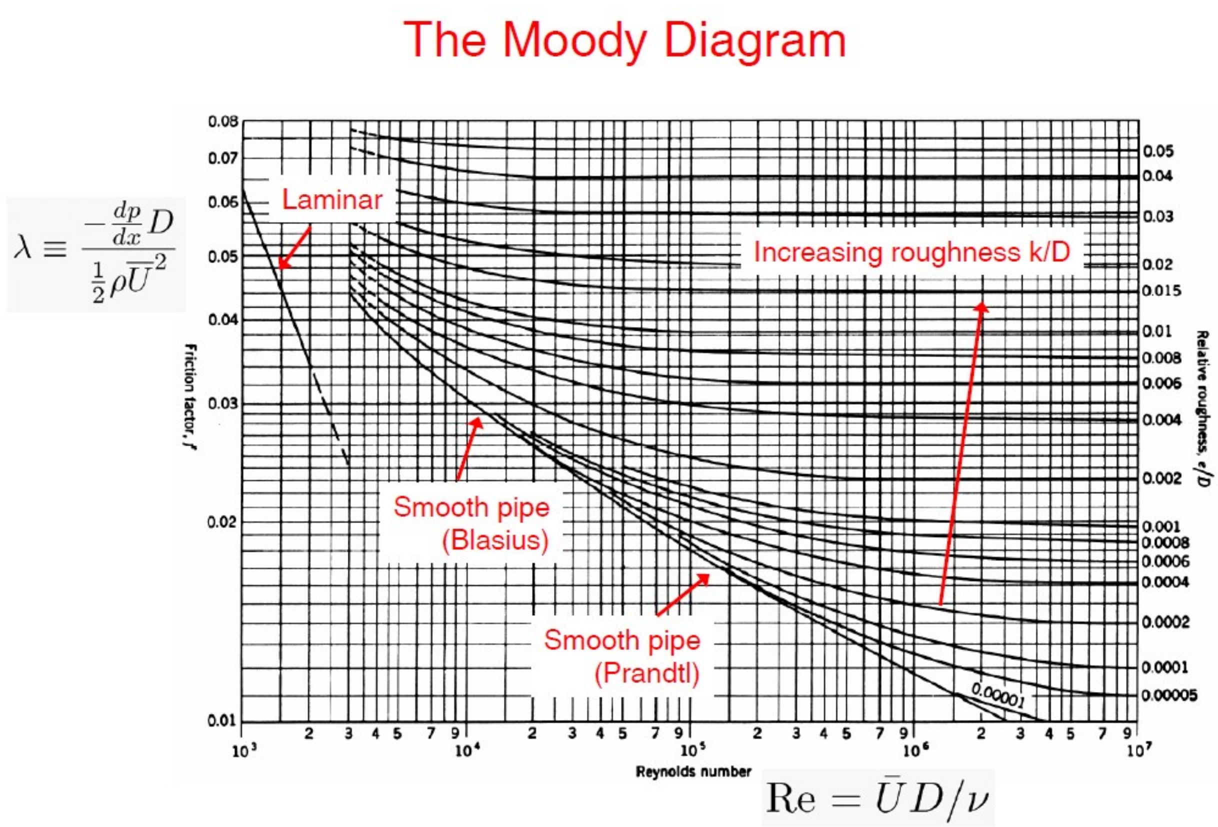

Figure 6 : Moody Diagram *[83]*.

Head loss equation is *calculated using as:*

$$h_f = ¿\, f \cdot \frac{L}{D} \cdot \frac{v_x^2}{2g} \quad \text{(m)}$$ Error: Reference source not found

Where h_f= Head losses (m), f = Friction factor, L = Length of pipe (m), D = Diameter of pipe (m) v_x = Water velocity (m/s), g = gravity (m/s^2). It is known to be a Darcy-Weisbach energy loss equation; it is relative to systems with a steady flow rate inside a closed circular pipe of any cross-section and it can be applicable for both turbulent and laminar flows [82]. The net head is obtained from:

$$h_n = h_g - h_f \quad \text{(m)}$$

Error: Reference source not found

where h_g= gross head (m), h_n= net head in (m), and h_f= head losses (m).

Head losses are caused by frictional drag, turbulences of flow and friction in penstock as well as magnetic losses in the turbine and generator. Net head is the difference between gross head and head losses. The absolute distance between the downstream at the power house and upstream at the intake point in a dam or along a river is referred to as gross head which is also called elevation difference [43]. Net head refers to gross head less all pipe losses due to friction and turbulence [82]. There are various methods employed to measure gross head which include topographic, digital elevation map (DEM), hose level and pressure gauge, sight and spirit levels, altimeter, hypsometer, clinometer, dumpy level, and theodolites which all depend on the objective of the researcher [43].

Power is produced from energy harnessed in falling water with a turbine of a specified efficiency, defined height, discharge rate, water density at gravitational acceleration acting upon it as

$$\text{Power P} = \frac{Energy}{time} = \frac{\rho g h Vol}{t} = \eta \rho g h Q (Watts) = \eta g h Q (kW)$$

Error: Reference source not found

where $\eta =¿$ efficiency of a turbine , P = Power in Watts (W), h= net head in (m), ρ= fluid density[kg/m^3](approx. 1000 kg/m^3 for water), g = gravitational acceleration (9.81 m/ s^2), Q = volume flow rate (m^3 /s) = $Vol/\triangle t$.

Having discharge and head, a suitable turbine can then be selected.

2.6 Penstock and turbine selection criteria.

The role of penstock is to convey water from the fore bay to the turbine thereby harvesting the potential and kinetic energy of water into mechanical energy [39]. The selection of materials for the various components of small hydropower projects particularly the penstock is one of the most challenging tasks as civil work components constitute a larger share from the overall cost of the hydropower project [72]. Studies are proving higher efficiencies and longer lifespan of some hydropower equipment such as the weight of steel equipment reduction by 50 % to 80 %, head loss reduction by 4 % to 20 % by the use of polymers and super hydrophobic materials, and reduction of bearing wear by 6 % by the use of novel bearing materials even though some materials are not yet competitive with respect to the cost of traditional materials [73].

The selection of penstock material, alignment, design and execution has different contributions in the cost of the project for different sites and is known to depend on geography and geology as well as on erection mode and material. Hence penstock material selection is subject to parameters such as surface roughness, design pressure, method of jointing, weight and ease of installation, availability and maintenance [39]. A linear assignment method was then considered with quantitative and qualitative attributes for choosing the most favourable material, factoring in yield strength, life, thickness, density, tensile strength, hardness, elastic modulus, maintenance cost, (cost and quantitative) data. These attributed qualities are ranked to come up with the best penstock [39].

Turbines have types designed to suit specific ranges of head, flow rate and shaft speed for which quantitative and qualitative analysis need to be made before choosing a certain turbine [16]. This means turbine selection is subject to specification (site condition and accessibility), selection (efficiency, power, portability and civil works), quantitative analysis (power equations based on head and flow rate) which leads to selection over impulse types (pelton and turgo), reaction types (axial and radial, archimedes screw and water wheels (overshot, breast shot and under short) [16].

On the other hand, qualitative analysis is purely based on a scoring mechanism between 1 (poor) and 5 (excellent) [16]. There also exists a criterion for weighing, candidate turbine choice, top level requirements and final turbine selection. On all of them, both qualitative and quantitative analysis are used to give a summation of 1 in total; they are then ranked to observe the most frequently high ranked or scored [16].

Turbine selection relies on the available head and flow rate (Figure 7**)** although their types are categorized by operating principles which are either reaction or impulse turbines with efficiency ranging between 0.70 and 0.85 [74]. Impulse turbines are for higher heads and they convert the kinetic energy of water jet hitting the turbine buckets with no pressure drop across turbines. They include Pelton, Turgo and Cross Flow turbines [74]. Reaction turbines are totally immersed in water, with angular and linear motion of water converted to shaft power. They derive power from pressure drop across the turbine, and examples include Propeller, Francis and Kaplan turbines [75].

Generators are either synchronous or induction. Synchronous generators are for off-grid connections while induction generators are used in both off-grid and grid connections. They have a robust construction with low cost and their power is fed to the grid at an efficiency between 0.94 and 0.97 [75].

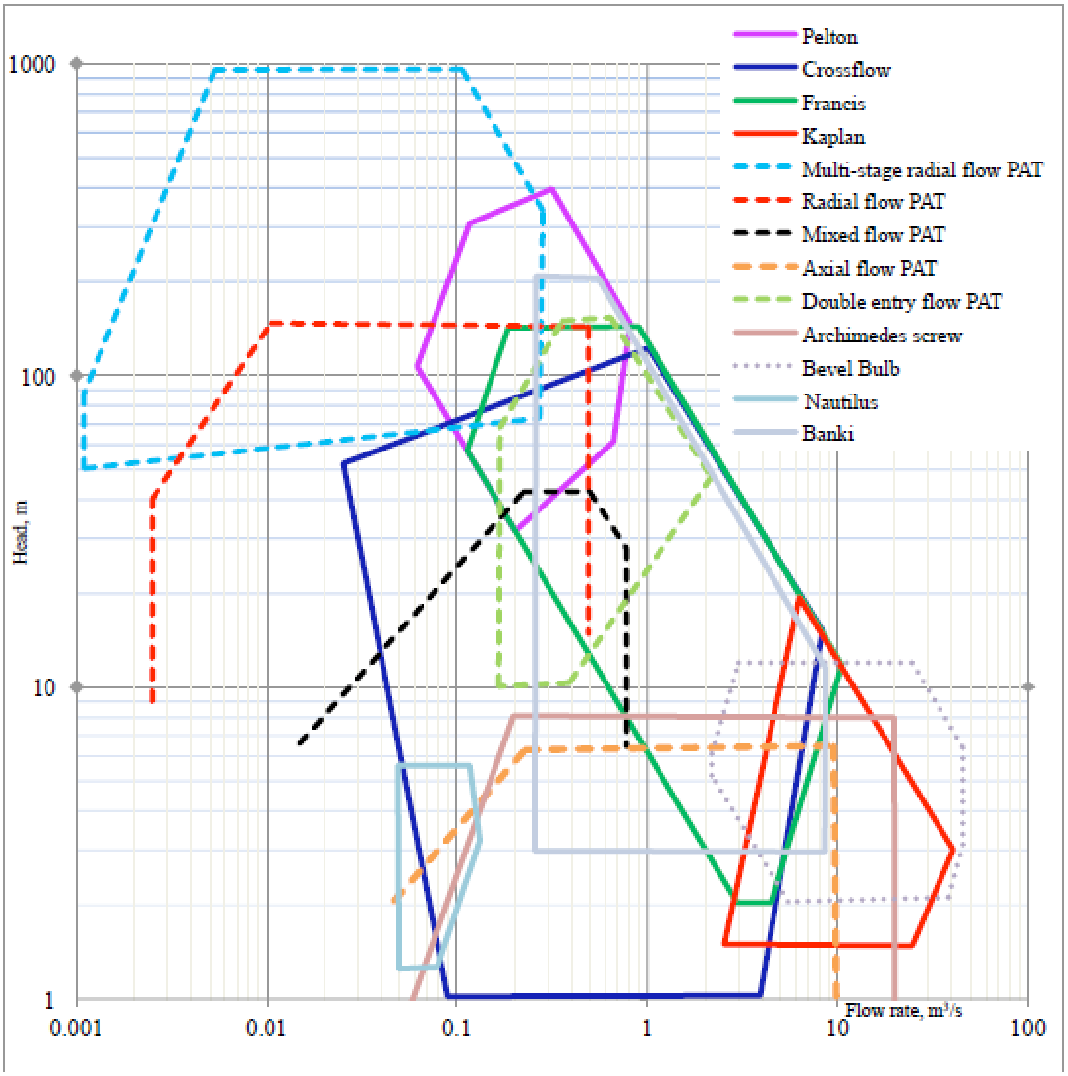

Figure 7 : Working ranges for different turbines [32].

2.7 Barriers/ challenges of hydropower

2.7.1 Legal barriers

Small hydropower (SHP) plants are subject to political and legislative laws in most countries but most importantly, the environmental license granted by the Ministry of environment; SHP plants are listed as special cases and their license is issued by the an autonomous corporation in Colombia [35]. This is also a case in Lesotho where a generation license is issued by LEC regulated by LEWA and subject to complex ministerial procedures [76]. Even though it is still suspected and proposed for future research, In Lesotho, the autonomy of regulatory bodies is marred by corruption and political influences [77]. This is still an issue in regulatory reforms as it hinders the independence of regulatory systems. [77].

2.7.2 Institutional barriers

Officials responsible for electrical distribution for the national grid the lack interest to meet electrical profitable scenarios since isolated areas are characterized by sparse and clustered populations and low level of energy consumption [35]. This is also a case in Lesotho where rural populations are scattered in clusters and have low energy consumption [20]. As small as Lesotho is, it is recommended to undergo the unbundling of the sole electricity utility (LEC) in order to allow for the inception of Independent Power Producers and independent players on generation, transmission and distribution [77]. This approach has been proven to have good results when an independent body is in regulation [77].

2.7.3 Technical and technological.

Rural projects on SHP plants development are carried out by personnel with lack of training plans for their watershed management and prevention, mitigation and response to natural disasters given possibility of extreme events and vulnerability [40]. There is lack of educational programs in the area of engineering and construction of SHP plants in terms of applied guide work to avoid oversizing; SHP stages, manual feasibility and preliminary design and project management manuals that aid in economizing time and resources for sustainability of the plant are needed [35]. In Lesotho, this is the case for Katse dam mini hydropower plant that has been abandoned for similar technical reasons [22].

2.7.4 Economic barriers.

There is usually high unit investment per kW installed and costly studies in relation to the total investment and administrative inefficiency and financial weakness of energy companies to develop a small hydropower project [35]. Since most of the equipment is imported with subsidies and incentives to technological energy facilities, this causes Lesotho to seek foreign investment because it cannot finance its available energy resources internally, leading to an increased price per kWh [20].

Chapter 3.0 – Methodology

3.1 Description of study area

The Metolong dam is a Water Supply Project proposed by the Lowlands Rural Water Supply and Sanitation (LRWSS) in the districts of Berea and Maseru. It is meant to benefit an estimated population of 350 000 residing in Maseru, Mazenod, Morija, Teyateyaneng and Roma with adequate safe water supply and sanitation since the existing safe water supply mechanisms could no longer meet water demand of the those areas [78]. The purpose of the project is to contribute to the achievement of Millennium Development Goals (MDGs) and Lesotho's Vision 2020 for improved health and social wellbeing of the population through universal water supply and sanitation access [78].

The total cost of the Metolong dam project is estimated at US$ 17.16 million which is equivalent to UA 11.374 million financed by ADF (African Development Fund – 57.3 %), RWSS-TF (Rural Water Supply and Sanitation Trust Fund – 24.4 %), World Bank (7 %) and Government of Lesotho (GoL – 11.3 %) [78].

Metolong dam consists of a 268 km^2 catchment area, 2.94 km^2 of reservoir surface area, and a mean annual runoff of about 66.3 million m^3 as illustrated in Figure 8 [79]. The dam stores 63.7 million m^3 of water and floods 16 km of the South Phuthiatsana river from the dam retaining wall in upstream direction [79].

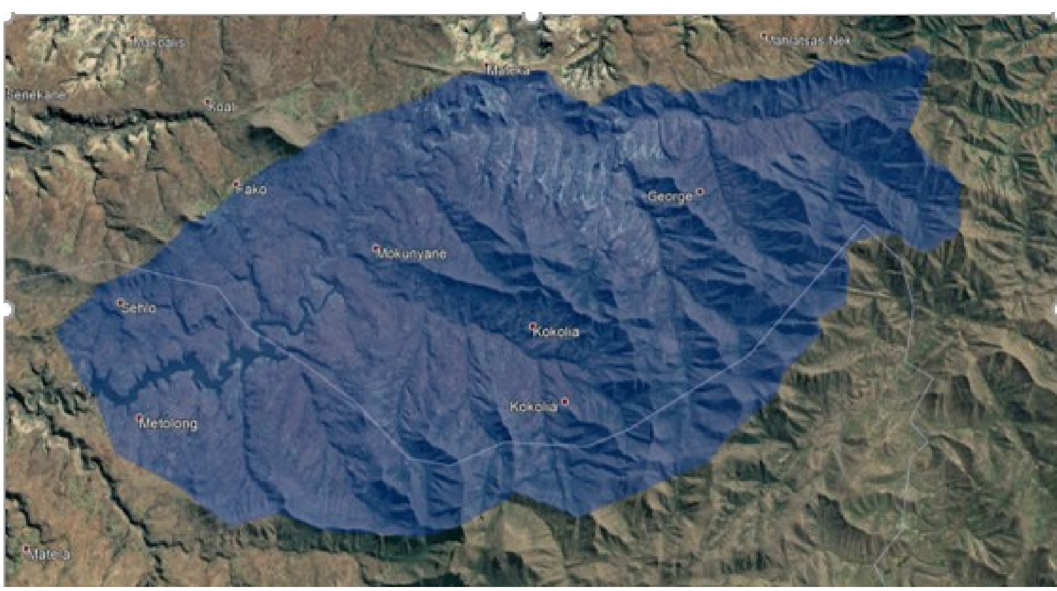

Figure 8 *:* Metolong Catchment area (Source – Metolong Dam Safety Department).

The Metolong Dam retaining wall is 83 m high and 278 m wide at the top as shown in Figure 9. It has a 78 m wide overflow spillway and has an intake-pipes consisting of seven draw-off levels.

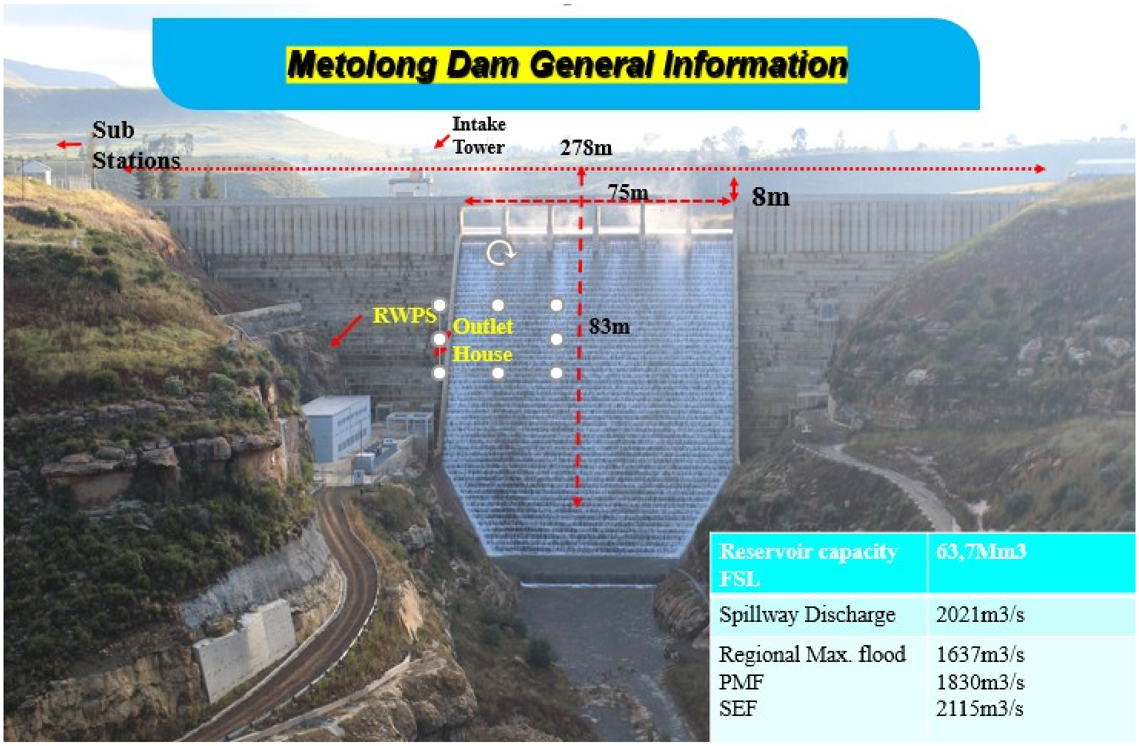

Figure 9 : Metolong Dam wall general information (Source – Metolong Dam Safety Department).

The dam wall was constructed across the Phuthiatsana River which is a major tributary to the Phuthi (Mohokare) river. Tributaries to the Phuthi river have major catchment areas dominated by the Clarens sandstone which is easily eroded by run-off water than the Basalt of the mountain region [80], hence the increase in turbid water that is seen in the Phuthiatsana and Phuthi rivers. Turbidity currents are flows caused by the difference in densities of suspended fine solid materials which belong to the family of sediment gravity currents shown in Figure 10 [81]. They are associated with causing hydro-abrasive erosion, pressure pulsation, reduced turbine efficiency and damage to other electro-mechanical equipment as well as hydraulic structures along the power water way [82].

It is important to know the quantity of sediment accumulating in a reservoir [83] as it imposes economic, technical and ecological challenges of the future market hydropower potential substantially [84]. When sediment particles come in contact with hydropower components, they cause hydro-abrasive erosion that slowly leads to cavitation, pressure pulsation, vibrations and eventually mechanical failures and finally plant shutdowns [85]. Apart from reservoir decrease in capacity, for many years engineers have had interest in reservoir sedimentation due to its effect of blocking hydraulic structures [50], which is illustrated in Figure 10.

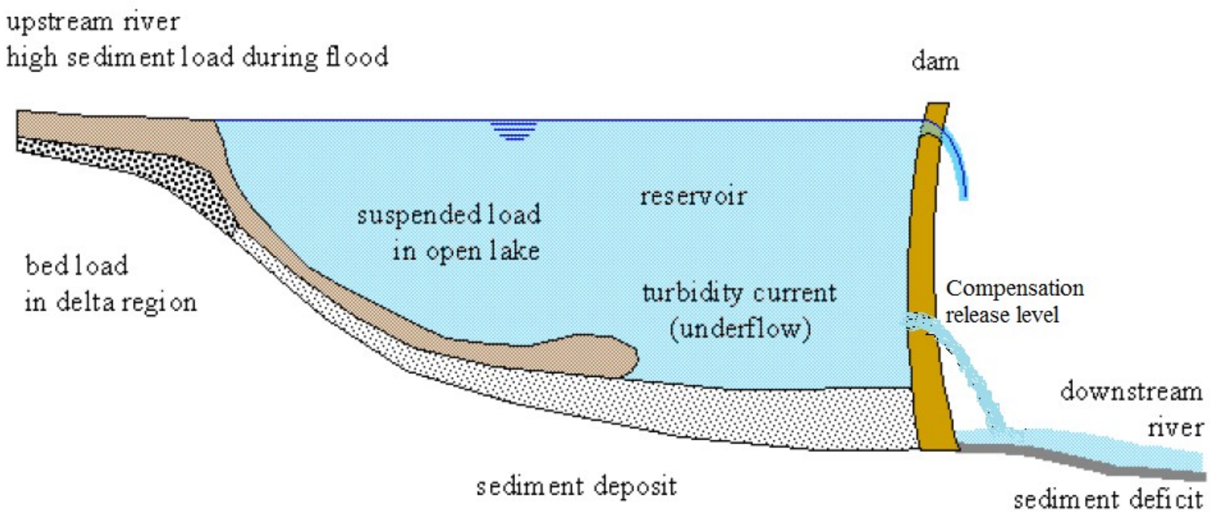

Figure 10: Sediment load reaching artificial reservoir during a flood. [81]

In a study entitled "Estimating the potential thermal impacts of water releases prior to construction of the dam", it was simulated that the Metolong reservoir will have strong thermal stratification in summer and destratification in winter which will negatively affect the biota [86].

3.2 Study description

This study has an advantage of being cheap to implement, with the benefit of exploring alternatives earlier in the system's lifecycle [87]. The Metolong Dam retaining wall has an intake tower with seven draw-off levels, a 1200 mm diameter mild steel pipe embedded inside a concrete wall with a gallery having different instruments measuring seepage and dam wall movements. The instream flow requirement (IFR) outlet is located towards the northeast of the raw water pump station as shown in Figure 9. The raw water pump station is located towards the end of the bottom right of the pipe layout and south of the Metolong dam wall as shown in Figure

9. In-stream Flow Requirement (IFR) is presented in Table 2 and is obtained from the Metolong Dam safety department which keeps the Phuthiatsana River flowing to maintain normal life at the Metolong dam down-stream. Data used in the study is from September 2016 to August 2019. IFR for each month of the year is used to estimate how much electricity can be generated from those releases. The Instream flow requirement is issued by the Lesotho Ministry of Water Affairs to the Metolong dam Safety department to release IFR as seen on Table 2**.** The Metolong dam water quality is monitored at four sampling points (SP1- S29° 20.03’ E027° 46.627’, SP2- S29° 19.79’ E027° 47.664’, SP3- S29° 19.408’ E027° 48.34’ and SP4- S29° 19.078’ E027° 49.613’) within the dam at different depths and seven draw-off levels in the intake pipes. The sampling points are aligned starting with sampling point 1 adjacent to the dam wall and sampling point 4 towards the northeast of the Phuthiatsana river where the water starts entering the dam. The dam wall different views are shown in Figure 11, Figure 12 and Figure 13.

Table 2: Instream flow requirement (IFR) (Adapted from Metolong dam safety department).

<table>
<tr><th rowspan="2">Month</th><th rowspan="2">Low flow[2] m³/s</th><th colspan="6">Floods[3]</th></tr>
<tr><th>Class 1: 2.2 m³/s</th><th>Class 2: 4.5 m³/s</th><th>Class 3: 7.9 m³/s</th><th>Class 5: 17.4 m³/s</th><th>Inter-annual floods</th><th>Total</th></tr>
<tr><td>Octorber</td><td>0.06</td><td rowspan="2">I</td><td></td><td></td><td rowspan="12">-</td><td rowspan="12">Not included in IFR volume</td><td rowspan="12">Annual[4]</td></tr>
<tr><td>November</td><td>0.13</td><td></td><td></td></tr>
<tr><td>December</td><td>0.21</td><td></td><td rowspan="2">I</td><td rowspan="3">I</td></tr>
<tr><td>January</td><td>0.25</td><td></td></tr>
<tr><td>February</td><td>0.31</td><td></td><td rowspan="2">I</td></tr>
<tr><td>March</td><td>0.31</td><td></td><td></td></tr>
<tr><td>April</td><td>0.34</td><td rowspan="3">I</td><td></td><td></td></tr>
<tr><td>May</td><td>0.31</td><td></td><td></td></tr>
<tr><td>June</td><td>0.27</td><td></td><td></td></tr>
<tr><td>July</td><td>0.13</td><td></td><td></td><td></td></tr>
<tr><td>August</td><td>0.07</td><td></td><td></td><td></td></tr>
<tr><td>September</td><td>0.05</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">M.m³</td><td rowspan="2">6.13</td><td>0.6x2</td><td>1.5x2</td><td>2.1x1</td><td>-</td><td>-</td><td rowspan="2">12.7</td></tr>
<tr><td>1.3</td><td>3.0</td><td>2.1</td><td></td><td>-</td></tr>
<tr><td>%MAR</td><td>13.4%</td><td>2.8 %</td><td>6.4 %</td><td>4.5 %</td><td></td><td>-</td><td>27.0 %</td></tr>
</table>

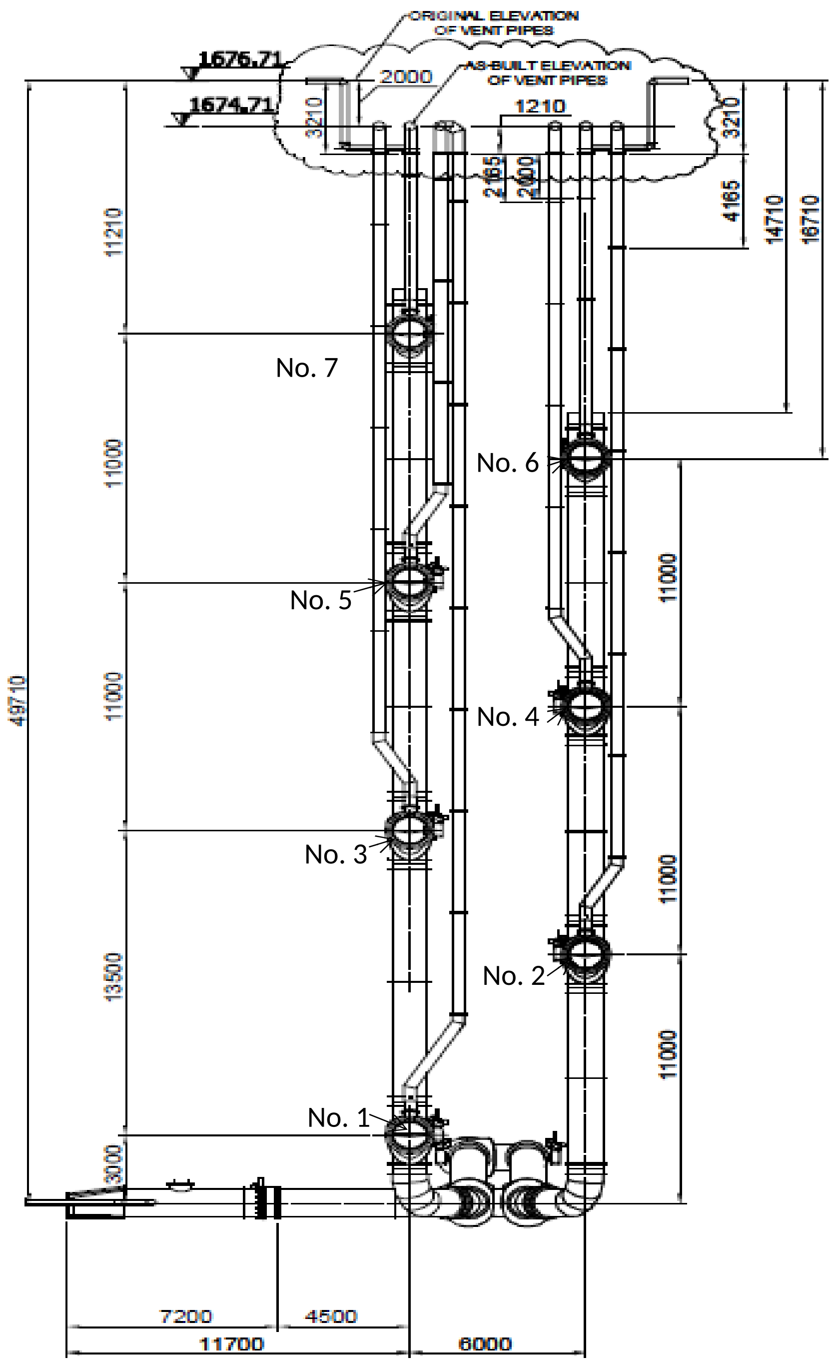

Figure 11: Side view of Metolong Dam intake tower, facing South-West (Source: Metolong dam safety department).

In Figure above, a side view of the Metolong dam intake tower (facing south-west) is shown with seven draw-off levels (labelled No. 7 down to No. 1). The distance between each draw-off level is 5500 mm and the draw-off levels are shown in descending order starting with the upper draw-off level as seven, followed by six, five, four, three, two and one as the lowest draw-off level.

Figure shows a side view of the Metolong Dam intake pipes (facing south-east) with the elevation distance of each draw-off level, distance in millimetres between each draw off-level and the length of the pipe buried inside the concrete dam wall. IFR location is labelled 1 and raw water pump station is labelled 2 as shown in Figure which is also depicted as a top/plan view of the Metolong dam intake tower and has the angles at which the intake pipes bend and length given in millimetres.

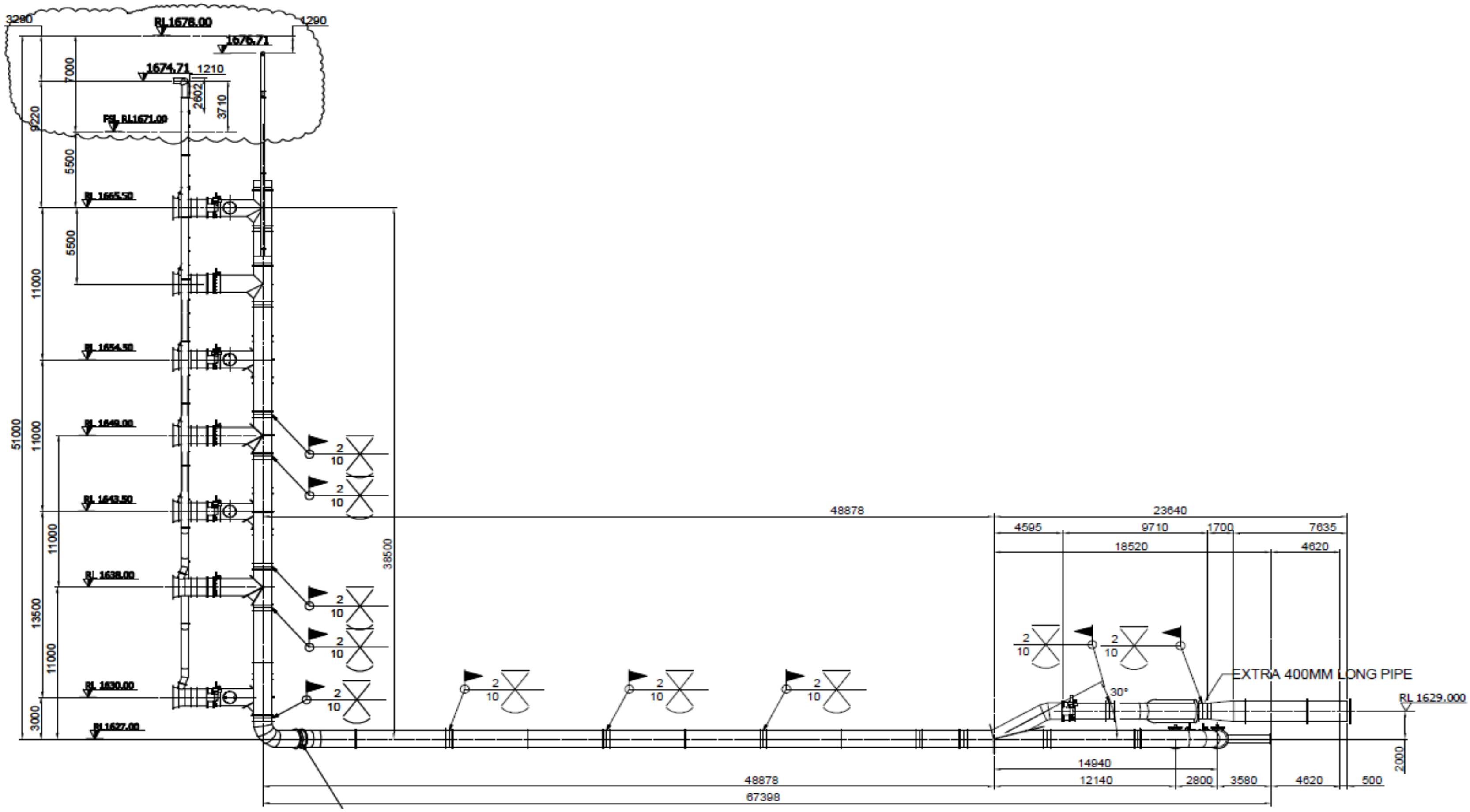

Figure 12: Side view of Metolong Dam intake pipes, facing South-East (Source: Metolong dam safety department).

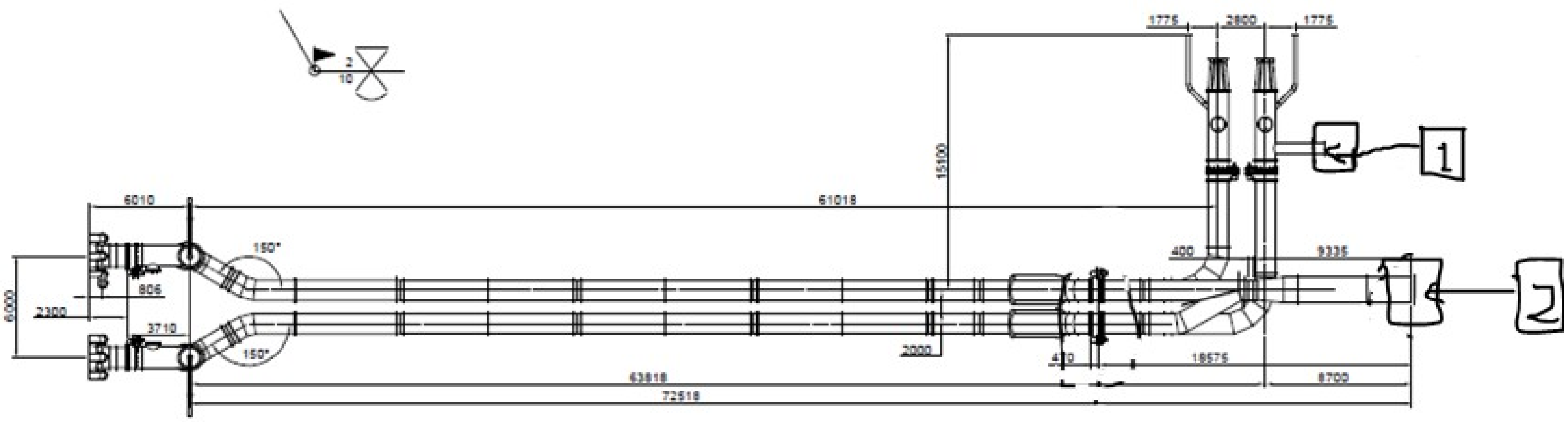

Figure 13: Top view of Metolong Dam intake pipes' horizontal arms (Source: Metolong dam safety department).

3.2 Data description and management methods

Monthly data for the head, flow rate and water temperature were used to calculate power that can be generated using data that was provided by the Metolong dam safety department. The data set of IFR flows was captured on a daily basis at 07h00 from the electronic flow meter and then reduced to monthly averages for ease of calculations as the IFR is different for each month. After the commissioning of the dam in 2016, many construction tasks in the dam were not yet completed. Hence, most data at water release points was omitted because the outlet house had to be closed to allow for construction work to finish. This data was excluded because it indicated the flow for the respective days as zero. Hence, it was omitted to give more reasonable and closer to accurate results.

3.3 Variables of interest

Microsoft excel spreadsheet was used to incorporate hydropower equations to ease calculations due to fluctuating head and flow rate. The variables of interest are water velocity, Reynold's number, friction factor, head, flow rate, water density, water temperature, air temperature (for correlation to water temperature) and power that can be generated. Head versus flow rate at IFR was studied from September 2016 to August 2019 data, to help choose a suitable turbine for the sites using Figure 7 in chapter 2.

Water velocity in the pipe for IFR will be calculated using Error: Reference source not found and kinematic viscosity (μ) will then be obtained using Table 1 which relies on the monthly average water temperature. Kinematic viscosity will then be used to find Reynolds number (R_e) using Error: Reference source not found. The Moody diagram (Figure 6) will then be used to estimate the friction factor and relative roughness. But for this particular case, the penstock used is mild steel as the Metolong dam is already functional for water consumption and the penstock is already imbedded in a concrete dam wall. The head loss can then be calculated using Error: Reference source not found, and the net head will be evaluated using Error: Reference source not found. Power can then be determined using Error: Reference source not found.

The assessment is made taking into considering three scenarios:

a) Hydropower estimates without considering temporal temperature variability.

   In this scenario water specific gravity and temperature were used to calculate power.

b) Hydropower estimates with temporal temperature variability.

c) In this scenario, actual water temperatures from the IFR were used to calculate power. Hydropower estimates with projected temporal temperature variability around the Metolong Dam.

   In this scenario, air temperatures obtained online from the Photovoltaic Geographical Information system [101], were related to water temperatures by multiplying the obtained air temperatures by a specific number with the purpose of establishing a relationship between air and water.

Chapter 4.0 - Results and Discussion

This chapter gives and discusses the findings observed from the study for the assessment of the hydropower potential for Metolong Dam, using the methodological approach discussed in chapter 3.

4.1 Head and flow duration curves for and IFR.

In Figure 14 and Figure 15, Metolong dam discharge and head duration curves are presented and how they vary over the study period.

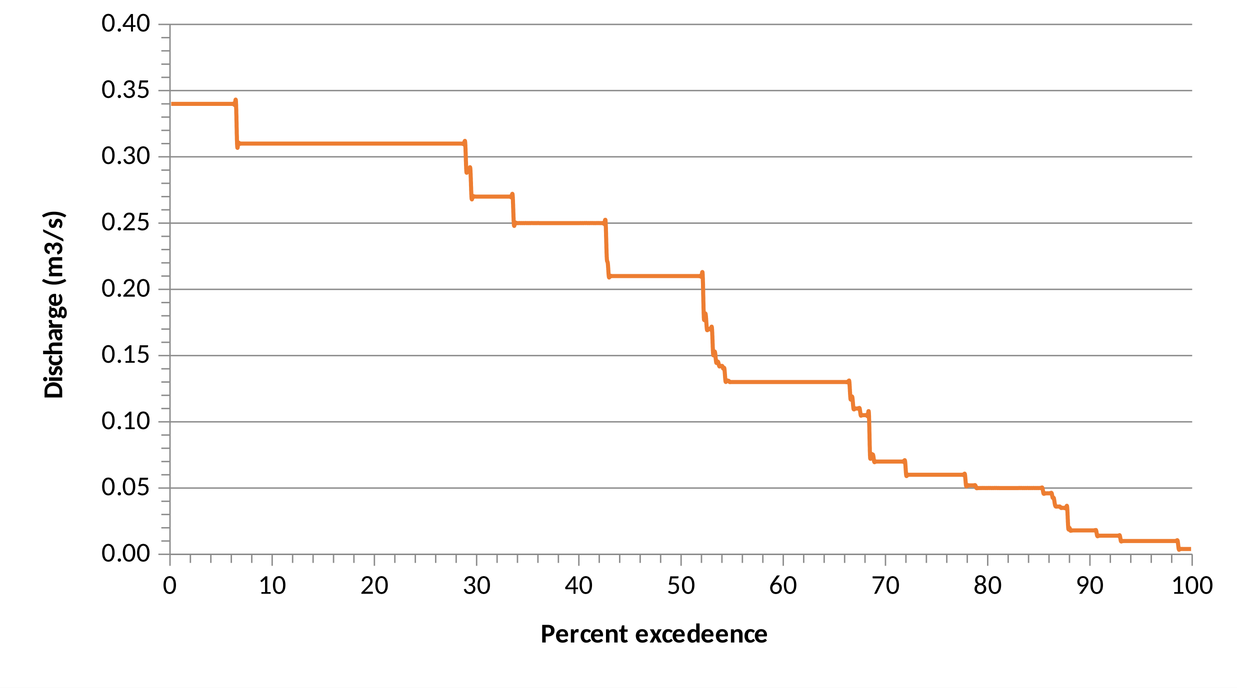

Figure 14: IFR flow duration curve.

In Figure 14, the discharge rate is plotted against percentage of exceedance to establish the design discharge so that a suitable turbine can be selected. The discharge rates occur at the head of 1627 m a. s. l. which is the in-stream flow requirement elevation. Here, the discharge does not follow a certain trend as there is a different flow for each month and other monthly flows are similar and closer to one another as observed in Table 2 which is an IFR order issued by the Lesotho Ministry of Water Affairs to the Metolong dam Safety department to be released into the Phuthiatsana River.

There seems to be an extended percentage exceedance clustered between 6% – 28 % in the discharge slightly above 0.3 m^3/s. This shows that the discharge falling between these probabilities has more frequency of occurrence. Most discharges are within the range between 30% – 86 % but the least discharge is 0.05 m^3/s. This implies that having a turbine that could handle this flow and the maximum of 0.34 m^3/s would be advantageous for power production for this site. The exceedance range of 86 % - 100 % is mostly experienced when the discharge valve is opened after a maintenance job. This data was collected in the period when more construction operations were carried out so the discharges obtained are less likely to produce any useful power.

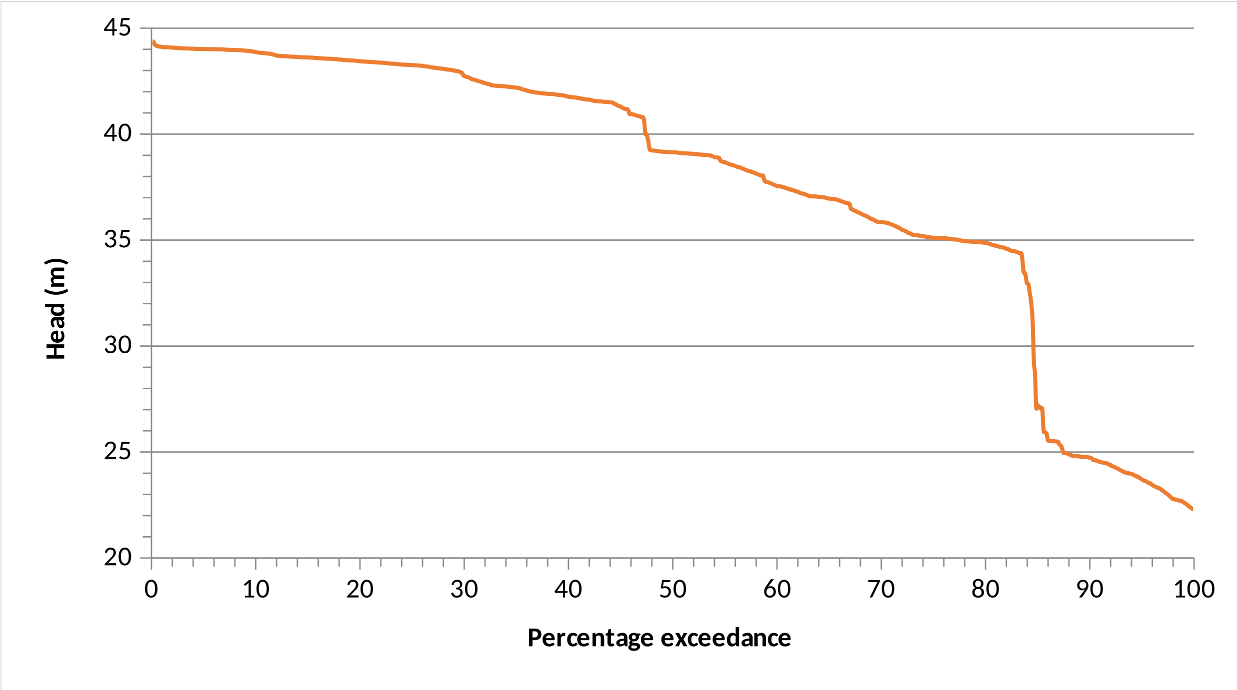

Figure 15: IFR head duration curve.

In Figure 15, head is plotted against percentage exceedance to determine how frequent a certain head occurs. The IFR head is measured at elevation of 1627 m a.s.l. whilst the highest spillway elevation is 1671.01 m a.s.l. This head also helps in the process of selecting a suitable turbine. The frequency of higher head occurrence is between 2 % and 46 % which corresponds to the ranges between 38 m – 44 m. The second head occurrence is 48 % to 84 % which ranges between 26 m – 38 m, and a third head occurrence of between 86 to 100 % ranges between 22 m – 26 m.

In range one, head is above 40 m and from the data provided, it occurred when the dam was accumulating water just before the first over flow in March 2019. Range two lies between 34 m - 38 m observed from the data for the period ranging between the end of 2017 and mid-2018 in which the dam head was rapidly accumulating as illustrated by the steepness of the graph. The third probability with the highest possibility of occurrence is between 15 m – 26 m which is the period when the data had just started being collected and the dam head was increasing.

From the head and flow duration curves for IFR, the design flow was chosen as 0.0015 – 0.34 m^3/s and the gross head as 33.69 m – 42.26 m. Using the approach given in the methodology section, the head losses were found to be 0.01349231 m – 1.041134531 m and the resulting net head was found to be 33.24236 – 41.74829 m. Using **Figure 7**, the net head and design discharge, the suitable turbine for the most frequent head and flow rate is found to be a Radial Flow PAT (Pump As Turbine) which falls within its design discharge (0.0025 – 0.5 m^3/s) and head (9 – 150 m).

A generator set is supplied together with the Radial flow (Pump As Turbine (PAT)). The mechanism between the turbine and generator is in such a way that when a generator rotor gets mechanical power from a turbine shaft, it converts it into electrical power. Thus, the generator efficiency depends upon the turbine shaft power and electrical output power. The turbine shaft power relies on the available flow rate and head. The generator frequency increases or decreases with the variation in the flow rate of water and that fluctuation disturbs the load. The head of above 20 m, with flow rate 0.01 – 0.25 m^3/s, gives 1500 rpm, which increases efficiency up to 85 % while head of above 30 m, with flow rate of 0.05 – 0.25 m^3/s, increases efficiency to 95 %. The selected generator is 80 % efficient since head varies from 20 m – 44 m and flow from 0.01 - 0.34 m^3/s. The most frequent head is 34 – 44 m for IFR while most frequent flow for IFR is 0.05 – 0.3 m^3/s . According to Figure 7, a Radial flow PAT is the suitable turbine to be installed at Metolong dam for IFR. This turbine has a minimum flow of 0.0015 m^3/s and a maximum flow of 0.5 m^3/s which will accommodate flows at IFR. The minimum flow for IFR is 0.05 m^3/s as shown in Figure 14; this makes the turbine functional 86 % of the time. Head suitability for radial flow PAT is 9 m minimum and 150 m maximum. Thus, the Metolong head fluctuates between 22 m as the lowest and 44 m as the highest at both IFR. The efficiency of a radial flow PAT is assumed to be 0.6 as its efficiency can reach up to 0.82. Depending on the flow and head at 0.0074 m^3/s flow rate and 30 m head, an efficiency of 0.82 was obtained [92]. A decision to assume efficiency as 0.6 was reached because at Metolong dam, head fluctuates between 20 m and 44 m.

4.2 Water velocity, Reynolds number, Friction factor and head loss results as affected by temperature from different scenarios.

Table 3 presents water velocity results and how they are impacted by the water temperature as calculated using Error: Reference source not found. This is a vital component of R_e as it determines how fast the water passes a particular point in time. This is a function of flow per unit area, so months inhibiting more IFR will ultimately have more water velocity.

Table 3: Water velocity from three scenarios differing by water temperature.

Months	Water velocity estimates without temporal temperature variability (m/s).	Water velocity estimates with temporal temperature variability (m/s).	Water velocity estimates considering projected temporal temperature variability around the Metolong Dam (m/s).
September	0.0335994	0.033599377	0.0335994
October	0.041115	0.041115027	0.041115
November	0.0751565	0.075156501	0.0751565
December	0.1830282	0.183028185	0.1830282
January	0.2210485	0.221048532	0.2210485
February	0.2741002	0.27410018	0.2741002
March	0.254029	0.254028973	0.254029
April	0.2473091	0.247309098	0.2473091
May	0.2033646	0.20336465	0.2033646
June	0.1688811	0.168881079	0.1688811

July	0.0831142	0.083114248	0.0831142
August	0.0353678	0.035367765	0.0353678

In Table 4, the results of Reynold's numbers are presented as impacted by the water temperature and water velocity from IFR. These results are calculated using Error: Reference source not found; this is done to estimate a friction factor (*f*) and relative pipe roughness from a Moody diagram shown in Error: Reference source not found. After determination of R_e, it is then related to f in the Moody diagram as will be seen in Table 5.

Table 4: Reynold's number results from three scenarios with different water temperatures.

Months	Reynold's number estimates without temporal temperature variability.	Reynold's number estimates with temporal temperature variability.	Reynold's number estimates considering projected temporal temperature variability around the Metolong Dam.
September	2572.36521	3086.523	3086.52318
October	3147.762691	3776.93	3776.92968
November	5753.974811	6904.065	6904.065007
December	14012.62101	16813.43	16813.4289
January	16923.45533	20306.07	20306.07355
February	20985.08461	25179.53	25179.5312
March	19448.43486	23335.74	23335.73972
April	18933.96182	22718.44	22718.43509
May	15569.5789	18681.59	18681.58767
June	12929.51987	15513.84	15513.84019
July	6363.219203	7635.084	7635.083655
August	2707.752852	3248.972	3248.971768

In Table 5, results of the friction factor are shown so as to calculate head losses from the IFR of the three scenarios using Error: Reference source not found. Friction factor is a function of Reynolds number and does not rely on penstock material properties [89].

Table 5: Friction factor results from the three scenarios.

Months	Friction factor estimates without temporal temperature variability.	Friction factor estimates with temporal temperature variability.	Friction factor estimates considering projected temporal temperature variability around the Metolong Dam.
September	0.028	0.024	0.043
October	0.042	0.042	0.044
November	0.021	0.034	0.032
December	0.026	0.025	0.027
January	0.026	0.027	0.026
February	0.026	0.028	0.025
March	0.026	0.026	0.025
April	0.027	0.026	0.025
May	0.027	0.025	0.027
June	0.029	0.025	0.027
July	0.032	0.032	0.032
August	0.026	0.042	0.043

Results shown in Table 6 represent the head losses incurred by water; this refers to the water power loss due to friction inside the penstock [89]. This retards water movement by dragging it and reducing its power before reaching the turbine. All IFR head losses are equal or less than one.

Table 6: Head loss results as from the three scenarios.

Months	Head loss (h_f) estimates without temporal temperature variability (m).	Head loss (h_f) estimates with temporal temperature variability (m).	Head loss (h_f) estimates considering projected temporal temperature variability around the Metolong Dam (m).
September	0.015644	0.013409231	0.024024872
October	0.035138	0.03513829	0.036811542
November	0.058706	0.095047829	0.08945678
December	0.431062	0.414482436	0.447641031
January	0.628751	0.652933894	0.628751157
February	0.966768	1.041134531	0.929584403
March	0.830367	0.830366906	0.798429717
April	0.817286	0.787016274	0.756746417
May	0.552643	0.511706711	0.552643248
June	0.409346	0.352884169	0.381114902
July	0.109403	0.109403475	0.109403475
August	0.016096	0.026001279	0.026620357

In Table 7, gross head for IFR is shown. This is the potential energy (h_g) embedded in water before moving inside the penstock where it incurs losses of drag and turbulence.

Table 7: Gross head results from all the three scenarios.

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
H_g for IFR (m)	34.4	33.82	33.84	33.69	33.92	36.87	36.99	42.09	42.26	41.93	41.42	40.24

In Table 8, net head results are shown as the difference between gross head and head losses as shown in Error: Reference source not found. It is also observed that the increase in h_n is caused by increased f as a result of increased IFR that contributes to water velocity and water flow rate. Head losses for IFR are low in September and increase towards December all the way to May and June; they then decrease in July and August in a similar trend for all IFR scenarios.

Table 8: Net head results for the three scenarios.

Months	Net head estimates without temporal temperature variability (m).	Net head estimates with temporal temperature variability (m).	Net head estimates considering projected temporal temperature variability around the Metolong Dam (m).
September	34.38436	34.38659	34.37598
October	33.78486	33.78486	33.78319
November	33.78129	33.74495	33.75054
December	33.25894	33.27552	33.24236
January	33.29125	33.26707	33.29125
February	35.90323	35.82887	35.94042
March	39.15963	39.15963	39.19157
April	41.27271	41.30298	41.33325
May	41.70736	41.74829	41.70736
June	41.52065	41.57712	41.54889

July	41.3106	41.3106	41.3106
August	40.2239	40.214	40.21338

4.3 Hydropower estimates without temporal temperature variability.

In this scenario, the temperature of water is estimated to be 4^{o} C with the density of 1000 kg/m^3. The results are observed at IFR to estimate how much power can be produced given the conditions of water and temperature.

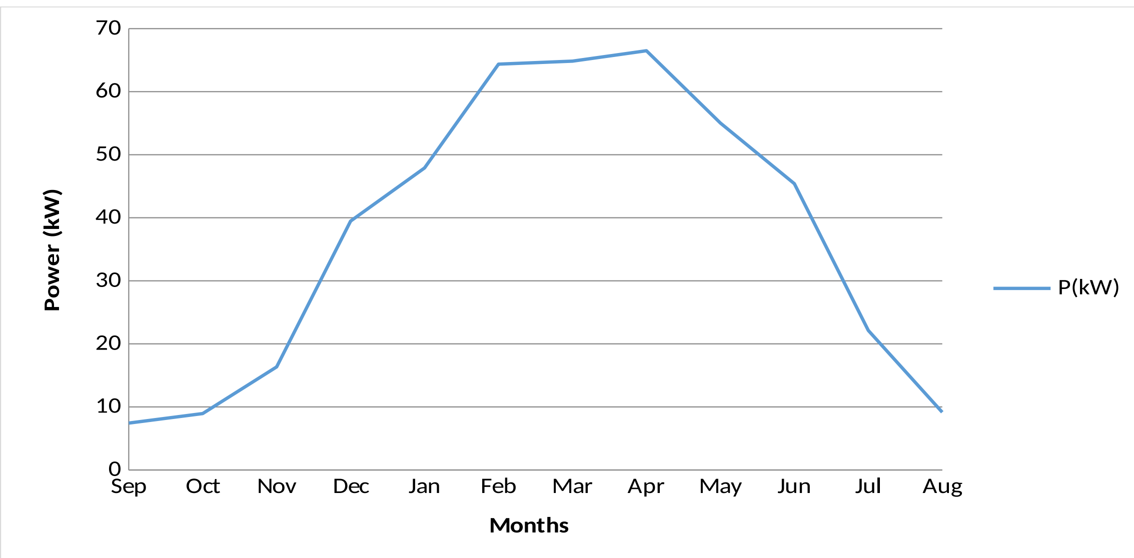

Figure 16: Power produced at IFR when water temperature and density are 4 ^{o}C and 1000 kg/m^3 respectively for different months.

The months of August, September and October from Figure 16 have the lowest power production due to low discharge as observed in Table 2. Power production begins to peak from November due to increases in the dam head. In December, the increase is brought by both increases in the dam head as rain showers begin to be more frequent at this season and in-stream flow requirement. Peaking of power production in January, February, March and April is also due to the increase in head and in-stream flow requirement. Head increases because of summer and autumn rains that fill up the Metolong dam. In May, June and July, the in-stream flow requirement declines, hence the decrease in power production as hydropower is a function of physical parameters of the dam head and flow rate [55].

4.4 Hydropower estimates with temporal temperature variability.

In this scenario, the actual water temperatures are used to study if they have any impact on the power produced for IFR.

Table 9: Actual water temperatures for respective months.

Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
WTW Temp (°C)	14.2	17.6	20.5	20.6	21	19.4	17.8	15.5	15	12	13.2	12.2
IFR Temp (°C)	10.4	10.5	10.6	10.6	10.8	11.2	11.5	11.8	11.3	10.8	11.2	10.4

In Table 9, actual water temperatures are presented as obtained from the Metolong dam safety department.

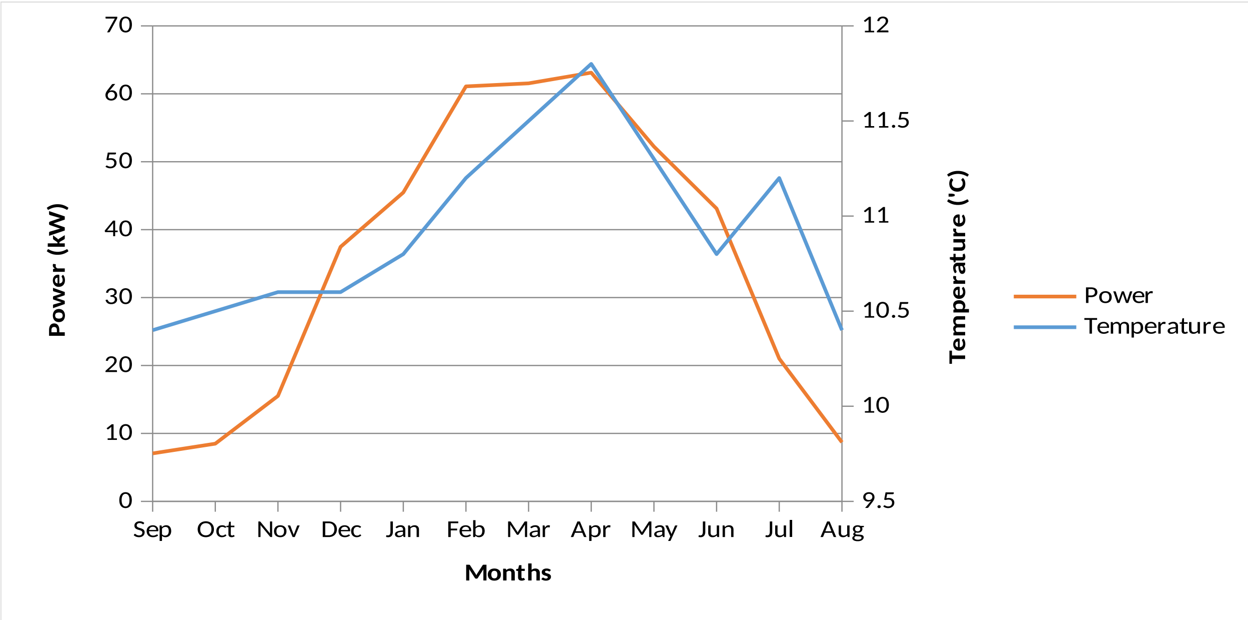

Figure 17: Power produced at IFR using actual water temperature and density for different months.

In *Error: Reference source not found***7,** power peaks from October to April due to the increase in IFR according to *Table 2*; it also contributed to the increased dam head, fuelled by summer rains which fill up the Metolong dam. In May, the power output begins to drop as there is also a decrease in IFR. June, July, August and September have the least power output due to low IFR and low dam head, as there are no rains in winter and spring. The months of September and August have the lowest water temperatures. Water temperature increases from November to April while June and July have temperatures of around 11^{o} C. The impacts of the temperature seem to only be limited to R_e as shown in Table 4.

Power production here resembles the one in Figure 16; this is a clear indication that water temperature does not have an influence on power production. It only affects R_e as seen from Table 4; this clearly shows that R_e is a function of water velocity, pipe diameter and kinematic viscosity (Error: Reference source not found).

4.5 Hydropower estimates considering projected temporal temperature variability around the Metolong Dam.

Table 10: Shows correlated water temperatures from air temperatures around Metolong dam.

Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Air Temp (°C)	14.5	16.6	18.6	18.5	207	18.6	17.6	13.5	10	6.9	6.6	9.7
Water Temp (°C)	10.15	11.62	13.02	13.65	14.49	13.02	12.32	9.45	7	4.83	4.62	6.79

In Table 10, air temperatures around the Metolong dam are obtained from [101]. The correlation used followed the one in a study conducted in 43 streams of Europe; the majority of streams indicated an increase in the water temperature of about 0.6 – 0.8 ^{o}C per 1 ^{o}C, an increase in air temperature and a few streams displayed a 1:1 (linear) air/water temperature relationship [91]. Therefore, in this study, the correlation followed is calculated using 0.7 air/water relationship as a mid-value between 0.6 – 0.8 ^{o}C. The purpose of correlating the air to water temperature is to find the temperature of water inside the Metolong dam using the relationship of air to water temperature as it is important in the investigation of how the water temperature affects power generation.

In Figure 18 below, the lowest power output is exhibited in September, October and August due to low IFR. From November, December until April, power peaks due to the increased IFR since there is an increase in head caused by summer rains. The power output begins to decline from May due to a decrease in IFR and dam head. There is an increase in the water temperature from July until January in a more or less uniform way. The water temperature begins to decline in January until June, with July having the lowest water temperature and January as the highest in these correlated water temperatures.

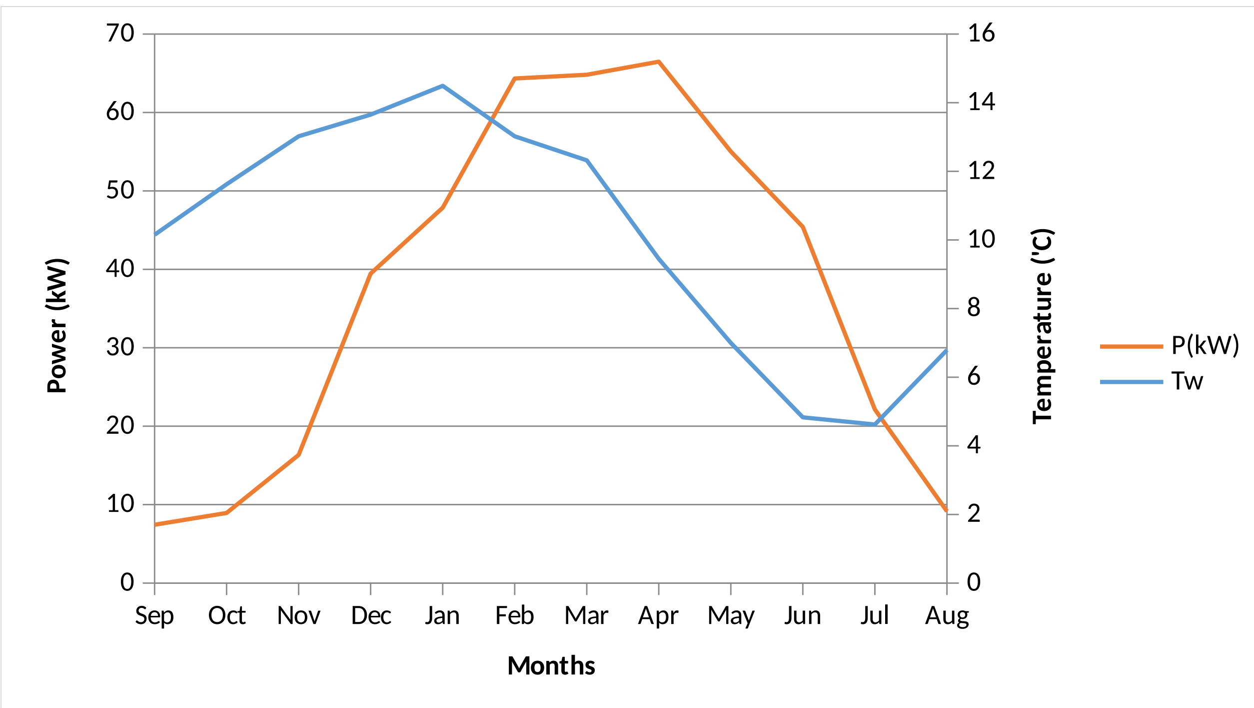

Figure 18: Power production using correlated water temperatures in Table 10 at IFR.

4.6 Seasonal variability of power projections as affected by water temperature and density.

Seasonally, the IFR fluctuates, so does dam head and water demand by consumers. This brings seasonal variations in power projection.

In Figure 19, power for different seasons of the year is plotted as it is affected by the water temperature and density at IFR. Seasonally, IFR and dam head vary for every month, so does power demand by consumers. In spring season, the months have low IFR as shown in Table 2. This results in the months having power projections of less than 10 kW for all scenarios of water temperature. The summer season is the beginning of the rainy season, so are dam head increases. Thus, the power projection in this season is around 34 kW, which is also due to January having high flow in IFR. In autumn, power projection is around 63 – 65 kW and IFR is high since it is a rainy season as shown in Table 2. The winter season has an average power projection of 41 kW because the month of May has high IFR and follows a rainy season. As a result, there is high head.

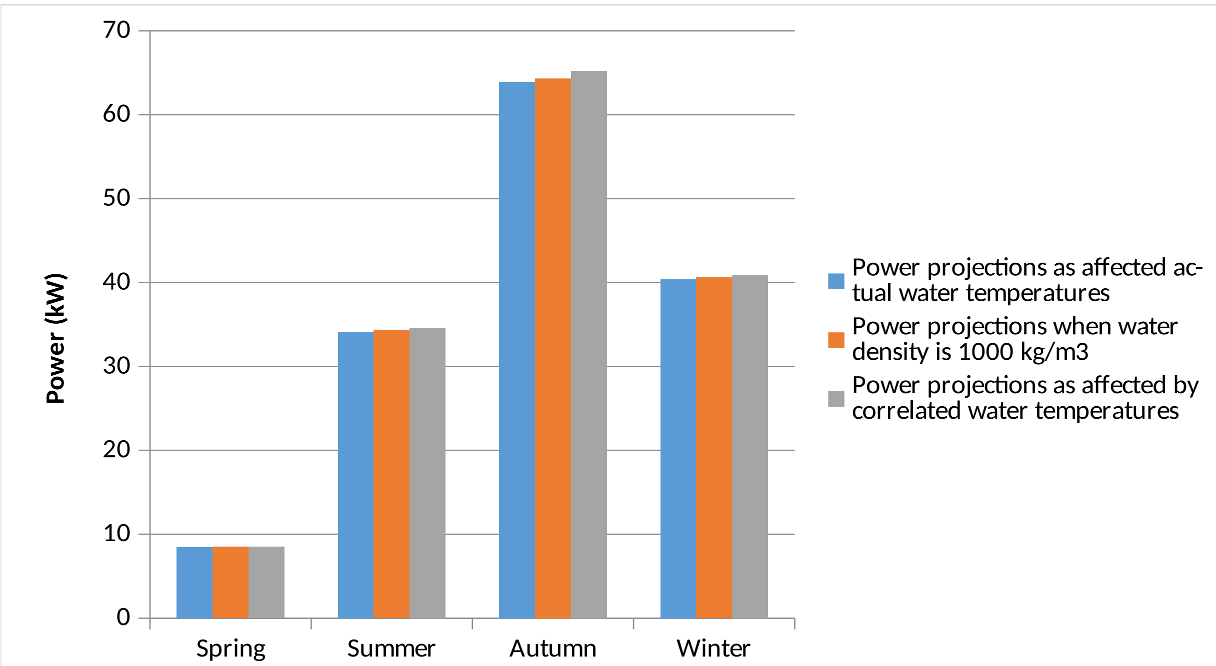

Figure 19: IFR Seasonal variations as affected by water temperature and density.

In general, IFR is characteristic of the rainfall pattern around the Metolong dam as seen in Table 2. Due to this fact, peaking electrical production is observed in the months of March, April and May, with a possibility of June following this annual precipitation cycle. These electrical production values are relatively small but can provide a good supplement to the existing 'Muela hydropower station if an independent power producer (IPP) makes use of the Metolong dam infrastructure, to produce and sell the electricity.

Other than that, Lesotho's peak electricity demand is 160 MW [14] which is still high given the local 'Muela hydropower station capacity and good business if the water utility company

(WASCO-IPP) goes for distributed generation or monthly net metering with the electricity utility company (LEC). Either of the two will result in the reduction of electricity cost for the WASCO and the creation of jobs as the hydropower facility will employ some personnel for its implementation, operation and maintenance. The Lesotho biennial report has also stated that there is an additional 150 MW capacity in the proposed dams of Hlotse, Senqu and Makhaleng.

Although the study is focused on the estimation of hydropower potential, there is a high possibility of sediment accumulation in the Metolong dam given the formation of soils present in the south of Phuthiatsana, in the Caledon basin cave sandstone which has a high erosive factor, propelled by cultivation practices within the catchment area by locals [93]. Unlike the Metolong dam, the ’Muela hydropower station has a site geology formed by Clarens the sandstone, outcropping of the entire site with a catchment area of 28 km^2 and terrain steeply sloped in the Maloti mountain western side [94]. This also leaves another research gap to study sedimentation rates between the Katse and Metolong dams, bearing in mind that Katse has Mohale as its upper reservoir with a different catchment area and soil orientation.

Although grid extension is expensive in rural areas as compared to urban areas due to the high cost of grid extension over scattered rural populations [16], generation at Metolong dam can help with additional electricity to supplement the present sources of electricity especially in peak demand hours so as to minimize imports and help withstand the load, even though production is not that much, especially in winter when IFR flow is low. This is also beneficial when extending the existing grid to withstand the load of incoming consumers since most rural households have low electricity consumption [17].

In terms of the turbine selection for the Metolong dam, the site has an advantage of accessibility. Since the dam is being used for water consumption only and not fishery, it has an advantage of an existing mild steel penstock buried inside a concrete dam wall, with little or no movement, which makes it good for hydropower generation. This makes it cheaper to install hydropower at this site since the penstock is already accounted for in the water consumption project. The remaining expenses will be for labour, turbines and generators at IFR.

The Metolong dam and Water Treatment Works is one of the energy intensive sections within WASCO, hence identifying and harnessing energy at IFR will help relieve the company from spending too much on energy consumed for pumping water to the treatment works. Unlike hydropower constructed over diversion water channel for forebay, hydropower built on dams has a problem of sedimentation in the dam which is likely to reduce the dam head with time if major tributaries to the dam are not taken care of in terms of constructing silt-traps and stone-bunds so as to reduce the rate of soil movement into the dam. Reduction in dam head will ultimately affect power production as head is the primary determinant of hydropower. Since the Metolong dam IFR is drawn from either of the bottom draw-off levels, there is a high likelihood for sand and silt to reach a turbine installed at the IFR, which will cause mechanical damage to the turbine.

Additionally, unlike wind and solar, hydropower is not prone to intermittency as its production is 24 hours. The only factor affecting its productivity is the seasonal flows or water demand as in the Metolong dam's case for months such as July, August and September. Although production can take all day and all year if no maintenance is done, there is usually planned maintenance schedules expected to occur.

The proposed hydropower at the Metolong dam will be grid connected hence it will require an induction generator of 0.955 efficiency as the results obtained for hydropower estimations incorporated a generator of that efficiency. It will be the decision of the operator if they opt for net metering or distributed generation and the benefits of one over the other. However, net metering seems to be best option for the proposed project.

Installing a hydropower mechanism at a high energy potential spot will be advantageous with minimum maintenance caused by siltation or sediment transported by the water to the turbine; unlike the one at IFR because it is drawn from either draw-off level 1, 2 or 3 and water there is likely to be turbid with presence of silt and soil particles drawn into the dam with storm water during rainy seasons. The licensing of the Metolong dam hydropower will be easier as LEC and WASCO are regulated by LEWA and both utilities belong to the government of Lesotho. Issuing a generation license to WASCO will have less legal barriers unlike for other IPPs in Lesotho or any other developing country.

Another important issue is to propose a fishery at the Metolong dam to allow for water-food-energy nexus which will be more like the existing Katse dam, though it provides energy at 'Muela and its micro-hydropower plant at its IFR is currently not functional [22]. Metolong dam will need to undergo detailed research in terms of water quality to determine which fish species is suitable for the water quality in the dam as well as profitable.

It is also important to benchmark on the last Environmental Impact Assessment (EIA) of Metolong dam and identify all the affected parties and how they are coping with the infrastructural development, their compensation if there was any and how their livelihoods have changed. This will ensure the good running of the project if the impacts it caused to the community after the construction and running of the dam are managed. The EIA will also help develop an Emergency Preparedness Plan (EPP) in order to have clear statistics of how many people downstream of the Metolong dam will be affected in an event of the dam collapsing or how many people need to be sensitized if the dam wall gives warning signs of a collapse. Benchmarking the EIA is very crucial as it should occur after every 5 years since there is population growth, infrastructural development, villages growth and properties are developed every year around the dam and downstream of the dam. Despite the social, environmental and economic impacts associated with hydropower, which it tries to adhere to as there are the pillars of sustainability, it still seeks to accomplish a couple of Sustainable Development Goals (SDG); namely:

- SDG 3 - reduce severe health impacts of air pollution;

- SDG 6 - ensure water availability and sustainable management of water;

- SDG 7 - ensure access to affordable and clean energy; and

- SDG 13 – take urgent action to combat climate change [96].

4.7 Comparison of the results to other studies

For IFR, the Manantali Dam in the Senegal River basin had to undergo flood releases that affected the outlet and turbine-generator which had a capacity of 480 m^3/s while flood releases needed were 2000 m^3/s [97]. For Metolong, IFR ranges from 0.05 m^3/s to 0.34 m^3/s and flood classes are as follows; class 1 (2.2 m^3/s), class 2 (4.5 m^3/s), class 3 (7.9 m/s) and class 4 (17.4 m^3/s) but ever since the commissioning of the dam in November 2015, only flood class 1 has been experienced. This means that optimum power production can be achieved during flood classes while feeding into the Phuthiatsana River also continues.

4.8 Project finance

For the sustainability of most investment projects, project finance ensures the future cash flow of such projects. Ensuring the expected income of proposed projects will cover the debt and equity obligations provided by lenders and shareholders is very vital [98]. Investors and lenders especially in developing economies need to undergo special financing arrangements with governments of such developing countries for financing of large energy infrastructure [99]. This is because project finance is an influential tool for mobilizing capital for renewable energy projects which face challenges in developing countries [100] as pointed out in section 2.7.

There are various proposed approaches used that differ from country to country on how projects can be financed. In the case of financing a proposed hydropower at Metolong dam, there is no clear approach of how this can be achieved as Lesotho is still developing policy tools to properly equip the Ministry of energy on how to oversee project development from financing to licensing. The Metolong dam exists for water consumption, so developing a micro hydropower on site will be much cheaper as the Radial flow PAT is needed for energy generation with minor construction and installation costs. Operation and maintenance will be from WASCO as there are already qualified personnel for maintenance.

The Radial flow PAT set with generator which costs USD$ 27 000.00 can produce up to 100 kW with the maximum flow of 0.55 m^3/s. Installation and construction costs amount to USD$ 16 200.00. The construction and installation costs include the extension of a 350 mm pipe that was initially meant for hydropower generation during the construction of the dam. The recovery period of these expenses is 4 years as generation is subject to fluctuations of IFR and PPA negotiation signing.

4.9 Summary of results

From Figure 14 the most frequent discharge of 0.0025 – 0.5 m^3/s, falls within 30 % – 86 % exceedance range, implying that the hydropower plant will be able to generate most of the time. In Figure 15, a head duration curve shows 15 m- 26 m as the most frequent head and falls within the range of a chosen turbine (9 m – 150 m) but after 2018, the most frequent head became 34 m – 44 m due to rains leading to water accumulation in the dam. The efficiency of a turbine generator was found to be dependent on flow rate as illustrated in section 4.1, but was assumed to be 0.6 in the power potential evaluation. The results of water velocity using temperature from the three scenarios seemed not to have significant impact on water velocity as presented in Table 3, but months with high IFR had high velocity. The Reynold's number results in Table 4 showed that Reynold's number estimates without temporal temperature variability were low as compared to those with temporal temperature variability and those considering projected temporal temperature variability.

Friction factor results in Table 5 showed that friction factor estimates, considering projected temporal variability around Metolong dam, had highest friction factor as compared to estimates with temporal variability and those without temporal temperature variability. Head loss results in **Table 6** showed that head losses considering projected temperature variability around Metolong dam gave highest head losses as compared to head losses with temporal variability and those without temperature variability. In Table 8, net head results observed to be comparatively the same for each month for all the three scenarios. The results of power production showed a similar trend as influenced by head and flow rate in all the three scenarios, with a peak starting from November and beginning to decline in May as IFR drops and dam head is reduced due to decrease in rain showers. This is also observed in seasonal variations in Figure 19 as summer months begin to have the increase in power production followed by autumn then winter as influenced by dam head and IFR releases.

Chapter 5.0

5.1 Conclusion

In chapter one of the study, an overview of the hydropower status in Lesotho was provided. The problem and the research questions that needed to be addressed were identified. It further gave the scope of the study. In chapter two, the available literature was reviewed, with the aim of providing the general background of hydropower technologies and techniques with related barriers of renewable energy. In chapter three, the methodology of the study was outlined with details of study area, together with the approach and equations used on data provided Chapter 4 presented and analysed the results, linking them to the objectives and literature.

The study found that Metolong Dam has 23 m – 44 m head for IFR with water releases of 0.05 m^3/s – 0.3 m^3/s; which produces 7 kW on average for September due to the least flow and 65 kW on average in April due to the high dam head and increased flow. The results also showed that the water temperature had no significant effect on hydropower production. This is in the event that the Radial flow PAT of 0.6 efficiency and the generator of 0.955 efficiency were installed at IFR site. This showed that if hydropower was considered in the construction of the dam or could be proposed as beneficial for distributed generation, economic benefits would make good turnover for the utility company (WASCO) if they were to sell power to LEC (Lesotho Electricity Company). Hydropower can also be maximized during floods and dam overflows beyond 2.0 m^3/s at IFR. The autumn and winter months have more hydroelectricity projections. This is also evident from monthly hydroelectricity projection from the three scenarios mainly due to the high IFR dam head, which extends into winter months. The financing of this project is also not expected to exceed $50 000 as most of the penstock material is already installed and the recovery period will not exceed 4 years due to fluctuations of IFR.

5.2 Recommendations

Since the study failed to address the issue of turbidity current occurrence in the dam, it is therefore recommended that future studies should focus on the simulation of the impacts of turbidity currents on hydropower potential for Metolong dam. Construction of silt-traps at major tributaries supplying water to Metolong dam is also encouraged as it will reduce the quantity of sand and silt entering the dam. Within the Metolong dam catchment area, it will be of best interest of the proposed hydropower facility to hold public gatherings to advice the farmers to change from intensive cultivation or convention agriculture to conservation agriculture so as to reduce the stability soil eroded by wind or water. This will ensure good soil cover while also making soil resistant to erosion. For this to succeed there should be subsidies provided by the hydropower facility of the dam on weed controlling chemicals/herbicides as well as pesticides since weeds attract pests and insects. It is also recommended that another study be conducted to measure sedimentation rates between the Metolong dam and Katse dam since Katse dam has Mohale dam as its upper reservoir and the sites geology from the three sites are different and have different catchment areas

References

[1] International Energy Agencyl, ‘WORLD ENERGY OUTLOOK 2019’, Energy report 2019 p. 810.

[2] M. Panić, M. Urošev, A. Milanović Pešić, J. Brankov, and Ž. Bjeljac, ‘Small hydropower plants in Serbia: Hydropower potential, current state and perspectives’, *Renew. Sustain. Energy Rev.*, vol. 23, pp. 341–349, Jul. 2013, doi: 10.1016/j.rser.2013.03.016.

[3] S. Mishra, S. K. Singal, and D. K. Khatod, ‘Optimal installation of small hydropower plant—A review’, *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 3862–3869, Oct. 2011, doi: 10.1016/j.rser.2011.07.008.

[4] C. Hauer *et al.*, ‘State of the art, shortcomings and future challenges for a sustainable sediment management in hydropower: A review’, *Renew. Sustain. Energy Rev.*, vol. 98, pp. 40–55, Dec. 2018, doi: 10.1016/j.rser.2018.08.031.

[5] C. S. Kaunda, C. Z. Kimambo, and T. K. Nielsen, ‘Potential of Small-Scale Hydropower for Electricity Generation in Sub-Saharan Africa’, *ISRN Renew. Energy*, vol. 2012, pp. 1–15, 2012, doi: 10.5402/2012/132606.

[6] M. R. Nogueira Vilanova and J. A. Perrella Balestieri, ‘Energy and hydraulic efficiency in conventional water supply systems’, *Renew. Sustain. Energy Rev.*, vol. 30, pp. 701–714, Feb. 2014, doi: 10.1016/j.rser.2013.11.024.

[7] S. Mishra, S. K. Singal, and D. K. Khatod, ‘Optimal installation of small hydropower plant—A review’, *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 3862–3869, Oct. 2011, doi: 10.1016/j.rser.2011.07.008.

[8] J. Zhang, C.-Y. Luo, Z. Curtis, S. Deng, Y. Wu, and Y. Li, ‘Carbon dioxide emission accounting for small hydropower plants—A case study in southwest China’, *Renew. Sustain. Energy Rev.*, vol. 47, pp. 755–761, Jul. 2015, doi: 10.1016/j.rser.2015.03.027.

[9] Y. Zhang *et al.*, ‘Macroscopic-microscopic coupled water-energy nexus simulation and behavior optimization under uncertainty’, *Ecol. Eng.*, vol. 179, p. 106613, Jun. 2022, doi: 10.1016/j.ecoleng.2022.106613.

[10] R. Li *et al.*, ‘Water–energy–carbon nexus at campus scale: Case of North China University of Water Resources and Electric Power’, *Energy Policy*, vol. 166, p. 113001, Jul. 2022, doi: 10.1016/j.enpol.2022.113001.

[11] N. C. Tudose *et al.*, ‘Climate services for sustainable resource management: The water—energy—land nexus in the Tărlung river basin (Romania)’, *Land Use Policy*, vol. 119, p. 106221, Aug. 2022, doi: 10.1016/j.landusepol.2022.106221.

[12] P. R. Yoon, S.-H. Lee, J.-Y. Choi, S.-H. Yoo, and S.-O. Hur, ‘Analysis of climate change impact on resource intensity and carbon emissions in protected farming systems using Water-Energy-Food-Carbon Nexus’, *Resour. Conserv. Recycl.*, vol. 184, p. 106394, Sep. 2022, doi: 10.1016/j.resconrec.2022.106394.

[13] Y. Liu, Q. Tan, X. Zhang, J. Han, and M. Guo, ‘How does electricity supply mode affect energy-water-emissions nexus in urban energy system? Evidence from energy transformation in Beijing, China’, *J. Clean. Prod.*, vol. 366, p. 132892, Sep. 2022, doi: 10.1016/j.jclepro.2022.132892.

[14] Lesotho Meteorological Services, Government of Lesotho, Global Environment Facility, United Nations Environment Programme ‘Lesotho-Biennial-Update-Report’ Report 2021, www.lesmet.org.ls.

[15] B. M. Taele, K. K. Gopinathan, and L. Mokhuts'oane, 'The potential of renewable energy technologies for rural development in Lesotho', *Renew. Energy*, vol. 32, no. 4, pp. 609–622, Apr. 2007, doi: 10.1016/j.renene.2006.02.014.
[16] S. J. Williamson, B. H. Stark, and J. D. Booker, 'Low head pico hydro turbine selection using a multi-criteria analysis', *Renew. Energy*, vol. 61, pp. 43–50, Jan. 2014, doi: 10.1016/j.renene.2012.06.020.
[17] M. Mpholo *et al.*, 'Rural Household Electrification in Lesotho', in *Africa-EU Renewable Energy Research and Innovation Symposium 2018 (RERIS 2018)*, M. Mpholo, D. Steuerwald, and T. Kukeera, Eds. Cham: Springer International Publishing, 2018, pp. 97–103. doi: 10.1007/978-3-319-93438-9_8.
[18] B. M. Taele, L. Mokhutšoane, and I. Hapazari, 'An overview of small hydropower development in Lesotho: Challenges and prospects', *Renew. Energy*, vol. 44, pp. 448–452, Aug. 2012, doi: 10.1016/j.renene.2012.01.086.
[19] B. Ogayar, P. G. Vidal, and J. C. Hernandez, 'Analysis of the cost for the refurbishment of small hydropower plants', *Renew. Energy*, vol. 34, no. 11, pp. 2501–2509, Nov. 2009, doi: 10.1016/j.renene.2009.03.027.
[20] B. M. Taele, K. K. Gopinathan, and L. Mokhuts'oane, 'The potential of renewable energy technologies for rural development in Lesotho', *Renew. Energy*, vol. 32, no. 4, pp. 609–622, Apr. 2007, doi: 10.1016/j.renene.2006.02.014.
[21] B. M. Taele, K. K. Gopinathan, and L. Mokhuts'oane, 'The potential of renewable energy technologies for rural development in Lesotho', *Renew. Energy*, vol. 32, no. 4, pp. 609–622, Apr. 2007, doi: 10.1016/j.renene.2006.02.014.
[22] Ministry of Energy and Meteorology,Lesotho Highlands Development Authority (LHDA),The Kingdom of Lesotho, 'DATA COLLECTION SURVEY ON SMALL-HYDROPOWER DEVELOPMENT PROJECT IN THE KINGDOM OF LESOTHO', Mar. 2020.
[23] L. Khaba and J. A. Griffiths, 'Calculation of reservoir capacity loss due to sediment deposition in the `Muela reservoir, Northern Lesotho', *Int. Soil Water Conserv. Res.*, vol. 5, no. 2, pp. 130–140, Jun. 2017, doi: 10.1016/j.iswcr.2017.05.005.
[24] A. G. Adeogun, B. F. Sule, and A. W. Salami, 'Cost effectiveness of sediment management strategies for mitigation of sedimentation at Jebba Hydropower reservoir, Nigeria', *J. King Saud Univ. - Eng. Sci.*, vol. 30, no. 2, pp. 141–149, Apr. 2018, doi: 10.1016/j.jksues.2016.01.003.
[26] D. Yang, Y. Yang, and J. Xia, 'Hydrological cycle and water resources in a changing world: A review', *Geogr. Sustain.*, vol. 2, no. 2, pp. 115–122, Jun. 2021, doi: 10.1016/j.geosus.2021.05.003.
[27] K. Luo and J. P. Moiwo, 'Sensitivity of the land surface hydrological cycle to human activities in China', *Gondwana Res.*, p. S1342937X22001071, Apr. 2022, doi: 10.1016/j.gr.2022.04.006.
[28] L. Strohmenger, P. Ackerer, B. Belfort, and M. C. Pierret, 'Local and seasonal climate change and its influence on the hydrological cycle in a mountainous forested catchment', *J. Hydrol.*, vol. 610, p. 127914, Jul. 2022, doi: 10.1016/j.jhydrol.2022.127914.
[29] W. Zhou *et al.*, 'Connections between the hydrological cycle and crop yield in the rainfed U.S. Corn Belt', *J. Hydrol.*, vol. 590, p. 125398, Nov. 2020, doi: 10.1016/j.jhydrol.2020.125398.

[30] G. Dayon, J. Boé, É. Martin, and J. Gailhard, ‘Impacts of climate change on the hydrological cycle over France and associated uncertainties’, *Comptes Rendus Geosci.*, vol. 350, no. 4, pp. 141–153, May 2018, doi: 10.1016/j.crte.2018.03.001.
[31] C. Liu and J. Xia, ‘Detection and Attribution of Observed Changes in the Hydrological Cycle under Global Warming’, *Adv. Clim. Change Res.*, vol. 2, no. 1, pp. 31–37, Mar. 2011, doi: 10.3724/SP.J.1248.2011.00031.
[32] O. J. Mdee, ‘Measurement methods for hydropower resources: a review’, p. 19.
[34] International Renewable Energy Agency, ‘RENEWABLE CAPACITY STATISTICS 2020.’, Jan. 2020. Accessed: Jul. 22, 2022. [Online]. Available: https://www.irena.org/Statistics/Download-Data.
[35] S. Morales, C. Álvarez, C. Acevedo, C. Diaz, M. Rodriguez, and L. Pacheco, ‘An overview of small hydropower plants in Colombia: Status, potential, barriers and perspectives’, *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1650–1657, Oct. 2015, doi: 10.1016/j.rser.2015.06.026.
[36] C. Alonso-Tristán, D. González-Peña, M. Díez-Mediavilla, M. Rodríguez-Amigo, and T. García-Calderón, ‘Small hydropower plants in Spain: A case study’, *Renew. Sustain. Energy Rev.*, vol. 15, no. 6, pp. 2729–2735, Aug. 2011, doi: 10.1016/j.rser.2011.03.029.
[37] H. S. Sachdev, A. K. Akella, and N. Kumar, ‘Analysis and evaluation of small hydropower plants: A bibliographical survey’, *Renew. Sustain. Energy Rev.*, vol. 51, pp. 1013–1022, Nov. 2015, doi: 10.1016/j.rser.2015.06.065.
[38] M. Panić, M. Urošev, A. Milanović Pešić, J. Brankov, and Ž. Bjeljac, ‘Small hydropower plants in Serbia: Hydropower potential, current state and perspectives’, *Renew. Sustain. Energy Rev.*, vol. 23, pp. 341–349, Jul. 2013, doi: 10.1016/j.rser.2013.03.016.
[39] R. Kumar and S. K. Singal, ‘Penstock material selection in small hydropower plants using MADM methods’, *Renew. Sustain. Energy Rev.*, vol. 52, pp. 240–255, Dec. 2015, doi: 10.1016/j.rser.2015.07.018.
[40] B. M. Taele, L. Mokhutšoane, and I. Hapazari, ‘An overview of small hydropower development in Lesotho: Challenges and prospects’, *Renew. Energy*, vol. 44, pp. 448–452, Aug. 2012, doi: 10.1016/j.renene.2012.01.086.
[41] R. M. Almeida *et al.*, ‘Strategic planning of hydropower development: balancing benefits and socioenvironmental costs’, *Curr. Opin. Environ. Sustain.*, vol. 56, p. 101175, Jun. 2022, doi: 10.1016/j.cosust.2022.101175.
[42] D. Hu, S. Li, Z. Jin, S. Lu, and D. Zhong, ‘Sediment transport and riverbed evolution of sinking streams in a dammed karst river’, *J. Hydrol.*, vol. 596, p. 125714, May 2021, doi: 10.1016/j.jhydrol.2020.125714.
[43] G. Wang, Q. Fang, L. Zhang, W. Chen, Z. Chen, and H. Hong, ‘Valuing the effects of hydropower development on watershed ecosystem services: Case studies in the Jiulong River Watershed, Fujian Province, China’, *Estuar. Coast. Shelf Sci.*, vol. 86, no. 3, pp. 363–368, Feb. 2010, doi: 10.1016/j.ecss.2009.03.022.
[44] H. J. Zhai, B. Hu, X. Y. Luo, L. Qiu, W. J. Tang, and M. Jiang, ‘Spatial and temporal changes in runoff and sediment loads of the Lancang River over the last 50 years’, *Agric. Water Manag.*, vol. 174, pp. 74–81, Aug. 2016, doi: 10.1016/j.agwat.2016.03.011.
[45] J. Chen, W. Zhou, S. Han, and G. Sun, ‘Influences of retrogressive erosion of reservoir on sedimentation of its downstream river channel—A case study on Sanmenxia Reservoir and the Lower Yellow River’, *Int. J. Sediment Res.*, vol. 32, no. 3, pp. 373–383, Sep. 2017, doi: 10.1016/j.ijsrc.2017.02.007.

[46] M. M. Bunyasi, S. M. Onywere, and M. K. Kigomo, ‘Sustainable Catchment Management: Assessment of Sedimentation of Masinga Reservoir And its Implication on the Dam’s Hydropower Generation Capacity’, *Int. J. Humanit. Soc. Sci.*, vol. 3, no. 9, p. 14, 2013.

[47] S. Wang, X. Qian, Q. H. Wang, and W. Xiong, ‘Modeling Turbidity Intrusion Processes in Flooding Season of a Canyon-Shaped Reservoir, South China’, *Procedia Environ. Sci.*, vol. 13, pp. 1327–1337, 2012, doi: 10.1016/j.proenv.2012.01.125.

[48] S. W. Chung, M. R. Hipsey, and J. Imberger, ‘Modelling the propagation of turbid density inflows into a stratified lake: Daecheong Reservoir, Korea’, *Environ. Model. Softw.*, vol. 24, no. 12, pp. 1467–1482, Dec. 2009, doi: 10.1016/j.envsoft.2009.05.016.

[49] A. J. Schleiss, M. J. Franca, C. Juez, and G. De Cesare, ‘Reservoir sedimentation’, *J. Hydraul. Res.*, vol. 54, no. 6, pp. 595–614, Nov. 2016, doi: 10.1080/00221686.2016.1225320.

[50] O. Sawadogo, G. R. Basson, and S. Schneiderbauer, ‘Physical and coupled fully three-dimensional numerical modeling of pressurized bottom outlet flushing processes in reservoirs’, *Int. J. Sediment Res.*, p. S1001627918301914, Feb. 2019, doi: 10.1016/j.ijsrc.2019.02.001.

[51] R. An and J. Li, ‘Characteristic Analysis of the Plunging of Turbidity Currents’, *J. Hydrodyn.*, vol. 22, no. 2, pp. 274–282, Apr. 2010, doi: 10.1016/S1001-6058(09)60055-X.

[52] A. K. Rai and A. Kumar, ‘Determination of the particle load based on detailed suspended sediment measurements at a hydropower plant’, *Int. J. Sediment Res.*, vol. 34, no. 5, pp. 409–421, Oct. 2019, doi: 10.1016/j.ijsrc.2019.04.001.

[53] A. Mulu and G. S. Dwarakish, ‘Different Approach for Using Trap Efficiency for Estimation of Reservoir Sedimentation. An Overview’, *Aquat. Procedia*, vol. 4, pp. 847–852, 2015, doi: 10.1016/j.aqpro.2015.02.106.

[54] A. G. Adeogun, B. F. Sule, and A. W. Salami, ‘Cost effectiveness of sediment management strategies for mitigation of sedimentation at Jebba Hydropower reservoir, Nigeria’, *J. King Saud Univ. - Eng. Sci.*, vol. 30, no. 2, pp. 141–149, Apr. 2018, doi: 10.1016/j.jksues.2016.01.003.

[55] M. Arnaiz, T. A. Cochrane, A. Calizaya, and M. Shrestha, ‘A framework for evaluating the current level of success of micro-hydropower schemes in remote communities of developing countries’, *Energy Sustain. Dev.*, vol. 44, pp. 55–63, Jun. 2018, doi: 10.1016/j.esd.2018.03.002.

[56] L. Lebel, P. Lebel, C. Chitmanat, and P. Sriyasak, ‘Benefit sharing from hydropower watersheds: Rationales, practices, and potential’, *Water Resour. Rural Dev.*, vol. 4, pp. 12–28, Oct. 2014, doi: 10.1016/j.wrr.2014.10.006.

[57] P. Gwimbi, P. Lebese, and K. Kanono, ‘Mainstreaming health impact assessments in environmental impact statements into planning obligations in post dam construction in Metolong, Lesotho: A qualitative investigation’, *Heliyon*, vol. 6, no. 7, p. e04362, Jul. 2020, doi: 10.1016/j.heliyon.2020.e04362.

[58] S. Morales, C. Álvarez, C. Acevedo, C. Diaz, M. Rodriguez, and L. Pacheco, ‘An overview of small hydropower plants in Colombia: Status, potential, barriers and perspectives’, *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1650–1657, Oct. 2015, doi: 10.1016/j.rser.2015.06.026.

[59] H. Zhang *et al.*, ‘Cascade hydropower plants operation considering comprehensive ecological water demands’, *Energy Convers. Manag.*, vol. 180, pp. 119–133, Jan. 2019, doi: 10.1016/j.enconman.2018.10.072.

[60] C. Penghao, L. Pingkuo, and P. Hua, ‘Prospects of hydropower industry in the Yangtze River Basin: China’s green energy choice’, *Renew. Energy*, vol. 131, pp. 1168–1185, Feb. 2019, doi: 10.1016/j.renene.2018.08.072.
[61] P. Razurel, L. Gorla, S. Tron, A. Niayifar, B. Crouzy, and P. Perona, ‘Improving the ecohydrological and economic efficiency of Small Hydropower Plants with water diversion’, *Adv. Water Resour.*, vol. 113, pp. 249–259, Mar. 2018, doi: 10.1016/j.advwatres.2018.01.029.
[62] I. Kougias, S. Szabó, F. Monforti-Ferrario, T. Huld, and K. Bódis, ‘A methodology for optimization of the complementarity between small-hydropower plants and solar PV systems’, *Renew. Energy*, vol. 87, pp. 1023–1030, Mar. 2016, doi: 10.1016/j.renene.2015.09.073.
[63] J. D. Hunt *et al.*, ‘Energy crisis in Brazil: Impact of hydropower reservoir level on the river flow’, *Energy*, vol. 239, p. 121927, Jan. 2022, doi: 10.1016/j.energy.2021.121927.
[64] J. S. Hecht, G. Lacombe, M. E. Arias, T. D. Dang, and T. Piman, ‘Hydropower dams of the Mekong River basin: A review of their hydrological impacts’, *J. Hydrol.*, vol. 568, pp. 285–300, Jan. 2019, doi: 10.1016/j.jhydrol.2018.10.045.
[65] F. W. Keppeler *et al.*, ‘Early impacts of the largest Amazonian hydropower project on fish communities’, *Sci. Total Environ.*, vol. 838, p. 155951, Sep. 2022, doi: 10.1016/j.scitotenv.2022.155951.
[66] A. Mayer, M. C. Lopez, and E. F. Moran, ‘Uncompensated losses and damaged livelihoods: Restorative and distributional injustices in Brazilian hydropower’, *Energy Policy*, vol. 167, p. 113048, Aug. 2022, doi: 10.1016/j.enpol.2022.113048.
[67] P. Razurel, L. Gorla, S. Tron, A. Niayifar, B. Crouzy, and P. Perona, ‘Improving the ecohydrological and economic efficiency of Small Hydropower Plants with water diversion’, *Adv. Water Resour.*, vol. 113, pp. 249–259, Mar. 2018, doi: 10.1016/j.advwatres.2018.01.029.
[68] V. Dadu, A. Dadu, D. Frunza, G. Catarig, F. Popa, and B. Popa, ‘Innovative Concepts Applied to Recent Small Hydropower Plants’, *Energy Procedia*, vol. 112, pp. 426–433, Mar. 2017, doi: 10.1016/j.egypro.2017.03.1106.
[69] R. Kumar and S. K. Singal, ‘Penstock material selection in small hydropower plants using MADM methods’, *Renew. Sustain. Energy Rev.*, vol. 52, pp. 240–255, Dec. 2015, doi: 10.1016/j.rser.2015.07.018.
[70] A. Berrada, Z. Bouhssine, and A. Arechkik, ‘Optimisation and Economic Modeling of Micro Hydropower Plant Integrated in Water Distribution System’, *J. Clean. Prod.*, p. S0959652619319894, Jun. 2019, doi: 10.1016/j.jclepro.2019.06.036.
[71] M. Arnaiz, T. A. Cochrane, A. Calizaya, and M. Shrestha, ‘A framework for evaluating the current level of success of micro-hydropower schemes in remote communities of developing countries’, *Energy Sustain. Dev.*, vol. 44, pp. 55–63, Jun. 2018, doi: 10.1016/j.esd.2018.03.002.
[72] R. Kumar and S. K. Singal, ‘Penstock material selection in small hydropower plants using MADM methods’, *Renew. Sustain. Energy Rev.*, vol. 52, pp. 240–255, Dec. 2015, doi: 10.1016/j.rser.2015.07.018.
[73] E. Quaranta and P. Davies, ‘Emerging and Innovative Materials for Hydropower Engineering Applications: Turbines, Bearings, Sealing, Dams and Waterways, and Ocean Power’, *Engineering*, vol. 8, pp. 148–158, Jan. 2022, doi: 10.1016/j.eng.2021.06.025.

[74] R. H. Sharma and R. Awal, ‘Hydropower development in Nepal’, *Renew. Sustain. Energy Rev.*, vol. 21, pp. 684–693, May 2013, doi: 10.1016/j.rser.2013.01.013.
[75] E. von Sperling, ‘Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects’, *Energy Procedia*, vol. 18, pp. 110–118, 2012, doi: 10.1016/j.egypro.2012.05.023.
[76] ‘Taele et al. - 2012 - An overview of small hydropower development in Les.pdf’.
[77] L. Z. Thamae, R. I. Thamae, and T. M. Thamae, ‘Assessing a decade of regulatory performance for the Lesotho electricity industry’, *Util. Policy*, vol. 35, pp. 91–101, Aug. 2015, doi: 10.1016/j.jup.2015.07.006.
[78] AFRICAN DEVELOPMENT BANK GROUP,KINGDOM OF LESOTHO, ‘Lesotho - Lowlands Rural Water Supply and Sanitation Project - Appraisal Report.pdf’, Jun. 2013.
[79] J. N. Rossouw and N. J. Walker, ‘Metolong Dam – Estimating the potential thermal impacts of water releases prior to construction of the dam’, p. 11, 2014.
[80] S. Makhoalibe, ‘Suspended sediment transport measurement in Lesotho’, p. 10.
[81] G. D. Cesare and N. A. B. Portner, ‘Modelling of erosion and sedimentation based on field investigations in Alpine reservoirs of hydropower schemes’, p. 25.
[82] D. Felix, I. Albayrak, R. M. Boes, and A. Abgottspon, ‘Sediment transport through the power waterway and hydro-abrasive erosion on turbines’, p. 9.
[83] A. Mulu and G. S. Dwarakish, ‘Different Approach for Using Trap Efficiency for Estimation of Reservoir Sedimentation. An Overview’, *Aquat. Procedia*, vol. 4, pp. 847–852, 2015, doi: 10.1016/j.aqpro.2015.02.106.
[84] C. Hauer *et al.*, ‘State of the art, shortcomings and future challenges for a sustainable sediment management in hydropower: A review’, *Renew. Sustain. Energy Rev.*, vol. 98, pp. 40–55, Dec. 2018, doi: 10.1016/j.rser.2018.08.031.
[85] A. K. Rai and A. Kumar, ‘Determination of the particle load based on detailed suspended sediment measurements at a hydropower plant’, *Int. J. Sediment Res.*, p. S1001627918300027, Apr. 2019, doi: 10.1016/j.ijsrc.2019.04.001.
[86] J. N. Rossouw and N. J. Walker, ‘Metolong Dam – Estimating the potential thermal impacts of water releases prior to construction of the dam’, p. 11, 2014.
[87] S. Kenyon, ‘Internet Use and Time Use: The importance of multitasking’, *Time Soc.*, vol. 17, no. 2–3, pp. 283–318, Sep. 2008, doi: 10.1177/0961463X08093426.
[88] B. Stoll, J. Andrade, S. Cohen, G. Brinkman, and C. Brancucci Martinez-Anido, ‘Hydropower Modeling Challenges’, NREL/TP--5D00-68231, 1353003, Apr. 2017. doi: 10.2172/1353003.
[89] S. Otuagoma, E. Ogujor, and P. Kuale, ‘DETERMINATION OF HEAD FOR SMALL HYDROPOWER DEVELOPMENT: A CASE STUDY OF RIVER ETHIOPE AT UMUTU’, *Niger. J. Technol.*, vol. 35, no. 1, p. 190, Dec. 2015, doi: 10.4314/njt.v35i1.26.
[90] R. Harvey, L. Lye, A. Khan, and R. Paterson, ‘The Influence of Air Temperature on Water Temperature and the Concentration of Dissolved Oxygen in Newfoundland Rivers’, *Can. Water Resour. J.*, vol. 36, no. 2, pp. 171–192, Jan. 2011, doi: 10.4296/cwrj3602849.
[91] J. C. Morrill, R. C. Bales, and M. H. Conklin, ‘Estimating Stream Temperature from Air Temperature: Implications for Future Water Quality’, *J. Environ. Eng.*, vol. 131, no. 1, pp. 139–146, Jan. 2005, doi: 10.1061/(ASCE)0733-9372(2005)131:1(139).
[92] . K. M., ‘PERFORMANCE OPTIMIZATION OF RADIAL FLOW CENTRIFUGAL PUMP IMPELLER USING CFD’, *Int. J. Res. Eng. Technol.*, vol. 05, no. 11, pp. 134–138, Nov. 2016, doi: 10.15623/ijret.2016.0511025.
[93] S. Makhoalibe, ‘Suspended sediment transport measurement in Lesotho’, p. 10.

[94] C. M. Wagner and B. Hein, ‘Design of the ~Muela hydropower station’, p. 7.
[95] M. Hamlehdar, H. Yousefi, Y. Noorollahi, and M. Mohammadi, ‘Energy recovery from water distribution networks using micro hydropower: A case study in Iran’, *Energy*, vol. 252, p. 124024, Aug. 2022, doi: 10.1016/j.energy.2022.124024.
[96] D. Cortés-Borda, J. Polanco, and M. Escobar-Sierra, ‘Social perception assessment of hydropower sustainability: A stepwise logistic regression modeling’, *Environ. Sci. Policy*, vol. 134, pp. 108–118, Aug. 2022, doi: 10.1016/j.envsci.2022.03.026.
[97] Eric Hoa and Jan Cools, ‘GOVERNING THE WATER-ENERGY-FOOD NEXUS: OPPORTUNITIES FOR BASIN ORGANISATIONS’, Nov. 2014.
[98] H. Jadidi, A. Firouzi, M. A. Rastegar, and M. Zandi, ‘Bayesian updating of solar resource data for risk mitigation in project finance’, *Sol. Energy*, vol. 207, pp. 1390–1403, Sep. 2020, doi: 10.1016/j.solener.2020.07.096.
[99] V. Nechifor, M. Basheer, A. Calzadilla, E. Obuobie, and J. J. Harou, ‘Financing national scale energy projects in developing countries – An economy-wide evaluation of Ghana’s Bui Dam’, *Energy Econ.*, vol. 111, p. 106065, Jul. 2022, doi: 10.1016/j.eneco.2022.106065.
[100] J. Barroco and M. Herrera, ‘Clearing barriers to project finance for renewable energy in developing countries: A Philippines case study’, *Energy Policy*, vol. 135, p. 111008, Dec. 2019, doi: 10.1016/j.enpol.2019.111008.
[101] European commission,‘‘*Photovoltaic Geographical Information System*’’. https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY. 19/05/2022