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## **Addis Ababa Institute of Technology**

### Center of Energy Technology

# **Techno-economic Investigation of a Micro Hydro Power System for Rural Electrification: A Case study of Lemere River, Hadya Zone, Ghibe Wereda**

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Energy Technology

Addis Ababa, Ethiopia

April 5, 2022

## DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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This MSc. thesis has been submitted for examination with my approval as an advisor.

\_\_\_\_\_

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This is to certify that the thesis prepared by: Frahiwot Midaksa entitled **“Techno-Economic Investigation of a Micro Hydro Power System for Rural Electrification: A Case study of Lemere River, Hadya Zone, Ghibe Wereda”** submitted in partial fulfillment of the requirements for the degree of Master of Science in Center of Energy Technology complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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## ABSTRACT

*Ethiopia has a huge hydroelectric power generation potential due to the abundant water resources in the country. It is, therefore, necessary to use efficiently the sources in the country for the enhancement of electrical energy. The main purpose of this thesis is to investigate the viability of a standalone Micro Hydro Power plant from Lemere River in Hadya Zone, Ghibe Wereda.*

*The power produced from the proposed plant is supplied to Geseda village to power home appliances, community service centers, churches and micro enterprises. The power demand of the village studied in detail. The study shows that a minimum load of 0.06 KW between 12:00 – 5:00 AM and a maximum load of 46.9 KW between 4:00 – 5:00 PM.*

*The data required for the potential assessment of rivers were collected from the respective organization. Accordingly, the gross head, the design flow rate and power output of the site is found out to be 22m, 0.352m<sup>3</sup>/s, and 48KW respectively. The design of civil structures, selection of electromechanical equipment's and also design of transmission system have been done. Additionally, the analysis and testing of this study were performed using RETScreen software tool to analyze and determine the Energy Model, Hydrology and load, flow duration curve of this potential site. The study is concluded by a sensitivity analysis properly adapted for the local market financial situation, in order to enlighten the decision makers on the expected profitability of the capital to be invested. According to the results obtained: The forebay was 12m in length and 1.2m in depth. Then finally penstock was 28m long with diameter of 386mm. The total cost of project was found to be 565,200USD, B/C ratio 6.2 and payback period 6.6 years. The result showed the viability of micro hydro power construction from the selected river Lemere.*

**Key words:** *Micro hydro power, design Flow rate, Head, potential assessment, sensitivity analysis, RETScreen.*

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## ABBREVIATIONS AND ACRONYMS

| <b>Abbreviations</b> | <b>Description</b>                                |
|----------------------|---|
| HPP                  | Hydro Power Plant                                 |
| MHS                  | Micro Hydro System                                |
| MHP                  | Micro Hydro Power                                 |
| HDPe                 | High Density Polyethylene                         |
| DC                   | Direct Current                                    |
| MOWIE                | Ministry Of Water, Irrigation And Energy          |
| IGC                  | Induction Generator Controller                    |
| DILC                 | Distributed Intelligent Load Controllers          |
| FDC                  | Flow Duration Curve                               |
| PvC                  | Polyvinyl Chloride                                |
| NPV                  | Net Present Value                                 |
| GPS                  | Global Position System                            |
| GIS                  | Geographic Information System                     |
| LT                   | Low Tension                                       |
| PSC                  | Pre Stressed Concrete                             |
| EME                  | Electro Mechanical Equipment's                    |
| BCR                  | Benefit To Cost Ratio                             |
| UPvC                 | Unplastified Polyvinyl Chloride                   |
| SNNPR                | Southern Nations Nationalities and Peoples Region |
| GHG                  | Green House Gas                                   |
| MHPP                 | Micro Hydroelectric Power Plants                  |
| GPM                  | Gallons Per Minute                                |
| LPM                  | Liters Per Minute                                 |
| ELC                  | Electronic Load Controllers                       |
| IGC                  | Induction Generator Controller                    |
| DILC                 | Distributed Intelligent Load Controllers          |
| FDC                  | Flow Duration Curve                               |

# CHAPTER ONE

## Introduction

This chapter introduces the research problems and descriptions of the study area and objectives to be achieved. The discussion includes the following aspects: Background, objectives, scope, and significance of this study. Besides, a problem statement provided which is the description of an issue currently existing which needs to be addressed.

### 1.1 Background of the Study

Energy is one of the basic inputs for all economic activities. Although electricity is not an end in itself, it is essential to facilitate social and economic activity. Electrification correlates closely with key aspects of sustainable development. Slow response to generation of electricity in Ethiopia, poses as a problem to development of the country. In this context, it is important to mention that expanding access to modern energy services for rural community is essential for achieving the Sustainable Development Goals[1]. Additionally, Electrification of remote villages using renewable energy resources in off-grid mode are a feasible option compared to uneconomical grid extension[2]. If it is also planned carefully and well adapted to the environmental conditions, micro hydropower schemes produce a continuous and predictable supply of electrical energy in comparison to other small-scale renewable technologies. It thus only has a little negative environmental impact. Negative socio-economic impacts are even insignificant in comparison. Further advantages include low distribution and running costs (requires no fuel and only low maintenance) as well as local implementation and management[3].

To build a micro hydropower system, access to flowing water needed. A sufficient quantity of falling water must be available, means that hilly or mountainous sites are best. Other considerations for a potential micro hydropower site include its power output and economics.

The selected Case Study River fulfills the requirements of developing micro hydro system and it is an option for the electrification of the village Geseda Kebele. Development of a micro hydro system at this site supposed to improve life standard of the community nearby the village. Therefore, the present work is concentrated on the systematic investigation of the techno-economic viability of MHP generation on selected Lemere River in Hadya Zone, Ghibe Wereda.

The main parameters that need to be determined in Small-scale Hydropower plants (SHPs) are the installed capacity and the cost, which are affected by the design flow, net head, turbines, tunnels, canals, penstocks, and other variables. All of these variables are analyzed in the pre-feasibility studies in order to find the optimum installed capacity and the cost of the plant. RETScreen is a computer program capable of estimating the amount of the energy to be generated and the investment and maintenance costs for small-scale hydropower projects. In this thesis, a brief pre-feasibility analysis was made for in the case study, using RETScreen software.

## 1.2. Description of the Site

The following section briefly describes about the selected micro hydropower potential area of the site. This section also includes the result of the survey works carried out in the project site.

**Location of the site:** Lemere River is a MHP potential river crossing near to Geseda village, located at SNNPR, Hadiya Zone, Ghibe Woreda in the kebele called Geseda, It situated at 360 Km south of Addis Ababa and 30 Km South West Hossana town. Geographically it lies at latitude and longitude of 7°33'N, 37°51'E.

**Physical Features:** The River has a total length of 68.9 mile or 110.883 km, a total catchments area of 282 km<sup>2</sup>. The annual rainfall of the Kebele ranges from 1,001 to 1,200 mm. The total number of households in the Kebele is more than 240. Most of the houses build close to each other, but there is no electric access. Currently, the community use kerosene, candle, and dry cell, diesel oil for lighting and biomass fuel for cooking.

Fig. 1.1 and Fig.1.2 below shows Geographical map of the selected site and Geseda village overview respectively.

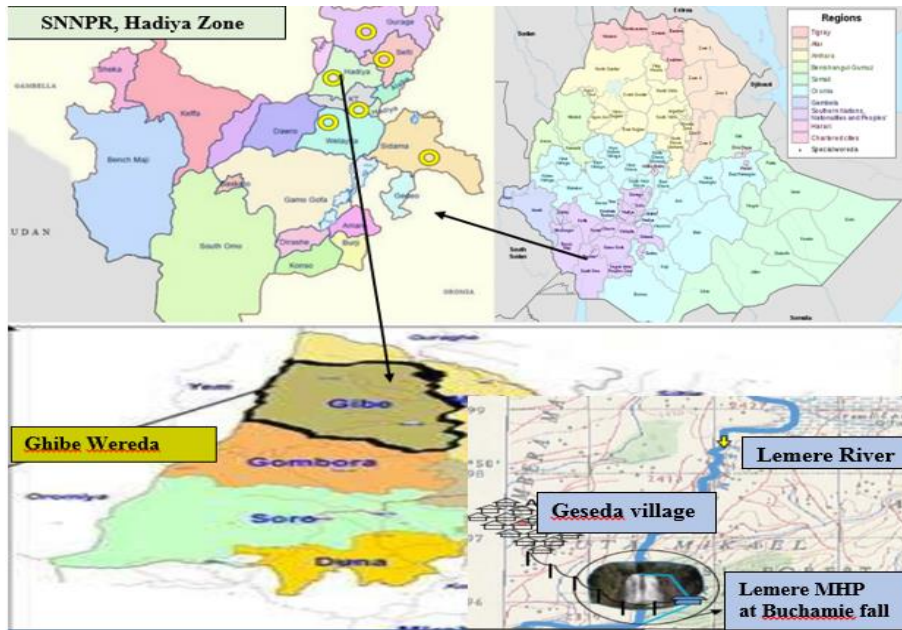


Figure 1.1: Geographically Map of the site.



Figure 1.2: Photograph of Geseda village and typical houses.

**Social Institutions:** - in this context, the social institutions mainly include schools; health post, religious institutions, Kebele administration office and farmers training centre (FTC).

There are 3 primary schools namely Geseda Kodada, Fulie Degaga and Gofora in the Kebele. Geseda Kodada was powered by solar energy; however, the system is not operational now while the other two schools haven't been powered by any source of energy yet.

The Kebele youth centre has its office in the Kebele centre. Farmers training centre, Geseda Kodada primary school and the Geseda health post are located nearby the Kebele youth centre.

There is a health post staffed by six health extension workers. The health post is located near to the Fulie Degaga primary school i.e. about 4.5 km from the proposed MHP scheme. It was powered by solar; however, it is not functional now.

**Micro and Small Enterprises (SMEs) and business activities:** There are eight shops and kiosks in the Kebele. They offer products for the daily need like soap, cooking oil, candles and matches, as well as important goods like stationeries. They also ensure the supply of kerosene, which is mostly used for lighting, and battery dry cells to operate radios. They also offer foodstuffs like biscuits and soft drinks. Local alcoholic drinks are produced exclusively by women. There are also 2 grain milling stations driven by diesel motors, a total of 5 tea rooms and 2 bakeries and four local restaurants are found in the Kebele. They are often situated within the owner's house or in an extension of it. The craftsmen in the community are carpenters and they are 8 in number. None of them operate permanent workshops, moving instead from one employment site to the next. There are also three micro and small businesses which actively engaged in phone charging activities.

**Power Generation Potential:** - Geseda Kebele is rich in water resources. The River flows throughout the year although the water amount is reduced during driest periods. By considering the gap and energy problem of Geseda Villagers this thesis is conducted to investigate techno-economic potential of Lemere River in Geseda village located at, Ghibe Woreda, Hadiya Zone of SNNP regional state. The generation potential of the river has been analyzed in chapter 3.

**Access to the site:** - The Kebele is slightly connected to the Homocho, Woreda's capital by a gravel Road transport, which offers good accessibility in almost throughout the year.

### 1.3. Statement of the Problems

In rural areas of Ethiopia, the supply of electricity has always been scarce due to the relative isolation from the national electricity distribution system. Extending the national grid to these areas is not up to the economic capacity of the country because of the high cost of transmission and the very low load factor in these areas. Using diesel generators for this isolated area as a source of energy is expensive and it is not environmentally friendly also.

As a result, the overwhelming majority of the rural people are characterized by low literacy level, poor health status and lack of descent employment due to lack of electricity. These facts are largely and the result of relatively low consumption of commercial energy.

Currently, the case study community in Geseda Kebele, Ghibe Woreda entirely depends on the energy sources like traditional biomass, gasoline, petrol, candles, battery for the radio etc., which is not economically feasible and also has huge health problem and negative environmental impact.

As a result of this they cost more than 472,735.56 birr/year for fossil fuel and deforest more than 4.3 hectare of land per year. This restricted the community from quality health service, education, modern life and modern farming practice. In addition it increases the work load of the community.

The absence of the power/electricity supply and utilities greatly impacts the lives of this rural community.

## 1.4. Objective of the Study

### 1.4.1 General Objective

The general objective of this thesis is to perform sizing and Techno-economic investigation of a micro hydro system for rural electrification at selected site of Lemere River in Hadya Zone, Ghibe Wereda in order to promote the development of MHP to enhance agro-processing, small scale industries, social services like education and health care.

### 1.4.2 Specific Objectives

- To collect all necessary hydrological data.
- To evaluate the micro hydro power potential of selected site.
- To determine load demand of the selected site area population.
- Design and sizing parts of a micro hydropower system (To design the forebay, penstock and selection of the turbines).
- To prepare the cost estimates, Bill of quantities, Economic analysis and operation and maintenance plan.

## 1.5. Significance of the Study

This research can be used as the project implementation document (PID) for the development of Micro hydropower plant at Lemere River, Ghibe Woreda, Hadiya Zone. The result of this research, will initiate policy makers, income generating small enterprises like hair cutting and beauty salons, saw milling machines, etc for the development of MHP in the area. Generally, this study will give answer to the power demand of the community if there is a concerned body/governmental or non-governmental organizations who can work on the practical implementation of the project. A successful implementation of this research project is intended to give initiation for other similar projects to be expanded in other rural area of the country.

## 1.6. Scope/Delimitation of the Study

The research covers only design of civil structure component, selection of electro mechanical equipment's, and socio economic feasibility analysis of a micro hydro system in the selected case study of Ethiopia.

This Case study cannot proceed beyond MHP System Simulation using RETscreen software due to two main reasons.

Firstly, due to financial issues and time scope since micro-hydropower plant requires large cost for implementation and time. Secondly, due to geographical issues like MHP requires other construction facilities like road, deforestations and others to install the Micro-Hydropower systems.

### 1.7. Organization of the Study

The thesis will be structured in six main chapters excluding references and appendixes which will provide supplementary information for readers whenever required.

**Chapter one:** discuss background of the study, introduces topic of the study then narrowing the topic and describe the specific area of study, problem statement, research objectives (general and specific), significance of the study, scope of the study and limitations.

**Chapter two:** this chapter specifically focuses on theoretical review, past studies on the subject in an effort to highlight the relationship of those researches and this research.

**Chapter three:** this chapter presents a detail discussion about the research design approaches, data collection and analysis which have been employed in this study in acquiring the necessary information to fulfill the objective of the study.

**Chapter four:** deals about Sizing and selection of MHP system component.

**Chapter five:** RET Screen analysis; result and discussion of the research work are presented.

Finally, in **chapter six presents conclusion and recommendation** based on the result of the research work.

## CHAPTER TWO

### Literature Review

In this chapter, some of the available relevant literature has been discussed below to have an insight of the previous work done on the subject. It will specifically focus on theoretical review, past studies on the subject in an effort to highlight the relationship of those researches and this research and a review of some of the literature on the variables of the research.

#### 2.1. Theoretical Review

Hydropower is a system converting the pressure energy and kinetic energy of water into more easily used electrical energy. It is usually restricted to the generation of shaft power from falling water. The power is then used for direct mechanical purposes or, more frequently, for generating electricity[5]. The three main types of hydropower are known as run-of-river hydropower, storage (or reservoir) hydropower and Pump storage hydropower schemes[6].

**Run-of-river:-**Run-of-river schemes generate electricity by immediate use of the inflow. As a result, run-of-river HPPs are subject to weather and seasonal variations resulting in variable power generation. Most run-of-river schemes have no storage capacity, or limited storage, which limits peak power operation to a few hours.

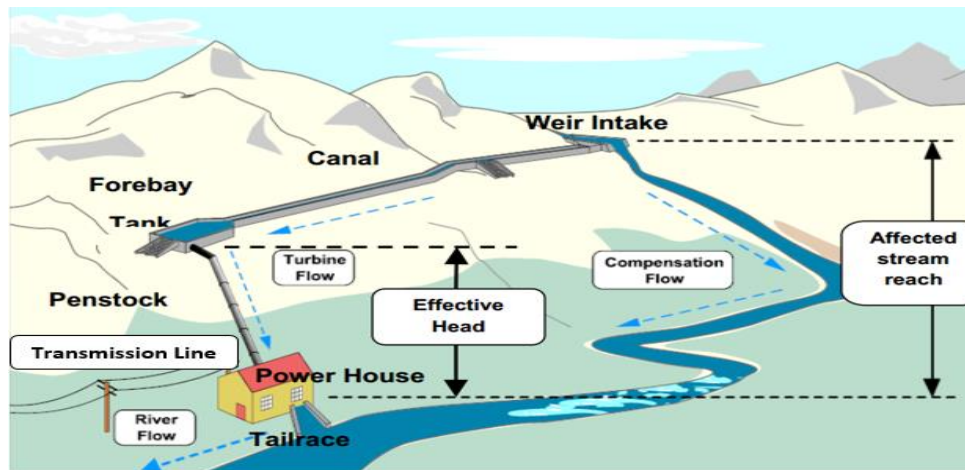
**Storage hydropower:-**Involves creating a large dam within which water sufficient for weeks, months or even years of generating capacity can be stored.

**Pumped storage:-**Plants are HPPs that can store water by pumping it from a lower reservoir or a river to a higher reservoir. Water is pumped during off-peak hours (lower power demand/ lower priced supply) by reversing turbine operation to make more water available to generate electricity during peak demand periods.

##### 2.1.1 Micro hydropower Overview

Micro-Hydroelectric Power is used in the rural electrification and does not necessarily supply electricity to the national grid. They are utilized in isolated and off-grid applications for decentralized electrification. Micro-hydro is relatively small power sources, usually the application of hydroelectric power sized for small communities, single families or small enterprise. A Micro hydro generating station can be described under two main headings: civil works, and electromechanical equipment's, for water diversion the river water level has to be

raised by a barrier, the **weir**, which also controls the water flow. The water is diverted at the **intake** and conveyed by the **channel** along the landscape's contour lines. The spillways protect against damage from excessive water flow. Water then enters a desilting tank where, if any impurities are removed in it and is slowed down and collected in the **forebay**, to be stored, from where it enters into the **penstock**, the pressure pipe conveys the water to the **power house** where the power conversion turbine and generating equipment is installed. The **turbine** converts the potential energy of the water into mechanical energy. The mechanical energy is then converted into electrical energy with the help of a **generator**, the electrical Power generated then deliver to its destination through **transmission lines** finally the water is discharged via the draft tube or a **tail race channel** in case of cross flow or Pelton turbines[9], [10]. Fig.2.1 below shows a typical layout and components of a Micro Hydropower system.



**Figure 2.1: Run of the river type Micro Hydro Project System Schematic[11].**

Figure 2.2 shows how the component parts of a micro-hydro system convert power from one form to another as it flows through the system.

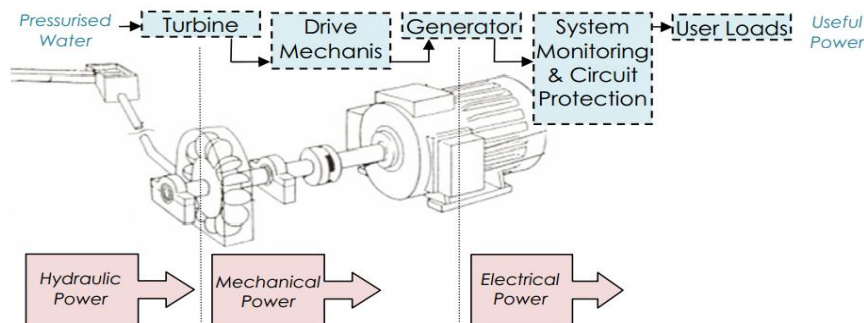
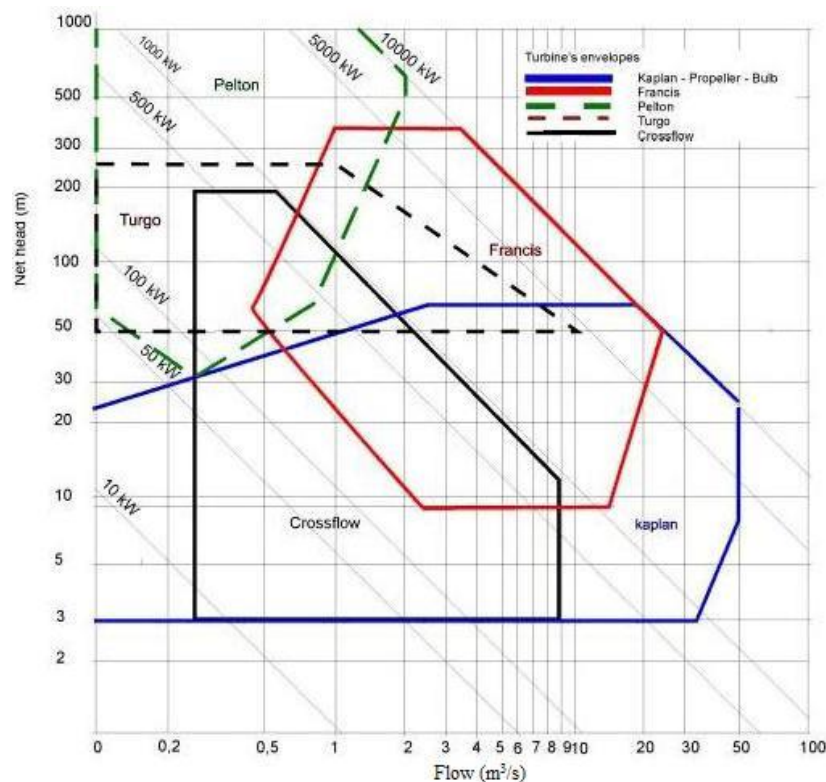


Figure 2.2: Block diagram of a typical micro-hydro system[12].

### 2.1.2 Hydropower Turbine Selection

The selection of a turbine depends on the net head, design flow rate, and the available power of the system. Based on these three parameters, the hydropower turbine is selected from figure below.



**Figure 0.2: Hydropower Turbines selection chart in terms of flow rate, net head, and power capacity (Adejumobi & Shobayo, 2015)**

### 2.1.3 RETScreen Software

RETScreen Software is available software developed by Natural Resources CAMNET Energy Technology Centre, Canada. It is excel-based software that allows predictions of renewable energy projects, including MHPs from both physical and financial perspectives. The software calculates the flow availability, potential power capacity, the capital costs, the operating costs, the amount of energy to be generated, and the payback period. The required data to be entered by

the user for energy model, cost analysis, and financial analysis worksheets are given in table-2-1 below (Yuce & Yuce, 2016).

Table 0-1: The Required Data for Energy Model, Cost Analysis, and Financial Analysis in RETScreen Software (Yuce & Yuce, 2016).

| Energy Model  | Cost Analysis  | Financial Analysis   |
|---|--|--|
| <ul style="list-style-type: none"> <li>• Gross Head (m)</li> <li>• Percent firm flow available (%)</li> <li>• Residual flow (m<sup>3</sup>/s)</li> <li>• Design flow (m<sup>3</sup>/s)</li> <li>• Number of turbines</li> <li>• Flow Duration Curve</li> <li>• Electricity export rate (\$/MW-h)</li> </ul> | <ul style="list-style-type: none"> <li>• Feasibility study (\$)</li> <li>• Development (\$)</li> <li>• Engineering (\$)</li> <li>• Hydro turbine (\$/kW)</li> <li>• Road construction ((\$/km)</li> <li>• Labor ((\$/project)</li> </ul> | <ul style="list-style-type: none"> <li>• Fuel cost escalation rate (%)</li> <li>• Inflation rate (%)</li> <li>• Project life (year)</li> <li>• Incentives and grants ((\$)</li> <li>• Debt ratio (%)</li> <li>• Debt interest rate (%)</li> <li>• Effective income tax rate (%)</li> </ul> |

### 2.3 Previous works

Researchers accomplished their research on different Micro Hydro system design and development analysis approach for remote area electrification. Among the studies conducted some of them are being selected and reviewed in this paper to get a critical written account of the current state of research on a selected topic.

2016, Alie Wube Dametew [10], He Tries to addresses power generation for rural applications by means of small hydropower plants by using cross-flow turbine systems. The Cross-flow turbines are considered best for micro-hydro projects with a head of (5) meters or less and water flow rate (1.0) m<sup>3</sup>/s or less. The design parameters such as, Turbine material, runner diameter, runner length, water jet thickness, blade spacing, radius of blade curvature, turbine power, turbine speed, number of blades, and any losses in the pipe due to friction, were determined at maximum turbine efficiency.

2010, António Roque.et.al [11], the authors presents an overview of available technical solutions to be used in micro-hydro power plants and proposes suitable equipment for a particular solution,

based on an average height of water of 25 m, an average water flow rate of 1.7 m<sup>3</sup>/s and a global efficiency of 80% and also an economic analysis of the considered power plant.

2017, S. O. Anaza.et.al [12], Carried out an overview of micro-hydro system by reviewing some of its basic components such as turbine and generator that make this conversion process possible. Estimating micro-hydro energy potential which is a function of Head and Flow rate, planning, advantages and its limitation also reviewed to provide the basic knowledge of micro-hydro system.

2013, Bilal Abdullah Nasir [13], he perform the design procedure of micro-hydro power plant by a Matlab Simulink computer program to calculate all the design parameters to show construction of micro-hydroelectric project was feasible in the project site and there were no major problems apparent at the design and implementation stages of the micro-hydro-electric power plant. He reports on the design in Matlab Simulink procedure and implementation of micro-hydro-electric power plant taking into account a lot of design considerations such as site survey, measuring of head and water flow rate, civil work components (weir, trash rack, intake, channel and penstock), selection of hydraulic turbine type and dimensions and specifications of electrical power generator.

2016, Zelalem Girma [15], He studied technical and economic feasibility of grid connected small scale hydropower construction in selected site of the Kulfo River in southern Ethiopia. He presents the general overview of Ethiopia electric power situation; small scale hydropower situation and barriers and drivers for its development; site assessment and cost estimation methods He also presents techno-economic analysis of small scale hydropower development on the Kulfo River in southern Ethiopia. Technical and economic feasibility of the site have been studied by using HOMER, RETscreen, and SMART Mini-IDRO software.

(Anaza et al., 2017):- conducted research work on “micro-hydroelectric energy generation, an overview.” This study reviewed that, as the human population and activities are progressively developing, it is almost certain that the demand for energy worldwide is increasing as well, and this trend is most likely to continue in the future. This article review aims to overview about micro hydro-power system by reviewing some of the basic components (like turbine and generators) including micro-hydro project planning, estimation of micro-hydropower potential which is based on head and flow rate, advantages/disadvantages of micro-hydropower. This article also overviews about three steps to make the micro-hydro projects to be successful. These

are project formulation and layout, engineering design and layout optimization, and definition of project layout are considered as a must.

When come up to current study, to overcome the problem of lack of maintenance human power (technician) as well as to down frequency of accidental trouble on the plant, the work is carried out with local trained personnel's to minimized labor cost, for that reason, the study suggested to train the household, in order to carried out the construction as well as the maintain by themselves, and to take visual inspection. The work of the thesis is to replace kerosene for lighting and diesel for power system with micro hydro power that is great change to the society because they will get additional access that haven't.

## **CHAPTER THREE**

### **Research Methodology**

This chapter presents a detail discussion about the type of research design approaches which have been employed in this study in acquiring the necessary information to fulfill the objective of the study. Moreover, topics related to method of data collection, materials, data analysis and interpretation tools are included.

#### **3.1 Research design and Approaches**

This study has the following research approaches:

- Focusing firstly on gaining a wide and comprehensive understanding of the chosen subject area, a literature review was completed. The knowledge gained from the literature review was then applied to the particular situation of the chosen site. The most suitable applications of different technology were analyzed before being selected and recommended in this report.
- The research is intended to carry out the design of civil structure component, selection of electro mechanical equipment's, and socio economic feasibility analysis of a micro hydro system. For the development of a micro hydro system to the case study area secondary data like flow rate and head of the river have been collected from ministry of water, irrigation and energy, the data were then validated with the field work also, data for number of households, social institutes and business centers in the Geseda Keble have been collected from the Ghibe Wereda statistics department and from the site survey which was used to determine how much power can be supplied from the micro hydro power development and for energy demand analysis.
- After this, selection of electromechanical and design of a micro hydropower system component for the selected site completed, and then cost analysis of the MHPP was done.
- Finally, technical, environmental and economic feasibility of the micro hydropower system is analyzed using RETScreen software. The following flow chart shown in Fig.3.1 illustrates the methodology that is followed to undertake the thesis work.

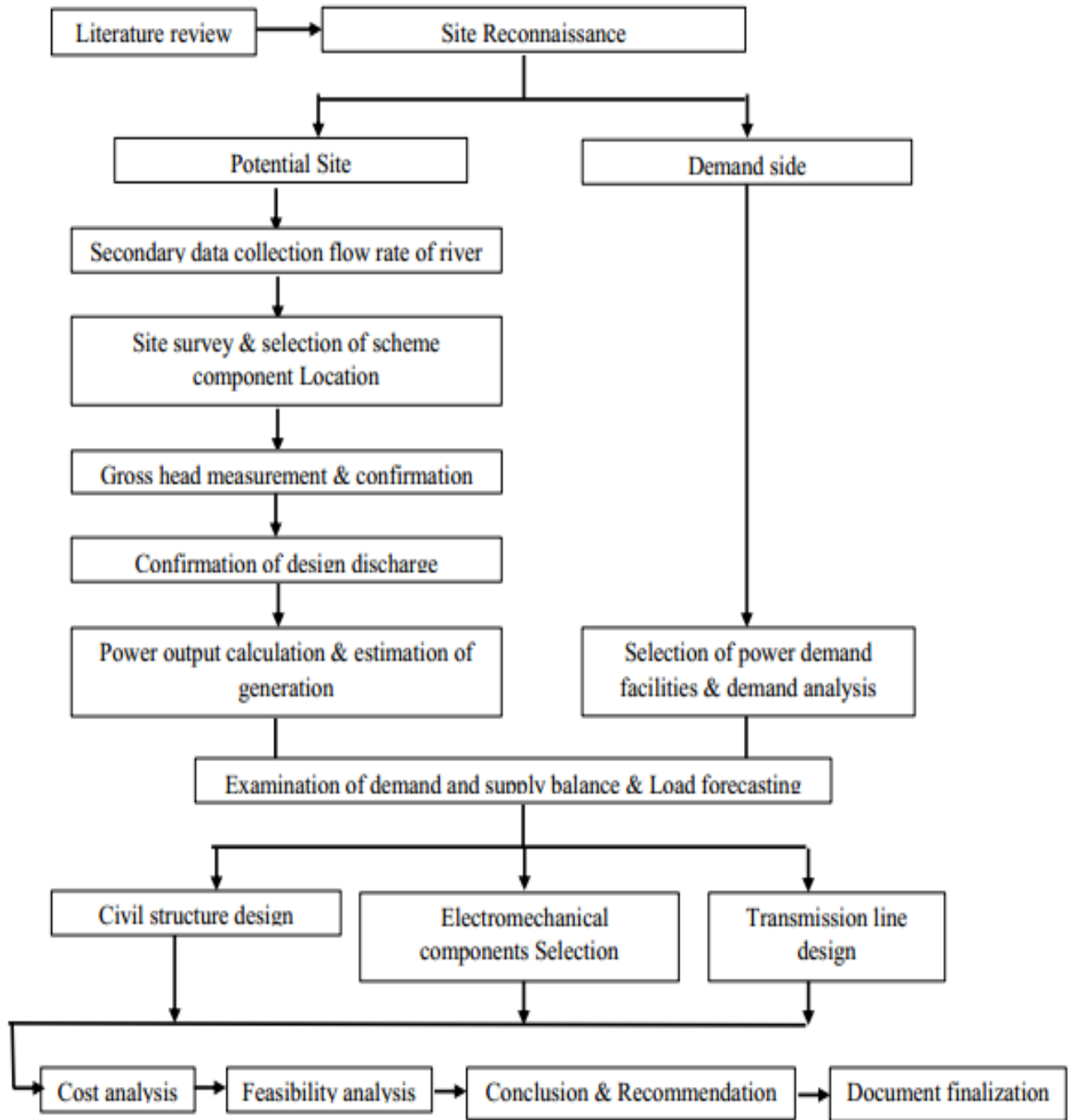


Figure 3.1: Methodological flow chart

### 3.2. Data Source and Analysis

Primary and Secondary sources of data used for data analysis. Primary data used to get empirical investigation. Thus, this study used physical observation and interviews in order to identify the problems in the existing site related to electrical energy.

Secondary sources was provided with a theoretical investigation of research problems collected from internet, and Procedures of the industries, different researches, literature, books, and journals to know what prior researchers have theorized about the subject.

Secondary data for flow rate of the river is collected from ministry of water, irrigation and energy, the collected data also validated with the field work, for secondary data validation the river discharge was measured by floating or velocity-area method. Determination of forebay, penstock position and power plant location, determining water head using spirit level and plank method, meeting some representatives of the community members and interview to get impression about the construction of the scheme and the willingness to pay bill of the electricity generated regarding in gaining community feedback members of the community was interviewed to get an impression of a hydro power scheme.

Collecting data about the statistics of business centers in the kebele, number of households, social institutions, around 1.5 Km from the proposed power house which are included to be supplied from the generated MHP, from the kebele chairman and by doing rough assessment at the site for power demand determination of Lemere village also assessments of mini-grid transmission lines for the village considered during site visit.

Photographs are taken which shows field activity's, former river Lemere use for the purpose of traditional grain mill, sample business centers like mobile charging center using solar energy, beauty salon, grain mill working with fuel, tea rooms and social institutions to get overall understanding about the site. Finally, Collection of metrological data such as precipitation, temperature, evaporation and wind and solar radiation on the selected site has been made.

### 3.3 Data Gathering Instruments

Some of the tools that are used for primary and secondary data collection purposes include Portable GPS equipment to locate exact coordinate location of site and system components, recording equipment and camera, (Tape measure, 4m Yard stick or plank, a spirit level, String) for head measurement, (Tape measure, stop watch, yard stick, buoyant object, 2 markers to put on the channel bank) is used for discharge measurement. Data analysis: specific and required data for Lemere MHP site were then made available and analyzed in XL sheets and also RET Screen software.

### 3.4. Methods of Data Analysis and Presentation

The Data Analyses have been done by using different research techniques, so that to round off the study with a summary of findings.

The river flow at a project site is considered reasonably reliable based on data taken for more than 25 years from a nearby gauging station. Well recorded and documented flow data of Lemere River where collected from Ministry of Water Irrigation and energy. Out of these the recent twenty years data were used which is starting from 1986-2006 to determine the design discharge rate of the river.

The data presented in annex A and the summary of the result presented in table 3.1 below and flow duration curve is developed by the summarized data using rank order analysis technique.

Table 3.1: Summary of 20 years stream flow data.

| Month | Monthly flow (m <sup>3</sup> /s) | Month | Monthly flow in Descending Order | Rank (n) | Frequency (F=N/n) | Probability of Exceedance (1/Fx100) |
|-------|----------------------------------|-------|----------------------------------|----------|-------------------|-------------------------------------|
| Jun   | 0.532                            | Aug   | 31.26                            | 1        | 12                | 8.3                                 |
| Feb   | 0.378                            | Sep   | 24.509                           | 2        | 6                 | 16.6                                |
| Mar   | 0.352                            | Jul   | 21.91                            | 3        | 4                 | 25                                  |
| Apr   | 0.476                            | Oct   | 13.235                           | 4        | 3                 | 33.3                                |
| May   | 2.716                            | Jun   | 7.659                            | 5        | 2.4               | 41.6                                |
| Jun   | 7.659                            | Nov   | 5.93                             | 6        | 2                 | 50                                  |
| Jul   | 21.91                            | May   | 2.716                            | 7        | 1.71              | 58.3                                |
| Aug   | 31.26                            | Dec   | 1.662                            | 8        | 1.5               | 66.6                                |
| Sep   | 24.509                           | Jun   | 0.532                            | 9        | 1.33              | 75                                  |
| Oct   | 13.235                           | Apr   | 0.476                            | 10       | 1.2               | 83.3                                |
| Nov   | 5.93                             | Feb   | 0.378                            | 11       | 1.09              | 91.6                                |
| Dec   | 1.662                            | Mar   | 0.352                            | 12       | 1                 | 100                                 |
|       |                                  |       |                                  | N=12     |                   |                                     |

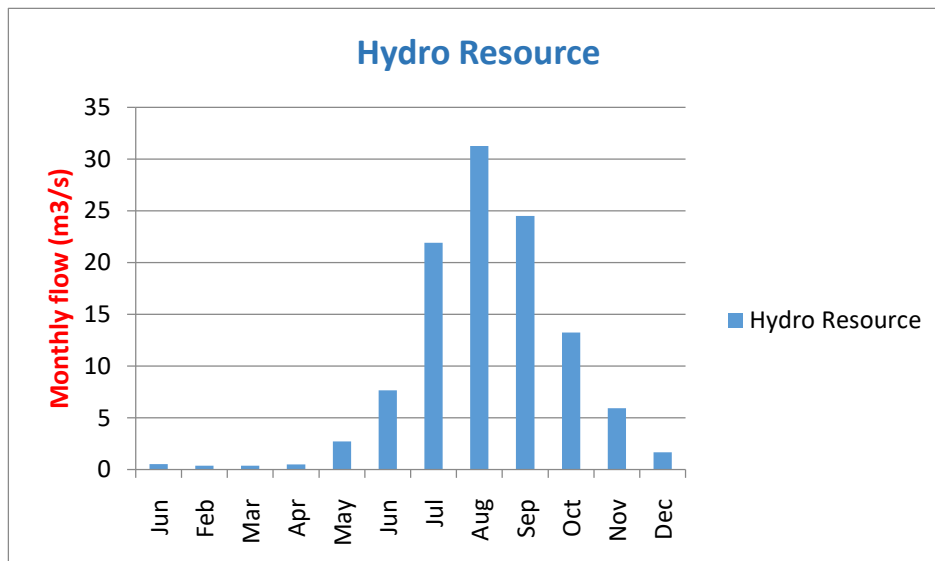


Figure 3.2: Summary of 20 years annual flow rate of Lemere River.

Validations of the collected data for flow rate, measurement were done by floating method or velocity-area method in which a piece of wood about 30 cm long and 5 cm wide was used to float in the river at the upstream of the intake or diversion weir. This was followed by measuring the river depth, width and average water velocity.

### 3.4.1 Energy Demand Assessment

In this specific thesis, two parameters found which are generating potential and estimated demand, and then adjustment is made by giving priority for important loads to be approximated to the generating capacity of the proposed MHP scheme. It was assumed that the electricity to be generated is used for; power home appliances, community service centers, churches, agricultural machines and micro enterprises.

Accordingly, this section discusses how the load estimation was calculated considering the demand type and quantity including lighting, cooking, communication, entertainment, production such as pumping, milling and bread baking, community service such as schools and health centers and future power need of the community as result of population growth and life style improvement.

#### I. Household Loads

The energy requirement of the households in the given village is different depend on their current economic status. Therefore, the households demand classified in to two categories i.e. small and large houses. Geseda village has 240 households for this houses; the domestic load power consumption summarized in Table 3.2 and Table 3.3 below.

Table 3.2: Type of loads used for a typical large houses (80 in number)

| No | Load Type        | Power in watt | Qty | Total Load [Kw] | Operating hours     |      | Daily Energy Demand [kWh/d] |
|----|------------------|---------------|-----|-----------------|---------------------|------|-----------------------------|
|    |                  |               |     |                 | Period              | hr/d |                             |
| 1  | Lights-CFL       | 11            | 2   | 1.76            | 6:00 PM - 12:00 AM  | 6    | 10.56                       |
| 2  | TV 19" Color     | 70            | 1   | 5.6             | 12:00 PM - 2:00 PM  | 2    | 11.2                        |
|    |                  |               |     |                 | 2:00 PM - 11:00 PM  | 3    | 16.8                        |
| 3  | Radio            | 15            | 1   | 1.2             | 6:00 AM - 8:00 AM   | 2    | 2.4                         |
|    |                  |               |     |                 | 5:00 PM - 11:00 PM  | 6    | 7.2                         |
| 4  | Cooking stoves   | 380           | 1   | 30.4            | 5:00 AM - 7:00 AM   | 2    | 60.8                        |
|    |                  |               |     |                 | 10:00 AM - 12:00 PM | 2    | 60.8                        |
|    |                  |               |     |                 | 4:00 PM - 6:00 PM   | 2    | 60.8                        |
| 5  | Miscellaneous    |               |     | 0.3             | 6:00 AM - 6:00 PM   | 12   | 3.6                         |
|    | <b>Sub total</b> |               |     | <b>39.26</b>    |                     |      | <b>234.16</b>               |

Table 3.3: Type of loads used for a typical small houses (160 in number)

| No | Load Type        | Power in watt | Qty | Total Load [Kw] | Operating hours    |      | Daily Energy Demand [kWh/d] |
|----|------------------|---------------|-----|-----------------|--------------------|------|-----------------------------|
|    |                  |               |     |                 | Period             | hr/d |                             |
| 1  | Lights-CFL       | 11            | 1   | 1.76            | 6:00 PM - 12:00 AM | 6    | 10.56                       |
| 2  | TV 19" Color     | 70            | 1   | 11.2            | 12:00 PM - 2:00 PM | 2    | 22.4                        |
|    |                  |               |     |                 | 2:00 PM - 11:00 PM | 3    | 33.6                        |
| 3  | Radio            | 15            | 1   | 2.4             | 6:00 AM - 8:00 AM  | 2    | 4.8                         |
|    |                  |               |     |                 | 5:00 PM - 11:00 PM | 6    | 14.4                        |
| 4  | Miscellaneous    |               |     | 0.2             | 6:00 AM - 6:00 PM  | 12   | 2.4                         |
|    | <b>Sub total</b> |               |     | <b>15.56</b>    |                    |      | <b>88.16</b>                |

## II. Public Loads

Public loads power consumption include health post, religious institute, schools, church and small business enterprises which are summarized in the Table's 3-4.

Table 3.4: Type of loads used for a typical Health Post.

| No | Load Type            | Power in watt | Qty | Total Load [Kw] | Operating hours     |      | Daily Energy Demand [kWh/d] |
|----|----------------------|---------------|-----|-----------------|---------------------|------|-----------------------------|
|    |                      |               |     |                 | Period              | hr/d |                             |
| 1  | Vaccine Refrigerator | 60            | 1   | 0.06            | 12:00 AM - 12:00 PM | 24   | 1.44                        |
| 2  | Lights-CFL           | 11            | 3   | 0.033           | 6:00 PM - 10:00PM   | 4    | 0.132                       |
| 3  | Sterilizer           | 1000          | 1   | 1               | 8:00 AM - 12:00PM   | 4    | 4                           |
| 4  | Miscellaneous        |               |     | 0.02            | 6:00 AM - 6:00 PM   | 12   | 0.24                        |
|    | <b>Sub total</b>     |               |     | <b>1.113</b>    |                     |      | <b>5.812</b>                |

Table 3.5: Type of loads used for typical Schools.

| No | Load Type        | Power in watt | Qty | Total Load [Kw] | Operating hours    |      | Daily Energy Demand [kWh/d] |
|----|------------------|---------------|-----|-----------------|--------------------|------|-----------------------------|
|    |                  |               |     |                 | Period             | hr/d |                             |
| 1  | Lights-CFL       | 10            | 32  | 0.32            | 6:00 PM - 9:00 PM  | 3    | 0.96                        |
| 2  | Computer         | 100           | 2   | 0.2             | 8:00 AM - 12:00 PM | 4    | 0.8                         |
|    |                  |               |     |                 | 2:00 PM - 6:00 PM  | 4    | 0.8                         |
| 3  | Radio            | 15            | 1   | 0.015           | 8:00 AM - 12:00 PM | 4    | 0.06                        |
|    |                  |               |     |                 | 2:00 PM - 6:00 PM  | 4    | 0.06                        |
| 4  | TV 19" Color     | 70            | 1   | 0.07            | 8:00 AM - 12:00 PM | 4    | 0.28                        |
|    |                  |               |     |                 | 2:00 PM - 6:00 PM  | 4    | 0.28                        |
| 5  | Miscellaneous    |               |     | 0.2             | 6:00 AM - 6:00 PM  | 12   | 2.4                         |
|    | <b>Sub total</b> |               |     | <b>0.805</b>    |                    |      | <b>5.64</b>                 |

Table 3.6: Type of loads used for a typical church.

| No | Load Type        | Power in watt | Qty | Total Load [Kw] | Operating hours   |      | Daily Energy Demand [kWh/d] |
|----|------------------|---------------|-----|-----------------|-------------------|------|-----------------------------|
|    |                  |               |     |                 | Period            | hr/d |                             |
| 1  | Lights-CFL       | 11            | 5   | 0.055           | 6:00 PM - 9:00 PM | 3    | 0.165                       |
| 2  | Megaphone        | 50            | 1   | 0.05            | 2:00 PM - 6:00 PM | 4    | 0.2                         |
| 3  | Miscellaneous    |               |     | 0.2             | 6:00 AM - 6:00 PM | 12   | 2.4                         |
|    | <b>Sub total</b> |               |     | <b>0.305</b>    |                   |      | <b>2.765</b>                |

Table 3.7: Type of loads used for a typical small business enterprises.

| No | Load Type              | Power in watt | Qty | Total Load [Kw] | Operating hours   |      | Daily Energy Demand [kWh/d] |
|----|------------------------|---------------|-----|-----------------|-------------------|------|-----------------------------|
|    |                        |               |     |                 | Period            | hr/d |                             |
| 1  | Water Pump             | 2000          | 1   | 2               | 6:00 AM - 8:00 AM | 2    | 4                           |
|    |                        |               |     |                 | 4:00 PM - 6:00 PM | 2    | 4                           |
| 2  | Cafeteria & Restaurant | 2000          | 2   | 4               | 8:00 AM - 9:00 PM | 13   | 52                          |
| 3  | grain milling motors   | 3600          | 1   | 3.6             | 8:00 AM-5:00 PM   | 9    | 32.4                        |
| 4  | Small business Units   | 5000          | 1   | 5               | 8:00 AM - 6:00 PM | 10   | 50                          |
|    | <b>Sub total</b>       |               |     | <b>14.6</b>     |                   |      | <b>142.4</b>                |

Table 3.8: Geseda village daily total energy requirements summery.

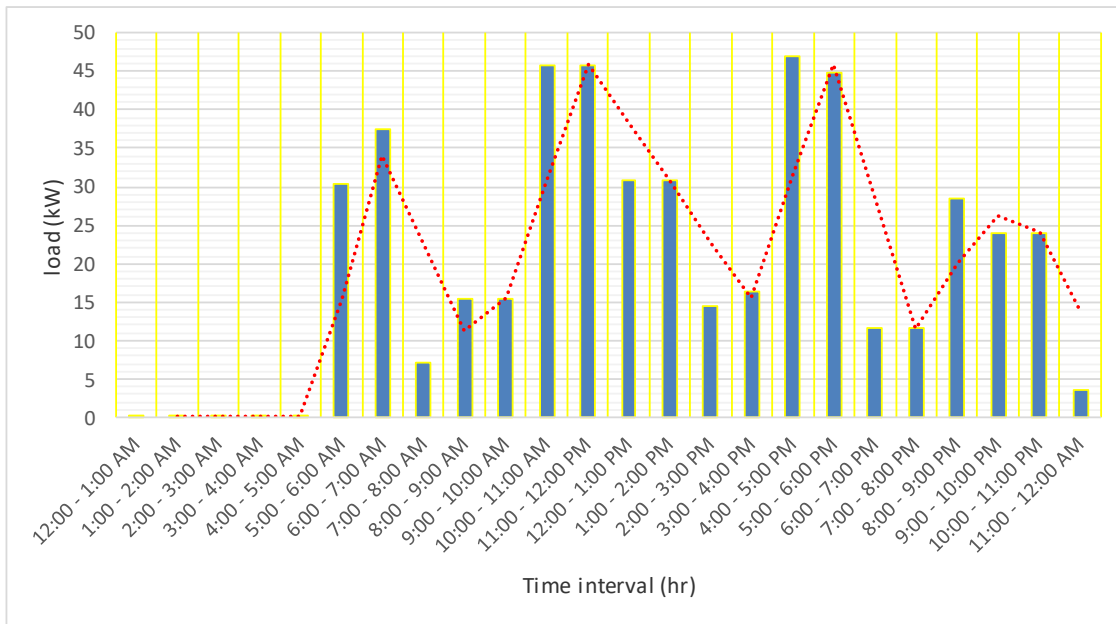
| No                         | Load Type              | Sub Total Load (Kw) | Sub Total Daily Energy Demand [kWh/d] |
|----------------------------|------------------------|---------------------|---------------------------------------|
| 1                          | Large House Loads(80)  | 39.26               | 234.16                                |
| 2                          | Small House Loads(160) | 15.56               | 88.16                                 |
| 3                          | Health Post            | 1.113               | 5.812                                 |
| 4                          | Schools                | 0.805               | 5.64                                  |
| 5                          | Church                 | 0.305               | 2.765                                 |
| 6                          | Small business         | 14.6                | 142.4                                 |
| <b>Total Energy Demand</b> |                        | <b>71.643</b>       | <b>478.937</b>                        |

### III. Load Demand Analysis

The above gross Power demand is analyzed based on time sequence to determine the maximum and minimum load requirement of the village the study shows that a minimum load of 0.06 kW between 12:00 – 5:00 AM and a maximum load of 46.9 kW between 4:00 – 5:00 PM as shown in table 3.9 below and figure 3.3 shows load profile Summary of Geseda Village.

Table 3.9: Total Loads used and their Scheduling of Geseda village.

| Time             | Total Load         | Time             | Total Load [kW]      |
|------------------|--------------------|------------------|----------------------|
| 12:00 - 1:00 AM  | <b>0.06 (min.)</b> | 12:00 - 1:00 PM  | 30.96                |
| 1:00 - 2:00 AM   | 0.06               | 1:00 - 2:00 PM   | 30.96                |
| 2:00 - 3:00 AM   | 0.06               | 2:00 - 3:00 PM   | 14.495               |
| 3:00 - 4:00 AM   | 0.06               | 3:00 - 4:00 PM   | 16.495               |
| 4:00 - 5:00 AM   | 0.06               | 4:00 - 5:00 PM   | <b>46.895 (max.)</b> |
| 5:00 - 6:00 AM   | 30.46              | 5:00 - 6:00 PM   | 44.895               |
| 6:00 - 7:00 AM   | 37.56              | 6:00 - 7:00 PM   | 11.588               |
| 7:00 - 8:00 AM   | 7.16               | 7:00 - 8:00 PM   | 11.588               |
| 8:00 - 9:00 AM   | 15.445             | 8:00 - 9:00 PM   | 28.388               |
| 9:00 - 10:00 AM  | 15.445             | 9:00 - 10:00 PM  | 24.013               |
| 10:00 - 11:00 AM | 45.845             | 10:00 - 11:00 PM | 23.98                |
| 11:00 - 12:00 AM | 45.845             | 11:00 - 12:00 PM | 3.58                 |



**Figure 3.3: Load profile Summary of Geseda Village.**

#### IV. Load Forecasting

In order to effectively plan and operate the rural electric power utility system, the load demand of the rural community must be accurately estimated and also forecasted, especially on long-term bases. On the bases of the outcome of such forecast, electric utility company can manage their resources to satisfy the forecasted demand using a least-cost plan. On the basis of forecasting periods, load forecasting can be categorized into short-term (i.e. from 1 hour to 1 week), medium term (i.e. from 1 week to 1 year), and long-term (i.e. for more than 1 year) time frames [2].

For this study, Load, projection for the village is considered from the country average. The electricity demand forecast considers both the peak demand for electricity and average demand throughout the year.

According to EEPCO electricity demand on rural areas will be expected to grow by 25% for the period up to 2020 [EEPCO]. From this Forecasting Estimation it is assumed the village Energy demand also will increase by 25% each year.

Therefore, for the village under study the current average energy demand is 485.90kWh/day average load is 20.25kW, Plant capacity is 48kW as it is calculated in the previous section of the analysis. Then the forecasted demand for the next 7 years is calculated in the table 3.10 below.

Table 3.10 Total Loads forecasting of Geseda village.

| Load forecasted (25% increase yearly) |                |                   |                            |                   |  |
|---------------------------------------|----------------|-------------------|----------------------------|-------------------|--|
| Fiscal Year                           | Peak load [kW] | Minimum load [kW] | Average Daily Demand [kWh] | Average load [kW] | Capacity Deference (Plant capacity-Peak load [kW]) |
| 2013 – 2014 EC                        | 46.90          | 0.06              | 485.90                     | 20.25             | 1.11   |
| 2015 E.C                              | 58.62          | 0.08              | 607.37                     | 25.31             | -10.62   |
| 2016 E.C                              | 73.27          | 0.09              | 759.21                     | <b>31.63</b>      | -25.27   |
| 2017 E.C                              | 91.59          | 0.12              | 949.02                     | <b>39.54</b>      | -43.59   |
| 2018 E.C                              | 114.49         | 0.15              | 1186.27                    | <b>49.43</b>      | -66.49   |
| 2019 E.C                              | 143.11         | 0.18              | 1482.84                    | <b>61.78</b>      | -95.11   |
| 2020 E.C                              | 178.89         | 0.23              | 1853.55                    | <b>77.23</b>      | -130.89  |

From the above Table 3.10 result the proposed Lemere MHP plant capacity can satisfy the current demand of the village, from 2015–2016 the average load demand satisfied with effective energy utilization schedule and training to the community. However from 2017 onwards the village energy demand growth will not be satisfied with proposed scheme. So an extension program needed according to the above long-term demand forecasting information.

### 3.4.2 Determination of the design flow

A plot of flow duration curve has been done based on the collected data above. It is a plot of flow versus the percentage of time. A flow duration curve reorders the flows in order of magnitude. It shows the relation between flows and lengths of time during which they are available. Using the rank-ordered technique with the help of XL, the flow duration curve is plotted.

The capacity estimate for firm power is then made by using the entire recorded flow data and plotting in a single flow duration curve.

The firm flow is the flow being available p% of the time, where p is a percentage specified by the user and usually between 90% and 100%. The firm flow is calculated from the available flow duration curve and the data presented [7]. Lowest mean annual flow used for the system design is **0.352 m<sup>3</sup>/s** as it is shown in the summary of data presented.

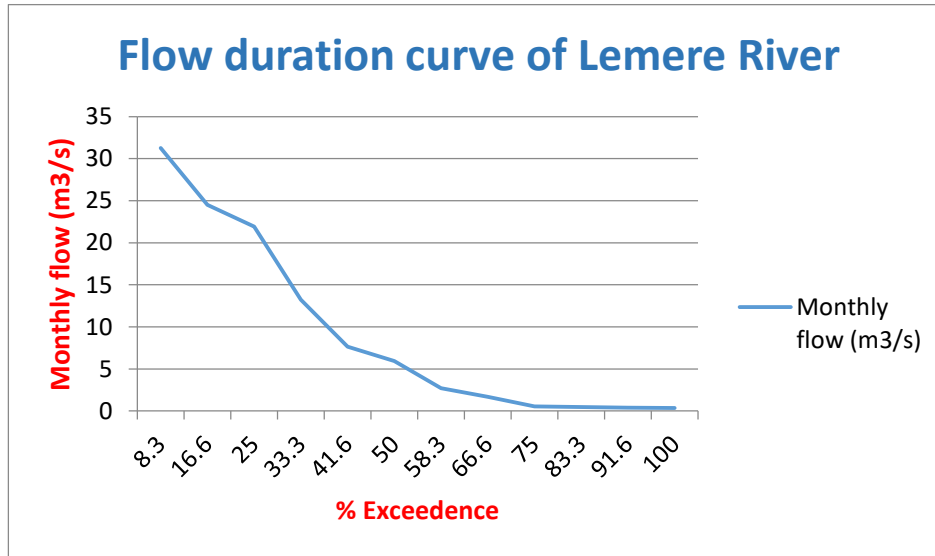


Figure 3.4: Flow duration curve of Lemere River at Buchamie fall.

### 3.4.3 Determination of Head (Elevation)

Head is the vertical distance that water falls from the forebay or intake to the turbine. It is measured in meters. The Gross Head ( $H_g$ ) is the maximum available vertical fall in the water, from the upstream level to the downstream level. The actual head seen by a turbine will be slightly less than the gross head due to losses incurred when transferring the water into and away from the machine. This reduced head is known as the Net Head [3].

The hydro system head measurements need to be made very accurately since these head measurements play an important role in determination of other hydroelectric system parameters as well. Such as; turbine selection, system efficiency and fluid dynamic issues, hydrodynamics of turbine blade design, penstock material and strength, valve types. All impacted directly by the head measurement. All of these in turn impact the engineering and financial side of the hydro system design.

Before measuring the water head, it is necessary to make sure to determine forebay, penstock position and power plant location first, as a basis of the plant design. In this thesis document preparation, to determine water head the spirit level and plank method is used among different hydraulic head measurement technique considering the specific site layout and ease of operation. The spirit level and plank method is a step-by step procedure to determine gross head tail water

level and upper water level (at waterfall/ forebay). It is also validated the gross head obtained from this measurement method by hand held Geographic Positioning System (GPS) device, from the measurements taken the gross head of Lemere river at Buchame fall is found to be 22 m.

#### 3.4.4 Calculation of Power Potential at Lemere River

The Power exploited ( $P_t$ ) from hydropower at a particular site is as given in the following equation below:

$$P_t = \eta Q h g \rho, \quad (1)$$

Where  $Q$  is the water flow rate (l/s or  $m^3/s$ ),  $H$  is the net head available at the inlet to the turbine (m),  $g$  is the gravitational constant ( $9.81 \text{ m/s}^2$ ),  $\rho$  is the density of water ( $1000 \text{ kg/m}^3$ ) and  $\eta$  is the overall energy conversion efficiency (hydraulic to shaft power).

The actual power that a micro hydropower plant produces can be calculated in the same way as the power output, but one must take into account some energy losses in the turbine, penstock and generator. Normally, a small hydro turbine has an efficiency of 70% but some good turbines can have an efficiency of 80% or even better [14].

The net head,  $H$  is equal to the difference between the gross head,  $H_g$  (the vertical distance between water surface level at the intake and at the turbine) and  $H_{tl}$ , total head losses due to the open channel, trash rack, intake and penstock. These losses were approximately equal to 10 % of gross head.

Therefore, the net head of Lemere River at Buchamie fall to be calculated as follow: i.e.  $H_g = 22$

$$H = H_g - H_{tl}$$

$$H = 22 - 22 \times 0.1$$

$$H = 20\text{m}$$

It is assumed that the overall efficiency of the system is taken as **70 %** it includes the efficiency of turbine, generator, and drive systems.

Using equation (1) and substituting the above net head and design flow values the power output,  $P_t$  of Lemere MHP system can be obtained, i.e.  $H = 20\text{m}$ ,  $Q = 0.352 \text{ m}^3/\text{s}$ .

$$P_t = 0.7 \times 0.352 \times 20 \times 9.8 \times 1000$$

$$P_t = 48 \text{ kW}$$

## CHAPTER FOUR

### Selection and design of MHP System Component

Based on primary and secondary data source and design parameters that discussed in chapter three, this chapter presents the selection and design of suitable type of MHP system components in order to make the MHP development more supportive for better investigation and productive for the proposed Lemere MHP scheme.

#### 4.1 Electromechanical Components Selection

Electromechanical components selection of equipment such as generator, turbines and control systems will be explained in this section.

##### 4.1.1 Generator Selection

The selected Lemere MHP site has the following data:

H=20m (net head), Q=0.352m<sup>3</sup>/s, g=9.8m/s<sup>2</sup>, η=70%, Power factor (pf) =80%

The proposed generator for this design is a four pole induction generator. This generator is always generating rated power when using an ELC. Since the ambient temperature of 25 degree Celsius the Temperature factor (A), Altitude factor (B), ELC Correction Factor(C) and Power Factor (D) values are 1.03, 0.945, 0.83 and 0.8 used respectively.

The output of generator is shown with *kVA* and calculated as follows:

$$P_g(\text{kVA}) = \left( \frac{1.3 \times g \times H \times Q \times \eta}{A \times B \times C \times \text{pf}(D)} \right) = \left( \frac{1.3 \times 9.8 \times 20 \times 0.352 \times 0.7}{1.03 \times 0.945 \times 0.83 \times 0.8} \right) = \mathbf{97\text{kVA}}$$

For induction generator the speed is a little higher than that of synchronous generator for excitation with slip.

$$\text{Given that, } S = -0.02, f = 50 \text{ Hz, } p = 4, N_o = \frac{120f}{p} = \frac{120 \times 50}{4} = 1500\text{rpm}$$

The rated rotational speed is specified as shown in following calculation:

$$N = (1 - s) \times N_o (\text{rpm}) = (1 - (-0.02)) \times 1500 = \mathbf{1530\text{rpm}}$$

Therefore, from induction generator manufacturers catalogue in the market, it is possible to order the required type of generator for Lemere micro hydropower plant, based on the rated output of generator (97kVA) with allowance and rated rotational speed of the generator (1530rpm).

#### 4.1.2 Turbine selection

Since, the gross head of Lemere MHP is 22m and the design discharge is  $Q=0.352\text{m}^3/\text{s}$ , and the estimated power out of scheme is 48kw, based on the discussion and Turbine selection chart in the literature section, the appropriate turbine for this proposed MHP system is **Kaplan turbine**.

#### 4.1.3 Turbine Generator alignment

The turbine-generator lay out can be either a horizontal or vertical shaft layout. In a horizontal shaft lay out, the turbine and the generator are at the same elevation connected by a horizontal shaft. On the other hand in vertical lay out the generator is on the top of the turbine, both connected by a vertical shaft. For this thesis work the horizontal arrangement is preferred due to more compactness and needs less floor area for the power house and design of hydraulic passages[34].

#### 4.1.4 Electronic load controllers (ELC)

ELC are equipment used as electrical brakes to regulate the rotational speed of the turbine by diverting power to connected dump loads. Dump loads, which are typically large resistive elements, are used to dissipate excessive electrical power. ELC may regulate, amplify, convert, and smooth the electrical signal from the generator, reducing the risk of damage to electrical appliances or personal injury. It allows constant power generation (no flow control) and maintains constant system frequency by dumping additional generated power to electric immersion heaters used as ballasts [36].

The choice of electronic load controller is largely dependent upon the type of generator installed in MHP. Therefore, the proposed generator for this design is a four pole induction generator so that when the induction generator is used in the MHP system it is necessary to install induction generator controllers

Sizing of ELC and associated Ballast for installed capacity < 100kW determined using the following analytical procedure [37];

$$\text{Size of ELC} = 0.6 \times \text{Installed Capacity in kW} = 0.6 \times 48\text{kW} = \mathbf{28.8 \text{ kW}}$$

$$\begin{aligned} \text{Size of Main Ballast} &= 1.2 \times 0.6 \times \text{Installed Capacity in kW} = 1.2 \times 0.6 \times 48\text{kW} \\ &= \mathbf{34.56 \text{ kW}} \end{aligned}$$

$$\text{Size of Extension} = 0.4 \times \text{Installed Capacity in kW} = 0.4 \times 48\text{kW} = \mathbf{19.2 \text{ kW}}$$

#### 4.1.5 Transmission and Distribution line design

This section demonstrates the sizing of transmission and distribution lines for specific case area Lemere Micro hydro power scheme.

**Sizing of Transmission Line Conductor:** As it is calculated previously, rated output of generator is (**97kVA**) but currently available generator rating is 110 KVA from the manufacture's catalogue [38]. Therefore, a generator rating of 110kVA selected for the following calculation:-

The output current supplied by the generator is calculated as:

$$I_{3\phi, \text{line}} = \frac{s_{\text{nom}}}{V_{3\phi, \text{line}}} = \frac{110\text{kVA}}{\sqrt{3} \times 415\text{V}} = \mathbf{153\text{A}}$$

The generator maximum continuous output current is calculated as;

$$I_{\text{conductor}} = 1.25 \times I_{3\phi, \text{line}} = 1.25 \times 153\text{A} = \mathbf{191.25\text{A}}$$

Therefore; the minimum capacity of the conductor selected must be greater than or equal to **191.25A**.

**Span Length and Number of pole determination:** Due to cost and availability consideration, LT (Low Tension) poles are entirely made out of hard wood is selected for this specific design and also low voltage lines without transformers is applied because this system is more easily understand and maintained by the local user.

Since, the distance between Buchamie fall to Geseda village is 1500 m, with a span of 20 m, number of wooden poles are required is calculated as follows.

$$\text{Number of poles} = \frac{1500\text{m}}{20\text{m}} = 75 \text{ poles}$$

## 4.2 Civil work design

The share of the civil work to the total cost of a MHP system is not less than 30%, so that proper design of the civil work is vital. Therefore, the design of the civil work components should be done carefully and most of the time it accounts more than 60% of the overall design of a MHP system [9]. The preliminary design of the civil work components depending on the available head and flow rate at the site considered are presented below [26].

### 4.2.1 Sizing of intake weir Orifice

For the design purpose the velocity of water to pass through the orifice is taken as,  $V = 1.3 \text{ m/s}$ . This value was so taken because for Micro Hydropower System the recommended velocity through the orifice during normal flow is (1.0 - 1.5 m/s). Based on this, the required area of the orifice is calculated as:

$$A = \frac{Q}{V} = \frac{0.352}{1.3} = 0.27 \text{ m}^2$$

It has also been determined from survey that normal water level in the river,  $h_r = 0.8 \text{ m}$  and assuming water level at headrace canal,  $h_h = 0.5 \text{ m}$  with respect to the river bed level (i.e. 100 mm above the upper edge of orifice to ensure submerged condition).

Now, letting  $C = 0.6$  (This value was taken because the orifice is planned to be of the roughly finished masonry type, whose value is normally taken to be 0.6).

It is also known from the previous literature discussion, design parameters for side intake that; the discharge through an orifice is calculated as:

$$Q = A \times V = A \times C\sqrt{2 \times g(h_f - h_h)}$$

$$Q = 0.27 \times 0.6\sqrt{2 \times 9.8(0.8 - 0.5)}$$

$$Q = 0.393 \text{ m}^3/\text{s} = \mathbf{393 \text{ l/s}}$$

$$Q_{\text{required}} = 0.352 \frac{\text{m}^3}{\text{s}} = 352 \text{ l/s},$$

Therefore, the above result indicate that orifice size is OK because the calculations of side intake can deliver 393l/s, the design is considered acceptable during the normal seasons [4,5,6].

During the flood season, the discharge through the orifice during flood flow can be calculated as follows:

Design flood level is about 0.6 m above the normal water level. Therefore it can be calculated that the design flood level,

$h_f = 0.6 \text{ m} + 0.8 \text{ m} = \mathbf{1.4m}$  (This is necessary in order limit the excess of flows during the flood season, especially summer time.)

$$Q_{\text{flood}} = A \times V = A \times C\sqrt{2 \times g(h_f - h_h)}$$

$$Q_{\text{flood}} = 0.27 \times 0.6\sqrt{2 \times 9.8(1.4 - 0.5)}$$

$$Q_{\text{flood}} = 0.680 \text{ m}^3/\text{s} = \mathbf{680 \text{ l/s}}$$

Therefore, this value will be important at the later stage when designing the spillway since the orifice is only designed to take 352 l/s, the excess flood flow can be discharged via a spillway at the gravel trap.

#### 4.2.2 Design of Headrace Canal

For Lemere MHP scheme, the selected headrace canal type is stone masonry in cement mortar depending on the conditions of the site. It is continuous and rectangular in shape.

The choice of this material was made because it is recommended that this type of material be used where the type of the soil is porous such as in the case of Lemere MHP construction site. Choosing other materials such as earthen or stone mud canal had the risk of leading to water seepage through the canal surface that could have caused landslides in the surrounding area[26].

The roughness coefficient and the side slope of the canal can be easily determined as: roughness coefficient of normal masonry with cement mortar ( $n=0.017$ ).

With this information, it is now possible to calculate the Cross sectional area of the headrace canal as,

$$A = \frac{Q}{V} = \frac{0.352}{1} = 0.352\text{m}^2$$

(Since the maximum recommended velocity for stone masonry with cement mortar is 1.5 m/s, the velocity is arbitrarily taken to be 1 m/s)

Now the next objective is to calculate the optimum height of the canal (H), width of the canal bed (W) and the width of the canal top (T) by using equation's stated in previous literature discussion Headrace Canal Design Parameters.

In case of a rectangular canal,  $N_s = 0$  and  $X = 2$

With this information it is possible to calculate the water depth in the canal (H) as follows:

$$H = \sqrt{\frac{A}{(X + N)}} = \sqrt{\frac{A}{2}} = \sqrt{\frac{0.352\text{m}^2}{2}} = 0.42\text{m}$$

With this information it is possible to calculate the bed width of the headrace canal (B) as follows:

$$B = X \times H = 2 \times 0.42\text{m} = 0.84\text{m}$$

The optimum width of the top of the canal (T) is determined as follows:

$$T = B + (2 \times H \times N_s) = 0.84\text{m}$$

It is known from the discussion of design condition that it is necessary to check if ;  
 $V < 0.8 V_c$

because in order to ensure that the water flows in a stable and uniform flow in the headrace canal the velocity of water must be 80% less than the critical velocity where critical velocity ( $V_c$ ) is,

$$V_c = \sqrt{\frac{(A \times g)}{T}} = \sqrt{\frac{(0.352 \times 9.8)}{0.84}} = 2.03 \text{ m/s}$$

$$0.8 V_c = 0.8 \times 2.03 = 1.624 \text{ m/s}$$

Therefore the velocity of the water (1 m/s) in the headrace canal is less than 80% the critical velocity ( $1.624 \text{ m/s}$ ). Therefore it can be considered that the design of this headrace canal is acceptable.

After determining that the design is acceptable, and calculating the internal canal dimensions now it is necessary to calculate the wetted perimeter of the headrace canal which is given by:

$$P = B + 2 \times H \times \sqrt{1 + N_s^2}$$

Where in special case of the rectangular canal,

$$P = B + 2 \times H = 0.84 + 2 \times 0.42 = 1.68\text{m}$$

This is followed by the calculation of the hydraulic radius (R) by;

$$R = \frac{A}{P} = \frac{0.352}{1.68} = 0.21\text{m}$$

Now the final dimension “bed slope” “S” needs to be calculated in order to design the head race canal and this is given by the Manning’s equation as follows.

$$S = \left( \frac{nV}{R^{2/3}} \right)^2 = \left( \frac{0.017 \times 1}{0.21^{2/3}} \right)^2 = 0.0023 = (1:435), \text{ (This slope value indicates that in a 1 m of drop in 435 m of horizontal canal length)}$$

Note that, in order to allow for the uncertainties in the design of the headrace canal it is necessary to allow for a “free board” of 300 mm if the water flow is less than 500 l/s and 400 mm of freeboard for water flow is in between 500 - 1000 l/s. Therefore, a freeboard of 300mm is selected for this study because the design flow, Q is 352 l/s which is less than 500l/s.

Now it is necessary to check for the size of the largest particle that can travel through the canal. This is necessary because beyond a certain size of particle, it is not desirable that they would pass through the canal, the maximum particle size in diameter that can be transported in the head race canal can be calculated by:

$$d = 11 \times R \times S = 11 \times 0.21 \times 0.0023 = 0.0053\text{m} = 5.3\text{mm}$$

i.e. Particles larger than **5.3mm** would settle in this headrace canal. Therefore, to avoid deposition upstream of the settling basin, the gravel trap must be designed to remove all particles greater than **5.3mm**. Figure 4.1 illustrates the design of the headrace canal in AutoCAD by putting in the above calculated dimensions.

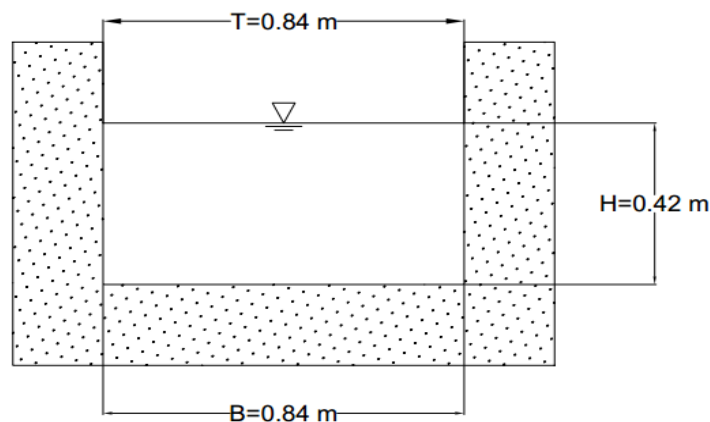


Figure 4.1: Representation of the headrace canal (AutoCAD)

#### 4.2.3 Design of overflow spillway

It was already pointed out in previous literature discussion overflow spillway Design Parameters that; the design of the spillway can be made with calculations of its different dimensions.

In designing the spillway, the following conditions need to be checked as follows: case 1: The spillway should be able to spill the excess flow (  $680 \text{ l/s} - 352 \text{ l/s}$  ) when there is no obstruction downstream and case 2: The spillway must be able to convey the entire flood flow of  $680 \text{ l/s}$  in case the headrace canal downstream gets obstructed (ponding case).

Note that the calculated maximum spillway length should be used in the design.

Case 1: To calculate the length of the spillway considering the actual flow of water that enters through the orifice and the head race canal (consider the excess flow i.e. the difference between flood flow and design flow). From known values the spillway length required for the design flow  $0.352 \text{ m}^3/\text{s}$  is calculated as follow,

$C_W = 1.6$  (a broad crested weir with round edges Weir coefficient)

$$Q_{\text{design}} = 0.352 \text{ m}^3/\text{s}$$

$Q_{\text{flood}} = 0.680 \text{ m}^3/\text{s}$ , (this was determined when the orifice for side intake was calculated)

$$h_{\text{overtop}} = h_{\text{flood}} - h_{\text{sp}} = 100\text{mm} \text{ (By convention)}$$

In this case the length of the spillway would be,

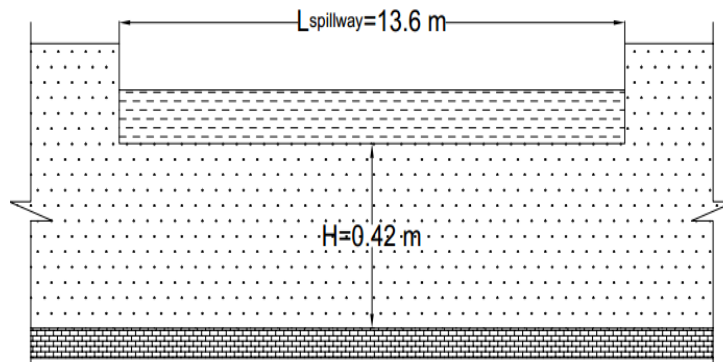
$$L_{\text{spillway}} = \left( \frac{Q_{\text{flood}} - Q_{\text{design}}}{C_W (h_{\text{flood}} - h_{\text{sp}})^{1.5}} \right) = \left( \frac{0.680 - 0.352}{1.6(0.1)^{1.5}} \right) = 6.56\text{m}$$

Case 2: consider what would be the length required if the design flow is  $0 \text{ m}^3/\text{s}$  (only the flow via the intake during flood)

In this case the length of the spillway would be,

$$L_{\text{spillway}} = \left( \frac{Q_{\text{flood}}}{C_w (h_{\text{flood}} - h_{\text{sp}})^{1.5}} \right) = \left( \frac{0.680}{1.6(0.1)^{1.5}} \right) = 13.6\text{m}$$

Note that; the calculated maximum spillway length should be used in the design in order to satisfy both of the above conditions. It is desirable that the spillway of length **13.6m** be constructed.



**Figure 4.2: Representation of the designed spillway (AutoCAD)**

#### 4.2.4 Design of the settling basin

Referring previous literature discussion about parameters for Construction of Settling Basin, the design of settling basin is conducted as follows:

As it is known for the design of settling basin, the first step is to choose arbitrarily suitable width of the settling basin.

It should be two to five times the width of the headrace canal; we know that the width of the headrace canal from previous calculations is **B = 0.84m**

The width of the settling basin (**W**) was chosen as **1.68 m** which is two times the width of the headrace canal (**B**) and is therefore allowed, so we have;

$$W = 1.68 \text{ m}$$

$$Q_{\text{design}} = 0.352 \text{ m}^3/\text{s}$$

$V_{\text{vertical}}$  = Fall velocity (For the settling particles of 0.3 mm diameter the fall velocity is taken as 0.03 m/s)

It is known that in order to calculate the settling length ( $L_{\text{settling}}$ ) of the settling basin the following equation is used,

$$L_{\text{settling}} = \frac{2 \times Q}{W \times V_{\text{vertical}}} = \frac{2 \times 0.352}{1.68 \times 0.03} = \mathbf{13.97\text{m}}$$

As the design parameter showed, the length of the settling basin should be four to 10 times of its width to check this here;

$L_{\text{settling}} / W = 13.97 / 1.68 = 8.3$ ; Which is approximated to eight times of the width. Hence, the design is acceptable. The required basin surface area ( $A$ ) is calculated using the following equation:

$$A = \frac{2 \times Q}{V_{\text{vertical}}} = \frac{2 \times 0.352}{0.03} = \mathbf{23.467\text{m}^2}$$

From this also the  $L_{\text{settling}}$  can be determined by:

$$L_{\text{settling}} = \frac{A}{W} = \frac{23.467}{1.68} = \mathbf{13.97\text{m}}$$

The next step is to calculate the,  $S_{\text{load}}$  of the settling basin, according to the recommended design parameters,  $T$  = silt emptying frequency in seconds = 12 hours = 12 x 60 x 60 = 43,200 seconds and  $C$  or the silt concentration of the incoming flow was given as  $0.5 \text{ kg/m}^3$ , therefore expected silt load is given by;

$$S_{\text{load}} = Q \times T \times C = 0.352 \times 43,200 \times 0.5 = \mathbf{7603 \text{ kg}}$$

Now, it is necessary to calculate the volume of the silt load, which is given by;

$S_{density}$  =Density of silt and it has been recommended that in absence of reliable data, the safe parameter is  $2600\text{kg/m}^3$ , which will be used in this case also;

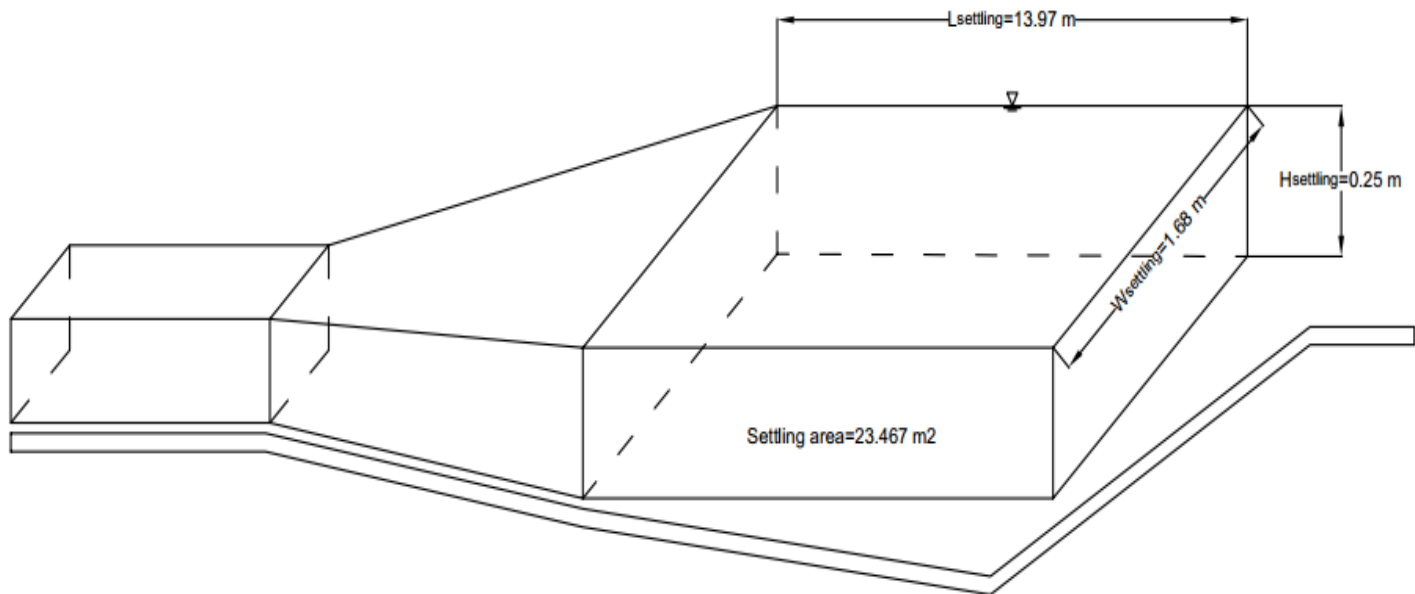
$P_{factor}$  = packing factor of sediments submerged in water = **0.5(50%)** as given. Therefore, the volume of the silt load now is given as,

$$VO_{silt} = \frac{S_{load}}{|S_{density} \times P_{factor}|} = \frac{7603}{|2600 \times 0.5|} = 5.85\text{m}^3$$

After calculating the volume of the silt, it is then necessary to calculate the average depth required for the settling basin ( $D_{collection}$ ) which can be given by;

$$D_{collection} = \frac{VO_{silt}}{(L_{settling} \times W)} = \frac{5.85}{(13.97 \times 1.68)} = \mathbf{0.25\text{m}}$$

Based on these dimensions, longitudinal view of the settling basin is designed in AutoCAD software as represented in below.



**Figure 4.3: Settling basin (AutoCAD)**

#### 4.2.5 Design of penstock pipe

The selected penstock material is mild steel for the Lemere MHP scheme. Since the nature of topography does not permit burying the penstock pipe, support piers are needed to withstand the weight of the pipes. After selecting the material for the penstock pipe, which was chosen as mild steel, it is necessary to determine its diameter.

From design parameters which was mentioned earlier in the literature review it was recommended that velocity of water  $V$  be somewhere between **2.5 m/s to 3.5 m/s**.

Set,  $V = 3.0 \text{ m/s}$

$Q = 0.352 \text{ m}^3/\text{s}$ , Design flow.

Therefore, diameter of the pipe is calculated to be:-

$$d_{\text{pipe}} = \sqrt{\left(\frac{4 \times Q}{\pi \times V}\right)} = \sqrt{\left(\frac{4 \times 0.352}{\pi \times 3.0}\right)} = 0.386\text{m} = \mathbf{386\text{mm}}$$

After selecting the material and the diameter of the penstock pipe it is necessary to calculate the head loss in the pipe length which is given as;

From the table of roughness in Appendix B value for different pipe materials,  $k$  is taken as 0.06 mm for uncoated mild steel.

To find the corresponding friction factor,  $f$  from Moody Chart situated in Appendix C calculate ratios for the designed penstock pipe using the calculated penstock diameter and design flow as follows.

The ratio  $k/d = 0.06/386 = 0.00016$

$1.2Q/d = (1.2 \times 0.352)/0.386 = 1.09 \text{ m}$

Where,

The corresponding friction factor,  $f$  from Moody Chart is taken as  $f = 0.015$

The estimated length of the penstock pipe is **28m** for Lemere Micro- hydropower scheme.

Average velocity inside pipe is chosen as 3 m/s

$$d_{\text{pipe}} = 0.386\text{m} = \mathbf{386\text{mm}}$$

$$h_f = \frac{f \times L \times V^2}{2 \times g \times d_{\text{pipe}}} = \frac{0.015 \times 28 \times 3^2}{2 \times 9.8 \times 0.386} = \mathbf{0.5\text{m}}$$

The next step is to calculate the thickness of the pipe which is depends on the pipe diameter and the material type for that first calculate the pressure wave velocity:

Given that,

$E = 2.0 \times 10^5 \text{ N/mm}^2$  The value of Young's Modulus for mild steel

$$d_{\text{pipe}} = 386\text{mm}$$

$T = 6\text{mm}$  (Nominal wall thickness)

$$a = \frac{1440}{\sqrt{\left(1 + \frac{2150 \times d}{E \times T}\right)}} = a = \frac{1440}{\sqrt{\left(1 + \frac{2150 \times 386}{2.0 \times 10^5 \times 6}\right)}} = \mathbf{1107.69 \text{ m/s}}$$

Now calculate the critical time which is given as,

$L = 28\text{m}$  Length of the penstock pipe

$a = 1107.69 \text{ m/s}$  Pressure wave velocity

$$T_c = \frac{(2 \times L)}{a} = \frac{(2 \times 28)}{1107.69} = \mathbf{0.05 \text{ sec}}$$

Optimum thickness of the penstock pipe can be determined as:

Divide the nominal wall thickness by 1.1 to allow for welding defects.

Divide the nominal wall thickness by 1.2 to allow for rolling inaccuracy of the flat sheets.

Therefore,

$$T_{\text{effective}} = \frac{6}{(1.1 \times 1.2)} = \mathbf{4.5 \text{ mm}}$$

#### 4.2.6 Design of forebay tank

From the above literature discussion above about forebay tank design parameters, here in this section the required variables are calculated as follows:-

The submergence head or the depth of water above penstock pipe should fulfil the criteria.

$$H_s \geq 1.5 \times V^2 / (2 \times g)$$

Where,

$V$  = The velocity of water in the penstock, which in this case is 3m/s;

$g = 9.8 \text{ m}^2/\text{s}$  Acceleration due to gravity

$$H_s \geq 1.5 \times 3^2 / (2 \times 9.8)$$

$$H_s \geq 0.69\text{m}$$

In other words, the submergence head of the forebay tank should be **0.69m**.

The diameter of the air vent or  $d_{\text{airvent}}$  which is calculated as,

$$d_{\text{airvent}}^2 = Q \times \left[ \frac{F}{E} \left( \frac{D}{t_{\text{effective}}} \right)^3 \right]$$

$$Q_{\text{design}} = 0.352 \text{ m}^3/\text{s} = 352 \text{ l/s}$$

$E = 2 \times 10^5 \text{ N/mm}^2$  (This value is the Young's modulus for the steel penstock material)

$D = 386\text{mm}$  Is the diameter of the penstock

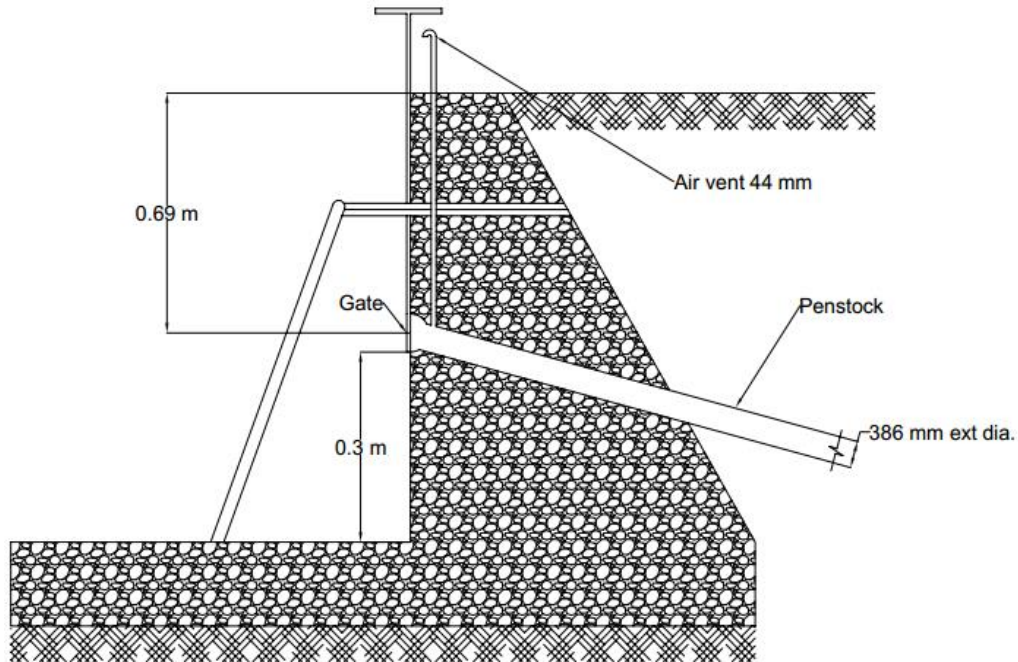
$t_{\text{effective}} = 4.5 \text{ mm}$  Is effective penstock wall thickness at upper end (mm)

$F$  = Safety factor (which is generally considered to be 5 for buried penstock pipe and 10 for the exposed pipe) In this case, it has been chosen as 10 because this design consists of exposed penstock pipes. Therefore,

$$d_{\text{airvent}}^2 = Q \times \sqrt{\left[ \frac{F}{E} \left( \frac{D}{t_{\text{effective}}} \right)^3 \right]}$$

$$d_{\text{airvent}}^2 = 352 \times \sqrt{\left[ \frac{10}{2 \times 10^5} \left( \frac{386}{4.5} \right)^3 \right]} = 1984.98\text{mm}^2$$

$$d_{\text{airvent}} = 44\text{mm}$$



**Figure 4.5: Design of the forebay tank with air vent shown (AutoCAD)**

The volume of forebay is obtained on the above basis whereas the area is calculated from empirical relations below [4]:

$$\text{Area of forebay, } AFB = \frac{70(\log(H)) [10^{0.51 \log(Q)}]}{}$$

$$\text{Length of forebay, } LFB = 1.6\sqrt{AFB}$$

$$\text{Width of forebay, } WFB = 0.625\sqrt{AFB}$$

$$\text{Depth of forebay, } DFB = \frac{180Q}{AFB}$$

Accordingly, substituting head and flow rate of the site, the area, length, width, and depth of forebay tank are 56m<sup>2</sup>, 12m, 4.7m and 1.2m respectively.

## CHAPTER FIVE

### **RET Screen Analysis; Result and Discussion**

The objective of this chapter is to investigate the viability analysis of a micro hydro power project in the selected site using RET screen.

Seven worksheets (Energy Model, Hydrology Analysis and Load Calculation (Hydrology & Load), Equipment Data, Cost Analysis, Greenhouse Gas Emission Reduction Analysis (GHG Analysis), Financial Summary and Sensitivity and Risk Analysis (Sensitivity)) are provided in the Small Hydro Project Workbook file (RET screen). The Energy Model, Hydrology & Load and Equipment Data worksheets are completed first. The Cost Analysis worksheet should then be completed followed by the Financial Summary worksheet and followed by the GHG Analysis and Sensitivity worksheets.

## 5.1 Site Information

Based on the geographical location of the site, metrological data is presented as follows:

**Table 5.1: Metrological data of the site**

| Site reference conditions   |                 |                      |                       |                                    |                      |            |                           |                           |                           |
|-----------------------------|-----------------|----------------------|-----------------------|------------------------------------|----------------------|------------|---------------------------|---------------------------|---------------------------|
| Climate data location       |                 | Ethiopia - Hossa'ina |                       |                                    | Facility location    |            | Ethiopia - Oromia - Silti |                           |                           |
|                             |                 | Unit                 | Climate data location |                                    | Facility location    |            | Source                    |                           |                           |
| Latitude                    |                 |                      | 7.6                   |                                    | 8.0                  |            |                           |                           |                           |
| Longitude                   |                 |                      | 37.9                  |                                    | 38.3                 |            |                           |                           |                           |
| Climate zone                |                 |                      | 3A - Warm - Humid     |                                    |                      |            | User-defined              |                           |                           |
| Elevation                   |                 | m                    | 1926                  |                                    | 2259                 |            | NASA - NASA               |                           |                           |
| Heating design temperature  |                 | °C                   | 12.0                  |                                    |                      |            | NASA                      |                           |                           |
| Cooling design temperature  |                 | °C                   | 27.1                  |                                    |                      |            | NASA                      |                           |                           |
| Earth temperature amplitude |                 | °C                   | 15.5                  |                                    |                      |            | NASA                      |                           |                           |
| Month                       | Air temperature | Relative humidity    | Precipitation         | Daily solar radiation - horizontal | Atmospheric pressure | Wind speed | Earth temperature         | Heating degree-days 18 °C | Cooling degree-days 10 °C |
|                             | °C              | %                    | mm                    | kWh/m <sup>2</sup> /d              | kPa                  | m/s        | °C                        | °C-d                      | °C-d                      |
| January                     | 20.8            | 36.9%                | 32.45                 | 5.86                               | 81.7                 | 3.6        | 24.6                      | 0                         | 334                       |
| February                    | 21.9            | 34.8%                | 27.85                 | 6.27                               | 81.6                 | 3.2        | 26.1                      | 0                         | 333                       |
| March                       | 22.3            | 42.2%                | 86.66                 | 6.26                               | 81.6                 | 3.0        | 26.6                      | 0                         | 381                       |
| April                       | 20.7            | 59.6%                | 126.20                | 6.01                               | 81.6                 | 3.1        | 23.7                      | 0                         | 320                       |
| May                         | 18.7            | 73.8%                | 159.46                | 5.81                               | 81.7                 | 2.9        | 20.4                      | 0                         | 268                       |
| June                        | 17.7            | 75.1%                | 136.16                | 5.24                               | 81.8                 | 2.8        | 19.0                      | 9                         | 231                       |
| July                        | 16.8            | 75.6%                | 143.69                | 4.61                               | 81.8                 | 2.3        | 17.9                      | 36                        | 212                       |
| August                      | 16.9            | 75.8%                | 135.98                | 4.86                               | 81.8                 | 2.1        | 17.9                      | 34                        | 215                       |
| September                   | 17.4            | 73.6%                | 146.25                | 5.55                               | 81.8                 | 2.3        | 18.5                      | 18                        | 222                       |
| October                     | 17.6            | 67.4%                | 113.97                | 5.93                               | 81.7                 | 2.9        | 18.7                      | 11                        | 237                       |
| November                    | 18.5            | 50.4%                | 47.27                 | 6.09                               | 81.7                 | 3.3        | 20.3                      | 0                         | 255                       |
| December                    | 19.6            | 41.3%                | 27.08                 | 5.97                               | 81.7                 | 3.5        | 22.4                      | 0                         | 299                       |
| <b>Annual</b>               | <b>19.1</b>     | <b>59.0%</b>         | <b>1,183.02</b>       | <b>5.70</b>                        | <b>81.7</b>          | <b>2.9</b> | <b>21.3</b>               | <b>108</b>                | <b>3,305</b>              |
| <b>Source</b>               | NASA            | NASA                 | NASA                  | NASA                               | NASA                 | NASA       | NASA                      | NASA                      | NASA                      |
| Measured at                 |                 |                      |                       |                                    | m                    | 10         | 0                         |                           |                           |

## 5.2 RETScreen Energy Model Worksheet

In RET Screen, hydrological data are specified as a flow-duration curve, which is assumed to represent the flow conditions in the river being studied over the course of an average year.

Basic assumptions related to hydrology analysis are:

*Maximum tail water effect;* at most sites, during high flows, the tail water level rises more than the level upstream of the intake and causes a reduction in the gross head. Consequently, during these periods, less power and energy are available. The tail water effect can be significant, especially for low-head sites. However, for this analysis 5-meter tail water effect is taken since the gross head is 22m which is consider being medium head.

*Hydraulic losses;* in a hydro plant, energy is lost as water flows through the water passages. For this analysis due to its long flows a value of 2% is appropriate to be taken. For generator 70% efficiency is taken and availability is taken as 100% due to requirement of increased maintenance. The screen capture of the analysis and results are shown in Table 5.2 and 5.3 below.

Table 5.2: Hydrology Analysis and Load Calculation

**Hydro turbine**

Description:

Note:

**Level**

---

**Hydro turbine - Level 2**

| Resource assessment              |                   |              |
|----------------------------------|-------------------|--------------|
| Proposed project                 |                   | Run-of-river |
| Hydrology method                 |                   | User-defined |
| Gross head                       | m                 | 22           |
| Maximum tailwater effect         | m                 | 5            |
| Residual flow                    | m <sup>3</sup> /s | 0.01         |
| Percent time firm flow available | %                 | 95%          |
| Firm flow                        | m <sup>3</sup> /s | 0            |

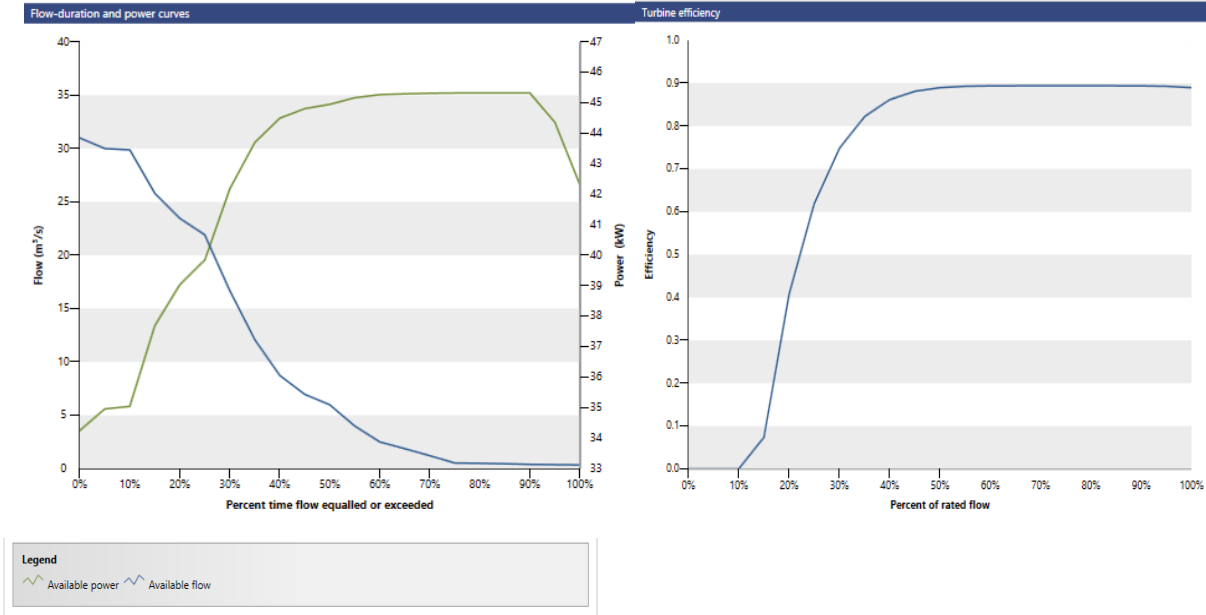
| Hydro turbine                     |                   |                           |
|-----------------------------------|-------------------|---------------------------|
| Design flow                       | m <sup>3</sup> /s | 0.37                      |
| Type                              |                   | Kaplan                    |
| Turbine efficiency                |                   | Standard                  |
| Number of turbines                |                   | 1                         |
| Manufacturer                      |                   | Canadian Hydro Components |
| Model                             |                   | Kaplan                    |
| Design coefficient                |                   | 4.15                      |
| Efficiency adjustment             | %                 | -2%                       |
| Turbine peak efficiency           | %                 | 89.4%                     |
| Flow at peak efficiency           | m <sup>3</sup> /s | 0.28                      |
| Turbine efficiency at design flow | %                 | 87%                       |

| <b>Losses</b>                    |            |                                       |         |
|----------------------------------|------------|---------------------------------------|---------|
| Maximum hydraulic losses         | %          |                                       | 7%      |
| Miscellaneous losses             | %          |                                       | 2%      |
| Generator efficiency             | %          |                                       | 70%     |
| Availability                     | %          |                                       | 100%    |
| <b>Summary</b>                   |            |                                       |         |
| Power capacity                   | kW         |                                       | 44.3    |
| Available flow adjustment factor |            |                                       | 1       |
| Capacity factor                  | %          |                                       | 96.2%   |
| Initial costs                    | \$/kW      |                                       | 5,200   |
|                                  | \$         |                                       | 230,389 |
| O&M costs (savings)              | \$/kW-year |                                       |         |
|                                  | \$         |                                       |         |
| Electricity export rate          |            | Electricity exported to grid - annual |         |
|                                  | \$/kWh     |                                       | 0.23    |
| Electricity exported to grid     | MWh        |                                       | 373     |
| Electricity export revenue       | \$         |                                       | 85,834  |

**Flow-duration and turbine efficiency curve data**

| %    | Flow<br>m <sup>3</sup> /s | Turbine<br>efficiency | Number of<br>turbines | Combined<br>efficiency |
|------|---------------------------|-----------------------|-----------------------|------------------------|
| 0%   | 31.00                     | 0.00                  | 0                     | 0.00                   |
| 5%   | 30.00                     | 0.00                  | 1                     | 0.00                   |
| 10%  | 29.88                     | 0.00                  | 1                     | 0.00                   |
| 15%  | 25.81                     | 0.07                  | 1                     | 0.07                   |
| 20%  | 23.46                     | 0.41                  | 1                     | 0.41                   |
| 25%  | 21.91                     | 0.62                  | 1                     | 0.62                   |
| 30%  | 16.68                     | 0.75                  | 1                     | 0.75                   |
| 35%  | 12.09                     | 0.82                  | 1                     | 0.82                   |
| 40%  | 8.73                      | 0.86                  | 1                     | 0.86                   |
| 45%  | 6.96                      | 0.88                  | 1                     | 0.88                   |
| 50%  | 5.98                      | 0.89                  | 1                     | 0.89                   |
| 55%  | 3.99                      | 0.89                  | 1                     | 0.89                   |
| 60%  | 2.50                      | 0.89                  | 1                     | 0.89                   |
| 65%  | 1.87                      | 0.89                  | 1                     | 0.89                   |
| 70%  | 1.21                      | 0.89                  | 1                     | 0.89                   |
| 75%  | 0.53                      | 0.89                  | 1                     | 0.89                   |
| 80%  | 0.50                      | 0.89                  | 1                     | 0.89                   |
| 85%  | 0.46                      | 0.89                  | 1                     | 0.89                   |
| 90%  | 0.40                      | 0.89                  | 1                     | 0.89                   |
| 95%  | 0.37                      | 0.89                  | 1                     | 0.89                   |
| 100% | 0.35                      | 0.89                  | 1                     | 0.89                   |

Based on the input data, the RETScreen also calculates the power capacity, capacity factor, electricity exported to grid and the revenue associated with electricity export.



**Figure 5.1: RETScreen generated flow, power and turbine efficiency curve**

Figure 5.1 above presents the flow, power and turbine efficiency duration curve generated by RET Screen. As depicted, the peak efficiency of the turbine around 89 % and this occurs in the range of 50% to 90% of the time.

### 5.3 RETScreen Financial Analysis

In this analysis, there are two levels of analysis: level 1 and level 2. In this study, level 2 analyses are selected.

The financial analysis worksheet contains financial parameters input items such as discount rate, debt ratio, etc. and a number of different economic and financial feasibility indicators, such as internal rate of return (IRR), return on investment (ROI), and net present value (NPV).

The necessary input data for financial analysis worksheet is given in table 5.3:

The total initial costs represent the total incremental investment that must be made to bring the proposed case facility on line, before it begins to generate savings and/or revenue. The total initial costs are the sum of the estimated feasibility study, development, engineering, power system, heating system and cooling system or energy efficiency measures and balance of system

& miscellaneous costs and are inputs in the calculation of the simple payback, the net present value and the project equity and debt.

It is important to note that the range of possible costs listed throughout the RETScreen user manual **do not include sales taxes**. In a number of jurisdictions, clean energy project costs are often exempt from sales taxes. Users will have to consider these costs for their region when preparing their evaluations. For example, if in a particular region sales tax is applicable to the cost of an energy project then the user must add the amount of sales tax to the cost of the project chosen from the proposed range of values.

Table 5.3: RET Screen financial input data

| RETScreen - Financial Analysis |       |         | Annual revenue   |                      |        |
|--------------------------------|-------|---------|--|----------------------|--------|
| <b>Financial parameters</b>    |       |         | <b>Electricity export revenue</b>                                    |                      |        |
| <b>General</b>                 |       |         | Electricity exported to grid   | MWh ▾                | 373    |
| Inflation rate                 | %     | 2.5%    | Electricity export rate  | \$/kWh ▾             | 0.23   |
| Discount rate                  | %     | 11%     | Electricity export revenue   | \$                   | 85,834 |
| Project life                   | yr    | 50      | Electricity export escalation rate                                   | %                    | 5%     |
| <b>Finance</b>                 |       |         | <b>GHG reduction revenue</b>   |                      |        |
| Incentives and grants          | \$    |         | Gross GHG reduction  | tCO <sub>2</sub> /yr | 176    |
| Debt ratio                     | %     | 70%     | Gross GHG reduction - 50 yrs   | tCO <sub>2</sub>     | 8,805  |
| Debt                           | \$    | 395,640 | GHG reduction revenue  | \$                   | 0      |
| Equity                         | \$    | 169,560 | <b>Other revenue (cost)</b> <input type="checkbox"/>                 |                      |        |
| Debt interest rate             | %     | 9%      | <b>Clean Energy (CE) production revenue</b> <input type="checkbox"/> |                      |        |
| Debt term                      | yr    | 15      |  |                      |        |
| Debt payments                  | \$/yr | 49,083  |  |                      |        |

Table 5.4: RETScreen financial Analysis Result

| Costs   Savings   Revenue |       |    | Initial costs (credits) |   |        | Amount         |   |    | Adjustment factor |         |    | Amount      |                                   |        | Relative costs |   |    |        |                |      |             |
|---------------------------|-------|----|-------------------------|---|--------|----------------|---|----|-------------------|---------|----|-------------|-----------------------------------|--------|----------------|---|----|--------|----------------|------|-------------|
| <b>Initial costs</b>      |       |    | Feasibility study       | \$                                      | 14,000 |                | 1 | \$ | 14,000            |         | 3% | Development | \$                                | 18,000 |                | 1 | \$ | 18,000 |                | 3.8% |             |
|                           | 2.5%  | \$ | 14,000                  | Engineering                             | \$     | 5,000          |   | 1  | \$                | 5,000   |    | 1.1%        | Power system                      | \$     | 222,000        |   | 1  | \$     | 222,000        |      | 16.6%       |
|                           | 3.2%  | \$ | 18,000                  | Balance of system & miscellaneous       | \$     | 306,200        |   | 1  | \$                | 306,200 |    | 24%         | Road construction                 | \$     | 113,000        |   | 1  | \$     | 113,000        |      | 6.2%        |
|                           | 0.88% | \$ | 5,000                   | <b>Total initial costs</b>              |        | <b>565,200</b> |   |    |                   |         |    | 0.42%       | Substation                        | \$     | 2,000          |   | 1  | \$     | 2,000          |      | 3.2%        |
|                           | 39.3% | \$ | 222,000                 | <b>Annual costs and debt payments</b>   |        |                |   |    |                   |         |    | 33.1%       | Balance of system & miscellaneous | \$     | 15,000         |   | 1  | \$     | 15,000         |      | 8.7%        |
|                           | 54.2% | \$ | 306,200                 | Debt payments - 15 yrs                  | \$     | 49,083         |   |    |                   |         |    | 8.7%        | Canal                             | \$     | 156,000        |   | 1  | \$     | 156,000        |      |             |
|                           |       |    |                         | <b>Total annual costs</b>               | \$     | <b>49,083</b>  |   |    |                   |         |    |             | Other                             | \$     | 41,000         |   | 1  | \$     | 41,000         |      |             |
|                           |       |    |                         | <b>Annual savings and revenue</b>       |        |                |   |    |                   |         |    |             | Subtotal:                         | \$     | 212,000        |   |    | \$     | 212,000        |      |             |
|                           |       |    |                         | Electricity export revenue              | \$     | 85,834         |   |    |                   |         |    |             | <b>Total initial costs</b>        | \$     | <b>471,000</b> |   |    | \$     | <b>471,000</b> |      | <b>100%</b> |
|                           |       |    |                         | <b>Total annual savings and revenue</b> | \$     | <b>85,834</b>  |   |    |                   |         |    |             |                                   |        |                |   |    |        |                |      |             |

Table 5.5: Financial results output of the project calculated by RET Screen

| Financial viability       |                     |         |
|---------------------------|---------------------|---------|
| Pre-tax IRR - equity      | %                   | 33.8%   |
| Pre-tax IRR - assets      | %                   | 15.6%   |
| Simple payback            | yr                  | 6.6     |
| Equity payback            | yr                  | 3.6     |
| Net Present Value (NPV)   | \$                  | 886,253 |
| Annual life cycle savings | \$/yr               | 98,019  |
| Benefit-Cost (B-C) ratio  |                     | 6.2     |
| Debt service coverage     |                     | 1.8     |
| GHG reduction cost        | \$/tCO <sub>2</sub> | -557    |
| Energy production cost    | \$/kWh              | 0.155   |

Table 5.4 and 5.5 present the financial analysis of RETScreen. The project annual cost found to be 49,083 USD. The total annual costs are calculated by the model and represent the yearly costs incurred to operate, maintain and finance the proposed case facility. It is the sum of the O&M costs (or savings), fuel cost for the proposed case and debt payments. Note that the total annual costs include the reimbursement of the "principal" portion of the debt which is not, strictly speaking, a cost but rather an outflow of cash. The implementation of the project would have a gross annual GHG emission reduction of **557 tCO<sub>2</sub>**.

The annual revenue for this study is the electricity export revenue and it is found to be 85,834 USD. The pre-tax equity internal rate of return equals to 33.8 %, the simple payback time equals to 6.6 years, and net present value is 886,253 USD. The model calculates the equity payback, which represents the length of time that it takes for the owner of a facility to recoup its own initial investment (equity) out of the project cash flows generated. The equity payback considers project cash flows from its inception as well as the leverage (level of debt) of the project, which makes it a better time indicator of the project merits than the simple payback. The model uses the year number and the cumulative after-tax cash flows in order to calculate this value.

## 5.4 Sensitivity and Risk Analysis

The sensitivity and risk analysis worksheet can help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. In this study, the effect of the following parameter is investigated: initial investment, electricity export rate, debt ratio, debt interest rate, debt rate, annual O&M cost on the Equity payback of the project. The user selects, from the options in the drop-down list, the financial indicator to be used for the sensitivity analysis. Modifying the selection in this cell will change the results in the worksheet.

Table 5.6: The result of sensitivity analysis

**RETScreen - Sensitivity & Risk Analysis** Subscriber: TEAM FFF 2016

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**Sensitivity analysis**

Perform analysis on:

Sensitivity range:

Threshold:  yr

---

**- Remove analysis**

| Debt ratio |        | 0.0%       |
|------------|--------|------------|
| %          |        | 3.5        |
| 60%        | -25.0% | 3.1        |
| 70%        | -12.5% | <b>2.4</b> |
| 80%        | 0.0%   | 1.5        |
| 90%        | 12.5%  |            |
| 100%       | 25.0%  | Immediate  |

---

**- Remove analysis**  %

| Debt ratio |        | 6.75%     | 7.88%     | 9.00%      | 10.13%    | 11.25%    |
|------------|--------|-----------|-----------|------------|-----------|-----------|
| %          |        | -25.0%    | -12.5%    | 0.0%       | 12.5%     | 25.0%     |
| 60%        | -25.0% | 3.3       | 3.4       | 3.5        | 3.7       | 3.8       |
| 70%        | -12.5% | 2.8       | 2.9       | 3.1        | 3.2       | 3.4       |
| 80%        | 0.0%   | 2.1       | 2.3       | <b>2.4</b> | 2.6       | 2.8       |
| 90%        | 12.5%  | 1.2       | 1.4       | 1.5        | 1.7       | 1.9       |
| 100%       | 25.0%  | Immediate | Immediate | Immediate  | Immediate | Immediate |

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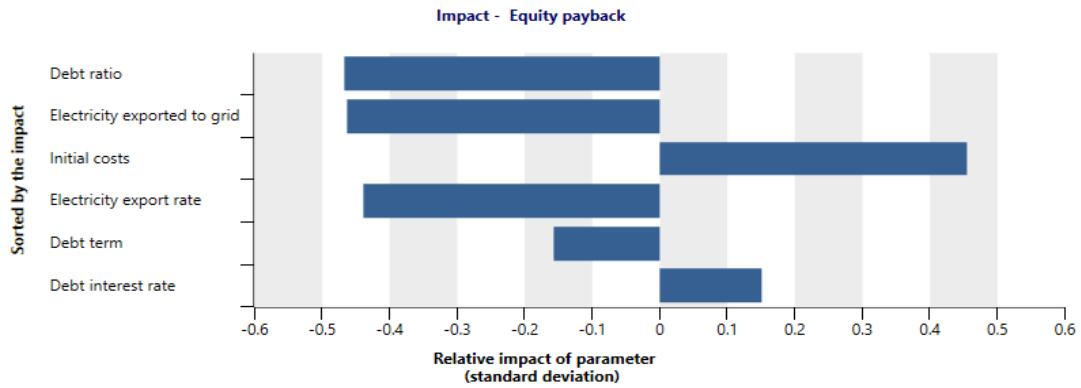
**Risk analysis**

Perform analysis on:

Number of combinations:

Random seed:

| Parameter                    | Unit   | Value   | Range (+/-)                      | Minimum | Maximum |
|------------------------------|--------|---------|----------------------------------|---------|---------|
| Initial costs                | \$     | 184,000 | <input type="text" value="25%"/> | 138,000 | 230,000 |
| Electricity exported to grid | MWh    | 307.88  | <input type="text" value="25%"/> | 230.91  | 384.84  |
| Electricity export rate      | \$/MWh | 100.00  | <input type="text" value="25%"/> | 75.00   | 125.00  |
| Debt ratio                   | %      | 80.0%   | <input type="text" value="25%"/> | 60.0%   | 100.0%  |
| Debt interest rate           | %      | 9.00%   | <input type="text" value="25%"/> | 6.75%   | 11.25%  |
| Debt term                    | yr     | 15      | <input type="text" value="25%"/> | 11      | 19      |



|                                    |    |     |
|------------------------------------|----|-----|
| Median                             | yr | 2.4 |
| Level of risk                      | %  | 10% |
| Minimum within level of confidence | yr | 1.3 |
| Maximum within level of confidence | yr | 4.5 |

Figure 5.2: Impact graph of the risk analysis result

The software recalculating the energy production cost to assess the impact of each cost and economic parameters on the project profitability.

Figure 5.2 presents the distribution graph of the risk analysis result. As depicted in the figure, the distribution graph is relatively narrow, which indicate that the Equity payback in this case has a relatively low standard error.

The median of Equity payback is 2.4 year, when the level of risk takes 10%, the minimum level of confidence is 1.3 year, and the maximum level of confidence is 4.5year.

## CHAPTER SIX

### Conclusion And Recommendations

This chapter provides the summary of major findings from the analysis, conclusions and forwarded recommendations based on the result of the present study. Furthermore, it also includes limitations and directions for further studies on the subject matter.

#### 6.1 Conclusion

In this study, the sizing and Techno-economic analysis of small-scale hydropower plant development in a Case study of Lemere River, Hadya Zone, Ghibe Wereda was conducted to assess the viability of installing a 48kW central grid small scale hydropower plant. The metrological data, flow duration data and the necessary financial parameters such as inflation rate, discount rate, and debt interest rate were used for the analysis as input data inside the RETScreen Expert software. Based on the input information, software calculates the total amount of energy generated by the hydro turbine and exported to grid, the amount of greenhouse gas emission that will be reduced annually, the cost of the project, the revenue from the project, the cash flow and economic indicators. The sensitivity and risk associated with usage of economic parameters are also done.

Based on the findings of this study the following conclusions are drawn.

- The design flow from the selected river is  $0.352 \text{ m}^3/\text{s}$  at the gross head of 22 m.
- The selected river has a power generated potential of 48 Kw of electricity
- The Civil components such as intake structure, headrace canal to divert the water from the source, forebay tank, settling basin and the penstock assembly were all designed and their sketches are shown in chapter 4.
- All financial indicators showed that small hydropower development is profitable in the proposed site. The RETScreen software result shows that the project has initial cost of 565,200 USD with benefit cost ration of 6.2. And for a project to be profitable the NPV should be greater than or equal to zero and the Benefit-Cost ratio has to be greater than 1.0. If this so the project is expected to deliver a profit to its investors.
- The sensitivity and risk analysis indicated that, the increase of electricity export rate, debt ratio and debt term would increase the net present value. Electricity exported to grid has

the highest sensitivity ranking and is the most important, followed by electricity export rate and initial cost. This indicates that the values have to be assessed carefully to have a greater certainty.

## 6.2 Limitation of the Study and Suggestions for Future Studies

In the above section, the design of electro-mechanical components especially the turbine is noticeably determined. Hence, it can be manufactured locally based on the design parameters or import from abroad by specifying the main calculated variables. However, the recommended type of generator can readily be procured from well-known manufacturers around the world. Regarding the design of civil work components, almost all components are designed based on the measured flow rate and gross head of the scheme.

The design amendment in the Lemere Micro- hydropower scheme is required due to the fact that some parts of the head works are to be rehabilitated. The major amendments have to be done are the rehabilitation of the existing headrace and forebay and lining of the headrace floor with concrete. This is used to keep the level from seepage and turbulence. There should be a retaining wall by the rear side of the powerhouse to protect the sliding soil, rolling stones and erosion from uphill to the powerhouse.

Therefore, it is better to confirm the detail design of civil work components by an experienced civil engineer or hydropower engineer prior to the implementation of the project. The design drawing of the civil work components can also be prepared by the same professionals. The other activity to be done is proper cable sizing and selection of electric poles. The installation of local grid/distribution lines can be done by micro and small enterprises (SMEs) that are engaged in installation of transmission and distribution lines through the Universal Electric Access Program (UEAP).

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## APPENDIX

### Appendix A: Hydrology Data Summary

Annual Report of Daily Data: Instantaneous Daily

Flow Station Number: 113019

Station Name: LEMERE at HOSSANA.

Time-Series Type: Flow (cumecs)

Latitude: 7°33'N

Longitude 37°51'E

Elevation: 8:00- 1,600m

| Year: 1980  |       |       |       |       |        |        |         |         |         |         |        |        |
|-------------|-------|-------|-------|-------|--------|--------|---------|---------|---------|---------|--------|--------|
|             | Jan   | Feb   | Mar   | Apr   | May    | Jun    | Jul     | Aug     | Sep     | Oct     | Nov    | Dec    |
| Mean        | 0.447 | 0.303 | 0.256 | 0.319 | 0.458  | 2.208  | 15.974  | 43.226  | 27.454  | 15.032  | 3.564  | 1.201  |
| Flow (MCM)  | 1.197 | 0.759 | 0.687 | 0.828 | 1.228  | 5.723  | 42.785  | 115.776 | 71.161  | 40.261  | 9.238  | 3.216  |
| Maximum     | 0.581 | 0.397 | 0.377 | 0.746 | 2.395  | 5.252  | 44.246  | 95.854  | 49.102  | 39.769  | 20.073 | 4.809  |
| Minimum     | 0.319 | 0.25  | 0.163 | 0.193 | 0.204  | 0.319  | 5.222   | 27.459  | 11.914  | 6.007   | 0.991  | 0.478  |
| Runoff (mm) | 4.246 | 2.69  | 2.436 | 2.935 | 4.354  | 20.296 | 151.718 | 410.554 | 252.344 | 142.77  | 32.759 | 11.403 |
| Year: 1981  |       |       |       |       |        |        |         |         |         |         |        |        |
| Mean        | 0.332 | 0.195 | 0.114 | 0.071 | 0.143  | 2.445  | 16.202  | 39.115  | 29.526  | 13.65   | 2.635  | 0.788  |
| Flow (MCM)  | 0.889 | 0.472 | 0.304 | 0.183 | 0.383  | 6.336  | 43.395  | 104.766 | 76.531  | 36.561  | 6.829  | 2.109  |
| Maximum     | 0.478 | 0.275 | 0.177 | 0.136 | 1.128  | 6.931  | 30.165  | 66.188  | 49.849  | 27.732  | 5.871  | 3.212  |
| Minimum     | 0.226 | 0.106 | 0.083 | 0.037 | 0.036  | 0.544  | 2.029   | 20.719  | 18.075  | 3.416   | 1.068  | 0.059  |
| Runoff (mm) | 3.153 | 1.673 | 1.079 | 0.649 | 1.357  | 22.469 | 153.884 | 371.509 | 271.387 | 129.648 | 24.216 | 7.48   |
| Year: 1982  |       |       |       |       |        |        |         |         |         |         |        |        |
| Mean        | 0.758 | 0.272 | 0.222 | 0.092 | 0.056  | 0.822  | 11.003  | 23.845  | 31.425  | 17.274  | -      | 0.944  |
| Flow (MCM)  | 2.031 | 0.658 | 0.595 | 0.239 | 0.151  | 2.13   | 29.471  | 63.866  | 81.455  | 46.266  | -      | 2.529  |
| Maximum     | 2.348 | 0.884 | 0.654 | 0.478 | 0.482  | 3.068  | 26.869  | 40.415  | 67.424  | 39.765  | -      | 2.281  |
| Minimum     | 0.039 | 0.014 | 0     | 0.001 | 0.006  | 0.028  | 0.574   | 12.494  | 14.25   | 8.809   | -      | 0.183  |
| Runoff (mm) | 7.203 | 2.333 | 2.11  | 0.849 | 0.536  | 7.555  | 104.508 | 226.474 | 288.846 | 164.063 | -      | 8.966  |
| Year: 1984  |       |       |       |       |        |        |         |         |         |         |        |        |
| Mean        | 0.494 | 0.351 | 0.39  | 0.297 | 1.067  | 9.764  | 25.005  | 29.037  | 19.605  | 3.495   | 1.332  | 0.804  |
| Flow (MCM)  | 1.323 | 0.88  | 1.044 | 0.77  | 2.857  | 25.309 | 66.973  | 77.772  | 50.816  | 9.361   | 3.452  | 2.152  |
| Maximum     | 0.667 | 0.414 | 0.519 | 0.555 | 5.281  | 17.768 | 41.826  | 40.86   | 33.899  | 11.746  | 2.991  | 1.374  |
| Minimum     | 0.382 | 0.289 | 0.279 | 0.165 | 0.228  | 2.282  | 14.238  | 20.485  | 7.686   | 1.465   | 0.92   | 0.547  |
| Runoff (mm) | 4.69  | 3.119 | 3.702 | 2.731 | 10.132 | 89.747 | 237.492 | 275.786 | 180.197 | 33.194  | 12.241 | 7.632  |
| Year: 1985  |       |       |       |       |        |        |         |         |         |         |        |        |
| Mean        | 0.465 | 0.338 | 0.398 | 0.534 | 2.741  | 9.018  | 26.784  | 30.149  | 19.774  | 6.267   | 2.748  | 1.592  |
| Flow (MCM)  | 1.246 | 0.817 | 1.065 | 1.384 | 7.342  | 23.376 | 71.739  | 80.75   | 51.254  | 16.786  | 7.123  | 4.263  |
| Maximum     | 0.667 | 0.478 | 2.024 | 1.685 | 13.937 | 20.744 | 61.945  | 48.867  | 37.727  | 16.715  | 5.395  | 8.99   |
| Minimum     | 0.418 | 0.215 | 0.228 | 0.18  | 0.256  | 1.135  | 14.022  | 19.518  | 9.172   | 2.069   | 1.294  | 0.446  |
| Runoff (mm) | 4.417 | 2.898 | 3.778 | 4.906 | 26.035 | 82.893 | 254.392 | 286.347 | 181.75  | 59.523  | 25.26  | 15.118 |
| Year: 1986  |       |       |       |       |        |        |         |         |         |         |        |        |
| Mean        | 0.337 | 0.308 | 0.192 | 0.335 | 2.254  | 11.58  | 26.874  | 26.742  | 16.892  | 13.739  | 3.658  | 1.631  |

|                   |       |       |       |        |        |         |         |         |         |         |        |        |
|-------------------|-------|-------|-------|--------|--------|---------|---------|---------|---------|---------|--------|--------|
| Flow (MCM)        | 0.903 | 0.746 | 0.513 | 0.868  | 6.038  | 30.014  | 71.98   | 71.626  | 43.784  | 36.797  | 9.482  | 4.369  |
| Maximum           | 0.473 | 0.382 | 0.267 | 2.274  | 10.11  | 20.77   | 43.202  | 49.557  | 29.249  | 32.878  | 11.529 | 3.935  |
| Minimum           | 0.252 | 0.224 | 0.111 | 0.093  | 0.282  | 5.616   | 9.524   | 12.316  | 6.364   | 5.479   | 1.502  | 0.835  |
| Runoff (mm)       | 3.201 | 2.646 | 1.819 | 3.078  | 21.411 | 106.434 | 255.248 | 253.995 | 155.264 | 130.487 | 33.625 | 15.494 |
| <b>Year: 1988</b> |       |       |       |        |        |         |         |         |         |         |        |        |
| Mean              | 0.717 | 0.435 | 0.31  | 0.29   | 0.897  | 8.148   | 23.684  | 27.811  | 23.39   | 12.079  | 3.485  | 1.153  |
| Flow (MCM)        | 1.92  | 1.09  | 0.831 | 0.752  | 2.403  | 21.118  | 63.436  | 74.49   | 60.626  | 32.353  | 9.032  | 3.087  |
| Maximum           | 0.913 | 0.498 | 0.443 | 0.342  | 2.635  | 18.883  | 33.18   | 37.149  | 36.26   | 28.935  | 11.111 | 1.559  |
| Minimum           | 0.503 | 0.377 | 0.231 | 0.256  | 0.242  | 1.749   | 12.847  | 20.332  | 13.979  | 5.105   | 1.569  | 0.891  |
| Runoff (mm)       | 6.809 | 3.866 | 2.948 | 2.668  | 8.522  | 74.888  | 224.95  | 264.148 | 214.986 | 114.727 | 32.03  | 10.947 |
| <b>Year: 1989</b> |       |       |       |        |        |         |         |         |         |         |        |        |
| Mean              | 0.714 | 0.384 | 0.398 | 0.359  | 1.101  | 8.419   | 29.823  | 33.419  | 16.917  | 7.186   | 2.151  | 1.264  |
| Flow (MCM)        | 1.913 | 0.928 | 1.066 | 0.93   | 2.95   | 21.822  | 79.878  | 89.51   | 43.85   | 19.248  | 5.574  | 3.387  |
| Maximum           | 0.994 | 0.423 | 0.66  | 0.906  | 3.902  | 21.309  | 53.578  | 55.595  | 30.02   | 20.878  | 7.16   | 2.323  |
| Minimum           | 0.423 | 0.297 | 0.235 | 0.224  | 0.29   | 1.009   | 16.971  | 19.426  | 8.473   | 2.941   | 1.151  | 0.835  |
| Runoff (mm)       | 6.784 | 3.292 | 3.782 | 3.299  | 10.46  | 77.384  | 283.256 | 317.411 | 155.495 | 68.256  | 19.767 | 12.01  |
| <b>Year: 1990</b> |       |       |       |        |        |         |         |         |         |         |        |        |
| Mean              | 0.67  | 0.478 | 0.383 | 0.335  | 0.642  | 0.961   | 10.006  | 15.909  | 7.713   | 5.827   | 1.126  | 0.529  |
| Flow (MCM)        | 1.794 | 1.156 | 1.025 | 0.869  | 1.718  | 2.491   | 26.8    | 42.611  | 19.991  | 15.606  | 2.92   | 1.417  |
| Maximum           | 1.072 | 0.625 | 0.478 | 0.575  | 2.087  | 4.109   | 22.645  | 52.296  | 21.707  | 19.007  | 1.738  | 0.85   |
| Minimum           | 0.54  | 0.298 | 0.321 | 0.256  | 0.313  | 0.347   | 2.323   | 4.148   | 1.563   | 1.873   | 0.679  | 0.355  |
| Runoff (mm)       | 6.361 | 4.099 | 3.635 | 3.081  | 6.093  | 8.832   | 95.034  | 151.104 | 70.89   | 55.34   | 10.354 | 5.026  |
| <b>Year: 1991</b> |       |       |       |        |        |         |         |         |         |         |        |        |
| Mean              | 0.379 | 0.217 | 0.203 | 1.095  | 1.099  | 11.98   | 22.349  | 21.332  | -       | -       | 2.02   | 0.743  |
| Flow (MCM)        | 1.016 | 0.525 | 0.544 | 2.837  | 2.944  | 31.051  | 59.86   | 57.134  | -       | -       | 5.235  | 1.989  |
| Maximum           | 0.493 | 0.278 | 0.561 | 2.556  | 9.498  | 33.426  | 37.815  | 32.666  | -       | -       | 3.812  | 1.406  |
| Minimum           | 0.282 | 0.135 | 0.154 | 0.351  | 0.418  | 1.355   | 12.969  | 13.662  | -       | -       | 1.04   | 0.498  |
| Runoff (mm)       | 3.604 | 1.862 | 1.928 | 10.061 | 10.438 | 110.112 | 212.268 | 202.605 | -       | -       | 18.565 | 7.053  |
| <b>Year: 1992</b> |       |       |       |        |        |         |         |         |         |         |        |        |
| Mean              | 1.02  | -     | -     | 0.563  | 1.204  | 3.545   | -       | 34.905  | 36.975  | -       | 1.715  | 1.094  |
| Flow (MCM)        | 2.733 | -     | -     | 1.458  | 3.224  | 9.19    | -       | 93.488  | 95.839  | -       | 4.445  | 2.93   |
| Maximum           | 1.34  | -     | -     | 0.72   | 4.4    | 18.34   | -       | 54.7    | 87.7    | -       | 2.33   | 1.51   |
| Minimum           | 0.84  | -     | -     | 0.44   | 0.57   | 0.78    | -       | 18.94   | 9.63    | -       | 1.42   | 0.84   |
| Runoff (mm)       | 9.691 | -     | -     | 5.172  | 11.431 | 32.587  | -       | 331.519 | 339.855 | -       | 15.763 | 10.389 |
| <b>Year: 1993</b> |       |       |       |        |        |         |         |         |         |         |        |        |
| Mean              | -     | 0.615 | 0.466 | 1.323  | 1.525  | 15.825  | 26.434  | 37.799  | -       | 17.061  | -      | -      |
| Flow (MCM)        | -     | 1.489 | 1.247 | 3.43   | 4.086  | 41.018  | 70.8    | 101.241 | -       | 45.695  | -      | -      |
| Maximum           | -     | 0.789 | 0.693 | 3.192  | 5.385  | 41.587  | 43.743  | 70.595  | -       | 31.64   | -      | -      |
| Minimum           | -     | 0.457 | 0.261 | 0.631  | 0.457  | 0.823   | 14.855  | 22.116  | -       | 0.352   | -      | -      |
| Runoff (mm)       | -     | 5.279 | 4.422 | 12.162 | 14.488 | 145.455 | 251.065 | 359.01  | -       | 162.041 | -      | -      |
| <b>Year: 1994</b> |       |       |       |        |        |         |         |         |         |         |        |        |

|                   |       |       |       |       |        |         |         |         |         |         |        |        |
|-------------------|-------|-------|-------|-------|--------|---------|---------|---------|---------|---------|--------|--------|
| Mean              | -     | -     | 0.368 | 0.362 | 0.994  | 9.793   | 24.113  | 39.82   | 21.097  | 3.191   | 1.529  | -      |
| Flow (MCM)        | -     | -     | 0.985 | 0.937 | 2.664  | 25.383  | 64.585  | 106.653 | 54.684  | 8.546   | 3.962  | -      |
| Maximum           | -     | -     | 0.546 | 0.64  | 2.045  | 19.797  | 47.104  | 168.597 | 41.155  | 8.295   | 2.136  | -      |
| Minimum           | -     | -     | 0.202 | 0.236 | 0.383  | 1.882   | 14.5    | 18.565  | 3.925   | 0.737   | 1.221  | -      |
| Runoff (mm)       | -     | -     | 3.494 | 3.323 | 9.445  | 90.012  | 229.025 | 378.203 | 193.916 | 30.304  | 14.05  | -      |
| <b>Year: 1995</b> |       |       |       |       |        |         |         |         |         |         |        |        |
| Mean              | -     | 0.25  | -     | -     | 1.791  | -       | 18.431  | 33.544  | 24.52   | -       | -      | 1.009  |
| Flow (MCM)        | -     | 0.604 | -     | -     | 4.796  | -       | 49.367  | 89.844  | 63.557  | -       | -      | 2.703  |
| Maximum           | -     | 0.322 | -     | -     | 17.015 | -       | 32.147  | 62.724  | 50.062  | -       | -      | 3.799  |
| Minimum           | -     | 0.202 | -     | -     | 0.228  | -       | 7.404   | 16.089  | 11.766  | -       | -      | 0.766  |
| Runoff (mm)       | -     | 2.141 | -     | -     | 17.008 | -       | 175.059 | 318.597 | 225.379 | -       | -      | 9.584  |
| <b>Year: 1996</b> |       |       |       |       |        |         |         |         |         |         |        |        |
| Mean              | 0.521 | -     | 0.289 | 0.546 | 5.659  | 12.174  | 29.179  | 31.794  | 23.041  | 10.083  | 2.278  | 0.985  |
| Flow (MCM)        | 1.396 | -     | 0.774 | 1.414 | 15.157 | 31.554  | 78.154  | 85.156  | 59.722  | 27.007  | 5.904  | 2.638  |
| Maximum           | 0.751 | -     | 0.767 | 3.524 | 21.341 | 24.719  | 88.624  | 59.063  | 46.035  | 33.19   | 4.569  | 1.7    |
| Minimum           | 0.381 | -     | 0.171 | 0.198 | 0.59   | 5.875   | 11.184  | 15.194  | 9.506   | 2.578   | 1.488  | 0.693  |
| Runoff (mm)       | 4.95  | -     | 2.744 | 5.015 | 53.749 | 111.894 | 277.142 | 301.973 | 211.781 | 95.77   | 20.937 | 9.356  |
| <b>Year: 1997</b> |       |       |       |       |        |         |         |         |         |         |        |        |
| Mean              | 0.5   | 0.279 | 0.326 | -     | -      | -       | -       | -       | 22.976  | 16.98   | 7.454  | 2.369  |
| Flow (MCM)        | 1.34  | 0.674 | 0.874 | -     | -      | -       | -       | -       | 59.554  | 45.479  | 19.321 | 6.344  |
| Maximum           | 0.644 | 0.402 | 0.611 | -     | -      | -       | -       | -       | 45.114  | 41.736  | 20.421 | 8.874  |
| Minimum           | 0.402 | 0.12  | 0.11  | -     | -      | -       | -       | -       | 11.691  | 6.345   | 3.1    | 1.33   |
| Runoff (mm)       | 4.75  | 2.391 | 3.1   | -     | -      | -       | -       | -       | 211.183 | 161.274 | 68.513 | 22.497 |
| <b>Year: 1998</b> |       |       |       |       |        |         |         |         |         |         |        |        |
| Mean              | -     | -     | -     | -     | -      | 9.478   | 21.491  | 30.293  | 22.65   | 18.188  | -      | -      |
| Flow (MCM)        | -     | -     | -     | -     | -      | 24.566  | 57.562  | 81.136  | 58.708  | 48.715  | -      | -      |
| Maximum           | -     | -     | -     | -     | -      | 26.016  | 37.038  | 66.063  | 35.59   | 40.195  | -      | -      |
| Minimum           | -     | -     | -     | -     | -      | 1.775   | 11.048  | 16.767  | 13.657  | 6.31    | -      | -      |
| Runoff (mm)       | -     | -     | -     | -     | -      | 87.114  | 204.121 | 287.717 | 208.183 | 172.749 | -      | -      |
| <b>Year: 2000</b> |       |       |       |       |        |         |         |         |         |         |        |        |
| Mean              | 0.711 | 0.314 | -     | -     | -      | -       | -       | -       | -       | -       | -      | -      |
| Flow (MCM)        | 1.905 | 0.787 | -     | -     | -      | -       | -       | -       | -       | -       | -      | -      |
| Maximum           | 1.09  | 0.491 | -     | -     | -      | -       | -       | -       | -       | -       | -      | -      |
| Minimum           | 0.451 | 0.139 | -     | -     | -      | -       | -       | -       | -       | -       | -      | -      |
| Runoff (mm)       | 6.755 | 2.791 | -     | -     | -      | -       | -       | -       | -       | -       | -      | -      |
| <b>Year: 2001</b> |       |       |       |       |        |         |         |         |         |         |        |        |
| Mean              | -     | -     | -     | -     | -      | -       | -       | -       | -       | -       | -      | 1.252  |
| Flow (MCM)        | -     | -     | -     | -     | -      | -       | -       | -       | -       | -       | -      | 3.353  |
| Maximum           | -     | -     | -     | -     | -      | -       | -       | -       | -       | -       | -      | 1.956  |
| Minimum           | -     | -     | -     | -     | -      | -       | -       | -       | -       | -       | -      | 0.884  |

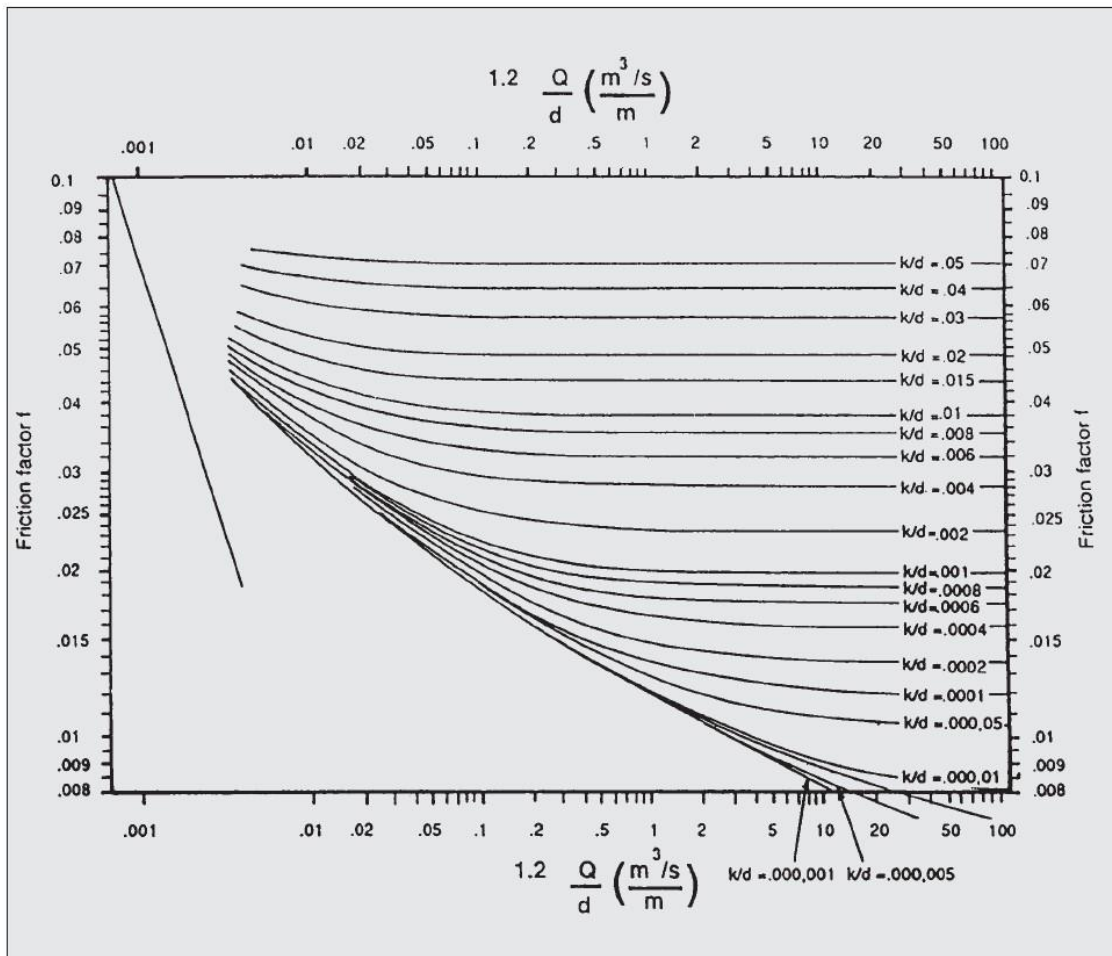
|                   |       |       |       |       |       |        |         |         |         |         |        |        |       |
|-------------------|-------|-------|-------|-------|-------|--------|---------|---------|---------|---------|--------|--------|-------|
| Runoff (mm)       | -     | -     | -     | -     | -     | -      | -       | -       | -       | -       | -      | -      | 11.89 |
| <b>Year: 2002</b> |       |       |       |       |       |        |         |         |         |         |        |        |       |
| Mean              | 0.74  | 0.404 | 0.279 | 0.325 | 0.397 | 8.334  | -       | -       | -       | -       | -      | -      | -     |
| Flow (MCM)        | 1.983 | 0.978 | 0.748 | 0.844 | 1.065 | 21.602 | -       | -       | -       | -       | -      | -      | -     |
| Maximum           | 0.932 | 0.63  | 0.397 | 0.51  | 1.46  | 29.712 | -       | -       | -       | -       | -      | -      | -     |
| Minimum           | 0.491 | 0.232 | 0.168 | 0.22  | 0.224 | 0.736  | -       | -       | -       | -       | -      | -      | -     |
| Runoff (mm)       | 7.032 | 3.47  | 2.653 | 2.992 | 3.775 | 76.602 | -       | -       | -       | -       | -      | -      | -     |
| <b>Year: 2005</b> |       |       |       |       |       |        |         |         |         |         |        |        |       |
| Mean              | 0.439 | 0.272 | 0.378 | 0.202 | 0.214 | 7.562  | 28.267  | 25.204  | 26.501  | 4.708   | 1.573  | 0.804  |       |
| Flow (MCM)        | 1.177 | 0.658 | 1.011 | 0.523 | 0.574 | 19.6   | 75.711  | 67.506  | 68.69   | 12.61   | 4.078  | 2.153  |       |
| Maximum           | 0.578 | 0.332 | 0.886 | 0.252 | 0.451 | 21.527 | 59.42   | 48.685  | 48.647  | 14.625  | 3.841  | 1.55   |       |
| Minimum           | 0.322 | 0.202 | 0.228 | 0.164 | 0.164 | 0.987  | 12.78   | 11.467  | 15.341  | 1.929   | 0.835  | 0.246  |       |
| Runoff (mm)       | 4.173 | 2.333 | 3.586 | 1.855 | 2.037 | 69.503 | 268.479 | 239.383 | 243.58  | 44.716  | 14.462 | 7.635  |       |
| <b>Year: 2006</b> |       |       |       |       |       |        |         |         |         |         |        |        |       |
| Mean              | 0.366 | 0.201 | 0.144 | 0.422 | 0.368 | 3.626  | 21.488  | 23.637  | 24.148  | 12.125  | 2.254  | 1.11   |       |
| Flow (MCM)        | 0.979 | 0.502 | 0.386 | 1.093 | 0.987 | 9.397  | 57.555  | 63.31   | 62.592  | 32.477  | 5.843  | 2.974  |       |
| Maximum           | 0.491 | 0.252 | 0.358 | 1.859 | 3.035 | 13.311 | 35.677  | 62.733  | 56.508  | 33.762  | 8.639  | 4.023  |       |
| Minimum           | 0.252 | 0.139 | 0.062 | 0.096 | 0.064 | 0.402  | 10.362  | 10.774  | 10.723  | 2.187   | 1.271  | 0.276  |       |
| Runoff (mm)       | 3.473 | 1.782 | 1.368 | 3.876 | 3.499 | 33.324 | 204.094 | 224.504 | 221.958 | 115.165 | 20.718 | 10.545 |       |

## Appendix B: Roughness value, 'k' in mm for different pipe materials

| Material                                     | Roughness value, k (mm) |
|--|-------------------------|
| Smooth pipes<br>PVC, HDPE, MDPE, Glass fiber | 0.06                    |
| Concrete                                     | 0.15                    |
| Mild steel                                   |                         |
| uncoated                                     | 0.06                    |
| Galvanized                                   | 0.15                    |

## Appendix C: Moody Chart

The Moody chart or Moody diagram is a graph used to find friction factor for turbulent flow in the pipe for head loss calculation.



## Appendix D: Float method for discharge measurement

Float-area method is simply measure the velocity of the water by timing how fast the floating object going from point **A** to point **B** and take depth at a regular interval and width measurement of the water across the channel to calculate the area of water in the channel.

### Materials:

- Tape measure ( 7m, and it is long enough to stretch across the channel )
- Stop watch
- Yard stick (or other stiff measuring device to measure depth)
- Buoyant object
- 2 markers to put on the channel bank

### Steps:

- Identify a straight section of the river, uniform in grade and minimum turbulence.

- Determine the float distance marking two point along the length of the channel at least 7m this length will be distance.
- Measure depth across the channel approximately 0.5m intervals add up all the depth, divide with how many depth taken to get over all average depth across the width of the channel.
- Measure the respective width of the stream.
- Float the buoyant object and take time, repeat this process three time and average all the three results together use this average time entry, now we can determine the flow in  $\frac{m^3}{s}$  by multiplying  $w \times d \times \frac{D}{t} = A \times V$  often Hydrologist ding flow measurement recommend to take correction factor 0.85 used because water at less shallower depth is moving less quickly.

Where:

$w$  = Width

$d$  = Average depth

$D$  =Distance from point A to B

$t$  = Average time

Figure below shows pictures taken during the flow measurement:



Figure 2:  
Floating  
method  
flow

measurement

**Calculation:**

The depth at a typical equally spaced distance across the width of the river and its area is calculated as follows:-

| Width: 10m |          |                             |                                 |   |
|------------|----------|-----------------------------|---------------------------------|---|
| No of runs | depth(m) | Equally spaced interval (m) | Average depth=d=(d1+d2+d3+d4)/4 | Area between two consecutive points=WXd |
| d1         | 0.80     | 0.5                         | 0.7525                          | 7.525                                   |
| d2         | 0.84     | 0.5                         |                                 |   |
| d3         | 0.73     | 0.5                         |                                 |   |
| D4         | 0.64     | 0.5                         |                                 |   |

Float distance marked two point is 7m. The time it takes the buoyant object (i.e. the plastic bottle) to float the measured distance has recorded 4 times and take the average of the measurement, and the velocity is calculated as follows:-

| Distance: 7m |                           |                                |                        |   |
|--------------|---------------------------|--------------------------------|------------------------|---|
| No of runs   | Time taken to float (sec) | Average time=t=(t1+t2+t3+t4)/4 | Surface velocity=V=D/t | Adjusted Velocity With the correction factor=V X 0.85 |
| t1           | 11.57                     | 10.85                          | 0.645                  | 0.548   |
| t2           | 10.29                     |                                |                        |   |
| t3           | 10.44                     |                                |                        |   |
| t4           | 11.11                     |                                |                        |   |

Therefore, the discharge of the river is calculated as follows:

$$Q = A \times V$$

$$Q = 7.525 \text{ m}^2 \times 0.548 \text{ m/s}$$

$$Q = 4.125 \text{ m}^3/\text{s}$$

## Appendix E: Spirit level and plank Method River head measurement

The spirit level and plank method is a step-by step procedure to determine gross head, tail water level and upper water level (at waterfall/ forebay) using a spirit level and plank.

### Materials:

- Tape measure
- 4m Yard stick ( plank)
- A spirit level
- String

Figure below shows pictures taken during the river head measurement:



Figure 3: Spirit level and plank method head measurement

### Calculation:

Measured heights:-

$$h_1 = 4m, h_2 = 4m, h_3 = 4m, h_4 = 4m, h_5 = 4m, h_6 = 2m$$

Therefore, from the measurements taken the gross head of Lemereriver at Buchame fall is calculated as follows:

$$H_g = h_1 + h_2 + h_3 + h_4 + h_5 + h_6$$

$$H_g = 4m + 4m + 4m + 4m + 4m + 2m$$

$$H_g = 22m$$