Performance Evaluation of an Existing Multi-Village Piped Water Supply Scheme and Identification of Intervention Mechanisms, the case of Teyfe Water Supply Project in Ethiopia

Mustefa Jemal

A Thesis Submitted to the Department of Water Resources Engineering,

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in

Water Resources Engineering (Water Supply and Environmental Engineering)

Office of Graduate Studies

Adama Science and Technology University

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Adama, Ethiopia

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Declaration

I hereby declare that this Master Thesis entitled “Performance Evaluation of an Existing Multi-Village Piped Water Supply Scheme and Identification of Intervention Mechanisms, the case of Teyfe Water Supply Project in Ethiopia” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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Name of student	Signature	Date

Recommendation of Advisor

I, the advisor of this thesis, hereby certify that I read the revised version of the thesis entitled "Performance Evaluation of an Existing Multi-Village Piped Water Supply Scheme and Identification of Intervention Mechanisms, the case of Teyfe Water Supply Project in Ethiopia" prepared under my guidance by Mustefa Jemal submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resources Engineering (specialize in Water Supply and Environmental Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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Major Advisor	Signature	Date

Approval Page of M.Sc. Thesis

I, the advisor of the thesis entitled "Performance Evaluation of an Existing Multi-Village Piped Water Supply Scheme and Identification of Intervention Mechanisms, the case of Teyfe Water Supply Project in Ethiopia" and developed by Mustefa Jemal, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

____________________	______________________	_______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Mustefa Jemal have read and evaluated the thesis entitled "Performance Evaluation of an Existing Multi-Village Piped Water Supply Scheme and Identification of Intervention Mechanisms, the case of Teyfe Water Supply Project in Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water resource (specialize in Water Supply and Environmental Engineering).

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LIST OF ACRIMONY AND ABBREVIATIONS

ADD	Average Day Demand
DCI	Ductile Cast Iron pipes
EME	Electro-Mechanical Equipment
ESRI	Environmental System Research Institute
GH	Generator House
GIS	Geographical Information System
GPS	Geographical Positioning System
HC	House Consumption
HDPE	High Density Polyethylene
HG	Hydraulic Grade
KPI	Key Performance Indicator
L/C/D	Litre /Capita/Day
MDD	Maximum Day Demand
MoWE	Ministry of Water and Energy
PHD	Peak Hour Demand
SDG	Sustainable Development Goal
TDD	Total Domestic Demand
TMVWSP	Teyfe Multi-Village Water Supply Project
TNDD	Total Non-Domestic Demand
UN	United Nations
UNCEF	United Nations Children's Fund
uPVC	Unplasticized Polyvinyl Chloride
UTM	Universal Traverse Marketer
WaSH	Water Supply, Sanitation and Hygiene
WHO	World Health Organization
YCP	Yard Connection Private
YCS	Yard Connection Shared

Abstract

Water is one of the basic elements for the sustenance of human life; however, the water supply coverage in Ethiopia accounts only 49%. Beside low scheme coverage, the poor performance and scheme unsustainability become a problem to manage the ever increasing demands. Teyfe Multi-Village water supply system was constructed to give service for 69,699 people living in eight kebeles and two rural towns. Frequent breaking of pipes, uneven water distribution and high energy consumptions are the problems identified for which this research was conducted. . Analysis of demands for the design period of the project, performance evaluation of the major system components and identification of intervention mechanisms for the system improvements were the specific objectives of this studies. Demand was computed for the proposed design period using projected population and unit rate consumptions considering different mode of services. Performance evaluation of EME, reservoirs and source were carried out comparing the existing component capacity against the capacity of the computed using the respective standard equations and national guide lines. Hydraulic analysis was conducted employing WaterGEMS software to evaluate the pressure and velocity of both transmission and distribution pipe lines. Sample surveying was also conducted to assess the utility management potential. From result of the Demand analysis, 40.78 L/s maximum day demand (MDD) is required to address the water supply coverage for the intended design period. Regarding system component performance, the source has a discharge capacity of 61.8 L/s and sufficient for project life time. However, only 30 L/s, accounting 73.56% of MDD, is currently taken from this source. Distribution lines nodes were exposed to high pressure (80–183 m), which can break pipes; moreover, 51.43% of the pipe has velocity less than the recommended 0.6 m/s, which might result in stagnant water formation. All existing reservoirs were evaluated and found sufficient to balance the MDD required. Regarding electro-mechanical equipment (EME), pumps at station wet well 1, 2 and 3 can give full service up to 2032, supplying 30 L/s and the pump in wet well 4, with discharge 12.5 l/s, serves only up to 2027. All associated power plants, with the exception of the generator in wet well 4, were designed oversized and subjected to high energy consumption. Furthermore the user community has not yet completely utilized the system due to long distance travelled (>1km) to collect water and the high water tariff (100 birr/m3) accounting 65.95 and 99.02 %, respectively and hence low customer satisfaction achived. Substantial loss of water (46%) also indicates poor water resource management of the utility. As an intervention mechanism optimized pipe layout was proposed to minimize the energy consumption of power plant and control valves of different kinds and chambers used to reduce static pressures and remove silts were also suggested. Preparation of adequate business plan used to enable utility to improve system management was also recommended.

Key words*:* multi-village WSS, performance evaluation, pressure, pump, water demand, WSS

CHAPTER ONE: INTRODUCTION

1.1. Background

Water supply is a basic human need for both domestic and industrial purposes. Many efforts have been so far made across the globe to improve water supply coverage. However, the United Nations Sustainable Development Goal (SDG) report states that over 2.2 billion people still do not have access to safe drinking water (UN, 2023). UNCEF and WHO (2023) also reported that global water supply coverage in rural and urban areas accounted for 73 and 81%, respectively and Sub-Saharan African nations, with an average coverage of 31 and 53 % for rural and urban areas, respectively, are the least fortunate to have access to clean water supplies.

Ethiopia is one of the countries in Sub-Saharan countries where large of the population faces water shortage. According to the WaSH inventory-II of 2021, conducted by water development commission under Water, Irrigation and Energy Ministry, water supply coverage accounts 47, 57, and 49 %, for rural, urban and total, respectively. Of all the reported rural water supply systems, over 60 % come from groundwater sources, such as hand-dug wells, shallow wells, and boreholes. In addition, the inventory revealed that, of the rural piped systems that are available, 19 % utilize diesel-driven generators for water pumping, 65 % rely on gravity, 3 and 2 % employ grid and solar systems, respectively and the remaining 11 % uses mixed energy sources (MoWE, 2021).

Different types of water supply systems are being employed to provide water for underprivileged communities. Rural piped water supply projects spanning over multiple villages are one of the approaches used these days, taking into account a number of benefits. Multi-village schemes (MVSs), connecting hundreds of villages and small towns into a bulk water distribution network, represent an emerging frontier for rural water supply in low and middle income countries. The majority of rural water supply projects are large-scale initiatives for single-village communities, but interest in multi-village schemes is growing because they offer a long-term, workable solution to the severe water scarcity that many regions face. These projects also help to capture economies of scale by providing complete coverage of rural areas for high quality service (Bharambe & Wayal, 2016).

The distribution of rural water supply services is increasingly moving towards piped water projects globally as a result of rising aspirations among rural residents and improving living standards. Transporting water across large distances is the only option when local water sources are insufficient or unsafe to drink, such as when the water is of low quality. Once more, state economies dictate that a single system must serve several settlements or villages. Typical example is the Purna river basin region of India, where the Amravati district is located. Due to the saline aquifer intrusion spanning over area of approximately 5,000 km^2, surface water schemes were developed for the district's community of 156 villages and two towns with piped system for residential use (Hutchings et al., 2020).

A water supply system uses a variety of elements to work as intended and effectively. A malfunction in any one of the components could cause the system to stop functioning altogether or operate less efficiently. The main reasons for intermittent water distribution in the water supply system are a high rate of population growth, a lack of available source water, the size of the treatment plant, the capacity of the reservoirs and storage tanks, power outages that prevent the operation of the water pumps, high leakage issues, or a combination of these factors (Renwick, 2013). This has indicated that wherever evaluating water supply system performance, collective evaluation of each and every parcel of the system component is more reliable than focusing on specific component. Bharambe & Wayal (2016) conducted a study on the Aghai rural regional water supply scheme (Multi Village) in India and they clearly indicated a design problem wherein the existing water is insufficient to reach the beneficiaries evenly, the reservoir capacities were insufficient for the current and future, and the transmission pipe material was operating below the required pressure. As a result, they recommended that some parts of the water supply needed to be replaced, and that modifications and design reviews were suggested to overcome the issues.

Many multi-village water supply systems addressing water supply problem of rural, small and medium town have been developed in Ethiopia in areas with severe water shortage and this had led to committed community involvement in planning, design and management of the schemes (MoWIE, 2013). Besides this usual intervention, recently climate resilient water supply, sanitation and hygiene projects have been initiated by ministry of water and energy with the objective of securing the water supply projects in areas where climate effect on water supply sources threaten scheme sustainability. Low land areas with low water resource potential are hence the focus areas, and spanning single sources to a number of villages is taken as strategy of solution making.

This study has focused on the Teyfe Multi-Village Water Supply Project, which provides services for eight rural kebeles and two rural towns. The system is currently under operation;

however, the utility has encountered significant challenges in delivering the required services. Uneven distribution of water was observed at some water points, and hence users were waiting in long lines to collect water. High water loss due to the bursting of pipes in some of its sections is the other critical problem, and this has created frequent service interruptions and significant losses. On the other hand, the existing power plants, especially the diesel generator installed to be used as a standby during power outages, consume a lot of energy, and utilities can't afford the fuel supply. Thus, the overall goal of the study was to systematically identify the root causes for the aforementioned problems and to suggest practical solutions thereby contribute for sustainability of the system. The study had assessed the management practices, examined the system's design to ensure service delivery, and evaluated the system's demand distribution throughout its design period. It had also examined the performance of each basic components in detail.

A variety of approaches were employed to oversee the objectives set in accordance with internationally and nationally recognized scientific approaches. To ascertain whether the source's capacity can guarantee the necessary supply throughout the design period, the demand of the beneficiaries was assessed. Throughout the pipe layout, the allowable pressure and velocity was determined, which governs the pipe nominal pressure and diameter size. Assessing for capacity of the electromechanical equipment was also the other component for which the system performance determined comparing the calculated pump and power plant parameters such as pump head, design discharge and power plant against the existing mentioned parameters and capacities. Following an assessment of the gap and the effectiveness of the current systems, the study went on to look for intervention mechanisms using a systematic design review and key management performance indicators. Based on the particular findings, these tools were used to provide appropriate recommendations that aid in problem solving.

1.2. Statement of the Problem

According to MoWIE (2021) the non-functionality rate of rural water supply schemes, 29,204 (19%) of the 155,482 total rural water supply schemes that were identified at the time of inventory were non-functional for a variety of reasons. There are 27,476 on-spot schemes out of the total non-functional schemes, meaning that on-spot water supply schemes account for 17.67% of the non-functionality while sources of rural piped water supply systems account for 1.1% (1,728 in number) whereas non-functionality for rural piped system (RPS) sources is 13.8%.

Based on the information obtained from the study area's water supply development sector, the groundwater potential of the district is inadequate, with maximum yield of 6 l/s at restricted localities. Scarcity of potential sources in the area therefore forced the government to adopt the Saqata spring sources with 100 l/s yield from single point and used to reach the villages in Burka Dhintu woreda and Teyfe town. The project 1st stage construction was completed 1n 2010 but malfunctioned without giving any service due to submerged of surface pumps with floods in the source area and uncontrolled main pipe line leakage at various of its sections. Later it was redesigned and accordingly construction completed in 2023 to solve the water supply shortage of eight rural kebeles and two small towns, with the total of 69,699 beneficiaries.

But according to the utility's annual report (TMVWSP,2023), problems like unequal water distribution among consumers, significant pipe leakage along main and branching pipe lines, and high operating expenses of the electro-mechanical equipment appeared as critical challenges of the system. Because of the aforementioned issues, only 47.65% of the estimated total population has access to water; as a result, comprehensive intervention is required to assure the scheme's sustainability. Thus, it is essential to identify the underperforming components of the system and then undertake a redesign to replace, augment, or reposition the assets as necessary in order for the system to provide the originally anticipated services. Thus, the purpose of this study is to forward solution for the current existing problem.

1.3. Objectives of the Study

1.3.1. General objective

This study's overarching rationale is to pinpoint the challenging issues of Teyfe Multi-village water supply system as a whole and then to propose the best course of action to improve system performance and service delivery.

1.3.2. Specific objectives

i. To undertake demand analysis of Teyfe Multi-Village water supply system
ii. To assess the performance of Teyfe MVWSP components
iii. To propose interventions for the Teyfe MVWSP system improvement

1.4. Research Questions

In line with the stated specific objectives, the research tried to get answers to the following research questions.

i. What is the total demand of the beneficiaries at the end of the design period?
ii. Are the components of Teyfe MVWSP performing as required, to sustainably serve the user communities?
iii. What types of interventions are required to improve the water supply service of the system?

1.5. Significance of the Study

In this study, the components of the water supply were evaluated against their specific parameters following all the engineering principles and ethics for the intended design horizon and latter compared with the existing system to identify the gaps and formulate the solution as required. Thus, the findings of this study are crucial for the water supply sectors in charge of overseeing the system and guaranteeing the sustainability of the dependable water supply service. Moreover, the study will benefit the water users, if the existing problems, such as high leakage of pipes, significant power consumption of power plants and intermittent water distribution improved as per the finding. The data gathered for this study may also assist the government or any agency planning for project expansion or upgrade wherever needed. It can also facilitate bases for further research works to optimize the working efficiency of the system in one way or the other.

1.6. Scope and Limitations

The research assessed the performance level of the whole water supply system components according to the required engineering evaluation criteria such as demand distribution system, capacity of reservoirs and electromechanical equipment, pipe size, material and pressures at junction points and booster station arrangements. Design review of existing system to optimally utilize assets is another part of this research.

The component structure construction quality, system-wide water quality analysis, business plan and financial systems, or economic analysis are all outside the scope of this study. Proposal of intervention mechanism based on utility management performance through selected key performance indicators and design review on some components of the system were also included in this research work.

Distribution line Construction methods was taken as one of the area of studies which gives due consideration to the pipe material allocated along the line routes, formation type over which the pipe laid, trench depth and bedding system. From above mentioned check lists trench depth and bedding system not mentioned on the typical drawing and profile of existing as- built drawing and this was taken as limitation for studies. To solve this information was gathered from utility staff who engaged in the construction from the very begging and maintenance history records of utilities.

1.7. Thesis organization

The main body of the Thesis is classified in to five chapters and started with an introduction which includes background of the study, statement of the problem, objectives of the study, research questions, delimitation and limitation of the study and Thesis organization. Literature review is the second chapter which presents the comprehensive development of the problem background. In the third chapter Materials and methods of studies used to materialize the research were included. Result and discussion are the fourth chapter where the analysis of data presented indicated using the proposed methodologies and materials in different forms. The fifth and final part of the study are conclusion and recommendations which the summary and reflections given based on the result of the thesis.

CHAPTER TWO: LITERATURE REVIEW

In this chapter, a number of literatures pertaining to the performance and identify intervention mechanisms of multi-village water supply systems were reviewed in order to provide insightful information for the research work, which had taken into account basic parameters like source capacity, demand for water supply, and the effectiveness of the system's individual components in providing the necessary services.

2.1. Water supply Coverage:

Access to water is vital for sustainable human socio-economic development .Water supply coverage is defined in its broad terms as addressing maximum water demand equitably at required proximity and quality to all needy peoples.

2.1.1. Rural Water Supply Coverage

According to Sustainable Development Goal (SDG) by 2030, under clause 6.1 calls for the complete coverage of safely managed drinking water. The indicators of "safely managed drinking water" are: it must be contaminant free, available on-site when needed, and accessible when necessary (Hutton, 2016).

In the first UN Water Conference in almost 50 years, attendees at the United Nations Water Conference stressed the need for more action to provide fair access to water for everyone and according to the report the current trends shows that, despite advancements, the globe falls short of achieving the SDGs relating to water. 2.2 billion People lacked access to securely managed drinking water, 3.5 billion to safely managed sanitation, and 2 billion to even the most basic hand hygiene facilities (UN, 2023). The survival of these people on a habitable Earth hinges on funding efforts to address the water issue as it devoid of basic human rights.

According to the WaSH inventory-II of 2021, conducted by water development commission under Water, Irrigation and Energy Ministry of Ethiopia, rural water supply coverage accounts was 47%. Of all the reported rural water supply systems, over 60% come from groundwater sources, such as hand-dug wells, shallow wells, and boreholes. In addition, the inventory revealed that, of the rural piped systems that are available, 19 % utilize diesel-driven generators to raise water, 65 % rely on gravity, 3 and 2 % employ grid and solar systems, respectively and the remaining 11 % uses mixed energy sources (MoWE, 2021).

2.1.2. Urban Water Supply Coverage

Global urban water supply coverage increased from 85 to 86%, according to the UNCEF/WHO joint monitoring program report, which was conducted to determine the results of sustainable development goal intervention between 2015 and 2020 under the title progress on household drinking water, sanitation, and hygiene (WHO, 2021). The same report indicates that Sub-Saharan Africa accounted for 54% of the total, with Ethiopia barely managing to reach 50%. The main factors contributing to the low coverage of the safely managed water supply service are high water demand, rapid urbanization, shrinking water supply sources, mismanagement of water, deteriorating water quality, low functionality of the existing water supply system components (technical problems), institutional capacity limitations, and a lack of effective and proper planning (MoWIE, 2017).

2.2. Population Forecasting and Demand Analysis

The fundamental factors considered while conducting population forecasting are base population, growth rate and design period of the project. Water supply demand is then calculated using the projected population and water consumption rate of the specified communities.

2.2.1. Design period

The length of design period depends on factors like rate of population growth; fund availability, interest rate in case the fund is from loan and useful life of the facilities or equipment. In economic terms, design period is a period within which long term projected water demands are estimated for a least cost project period; in other words it is the time period in years within which the initial capital outlay and succeeding outlays for expansion and rehabilitation can be rationally recovered or looked for. In general, design periods should be neither too short nor too long. Both cases have their own advantages and disadvantages.

Table 1: Advantage and disadvantage of design period of short and long periods

Design period	Advantage	Disadvantage
Short Period (< 10 years)	✓ Low initial investment cost ✓ Effective use of available limited water sources	✓ Need to upgrade system capacity after few years ✓ Underutilization as most of the water works facilities are more viable to plan for one phase

Long Period (10 -15 years)	✓ Water system facilities are capable to meet demands over a longer period. ✓ No major investment cost is expected in 10- 15 year design period.	✓ High initial capital cost ✓ Requires high initial tariffs & hence challenging affordability capacity of the current community

2.2.2. Population forecasting

Any designed water supply project has its own useful period for which the beneficiaries get adequate services. Hence conducting population projection is the primary step to undertake the demand analysis. Though there are various methods for population projection, the four commonly used are highlighted as follows with their equation.

i. Arithmetical Increase or Arithmetical Mean Method

This projection method gives low value and is generally applicable for wider areas with scattered settlements and low potential for development or already well settled &established communities and hence no more fast growth expected

$P_n = P_o + n\bar{x}$ -- *(2.1)*

Where, *Po* - last known population; *Pn* - population (predicted) after 'n' number of decades; n - Number of decades between *Po* and *Pn* and $\bar{x}$ - the rate of population growth.

ii. Incremental Increase Method

This method is adopted for average-sized towns under normal conditions, where the rate of population growth is not constant i.e., either increasing or decreasing. It is a combination of the arithmetic increase method and geometrical increase method. Population predicted by this method lies between the arithmetical increase method and the geometrical increase method.

$Pn = (Po + n\bar{x}) + ((n\ (n+1))/2)^* \bar{y}$ -- (2.2)

Where, *Po* - last known population; *Pn* - population (predicted) after 'n' number of decades; n - Number of decades between *Po* and *Pn;* $\bar{x}$ - mean or average of increase in population and $\bar{y}$ - algebraic mean of incremental increase (an increase of increase) of population.

iii. Geometrical Increase Method

This method is adopted for young and developing towns, where the rate of growth of population is proportional to the population at present. Therefore, it is assumed that the percentage increase in population is constant. It is similar to compound interest calculations. This projection method gives higher value and is suitable for settlements with good potential for development and large scope for vast expansion.

$Pn = Po\,[1 + (r/100)]^{n}$-- *(2.3)*

Where, *Po* - last known population; *Pn* - population (predicted) after *'n'* number of decades; n - Number of decades between *Po* and *Pn* and *r* – Population growth rate = (increase in population/initial population) * 100 (%).

iv. Exponential method

In this projection method, very high value is generated and could only be used if in addition to reasons under (iii), the baseline population is presumed to be underestimated.

$Pn = Po * e^{\left(\frac{r\,x\,n}{100}\right)}$--- *(2.4)*

Where, Po - last known population; Pn - population (predicted) after 'n' number of decades; n - Number of decades between *Po* and *Pn* and *r* – Population growth rate = (increase in population/initial population) * 100 (%).

2.2.3. Water demand projection

The demand for water supplies rises quickly over time due to factors such as population growth, better living standards, industrial expansion, and climatic change (Wang *et al*., 2016). Rosegrant and Ringler (1999) also described that, there is a projected substantial growth in the non-agricultural uses of water in households, industry, and environmental and ecological targets. Thus, provided demand projections are made appropriately, the water supply system that has been designed can support this rising demand.

Different guide lines, design criteria's and immediate transformation plans are developed for town and rural water supply to use for water supply system designing. Demand projection depending on the consumption rate and mode of services are among for which the criteria's is set. MoWE has provided design guide lines in 2006 for town and in 2021 for rural water supply design.

i. Mode of water service for Rural and towns

The most widely used modes of service are the public tap, shared and private yard connections, and house connections. Table 2 illustrates the indicative projected mode of service for rural water supply (MoWE, 2021), which takes into consideration the likelihood of the project area's potential for development.

Table 2: Forecasted Mode of water service

Likelihood of Project area`s potential for development	Baseline (%)				End of Design period (%)			
	PF	YCS	YCP	HC	PF	YCS	YCP	HC
High	70	20	30	10	50	30	15	15
Medium	80	20			65	25	10	
Low	95	5			80	20		

PF-Public Fountain, YCS –Yard Connection Shared, YCP-Yard Connection Private, HC-House Connection

Source: MoWE, Rural water supply design guideline published in 2021

For town water supplies the published manual used for the design did not states the mode of service percentage over the years. However using existing mode of service data, consultants in Ethiopia have used increasing trend for all modes except public fountain. In the study of Mega town the percentage distribution of the mode of service is shown in Table 3.

Table 3: Forecasted % of Mode of water service, Mega town

Mode of Service	2021	2031	2041
HC	0.5	1.5	2
YCP	2.5	25	50
YCS	3	30	40
PF	94	43.5	8

Source: Oromia Water and Energy Bureau, 2019

Dega town water supply study and design document in Oromia region also used a slightly different mode of service percentages over the design period (ECO, 2017).

Table 4: Forecasted % of Mode of water service, Dega town

Mode of service	2024	2034	2044
HC	2	7	12
YCP	18	20.5	23
YCS	10	15	20
PF	70	57.5	45

Source: Engineering Corporation of Oromia, 2021

ii. Per capita water consumption

The amount of water used per person varies depending on a number of factors, including the mode of service, water use culture, level of service, community size, standard of living, quantity and quality of water, water tariffs, and long and seasonal term climate conditions. Rural water supply per capita water consumption is taken as 135 l/c/d, which is too large when compared to MoWE design criteria (Rangaiah et al., 2021). MoWE guidelines and design requirements were also issued in 2021, along with a per capita production that took the previously mentioned elements into account.

Table 5: Per capita water consumption pattern over the design period for rural community

Mode of services Type	**Per capita demand L/c/d**		
	Initial	**10^{th} years from**	**15^{th} years from**
On spot schemes	25	25	25
Public tap(PT)	25	30	30
At premise shared (YCS)	35	40	40
At premise private(YCP)	40	45	50
House connection(HC)	50	55	60

Source: MoWE, Rural water supply design guide line published in 2021

MoWE also has the 2006 published design criteria manual for town water supply and the per capita water consumption rate is indicated in the Table 6.

Table 6: Per capita water consumption pattern over the design period for urban in L/c/d

Mode of services Type	**Stage 1**	**Stage 2**
House connection (HC)	50	70
At premise private (YCP)	25	30
At premise shared (YCS)	30	40
Public tap (PT)	20	25

Source: MoWE, Town water supply design guide line published in 2006

iii.Demand categories:

Domestic water demand

Domestic Demand is the demand for household use to satisfy basic physiological, hygienic and environmental needs. These are water required for drinking, cooking, bathing, washing cloth, and minimal garden watering. Livestock demand unless used for commercial purpose is also included in domestic water demand. It was the portion of water supply, which is used in the home and the largest portion of the total demand for most water systems (Keshavarzi et al., 2006). Equation 2.5 illustrates domestic water demand is determined by population, service mode types, and per capita water demand.

Domestic demand (DD) =P x PCD X PSM-- *(2.5)*

Where; *P*= population in number; *PCD*= Per capita demand in *L/C/D* and *PSM*= Percentage of service mode in *%*.

Non-Domestic water demand

Water is necessary for the daily operations of other socioeconomic activities. Water needed for businesses, public and commercial organizations, industry, livestock (if necessary), and other uses is considered non-domestic water demand. Like the requirements for residential water, each of these categories has unique water requirements that change over the design phase. These need to be evaluated, forecasted, and added in order to get the overall water demand estimate.

One method used to ascertain the non-domestic demands is gathering baseline data on the number of institutions in the project region, as well as commercial demands from establishments like markets, hotels, and restaurants. On the other hand, it is also possible to forecast demand as a percentage of domestic demands. In accordance with the guidelines developed for the technical design of rural water supply, institutions and the general public may use two to six percent of household consumption.

Non-Revenue water (NRW)

Non-Revenue water (NRW) is water produced (thus resulting in expenses) but not billed due to leaks, overflows, theft, arbitrary free provision, utility usages, etc. NRW ratio in water distribution networks determined also as the ratio of losses from unbilled authorized consumption and apparent and real losses to the total water supply. The international benchmarking network for water and sanitation utilities (IBNET) provides information from over 900 utilities that are operational in 44 developing nations (Kanchana et al., 2018). This database indicates that in the countries under consideration, the average percentage of NRW is about 35% which significant Figure and made impact on water supply demand and operational management. Therefore, a provision should be established, otherwise, the intended source capacity would not be adequate to meet the customers' consumption needs. According to design guide line (MoWE, 2021) for rural water supply, the NRW classified as for on spot schemes, RPS with greater than 15 km and less than km as shown in Table 8.

Table 8: NRW classified for rural water supply based on scheme type

Water supply system size	**Planned**	**NRW at start**	**NRW at end (%)**
On spot schemes	Up to 500	5	5
RPS with pipe less than 15km	Up to 10000	18	15
RPS with pipe greater than 15km	> 10000	20	15

Town water supply also adopt % of NRW of decreasing order with narrative of anticipated skill development of the operation and maintenance team to improve against the factors favor NRW increment such as old age of pipes. Based on this proposal the estimated NRW % in terms of total water consumption was shown as follows.

Table 9: Losses as % of total water demand

Start year	5 years	10 years	15 years	20years
40	35	30	27.5	25

Source: MoWE, Town water supply design guide line published in 2006

The percentage of NRW can be also easily determined using water production and consumption data as indicated in the equation 2.6.

$$NRW\,(\%) = ((YWP - YWC) / YWP)*100 \text{ -- } (2.6)$$

Where: *NRW* = Non-revenue water (in % of production); *YWP* = Yearly Water Production (m^3 /year); *YWC* = Yearly Water Consumption (m^3/year)

iv. Water supply demand variations

The average water demand changes on hourly, daily or weekly bases due to various factors among which particular occasion such as holidays, season (Bergel et al., 2017), price of water consumption (Koledo, 2016) and climate (Chang et al., 2014). The capacity of the system components therefore capable of managing the demand variation due to the aforementioned other factors as required. Average water demand: The sum up of domestic and all non-domestic demand gives average water demand (Venkatesshawara, 2005)

$$ADWD = DWD + NDWD\,(PWD+IWD+CWD+LWD) + NRW \text{------------------------------ } (2.7)$$

Where: *ADWD*-Average day water demand, *DD* –Domestic water demand, *NDWD*-Non-domestic water demand, *PWD*-Public water demand, *IWD*-Institutional water demand, *CWD*-Commercial water demand, *NRW*-Non –revenue water and *LWD*-Livestock water demand.

Maximum day demand: One of these demand circumstances, known as maximum day demand (MDD), is the greatest amount of water needed in a single day over the course of a year. The reality that different regions have widely differing climates and that there is year-round variation in water use. Peak seasonal parameters are anticipated to be impacted by climate change, with greater temperature differences leading to higher water demands during the warmest times of the year. In addition to seasonal fluctuations, a lot of communities show a demand cycle wherein certain days of the week have stronger demand than others. The maximum day factor (MDF), which is defined as the quotient of maximum day demand over average day demand, will be applied in this case.

MDD = MDF X ADD--- *(2.8)*

Where: *MDD*-Maximum day demand, *MDF* –Maximum day factor and *ADD*- Average day demand.

Peak hour demand: Water demand also varies greatly from hour to hour during the day. This is termed as Peak hour demand and represents the highest hourly demand in a single day. The hourly variation in domestic water demand during the day is much greater and practically, two peak periods can be observed: One in the morning and one late in the afternoon. The peak hour demand can again be taken into account with the use of hourly peak factor (PHF), which is expressed as the quotient of Peak Hour Demand over a Day of maxim Demand, often expressed as peak of the peak expressed as quotient Peak hour demand over Maximum day demand.

PHD= PHF X MDD--- *(2.9)*

Where: *PHD* - Peak hour demand and *PHF* – Peak hour factor

The peak hourly demand is usually estimated by adding allowances to ADD or MDD based on population size.

Table 10: MDD and PHD demand factors according to 2021 rural design manual

Demand parameters	Demand factors
Minimum day Demand	0 to 0.3 of the average day demand
Average day Demand(ADD)	1.0
Maximum Day Demand(MDD)	1.1 to 1.5 of ADD
Peak hours demand(PHD)	1.5 to 2.0 of MDD(for Population>15,000)
	2.0 to 2.5 of MDD(for Population<15,000)

Source: MoWE, Town water supply design guide line published in 2021

For town water supply the study guide line produced by MoWE (2006) fixes the hourly variation based on the population size.

Table 11: Peak hour demand factors used for water consumption

Population range	Peak hour factor
< 20000	2
20001 to 50000	1.9
50001 to 100000	1.8
> 100000	1.6

Source: MoWR, Urban Water Supply Design Criteria, 2006

2.3. Rural piped Water supply system components

Most of the rural water supply systems have similar basic components such as sources (spring, surface water with treatment plant, boreholes), pipes, valves, reservoirs, water points and electro-mechanical equipment.

2.3.1. Water sources selection

Water enters the system volume through the sources, which are the fundamental part from which the other components help it reach the user community. When choosing the sources, important variables such as water quality, capacity, economic viability, and sustainability in the future are taken into account. Thus, given the opportunities that are available, it is a comprehensive strategy to address difficult issues and a way to combine a number of variables and models to include all relevant interacting elements in the decision-making process (Al-Zubi et al., 2002). As long as all other basic requirements are met, water sources should be able to meet the community's daily maximum demand where Source capacity is equal to MDD.

2.3.2. Service reservoir

Service reservoir is one of the integral part of the distribution system used to meet the fluctuating demand with constant rate of supply from source or treatment plant. It has also advantages of managing pressures, reduce pump working hours and store water to be used during emergency cases. In addition to using appropriate materials for construction, the reservoir's location must command the suggested areas with adequate head and maintain the necessary services.

Following the MoWE of Ethiopia's technical guidelines, 1/3 to ½ of the MDD is used to calculate the reservoir's volume. Nonetheless, the system's water balance or pumping rate is properly taken into account for wet wells.

$$RC = MDD \times 1/3(\text{minimum}) \text{ to } MDD \times 1/2 \text{ (Maximum)} \quad \text{------------------------------------} \quad (2.10)$$

Where; *RC* – Reservoir capacity, *MDD*- Maximum Day Demand

2.3.3. Hydraulic Analysis

The primary fundamental principles of fluid flow that control the flow through pipe networks are the conservation of mass, energy, and the head loss of the pipe produced by friction. When discussing the conservation of mass, the total mass of all flows entering a network of pipes is equal to the total mass of all flows exiting the networks at points of consumption or junction. A term for the accumulation of water at such needs is provided in case the storage is used in the extended period simulation. The mathematical representation of the conservation of mass is:

$\sum (Qi - Ui) - ds / dt = 0$ -- *(2.11)*

Where: Qi - inflow to node in the ith pipe (m/sec^2); Ui - water used or leaving at the ith node ((m/sec^2) and; ds / dt is change in storage (m/sec^2)

With regard to conservation of energy Bernoulli's equation of flow properties is basically used with the principle of the difference in energy between two points in a network must be the same regardless of the flow path (Walski et al., 2003). This will be true if the fluid assumed incompressible. It consists of the pressure head, elevation head, and velocity head. There may be also energy added to the system (such as by a pump), and energy removed from the system (due to friction). For hydraulic analysis, this principle can be represented in terms of a head as Equation. 2.12:

$Z_1 + P_1 \gamma + V_1{}^2/2g + \sum h_p = Z_2 + P_2 \gamma + V_2{}^2/2g + \sum h_l + \sum h_m$ ----------------------- *(2.12)*

Where: $Z_1$and $_2$=elevation at point 1and *2* respectively (m); $P_1$and $_2$ = pressure at point 1and *2*, respectively (N/m^2); γ =fluid (water) specific weight (N/m^3); $V_1$and *2* = Velocity at point *1* and *2* respectively (m/s); g = acceleration due to gravity (m/sec^2); *hp* = pumping head gain (m); h_l = head loss in pipes (m) and h_m = head loss due to minor losses (m)

Friction loss in pipes: The main element influencing water flow in pipes is head loss. It is related to pipe diameter, pipe material, flow velocity, and discharge amount. The Colebrook, Hazen-Williams, and Darcy-Welsbach empirical equations are frequently employed. According to Lahiouel et al. (2005), the head loss in smooth pipes that maintain a laminar or transitional flow well predicted using both the Darcy-Wesbatch and Hazan William head loss formulas than turbulent flows. The most widely recognized theoretically correct formula is the Darcy-Welsbach formula. It is applicable to all types of fluids and to general flow regimes. Nonetheless, the Hazen-Williams formulas are widely utilized in the design of water supplies.

$hl = 10.7\, L\, D^{4.87} * (Q/C)^{1.85}$ -- *(2.13)*

Where: *hl*= head loss due to friction (m); *L*= Length of pipes (m); *D*= Pipe Diameter (m); *Q*= Pipe flow rate (m3 /sec) and *C*= Hazen-Williams Coefficient (Dimensionless)

2.3.4. **Water Supply System Modelling and Simulation Software's**

WaterCAD, EPANET, Cybernet , H_2ONET and WaterGEMS are among the available software widely used for analysis of water distribution system.

EPANET software: used to model water quality phenomena as reactions within the bulk flow and reactions within the pipe wall. The hybrid approach has at least partially addressed the low-flow convergence issues inherent in node-oriented systems, and the program's solution methods are incredibly quick. It displays an eye-catching output mapping with color coding. With the help of this program, head loss, pressure, and water quality of the distribution can generally be accurately reproduced. Comparing EPANET to commercial modeling packages, the only drawback is that data input is done using a text editor.

WaterCAD Software: produced and marketed by Haestad Methods of Waterbury, Connecticut, is a stand-alone hydraulic modeling program containing its own graphical editor and strong modeling capabilities that features a Windows-based interface to EPANET. WaterCAD can produce a distribution system network either scaled or schematically and with or without underlying DXF background maps. The resulting network has sufficient annotation capabilities in WaterCAD, and it can be color-coded to indicate modeling results. A scenario management tool, the ability to analyze fire flow and water quality, and the ability to graph and profile model results and system appurtenance characteristics are just a few of the modeling tools offered by WaterCAD. In addition, it has the capacity to create contour plots that illustrate high pressure zones, low fire flow availability, hydraulic grade line elevation, and numerous other important system characteristics. The software also offers simulation evaluations for both extended periods and steady states. Tables that are immediately integrated into the modeling environment are used by WaterCAD for both data entry and output, in place of a text editor. To provide data for the model, input may be written to and output can be written from these tables using database connectivity feature. Furthermore, WaterCAD can import and export model data via the shapefile to interact with the GIS program from Environmental Systems Research Institute, Inc. (ESRI).

Cybernet Software: The hydraulic modeling features of Cybernet, which is likewise developed and distributed by Haestad Methods, are identical to those of WaterCAD, but it can function inside the AutoCAD environment for Windows. In other words, Cybernet is essentially WaterCAD. All of AutoCAD release 14's features are available to the user in this operating environment, enabling graphical compatibility with other drawings created inside an organization. Along with the modeling results, the AutoCAD environment provides the program with far more graphical flexibility in producing high-quality graphical output.

H_2ONET Software: is a modeling program provided by MW Soft, Inc., a software subsidiary of Montgomery-Watson out of Pasadena, California, which features a Windows-based AutoCAD interface to EPANET. Like Cybernet, H2O NET uses the AutoCAD release 14 environment to create network model drawings with all the capabilities of AutoCAD; however, H2ONET requires AutoCAD and cannot operate as a stand-alone program. H2ONET provides a large range of modeling capabilities, including scenario management, fire flow modeling and fire hydrant analysis, and water quality analysis. Some of the features that set H2ONET apart include a supervisory control and data acquisition (SCADA) interface, which allows for the extraction of real-time modeling data directly from a SCADA system in an ASCII format for use in model calibration and operator emergency response training; and an energy management module for use in identifying the most energy-efficient and cost-effective operational policies.

WaterGEMS Software: has become a widely adopted and recognized software solution in the water industry, used by water utilities, engineering consultants, and researchers worldwide. The key advantages of WaterGEMS over other software's is mentioned below

Hydraulic Modeling Capabilities: Offers more advanced hydraulic modeling features compared to others. It has improved capabilities for modeling complex water distribution networks, including support for extended period simulation, water quality analysis, and advanced optimization algorithms.

Geospatial Integration: Has stronger integration with geographic information systems (GIS) data, allowing users to directly import and utilize GIS data in their hydraulic models. This streamlines the model building process and improves the spatial accuracy of the analysis.

Scenario Management: Provides a more robust scenario management system, making it easier to compare and analyze multiple alternatives or "what-if" scenarios. This is particularly useful for evaluating the impact of infrastructure changes, operational strategies, or demand patterns on the performance of the water distribution system.

Optimization Tools: includes advanced optimization tools, such as pumping cost optimization and water quality optimization, that can help users identify the most efficient and cost-effective solutions for their water distribution systems.

User Interface and Visualization: Generally has a more intuitive and user-friendly interface compared to others, with improved data visualization and reporting capabilities. This can enhance the overall user experience and make it easier to interpret and communicate model results.

Scripting and Customization: provides more options for scripting and customization, allowing users to automate repetitive tasks, create custom reports, and integrate the software with other applications or data sources.

Therefore the capability and new package used for hydraulic analysis make the WaterGEMS more preferable than others and currently used by most of the concerned professionals.

2.3.5. Pump data and capacity determination

Pumps are hydraulic devices that transform rotational mechanical energy into hydraulic energy for the purpose of raising water to higher altitudes from where water is distributed to predefined pressure zone delineated. Using either electrical power (motor) or solar, diesel, or steam energy can be produced to run the pumps.

Pump data: the pump is designed to lift the required amount of flow rates to specified elevations with adequate efficiency. In another terms maximum day demands, total imparted heads and pump efficiency are the major data required for fixing the pump capacity. The total heads includes friction head through transmission pipe line, valves and fittings, delivery head extending from dynamic water level to highest level of reservoir and suction head if there is any. The overall efficiency of a pump is the product of three individual efficiencies mechanical, volumetric and hydraulic. Mechanical efficiency includes losses in the bearing frame, stuffing box and mechanical seals. Volumetric efficiency includes losses due to leakage through the wear rings, balancing holes and vane clearances in the case of semi open impellers. Hydraulic efficiency includes liquid friction and other losses in the volute and impeller. Since energy cost is much related with the pump efficiency and has crucial effect on running costs Araceli M et al., (2019) suggested that energy costs are proved to be a great fraction of the full cost of the installation, and they need to be considered from the first phase of the design.

Pump capacity: The capacity of the pump is a function of the fluid unit weight, total head to lift water, flow rate amount and pump over all efficiencies as shown in the equation 2.14.

$$Pc = \gamma QH/\mu \text{ --- } (2.14)$$

Where: Pc= pump capacity in kw; γ- Unit weight of water in KN/m^3; H- Pump total head in m; Q- Flow rate in m^3/s and μ - pump efficiency varying from 0.65 to 1

In order to reduce the impact of altitude and ensure the safety of the pump the pump capacity is increased by 12% and 10% respectively. At the point of discharge, the total head (H) is the sum of the static, friction, and velocity heads; the pump's discharge (Q) is the maximum volume of demand divided to working hour of the pump. In case of direct pump feeding maximum day demand should be replaced with peak hour demand.

The impact of impeller speed and diameter on center fugal pumps has a substantial input on power consumption and pressure, with rates of 23 & 22% and 33 & 21%, respectively (MoWE, 2021). For this reason, care should be taken while assessing the performance of the pump.

Pump performance curves are often used to identify or anticipate changes in process parameters (such as flow, differential head, efficiency, power consumption, etc.). They can be produced and received from the original equipment manufacturer.

2.3.6. Power plants

Transformers or power generating plants such as solar and diesel generators are very essential to run the pumps whenever required. The capacity of these plants depending mainly on pump capacities. For transformer sizing resulting maximum. Steady load power in KVA and permissible loading percentage (%) are required and determined in equation 2.15.

$$PT = (Prmsl \times 100)/\text{Permissible loading percentage } (\%) \text{ -------------------------- } (2.15)$$

Where: *PT* =Trans. Rating (KVA); *Prmsl*=Resulting Max. Steady load power in KVA and Permissible loading percentage (%) for Oil type 80% and Dry type 90%. In case of Dispel generator power sources an allowance of 150-300% of pump motor capacity used to determine the power capacity (MoWE, 2021).

2.4. Model Calibration and Validation

Model simulation tools may contain uncertainties from many angles, which could cause their output to deviate from the real measured data. As a result, it calls for adjusting various model-setting parameters. Parameter adjustments are made until the model is deemed appropriate and that is termed as model calibration. Comparing the model's behavior after calibration to that of the actual system is the process of validation.

The uncertainty of the results from water distribution network modelling is caused by many factors, which can be classified according to Hutton et al., (2014) in structural, measurements and parameter uncertainty. Structural uncertainty is related to the representation of the real system, such as model aggregation. Measurement uncertainty concerns the inability of measurement devices to capture the temporal and spatial variation of consumer demand and to errors related to the measure itself. Parameter uncertainty refers to the errors of the choice of variables used to model the system. According to Kang and Lansey (2011), pipes roughness and water demands are the most uncertain input parameters in a hydraulic model because they are not directly measurable. Moreover, given also the general lack of information regarding the hydraulic state of the networks, the calibration problem is typically ill-posed, meaning that the number of measurements is much smaller than the variables.

Determining whether to employ extended simulation or steady state model simulation is crucial for managing the parameters that need to be changed. The model parameters were calibrated in a steady state to correspond with the pressures and flow rates found in the static data. Over the course of a lengthy calibration process, the model's parameters will be changed to account for fluctuating pressures, flows, and tank water level trends. Most of the time, changes in pipe roughness will be more noticeable in the steady state calibration, while changes in the distribution of demands will be more noticeable in the extended period calibration. Therefore, one possible calibration strategy can be to use the pressure and flow test results from the physical network to fine-tune the pipe roughness parameter values, and then use the flow, pressure, and water level telemetry data to try to fine-tune the distribution of demands (Ormsbee & Lingireddy, 1997)

The process of validating a model involves contrasting its output with numerical data that has been independently obtained through experiments or filed observation. The correlation coefficient equation will be used to manually validate the model.

$$R^2 = \sum (x-\bar{x})(y-\bar{y}) / \sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2} \text{--} (2.16)$$

Where: R^2=correlation coefficient; X and y are the simulated and field measurement pressure values respectively and $\bar{x}$ and $\bar{y}$ are the average value of simulated and field measurement pressure values respectively. Coefficient of determination (R^2) describes the degree of linearity between simulated and measured data. R^2 range between 0 and 1, which describes the proportion of the variance in the measured data and is explained by the model, higher values indicate less error variance. Typically, $R^2 > 0.5$ is considered acceptable (Santhi et al., 2001).

2.5. Water supply scheme Operational management

Once the water supply scheme constructed and made ready for service, adequate management systems need to be established. These includes administration, operational and financial management to ensure the sustainability of the system for the proposed design period. According to the document of rural water supply operation and maintenance strategic frame work MoWE (2018), ownership development, status of managing bodies, technology choice, operation and maintenance management, technical service support, community mobilization and capacity building, supply chain, financing and monitoring and reporting are among the major factors that must be given due consideration to cater the challenges regarding operation, maintenance and management of the water supply schemes.

There has only been one model for continuous service delivery in rural regions, which is the community WASH Committees (WASHCOs), with the exception of self-supply. Public water utilities may be designated to administer urban networks in towns, while Rural Water Boards are becoming a more popular management model for multi-village projects (MWA, 2019). For town water supply utilities IWA , AWWA,WB and MoWE and others have their own performance indictors which is used to evaluate the management of the water supply system from perspective of Water Resources/Environmental, Physical/Asset, Personnel/Staff, Water quality/public health, Operational, Quality of service/ customer service and Economic/financial/pricing.

Performance indicators for developing countries: according to the Bangladesh Government, due to lack of effective management the water supply utilities are not performing well. The water sanitation program in South Asia (WSP-SA) helped improve the performance and benchmarks for water utility project. The concept of performance benchmarking was introduced in June 2005 for 11 utilities that can serve 21000 to 10,000 people (Haider, et al., 2014). Similar study conducted by World Bank to assess the program effectiveness over 30 urban water utilities through Bangladesh, Pakistan and Indian under WSP-SA (WB, 2011). In these countries, water supply provision of utilities are five hour per day. Because of three-year period (2006 -2009) of the benchmark performance evaluation process, Rajkot, India increased by 48% in billing and 31% in collection. Whereas the benchmarking process in South Asia countries is currently focused on metering water demands and revenue collection to achieve the operational and financial requirements (WB, 2011).

2.5.1. Ethiopian utility Management Performance Module

Ethiopian MoWE(2013) has also prepared performance indicator module to evaluate utility management performance using selected key performance indicators categorized in three major parts: Customer satisfaction, Water resource management and Financial management

Customer satisfaction

$$\textit{Access addressed of 2024} = \frac{population\ served\ at\ recomended\ distance}{projected\ population\ for\ 2024} \text{ ----------- } (2.17)$$

Water resource management

$$\textit{None revenue water} = \frac{supplied\ water - billed\ water\ for\ consumption}{supplied\ water} * 100\% \text{ ------ } (2.18)$$

Financial resource Management

$$\textit{Cost recovery} = \frac{Revenue\ collected\ in\ Birr}{operational\ cost\ in\ Birr} \text{ -- } (2.19)$$

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Project Location

Teyfe Multi-Village water supply system is situated in the Southeast of the of Oromia region, West Hararge zone, Burka Dhintu district. Teyfe town, the capital of the district, is the largest rural town within the project's boundaries. The town is located at 460 km from the capital of the Oromia regional state, Addis Ababa, and at 150 km from Chiro, the capital of the Zonal division. Using the projection of the universal transverse marketer (UTM) adindan datum of zone 37, the command area is bounded between geographic grid coordinates of 70200 and 78300 m Easting and 88100 and 95980 m Northing. The system service area is stretched along the south west direction between Sakata and Dhungeta valley in the NE and SW parts, respectively. It comprises eight rural kebeles and two rural towns. The project kebeles are Meta Arba, Kurfa Roko, Kurfa Galma, Dhadacha Hina, Teyfe, Burka Ramis, Burka Oda and Walda Siso.The current total beneficiaries is counted 53136 according to the data gathered from utility.

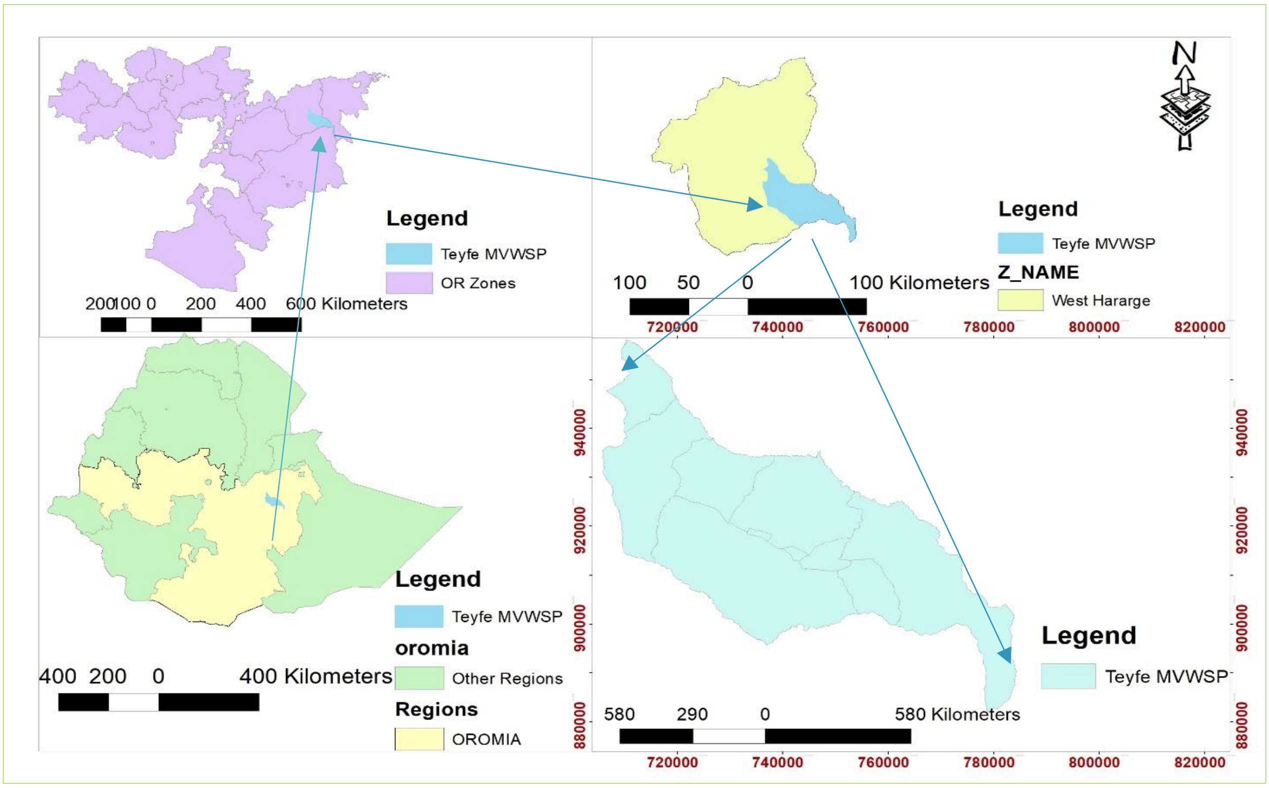


Fig. 1: Location map of the study area

3.1.2. Topography and Drainage

The topography of the project area is plain land of gentle sloping with a valley about 15km before reaching Teyfe rural town. The altitude of the project area varies from 1693 m.a.s.l (at the reservoir site) at Meta Arba extending up to 1400 m.a.s.l at the rear end of the project distribution line in Burka Oda kebele (LGDCP, 2020).

3.1.3. `Climate of the Project Area

The project area can be classified majorly as warm Temperate and few portion fall under Temperate Climate category with mean annual temperature between 18^{o} C and 27 ^{o} C and mean annual rainfall is ranging from 1000mm -1250mm as per the data obtained from woreda Agricultural office. The nearest metrological station is found in Bedesa town having a distance range of 70-143km from nearest to far end of the project catchment or reach (BDWAO,2024).

3.1.4. Existing Water Supply System

The existing water supply system is a motorized spring with estimated discharge of 61.8 l/s out of which only 30 l/s currently utilized. Four booster station equipped with four submersible and five surface pump and power plants from hydroelectric power and diesel generator installed at all pumping stations. uPVC, HDPE and DCI Pipes having diameter size in the range between 100mm-250mm laid with necessary fittings and valves. The existing reservoirs have capacity of 150, 300(2), 400 and 1500 m^3 and one elevated concrete tanker with capacity of 250m3 also constructed to give services. As point of water collection 31 public fountain with six faucet constructed for different villages in the corridor of the projects (LGDCP, 2020). See Annex-1 for detail of the aforementioned components.

The system was administered by utility established at woreda level and technical personnel's and skilled man powers such as electro-mechanical engineers, plumbers and water supply engineers existing at woreda water and energy office used to give service where ever required.

Revenue was collected using the water seller selected from community in volunteer and money deposited in utility account at the end of every weeks. Annex -8 shows water production, billed amount of water, revenue collected and office expenditure since the project was begun to give services.

3.2. Materials Used

Different types of materials were used for the collection, analysis and evaluation of data from different sources and from project sites. The materials used are shown in Table 12.

Table 12: Materials/Tools will be used for data collection and analysis

S/No	Material/Tools type	Purpose
1	GPS	To Collect location data at site level
2	Pressure gauges	To Collect pressure readings at water points and Nodes
3	meters	To measure length wherever required
4	Water meter	To measure pipe flow rate
4	WaterGEMS software Supported With arc map	For modeling and to conduct hydraulic analysis of the distribution system
5	Arc GIS 10.4	To prepare location Maps and shape files to use as integral part in WaterGEMS for hydraulic analysis
6	AutoCAD 2018	To prepare drawings of the system components
7	Excel spreadsheet	To organize elevation data, nodal base water demand requirement of distribution network simulation and for manual pressure validation
8	Digital Camera	To take pictures /photos during data collection

3.3. Methods of Data Collection

Collection of appropriate data from different sources or directly measuring at filed level is one of the major tasks in any research works. In its broad classes these data can be classified as Primary and secondary data. Primary data are those data collected by investigator directly using different methodologies such as direct observations or measuring and personal interviews. secondary data collection are those data collected by some other person for various purposes and obtained from government publications, censuses, internal records of the organization, books, journal articles, websites and reports. In the process of data collection check lists and formats will ahead of prepared to systematically gathering and analyzing of the data. Data verification will also conducted to avoid fragmented and unrealistic data.

3.4.1 Primary Data Collection

Source Flow Rate: determining flow rate of the source is very important to check whether it can secure the required demand for the proposed design period or not. Stop watch and containers of known volume in this case the existing wet well were used to determine the discharge of the sources. To minimize errors the data were taken repeatedly and the average of all was taken as representative data.

Existing Electro-Mechanical Data: Existing pump and generator data were not available at office level and hence the basic information of the EME were collected by direct visiting of the stations.

Nodal Pressure Measurement: Measurements of pressure at nodal water locations were made in order to calibrate the water model instruments. Pressure gauge fixed at water point to measure the pressure and adequate samples of the existing water point data were taken.

System Performance Management Data Collection: data were collected in the sort of interviews and questionaries' especially from beneficiaries at house hold level or group discussion applying systematic approach of sample sizing. 5% of the beneficiary kebele adopted but including kebeles with different pressure zones is an obligatory to reach all the system service area and from selected kebeles the household sample is taken as per the equation 2.20.

$$ni = \frac{NiS}{N} \text{--} (2.20)$$

Where, *ni*= number of samples for each village, *Ni*= number of households in the village

$$S\ (\text{Total number of sample}) = \frac{sum\ of\ house\ hold\ numbers\ in\ the\ village\ x5}{100}$$

3.4.2. Secondary Data Collection

Population Data: Beneficiary population of the scheme were gathered from the utility administering the system. CSA report, Kebele administration and woreda finance and economic development office are also the other alternative sources to obtain population related data such as base population and population growth rate.

System lay out Data: The major components in the water supply system lay out data are pipe data, reservoir capacity and location and data for control valve with their protection chambers. The pipe network data includes length, diameter, pipe material, ages and related fittings of pipes. With regard to reservoirs its capacity, depth, ground elevation and its distribution are the major information required. Control valve types, capacities and locations are also other important data given due consideration. These all data obtained from as built drawings found in water utilities established at woreda level and the project implementing entity, Oromia water and energy bureau.

Water Production and Consumption Data: Water production is easily accessible as utilities collect it on a monthly or annual basis from a water meter that is positioned at the source area. Water points comprise the majority of the existing service method in this multi-village rural water supply, with regard to water usage. As a result, the utilities became the focal focus of this data source since the water usage at the 31public fountains currently in use is gathered and reported to them.

Topographic Data of the Pipes and Other Component Structures: Almost all the hydraulic analysis of the water supply system use topographic data as the major input. Therefore it is important to have detail topographic data comprising elevation and location data. These data are at large used during design and implementation and kept safe for future works such as project expansion and upgrading, the client of the project and utility of the system can avail the required data.

3.4. Water Supply Demand Analysis Methods

The basic elements used for the analysis of demands are forecasted population, unit rate consumption, type of demand category and mode of the service adopted. For population projection different methods adopted as per the beneficiary under consideration which includes the socio-economic factors in to consideration. According to MoWE (2021) guide line different alternative population projection method mentioned but geometric progression method was applied as per equation 2.3 in this study case because most of the consultants and government offices used it taking in to account high reproduction trend of the community under consideration. Utility has identified the current number of users in each beneficiary village and hence it was used as base population for projection.

The per capita consumption is taken from design manuals as shown in Tables 5 and 6 for rural areas and towns, respectively. Regarding mode of service medium level distribution proposed based on the likelihood of project area`s potential for development as described in Table 4 for rural villages. Once domestic demand determined, using equation 2.5, non-domestic demands were computed from it in percentage. Total day water demand was eventually derived by adding up all of the domestic and non-domestic demands. Equation 2.6 was used to provide allowances for the NRW analysis from total day demand and summing up all this demands, the average day water demand was analyzed as per equation 2.7 which is also called base demand of the community under consideration.

Demand variation: Due to different factors, the demand can vary over the hours of the days, weeks, monthly bases and seasons. Therefore allowances was made to average day water demand to address for any water consumption going beyond the average demand. According to design criteria published (MoWE, 2021) for rural water supply the daily and hourly factors recommended are summarized in the Table 13.

Table 13: Maximum day and peak hour factors in terms of average day demand

Demand Parameters	Factor of average demand	
	minimum	Maximum
Maximum day demand	1.1	1.5
Peak hour demand	1.5	2.5

3.5. Methods of Performance Evaluation of the Water Supply System

The water supply system consists of various components that work together to ensure that system operates correctly and provides the necessary service. Because the majority of the component systems are interconnected, the loss of one essential component could result in a reduction of service quality or create a complete disruption.

3.5.1. Water Source

Water source is one of the core component of water supply system and according to the standard set, the source's capacity should be sufficient to reach all of the communities. As a result, the community's daily water demand must be met by the current supply, the Burqa Dhintu spring. To determine the source flow rate, stop watch and water container in this case the underground wet well was used. The discharge was then computed and compared to the maximum day demand to determine whether or not the source is sufficient.

3.5.2. Transmission Line

Water is delivered from pumping station to reservoir or any other booster station wet wells through transmission line. Teyfe water supply project has four booster station to reach the entire community. Hence this transmission pipe line was checked to meet for two basic requirements. The first requirement is its capacity to uphold the required maximum day demand between booster stations. The second obligation is its economic viability where the head loss developed during the pump working time must be small enough to reduce pump head which indirectly have relation with running cost of power plants. To check for hydraulic performance of the transmission line WaterGEMS software was used. From obtained output the developed hydraulic pressure within pipe section was checked comparing with the existing pipe nominal pressure.

3.5.3. Distribution Network Pipe

Once the water reach service reservoir distribution line will take water to user communities aided by gravity forces. Model simulation of the pipe network was conducted using existing pipe line data (length between nodal point's, pipe diameters, pipe material, fitting along the line), allocating demand and inserting nodal elevations to WaterGEMS software. The performance of the pipe network checked based on the analysis result where pressure head and velocity expected to fall in the range 10m-80m and 0.6-2.5m/s respectively according to MoWE design criteria. The maximum static pressure was tested during minimum consumption during the night time and minimum pressure checked during the peak hour consumption. With regard to velocity the result was checked for minimum and maximum consumption hours in the network.

3.5.4. Hydraulic Water Model

Modeling Tools: To analyze and improve the existing water distribution system, a model was developed utilizing Bentley WaterGEMS aided with Auto cad 2018. The model considers links (pipes) and nodes as physical characteristics of the system. Existing link information, pipe roughness coefficient and diameter were inserted and for nods base demand and elevation encoded to run simulation. Base demand were distributed over the nodes based on the population size of each village as shown in Annex-2. In case reservoirs or tanks existing in the system tank elevation data, shape of the reservoir and location were the important data encrypted. In the same way pump data such as pump operation schedule, flow rate, head and pump efficiency data were used to simulate the system.
Both EPS and steady state simulation can be used to analyze water supply system. EPS is a dynamic simulation that models the changes in the water distribution system over time. It takes into account factors such as; Variations in water demand, Pump operations, Tank levels and Valve positions.

Steady-state analysis, on the other hand, is a static simulation that models the system at a specific point in time, assuming that all the system's parameters (e.g., demands, tank levels, pump operations) are constant. This type of analysis is useful for; Evaluating the system's, hydraulic conditions, such as pressures and flows, under a specific set of conditions, sizing pipes, pumps, and other components, analyzing the impact of changes in the system, such as the addition of new demands or the expansion of the network.

Steady-state analysis is often used as a starting point for more detailed EPS modeling, as it provides a baseline understanding of the system's behavior. Consumptions pattern multipliers are not fixed even for large towns in Ethiopia to use EPS and majority of consultants adopted from similar towns of foreign countries. For rural villages therefore it is better to use steady state for it can help in the evaluation of the system and do not need multiplier factors over the times. For static pressure evaluation in distribution line zero flow condition adopted and for maximum flow condition a factor of two used to multiply the base or average demands.

Model Calibration and Validation:

Model Calibration: For hydraulic performance evaluation WaterGEMS software was used as tool of modelling. However the output of this model is accepted if it coincides with the actual filed level measured values. To achieve this, pipe roughness coefficient was adjusted until the difference of the model predicted values and filed level tested data fall in the range of accepted range which is >=85% according to Tomas. M et al., (2003). Sample size and location to take filed level actual measurements is very essential to represent the entire system and come up with sound model calibration.

Sample Size: The sample data collected in any water supply network is related to its links and nodes. The water consumption nodes of Teyfe multi-village water supply project are water points of six faucets where pressure data was collected. According to AWWA (2005) the sample size for pressure at nodes >=3%. In this study case water points were used as nodes to measure pressure using gauges and in this study case data from 71.87% of the water points collected.

Sample Location: Walski et al., (2003), recommends that it is better to conduct random sampling where the point have adequate length from boundary nodes in the networks and have high pressure and flow rate. Since the majority of the pipe network is a branching system and the water points are between 0.2 and 2 km apart from the main distribution line, inclusive point data were taken to ensure that representative and confidential data was gathered.

Model Validation: After conducting model calibration model simulated results and data obtained from filed measurement were compared using coloration coefficient R^2 and values fall between 0 and 1. $R^2 > 0.5$ were accepted and as it closes to 1 the strong relation observed.

3.6.5. Reservoir Capacity Analysis:

Service reservoir has multiple advantages among which reserving water at minimum consumption hours and balance the peak hour demand during maximum consumption time. It has also an advantage of storing water for fire hydrants and emergency case where pumps are getting maintained or power outage encountered. Therefore, proper design of service reservoir is required taking in to consideration the necessary design parameters. In these case equation 2.10 was adopted to size the reservoir of Teyfe multi-village rural water supply project and the result were compared with the existing reservoirs to evaluate its performance.

3.6.6. Assessment on EM Equipment Performance:

The design of electro-mechanical equipment, which mostly consists of pumps and power plants, is one of the main important factors taken into account when analyzing the performance of the water supply system. To impart head and get the water to reservoirs or other booster stations, pump units are needed. Its head, discharge, and operating efficiency must therefore be properly taken into consideration. In order to assess the current pumps in the system, their operating efficiency were assessed using the manufacturer's pump curve data. The pumps' capacity to deliver the required discharge with an adequate design head was also examined. Equation 2.14 was used to determine the pump capacity based on the maximum daily demand, total head (which includes the delivery head and friction head), and other input parameters.

Diesel generator and hydroelectric power plans are the sources of energy used to run the pumps in Teyfe multi-village rural water supply projects. Equation 2.15 can be used to determine the power plant's transformer capacity, and according to the MoWE guidelines, a generator's capacity should be 150–300% of the pump motor's capacity. It is clear that the existing power plants are currently giving service and there is no doubt about power limitation. However the excessive power production which has substantial effect on the operational cost of the system need to be evaluated using the aforementioned method at all pumping stations.

3.7. Intervention Mechanisms

3.7.1. Water Supply Scheme Management

Rural water supply scheme management models are either rarely managed on establishing utilities or community based administered by WaSH committees and water boards, particularly for multi-village schemes. The present study aims to identify the management gaps using a combination of qualitative and quantitative analysis, and finally recommendations were given for potential solutions. The scheme is administered by utility and hence the management of scheme was evaluated with respect to utility performance from perspective of Access Addressed, Non-Revenue Water (NRW), Cost Recovery Service, Quality or availability of water supply, System Complexity and Customers Number Ratio.

Access Addressed: In growth and transformation plan II the maximum distance travelled to collect water from water points in the town is 500m and for rural community 1km.Therefore the utility performance was evaluated from perspective of the percentage of population getting water at mentioned distances from residues and this can be considered in the customer satisfaction protocol.

NRW: As indicated in Table 7 NRW is the water lost from system due to unbilled authorized consumption, apparent loss and physical losses. It is therefore the difference between system input or supplied water and water for which revenue collected. Hence high value of NRW indicates poor performance of the management system, commercial practice and inadequate pipe line maintenance.

Cost Recovery: It is the ratio of the total annual revenue collections from the billed service and subsides to the total annual operational expenses (excluding depreciation and debt-related expenditures). This indicator measures the tariff cost recovery of the utility. This is a key measure of a utility's ability to cover its operating and maintenance costs (excluding interest and depreciation) from revenues, without reliance on external subsidies, and is generally perceived as an indication of a commercial approach to the provision of a public service.

Service Quality/Service Availability in a Day: This is an important performance indicator where utilities evaluated in terms of their service duration in hour per day. Well performing utilities can serve beneficiaries 24 in a day.

System Complexity: It is the complexity of several input water sources compared to one single water source. High levels of investment, maintenance, and human resources are required for a complicated system. It puts more work on management and operators than a non-complex system. As a result, it is considered one of the factors used to test utility performance

Customer Number Ratio: It the ratio of total customer number (domestic and non-domestic) to the total house hold.

With regard to operation Inspection and maintenance of physical assets, Instrumentation calibration, Electrical and signal transmission equipment installation, Mains, valves, and service connection rehabilitation, pumps rehabilitation, water losses, failures, water metering efficiency and water quality monitoring were considered.

Sample Data Analysis: Finding the management gaps began with evaluating utility performance using key performance indicators. Subsequently, the required intervention strategies suitable for certain difficulties were put out in order to enhance future performance.

3.7.2. Methods Used for Design Review

While conducting the design review the finding of the performance evaluation is taken as an input and it was conducted in areas where there is a gap to propose the bridging mechanism based on the engineering principles for each component as stated in this document. To make it more practical the existing system was taken as the major parts to work on where only some modification that can increase the efficiency of the system utilization were dealt with. Table 14 shows some of the modification taken in to account according to the gap that identified.

Table 14: Some of the design review check lists

S. №	System component	Review area	Equation. № or software used
1	Pipe line	Material adequacy, pressure and flow velocity in the network, requirement of pressure break, arrangement of valves, fittings and chambers, pipe diameter	WaterGEMS

2	Service reservoir	Reservoir capacity as per its particular service ,location based on the demand and pump station orientation	2.10
3	Pump	Capacity of the pump, head ,flow rates and pump efficiency, pump station orientation, working hour of the pump	2.14
4	Power plants	Diesel generator and transformer capacity	2.15

As noted in the Table 14, the fundamental equation explained under the methodologies used to evaluate the system performances for each component were the equation or software used to analyze the design review of the system for the components.

3.6. Research Design and Procedure

In order to create a more sustainable water supply system, this study primarily focuses on two main areas: Evaluating the overall performance of the water supply system under consideration and identification of interventions through system management and design reviews.

Gathering data such as Population, Pipe nodal and link, reservoir capacity, EME and pipe route soil formation, sample survey data was the primary step to organize the research works. Using these data, hydraulic simulation of water supply system and capacity determination of components conducted to identify gaps based on standard set of parameters, relative capacity compared to existing components and against standards.

Based on the gap identified possible hypothesis were set from management and design review aspects and analysis were accordingly conducted to identify respective intervention mechanisms. Finally the research was winded up with potential recommendation that proposed to bridge system problems identified. A synopsis of the entire study protocol is provided in the framework as show in Figure 2.

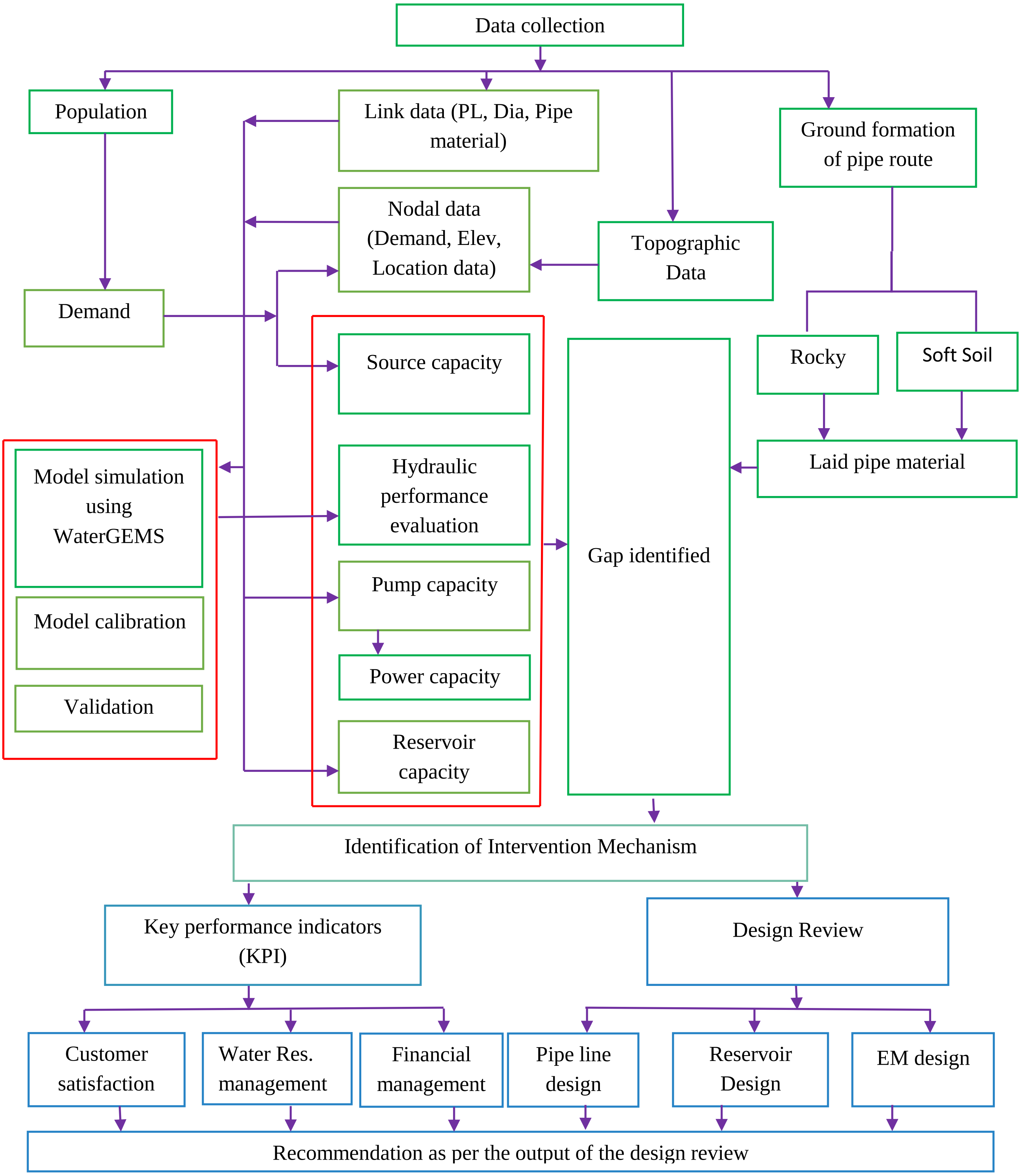


Fig 2: Research Design and Procedure framework of Teyfe MVWSP

CHAPTER FOUR: RESULT AND DISCUSSIONS

4.1. Water Demand Analysis

In the water demand analysis process primarily categories of the demands and the time for which the demand forecasted have significant input. The existing project design period was fixed 20 years according to previous studies conducted and this became the reference to fix the active useful period of the system. Based on the projected beneficiary population, standard consumption rates, mode of service proportion and demand variations demand analysis was conducted.

4.1.1. Population projection

Geometric progression was applied to determine the projected population over the design period. Utility is the only dependable source to collect the base population due to the absence of trusted data source for small administrative division of beneficiaries as like of villages. The growth rate data obtained from CSA report of 1994 and since it was only set up to 2030 and the design period is up to 2041, linear extrapolation was used to fix the remaining growth rate. Based on this approach population projections of the beneficiaries was conducted.

Table 15: Projected Population of Teyfe Mult-Village beneficiary (2023-2041)

Description	**Design period**			
	2023	**2024**	**2030**	**2041**
Urban				
Growth rate	3.51	3.51	3.19	3.03
Teyfe	6141	6356	7734	10807
Kurfa Roko	4320	4471	5440	7602
Total	10461	10828	13174	18409
Rural				
Growth rate	1.68	1.68	1.16	0.93
Meta Arba	4057	4125	4476	5001
Kurfa Gelma	6667	6779	7355	8218
Dhadacha Hina	12181	12385	13437	15014
Burka Ramis	5881	5980	6488	7249
Dimtu Boreda	3779	3843	4169	4658
Burka Oda	2548	2590	2810	3140
Abdi guddina	3208	3262	3539	3955
Rada dibicha (walta siso)	3290	3345	3629	4055
Total	41611	42310	45904	51290
Grand Total	52071	53138	59079	69699

4.1.2. Determination of Water demand

According to equation 2.5, projected population and per capita consumption rate are the elements used to calculate domestic demands. The per capita consumption rate can be either determined by adopting from design manual or calculated from the currently observed consumption records. Annex-8 Shows detail Utility water production and billed amount and the consumption rate computed from this data was shown in Table 16.

Table 16: Calculated per capita water consumption based on utility water utilization

Average Water production (m3/day) (2023-2024) (a)	Average Consumption (m3/day) (b)	Average Water loss (m3/day) (a-b)	Population	Consumption rate (L/c/day)
24624	13090.57	11533.43	25318	25.14

The rural design manual of 2021 indicated that per capita consumption rate fall in the range between 25l/c/d and 60l/c/d for public tap and house connection mode respectively and for urban according to the 2006 design manual the minimum and maximum consumption rate is 20l/c/d for public tap and 70l/c/d for house connection users. Detail of the per capita consumption rate mentioned in Table 5 and 6.

Hence using the forecasted population and per capita consumption rate for the design period, domestic demand of the population within the reach of system computed using equation 2.5.

Non domestic demand is the other categories of demand and the design manual recommends either directly gathering data of the existing institutions, commercial centers and industries or adopting percentage of the domestic demands. The second technique was thought to be more feasible in this research scenario because the study area is still in its early stages of development and using the current data could reduce the pool of potential consumers, which is expected to grow in the future.

Non-revenue water for all demand categories also considered as it has considerable effect in water supply system demands. Design manual for both rural and town recommends as percentage of the total day water demand and follows a decreasing approaches taking in to consideration the gradual improvements of operation and maintenance skills of staffs in the management sectors.

It is not possible to properly fulfill the demands for which the system units were designed by computing all of these demands alone. Hourly and daily allowances of the average demand must be taken into account in order to guarantee sufficient sources and system unit capacities. The design handbook suggests an average demand of 1.1 to 1.5 for daily maximum demand, and an allowance for peak hour consumption based on population size. In this specific project, the average demand increased by 200% for the population at the end of the design period.

Table 17: Summary of water demand analysis for design period of 2024-2041

Demand variation	**unit**	**Design Period**				
		2023	**2024**	**2030**	**2032**	**2041**
Average day demand	m^3/d	1738.73	1789.92	2232.66	2392.19	3203.18
	l/s	20.12	20.72	25.84	27.69	37.07
Maximum day factor		1.1	1.1	1.1	1.1	1.1
MDD In terms of ADD	m^3 /d	1912.60	1968.91	2455.93	2631.41	3523.49
	l/s	22.14	22.79	28.43	30.46	40.78
Peak hour demand factor		2	2	2	2	2
PHD in terms of ADD	m^3/d	3480.93	3583.41	4469.79	4784.38	6412.76
	L/s	40.29	41.47	51.73	55.38	74.22

Where: *MDD*-Maximum day demand, *ADD*- Average day demand. *PHD* - Peak hour demand and *PHD* – Peak hour Demand

Currently only 30 L/s discharge was taken from source which accounts 73.57% of the end design period estimated MDD. As described in this document under item 1.2.1, the water taken from the source spring was measured to give 61.8L/s which is greater than the analyzed maximum day demand. Yet the installed pump in the wet wells has the capacity of 30L/s as aforementioned and hence the EME needs upgrading after 2032 as shown in Fig 3.

MoWE also set two stage of design for EME because the equipment design period ends with in the first stage and again the operational cost reduced due to small size of equipment’s in this time compared to last stage large capacity equipment’s going to be replaced. As shown in table 17, the average day demand computed for the entire design period was 37.07 L/s and when converting to per capita consumption rate it becomes 45.95L/c/d .According to GTP II for rural community 25L/c/d proposed at 1km radius and for towns with population less than 20000, 40L/c/d fixed (Temesgen,2019) . Hence the analyzed demand accommodate the requirement of both rural and town according to the GTP II set design criteria.

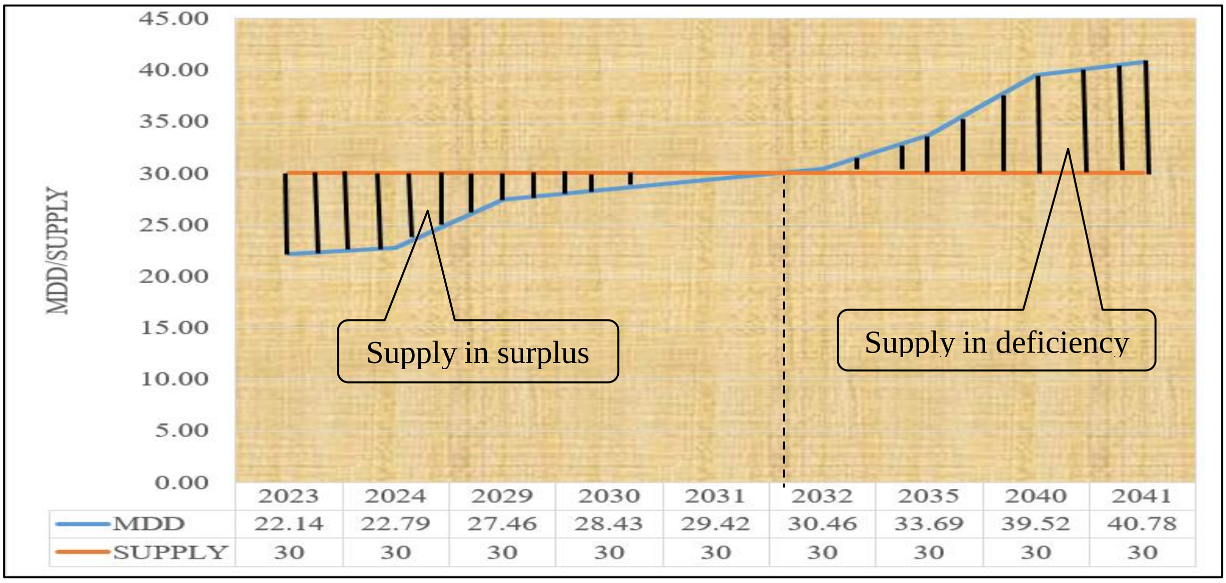


Fig 3: Supply versus Maximum day demand curve

Table 18: Detail demand analysis of Teyfe Multi-Village water supply project

Description	Unit						Design Period									
		2023	2024	2031	2032	2041	2023	2024	2031	2032	2041	2023	2024	2031	2032	2041
		Rural Town					Rural Villages					Total				
Population																
Rate(r)	%	3.51	3.51	3.19	3.19	2.87	1.68	1.68	1.16	1.16	0.93					
Population	No.	10461	10828	13595	14028	18409	41611	42310	46437	46976	51290	52071	53138	60031	61004	69699
Coverage by service type																
HC	%	0	0	4.32	4.94	10.5	0	0	0	0	0					
YCP	%	0	0	9.16	10.47	22.25	0	0	4.12	4.71	10					
YCS	%	0	0	7.62	8.71	18.5	0	0	10.29	11.76	25					
PF	%	100	100	78.99	75.99	48.75	100	100	85.59	83.53	65					
Population served by																
HC	No	0	0	588	693	1933	0	0	0	0	0					
YCP	No	0	0	1246	1469	4096	0	0	1912	2211	5129					
YCS	No	0	0	1036	1221	3406	0	0	4780	5527	12822					
PF	No	10461	10828	10738	10659	8974	41611	42310	39744	39238	33338					
Per Capita Demand																
HC	L/c/d	50	51.11	58.89	60.00	70	50	50.56	54.44	55.00	60					
YCP	L/c/d	25	25.28	27.22	27.50	30	40	40.56	44.44	45.00	50					
YCS	L/c/d	30	30.56	34.44	35.00	40	35	35.28	37.22	37.50	40					
PF	L/c/d	20	20.28	22.22	22.50	25	25	25.28	27.22	27.50	30					
SEF		0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9					
CF		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15					
TDD	M3/d	216.5	227.3	354.80	377.32	640.42	1076.6	1106.93	1391.92	1434.28	1831.4	1293.21	1334.2	1746.72	1811.60	2471.85
	l/s	2.51	2.63	4.11	4.37	7.41	12.46	12.81	16.11	16.60	21.20	14.97	15.44	20.22	20.97	28.61
PD (6%)	m3/d	12.99	13.63	21.29	22.64	38.43	64.60	66.42	83.52	86.06	109.89	77.59	80.05	104.80	108.70	148.31
	l/s	0.15	0.16	0.25	0.26	0.44	0.75	0.77	0.97	1.00	1.27	0.90	0.93	1.21	1.26	1.72
ID (3%)	m3/d	6.50	6.82	10.64	11.32	19.21	32.30	33.21	41.76	43.03	54.94	38.80	40.03	52.40	54.35	74.16
	l/s	0.08	0.08	0.12	0.13	0.22	0.37	0.38	0.48	0.50	0.64	0.45	0.46	0.61	0.63	0.86
Total TNDD	m3/d	19.49	20.45	31.93	33.96	57.64	96.90	99.62	125.27	129.09	164.83	116.39	120.08	157.20	163.04	222.47
	l/s	0.23	0.24	0.37	0.39	0.67	1.12	1.15	1.45	1.49	1.91	1.35	1.39	1.82	1.89	2.57
TD (TDD+TNDD)	m3/d	236.0	247.7	386.74	411.28	698.06	1173.6	1206.55	1517.19	1563.37	1996.3	1409.60	1454.3	1903.92	1974.65	2694.32
	l/s	2.73	2.87	4.48	4.76	8.08	13.58	13.96	17.56	18.09	23.10	16.31	16.83	22.04	22.85	31.18
NRW	%	40	39.44	35.56	35.00	30	20%	19.72	17.78	17.50	15					
	m3/d	94.41	97.70	137.51	143.95	209.42	234.72	237.96	269.72	273.59	299.44	329.12	335.66	407.23	417.54	508.86
	l/s	1.09	1.13	1.59	1.67	2.42	2.72	2.75	3.12	3.17	3.47	3.81	3.88	4.71	4.83	5.89
ADD	m3/d	330.4	345.4	524.24	555.23	907.48	1408.3	1444.51	1786.91	1836.95	2295.7	1738.73	1789.9	2311.15	2392.19	3203.18
	l/s	3.82	4.00	6.07	6.43	10.50	16.30	16.72	20.68	21.26	26.57	20.12	20.72	26.75	27.69	37.07

4.2. Water supply system component performance

Water supply system comprises different components used to address the service required with in the anticipated useful project period starting from source to end users. The performance of the entire system components evaluated against the nationally and internationally set design standards and criteria's. The project was anticipated as one phase project where all the installed components expected to give the required service for the entire design period without any intermediate interventions.

4.2.1. Source capacity

The source of TMVWSS is a large spring with discharge greater than 100 L/s and used mainly for the mentioned projects and the remaining overflows used for some irrigation farming's at the edge of streams downstream of the source.

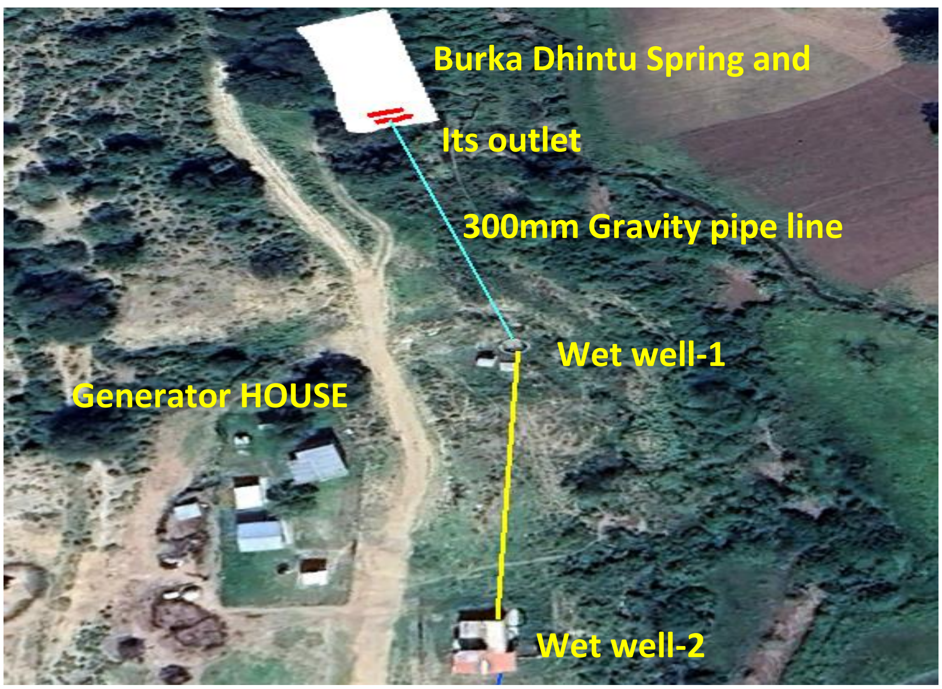


Fig 4: System components in source area

The discharge at Wet well -1 is the dependable yield as an input to the system. The water enters the wet well with two pipes having diameter of 300mm.The discharge measurement was taken at WW-1 using wet well as container and stop watch. To keep the measurement of discharge on its regular flow the usual depth of water at spring outlet chamber was used as controlling point and data are taken at 1.2m depth until the wet well refill to its initial high level. To refill it takes

1m and hence the volume water calculated to be 12.56m^3 and in 3 round data, time taken was 200,210 and 200 seconds and from this the source discharge computed 62.8m L/s two times and 59.81 L/s once and from the average of the three records source yield becomes 61.8 L/s.

The maximum day demand at the design period determines the capacity of the source as per the design manual (MoWE,2021) computed 40.87L/s which indicated that the existing source can sufficiently uphold the required supply for the proposed design period. However only 30l/s of the water taken from the sources and this account for 73.57% of the maximum day demand estimated for the design period. Negasa.S and Kebede.H (2023) indicated that the daily production from Muka Turi borehole source is less than the maximum day demand and hence described that the source is not sufficient to address the required demands as per the design standard.

4.2.2. Performance evaluation of pipe line system

4.2.2.1. Model set up and demand allocation

Model set up was conducted based on the existing project reach. Pipe line laying is following the construction of water points and taken as end users at large except for very little pipe network in Teyfe town. Demand allocation was carried out as per the population seize of each village located in two towns and eight kebeles as shown in Table 15.The average per capital consumption at end design period was calculated 45.953L/c/d and each village and the existing zone consumption share was accordingly computed as shown in Annex-2.

4.2.2.2. Model calibration and Validation

Sample size and Location

TMVWSP is a branched system currently feeding the user communities through water points and hence the pressures data were easily collected using the necessary tools and equipment's. The major line size are in the range of 100-250mm and it was not adequate to take data of junction points on this line due to the absence of equivalent size pressure gauges. 71.88% of the existing water point or data of 23 water points from the existing 32 was gathered making inclusive of all pressure zones. For model application the current supply taped from sources and peak hour demands were adopted for entire pipe network simulation. For Model validation the pressure data of 5 water points collected. See observed data in Table 19 and 20, and photos under Annex-3 while collecting observed data at water points.

Table 19: Distribution line filed level data for Calibration at water points

zone	Water points	Location			Observed Pressure in m
Zone-1		x	y	z	
	WP-1	708,434.08	944,431.35	1,432.00	7.00
	WTP_2	708,434.08	944,431.35	1,644.82	21.68
	WP_3	709,665.57	944,319.48	1,633.91	37.44
	WP_7	711,995.10	942,533.50	1,630.23	35.67
	WP_8	710,839.99	942,486.83	1,632.40	27.05
	WP_9	713,653.22	937,915.49	1,591.79	64.76
	WP-10	715,471.38	938,922.46	1,585.00	62.30
Zone-2	WP-12	717,339.12	937,669.07	1,514.00	53.50
	WP-13	717,311.06	937,665.83	1,514.00	26.50
	WP_14	722,731.35	931,342.20	1,429.98	103.77
	WP_17	724,574.80	929,150.76	1,440.36	59.89
	WP-18	725,086.00	926,788.00	1,478.00	10.15
Zone-3	WP-21	729,456.81	920,408.11	1,556.25	20.00
	WP-22	729,239.49	920,447.87	1,559.12	16.23
Zone-4	WP-24	734,412.89	918,938.58	1,553.23	12.52
	WP_25	737,265.73	918,120.26	1,537.56	26.44
	WP-26	739,117.06	917,472.19	1,554.30	0.3
	WP-27	742,536.51	914,916.59	1,549.37	15.63
	WP-28	742,563.92	913,613.60	1,534.60	20.55
	WP-29	744,096.56	912,375.07	1,528.90	11.25
	WP_30	753,805.17	910,857.65	1,442.19	116.56
	WP-31	759,537.79	910,169.09	1,392.60	166.65
	WP_32	765,613.91	903,826.97	1,395.16	162.96

Table 20: Distribution line filed level data at water points for validation

zone	Water points	Location			Observed pressure in m
		X(m)	Y(m)	Z(m)	
1	WP_4 (Kurfa Town1)	710,777.95	942,711.88	1,636.09	9.47
	WP_5(Kurfa Town2)	710,804.73	942,522.83	1,634.86	9.64
	WP_6(Kurfa Town 3)	710,839.99	942,486.83	1,632.40	23.35
	WP_11(Baka)	713,653.22	937,915.49	1,591.79	53.62
2	WP_15 (Koeti P/School)	722,765.47	931,353.07	1,429.98	93.87
	WP_16 (Haro Hiro)	723,752.01	929,577.73	1,432.11	68.34
	WP-19	728,855.99	926,849.87	1,470.00	-1.75
	WP_20 (Dhadacha Hinna)	727,496.13	925,133.84	1,486.74	11.76
3	WP-23 (Boke Wako)	732,696.29	920,402.36	1,553.50	2.00

Model calibration

Ormsbee and Lingireddy (1997) state that calibration procedures can involve modifying system requirements, throttling valves, smoothing or roughening pipes, altering pump operating conditions, and modifying other model parameters that influence simulation outcomes. In this study, the model parameters were calibrated in a steady state to align with the pressures derived from field observations. While the extended period calibration is more sensitive to variations in the distribution of demands, the steady state calibration will often be more sensitive to changes in pipe roughness. The WaterGEMS software's has package of Darwin Calibrator module that can be used to fine-tune the pipe roughness parameters so that the simulated and observed values reasonably match as shown in Annex-4. The preliminary pipe roughness value estimation, as displayed in Table 21 derived from the rural water supply design manual published in 2021which mainly considers pipe material type and service age in to consideration. The pressure filed data were collected and shown in Table 19 encoded in to software and after consecutive iteration the result having coefficient of determination R^2 = 0.997 obtained and according to AWWA (2012), the value of R^2 >0.5 is considered acceptable for model performance. After model calibration the revised C value was used in the pipe line performance of the hydraulic analysis.

Table 21: Revised C value during calibration

Pipe Material	Original C value	Revised C value
uPVC	140	126
DCI	130	117
HDPE	150	120
GS	120	72

After model simulation the correlation graph of the simulated result versus filed data collected was depicted as shown in Fig 6.

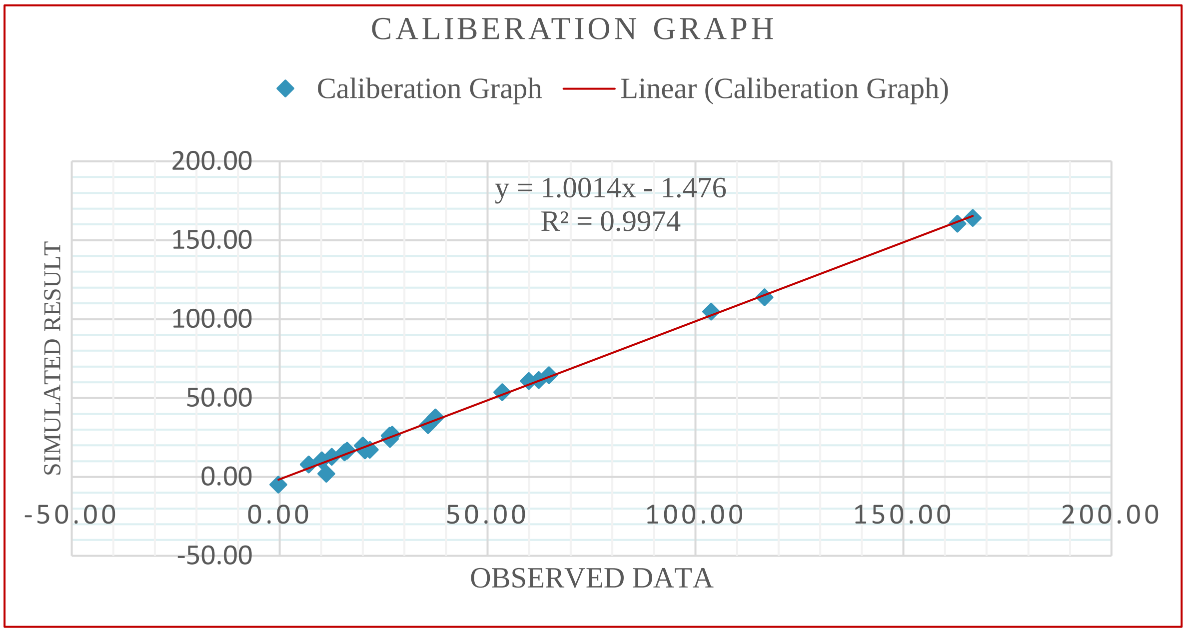


Fig 5: model calibration using Darwin model calibrator package in WaterGEMS software

The other model calibration performance criteria is Root mean Square error (RMSE) and according to ATSDR (2000) explained that RMSE of pressure difference of ± 15.2kPa (± 1.52m) to a maximum difference of ± 50.3kPa (± 5.03m) characterizes a good performance set and in this study case RMSE= 1.47.

Model validation

After calibrating the model, the corrected C values for all pipes were used in the model simulation and the result for other water points were checked if well correlated with the measured filed data. For this purpose the data of five water points were collected as shown in Table 20 and the correlation coefficient in this case is R^2= 0.987 shows the model was well calibrated to undertake simulations for further works such as pipe network performance evaluation .

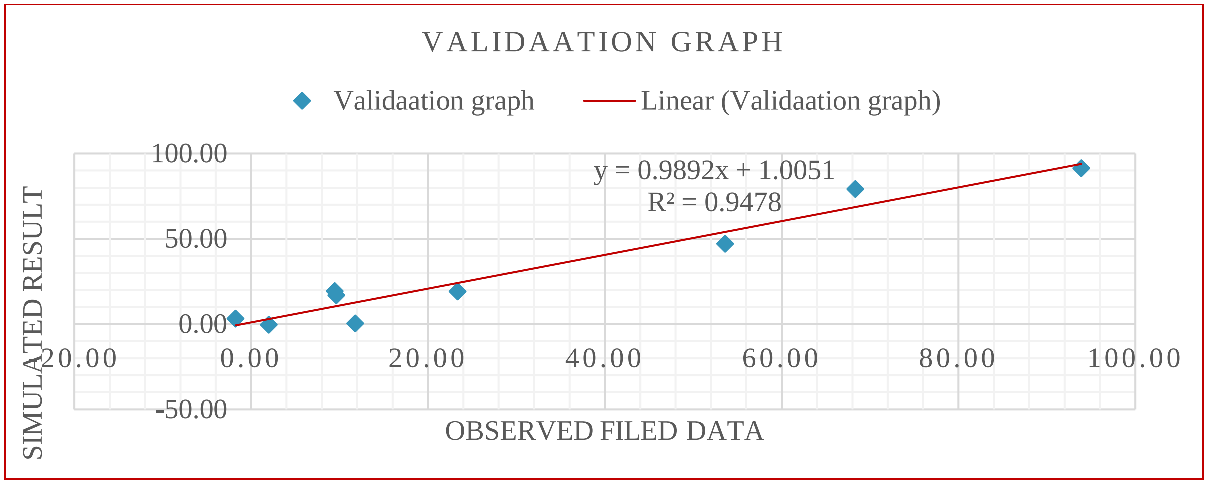


Fig 6: model calibration using Darwin model calibrator package in WaterGEMS software

I. Transmission Pipe line performance evaluation

TMVWSP has four pipe line section through which the water transferred to reservoirs and booster stations. The project was designed as one phase project for 20 years 2022-2041 service period according to LGDC (2020) design review document. Hence the performance evaluation was conducted for the entire design period. The constructed pipe were uPVC and DCI pipes with different PN to resist the static and pump induced pressure. High pressure and velocities are generated during pump working hours and the pipe performance was checked for the amount of these parameters against the nominal pressure of the pipes and the result was indicated in Table 22.

Table 22: Nodal Result of Transmission line at all times

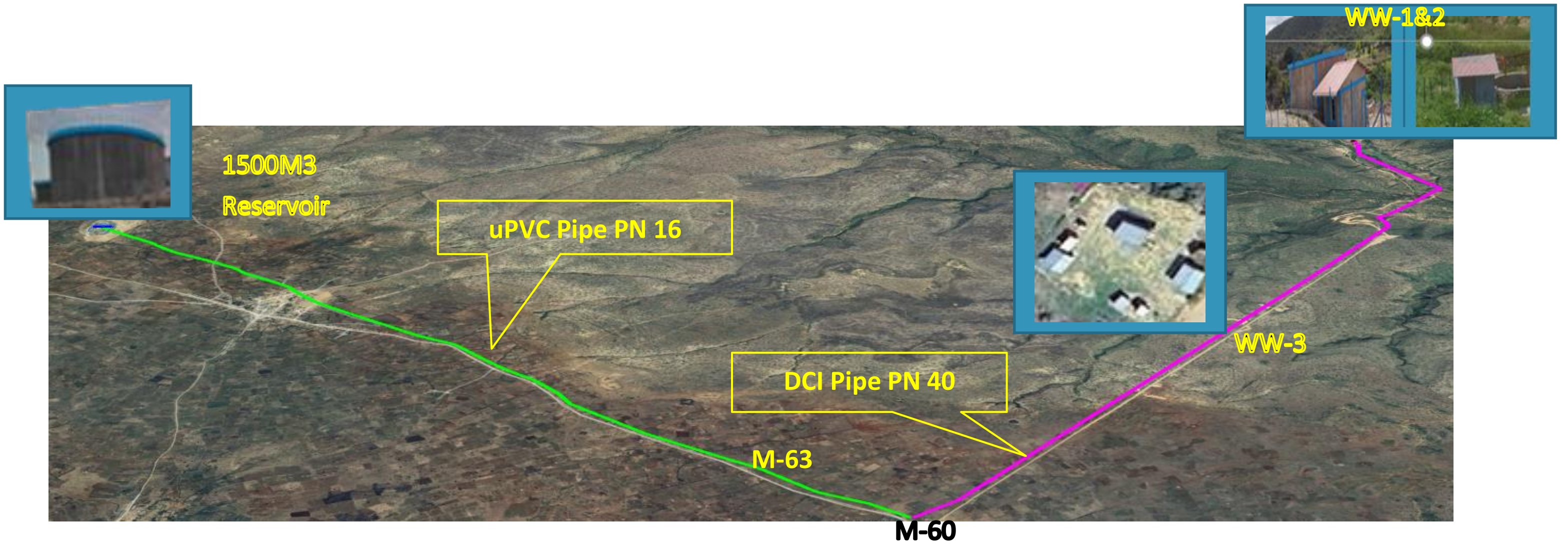
Junction Location	**Pressure Range (m)**	**Pipe material**	**L (m)**	**D (mm)**	**PN(m)**	**MDD (L/s)**	**Remark**
WW-1 to J-111	18-35.75	GS	38	150	16	40.79	Safe
	5-18	DCI	70	300	16	40.78	"
WW-2 to J-113	6-333.5	DCI	3875	200	400	40.78	"
WW-3 to 1500 Reservoir	174-381.5	DCI	6282	200	400	40.78	"
	6 – 174	uPVC	8386	200	160	40.78	Partially exceeds Pipe PN

WW-4 to J-779	35.7 - 154.5	DCI	4626	150	25	20	Safe
J-779 to JM-792	15.72-35.7	uPVC	930	150	16	20	“
JM-792 to 300 Res	5.65-15.72	uPVC	1214	150	16	13.2	“
JM-792 to 250 Res	15.03-0.00	DCI	61	100	16	7.04	“

WW-Wet Well, L-length, D-Diameter, V-velocity

From the analysis result in the Table 22, the pressure imparted by pump to water against the geodetic difference and head due to pipe line friction is getting below the nominal pressure for DCI pipe PN 40 and uPVC pipe PN 16 partially (M-63 TO 1500m3 reservoir). uPVC pipe laid between Junction M-60 to M-63 having length of 1.2km nominal pressure was found exceeded and hence need replacement with pipe PN 25 after 2032 where large pumps changed to equip the increasing demands. In all transmission pipe lines the internal pressure was checked greater than the minimum pressure allowable (5m) according to rural design manual which is important in the pipe line system to protect the external intrusion of pollution through damaged parts of the pipe or faulty joints. Regarding the discharging velocity all are within the allowable range (0.6-2m/s) except the GS pipe at immediate outlet of the pumps of WW-1 where its velocity is 2.31m/s and having length of 38m.

The overall finding showed that the pipe of transmission line can perform up to design period except for GS pipe with high velocity at the out let of wet well-1 and 1.2km uPVC pipe aforementioned which gives service the 1st stage of the project.



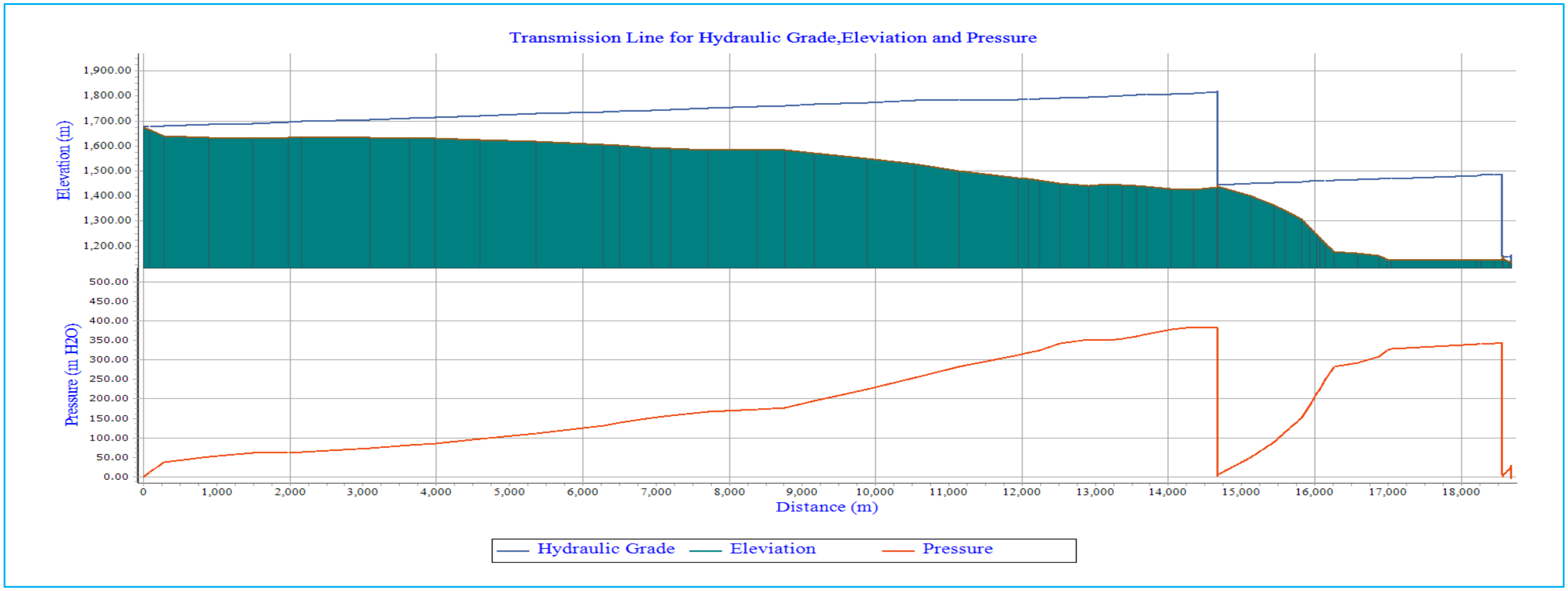


Fig 7: Transmission line profile from WW-1 to 1500 m^3 Reservoir

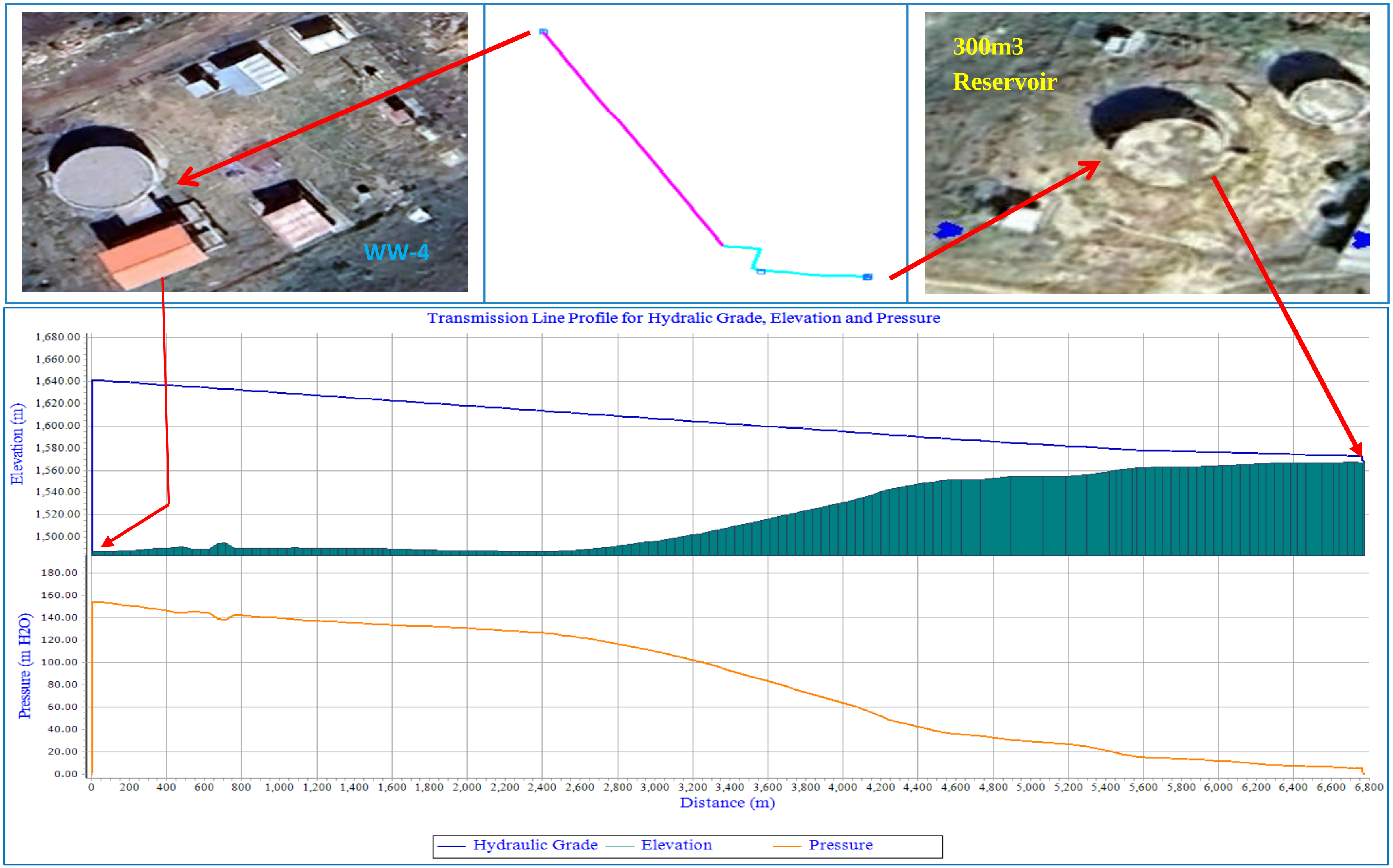


Fig 8: Transmission line profile from WW-4 to 300 m^3 Reservoir

II. Distribution Line performance

In the entire network of existing distribution system the pipeline size ranges between 50mm – 250mm and the material types are HDPE, uPVC, and DCI.

Velocity and pressure in the links and junction points were the parameters observed for minimum and maximum flow conditions to determine the performance of the distribution pipes together with pipe nominal pressure. The minimum flow condition during the night time and low consumption hours are important to be considered to identify the maximum pressure (static pressure) that can be developed in any gravity flow system and the maximum flow condition helps to detect the minimum pressure and velocity ranges against the allowable standard. The detailed hydraulic analysis result of nodes and links is attached in annex-5 of this study paper.

The pressure at nodes in minimum flow hours were ranging from 1.11m at node DL-230 to 183m at node DL-1508. In this flow conditions the minimum pressure nodes at large have proximity to reservoir and break pressure chambers. This is the usually expected situations which do not have any effect on the system as no nodal consumption point in the area. But for the pressure greater than the maximum permitted value (80m) needs alternative solutions and in this particular case the nodes distributed over 30.63km identified to fall under static pressure of 80m to 183m which shows the pressure is above allowable limit.

Table 23: Hydraulic pressure in distribution pipe at minimum flow condition at 0: 00 AM

Junction Location	Computed P (m)	Pipe PN(b	Existin g PM	Length in m	Remark
1500m3 Res-DL 4,50m3 BPT to J- 235,J-671 to WW-4,J-811 to WP-20 and J-12 to DL-84 and DL- 76 to J-103	0-8.94	10	uPVC/ DCI	2487/63	Out let Pipes close to reservoirs and BPT
DL-4 to 50m3 BPT , J-236 to J-385,J-563 to J-671,Nodes on all HDPE pipes,J-103 to WP-23,DL-84-DL -1046 including Nodes on all uPVC side branches	10-80m	16/25 /16	uPVC/ DCI/H DPE	43002/6 536/406 5	Pressure fall in the recommended range
J-385 to J-562,DL-1046 to DL-1138 with all uPVC side branch	80-100	16/25	uPVC/ DCI	2003/83 55	Pressure greater than the allowable Limit

DL-1146 to DL-1447 and DL-1826 to DL-1946 including the side branches	100.87-159.17	16	uPVC	10836	“
DL-1457 to DL-1817 and DL-1854 to WP_32 (Chale)	160.11-183.02	16	HDPE	4079	Pressure fall in the recommended range

When looking at breaking records of pipes from utility documentation, it frequently occurred in areas where pressure is greater than 80m. The main line between A &B shown in Fig 10 is DCI material with PN 25 bar and the pressure ranges up to 100m.Hence the main line pipe has been kept safe, however the branching pipes with PN 10 bar and uPVC material burst especially at junction points where the pressure can be the major cause. The other pressure-prone area with a large pipe break-up history is the section of the pipe between C&D as per Fig 10. The simulated pressure in this area goes as high as 183m but the existing pipes are uPVC pipes with PN 16 bar.

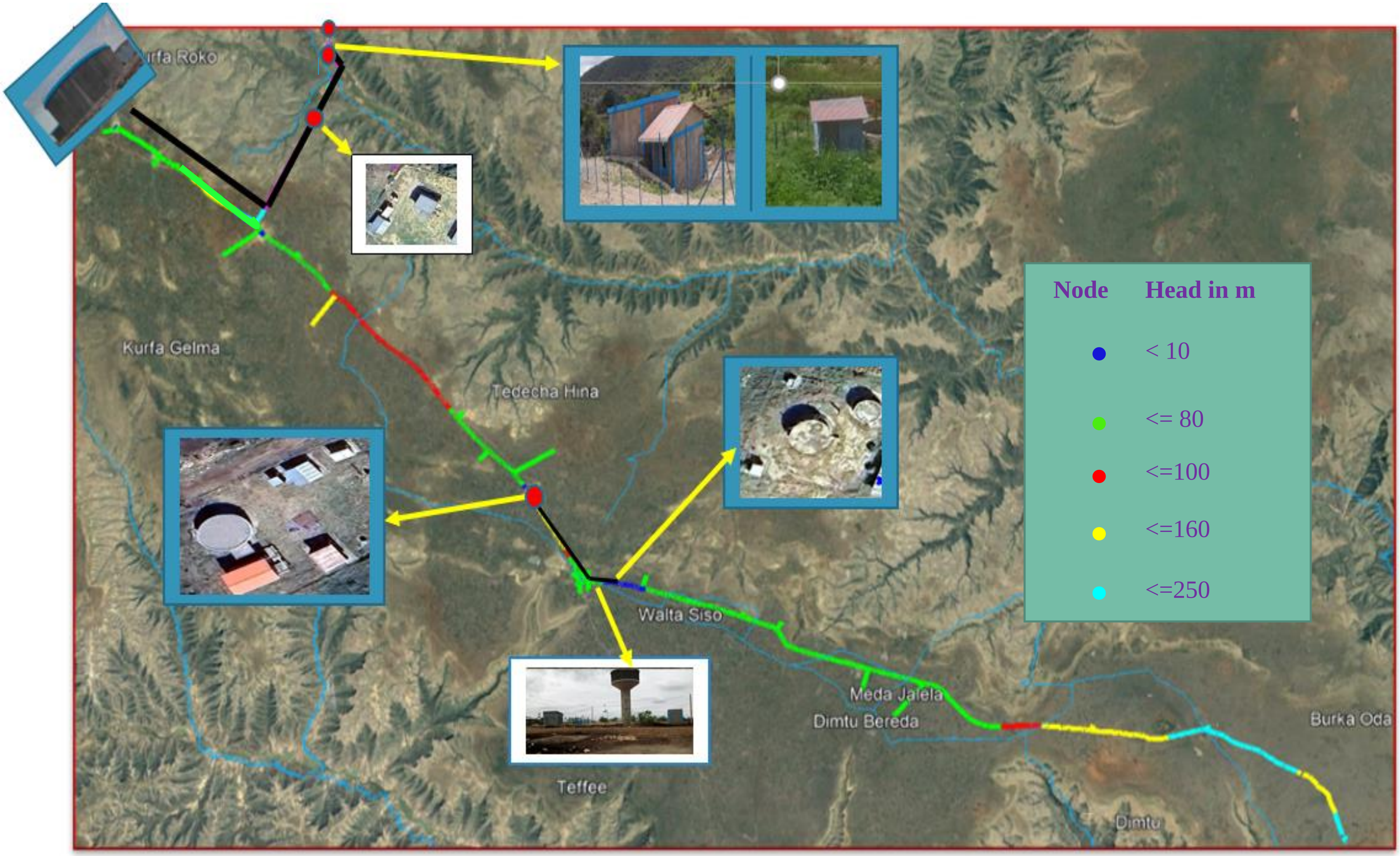


Fig 9: Pipe Lay out of the distribution Line and Nodes pressure at 0:00 Hrs

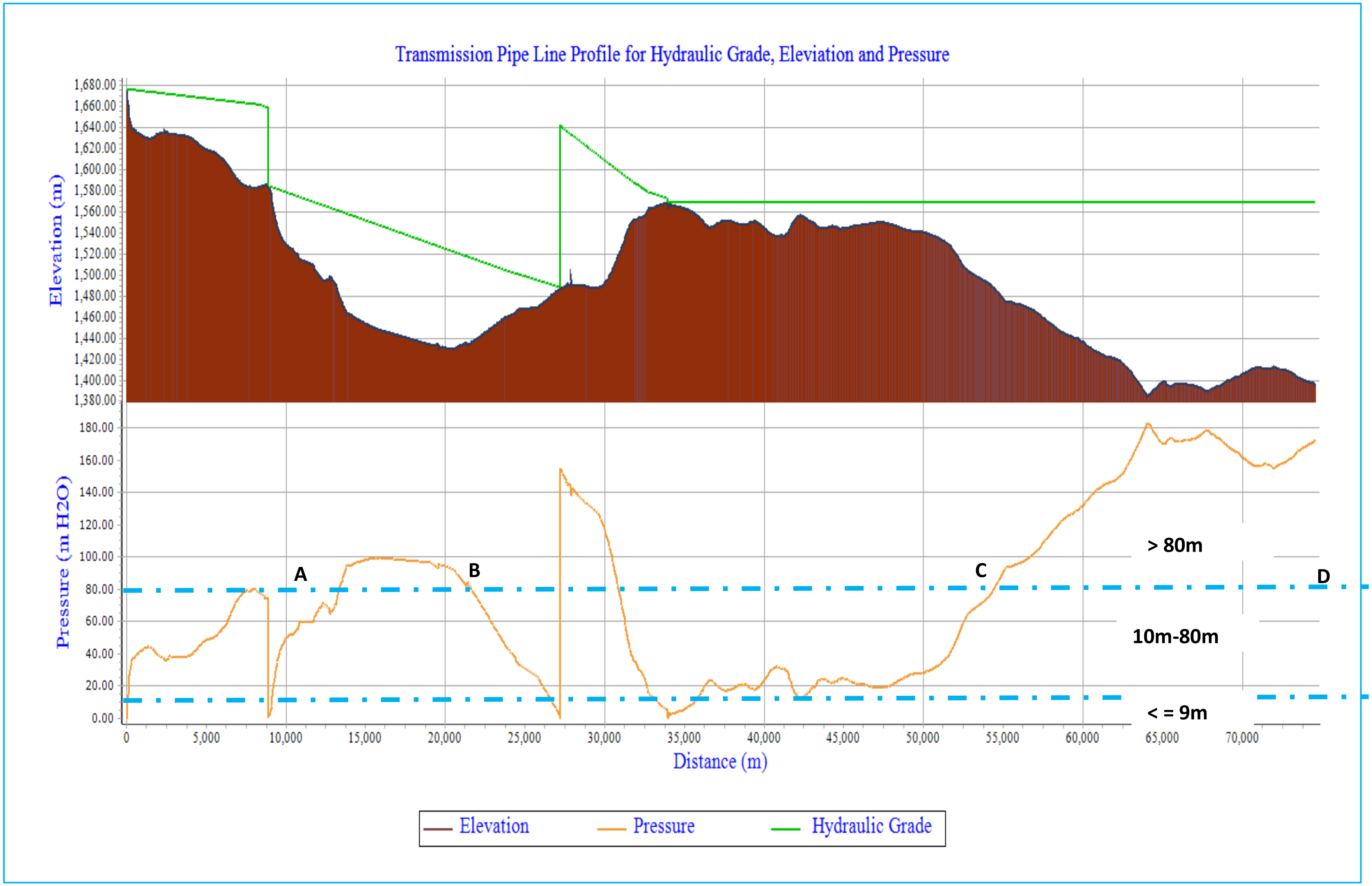


Fig 10: Profile of the pressure in distribution Line at 0: 00AM

The performance of the distribution line were also evaluated for maximum flow condition where link velocity and node pressure are the dependable parameters. From continuity equation principles, flow and velocity have direct relations and hence at maximum peak hour consumption maximum velocity created. However in the case of pressure due to increasing of pipe line friction, the pressure at nodal points was getting decreasing in the direction of flow. Extended simulation period was used to check pressure variation at different consumption hours.

From the existing 23 water points taken as end nodes of the branched system 11 water points have found negative pressure (-8.68 to -83.47m) due small to pipe size which resulted in substantial friction head losses and many other nodes close to reservoirs and break pressure tanks also have pressure less than 10m. The detail was attached in Annex 5. The velocity of the links in peak hour demand ranges between 0.13-2.19 m/s and the detail was summarized in Table 24.

Table 24: summary of the velocities at peak hours 8:00AM

Velocity Range in m/s	**Pipe line covered in m**	**%**
0.16-0.6	45158	51.43
0.6-2.28	42648	48.57

According to rural water supply design manual of 2021, the velocity in branched distribution system has to get in the range of 0.6 to 2.5m/s and from the result of the hydraulic analysis it was observed that 51.43% of the pipes fail to attain the minimum velocity required. Therefore this will bring about the deposition of silts along the pipe line and hence become potential health risks on end users. The maximum velocity determined are within the permissible limit and problems like pipe abrasion or pipe wearing not expected to happen.

The maximum pressure in the main is considered not to exceed 80m to limit leakage and stress on pipes (Mosissa, 2008). According to (Totsuka et al., 2004), those consumers further away from supply points always collect less water than those nearer to the source due to pressure losses in the network, which increase as far as the source. Pressure was increased as elevation decreased and vice versa. Households located at a higher elevation and close to the reservoir site have access to water at low water pressure (Mekonnen, 2014).

4.2.3. Performance Evaluation of Reservoir capacity

To ensure the balancing and storage services, three distinct reservoirs are included throughout the TMVWSP water supply system. The ability of the reservoir to provide the necessary services is therefore closely correlated with its performance. According to the design specifications of the rural water supply, the reservoir's capacity is between 1/3 and 1/2 of the maximum daily demand. The computed capacity is presented in Table 25, taking into account the distribution of the maximum daily demand for the three pressure zone

Table 25: Computed reservoir capacity of the three pressure zones

Pressure zone	Existing Reservoir capacity in m3	MDD under each zone m3/d	Calculated reservoir capacity m3 (1/3 to ½ of MDD)
1	1500	3523.4	1174-1762
2	250	586.40	195-293
3	450	1135.3	379-568

All the existing reservoirs capacity were found within the range of the allowed capacity as per the rural design manual of 2021 including fire and emergency demands and therefore can perform well as required for the proposed design period. They were also located in the place where they can command the user community water points.

4.2.4. Performance evaluation of the electromechanical equipment

Pumps and power plants are the major equipment's used in the transfer of water from source to the required reservoir or booster stations. TMVWSP has four pumping stations

Table 26: Existing Pumps and power plants in four Pumping stations of TMVWSP

Station	Pump			Generator Capacity (KVA)	Transformer Capacity (KW)
	H (m)	Q (L/s)	P (KW)		
WW-1	26	28	30	750	300
WW-2	332	28	129		
WW-3	330	28	160	750	300
WW-4	130	12.5	30	100	300

WW-Wet Well, H-Head, P-Power -Discharge

When evaluating the electro-mechanical equipment's (EME) performance, this study solely looked at the hydraulic performance of the unit for the project's design period. According to

MoWE design manual of 2006, the economic lives of EME is 10 years (completed in stage 1), despite the fact that previous studies did not explicitly state that the EME was designed for stage 1 or to be used in both stages. The main reason for this recommendation is that operational expenses cannot be controlled if the end design period data is used to determine the EME's capacity to use in both stages, and again, the EME's efficiently serving for the first stage only. Following this, performance evaluation was conducted for the first 10 years according to MoWE with regard to their specific parameters.

Pump Performance evaluation: The project was getting functional in 2023 and the EME expected to give service until 2032.Hence the analyzed maximum day, calculated total head and power of the pump were compared with the currently functioning system to evaluate the pump performance. All the pumps and power unit have stand-by EME and assumed to work for 24 hours and the maximum day demand for 2032 in three booster station WW-1, WW-2 and WW-3 is 30.46L/s and the 4th wet well 14.87L/s. The WaterGem CAD was used to check the capability of the equipment's with the input data of existing pumps (head, discharge and pump efficiency), topographic and pipe data. The result was summarized as shown in Table 27.

Table 27: Simulated pump capacity data, its actual output and specification comparison

Pump Station	**Simulated pump data**		**Actual pump out put**		**Existing pump specification at duty point**		**% addressed relative to 2032 MDD required**
	H (M)	Q (L/s)	H (M) from pressure gauge	Q (L/s) From digital flow meter	H (M)	Q (L/s)	
WW-1	24.69	30.04	24	30	26	28	98.49
WW-2	318.46	29.66	310	30.15	332	28	98.98
WW-3	315.22	29.82	320	30.05	330	28	98.65
WW-4	127	15	125	12.5	130	12.5	84.06

H-Head, P-Power, WW-Wet Well

The simulated result and actual output of the pump are very close to each other with both discharge and total head except for WW-4 pump. On other hand the discharge of the pump output is increasing relative to pump specification data due to decreasing of total head in actual cases and this shows pump is working out of its duty point.

From hydraulic analysis therefore the 1st stage system operation can be fully supplied with existing pump unit for the MDD until 2032 which is 30.46 L/s except for WW-4 pumps that can give full service only up to 2027 for zone 2 and 3 with discharge capacity of 12.5L/s and detail can be seen under Annex-2. In addition to the above findings, all pumps were identified that their duty or working point shifted from manufacturers pump curve set and this lead to a significant decrease in the pump's overall efficiency, resulting in higher energy consumption and reduced cost-effectiveness. Giugni et al. (2014) studied the effects of pipe network layout and demand patterns on the efficiency of water supply pumps. They concluded that optimizing the pump selection and operating conditions based on the system's characteristics can lead to significant energy savings, with potential efficiency improvements of 10-20%.

Power plant performance evaluation: As mentioned in Table 28 both hydroelectric and diesel generator power source as regular and standby respectively are used for TMVWSP. Capacity of the diesel generator was designed taking 150-300% of the pump motor capacity and Transformer was calculated using equation 2.15. The performance of the equipment’s evaluated from perspective of capacity to run the existing pumps and their economic advantage in consuming the possible minimum energy.

Table 28: Existing and computed power plant capacities of the booster stations

Booster station	Existing power plant in KVA		Computed power plant capacity in KVA	
	Diesel Generator	Transformer	Diesel Generator	Transformer
WW-1	750	300	272-543	200
WW-2				
WW-3	750	300	270-540	200
WW-4	100	300	53-106	50

Except for WW-4 generator capacity, all existing power plant units have larger capacity to be used in 1st phase and this is currently observed to bring the challenge of excessive expense due to high energy consumption.

4.2.5. Pipe line construction:

At the time of construction, some distribution pipe were wrongly allocated against the pipe route soil formations as per the data collected and this has subjected the pipe easily and frequently broken. The detail laid distribution pipe information together with soil formation along the route discussed as shown in Table 29.

Table 29: Distribution Pipe material versus its route soil formation

S. No	Pipe line section	Pipe Material	D in mm	L in m	Soil Formation
1	1500m3 Reservoir – DL-84	uPVC	250	3196	Rocky
2	DL-84-J-46	uPVC/DCI	250,200,150	53735	Red clay
2	J-46-J-1719	uPVC	100	7790	Rocky
4	J-1719	uPVC	100	2725	Black cotton

Source: LGDC (2020) Design review report

As can be seen from Table 29 uPVC pipe was constructed over the rocky formation and due to the nature of the pipe material it can be easily pierced and subjected to leakage. It was also visually observed that some parts of these pipes are exposed to air and hence easily damaged by animals or can be weathered to lose its strength in the long run.

4.3. Identification of interventions for Teyfe MVWSP system improvement

4.3.1. Intervention conducting design review

This section of the document outlines the interventions utilized to enhance the system's performance in the present and future with regard to providing the service for which it was intended and guaranteeing an appropriate management system. This notion was first established and then supported by further interventions that were suggested and supported by fundamental engineering methods and approaches under the following assumptions.

Assumption 1: The system incurs operational costs due to the overall uneconomical model setup and component layout, which includes reservoirs location and pumping stations. Operational cost considerations should be the primary items on the checklist of study and design, not something to be considered after construction.

The first step towards having the necessary cost-effective project is understanding command area with regard to system components at the early stage of planning and design.

In TMVWSP the location arrangement of the reservoir was not optimally considered to reduce the running costs of operation and maintenance. As shown in Fig 12(a) all the maximum day demand pumped from WW-3 to 1500 m3 reservoir according to the implemented project to command the whole beneficiaries from this reservoir. In this research paper it was observed that the topographic feature in the project corridor has another alternative reservoir location that can benefit in minimizing energy cost used to run pumps and deliver water from WW-3 to 1500 Reservoir.

According to model analysis conducted through proposal of new reservoir location at current existing 50m^3 break pressure tank, the power utilization can be decreased by 18.45% and this has significant implication on expenses of operation and management. Table 30 summarizes the comparative advantage of the existing and modified system model through rearrangement of reservoir and revision of EME capacity with MDD of end design period using WaterGEMS simulation for H & Q and equation 2.14 for capacity determination assuming pump efficiency of 70%. See Annex-5 (III) to find the simulated head in both cases.

Table 30: Comparative advantage of existing and revised TMVWSP model

Existing lay out computed Pump data for 2041			Revised model computed Pump data for 2041		
Q (m3/s)	H (m)	PC (kw)	Q (m3/s)	H (m)	PC (kw
40.80	390.81	222.35	40.80	318.69	182.13

Assumption-2: Replacement of pipes with PN 25 is required in stage two operation of electro-mechanical equipment if the current lay out not revised.

It is clear that in the second phase the current EME will be replaced with larger head pumps to lift the end design period supplies (40.78L/s).This will therefore create high pressure > 160m on the existing transmission line pipe as per the hydraulic analysis conducted and hence uPVC pipe line with PN 16 between node M-60 to M-63 having length of 1.2km will be exceeded and so need replacement. But if the current lay out revised as shown in Fig 12(b) the pump pressure become lower than the PN of the mentioned pipe section and safe flow will be achieved.

The revised layout of the system shown in Fig 112 indicating the location of proposed new reservoir and pumping system

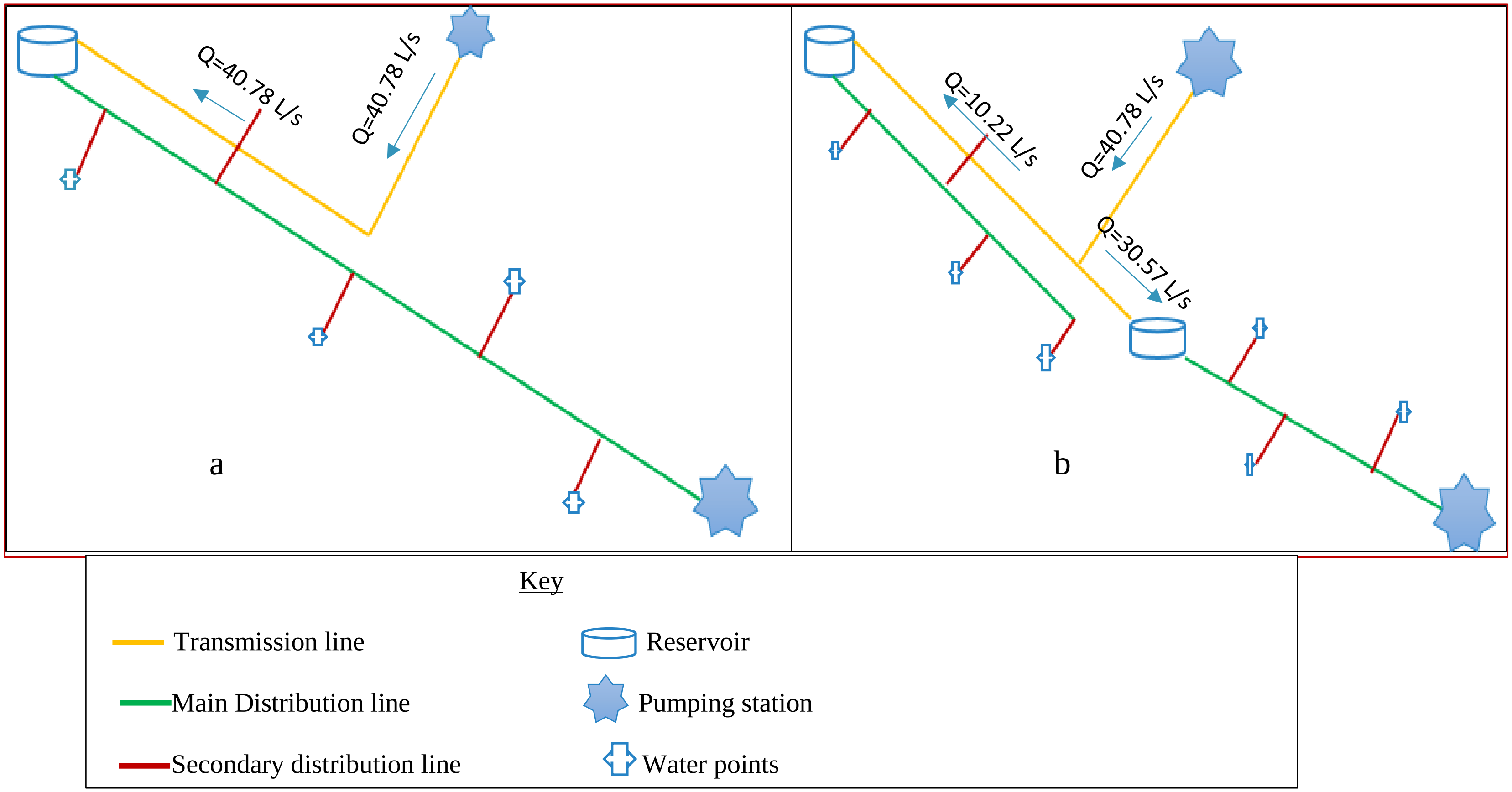


Fig 12: Typical diagram of Existing and revised system layout

As indicated above, the reduction in pump capacity led to a corresponding decrease in power plant consumable energy. The energy needed to operate the pump in WW-3 drops from 670 to 546 KVA if 300% of the pump capacity adopted in accordance with the design criteria referenced elsewhere in this study which states that the power plant's capacity should be 150–300% of the pump's size.

To visualize the significant change due to modified layout the relative graph of head was shown in Fig13 for the same design period maximum day flow.

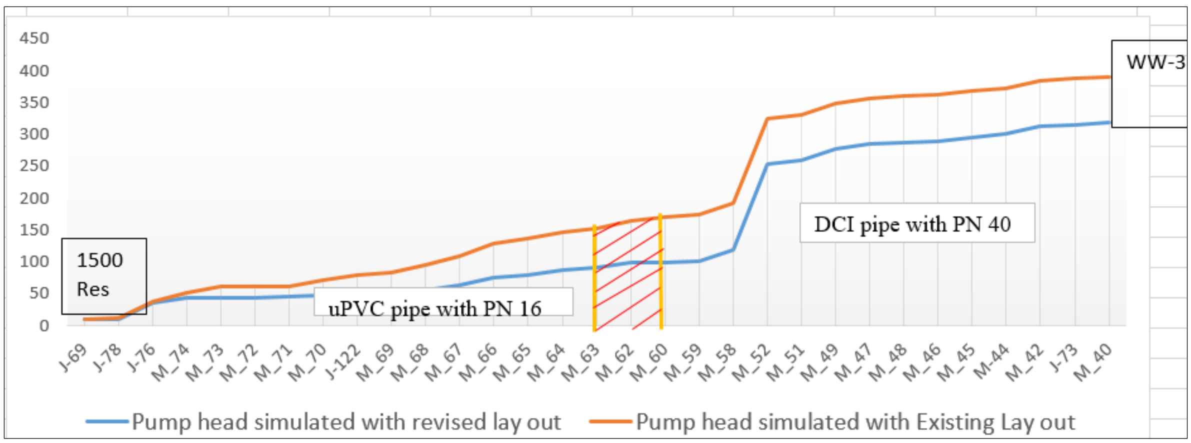


Fig 13: Simulated hydraulic analysis for transmission line between 1500m3 and wet well -3 for existing and revised lay out

Assumption 3: Adequate components such as valves and break pressure systems should be incorporated to keep the system safe and well-functioning.

Over the total length of the distribution pipes control valves are very essential to manage flows. The data collected indicate that at all junctions branching to water points the main line remain open without any gate valves and make hard to control flow of water during maintenance and other operational activities. Hence the breaking of pipes at some points of the main line subjects to loss of all the water in the pipe up stream of the broken point. However 10 gate valves arbitrarily installed on 67km length main distribution line though not sufficient to manage the operation works. Based on the pipe length between the gate valves, the possible water loss in a single point of breakage computed and shown in Table 31 to remark how critical the problem is.

Table 31: Maximum Water Volume Lost in m^3 when Pipeline broken

Susceptible Pipe end points	L (m)	D (mm)	Water Volume could be lost (m3)
1500 Res-GV-2	8516.4	250	0.00-417.84
GV2-GV-3	2495	200	0.00-78.34
GV4-GV-5	3246	200	0.00-101.92
GV-5 -GV -6	3557	200	0.00-111.69
GV-6 - WW-4	6055	200	0.00-190.13
WW-4 - GV-7	7051	250	0.00-345.94
GV-7-GV-8	6341	250	0.00-311.11
GV-8-GV-9	8700	150	0.00-153.66
GV-9-GV-10	4385	150	0.00-77.45
GV-10-GV-11	9760	100	0.00-76.62

Therefore it was important to install gate valves at junction points and the main line at recommended length to reduce the possible water losses in any circumstance of pipe breakage. System complexity, pipe diameter, terrain and access, and system criticality are some of the factors that enforce the closer installation of valves. The UK's Water Industry Specification (WIS) 4-08-02 and the Indian Standard IS 12288 suggest gate valve spacing at a distance of 1 to 2 km.

High static pressure above the recommended amount of 80 meters occurred in the part of the pipe between A&B and C&D, as detailed in the performance evaluation of the distribution pipeline and illustrated in Fig 10. For the pipeline to remain safe and the water to flow smoothly, this pressure must be lowered using break pressure tanks or pressure-lowering valves. As a result, a design review was carried out, and the pressure profile was modified to meet the design requirements. The section of the pipeline between A&B on Fig 10 pressure-reducing valves proposed to be installed at junction 278 and static maximum pressure of 99.28m was reduced only to 92.73m which is still greater than 80m. Due to the topographic setup in this pipeline section further decreasing of head will affect the flow of water at maximum hour consumption. To solve this problem it was seen better to adopt the existing pipes as it was because the constructed pipe material of this section was DCI pipe with PN 25 and therefore can resist the pressure that break the pipes provided that the branching uPVC pipe with PN 16 to the water points and fittings at junctions area must be replaced with GS pipe & PN >= 16 PN.

Regarding pipe line between C& D as per Fig 10 break pressure chamber and pressure reducing valves were proposed at junction DL-1316 and J-1046 respectively to bring down the maximum pressure mentioned in Table 23 to the range of allowable limit. The maximum pressure at static pressure in this area was ranging between 2.06m around break pressure tank to 76.46m and hence the pipe will get safe according to design review.

On the other hand the system was also checked for velocities in the entire system for maximum flow condition and as described in Table 24 majority of the pipe line fail to attain the minimum velocity required. This low velocities occurred in main line pipe size and the probability of formation of stagnant water in the pipe is high. This problem can be solved by changing the pipe sizes. But it is not practical to replace the entire pipe quantity accounting 51.13% of the system as per Table 24.Hence it is more convenient to use flushing valves at sagging points and frequently cleaning the silts that may be deposited in the pipe routes.

The data collected also did not indicate adequate quantity of air release valves at crest points of the pipe profile to avoid the trapped air accumulation that undermine the smooth flow of water. Even though water collection points can be used as air releasing points in distribution lines the long distance between these water collection centers favors the formation of air pocket at summit points of pipes. Therefore adequate amount of air release to be installed to reduce the impact of air blocking on distribution water flow.

Table 32: Proposed Gate valve, Flush and Air release Valve location and

Gate valve		**Flush Valve**		**Air release valve**	
Nodes or Junctions	**D(mm)**	**Nodes**	**D (mm)**	**Nodes**	**D (mm)**
At all Junction points to water point	Varies	DL-311,J-536	200	J-373,DL_-670, DL-422	250
DL-196,	250	JM-732	150	J-695	200
DL-257,DL-312,J-482,J-425,J-598,DL_-130,DL_-257,DL_-490,DL_-578,	200	DL_-134, DL_-239, DL_-344, DL_346, DL_-490, DL_-546	250	J-817	150
DL_-742,DL_-913,DL_-1016, DL_-1112,DL_-1204,DL_-1406	150	DL_-1508, DL_-1699, DL_-1582, DL_-1885	100	DL_-1908, J-45	100
J-46, DL_-1667, DL_-1769, DL_-1877, DL_-1973. DL_-2033	100				

4.3.2. Performance management intervention

A multi-village water supply scheme's overall success and sustainability are greatly influenced by the utility's performance. Implementing focused improvement initiatives, recognizing capacity shortages, and conducting thorough assessments can all contribute to enhancing the utility's capacity to provide equitable and dependable water services.

Before proposing the intervention mechanisms this study identified the existing performance of the utility using key performance indicators (KPI) as per MoWE (2013) used to evaluate utilities for grading. For allocating weighing score the performance indicator classified in to three major categories and the detail weighing criteria for selected key performance indicated in Annex 6.

Table 33: Weight Score for the Selected Key performance Indicators as per MoWE

S/No	Description	Weightage in
1	**Customer Satisfaction**	**50**
1.1	Access coverage	20
1.2	Service quality/water availability	20
1.3	Customer number	10
2	**Water resource Management**	**30**
2.1	NRW	20
2.2	System complexity	10
3	**Financial resource management**	**20**
3.1	Cost recovery	20
	Total	**100**

i. Analysis of utility performance based on criteria set by MoWE

Customer satisfaction

- ✓ Access addressed of 2024 $= \frac{\text{population served at recomended distance}}{\text{projected population for 2024}}$

Access addressed of 2024 $= \frac{25317}{53138}$*100% =47.65%

- ✓ Water availability: 8hr/day (Morning from 8-11am and after noon from 2 -5pm) as per information obtained from utility
- ✓ Customer number ratio = 0

Water resource management

- ✓ None revenue water = $\frac{\text{supplied water} - \text{billed water for consumption}}{\text{supplied water}}$*100%

Average none revenue water (2023-2024) = $\frac{(249480-190958.15)m3}{249480m3}$*100% =23.46%

- ✓ System complexity = spring pumping

Financial resource Management

- ✓ Cost recovery = $\frac{\text{Revenue collected in Birr}}{\text{operational cost in Birr}}$

Cost recovery = $\frac{13090572}{8085380}$ = 1.62

The individual weighting was taken from the categorization Table shown under Appendex-5 and after the aforementioned key performance indicators were completed, making the overall weighting 33%. This puts the utility in the category of low performing according to the MoWE categorization.

Table 34: TMVWSP utility performance as per the computed KPI

S/No	Description	Weightage in %
1	Customer Satisfaction	5
1.1	Access coverage	0
1.2	Service quality/water availability	5
1.3	Customer number ratio	0
2	Water resource Management	8
2.1	NRW	2
2.2	System complexity	6
3	Financial resource management	20
3.1	Cost recovery	20
	Total	33

Table 35: Performance level of utilities as per MoWE

S. No	Utility performance level	KPI Score in
1	High performer	> = 85
2	Moderate performer	50-84.99
3	Low performer	< 50

The above result highlights the utility underperforms in both customer satisfaction and water resource management. The reason for customer satisfaction was found not all about the supply problem rather community are not willing to use the system as required. A survey was done in this issues to find out why the beneficiaries were not using the system appropriately, as access coverage and water availability were found to be hampered by the community's low interest to use the water supply systems. A sample of population interview data was collected from 7 water points, or 22% of the total number that are located in 2 rural towns and 8 rural villages and summary indicated under Annex-7. Again to ensure the reliability of the data, 70% of the kebeles were considered out of which 5% households selected as data informants.

From 5% of the population samples (511 household representative interviewed), 65.95% of the respondents stated that the large travel distance (more than 1 km) to collect water from the location of the water point was one reason for the low interest in existing water supply system. The maximum water point location distance from the user community, under GTP-II, is 1 km for 25 l/c/d. 99.02% of the respondents again stated that they cannot afford the utility tariff rate of 100 Birr/m3. For comparison 5 utility of similar level water point tariff was collected as shown in Annex-9 and it ranges from 13.5 to 46 birr/m3 and hence, despite the fact that most utility tariffs differ depending on their particular characteristics such as energy source, source type, and human resource availability, TMVWSP tariff is quite expensive to use and need revision of business plan.

Regarding water resource management the major problem as discussed in this research was the physical loss due to excessive pressure which further aggravated by the absence of gate valves at recommended distance along the pipe line and hence the NRW has got 46.06% which puts threats on the sustainability of the system if urgent measures not taken. On the other hand the conducted interview indicates that the participation of user communities from the beginning of project plan to the end construction period was found very low where 90.41% not partook in one way or the other and this remakes that sense of owner ship which contribute lot in project sustainability undermined. Above all no awareness (0%) so far given by utility to motivate beneficiaries to use the scheme and hence fundamental change needed on the current management trend of the utility.

CHAPTER FIVE CONCLUSIONS AND RECOMMENDATIONS

This research was conducted to bridge the gaps of TMVWSP which currently serve 2 towns and 8 rural kebeles through constructed 32 water points. The collected data of the research under each objectives was briefly analyzed to come up with the reliable results and the following conclusion and recommendation were made based on the findings obtained.

5.1. Conclusion

Teyfe MVWSP is a motorized spring system accompanied with different components and predicted to address the MMD of 40.78L/s in the proposed design period. The existing spring source was measured to give 61.8L/s and can sufficiently supply to meet the required demand. However the currently installed pumps can only supply 30L/s and hence with in the useful life time of the project, the electromechanical need upgrading to adequately serve the purpose.

The existing transmission line can uphold the MDD required at the end of the design period except 1.2km uPVC pipe line between WW-3 and 1500m^3 reservoir .The pressure and velocity ranges between 5-385m and 2-6m/s respectively. The maximum head is due to significantly steep topographic nature of the pipe routes and equivalent pipe with PN 40 laid to avoid the possible effects of pressure except the aforementioned upvc pipe lene section. The velocity calculated were also in the recommended ranges with exception of GS pipe having 38m at out let of WW-1 where the allowable limit of velocity exceeded by 0.3m/s and do not have significant problem .

With regard to distribution line, analysis was conducted for minimum and maximum flow condition to check pipe performance with respect to pressure and velocity respectively. Maximum pressure of 80-183m occurred in the pipe line section between Node J-385 to WP-32 where its PN is 16 and hence this sort of condition needs pressure relief components. The maintenance history of the utility proofs the result facts where pipes are broken in the mentioned area frequently. Minimum velocity less than 0.6m/s occurred in 53.06% of the pipe length and this has happened mostly in large pipe segment of the system. Changing this huge quantity of pipe is not practical and hence it is better to install valves that used to flush where ever silts stored in the sagging points of the pipe due to this low velocity.

EME were the other components for which the system performance was evaluated and the existing pumps in all booster stations except at WW-4 can serve the purpose up to 2032 where the discharge is nearly 30L/s, similar to pump capacity. Pump at WW-4 lifts only 12.5L/s for pressure zone 3 beneficiaries and it can serve only up to the year 2027.On the other hand the existing power plants (Generator and Transformer) were compared with the computed sizes of same equipment's and power plants at WW-1 and WW-2 , and WW-3 were found oversized with 18.45% increment than required. This puts significant operational loads due to high energy consumption. In WW-4 the generator alone fit with the size computed whereas the transformer capacity is still larger than the computed capacity.

Following the aforementioned gaps identified during performance evaluation, intervention mechanisms were proposed employing design review and evaluation of existing managements using KPI. In the design review section the new proposed pipe lay out system identified and it was proved to offer three major advantage; significantly minimize the energy consumption of power plants and decrease the capital cost used to purchase the new pipe going to be replaced and large size power plant supplied in 2^{nd} stage.

On another hand for the frequently breaking distribution line, PRV and break pressure tanker were proposed to bring down the excessive pressure to allowable limit.

Finally the performance of the utility evaluated using the selected KPI and failure on customer satisfaction identified. On this basis the reason utility fail to achieve good performance at large was identifies and found less water use of beneficiaries. Therefore further sample survey was conducted among communities why communities do not use the water as required and problem of affordability and long distance accounts 99.02 & 65.95 respectively. Sense of ownership developed so far together with effort done to crate water use awareness are also identified very low.

Hence in this research study different essential finding were obtained and these may help the clients if put in to implementation and again can be used by other entities who need to undertake further studies using it as an input.

5.2. Recommendation

The following insightful recommendation were given based on the finding of the thesis result to bridge the gap identified

- The existing water supply taken from source using pumps can sufficiently serve the user community up to the year 2032 with discharge of 30L/s .However the design discharge required up to 2041 or end of design period was computed 40.78L/s and hence deficiency will confronts before the useful period of the project expire. Therefore 11.78L/s of additional discharge is required after 2032 and this will be solved through provision of adequate capacity pumps in the 2^{nd} stage of the project.
- The existing lay out of TMVWSP is not cost effective and should be optimized. Under identification of intervention mechanisms, new location of additional reservoir proposed at side of the existing $50m^3$ break pressure chamber. In this approach energy can be saved, existing uPVC transmission pipe (1.2km) not changed due to increasing pressure head of pumps in the second stage, the pump and power plant capacity going to be replaced in second stage at pump station 3 will get decreasing and hence capital cost minimized. However in all this advantageous circumstances, the new lay out also needs construction of additional reservoir that will cost the utility and hence detail economic analysis must be conducted before going to use the finding of this research result to discern the best alternative.
- The hydraulic analysis of the distribution line shows that, considerable segment of the pipe line fall under excessive pressure ranging between 80-183m.This will therefore subject to loss of water and increase maintenance costs. However the utility can easily control the pressure proposing new PRV and break pressure tanks as required, especially for pressure prone areas discussed in the result section.
- The distribution line system also lacks adequate amount of essential valves. Gate valves at branching junction points and at standard recommended distance interval should be installed to use during maintenance works and save the loss of water when pipe breaks. Even though there are many sagging points on the pipe profiles that favors accumulation of silts, only one flushing valves exists along the routes and this should be also improved. Additional air release valves also required at crest pipe profile points especially in areas where distance between water points is significant.
- Lack of Proper pipe material allocation according to respective soil formation in some section of the pipe line become the problem for frequent breaking of pipes and hence uPVC pipe line between laid

over rocky soil formation and should be replaced with ridged material pipes such as GS and DCI and properly bedded. For exposed pipes or laid above ground the same measure should be taken and again supporting structures like anchor blocks must be constructed.

- The management performance of the utility should be enhanced to improve customer satisfaction as majority of the community still in lack of potable water use though adequate supply is available. The main problems identified through sample survey were water tariff and the distance travelled to collect water. Both causes were observed reasonable when compared with other utilities and following guides set respectively. According to respondents 100birr/m3 is paid which is two folds of maximum tariff of other utilities. This must be revised preparing adequate business plan that outlays different revenue collection options and sets expense minimizing strategies such as converting energy sources to solar systems, initiate customers to use different mode of services like yard connection and increasing working hour of systems if not the water supply system will miss its major target. Regarding travelling distance, the available water points are not sufficient and again additional pipe line needed to reach community at recommended proximity. In the distribution system the research result show that the head in most water points is negative during maximum consumption hours. The major causes of this was mentioned the size of pipe to manage the demand and replacing pipe with larger size by itself do not solve problem if additional water consumption points not constructed and instead of dismantling the existing smaller pipes it is better to use alternative pipe routes and share the discharge.

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ANNEX

Annex-1: Existing components of Teyfe water supply system

S. No	Component	Description	
1	Source: Spring	Discharge capacity: 61.8 L/s	
2	Pumps	At wet well-1: H = 26m, Q=28 L/s, Power = 15KW, No=2	
		At wet well -2: H = 332m, Q=28 L/s, Power = 129KW, No=2	
		At wet well-3: H = 330m, Q=28 L/s, Power =160KW, No =2	
		At wet well-4: H = 130m, Q=12.5 L/s, Power =30KW, No =3	
3	Generators	Wet well - 1&2 : Capacity 750 KVA, No =1	
		Wet well -3: Capacity 750 KVA, No =1	
		Wet well - 4 : Capacity 100 KVA, No =1	
4	Transmission Pipe	DCI pipe: DN 200 = 10174m, DN 300= 70m, GS Pipe DN 150=38m, uPVC pipe DN 200 =8386m	
5	Distribution Line		
	Pipe Material	**Pipe Diameter(mm)**	**Pipe Length (m)**
	HDPE	110	4110
	uPVC	63	17814
		110	10518
		160	18762
		225	12223
		280	13432
	Total		72749
	DCI	100	61
		150	4661
		200	14959
		250	69
	Total		19750

Annex-2: Demand Allocation for each village and pressure Zone

Zone	Description	Design period						Average Consumption share in L/s						Zonal Average consumption in L/s					
	year	**2023**	**2024**	**2027**	**2030**	**2032**	**2041**	**2023**	**2024**	**2027**	**2030**	**2032**	**2041**	**2023**	**2024**	**2027**	**2030**	**2032**	**2041**
	Average consumption rate in L/c/d							33.38	33.69	35.71	37.79	39.05	45.95						
1	Kurfa Roko	4320	4471	4936	5440	5793	7602	1.67	1.74	2.04	2.38	2.62	4.04	10.52	10.82	12.07	13.43	14.31	19.06
	Meta Arba	4057	4125	4302	4476	4580	5001	1.57	1.61	1.78	1.96	2.07	2.66						
	Kurfa Gelma	6667	6779	7070	7355	7526	8218	2.58	2.64	2.92	3.22	3.40	4.37						
	Dhadacha Hina	12181	12385	12916	13437	13751	15014	4.71	4.83	5.33	5.88	6.22	7.99						
2	Teyfe	6141	6356	7017	7734	8498	10807	2.37	2.48	2.90	3.38	3.84	5.75	2.37	2.48	2.90	3.38	3.84	5.75
3	Burka Ramis	5881	5980	6236	6488	6639	7249	2.27	2.33	2.58	2.84	3.00	3.86	7.23	7.42	8.19	9.03	9.55	12.26
	Dimtu Boreda	3779	3843	4008	4169	4267	4658	1.46	1.50	1.66	1.82	1.93	2.48						
	Burka Oda	2548	2590	2701	2810	2876	3140	0.98	1.01	1.12	1.23	1.30	1.67						
	Abdi guddina	3208	3262	3402	3539	3622	3955	1.24	1.27	1.41	1.55	1.64	2.10						
	Rada dibicha	3290	3345	3489	3629	3714	4055	1.27	1.30	1.44	1.59	1.68	2.16						
	Grand Total	52072	53136	56078	59077	61266	69699	20.12	20.72	23.16	25.84	27.69	37.07	20.12	20.72	23.16	25.84	27.69	37.07

Annex-3: Photos taken while collecting Observed data of pressure at water points using pressure gauge

Annex-4: Calibration and Validation data and analysis

a. Calibration

Water points	Observed Pressure in m(X)	Simulated Pressure in m(Y)	X-Xav	Y-Yav	(X-Xav) * (Y-Yav)	$(X-Xav)^2$	$(Y-Yav)^2$
WP-1	7	7.98	-39.88	-39.25	1565.29	1590.414	1540.563
WTP_2	21.68	20.14	-25.2	-27.09	682.668	635.04	733.8681
WP_3	37.44	38.52	-9.44	-8.71	82.2224	89.1136	75.8641
WP_7	35.67	35.15	-11.21	-12.08	135.4168	125.6641	145.9264
WP_8	27.05	29.69	-19.83	-17.54	347.8182	393.2289	307.6516
WP_9	64.76	67.89	17.88	20.66	369.4008	319.6944	426.8356
WP-10	62.3	66.45	15.42	19.22	296.3724	237.7764	369.4084
WP-12	53.5	54.22	6.62	6.99	46.2738	43.8244	48.8601
WP-13	26.5	25.71	-20.38	-21.52	438.5776	415.3444	463.1104
WP_14	103.77	102.62	56.89	55.39	3151.1371	3236.472	3068.052
WP_17	59.89	59.16	13.01	11.93	155.2093	169.2601	142.3249
WP-18	10.15	11.65	-36.73	-35.58	1306.8534	1349.093	1265.936
WP-21	20	19.8	-26.88	-27.43	737.3184	722.5344	752.4049
WP-22	16.23	16.58	-30.65	-30.65	939.4225	939.4225	939.4225
WP-24	12.52	13.21	-34.36	-34.02	1168.9272	1180.61	1157.36
WP_25	26.44	27.01	-20.44	-20.22	413.2968	417.7936	408.8484
WP-26	-0.3	-1.17	-47.18	-48.4	2283.512	2225.952	2342.56
WP-27	15.63	16.29	-31.25	-30.94	966.875	976.5625	957.2836
WP-28	20.55	20.15	-26.33	-27.08	713.0164	693.2689	733.3264
WP-29	11.25	9.37	-35.63	-37.86	1348.9518	1269.497	1433.38
WP_30	116.56	116.34	69.68	69.11	4815.5848	4855.302	4776.192
WP-31	166.65	166.5	119.77	119.27	14284.9679	14344.85	14225.33
WP_32	162.96	162.95	116.08	115.72	13432.7776	13474.57	13391.12
Sum	1078.2	1086.21	-0.04	-0.08	49681.8902	49705.29	49705.63
Average	46.88	47.23					

$$R^2 = \frac{\sum(\mathrm{X-Xav})(\mathrm{Y-Yav})}{\sqrt{\sum 9\mathrm{X-Xav})^2+(Y-Yav)^2}} = 0.9974$$

b. Validation

Water points	Observed Pressure in m(X)	Simulated Pressure in m(Y)	X-Xav	Y-Yav	(X-Xav)* (Y-Yav)	$(X-Xav)^2$	$(Y-Yav)^2$
WP_4	9.47	19.4	-20.83	-11.31	235.5873	433.8889	127.9161
WP_5	9.64	16.93	-20.66	-13.78	284.6948	426.8356	189.8884
WP_6	23.35	19.12	-6.95	-11.59	80.5505	48.3025	134.3281
WP_11	53.62	47.19	23.32	16.48	384.3136	543.8224	271.5904
WP_15	93.87	91.43	63.57	60.72	3859.97	4041.145	3686.918
WP_16	68.34	79.19	38.04	48.48	1844.179	1447.042	2350.31
WP-19	-1.75	3.21	-32.05	-27.5	881.375	1027.203	756.25
WP_20	11.76	0.31	-18.54	-30.4	563.616	343.7316	924.16
WP-23	2	-0.36	-28.3	-31.07	879.281	800.89	965.3449
Sum	270.30	276.42	240	245.71	9013.57	9112.86	9406.71
Average	30.03	30.71					

$$R^2 = \frac{\sum(\mathrm{X-Xav})(\mathrm{Y-Yav})}{\sqrt{\sum 9\mathrm{X-Xav})^2+(Y-Yav)^2}} = 0.9478\text{, av-average}$$

Annex - 5: Nodal and link output at static and peak hour consumption for distribution line and Nodal output for existing and revised lay out of Transmission line

I. Nodal hydraulic output at minimum flow condition for existing and revised system in critical areas at 0:00Hrs

Node ID	Before Design review		After Design Review		Elevation (m) Before Design review	Node ID	Before Design review		After Design Review		Remark
	HG(m)	P (m)	HG(m)	Node ID			HG(m)	P (m)	HG(m)	P (m)	
DL-230	1,584.18	1.1	1,584.38	1.3	1,583.08	J-349	1,583.39	5.94	1,583.56	6.1	Reservoir and Break Pressure Area and No need of any change
DL_-8	1,568.40	1.65	1,568.40	1.65	1,566.74	DL_-60	1,568.37	6.01	1,568.35	5.99	
DL-231	1,583.96	2.07	1,584.06	2.18	1,581.88	DL_-62	1,568.37	6.16	1,568.35	6.13	
DL_-12	1,568.40	2.12	1,568.39	2.12	1,566.27	J-674	1,489.42	6.27	1,489.29	6.13	
DL_-14	1,568.40	2.31	1,568.39	2.31	1,566.08	DL_-64	1,568.37	6.55	1,568.34	6.52	
DL_-6	1,568.40	2.39	1,568.40	2.39	1,566.00	DL_-66	1,568.37	6.8	1,568.34	6.77	
DL_-16	1,568.39	2.5	1,568.39	2.49	1,565.89	DL_-68	1,568.37	7.1	1,568.34	7.08	
DL_-18	1,568.39	2.69	1,568.39	2.68	1,565.70	J-673	1,489.64	7.11	1,489.48	6.96	
DL_-20	1,568.39	2.86	1,568.39	2.85	1,565.53	DL_-70	1,568.37	7.36	1,568.34	7.33	
DL_-22	1,568.39	2.99	1,568.38	2.98	1,565.40	DL_-72	1,568.37	7.62	1,568.34	7.59	
DL_-24	1,568.39	3.1	1,568.38	3.1	1,565.28	J-672	1,489.83	7.87	1,489.65	7.69	
DL_-26	1,568.39	3.23	1,568.38	3.22	1,565.15	DL_-74	1,568.37	7.92	1,568.34	7.89	
DL_-28	1,568.39	3.35	1,568.38	3.34	1,565.03	DL-235	1,583.26	7.92	1,583.44	8.1	
J-788	1,568.40	3.44	1,568.40	3.44	1,564.95	DL_-78	1,568.36	8.13	1,568.33	8.1	
DL_-30	1,568.39	3.48	1,568.38	3.47	1,564.90	DL_-80	1,568.36	8.16	1,568.33	8.12	
DL_-32	1,568.39	3.67	1,568.37	3.66	1,564.71	DL_-76	1,568.36	8.22	1,568.33	8.19	
DL_-34	1,568.39	3.92	1,568.37	3.9	1,564.46	J-671	1,490.04	8.66	1,489.83	8.46	
J-677	1,488.83	3.98	1,488.76	3.91	1,484.84	DL_-82	1,568.36	8.9	1,568.33	8.87	
DL_-36	1,568.38	4.08	1,568.37	4.06	1,564.30	J-670	1,490.22	9.39	1,490.00	9.16	
DL_-44	1,568.38	4.18	1,568.36	4.17	1,564.19	J-349	1,583.39	5.94	1,583.56	6.1	
DL_-38	1,568.38	4.21	1,568.37	4.2	1,564.16	DL_-60	1,568.37	6.01	1,568.35	5.99	
DL_-40	1,568.38	4.34	1,568.37	4.33	1,564.03	DL_-62	1,568.37	6.16	1,568.35	6.13	
DL_-46	1,568.38	4.4	1,568.36	4.38	1,563.97	J-674	1,489.42	6.27	1,489.29	6.13	
DL_-42	1,568.38	4.48	1,568.37	4.47	1,563.89	DL_-64	1,568.37	6.55	1,568.34	6.52	
DL_-48	1,568.38	4.61	1,568.36	4.59	1,563.76	DL_-66	1,568.37	6.8	1,568.34	6.77	
J-676	1,489.04	4.78	1,488.94	4.69	1,484.25	DL_-68	1,568.37	7.1	1,568.34	7.08	
DL_-50	1,568.38	4.8	1,568.36	4.78	1,563.57	J-673	1,489.64	7.11	1,489.48	6.96	
DL_-52	1,568.38	4.98	1,568.36	4.96	1,563.39	DL_-70	1,568.37	7.36	1,568.34	7.33	
DL_-54	1,568.38	5.22	1,568.35	5.2	1,563.14	DL_-72	1,568.37	7.62	1,568.34	7.59	
DL_-56	1,568.37	5.56	1,568.35	5.54	1,562.80	J-672	1,489.83	7.87	1,489.65	7.69	
J-675	1,489.24	5.56	1,489.12	5.44	1,483.67	DL_-74	1,568.37	7.92	1,568.34	7.89	

DL_-58	1,568.37	5.8	1,568.35	5.78	1,562.56	DL-235	1,583.26	7.92	1,583.44	8.1	
J-560	1,514.87	80.15	1,511.99	77.27	1,434.56	J-532	1,521.68	91.61	1,518.08	88.02	
JM-727	1,559.23	80.5	1,551.72	73.01	1,478.56	J-531	1,521.89	91.79	1,518.27	88.17	
J-555	1,516.04	80.64	1,513.03	77.64	1,435.24	J-515	1,525.81	91.9	1,521.77	87.88	
J-559	1,515.11	80.83	1,512.20	77.93	1,434.11	J-530	1,522.15	91.99	1,518.50	88.35	
J-554	1,516.29	81.21	1,513.26	78.18	1,434.92	J-529	1,522.39	92.17	1,518.72	88.5	
J-558	1,515.32	81.48	1,512.39	78.55	1,433.68	J-354	1,556.92	92.25	1,549.65	84.99	
J-387	1,558.97	81.73	1,551.49	74.26	1,477.08	J-514	1,526.06	92.28	1,522.00	88.23	
J-553	1,516.53	81.75	1,513.47	78.7	1,434.61	J-528	1,522.64	92.35	1,518.93	88.65	
J-557	1,515.59	82.28	1,512.63	79.33	1,433.14	J-527	1,522.88	92.53	1,519.15	88.81	
J-552	1,516.78	82.35	1,513.70	79.28	1,434.26	J-522	1,524.11	92.61	1,520.25	88.76	
J-551	1,517.01	82.88	1,513.90	79.78	1,433.96	J-513	1,526.30	92.66	1,522.21	88.58	
J-388	1,558.72	82.95	1,551.26	75.51	1,475.60	J-526	1,523.12	92.71	1,519.36	88.97	
J-556	1,515.85	83.07	1,512.86	80.09	1,432.61	J-525	1,523.37	92.85	1,519.59	89.08	
J-550	1,517.26	83.46	1,514.13	80.33	1,433.63	J-398	1,555.87	92.97	1,548.71	85.83	
WP_16	1,515.81	83.53	1,512.82	80.55	1,432.11	J-524	1,523.61	93	1,519.81	89.2	
J-549	1,517.51	84.07	1,514.35	80.91	1,433.27	J-512	1,526.54	93.02	1,522.43	88.91	
J-389	1,558.47	84.18	1,551.04	76.77	1,474.12	J-521	1,524.35	93.04	1,520.46	89.16	
J-548	1,517.76	84.6	1,514.57	81.42	1,432.98	J-396	1,556.39	93.06	1,549.17	85.86	
J-547	1,518.01	85.21	1,514.79	82	1,432.63	J-397	1,556.13	93.09	1,548.94	85.92	
J-390	1,558.22	85.41	1,550.82	78.02	1,472.64	J-523	1,523.86	93.13	1,520.03	89.3	
J-546	1,518.24	85.76	1,515.00	82.53	1,432.31	J-792	1,568.01	93.17	1,511.89	37.16	
J-545	1,518.49	86.33	1,515.22	83.07	1,431.98	J-400	1,555.37	93.21	1,548.26	86.11	
J-391	1,557.96	86.61	1,550.58	79.25	1,471.17	J-399	1,555.62	93.22	1,548.48	86.1	
J-544	1,518.73	86.91	1,515.44	83.63	1,431.65	J-395	1,556.73	93.26	1,549.48	86.03	
J-543	1,518.97	87.46	1,515.66	84.15	1,431.34	J-519	1,524.83	93.28	1,520.90	89.36	
J-392	1,557.70	87.86	1,550.35	80.52	1,469.67	J-511	1,526.79	93.39	1,522.65	89.26	
J-542	1,519.23	88.05	1,515.89	84.72	1,431.00	J-520	1,524.59	93.47	1,520.68	89.57	
J-541	1,519.48	88.63	1,516.11	85.27	1,430.67	J-401	1,555.10	93.55	1,548.02	86.48	
J-540	1,519.73	89.22	1,516.33	85.83	1,430.33	J-518	1,525.08	93.71	1,521.12	89.76	
J-393	1,557.43	89.31	1,550.11	82.01	1,467.94	DL_1085	1,568.00	93.77	1,511.83	37.71	
J-539	1,519.97	89.77	1,516.55	86.36	1,430.01	J-510	1,527.03	93.77	1,522.87	89.61	
J-538	1,520.17	90.24	1,516.73	86.81	1,429.75	J-402	1,554.84	93.83	1,547.79	86.79	
J-537	1,520.43	90.45	1,516.96	86.98	1,429.80	J-517	1,525.33	93.84	1,521.34	89.86	
J-536	1,520.69	90.72	1,517.19	87.23	1,429.78	J-403	1,554.59	94.11	1,547.56	87.1	
J-394	1,557.21	90.82	1,549.91	83.53	1,466.21	J-509	1,527.29	94.15	1,523.10	89.97	
J-535	1,521.00	91.06	1,517.47	87.54	1,429.76	J-355	1,554.35	94.41	1,547.34	87.42	
J-534	1,521.18	91.22	1,517.63	87.68	1,429.77	J-358	1,527.49	94.46	1,523.28	90.26	
J-533	1,521.42	91.48	1,517.85	87.91	1,429.76	J-506	1,528.27	94.55	1,523.98	90.26	
J-404	1,554.26	94.56	1,547.26	87.58	1,459.51	J-480	1,534.73	95.79	1,529.76	90.83	

J-508	1,527.77	94.56	1,523.53	90.32	1,433.02	J-479	1,534.98	95.83	1,529.98	90.85	
J-505	1,528.52	94.58	1,524.20	90.26	1,433.75	J-478	1,535.22	95.88	1,530.20	90.87	
J-507	1,528.00	94.59	1,523.74	90.33	1,433.22	J-477	1,535.47	95.91	1,530.43	90.87	
J-504	1,528.76	94.6	1,524.42	90.26	1,433.97	J-476	1,535.71	95.95	1,530.64	90.89	
J-503	1,529.01	94.66	1,524.64	90.29	1,434.16	J-475	1,535.96	95.99	1,530.86	90.9	
J-405	1,554.14	94.67	1,547.16	87.7	1,459.28	J-416	1,551.35	96	1,544.65	89.32	
J-406	1,553.90	94.84	1,546.94	87.89	1,458.87	J-474	1,536.21	96.03	1,531.09	90.92	
J-502	1,529.26	94.87	1,524.86	90.48	1,434.20	J-473	1,536.47	96.07	1,531.32	90.93	
J-407	1,553.63	94.9	1,546.70	87.98	1,458.54	J-472	1,536.73	96.12	1,531.55	90.95	
J-501	1,529.51	94.91	1,525.09	90.5	1,434.41	J-471	1,536.96	96.16	1,531.76	90.97	
J-408	1,553.37	94.96	1,546.47	88.07	1,458.22	J-470	1,537.21	96.2	1,531.98	90.98	
J-500	1,529.76	94.96	1,525.31	90.52	1,434.61	J-417	1,551.10	96.24	1,544.43	89.58	
J-499	1,530.01	95	1,525.53	90.54	1,434.81	J-469	1,537.46	96.24	1,532.20	91	
J-498	1,530.25	95.04	1,525.75	90.55	1,435.02	DL_1112	1,567.99	96.26	1,511.76	40.15	
J-497	1,530.49	95.08	1,525.97	90.56	1,435.22	J-468	1,537.71	96.27	1,532.43	91	
J-409	1,553.15	95.12	1,546.27	88.26	1,457.83	J-467	1,537.95	96.31	1,532.65	91.02	
J-496	1,530.75	95.12	1,526.20	90.58	1,435.44	J-466	1,538.21	96.36	1,532.88	91.04	
J-495	1,530.98	95.16	1,526.41	90.59	1,435.63	J-465	1,538.46	96.4	1,533.11	91.05	
J-494	1,531.25	95.2	1,526.64	90.61	1,435.85	J-464	1,538.71	96.45	1,533.32	91.08	
J-410	1,552.88	95.23	1,546.03	88.39	1,457.46	J-463	1,538.95	96.49	1,533.54	91.09	
J-493	1,531.48	95.25	1,526.85	90.63	1,436.04	J-418	1,550.85	96.5	1,544.21	89.87	
J-492	1,531.75	95.29	1,527.09	90.65	1,436.26	J-462	1,539.19	96.53	1,533.76	91.1	
J-411	1,552.63	95.31	1,545.80	88.5	1,457.12	WP_15	1,526.71	96.54	1,522.57	92.41	
J-491	1,531.99	95.33	1,527.30	90.66	1,436.46	J-461	1,539.45	96.58	1,533.99	91.12	
DL_1100	1,567.99	95.38	1,511.79	39.29	1,472.42	J-419	1,550.60	96.6	1,543.98	90	
J-412	1,552.36	95.38	1,545.57	88.6	1,456.79	J-357	1,539.71	96.63	1,534.22	91.15	
J-490	1,532.23	95.39	1,527.52	90.69	1,436.65	J-420	1,550.34	96.68	1,543.75	90.1	
J-489	1,532.50	95.42	1,527.76	90.7	1,436.88	J-460	1,539.96	96.69	1,534.44	91.19	
J-488	1,532.73	95.47	1,527.97	90.72	1,437.07	J-421	1,550.09	96.77	1,543.53	90.22	
J-487	1,532.98	95.51	1,528.20	90.73	1,437.28	J-459	1,540.21	96.77	1,534.67	91.24	
J-413	1,552.12	95.53	1,545.34	88.77	1,456.39	J-458	1,540.46	96.84	1,534.89	91.28	
J-486	1,533.22	95.56	1,528.41	90.76	1,437.47	J-422	1,549.83	96.86	1,543.30	90.34	
J-485	1,533.48	95.6	1,528.64	90.77	1,437.69	J-457	1,540.70	96.9	1,535.11	91.32	
J-484	1,533.72	95.64	1,528.85	90.79	1,437.88	J-423	1,549.59	96.97	1,543.08	90.47	
J-483	1,533.97	95.68	1,529.08	90.8	1,438.10	J-456	1,540.96	96.97	1,535.34	91.36	
J-414	1,551.87	95.69	1,545.12	88.96	1,455.98	WP_14	1,541.25	97.03	1,535.60	91.39	
J-482	1,534.21	95.7	1,529.29	90.79	1,438.32	J-424	1,549.33	97.05	1,542.85	90.58	
J-415	1,551.61	95.72	1,544.89	89.01	1,455.70	J-356	1,541.29	97.06	1,535.63	91.42	
J-481	1,534.48	95.75	1,529.53	90.82	1,438.53	J-455	1,541.48	97.06	1,535.81	91.39	
DL_1121	1,567.98	97.07	1,511.74	40.93	1,470.72	DL_1180	1,567.96	107.69	1,511.58	51.43	

J-454	1,541.71	97.09	1,536.01	91.4	1,444.42	DL_1188	1,567.96	109.67	1,511.56	53.4	
J-453	1,541.95	97.13	1,536.23	91.42	1,444.63	DL_1197	1,567.95	111.99	1,511.54	55.69	
J-425	1,549.08	97.14	1,542.62	90.7	1,451.74	WP-13	1,556.57	112.35	1,549.25	105.04	
J-452	1,542.21	97.19	1,536.46	91.45	1,444.83	DL_1204	1,567.95	113.53	1,511.52	57.22	
J-451	1,542.47	97.23	1,536.69	91.47	1,445.04	DL_1215	1,567.94	116.17	1,511.49	59.83	
J-426	1,548.83	97.24	1,542.39	90.82	1,451.39	DL_1223	1,567.94	118.09	1,511.47	61.74	
J-450	1,542.72	97.27	1,536.92	91.48	1,445.25	DL_1231	1,567.94	120.04	1,511.45	63.66	
J-430	1,547.82	97.31	1,541.49	91	1,450.31	DL_1238	1,567.93	121.68	1,511.43	65.29	
J-449	1,542.98	97.32	1,537.15	91.51	1,445.46	DL_1245	1,567.93	122.66	1,511.42	66.26	
J-431	1,547.56	97.35	1,541.26	91.06	1,450.01	DL_1252	1,567.93	123.8	1,511.40	67.38	
J-448	1,543.24	97.36	1,537.38	91.52	1,445.68	DL_1259	1,567.93	124.94	1,511.38	68.51	
J-447	1,543.49	97.4	1,537.61	91.53	1,445.89	WP_30	1,567.67	125.23	1,511.10	68.77	
J-427	1,548.57	97.45	1,542.16	91.06	1,450.92	DL_1268	1,567.92	125.65	1,511.36	69.2	
J-446	1,543.74	97.45	1,537.83	91.56	1,446.09	DL_1271	1,567.92	125.89	1,511.35	69.43	
J-445	1,544.00	97.5	1,538.07	91.57	1,446.31	DL_1276	1,567.92	126.73	1,511.34	70.27	
J-432	1,547.31	97.54	1,541.03	91.28	1,449.57	DL_1283	1,567.92	127.71	1,511.33	71.23	
J-444	1,544.24	97.54	1,538.28	91.59	1,446.51	DL_1292	1,567.92	128.56	1,511.31	72.06	
J-429	1,548.06	97.55	1,541.71	91.2	1,450.32	DL_1300	1,567.92	130.53	1,511.29	74.02	
J-443	1,544.51	97.58	1,538.52	91.61	1,446.73	DL_1309	1,567.92	131.86	1,511.28	75.34	
J-437	1,546.03	97.6	1,539.89	91.47	1,448.24	DL_1324	1,567.91	135.32	1,434.41	2.08	
J-442	1,544.76	97.62	1,538.75	91.62	1,446.94	DL_1332	1,567.91	137.3	1,434.41	4.07	
J-436	1,546.28	97.64	1,540.11	91.48	1,448.45	DL_1341	1,567.91	139.25	1,434.41	6.01	
J-428	1,548.32	97.67	1,541.93	91.3	1,450.45	DL_1349	1,567.91	140.81	1,434.41	7.58	
J-435	1,546.56	97.67	1,540.36	91.48	1,448.70	DL_1357	1,567.91	141.64	1,434.40	8.41	
J-441	1,545.02	97.67	1,538.98	91.64	1,447.15	DL_1364	1,567.91	142.59	1,434.40	9.35	
J-434	1,546.80	97.69	1,540.58	91.48	1,448.91	DL_1371	1,567.91	143.66	1,434.40	10.42	
J-440	1,545.26	97.72	1,539.20	91.66	1,447.35	DL_1378	1,567.91	144.49	1,434.40	11.26	
J-433	1,547.05	97.73	1,540.80	91.49	1,449.13	DL_1389	1,567.90	145.64	1,434.40	12.4	
J-439	1,545.54	97.76	1,539.45	91.68	1,447.58	DL_1406	1,567.90	147.04	1,434.40	13.81	
J-438	1,545.78	97.81	1,539.66	91.7	1,447.78	DL_1425	1,567.90	149.68	1,434.39	16.44	
DL_1138	1,567.98	99.2	1,511.69	43.03	1,468.58	DL_1435	1,567.90	152.34	1,434.39	19.1	
DL_1146	1,567.97	100.44	1,511.67	44.25	1,467.33	DL_1908	1,567.72	154.33	1,434.22	21.09	
DL_1154	1,567.97	101.75	1,511.65	45.55	1,466.01	DL_1848	1,567.74	155.39	1,434.24	22.15	
DL_1163	1,567.97	103.55	1,511.63	47.32	1,464.21	DL_1858	1,567.74	155.68	1,434.23	22.45	
DL_1172	1,567.96	105.76	1,511.60	49.51	1,461.99	DL_1917	1,567.72	155.73	1,434.21	22.5	
DL_1867	1,567.73	155.74	1,434.23	22.5	1,411.68	DL_1927	1,567.72	156.52	1,434.21	23.28	
DL_1447	1,567.89	156.12	1,434.39	22.88	1,411.46	DL_1877	1,567.73	156.62	1,434.23	23.39	
DL_1897	1,567.72	156.24	1,434.22	23	1,411.17	DL_1837	1,567.74	156.69	1,434.24	23.45	
DL_1885	1,567.73	157.13	1,434.22	23.9	1,410.28	DL_1611	1,567.81	170.72	1,434.30	37.49	
DL_1937	1,567.71	157.45	1,434.21	24.21	1,409.95	DL_1605	1,567.81	171.07	1,434.31	37.83	

DL_1946	1,567.71	158.4	1,434.21	25.17	1,408.99	DL_1570	1,567.82	171.12	1,434.32	37.88	
DL_1826	1,567.75	158.52	1,434.24	25.28	1,408.91	DL_1621	1,567.81	171.36	1,434.30	38.12	
DL_1954	1,567.71	159.45	1,434.20	26.21	1,407.94	DL_1548	1,567.84	171.56	1,434.34	38.33	
DL_1457	1,567.89	159.6	1,434.39	26.37	1,407.97	DL_1634	1,567.80	171.78	1,434.30	38.54	
DL_1817	1,567.75	159.84	1,434.24	26.6	1,407.59	DL_1593	1,567.81	171.84	1,434.31	38.6	
DL_1962	1,567.71	160.52	1,434.20	27.29	1,406.86	DL_1646	1,567.80	171.88	1,434.29	38.65	
DL_1806	1,567.75	160.93	1,434.25	27.69	1,406.50	WP_32	1,567.64	172.13	1,434.14	38.9	
DL_1973	1,567.70	162.74	1,434.20	29.51	1,404.63	DL_1740	1,567.77	172.14	1,434.27	38.91	
DL_1467	1,567.89	163.48	1,434.39	30.25	1,404.08	DL_1487	1,567.89	172.51	1,434.38	39.28	
DL_1796	1,567.75	164.24	1,434.25	31.01	1,403.18	DL_1656	1,567.80	172.54	1,434.29	39.3	
DL_1785	1,567.76	164.7	1,434.25	31.46	1,402.73	DL_1733	1,567.77	173.26	1,434.27	40.03	
DL_1983	1,567.70	164.79	1,434.20	31.55	1,402.58	DL_1582	1,567.82	173.41	1,434.31	40.17	
DL_1778	1,567.76	165.4	1,434.26	32.16	1,402.03	DL_1667	1,567.79	173.74	1,434.29	40.51	
DL_1991	1,567.70	165.5	1,434.19	32.27	1,401.86	DL_1725	1,567.78	173.84	1,434.27	40.61	
DL_2000	1,567.69	166.74	1,434.19	33.5	1,400.62	DL_1538	1,567.85	174.4	1,434.35	41.16	
DL_1769	1,567.76	167.39	1,434.26	34.16	1,400.03	WP-31	1,567.71	174.76	1,434.21	41.53	
DL_2008	1,567.69	167.75	1,434.19	34.52	1,399.60	DL_1719	1,567.78	174.9	1,434.27	41.67	
DL_1477	1,567.89	167.8	1,434.39	34.57	1,399.75	DL_1678	1,567.79	175.04	1,434.28	41.8	
DL_1760	1,567.77	168.41	1,434.26	35.17	1,399.02	DL_1710	1,567.78	175.53	1,434.28	42.29	
DL_2018	1,567.69	169.05	1,434.19	35.81	1,398.30	DL_1497	1,567.89	176.57	1,434.38	43.34	
J-45	1,567.82	169.28	1,434.32	36.05	1,398.20	DL_1689	1,567.79	176.96	1,434.28	43.72	
DL_1558	1,567.83	169.49	1,434.33	36.25	1,398.00	DL_1528	1,567.86	177.38	1,434.36	44.15	
DL_2027	1,567.69	169.77	1,434.18	36.54	1,397.57	DL_1699	1,567.78	177.66	1,434.28	44.43	
DL_1752	1,567.77	170.03	1,434.26	36.8	1,397.39	J-46	1,567.89	179.96	1,434.38	46.72	
DL_2033	1,567.68	170.61	1,434.18	37.38	1,396.73	DL_1518	1,567.87	180.78	1,434.37	47.54	
DL_-1508	1,567.88	182.51	1,434.38	49.27	1,385.01						

II. Link output at peak hour consumption for existing system

Label	L(m)	Dia(mm)	Mat	C	Q (L/s)	V (m/s)	Label	L(m)	Dia(mm)	Mat	C	Q (L/s)	V (m/s)
P-52	36	250	uPVC	126	48.55	0.99	P-106	46	250	uPVC	126	43.33	0.88
P-53	45	250	uPVC	126	48.55	0.99	P-107	46	250	uPVC	126	43.33	0.88
P-54	39	250	uPVC	126	48.55	0.99	P-108	46	250	uPVC	126	43.33	0.88
P-55	70	250	uPVC	126	48.55	0.99	P-109	49	250	uPVC	126	43.33	0.88
P-56	30	250	uPVC	126	45.93	0.94	P-1307(2)	4	80	DCI	117	40.8	8.12
P-57	46	250	uPVC	126	45.93	0.94	P-1223	5	150	GS	72	40.79	2.31
P-58	46	250	uPVC	126	45.93	0.94	P-164	24	250	uPVC	126	35.1	0.72
P-59	46	250	uPVC	126	45.93	0.94	P-165	46	250	uPVC	126	35.1	0.72
P-60	46	250	uPVC	126	45.93	0.94	P-166	46	250	uPVC	126	35.1	0.72
P-61	46	250	uPVC	126	45.93	0.94	P-167	46	250	uPVC	126	35.1	0.72
P-62	46	250	uPVC	126	45.93	0.94	P-168	46	250	uPVC	126	35.1	0.72
P-63	24	250	uPVC	126	45.93	0.94	P-169	46	250	uPVC	126	35.1	0.72
P-64	22	250	uPVC	126	45.93	0.94	P-170	46	250	uPVC	126	35.1	0.72

P-65	46	250	uPVC	126	45.93	0.94	P-171	46	250	uPVC	126	35.1	0.72
P-66	46	250	uPVC	126	45.93	0.94	P-172	46	250	uPVC	126	35.1	0.72
P-67	55	250	uPVC	126	45.93	0.94	P-173	46	250	uPVC	126	35.1	0.72
P-68	36	250	uPVC	126	43.33	0.88	P-174	46	250	uPVC	126	35.1	0.72
P-69	46	250	uPVC	126	43.33	0.88	P-175	46	250	uPVC	126	35.1	0.72
P-70	46	250	uPVC	126	43.33	0.88	P-176	46	250	uPVC	126	35.1	0.72
P-71	46	250	uPVC	126	43.33	0.88	P-177	46	250	uPVC	126	35.1	0.72
P-72	46	250	uPVC	126	43.33	0.88	P-178	45	250	uPVC	126	35.1	0.72
P-73	20	250	uPVC	126	43.33	0.88	P-179	46	250	uPVC	126	35.1	0.72
P-74	25	250	uPVC	126	43.33	0.88	P-180	46	250	uPVC	126	35.1	0.72
P-75	46	250	uPVC	126	43.33	0.88	P-181	46	250	uPVC	126	35.1	0.72
P-76	46	250	uPVC	126	43.33	0.88	P-182	46	250	uPVC	126	35.1	0.72
P-77	46	250	uPVC	126	43.33	0.88	P-183	46	250	uPVC	126	35.1	0.72
P-78	46	250	uPVC	126	43.33	0.88	P-184	46	250	uPVC	126	35.1	0.72
P-79	50	250	uPVC	126	43.33	0.88	P-185	46	250	uPVC	126	35.1	0.72
P-80	87	250	uPVC	126	43.33	0.88	P-247	46	200	uPVC	126	34.38	1.09
P-81	46	250	uPVC	126	43.33	0.88	P-248	114	200	uPVC	126	34.38	1.09
P-82	26	250	uPVC	126	43.33	0.88	P-249	24	200	DCI	117	34.38	1.09
P-83	20	250	uPVC	126	43.33	0.88	P-250	39	200	DCI	117	34.38	1.09
P-84	46	250	uPVC	126	43.33	0.88	P-251	52	200	DCI	117	34.38	1.09
P-85	46	250	uPVC	126	43.33	0.88	P-252	46	200	DCI	117	34.38	1.09
P-86	92	250	uPVC	126	43.33	0.88	P-253	46	200	DCI	117	34.38	1.09
P-87	40	250	uPVC	126	43.33	0.88	P-254	46	200	DCI	117	34.38	1.09
P-88	52	250	uPVC	126	43.33	0.88	P-255	46	200	DCI	117	34.38	1.09
P-89	46	250	uPVC	126	43.33	0.88	P-256	46	200	DCI	117	34.38	1.09
P-90	46	250	uPVC	126	43.33	0.88	P-257	46	200	DCI	117	34.38	1.09
P-91	46	250	uPVC	126	43.33	0.88	P-258	46	200	DCI	117	34.38	1.09
P-92	46	250	uPVC	126	43.33	0.88	P-259	46	200	DCI	117	34.38	1.09
P-93	46	250	uPVC	126	43.33	0.88	P-260	46	200	DCI	117	34.38	1.09
P-94	46	250	uPVC	126	43.33	0.88	P-261	29	200	DCI	117	34.38	1.09
P-95	46	250	uPVC	126	43.33	0.88	P-262	63	200	DCI	117	34.38	1.09
P-96	46	250	uPVC	126	43.33	0.88	P-263	46	200	DCI	117	34.38	1.09
P-97	46	250	uPVC	126	43.33	0.88	P-264	46	200	DCI	117	34.38	1.09
P-98	46	250	uPVC	126	43.33	0.88	P-265	46	200	DCI	117	34.38	1.09
P-99	52	250	uPVC	126	43.33	0.88	P-266	46	200	DCI	117	34.38	1.09
P-100	86	250	uPVC	126	43.33	0.88	P-267	46	200	DCI	117	34.38	1.09
P-101	45	250	uPVC	126	43.33	0.88	P-268	46	200	DCI	117	34.38	1.09
P-102	93	250	uPVC	126	43.33	0.88	P-269	46	200	DCI	117	34.38	1.09
P-103	45	250	uPVC	126	43.33	0.88	P-270	46	200	DCI	117	34.38	1.09
P-104	47	250	uPVC	126	43.33	0.88	P-271	46	200	DCI	117	34.38	1.09
P-105	46	250	uPVC	126	43.33	0.88	P-272	64	200	DCI	117	34.38	1.09
P-1306	70	300	DCI	117	40.79	0.58	P-273	73	200	DCI	117	34.38	1.09
PL-1304	3	80	GS	72	40.79	8.11	P-274	35	200	DCI	117	34.38	1.09
PL-1305	5	100	GS	72	40.79	5.19	P-275	57	200	DCI	117	34.38	1.09
PL-1306	38	150	GS	72	40.79	2.31	P-276	46	200	DCI	117	34.38	1.09
P-110	42	250	uPVC	126	38.59	0.79	P-277	46	200	DCI	117	34.38	1.09
P-111	46	250	uPVC	126	38.59	0.79	P-278	46	200	DCI	117	34.38	1.09
P-112	46	250	uPVC	126	38.59	0.79	P-279	46	200	DCI	117	34.38	1.09
P-113	91	250	uPVC	126	38.59	0.79	P-280	46	200	DCI	117	34.38	1.09
P-114	46	250	uPVC	126	38.59	0.79	P-281	46	200	DCI	117	34.38	1.09
P-115	46	250	uPVC	126	38.59	0.79	P-282	46	200	DCI	117	34.38	1.09

P-116	45	250	uPVC	126	38.59	0.79	P-283	46	200	DCI	117	34.38	1.09
P-117	47	250	uPVC	126	38.59	0.79	P-287	46	200	DCI	117	34.38	1.09
P-118	92	250	uPVC	126	38.59	0.79	P-288	46	200	DCI	117	34.38	1.09
P-119	46	250	uPVC	126	38.59	0.79	P-289	46	200	DCI	117	34.38	1.09
P-120	46	250	uPVC	126	38.59	0.79	P-290	46	200	DCI	117	34.38	1.09
P-121	46	250	uPVC	126	38.59	0.79	P-1322	92	200	DCI	117	34.38	1.09
P-122	46	250	uPVC	126	38.59	0.79	P-1331	46	200	uPVC	126	34.38	1.09
P-123	46	250	uPVC	126	38.59	0.79	P-186	46	250	uPVC	126	33.4	0.68
P-124	92	250	uPVC	126	38.59	0.79	P-187	46	250	uPVC	126	33.4	0.68
P-125	46	250	uPVC	126	38.59	0.79	P-188	46	250	uPVC	126	33.4	0.68
P-126	46	250	uPVC	126	38.59	0.79	P-189	50	250	uPVC	126	33.4	0.68
P-127	46	250	uPVC	126	36.85	0.75	P-190	42	250	uPVC	126	33.4	0.68
P-128	46	250	uPVC	126	36.85	0.75	P-191	46	250	uPVC	126	33.4	0.68
P-129	46	250	uPVC	126	36.85	0.75	P-192	46	250	uPVC	126	33.4	0.68
P-130	63	250	uPVC	126	36.85	0.75	P-193	46	250	uPVC	126	33.4	0.68
P-131	28	250	uPVC	126	36.85	0.75	P-194	46	250	uPVC	126	33.4	0.68
P-132	46	250	uPVC	126	36.85	0.75	P-195	46	250	uPVC	126	33.4	0.68
P-133	46	250	uPVC	126	36.85	0.75	P-196	46	250	uPVC	126	33.4	0.68
P-134	46	250	uPVC	126	36.85	0.75	P-197	46	250	uPVC	126	33.4	0.68
P-135	46	250	uPVC	126	36.85	0.75	P-198	46	250	uPVC	126	33.4	0.68
P-136	46	250	uPVC	126	36.85	0.75	P-199	46	250	uPVC	126	33.4	0.68
P-137	59	250	uPVC	126	36.85	0.75	P-200	46	250	uPVC	126	33.4	0.68
P-138	33	250	uPVC	126	36.85	0.75	P-201	46	250	uPVC	126	33.4	0.68
P-139	46	250	uPVC	126	36.85	0.75	P-202	46	250	uPVC	126	33.4	0.68
P-140	46	250	uPVC	126	36.85	0.75	P-203	46	250	uPVC	126	33.4	0.68
P-141	46	250	uPVC	126	36.85	0.75	P-204	46	250	uPVC	126	33.4	0.68
P-142	46	250	uPVC	126	36.85	0.75	P-205	46	250	uPVC	126	33.4	0.68
P-143	46	250	uPVC	126	36.85	0.75	P-206	46	250	uPVC	126	33.4	0.68
P-144	46	250	uPVC	126	36.85	0.75	P-207	46	250	uPVC	126	33.4	0.68
P-145	46	250	uPVC	126	36.85	0.75	P-208	19	250	uPVC	126	33.4	0.68
P-146	46	250	uPVC	126	36.85	0.75	P-209	27	250	uPVC	126	33.4	0.68
P-147	46	250	uPVC	126	36.85	0.75	P-210	46	250	uPVC	126	33.4	0.68
P-148	46	250	uPVC	126	36.85	0.75	P-211	46	250	uPVC	126	33.4	0.68
P-149	45	250	uPVC	126	36.85	0.75	P-212	46	250	uPVC	126	33.4	0.68
P-150	47	250	uPVC	126	36.85	0.75	P-213	46	250	uPVC	126	33.4	0.68
P-151	46	250	uPVC	126	36.85	0.75	P-214	46	250	uPVC	126	33.4	0.68
P-152	46	250	uPVC	126	36.85	0.75	P-215	46	250	uPVC	126	33.4	0.68
P-153	46	250	uPVC	126	36.85	0.75	P-216	46	250	uPVC	126	33.4	0.68
P-154	46	250	uPVC	126	36.85	0.75	P-217	46	250	uPVC	126	33.4	0.68
P-155	28	250	uPVC	126	36.85	0.75	P-218	63	250	uPVC	126	33.4	0.68
P-156	18	250	uPVC	126	35.1	0.72	P-219	28	250	uPVC	126	33.4	0.68
P-157	46	250	uPVC	126	35.1	0.72	P-220	46	250	uPVC	126	33.4	0.68
P-158	46	250	uPVC	126	35.1	0.72	P-221	46	250	uPVC	126	33.4	0.68
P-159	46	250	uPVC	126	35.1	0.72	P-222	46	250	uPVC	126	33.4	0.68
P-160	46	250	uPVC	126	35.1	0.72	P-223	46	250	uPVC	126	33.4	0.68
P-161	46	250	uPVC	126	35.1	0.72	P-224	46	250	uPVC	126	33.4	0.68
P-162	41	250	uPVC	126	35.1	0.72	P-225	46	250	uPVC	126	33.4	0.68
P-163	27	250	uPVC	126	35.1	0.72	P-226	52	250	uPVC	126	33.4	0.68
P-233	33	250	uPVC	126	33.4	0.68	P-227	40	250	uPVC	126	33.4	0.68
P-234	22	250	uPVC	126	33.4	0.68	P-228	46	250	uPVC	126	33.4	0.68
P-235	37	250	uPVC	126	33.4	0.68	P-229	46	250	uPVC	126	33.4	0.68

P-236	46	200	uPVC	126	33.4	1.06	P-230	46	250	uPVC	126	33.4	0.68
P-237	46	200	uPVC	126	33.4	1.06	P-231	46	250	uPVC	126	33.4	0.68
P-238	46	200	uPVC	126	33.4	1.06	P-232	46	250	uPVC	126	33.4	0.68
P-239	46	200	uPVC	126	33.4	1.06	P-336	48	200	DCI	117	32.68	1.04
P-240	46	200	uPVC	126	33.4	1.06	P-337	24	200	DCI	117	32.68	1.04
P-241	46	200	uPVC	126	33.4	1.06	P-338	24	200	DCI	117	32.68	1.04
P-242	46	200	uPVC	126	33.4	1.06	P-339	44	200	DCI	117	32.68	1.04
P-243	46	200	uPVC	126	33.4	1.06	P-340	45	200	DCI	117	32.68	1.04
P-244	46	200	uPVC	126	33.4	1.06	P-341	46	200	DCI	117	32.68	1.04
P-291	46	200	DCI	117	32.68	1.04	P-342	44	200	DCI	117	32.68	1.04
P-292	46	200	DCI	117	32.68	1.04	P-343	49	200	DCI	117	32.68	1.04
P-293	46	200	DCI	117	32.68	1.04	P-344	45	200	DCI	117	32.68	1.04
P-294	46	200	DCI	117	32.68	1.04	P-345	46	200	DCI	117	32.68	1.04
P-295	46	200	DCI	117	32.68	1.04	P-346	43	200	DCI	117	32.68	1.04
P-296	46	200	DCI	117	32.68	1.04	P-347	45	200	DCI	117	32.68	1.04
P-297	46	200	DCI	117	32.68	1.04	P-348	47	200	DCI	117	32.68	1.04
P-298	46	200	DCI	117	32.68	1.04	P-349	45	200	DCI	117	32.68	1.04
P-299	46	200	DCI	117	32.68	1.04	P-350	48	200	DCI	117	32.68	1.04
P-300	46	200	DCI	117	32.68	1.04	P-351	40	200	DCI	117	30.98	0.99
P-301	46	200	DCI	117	32.68	1.04	P-352	52	200	DCI	117	30.98	0.99
P-302	46	200	DCI	117	32.68	1.04	P-353	35	200	DCI	117	30.98	0.99
P-303	46	200	DCI	117	32.68	1.04	P-354	63	200	DCI	117	30.98	0.99
P-304	46	200	DCI	117	32.68	1.04	P-355	47	200	DCI	117	30.98	0.99
P-305	46	200	DCI	117	32.68	1.04	P-356	46	200	DCI	117	30.98	0.99
P-306	46	200	DCI	117	32.68	1.04	P-357	46	200	DCI	117	30.98	0.99
P-307	46	200	DCI	117	32.68	1.04	P-358	46	200	DCI	117	30.98	0.99
P-308	46	200	DCI	117	32.68	1.04	P-359	48	200	DCI	117	30.98	0.99
P-309	46	200	DCI	117	32.68	1.04	P-360	47	200	DCI	117	30.98	0.99
P-310	46	200	DCI	117	32.68	1.04	P-361	46	200	DCI	117	30.98	0.99
P-311	46	200	DCI	117	32.68	1.04	P-362	44	200	DCI	117	30.98	0.99
P-312	46	200	DCI	117	32.68	1.04	P-363	16	200	DCI	117	30.98	0.99
P-313	46	200	DCI	117	32.68	1.04	P-364	21	200	DCI	117	30.98	0.99
P-314	46	200	DCI	117	32.68	1.04	P-365	44	200	DCI	117	30.98	0.99
P-315	46	200	DCI	117	32.68	1.04	P-366	48	200	DCI	117	30.98	0.99
P-316	46	200	DCI	117	32.68	1.04	P-367	47	200	DCI	117	30.98	0.99
P-317	46	200	DCI	117	32.68	1.04	P-368	41	200	DCI	117	30.98	0.99
P-318	46	200	DCI	117	32.68	1.04	P-369	48	200	DCI	117	30.98	0.99
P-319	46	200	DCI	117	32.68	1.04	P-370	46	200	DCI	117	30.98	0.99
P-320	46	200	DCI	117	32.68	1.04	P-371	47	200	DCI	117	30.98	0.99
P-321	46	200	DCI	117	32.68	1.04	P-372	45	200	DCI	117	30.98	0.99
P-322	46	200	DCI	117	32.68	1.04	P-373	46	200	DCI	117	30.98	0.99
P-323	46	200	DCI	117	32.68	1.04	P-374	46	200	DCI	117	30.98	0.99
P-324	46	200	DCI	117	32.68	1.04	P-375	47	200	DCI	117	30.98	0.99
P-325	10	200	DCI	117	32.68	1.04	P-376	45	200	DCI	117	30.98	0.99
P-326	35	200	DCI	117	32.68	1.04	P-377	46	200	DCI	117	30.98	0.99
P-327	48	200	DCI	117	32.68	1.04	P-378	46	200	DCI	117	30.98	0.99
P-329	42	200	DCI	117	32.68	1.04	P-379	46	200	DCI	117	30.98	0.99
P-330	46	200	DCI	117	32.68	1.04	P-380	45	200	DCI	117	30.98	0.99
P-331	46	200	DCI	117	32.68	1.04	P-381	47	200	DCI	117	30.98	0.99
P-332	46	200	DCI	117	32.68	1.04	P-382	44	200	DCI	117	30.98	0.99
P-333	46	200	DCI	117	32.68	1.04	P-383	48	200	DCI	117	30.98	0.99

P-334	43	200	DCI	117	32.68	1.04	P-384	46	200	DCI	117	30.98	0.99
P-335	139	200	DCI	117	32.68	1.04	P-385	46	200	DCI	117	30.98	0.99
P-392	46	200	DCI	117	30.98	0.99	P-386	47	200	DCI	117	30.98	0.99
P-393	46	200	DCI	117	30.98	0.99	P-387	46	200	DCI	117	30.98	0.99
P-394	43	200	DCI	117	30.98	0.99	P-388	46	200	DCI	117	30.98	0.99
P-395	50	200	DCI	117	30.98	0.99	P-389	44	200	DCI	117	30.98	0.99
P-396	45	200	DCI	117	30.98	0.99	P-390	47	200	DCI	117	30.98	0.99
P-397	46	200	DCI	117	30.98	0.99	P-391	45	200	DCI	117	30.98	0.99
P-398	44	200	DCI	117	30.98	0.99	P-502	45	200	DCI	117	26.53	0.84
P-399	50	200	DCI	117	30.98	0.99	P-503	47	200	DCI	117	26.53	0.84
P-400	45	200	DCI	117	30.98	0.99	P-504	46	200	DCI	117	26.53	0.84
P-401	46	200	DCI	117	30.98	0.99	P-505	48	200	DCI	117	26.53	0.84
P-402	46	200	DCI	117	30.98	0.99	P-506	45	200	DCI	117	26.53	0.84
P-403	48	200	DCI	117	30.98	0.99	P-507	47	200	DCI	117	26.53	0.84
P-404	43	200	DCI	117	30.98	0.99	P-508	46	200	DCI	117	26.53	0.84
P-405	47	200	DCI	117	30.98	0.99	P-509	44	200	DCI	117	26.53	0.84
P-406	45	200	DCI	117	30.98	0.99	P-510	47	200	DCI	117	26.53	0.84
P-407	46	200	DCI	117	30.98	0.99	P-511	47	200	DCI	117	26.53	0.84
P-408	47	200	DCI	117	30.98	0.99	P-512	46	200	DCI	117	26.53	0.84
P-409	47	200	DCI	117	30.98	0.99	P-513	47	200	DCI	117	26.53	0.84
P-410	45	200	DCI	117	30.98	0.99	P-514	43	200	DCI	117	26.53	0.84
P-411	47	200	DCI	117	30.98	0.99	P-515	47	200	DCI	117	26.53	0.84
P-412	47	200	DCI	117	30.98	0.99	P-516	45	200	DCI	117	26.53	0.84
P-413	45	200	DCI	117	30.98	0.99	P-517	47	200	DCI	117	26.53	0.84
P-414	40	200	DCI	117	30.98	0.99	P-518	36	200	DCI	117	26.53	0.84
P-415	35	200	DCI	117	30.98	0.99	P-519	50	200	DCI	117	24.31	0.77
P-1337	41	200	uPVC	126	30	0.95	P-520	51	200	DCI	117	24.31	0.77
P-1337	5	200	uPVC	126	30	0.95	P-521	41	200	DCI	117	24.31	0.77
P-416	61	200	DCI	117	28.75	0.92	P-522	45	200	DCI	117	24.31	0.77
P-417	47	200	DCI	117	28.75	0.92	P-523	48	200	DCI	117	24.31	0.77
P-418	46	200	DCI	117	28.75	0.92	P-524	53	200	DCI	117	24.31	0.77
P-419	45	200	DCI	117	28.75	0.92	P-525	36	200	DCI	117	24.31	0.77
P-420	46	200	DCI	117	28.75	0.92	P-526	51	200	DCI	117	24.31	0.77
P-421	47	200	DCI	117	28.75	0.92	P-527	42	200	DCI	117	24.31	0.77
P-422	47	200	DCI	117	28.75	0.92	P-528	46	200	DCI	117	24.31	0.77
P-423	47	200	DCI	117	28.75	0.92	P-529	49	200	DCI	117	24.31	0.77
P-424	46	200	DCI	117	28.75	0.92	P-530	49	200	DCI	117	24.31	0.77
P-425	44	200	DCI	117	28.75	0.92	P-531	46	200	DCI	117	24.31	0.77
P-426	45	200	DCI	117	28.75	0.92	P-532	42	200	DCI	117	24.31	0.77
P-427	47	200	DCI	117	28.75	0.92	P-533	49	200	DCI	117	24.31	0.77
P-428	47	200	DCI	117	28.75	0.92	P-534	54	200	DCI	117	24.31	0.77
P-429	45	200	DCI	117	28.75	0.92	P-535	38	200	DCI	117	24.31	0.77
P-430	47	200	DCI	117	28.75	0.92	P-536	43	200	DCI	117	24.31	0.77
P-431	45	200	DCI	117	28.75	0.92	P-790	40	250	uPVC	126	23.9	0.49
P-432	46	200	DCI	117	28.75	0.92	P-791	37	250	uPVC	126	23.9	0.49
P-433	44	200	DCI	117	28.75	0.92	P-792	43	250	uPVC	126	23.9	0.49
P-434	48	200	DCI	117	28.75	0.92	P-793	40	250	uPVC	126	23.9	0.49
P-435	47	200	DCI	117	28.75	0.92	P-794	40	250	uPVC	126	23.9	0.49
P-436	48	200	DCI	117	28.75	0.92	P-795	40	250	uPVC	126	23.9	0.49
P-437	46	200	DCI	117	28.75	0.92	P-796	40	250	uPVC	126	23.9	0.49
P-438	44	200	DCI	117	28.75	0.92	P-797	40	250	uPVC	126	23.9	0.49

P-439	46	200	DCI	117	28.75	0.92	P-798	40	250	uPVC	126	23.9	0.49
P-440	45	200	DCI	117	28.75	0.92	P-799	40	250	uPVC	126	23.9	0.49
P-441	46	200	DCI	117	28.75	0.92	P-800	40	250	uPVC	126	23.9	0.49
P-442	46	200	DCI	117	28.75	0.92	P-801	40	250	uPVC	126	23.9	0.49
P-443	49	200	DCI	117	28.75	0.92	P-802	40	250	uPVC	126	23.9	0.49
P-444	44	200	DCI	117	28.75	0.92	P-803	40	250	uPVC	126	23.9	0.49
P-445	47	200	DCI	117	28.75	0.92	P-804	40	250	uPVC	126	23.9	0.49
P-446	43	200	DCI	117	28.75	0.92	P-805	40	250	uPVC	126	23.9	0.49
P-447	47	200	DCI	117	28.75	0.92	P-806	40	250	uPVC	126	23.9	0.49
P-448	44	200	DCI	117	28.75	0.92	P-807	39	250	uPVC	126	23.9	0.49
P-449	47	200	DCI	117	28.75	0.92	P-808	37	250	uPVC	126	23.9	0.49
P-450	43	200	DCI	117	28.75	0.92	P-809	44	250	uPVC	126	23.9	0.49
P-451	49	200	DCI	117	28.75	0.92	P-810	40	250	uPVC	126	23.9	0.49
P-452	45	200	DCI	117	28.75	0.92	P-578	49	200	uPVC	126	22.09	0.7
P-453	44	200	DCI	117	28.75	0.92	P-579	42	200	uPVC	126	22.09	0.7
P-454	48	200	DCI	117	28.75	0.92	P-580	46	200	uPVC	126	22.09	0.7
P-455	44	200	DCI	117	28.75	0.92	P-581	46	200	uPVC	126	22.09	0.7
P-456	48	200	DCI	117	28.75	0.92	P-582	45	200	uPVC	126	22.09	0.7
P-457	43	200	DCI	117	28.75	0.92	P-583	48	200	uPVC	126	22.09	0.7
P-458	48	200	DCI	117	28.75	0.92	P-584	44	200	uPVC	126	22.09	0.7
P-459	45	200	DCI	117	28.75	0.92	P-825	40	250	uPVC	126	20.14	0.41
P-460	45	200	DCI	117	28.75	0.92	P-826	40	250	uPVC	126	20.14	0.41
P-461	45	200	DCI	117	28.75	0.92	P-827	40	250	uPVC	126	20.14	0.41
P-462	46	200	DCI	117	28.75	0.92	P-828	40	250	uPVC	126	20.14	0.41
P-463	47	200	DCI	117	28.75	0.92	P-829	40	250	uPVC	126	20.14	0.41
P-464	46	200	DCI	117	28.75	0.92	P-830	40	250	uPVC	126	20.14	0.41
P-465	45	200	DCI	117	28.75	0.92	P-831	40	250	uPVC	126	20.14	0.41
P-466	45	200	DCI	117	28.75	0.92	P-832	40	250	uPVC	126	20.14	0.41
P-467	46	200	DCI	117	28.75	0.92	P-833	40	250	uPVC	126	20.14	0.41
P-468	49	200	DCI	117	28.75	0.92	P-834	40	250	uPVC	126	20.14	0.41
P-469	43	200	DCI	117	28.75	0.92	P-835	40	250	uPVC	126	20.14	0.41
P-470	51	200	DCI	117	28.75	0.92	P-836	40	250	uPVC	126	20.14	0.41
P-471	37	200	DCI	117	28.75	0.92	P-837	40	250	uPVC	126	20.14	0.41
P-472	47	200	DCI	117	28.75	0.92	P-838	40	250	uPVC	126	20.14	0.41
P-473	46	200	DCI	117	28.75	0.92	P-839	40	250	uPVC	126	20.14	0.41
P-474	46	200	DCI	117	26.53	0.84	P-840	40	250	uPVC	126	20.14	0.41
P-475	46	200	DCI	117	26.53	0.84	P-841	40	250	uPVC	126	20.14	0.41
P-476	45	200	DCI	117	26.53	0.84	P-842	40	250	uPVC	126	20.14	0.41
P-477	47	200	DCI	117	26.53	0.84	P-843	40	250	uPVC	126	20.14	0.41
P-478	46	200	DCI	117	26.53	0.84	P-844	40	250	uPVC	126	20.14	0.41
P-479	44	200	DCI	117	26.53	0.84	P-845	40	250	uPVC	126	20.14	0.41
P-480	47	200	DCI	117	26.53	0.84	P-846	40	250	uPVC	126	20.14	0.41
P-481	46	200	DCI	117	26.53	0.84	P-847	40	250	uPVC	126	20.14	0.41
P-482	46	200	DCI	117	26.53	0.84	P-848	40	250	uPVC	126	20.14	0.41
P-483	45	200	DCI	117	26.53	0.84	P-849	40	250	uPVC	126	20.14	0.41
P-484	45	200	DCI	117	26.53	0.84	P-850	40	250	uPVC	126	20.14	0.41
P-485	46	200	DCI	117	26.53	0.84	P-851	40	250	uPVC	126	20.14	0.41
P-486	47	200	DCI	117	26.53	0.84	P-852	40	250	uPVC	126	20.14	0.41
P-487	46	200	DCI	117	26.53	0.84	P-853	40	250	uPVC	126	20.14	0.41
P-488	47	200	DCI	117	26.53	0.84	P-854	40	250	uPVC	126	20.14	0.41
P-489	44	200	DCI	117	26.53	0.84	P-855	40	250	uPVC	126	20.14	0.41

P-490	46	200	DCI	117	26.53	0.84	P-856	40	250	uPVC	126	20.14	0.41
P-491	45	200	DCI	117	26.53	0.84	P-857	40	250	uPVC	126	20.14	0.41
P-492	46	200	DCI	117	26.53	0.84	P-858	40	250	uPVC	126	20.14	0.41
P-493	48	200	DCI	117	26.53	0.84	P-859	40	250	uPVC	126	20.14	0.41
P-494	41	200	DCI	117	26.53	0.84	P-860	40	250	uPVC	126	20.14	0.41
P-495	48	200	DCI	117	26.53	0.84	P-861	40	250	uPVC	126	20.14	0.41
P-496	46	200	DCI	117	26.53	0.84	P-862	40	250	uPVC	126	20.14	0.41
P-497	33	200	DCI	117	26.53	0.84	P-863	40	250	uPVC	126	20.14	0.41
P-498	59	200	DCI	117	26.53	0.84	P-864	40	250	uPVC	126	20.14	0.41
P-499	48	200	DCI	117	26.53	0.84	P-865	40	250	uPVC	126	20.14	0.41
P-500	48	200	DCI	117	26.53	0.84	P-866	40	250	uPVC	126	20.14	0.41
P-501	39	200	DCI	117	26.53	0.84	P-867	40	250	uPVC	126	20.14	0.41
P-811	40	250	uPVC	126	23.9	0.49	P-868	40	250	uPVC	126	20.14	0.41
P-812	40	250	uPVC	126	23.9	0.49	P-869	40	250	uPVC	126	20.14	0.41
P-813	40	250	uPVC	126	23.9	0.49	P-870	40	250	uPVC	126	20.14	0.41
P-814	40	250	uPVC	126	23.9	0.49	P-871	40	250	uPVC	126	20.14	0.41
P-815	40	250	uPVC	126	23.9	0.49	P-872	40	250	uPVC	126	20.14	0.41
P-816	40	250	uPVC	126	23.9	0.49	P-873	40	250	uPVC	126	20.14	0.41
P-817	40	250	uPVC	126	23.9	0.49	P-874	40	250	uPVC	126	20.14	0.41
P-818	40	250	uPVC	126	23.9	0.49	P-875	40	250	uPVC	126	20.14	0.41
P-819	40	250	uPVC	126	23.9	0.49	P-876	40	250	uPVC	126	20.14	0.41
P-820	40	250	uPVC	126	23.9	0.49	P-877	40	250	uPVC	126	20.14	0.41
P-821	40	250	uPVC	126	23.9	0.49	P-878	58	250	uPVC	126	20.14	0.41
P-822	40	250	uPVC	126	23.9	0.49	P-648	43	150	DCI	117	20.05	1.13
P-823	40	250	uPVC	126	23.9	0.49	P-649	46	150	DCI	117	20.05	1.13
P-824	40	250	uPVC	126	23.9	0.49	P-650	48	150	DCI	117	20.05	1.13
P-1231	20	250	uPVC	126	23.9	0.49	P-651	48	150	DCI	117	20.05	1.13
P-537	49	200	DCI	117	22.09	0.7	P-652	45	150	DCI	117	20.05	1.13
P-538	47	200	DCI	117	22.09	0.7	P-653	48	150	DCI	117	20.05	1.13
P-539	46	200	DCI	117	22.09	0.7	P-654	47	150	DCI	117	20.05	1.13
P-540	49	200	DCI	117	22.09	0.7	P-655	41	150	DCI	117	20.05	1.13
P-541	45	200	DCI	117	22.09	0.7	P-656	48	150	DCI	117	20.05	1.13
P-542	46	200	DCI	117	22.09	0.7	P-657	47	150	DCI	117	20.05	1.13
P-543	46	200	DCI	117	22.09	0.7	P-658	45	150	DCI	117	20.05	1.13
P-544	24	200	DCI	117	22.09	0.7	P-659	46	150	DCI	117	20.05	1.13
P-545	38	200	DCI	117	22.09	0.7	P-660	47	150	DCI	117	20.05	1.13
P-546	31	200	DCI	117	22.09	0.7	P-661	42	150	DCI	117	20.05	1.13
P-547	46	200	DCI	117	22.09	0.7	P-662	49	150	DCI	117	20.05	1.13
P-548	47	200	DCI	117	22.09	0.7	P-663	43	150	DCI	117	20.05	1.13
P-549	44	200	DCI	117	22.09	0.7	P-664	49	150	DCI	117	20.05	1.13
P-550	46	200	DCI	117	22.09	0.7	P-665	43	150	DCI	117	20.05	1.13
P-551	47	200	DCI	117	22.09	0.7	P-666	47	150	DCI	117	20.05	1.13
P-552	42	200	DCI	117	22.09	0.7	P-667	43	150	DCI	117	20.05	1.13
P-553	50	200	DCI	117	22.09	0.7	P-668	49	150	DCI	117	20.05	1.13
P-554	45	200	DCI	117	22.09	0.7	P-669	42	150	DCI	117	20.05	1.13
P-555	44	200	DCI	117	22.09	0.7	P-670	47	150	DCI	117	20.05	1.13
P-556	47	200	DCI	117	22.09	0.7	P-671	46	150	DCI	117	20.05	1.13
P-557	45	200	DCI	117	22.09	0.7	P-672	48	150	DCI	117	20.05	1.13
P-558	46	200	DCI	117	22.09	0.7	P-673	47	150	DCI	117	20.05	1.13
P-559	45	200	DCI	117	22.09	0.7	P-674	44	150	DCI	117	20.05	1.13
P-560	47	200	DCI	117	22.09	0.7	P-675	48	150	DCI	117	20.05	1.13

P-561	48	200	DCI	117	22.09	0.7	P-676	45	150	DCI	117	20.05	1.13
P-562	42	200	DCI	117	22.09	0.7	P-677	44	150	DCI	117	20.05	1.13
P-563	49	200	DCI	117	22.09	0.7	P-678	47	150	DCI	117	20.05	1.13
P-564	44	200	DCI	117	22.09	0.7	P-679	29	150	DCI	117	20.05	1.13
P-565	42	200	DCI	117	22.09	0.7	P-680	29	150	DCI	117	20.05	1.13
P-566	49	200	DCI	117	22.09	0.7	P-681	36	150	DCI	117	20.05	1.13
P-567	45	200	DCI	117	22.09	0.7	P-682	89	150	DCI	117	20.05	1.13
P-568	46	200	DCI	117	22.09	0.7	P-683	51	150	DCI	117	20.05	1.13
P-569	47	200	DCI	117	22.09	0.7	P-684	46	150	DCI	117	20.05	1.13
P-570	97	200	DCI	117	22.09	0.7	P-685	44	150	DCI	117	20.05	1.13
P-571	41	200	DCI	117	22.09	0.7	P-686	43	150	DCI	117	20.05	1.13
P-572	48	200	DCI	117	22.09	0.7	P-687	54	150	DCI	117	20.05	1.13
P-573	47	200	DCI	117	22.09	0.7	P-688	42	150	DCI	117	20.05	1.13
P-574	46	200	DCI	117	22.09	0.7	P-689	46	150	DCI	117	20.05	1.13
P-575	40	200	DCI	117	22.09	0.7	P-690	46	150	DCI	117	20.05	1.13
P-576	49	200	DCI	117	22.09	0.7	P-691	46	150	DCI	117	20.05	1.13
P-577	47	200	uPVC	126	22.09	0.7	P-692	46	150	DCI	117	20.05	1.13
P-699	46	150	DCI	117	20.05	1.13	P-693	46	150	DCI	117	20.05	1.13
P-700	44	150	DCI	117	20.05	1.13	P-694	46	150	DCI	117	20.05	1.13
P-701	48	150	DCI	117	20.05	1.13	P-695	46	150	DCI	117	20.05	1.13
P-702	46	150	DCI	117	20.05	1.13	P-696	46	150	DCI	117	20.05	1.13
P-703	46	150	DCI	117	20.05	1.13	P-697	46	150	DCI	117	20.05	1.13
P-704	46	150	DCI	117	20.05	1.13	P-698	46	150	DCI	117	20.05	1.13
P-705	46	150	DCI	117	20.05	1.13	P-1237	118	150	uPVC	126	20.05	1.13
P-706	46	150	DCI	117	20.05	1.13	P-1238	114	150	uPVC	126	20.05	1.13
P-707	46	150	DCI	117	20.05	1.13	P-1239	120	150	uPVC	126	20.05	1.13
P-708	46	150	DCI	117	20.05	1.13	P-1240	97	150	uPVC	126	20.05	1.13
P-709	46	150	DCI	117	20.05	1.13	P-585	44	200	uPVC	126	19.87	0.63
P-710	46	150	DCI	117	20.05	1.13	P-586	45	200	uPVC	126	19.87	0.63
P-711	46	150	DCI	117	20.05	1.13	P-587	46	200	uPVC	126	19.87	0.63
P-712	46	150	DCI	117	20.05	1.13	P-588	50	200	uPVC	126	19.87	0.63
P-713	46	150	DCI	117	20.05	1.13	P-589	46	200	uPVC	126	19.87	0.63
P-714	46	150	DCI	117	20.05	1.13	P-590	43	200	uPVC	126	19.87	0.63
P-715	46	150	DCI	117	20.05	1.13	P-591	49	200	uPVC	126	19.87	0.63
P-716	46	150	DCI	117	20.05	1.13	P-592	46	200	uPVC	126	19.87	0.63
P-717	46	150	DCI	117	20.05	1.13	P-593	46	200	uPVC	126	19.87	0.63
P-718	46	150	DCI	117	20.05	1.13	P-594	43	200	uPVC	126	19.87	0.63
P-719	46	150	DCI	117	20.05	1.13	P-595	48	200	uPVC	126	19.87	0.63
P-720	46	150	DCI	117	20.05	1.13	P-596	45	200	uPVC	126	19.87	0.63
P-721	46	150	DCI	117	20.05	1.13	P-597	47	200	uPVC	126	19.87	0.63
P-722	46	150	DCI	117	20.05	1.13	P-598	45	200	uPVC	126	19.87	0.63
P-723	46	150	DCI	117	20.05	1.13	P-599	45	200	uPVC	126	19.87	0.63
P-724	46	150	DCI	117	20.05	1.13	P-600	49	200	uPVC	126	19.87	0.63
P-725	46	150	DCI	117	20.05	1.13	P-601	46	200	uPVC	126	19.87	0.63
P-726	46	150	DCI	117	20.05	1.13	P-602	41	200	uPVC	126	19.87	0.63
P-727	44	150	DCI	117	20.05	1.13	P-603	42	200	uPVC	126	19.87	0.63
P-728	46	150	DCI	117	20.05	1.13	P-604	49	200	uPVC	126	19.87	0.63
P-729	46	150	DCI	117	20.05	1.13	P-605	48	200	uPVC	126	19.87	0.63
P-730	46	150	DCI	117	20.05	1.13	P-606	48	200	uPVC	126	19.87	0.63
P-731	46	150	DCI	117	20.05	1.13	P-607	42	200	uPVC	126	19.87	0.63
P-732	46	150	DCI	117	20.05	1.13	P-608	49	200	uPVC	126	19.87	0.63

P-733	46	150	DCI	117	20.05	1.13	P-609	47	200	uPVC	126	19.87	0.63
P-734	46	150	DCI	117	20.05	1.13	P-610	50	200	uPVC	126	19.87	0.63
P-735	46	150	DCI	117	20.05	1.13	P-611	42	200	uPVC	126	19.87	0.63
P-736	46	150	DCI	117	20.05	1.13	P-612	46	200	uPVC	126	19.87	0.63
P-737	46	150	DCI	117	20.05	1.13	P-613	42	200	uPVC	126	19.87	0.63
P-738	46	150	DCI	117	20.05	1.13	P-614	40	200	uPVC	126	19.87	0.63
P-739	46	150	DCI	117	20.05	1.13	P-615	42	200	uPVC	126	19.87	0.63
P-740	46	150	DCI	117	20.05	1.13	P-616	50	200	uPVC	126	19.87	0.63
P-741	46	150	DCI	117	20.05	1.13	P-617	46	200	uPVC	126	19.87	0.63
P-742	46	150	DCI	117	20.05	1.13	P-618	44	200	uPVC	126	19.87	0.63
P-743	46	150	DCI	117	20.05	1.13	P-619	52	200	uPVC	126	19.87	0.63
P-744	47	150	DCI	117	20.05	1.13	P-879	43	250	uPVC	126	18.03	0.37
P-745	51	150	DCI	117	20.05	1.13	P-880	78	250	uPVC	126	18.03	0.37
P-746	56	150	DCI	117	20.05	1.13	P-881	61	250	uPVC	126	18.03	0.37
P-758	36	150	uPVC	126	20.05	1.13	P-882	60	250	uPVC	126	18.03	0.37
P-759	26	150	uPVC	126	20.05	1.13	P-883	60	250	uPVC	126	18.03	0.37
P-760	56	150	uPVC	126	20.05	1.13	P-884	59	250	uPVC	126	18.03	0.37
P-761	24	150	uPVC	126	20.05	1.13	P-885	61	250	uPVC	126	18.03	0.37
P-1221	6	150	DCI	117	20.05	1.13	P-886	60	250	uPVC	126	18.03	0.37
P-1222	65	150	DCI	117	20.05	1.13	P-887	60	250	uPVC	126	18.03	0.37
P-1235	164	150	uPVC	126	20.05	1.13	P-888	60	250	uPVC	126	18.03	0.37
P-1236	173	150	uPVC	126	20.05	1.13	P-889	62	250	uPVC	126	18.03	0.37
P-896	60	250	uPVC	126	18.03	0.37	P-890	58	250	uPVC	126	18.03	0.37
P-897	60	250	uPVC	126	18.03	0.37	P-891	60	250	uPVC	126	18.03	0.37
P-898	60	250	uPVC	126	18.03	0.37	P-892	60	250	uPVC	126	18.03	0.37
P-899	60	250	uPVC	126	18.03	0.37	P-893	60	250	uPVC	126	18.03	0.37
P-900	60	250	uPVC	126	18.03	0.37	P-894	60	250	uPVC	126	18.03	0.37
P-901	60	250	uPVC	126	18.03	0.37	P-895	60	250	uPVC	126	18.03	0.37
P-902	60	250	uPVC	126	18.03	0.37	P-951	80	250	uPVC	126	12.17	0.25
P-903	60	250	uPVC	126	18.03	0.37	P-952	60	250	uPVC	126	12.17	0.25
P-904	60	250	uPVC	126	18.03	0.37	P-953	60	250	uPVC	126	12.17	0.25
P-905	60	250	uPVC	126	18.03	0.37	P-954	79	250	uPVC	126	12.17	0.25
P-906	60	250	uPVC	126	18.03	0.37	P-955	80	250	uPVC	126	12.17	0.25
P-907	59	250	uPVC	126	18.03	0.37	P-956	81	250	uPVC	126	12.17	0.25
P-908	60	250	uPVC	126	18.03	0.37	P-957	80	250	uPVC	126	12.17	0.25
P-909	60	250	uPVC	126	18.03	0.37	P-958	80	250	uPVC	126	12.17	0.25
P-910	60	250	uPVC	126	18.03	0.37	P-959	79	250	uPVC	126	12.17	0.25
P-911	60	250	uPVC	126	18.03	0.37	P-960	81	250	uPVC	126	12.17	0.25
P-912	59	250	uPVC	126	18.03	0.37	P-961	57	250	uPVC	126	12.17	0.25
P-913	61	250	uPVC	126	18.03	0.37	P-962	61	250	uPVC	126	12.17	0.25
P-914	59	250	uPVC	126	18.03	0.37	P-963	79	250	uPVC	126	12.17	0.25
P-915	60	250	uPVC	126	18.03	0.37	P-964	80	250	uPVC	126	12.17	0.25
P-916	61	250	uPVC	126	18.03	0.37	P-965	80	250	uPVC	126	12.17	0.25
P-917	60	250	uPVC	126	18.03	0.37	P-966	80	250	uPVC	126	12.17	0.25
P-918	60	250	uPVC	126	18.03	0.37	P-967	79	250	uPVC	126	12.17	0.25
P-919	60	250	uPVC	126	18.03	0.37	P-968	81	250	uPVC	126	12.17	0.25
P-920	60	250	uPVC	126	18.03	0.37	P-969	80	250	uPVC	126	12.17	0.25
P-921	60	250	uPVC	126	18.03	0.37	P-970	80	250	uPVC	126	12.17	0.25
P-922	60	250	uPVC	126	18.03	0.37	P-971	80	250	uPVC	126	12.17	0.25
P-923	61	250	uPVC	126	18.03	0.37	P-972	80	250	uPVC	126	12.17	0.25
P-924	59	250	uPVC	126	18.03	0.37	P-973	80	250	uPVC	126	12.17	0.25

P-925	61	250	uPVC	126	18.03	0.37	P-974	80	250	uPVC	126	12.17	0.25
P-926	60	250	uPVC	126	18.03	0.37	P-975	80	250	uPVC	126	12.17	0.25
P-927	66	250	uPVC	126	18.03	0.37	P-978	80	250	uPVC	126	12.17	0.25
P-620	47	200	uPVC	126	17.64	0.56	P-979	80	250	uPVC	126	12.17	0.25
P-621	47	200	uPVC	126	17.64	0.56	P-980	80	250	uPVC	126	12.17	0.25
P-622	43	200	uPVC	126	17.64	0.56	P-981	80	250	uPVC	126	12.17	0.25
P-623	38	200	uPVC	126	17.64	0.56	P-982	80	250	uPVC	126	12.17	0.25
P-624	50	200	uPVC	126	17.64	0.56	P-983	79	250	uPVC	126	12.17	0.25
P-625	44	200	uPVC	126	17.64	0.56	P-984	80	250	uPVC	126	12.17	0.25
P-626	46	200	uPVC	126	17.64	0.56	P-985	81	250	uPVC	126	12.17	0.25
P-627	50	200	uPVC	126	17.64	0.56	P-986	79	250	uPVC	126	12.17	0.25
P-628	41	200	uPVC	126	17.64	0.56	P-987	81	250	uPVC	126	12.17	0.25
P-629	44	200	uPVC	126	17.64	0.56	P-988	80	250	uPVC	126	12.17	0.25
P-630	50	200	uPVC	126	17.64	0.56	P-989	80	250	uPVC	126	12.17	0.25
P-631	48	200	uPVC	126	17.64	0.56	P-990	80	250	uPVC	126	12.17	0.25
P-632	42	200	uPVC	126	17.64	0.56	P-991	80	250	uPVC	126	12.17	0.25
P-633	51	200	uPVC	126	17.64	0.56	P-992	80	250	uPVC	126	12.17	0.25
P-634	44	200	uPVC	126	17.64	0.56	P-993	80	250	uPVC	126	12.17	0.25
P-635	45	200	uPVC	126	17.64	0.56	P-994	80	250	uPVC	126	12.17	0.25
P-636	44	200	uPVC	126	17.64	0.56	P-995	79	250	uPVC	126	12.17	0.25
P-637	47	200	uPVC	126	17.64	0.56	P-996	80	250	uPVC	126	12.17	0.25
P-638	46	200	uPVC	126	17.64	0.56	P-997	81	250	uPVC	126	12.17	0.25
P-639	50	200	uPVC	126	17.64	0.56	P-998	79	250	uPVC	126	12.17	0.25
P-640	43	200	uPVC	126	17.64	0.56	P-999	82	250	uPVC	126	12.17	0.25
P-641	47	200	uPVC	126	17.64	0.56	P-1000	78	250	uPVC	126	12.17	0.25
P-642	47	200	uPVC	126	17.64	0.56	P-1001	100	250	uPVC	126	12.17	0.25
P-643	49	200	uPVC	126	17.64	0.56	P-1002	100	250	uPVC	126	12.17	0.25
P-644	47	200	uPVC	126	17.64	0.56	P-1003	80	250	uPVC	126	12.17	0.25
P-645	30	200	uPVC	126	17.64	0.56	P-1004	80	250	uPVC	126	12.17	0.25
P-928	75	250	uPVC	126	15.93	0.32	P-1005	80	250	uPVC	126	12.17	0.25
P-929	80	250	uPVC	126	15.93	0.32	P-1006	100	250	uPVC	126	12.17	0.25
P-930	80	250	uPVC	126	15.93	0.32	P-1007	52	250	uPVC	126	12.17	0.25
P-931	80	250	uPVC	126	15.93	0.32	P-1008	28	250	uPVC	126	12.17	0.25
P-932	105	250	uPVC	126	15.93	0.32	P-1009	81	250	uPVC	126	12.17	0.25
P-933	75	250	uPVC	126	15.93	0.32	P-1010	79	250	uPVC	126	10.13	0.21
P-934	80	250	uPVC	126	15.93	0.32	P-1011	84	250	uPVC	126	10.13	0.21
P-935	100	250	uPVC	126	15.93	0.32	P-1012	92	250	uPVC	126	10.13	0.21
P-936	80	250	uPVC	126	15.93	0.32	P-1013	80	250	uPVC	126	10.13	0.21
P-937	79	250	uPVC	126	15.93	0.32	P-1014	80	250	uPVC	126	10.13	0.21
P-938	80	250	uPVC	126	15.93	0.32	P-1015	80	250	uPVC	126	10.13	0.21
P-939	80	250	uPVC	126	15.93	0.32	P-1016	80	150	uPVC	126	10.13	0.57
P-940	80	250	uPVC	126	15.93	0.32	P-1243	47	100	HDPE	120	10.09	1.28
P-941	80	250	uPVC	126	15.93	0.32	P-1244	51	100	HDPE	120	10.09	1.28
P-942	80	250	uPVC	126	15.93	0.32	P-1232	19	250	DCI	117	9.01	0.18
P-943	80	250	uPVC	126	15.93	0.32	P-1233	30	250	DCI	117	9.01	0.18
P-944	80	250	uPVC	126	15.93	0.32	P-1017	80	150	uPVC	126	8.09	0.46
P-945	80	250	uPVC	126	15.93	0.32	P-1018	80	150	uPVC	126	8.09	0.46
P-946	80	250	uPVC	126	15.93	0.32	P-1019	80	150	uPVC	126	8.09	0.46
P-947	80	250	uPVC	126	15.93	0.32	P-1020	80	150	uPVC	126	8.09	0.46
P-948	80	250	uPVC	126	15.93	0.32	P-1021	80	150	uPVC	126	8.09	0.46
P-949	80	250	uPVC	126	15.93	0.32	P-1022	80	150	uPVC	126	8.09	0.46

P-1332	21	200	uPVC	126	15.42	0.49	P-1023	80	150	uPVC	126	8.09	0.46
P-1230	20	250	DCI	117	14.89	0.3	P-1024	80	150	uPVC	126	8.09	0.46
P-762	45	150	uPVC	126	13.14	0.74	P-1025	80	150	uPVC	126	8.09	0.46
P-763	51	150	uPVC	126	13.14	0.74	P-1026	80	150	uPVC	126	8.09	0.46
P-764	41	150	uPVC	126	13.14	0.74	P-1027	80	150	uPVC	126	8.09	0.46
P-765	46	150	uPVC	126	13.14	0.74	P-1028	80	150	uPVC	126	8.09	0.46
P-766	46	150	uPVC	126	13.14	0.74	P-1029	80	150	uPVC	126	8.09	0.46
P-767	46	150	uPVC	126	13.14	0.74	P-1030	80	150	uPVC	126	8.09	0.46
P-768	46	150	uPVC	126	13.14	0.74	P-1031	80	150	uPVC	126	8.09	0.46
P-769	46	150	uPVC	126	13.14	0.74	P-1032	80	150	uPVC	126	8.09	0.46
P-770	46	150	uPVC	126	13.14	0.74	P-1033	80	150	uPVC	126	8.09	0.46
P-771	46	150	uPVC	126	13.14	0.74	P-1034	80	150	uPVC	126	8.09	0.46
P-772	48	150	uPVC	126	13.14	0.74	P-1035	80	150	uPVC	126	8.09	0.46
P-773	46	150	uPVC	126	13.14	0.74	P-1036	80	150	uPVC	126	8.09	0.46
P-774	50	150	uPVC	126	13.14	0.74	P-1037	80	150	uPVC	126	8.09	0.46
P-775	44	150	uPVC	126	13.14	0.74	P-1038	79	150	uPVC	126	8.09	0.46
P-777	42	150	uPVC	126	13.14	0.74	P-1039	81	150	uPVC	126	8.09	0.46
P-778	44	150	uPVC	126	13.14	0.74	P-1040	80	150	uPVC	126	8.09	0.46
P-779	46	150	uPVC	126	13.14	0.74	P-1041	80	150	uPVC	126	8.09	0.46
P-780	41	150	uPVC	126	13.14	0.74	P-1042	80	150	uPVC	126	8.09	0.46
P-781	38	150	uPVC	126	13.14	0.74	P-1043	80	150	uPVC	126	8.09	0.46
P-782	42	150	uPVC	126	13.14	0.74	P-1044	80	150	uPVC	126	8.09	0.46
P-783	88	150	uPVC	126	13.14	0.74	P-1045	80	150	uPVC	126	8.09	0.46
P-784	59	150	uPVC	126	13.14	0.74	P-1046	81	150	uPVC	126	8.09	0.46
P-785	31	150	uPVC	126	13.14	0.74	P-1047	79	150	uPVC	126	8.09	0.46
P-786	46	150	uPVC	126	13.14	0.74	P-1048	220	150	uPVC	126	8.09	0.46
P-787	35	150	uPVC	126	13.14	0.74	P-1049	87	150	uPVC	126	8.09	0.46
P-1318	48	150	uPVC	126	13.14	0.74	P-1329	23	100	DCI	117	6.91	0.88
P-1318	8	150	uPVC	126	13.14	0.74	P-1050	133	150	uPVC	126	5.66	0.32
P-1242	3	100	HDPE	120	12.33	1.57	P-1051	202	150	uPVC	126	5.66	0.32
P-1242	35	100	HDPE	120	12.33	1.57	P-1052	199	150	uPVC	126	5.66	0.32
P-950	80	250	uPVC	126	12.17	0.25	P-1053	159	150	uPVC	126	5.66	0.32
P-1115	200	150	uPVC	126	3.24	0.18	P-1054	220	150	uPVC	126	5.66	0.32
P-1116	239	150	uPVC	126	3.24	0.18	P-1055	180	150	uPVC	126	5.66	0.32
P-1117	200	150	uPVC	126	3.24	0.18	P-1056	259	150	uPVC	126	5.66	0.32
P-1118	199	150	uPVC	126	3.24	0.18	P-1057	119	150	uPVC	126	5.66	0.32
P-1119	199	150	uPVC	126	3.24	0.18	P-1058	140	150	uPVC	126	5.66	0.32
P-1120	201	150	uPVC	126	3.24	0.18	P-1059	160	150	uPVC	126	5.66	0.32
P-1121	201	150	uPVC	126	3.24	0.18	P-1060	140	150	uPVC	126	5.66	0.32
P-1123	198	100	uPVC	126	3.24	0.41	P-1061	320	150	uPVC	126	5.66	0.32
P-1124	203	100	uPVC	126	3.24	0.41	P-1062	340	150	uPVC	126	5.66	0.32
P-1125	200	100	uPVC	126	3.24	0.41	P-1063	279	150	uPVC	126	5.66	0.32
P-1126	200	100	uPVC	126	3.24	0.41	P-1064	43	150	uPVC	126	5.66	0.32
P-1127	199	100	uPVC	126	3.24	0.41	P-1071	340	150	uPVC	126	5.66	0.32
P-1128	156	100	uPVC	126	3.24	0.41	P-1072	597	150	uPVC	126	5.66	0.32
P-1122	175	150	uPVC	126	3.24	0.18	P-1073	356	150	uPVC	126	5.66	0.32
P-1122	44	100	uPVC	126	3.24	0.41	P-1074	423	150	uPVC	126	5.66	0.32
P-1327	379	150	uPVC	126	3.24	0.18	P-1075	300	150	uPVC	126	5.66	0.32
P-1179	746	50	uPVC	126	2.62	1.34	P-1078	340	150	uPVC	126	5.66	0.32
P-1181	20	50	uPVC	126	2.62	1.34	P-1079	160	150	uPVC	126	5.66	0.32
P-1182	137	50	uPVC	126	2.6	1.33	P-1080	160	150	uPVC	126	5.66	0.32

P-1219	273	50	uPVC	126	2.42	1.23	P-1081	179	150	uPVC	126	5.66	0.32
P-1296	110	100	HDPE	120	2.24	0.29	P-1082	181	150	uPVC	126	5.66	0.32
P-1297	114	100	HDPE	120	2.24	0.29	P-1083	160	150	uPVC	126	5.66	0.32
P-1300	329	100	HDPE	120	2.24	0.29	P-1084	160	150	uPVC	126	5.66	0.32
P-1193	391	50	uPVC	126	2.22	1.13	P-1085	180	150	uPVC	126	5.66	0.32
P-1195	89	50	uPVC	120	2.22	1.13	P-1086	140	150	uPVC	126	5.66	0.32
P-1196	64	50	uPVC	126	2.22	1.13	P-1087	220	150	uPVC	126	5.66	0.32
P-1197	41	50	uPVC	126	2.22	1.13	P-1088	160	150	uPVC	126	5.66	0.32
P-1198	61	50	uPVC	126	2.22	1.13	P-1089	160	150	uPVC	126	5.66	0.32
P-1273	2,310	50	uPVC	126	2.22	1.13	P-1090	140	150	uPVC	126	5.66	0.32
P-1208	99	50	uPVC	126	2.1	1.07	P-1091	140	150	uPVC	126	5.66	0.32
P-1210	234	50	uPVC	126	2.1	1.07	P-1092	140	150	uPVC	126	5.66	0.32
P-1220	46	50	uPVC	126	2.04	1.04	P-1093	139	150	uPVC	126	5.66	0.32
P-1187	247	50	uPVC	126	1.74	0.89	P-1094	179	150	uPVC	126	5.66	0.32
P-1188	311	50	uPVC	126	1.74	0.89	P-1095	60	150	uPVC	126	5.66	0.32
P-1270	50	50	uPVC	126	1.74	0.89	P-1216	240	150	uPVC	126	5.66	0.32
P-1189	279	50	uPVC	126	1.7	0.87	P-1217	180	150	uPVC	126	5.66	0.32
P-1272	88	50	uPVC	126	1.7	0.87	P-1326	736	150	uPVC	126	5.66	0.32
P-1274	250	50	uPVC	126	1.7	0.87	P-1245	31	100	HDPE	120	5.6	0.71
P-1275	1,825	50	uPVC	126	1.7	0.87	P-1246	71	100	HDPE	120	5.6	0.71
P-1129	240	100	uPVC	126	1.62	0.21	P-1184(1)	380	50	uPVC	126	4.74	2.42
P-1130	219	100	uPVC	126	1.62	0.21	P-1253(1)	14	100	HDPE	120	4.48	0.57
P-1131	237	100	uPVC	126	1.62	0.21	P-1278	480	50	uPVC	126	3.76	1.92
P-1132	124	100	uPVC	126	1.62	0.21	P-1277(1)	81	50	uPVC	126	3.76	1.92
P-1133	198	100	uPVC	126	1.62	0.21	P-1277(2)	595	50	uPVC	126	3.76	1.92
P-1134	259	100	uPVC	126	1.62	0.21	P-1253(2)	272	100	HDPE	120	3.36	0.43
P-1135	240	100	uPVC	126	1.62	0.21	P-1096	100	150	uPVC	126	3.24	0.18
P-1136	198	100	uPVC	126	1.62	0.21	P-1097	140	150	uPVC	126	3.24	0.18
P-1137	219	100	uPVC	126	1.62	0.21	P-1098	180	150	uPVC	126	3.24	0.18
P-1138	219	100	uPVC	126	1.62	0.21	P-1099	158	150	uPVC	126	3.24	0.18
P-1139	219	100	uPVC	126	1.62	0.21	P-1100	179	150	uPVC	126	3.24	0.18
P-1140	200	100	uPVC	126	1.62	0.21	P-1101	140	150	uPVC	126	3.24	0.18
P-1141	217	100	uPVC	126	1.62	0.21	P-1102	160	150	uPVC	126	3.24	0.18
P-1142	177	100	uPVC	126	1.62	0.21	P-1103	160	150	uPVC	126	3.24	0.18
P-1143	120	100	uPVC	126	1.62	0.21	P-1104	180	150	uPVC	126	3.24	0.18
P-1144	158	100	uPVC	126	1.62	0.21	P-1105	160	150	uPVC	126	3.24	0.18
P-1145	139	100	uPVC	126	1.62	0.21	P-1106	160	150	uPVC	126	3.24	0.18
P-1146	240	100	uPVC	126	1.62	0.21	P-1107	140	150	uPVC	126	3.24	0.18
P-1147	159	100	uPVC	126	1.62	0.21	P-1108	140	150	uPVC	126	3.24	0.18
P-1148	180	100	uPVC	126	1.62	0.21	P-1109	140	150	uPVC	126	3.24	0.18
P-1149	180	100	uPVC	126	1.62	0.21	P-1110	220	150	uPVC	126	3.24	0.18
P-1150	139	100	uPVC	126	1.62	0.21	P-1111	161	150	uPVC	126	3.24	0.18
P-1151	220	100	uPVC	126	1.62	0.21	P-1112	178	150	uPVC	126	3.24	0.18
P-1152	200	100	uPVC	126	1.62	0.21	P-1257	29	150	DCI	108	0.11	0.01
P-1153	217	100	uPVC	126	1.62	0.21	P-1251(1)	272	100	HDPE	120	-1.12	0.14
P-1154	180	100	uPVC	126	1.62	0.21	P-1190(1)	2,085	50	uPVC	126	-1.7	0.87
P-1155	218	100	uPVC	126	1.62	0.21	P-1281	1,250	50	uPVC	126	-2.04	1.04
P-1156	219	100	uPVC	126	1.62	0.21	P-1192	42	50	uPVC	126	-2.22	1.13
P-1157	197	100	uPVC	126	1.62	0.21	P-1194	49	50	uPVC	126	-2.22	1.13
P-1158	178	100	uPVC	126	1.62	0.21	P-1276	673	50	uPVC	126	-2.22	1.13
P-1248	90	100	HDPE	120	1.12	0.14	P-1159	200	100	uPVC	126	1.62	0.21

P-1250	181	100	HDPE	120	1.12	0.14	P-1160	159	100	uPVC	126	1.62	0.21
P-1254	299	100	HDPE	120	1.12	0.14	P-1161	240	100	uPVC	126	1.62	0.21
P-1285	267	100	HDPE	120	1.12	0.14	P-1162	220	100	uPVC	126	1.62	0.21
P-1287	145	100	HDPE	120	1.12	0.14	P-1163	177	100	uPVC	126	1.62	0.21
P-1288	111	100	HDPE	120	1.12	0.14	P-1164	198	100	uPVC	126	1.62	0.21
P-1289	43	100	HDPE	120	1.12	0.14	P-1165	200	100	uPVC	126	1.62	0.21
P-1290	27	100	HDPE	120	1.12	0.14	P-1166	180	100	uPVC	126	1.62	0.21
P-1291	38	100	HDPE	120	1.12	0.14	P-1167	160	100	uPVC	126	1.62	0.21
P-1292	50	100	HDPE	120	1.12	0.14	P-1168	160	100	uPVC	126	1.62	0.21
P-1293	32	100	HDPE	120	1.12	0.14	P-1169	224	100	uPVC	126	1.62	0.21
P-1294	155	100	HDPE	120	1.12	0.14	P-1170	196	100	uPVC	126	1.62	0.21
P-1295	29	100	HDPE	120	1.12	0.14	P-1171	158	100	uPVC	126	1.62	0.21
P-1298	139	100	HDPE	120	1.12	0.14	P-1172	179	100	uPVC	126	1.62	0.21
P-1299	236	100	HDPE	120	1.12	0.14	P-1173	159	100	uPVC	126	1.62	0.21
P-1301	22	100	HDPE	120	1.12	0.14	P-1174	199	100	uPVC	126	1.62	0.21
P-1302	142	100	HDPE	120	1.12	0.14	P-1175	179	100	uPVC	126	1.62	0.21
P-1311	35	50	HDPE	120	1.12	0.57	P-1176	136	100	uPVC	126	1.62	0.21
P-1304	61	100	HDPE	120	0.4	0.05	P-1177	100	50	uPVC	126	1.62	0.83
P-1286	281	100	HDPE	120	-2.24	0.29	P-1128(2)	84	100	uPVC	126	1.62	0.21
P-1251	144	100	HDPE	120	-2.24	0.29	P-1284	250	50	uPVC	126	1.62	0.83
P-1282	2,125	50	uPVC	126	-2.42	1.23	P-1184(2)	11	50	uPVC	126	1.26	0.64
P-1190	116	50	uPVC	126	-3.4	1.73	P-755	127	100	HDPE	120	-4.48	0.57
P-1271	196	50	uPVC	126	-3.48	1.77	P-756	142	100	HDPE	120	-5.6	0.71

III. Nodal hydraulic output for existing and Revised layout of transmission line

Junction	Elevation in m	Simulated Pressure head in Existing Lay out in m	Simulated pressure head in Revised Lay out in m
J-69	1,444.96	10.34	10.34
J-78	1,676.36	11.32	10.58
J-76	1,676.50	38.12	35.72
M_71	1,677.85	51.41	43.29
M_74	1,676.94	60.85	43.73
M_72	1,677.71	61.09	44.16
M_70	1,678.52	61.88	45.58
J-122	1,678.91	72.14	47.79
M_73	1,677.37	79.05	48.06
M_69	1,679.16	83.06	48.87
M_68	1,679.60	95.08	55.61
M_67	1,680.15	109.3	63.2
M_66	1,680.81	128.63	74.66
M_65	1,680.97	135.75	79.81
M_64	1,681.27	147.47	87.93
M_63	1,681.47	153.42	91.58
M_60	1,682.32	164.93	98.12
M_62	1,681.84	170.2	98.64
M_59	1,686.35	173.39	101.31
M_58	1,690.63	191.63	119.55
M_52	1,721.86	325.39	253.29
M_51	1,723.46	331	258.89
M_49	1,726.50	349.23	277.12
M_47	1,733.47	356.99	284.87
M_48	1,730.64	359.95	287.83
M_46	1,735.63	361.85	289.73
M_45	1,737.64	367.59	295.47
M-44	1,739.08	372.74	300.62
M_42	1,742.69	384.27	312.15
J-73	1,750.29	388.06	315.93
M_40	1,745.97	390.81	318.69

Annex - 6: Weighting criteria for selected KPIs

S.No	Categorization Criteria	Individual weight (%)
1	Access Coverage	20
1.1	100%	20
1.2	80%-99.9%	15
1.3	60% - 79.9%	10
1.4	50% - 59.9%	5
1.5	< 50%	0
2	Cost Recovery	20
2.1	> 1.40	20
2.2	1.3 - 1.4	10
2.3	1.01 - 1.29	5
2.4	< 1.0	0
3	Non-Revenue Water	20
3.1	< 20%	20
3.2	20% - 25%	15
3.3	25.1% - 30%	10
3.4	30.1% - 35%	5
3.5	>35%	2
4	Service Quality/Service	20
4.1	20-24 hours	20
4.2	16 - 19.9 hours	15
4.3	12 - 15.9 hours	10
4.4	8 - 11.9 hours	5
4.5	< 8 hours	0
5	System Complexity	10
5.1	River/Dam Intake + WTP+	10
5.2	River/Dam Intake + WTP	8
5.3	BHs only	7
5.4	Spring - Pumping	6
5.5	Spring- Gravity	5
6	Customer Number/ Total	10
6.1	≥ 90%	10
6.2	75% - 89.9%	8
6.3	50% - 74.9%	6
6.4	20% - 49.9%	5
6.5	< 20%	4
	Total Weight	100

Annex-7: Sample data collected for utility management performance evaluation

a. Summary of respondents interview

Date: 10/4/2024-30/4/2024

Sample population

Beneficiary Kebele	**No of Water points(10% of existing)**	**Total HH No for 1 water point**	**Total No of informant selected 5% of HH**
Teyfe Town	1	578	29
Kurfa Gelma	1	1356	68
Dhadacha Hina	1	1769	88
Dimtu Boreda	1	1921	96
Burka Oda	1	1295	65
Abdi guddina	1	1631	82
Rada dibicha	1	1673	84
Total			511

Interview respondents

S.No	**Interview Questionaries'**	**Response**	**No of respondent**	**%**
1	Do you have regularly used the new water supply scheme	yes	29	5.68
		No	482	94.32
2	How much distance you have travelled to collect water from water point	Rural		
		<=1km	164	32.09
		>1km	318	62.23
		Town		
		<=0.5km	19	3.72
		>1km	10	1.96
3	Can you afford the current Cost of water	yes	5	0.98
		no	506	99.02
4	How do you see the Quality of water	good	511	100
		medium		0.00
		bad		0.00
5	For how many hours the water point left open for service	half a day	0	0.00
		hole day	0	0.00
		7-9hr/day	511	100.00
6	Did you have keeping queue to collect water	yes	356	69.67
		no	126	24.66
7	Did you have participated in this project (planning-construction) in one way or the other	yes	20	3.91
		no	462	90.41
8	Did you get any awareness on the new water supply system	yes	0	0.00
		No	511	100.00

Annex -8: Water Production, Billed amount, NRW, Revenue collected and Expenditure

i. Water Production, Billed amount and NRW

Month	water production supply in m3	water billed in m3	NRW in %
July	25920	14372.64	44.55
August	25920	11702.88	54.85
September	29160	11664.00	60.00
October	19440	12781.80	34.25
November	22680	13664.70	39.75
December	29160	16038.00	45.00
January	25920	16886.88	34.85
February	19440	9788.04	49.65
March	25920	13789.44	46.80
April	22680	10217.34	54.95
Total	246240	130905.72	46.84

ii. Revenue collected and expenditure in birr

Month	Revenue collected in birr	Expenditure
July	1,437,264.00	329,456.00
August	1,170,288.00	491,356.00
September	1,166,400.00	467,000.00
October	1,278,180.00	694,536.00
November	1,366,470.00	610,945.00
December	1,603,800.00	1,267,956.00
January	1,688,688.00	775,889.00
February	978,804.00	1,536,866.00
March	1,378,944.00	900,389.00
April	1,021,734.00	1,010,987.00
Total	13,090,572.00	8,085,380.00

Annex - 9: Water Tarif of similar villages and small towns

Scheme Name	Scheme Type	Tariff for water point/m3
Arboye Town and surrounding	BH	28
Sire town and surrounding	BH	46
Huruta-Dhera MVWSP	Motorized spring	13.5
Amereba Endeto MVWSP	Motorized spring &BH	22
Gimbichuu Fentale MVWSP	Motorized BH	18