University of Zimbabwe
Faculty of Engineering and the Built Environment.
Department of Construction and Civil Engineering.

Title : Improving Access to Potable Water in a Low-Income Urban Settlement.
Design of a Water Reticulation Network for Hopley, Harare.

By Jabulani Farai Mutezo
(R213343E)

A project report submitted in partial fulfullment of the requirements of the degree of BSc. (Honours) in Civil Engineering.

Supervisor : Dr. S.N. Misi.

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Declaration

I ,Jabulani F. Mutezo, fully declare that the following work, unless otherwise stated, is wholly the product of my work. Citations and references are inserted to indicate original authors and sources of information that was used in writing out this Project. This project has never been submitted for assessment or examination for any degree or course in any other university.

Signed…………………………………. Date……………..

Acknowledgements

First and foremostly, thanks be given to The Lord who makes all things possible for us in this life. I am also grateful for my parents who provide me with this opportunity to further my knowledge and continually support me in various ways throughout my studies. I would like to acknowledge my supervisor Dr Misi for providing guidance on how to approach this project. His knowledge and input gave me the direction I needed to complete this project. I also acknowledge the various professionals consulted at City of Harare. They were forthcoming with information and assisted greatly in the completion of this project.

Abstract

Key Words

Water Reticulation; Water and Sanitation Health; Potable Water; Sustainable Development Goals; Millennial Development Goals; Informal Settlement; Harare; Zimbabwe;

Abbreviations

1 Introduction

1.1 Background

This project aims to conduct the design of a Water Reticulation Network for Hopley, a high-density urban settlement in Harare. Residents of the Hopley settlement have no access to WASH facilities. Potable water is inaccessible to them. Designing a water reticulation network for the area would be the first step in remedying this crisis.

<u>Definitions:</u>
Water reticulation network is a system off interconnected pipes, fittings, valves, chambers, water storage facilities that serve the purpose of effectively distributing water from the municipality (supplier) to the residents (end consumers) of an area. (*How the Urban Water Cycle Works*, n.d.)

Potable water is water that is deemed suitable for human consumption on the basis of several parameters (chemical, biological and physical) (*How the Urban Water Cycle Works*, n.d.)

WASH facilities are water and sanitation health facilities as defined by the United Nations (Jones Rachael, 2015) These include but are not limited water supply infrastructure, waste disposal methods both liquid and solid including toilets with on and offsite sanitation technologies.

Informal settlements are residential areas where the houses are usually lacking or are cut off from, basic services and city infrastructure (United Nations Task Team, 2015).

<u>Background:</u>
High poverty and unemployment in Zimbabwe with up to 90% unemployment (Zimbabwe Congress of Trade Unions, 2017) coupled with high rates of rural to urban migration has led to a strain on the housing situation in the major cities in Zimbabwe. People migrate to urban centres in search of opportunities for employment and better living conditions. The widespread inability to secure employment then results in the proliferation of informal housing throughout the country. This has led to the emergence of informal settlements in and around the major cities of Zimbabwe as people are unable to afford housing.

Slums are the subset of informal settlements with the most deprived living conditions and are plagued by poverty, dilapidated housing and may be situated on land that is least suitable for human inhabitation. People living in slums experience poor living conditions with a lack of basic infrastructure and services (e.g., electricity, potable water, sewerage solutions), constant exposure to diseases and violence and the safety and health risks associated with living in poorly constructed structures which are not resistant to weather hazards (Mehta & Dastur, 2008).

The rise in number of informal settlements poses a challenge to local authorities that must be addressed. These areas prove to be breeding grounds for water borne and water washed diseases. Water borne diseases are infections spread through contaminated drinking water or food (e.g., diarrhoea and typhoid. Water washed diseases are infections spread due to the lack of proper sanitation and hygiene (e.g., roundworms and hookworms). (Puja s; et al., 1988). Inadequate water supplies, contaminated water sources and lack of solid waste disposal services led to the spread of many of the diseases. This has in turn emphasised the need for local authorities to upgrade the living conditions to safeguard the health of the people.

Figure 1: People Queuing for water at a Communal well

Figure 2: Residents in Hopley

Figure 3: Resident in Hopley abstracting water.

1.2 Problem Statement

The study area is not served by the local municipality with regard to wash facilities. This leaves households having to travel to fetch water from sources of questionable quality, buy water from water vendors or resort to the use of shallow unprotected wells.

these practices leave the population of the area at risk of water-washed and water-borne diseases

1.3 Main objective

The main objective of this project is to design and propose a water reticulation project for the Hopley area, extending the Phase 1 reticulation that was implemented by City of Harare.

1.4 Specific objectives and research questions

1. Conduct surveys and feasibility studies for the Hopley area.
2. Design the water reticulation network.
3. Make use of QGIS and EPANET for design.
4. Produce a BOQ. .

1.5 Justification

Residents of the Hopley settlement have no access to WASH facilities. Water for domestic use is sourced either from the nearby polluted Mukuvisi River, contaminated and unprotected well or water vendors who supply water of questionable origins that is oftentimes not suitable for human consumption. As a consequence, water borne diseases are prevalent within the local population as evidenced by the cases recorded in the 2019 cholera outbreak. In 2023 cholera is propagating throughout the city of Harare (and the greater Zimbabwe as a whole) and this project aims to rectify the crisis in one of the underprivileged vulnerable hotspots in the Capital.

The United Nations states that access to WASH facilities is a basic human right necessary for a fruitful and productive life, emphasizing the need for residents to have access to potable water.

Millennial Development Goal number seven targets ensuring environmental sustainability which is attainable through providing access to potable water to residents of the Hopley Settlement. This will decrease reliance on shallow wells and boreholes in the area, effectively preserving natural resources.

The Sustainable Development Goals are a set of global goals adopted by the United Nations to address social, economic, and environmental challenges. Heavy emphasis is placed on the need for people to have access to safe and clean water as will be elaborated in detail in **Chapter 2.5 (Sustainable Development Goals).**

Furthermore, City of Harare aims to achieve a world class status by 2025 and this design project falls in line with that target.

2 Literature Review

Water pipe network is an important part of social infrastructure. its design and operation must be carefully calibrated to provide the user with the required amount of clean water at the required location. In recent years, with the development of society, water consumption has increased significantly compared with the past, and the level of service satisfaction has also increased. This places emphasis on, efficient design and optimal management of water supply systems . Several optimization problems need to be solved this includes network design problems (Savic & Walters 1997), pump scheduling problems (Jung et al. 2015) and the optimal placement and operation of control valves (Nicolini & Zovatto 2009; Wright et al.2015).

By 2030, the population of African cities will increase by 40% and the current difficulties African cities face in providing sustainable water services will worsen (Jacobsen et al. 2012). There is a need for cities to adopt a more integrated, sustainable and flexible approach when it comes to management of their water supply approaches.

2.1 Hopley Informal Settlement

According to World Bank about 25% of Zimbabwe's urban population resides in slums or informal settlements. The latter experience a range of urban services gaps with settlers resorting to makeshift urban services arrangements such as through the use of pit latrines, shallow wells and shacks as housing facilities. Consequently, these conditions have deepened urban poverty and widened inequalities. In Harare, for instance, Dialogue on Shelter and the Zimbabwe Homeless People's Federation and City of Harare profiled and mapped 63 informal settlements. Hopley settlement is one of the upgraded slums located in the Southern part of Harare and is one of the poorest suburbs in the country with an average income of USD20 per month. It is a shantytown, with approximately 300.000 residents, that has mostly two-roomed brick and motor houses, makeshift wooden and plastic cabins. The settlement is an epicenter of depravity, poverty and socio-economic decay and prone to diseases outbreaks, high unemployment rate, a growing informal sector and limited infrastructural development (Mazbhelli, 2023)

City of Harare is experiencing a humanitarian crisis with an extremely polluted water resource for drinking water production, very low drinking water production capacity due to years of under investments, climate induced droughts and sky-high water losses (65%). This has resulted in large water starved areas and areas under extreme water rationing schemes. Overflowing and leaking sewers contaminate shallow wells whereas residents in a large part of the Southern suburbs, including Holey, use and drink this contaminated water from shallow wells. Noting that these wells also dry up in winter and force residents to buy expensive water from vendors and walk long distances to alternative (unsafe) water sources. This situation led to large scale cholera and typhoid outbreaks such as in 2018. New large-scale outbreaks are expected, parallel to a continuous incidence of diarrhea and typhoid cases in large parts of the city
(Harare Water Department and VEI (Netherlands), 2019).

The above water crisis particularly applies to Hopley, as an underdeveloped urban area that has never been connected to the main water and sanitation grid over the past 14 years. As will be described in the proposal, Hopley is a high-risk area for water borne diseases and cholera outbreaks (as indicated in the graphs and maps in this proposal). The proposal at hand will significantly reduce the risk of water borne diseases in area 6 of Hopley.

Hopley suburb (approximately 300.000 residents) is a township in the South of Harare without municipal water and sanitation services. City of Harare has not been able to provide the required infrastructure due to the highly unpredictable economic situation where planning for development projects increasingly becomes complex. The residents have endured the limited infrastructural development and illegal settlers have since invaded the area. The risk of a humanitarian tragedy with outbreaks of cholera and typhoid is imminent, given the extremely poor, availability of water and sanitation services in the area. Below the statistics are provided concerning watery and bloody diarrhoea in 2019 (Harare Water Department and VEI (Netherlands), 2019).

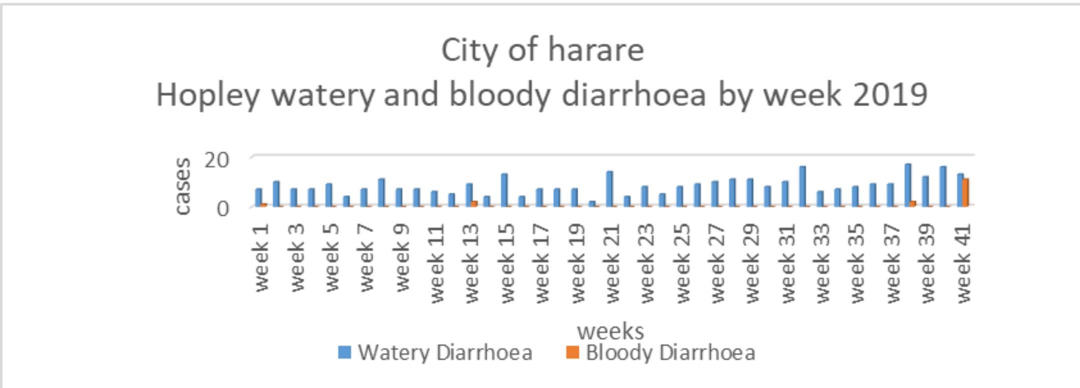

Figure 4:Cases of bloody diarrhoea in Harare in 2019

In 2008, Hopley was amongst the hard-hit areas from cholera. Since then, the City of Harare Health Service Department has raised awareness campaigns and the area has ceased to be a hotspot even though a number of cases were reported in the 2018 cholera outbreak and many diarrhoea cases are reported in 2019 and remains a high-risk area.

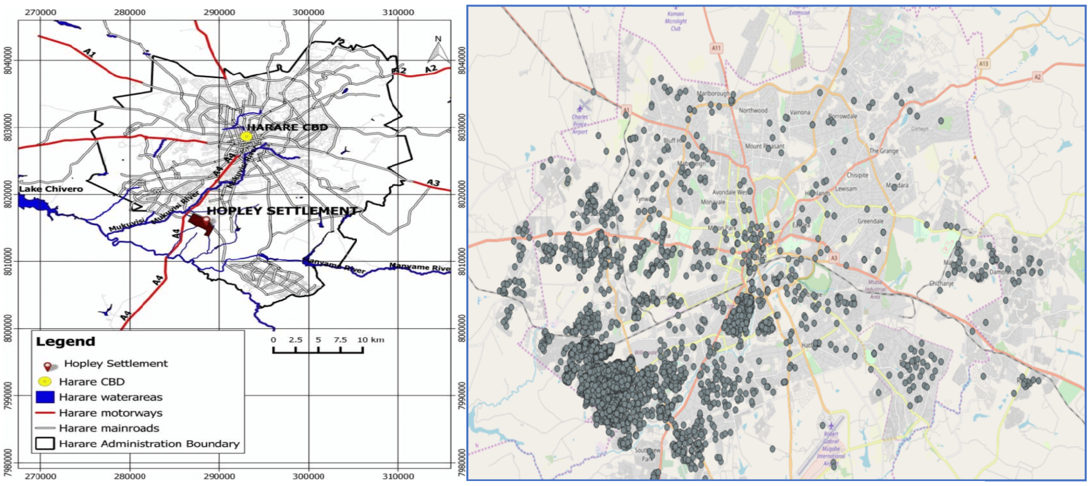

Figure 5: Recorded cholera cases in the period August-October 2018,

A large part of the boreholes in Hopley are not functional. Some of the boreholes have been decommissioned due to breakdowns while some have dried up due to the prolonged drought season that are believed to be a result of climatic changes. All the households have a shallow well that is used for drinking and sanitary use. A large part of Hopley (outside the targeted project area) is unplanned and attracted illegal settlers who have moved in search for affordable accommodation. On the same properties with shallow wells, Blair toilets were constructed as the most common type of waste water system in the area. Contamination is highly likely as these areas are still to be fully developed and regulated in terms of the Town and Country Regulations(Shoko Bartha, 2018).

Table 1: Pumping schedule in Harare

Ward	Average pumping days/week Aug-Oct 2019		Ward	Average pumping days/week Aug-Oct 2019		Ward	Average pumping days/week Aug-Oct 2019
Harare South	0		Mt. Pleasant	0,8		Budiriro	3,5
Harare Central	5,5		Borrowdale	0,3		Mufakose	2,8
Mbare	6,4		Mabvuku	0,8		Mufakose	2,8
Mbare	6,4		Tafara	0,8		Mufakose	2,8
Belvedere	3,4		Mabvuku	0,8		Kuwadzana	4,6
Harare Central	5,9		Hatfield	2,4		Kuwadzana	4,6
Avondale	0,4		Waterfalls	2,4		Dzivaresekwa	1,9
Highlands	0,4		Highfield	3,3		Dzivaresekwa	1,9
Greendale	0,3		Highfield	3,3		Marlborough	0,9
Sunningdale	6,4		Highfield	3,3		Hatcliffe	0,4
Mbare	6,4		Glen Norah	3,3		Budiriro	3,5
Mbare	6,4		Glen Norah	3,3		Kuwadzana Extension	6,7
Southerton	6,4		Glen Norah	3,3		Kuwadzana Phase 3	2
Kambuzuma	3,1		Glen View	3,6		Harare East	0
Warren Park	2,2		Glen View	3,6		Caledonia	0
Mabelreign	1		Glen View	3,6			

Because shallow wells and boreholes in the area have dried up, residents rely on water vendors. It is alleged that the vendors obtain water from a source close to the cemetery but they are left with no other options only for a river that is 45 minutes away where they wash clothes and bath. The river, Mukuvisi is highly contaminated with solid waste disposals, industrial effluent, informal activities such as car washing or farming along the river, and sewer discharge from most parts of Harare. The river runs across Harare from Middle East part of the Central Business District to the Southern parts of the city, see picture below

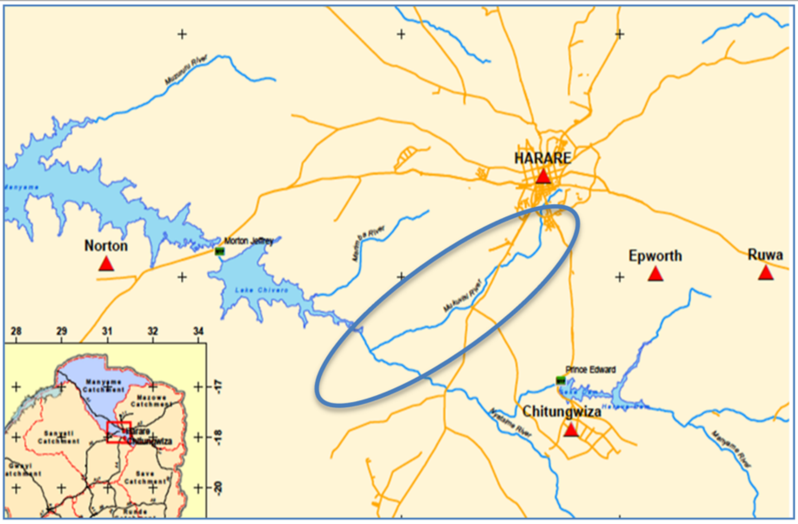

Figure 6: Mukivisi river shown

Figure 7: Pollution along the Mukuvisi River

A fourth source for water is water vendors. The source remains unknown to the residents who believe that the vendors are getting this water from a man-made lake close to the cemetery. The cemetery shares boarders with Hopley and some of the illegal settlers live a few meters away from the deceased(Harare Water Department and VEI (Netherlands), 2019).

Figure 7: Water Vendor shown on the left, obtained water shown on right

Water supplied by the vendors appears to be cleaner than the water obtained from the natural water spring (the fifth water source) at a nearby neighbourhood in Waterfalls, see picture of the dirty water from the spring above. Even though they do not use the water for cooking and drinking, the community buys the water for RTGS2.50 (=0,16 USD) per 20-liter container from the vendors.

The little water that is obtained at present is being used for cooking, drinking, bathing and sanitary purposes (source: interviews by Dialogue on Shelter with residents conducted in 2019). Many of the wells are protected brick and cement lining and closed on top. The water remains at risk for underground bacterial contamination.

On average households in the community earn USD20.00 per month. The money is not adequate enough for saving for further improvements in life and it is used mainly to buy food. Prostitution and stealing are important income avenues for most residents (Harare Water Department and VEI (Netherlands), 2019)

2.2 Dublin Principles

Mukonge and Harvey (2008) define Water Resources Management (WRM) as a broad sector encompassing water supply and sanitation. Efforts have been made to articulate WRM on an international level and this has led to development of the Integrated Water Resources Management (IWRM) approach defined by the Dublin Principles. In January 1992 a meeting was held in Dublin for the international Conference on Water and the Environment and from this meeting four principles emerged regarding IWRM. These are:

1. Fresh water must be viewed and regarded to be a finite and valuable resource that is critical for life, and to sustain development and the environment.
2. Water development and management should be acknowledged and prioritised by all parties including users, town planners and policymakers on all levels.
3. Women play a crucial role in the provision, management and safeguarding of water.

4. Water is a resource of economic value in all the various uses it has and should be recognised as such.

2.3Human Right to safe water and Sanitation

The human rights Council stipulated that access to safe drinking water and sanitation falls under the right to an adequate standard of living (Dignity (UN Human Rights (UNHR) 2021)). I result what a supply must be of suitable quality and quantity for households and individuals' usage encompassing drinking, washing, food processing and personal hygiene.(United Nations Task Team, 2015) The water must also meet standardised parameters including acceptable colour smell, taste, turbidity, and mineral ions are content so that individuals are not forced to obtain the water from polluted alternatives in an attempt to mitigate the unsatisfactory water provided to them. These water and sanitation facilities must be physically accessible and within safe limits for the entire population taking into account specific groups of people such as disabled, women, children and the elderly. The water provided must also be affordable to all segment of the population. Individuals and groups that do not have the capacity to pay for water must under no conditions be denied access to safe water (UN General Assembly 2008).

Through resolution 64V292 of July 28, 2010 the United Nations General assembly has the following rights explicitly acknowledged "We acknowledged that clean drinking water and sanitation are essential to the realisation of all human rights."
This resolution resulted in availability of assistance to member nations in building capacity of provision of safe water and WASH facilities for member nations as well as availability of finances especially in the developing countries.(Anna Kahumulo Tibaijuka, 2007)

2.4Millennium goals towards drinking water and sanitation.

The importance of safe drinking water and sanitation facilities has been continuously emphasised in the Millennium Development Goals. Goal number seven targets ensuring environmental sustainability. (Mekambe et al., n.d.)Access to drinking water for the poor, along with water quality and safety, remain serious concerns. Despite unprecedented progress, 768 million people worldwide still drew water from an unimproved source in 2011. Furthermore, concerns about the quality and safety of many improved drinking water sources persist. As a result, the number of people without access to safe drinking water may be two to three times higher than official estimates. Most people around the world aspire to piped drinking water supplies on their premises. Yet 38 per cent of the 6.2 billion people globally using an improved drinking water source do not enjoy the convenience and associated health and economic benefits of piped drinking water at home. Instead, they spend valuable time and energy queuing up at public water points and carrying heavy loads of water home, often meeting only minimal drinking water needs (Louis Jensen, 2013).

2.5Sustainable Development Goals

Several Sustainable Development Goals (SDGs) are directly related to water and public health. The SDGs are a set of global goals adopted by the United Nations to address social, economic, and environmental challenges. The following SDGs are particularly relevant to water and public health(Jones Rachael, 2015):

i. SDG 3: Good Health and Well-being - This goal aims to ensure healthy lives and promote well-being for all. Access to clean water and sanitation is essential for achieving this goal, as it helps prevent waterborne diseases and provides a foundation for good health.

ii. SDG 6: Clean Water and Sanitation - SDG 6 specifically focuses on ensuring the availability and sustainable management of water and sanitation for all. It aims to achieve universal access to safe drinking water, improve water quality, and ensure adequate sanitation and hygiene practices.

iii. SDG 11: Sustainable Cities and Communities - This goal addresses the importance of ensuring access to safe and inclusive water and sanitation services in urban areas. It emphasizes the need for adequate infrastructure, improved hygiene practices, and the protection of water resources in cities and human settlements.

iv. SDG 13: Climate Action - Climate change can have significant impacts on water resources and public health. SDG 13 calls for urgent action to combat climate change and its impacts, which includes addressing water-related challenges such as water scarcity, flooding, and the spread of waterborne diseases.

v. SDG 14: Life Below Water - While primarily focused on marine ecosystems,

vi. SDG 14 recognizes the importance of protecting and restoring water-related ecosystems, which can indirectly impact public health. Healthy aquatic ecosystems contribute to clean water supplies and support biodiversity that can influence human well-being.

vii. SDG 17: Partnerships for the Goals - Collaboration and partnerships are crucial for addressing water and public health challenges effectively. SDG 17 promotes the importance of multi-stakeholder cooperation, knowledge sharing, and capacity building to achieve sustainable development goals.

viii. By working towards these SDGs, governments, organizations, and communities can contribute to improving access to clean water, sanitation, and public health outcomes globally.

The importance of access to safe and adequate water facilities cannot be overstated. It is therefore imperative that populations of all communities be granted access to water and wash facilities in accordance with the sustainable development goals. Addressing the issues of water and sanitation is crucial for achieving progress across multiple SDGs. It requires investment in infrastructure, improved hygiene practices, education and awareness, and the promotion of equitable access to water and sanitation services(Mazbhelli j et al., n.d.).

Figure 8: THE 17 GOALS | Sustainable Development, n.d.

2.6National Development Strategies:

Zimbabwe aims to achieve an Empowered and Prosperous Upper Middle-Income Society by 2030 (Vision 2030). The National Development Strategy (NDS1) is aimed at progressing towards this during the period 2021-2025. The NDS1 is the country's medium-term development plan aimed at achieving sustainable economic growth, poverty reduction, and improved living standards for its citizens. The of the Zimbabwe National Development Strategy relating to water and WASH facilities include:

i. Sustainable environmental protection. Responsible water use and Safe treatment ensures the environment is protected and achieves sustainability.
ii. Social infrastructure can be improved by increasing access to WASH facilities. The effects of this then compound by reducing strain on the public health sector as a result of reduced illnesses (National Development Strategy 1 (*National Development Strategy 1 (2021-2025) | Veritaszim*, n.d.)

2.7Worldwide Water Crisis

utilising estimates from 84 nations from the year 2015 40% of the worldwide population had access to securely managed to sanitation amenities. These are facilities that safely and adequately dispose of human waste without posing any potential risk to other people in the nearby area or the environment itself. A further 30% of the worldwide population utilised a basic sanitation service. That is an improved facility that is not share. in that same in that same year two 2.2 billion people lacked and even basic level of service and 890 million people practised open defecations to dispose of solid human waste (The Sustainable Development Goals Report ,2018). Only 27 per cent of the population in least developed countries had basic hand washing facilities(Mazbhelli, 2023)

In the period from 1990 to 2015 massive strides have been made in ensuring clean and safe drinking water is made available to the approximately 2.6 billion people living in developing nations. Although this progress has been made in this area there are still measures to be taken to ensure everyone has access to wash facilities. Worldwide, 844 million people lack access to clean water. Without clean, easily accessible water, families and communities are locked in poverty for generations (UN STATS ,2018).
Women and children are worst the affected, children more because they are more susceptible to illnesses of dirty water and women and girls because they often stand the burden of carrying water for their families for an estimated 200 million hours each day (World Vision Inc. 2020).

Over the last three decades, Zimbabwe has experienced a measured decline in access to clean and safe water. In 1988, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) reported that over 84 percent of Zimbabweans had access to safe drinking water (HRW,2020). From 2000 to 2017, the percentage of people with access to safe water and basic water services decreased from 72 percent to 64 percent, and basic sanitation decreased from 46 percent to 36 percent. it is estimated that over 76% of rural people in developing countries have access to a dignified water source compared to the 97% of developed countries and over 94% of urban people in developing countries have a safe and clean water source also compared to the 100% of urban people in developed countries (UN MDG Report 2013).

2.8Factors contributing to water shortages.

i. Population growth

In urban areas there is a high demand for water which only increases over time as a function of population growth. There is an ever increasing level of water stress resulting in water shortages (Chenje, Sola and Paleney, 1998). In Harare before and soon after independence there were no major water woes compared to the current water shortages (Gary, 1991). Before independence there was less population due to colonial rules and in 1992 the population of Harare ballooned to 1 850 000 and this posed a major threat on pipe water supply leading to water shortages. This challenge can be remedied by adequate town planning. This refers to maintaining and upscaling infrastructure to deal with not only the current but the future predicted population size a town is expected to have.

ii. In adequate infrastructure.

In developing countries a challenge experienced is that of insufficient infrastructure to meet the growing demands of urban population resulting in extreme stress on the water supply network (World Bank and IUCN 2002). This is a game again caused by inadequate town planning, population growth, lack of anticipation for future demand needs (industrial, commercial) as well as a lack of capacity to invest in building new infrastructure. Another factor may be poor maintenance off already existing infrastructure resulting in breakdowns or a reduced capacity to meet service needs in urban areas. These factors combine resulting in extreme strain on the water supply system of an urban area(Jones Rachael, 2015).

iii. Urbanization

The rapid development and expansion of urban areas, particularly around Harare, has contributed mainly to water scarcity due to the current very high demand (Tevera and Moyo, 2000), increasing demand for water exceeds supply, resulting in permanent water shortages. Some areas have low water pressure during peak hours and some areas do not receive tap water. The current situation is that high rural migration contributes to water shortages in the capital Harare.

iv. Informal settlements

There are various factors which have contributed to the creation and proliferation of Hopley Zone slums settlements in the capital. Such factors encompass the role of Operation Murambatsvina(Restore Order), poverty compounded by the Economic Adjustment Programme, the burgeoning housing problem in the country in which the supply of housing and the associated settlement services delivery continued to lag behind, high rates of rural to urban migration which resulted in overstretching of the scarce accommodation resources in the capital as well as high unemployment rates brought about by a poorly performing economy of the country. Such factors led to the decline and or to the outstripping of resources available for accommodation which compelled the majority of the urban poor to resort to slum settlements as their only source of accommodation.

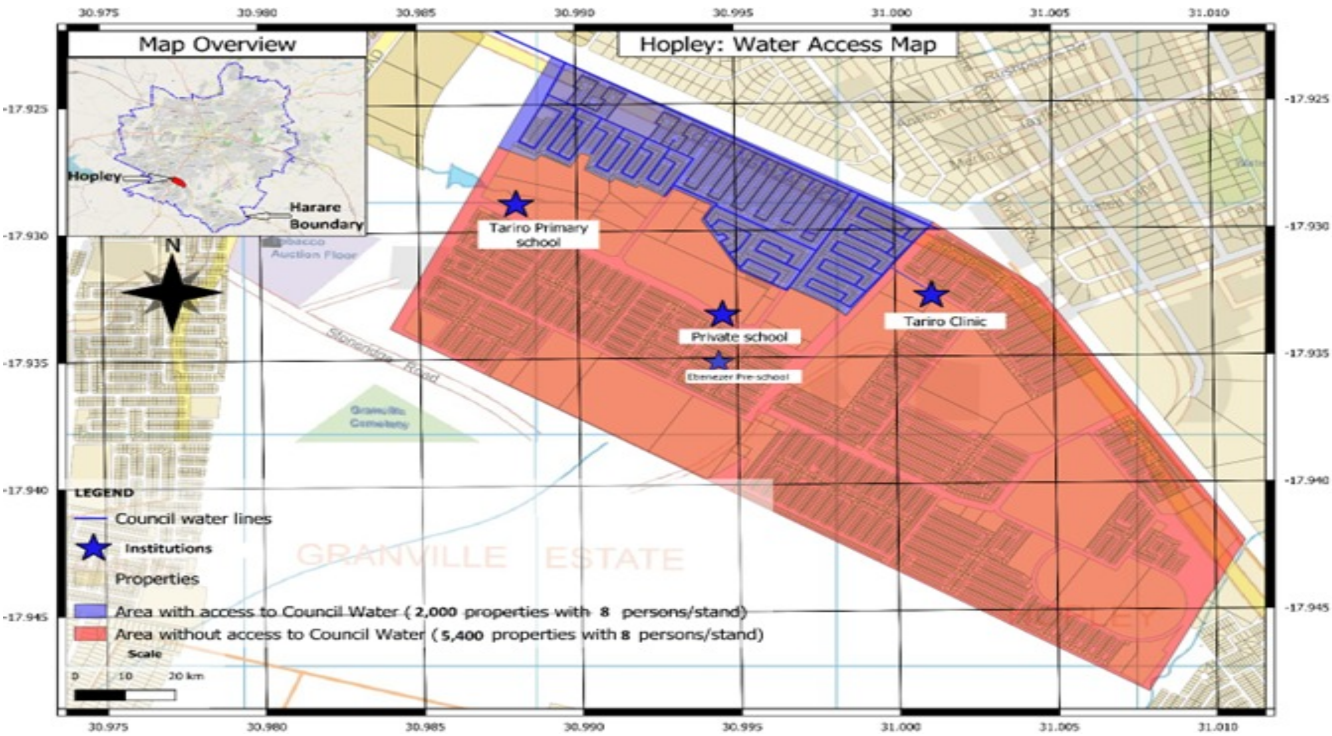

Figure 9: Hopley area water access map

As highlighted in the image above informal settlement of Hopley has limited access to wash facilities.

v. Pipe bursts

Water shortages are a result of mainline bursts, which lose a substantial volume of water while being transported to customers. An estimated 623 million cubic metres, or 29% of the total water provided in South Africa, are wasted from the 62 systems (Water Wheel, 2007). The amount of water wasted, lost, and used inefficiently is having a detrimental impact on communities' capacity to offer long-term services.

2.9 Causes of pipe bursts

Mains (pipes) bursts are caused by a variety of factors. Some of the common external factors relating to road opening activities are: direct damage of water mains and valves by indiscriminate or reckless use of construction plant, ground settlement or movement caused by excavation work, disturbance of lateral or vertical support to water mains and excessive stress or loading caused by piling, blasting, heavy mechanical plant or construction traffic. There are various internal factors which contribute to water pipe bursts and these are age of the pipes, water pressure, type of material, composition, joining methods, quality of initial installation, and contact with other structures, stress from traffic, frost loads, freezing soil around the pipes and rusting through age.

Minimizing water pipe bursts in water systems has many benefits for water providers and consumers alike. These include improved operational efficiency, lowered water systems operational costs, reduced potential for contamination, extended life of facilities. Early burst detection and repair systems are beneficial in urban areas where there is a large concentrated population to ensure minimum downtime and to mitigate the risk of diseases propagating through the community.

2.10 Pipe flow

Pipe flow refers to the movement of fluids through a closed conduit, typically pipes. The most conventional method to calculate the discharge rate following incompressible liquid pipeline rupture is to assume the pipeline remains full throughout the discharge process Loiacono (1987) .This type of flow is common in various engineering applications, such as water distribution systems, oil pipelines, and HVAC systems. The behaviour of fluid flow in pipes can be described using principles from fluid dynamics, including the concepts of laminar and turbulent flow.

i. <u>Type of flow:</u>

The type of flow describes the manner in which the fluid is moving to a conduit. There are different types of flow and these are dependent on the nature of the fluid itself, the velocity of the fluid, the diameter of the conduit and the density of the fluid. The type of flow of fluid experiences greatly influences the amount of energy dissipated as a fluid travels down the conduit. There are three distinct types of those and these are the laminar flow, turbulent flow and transitional floor.

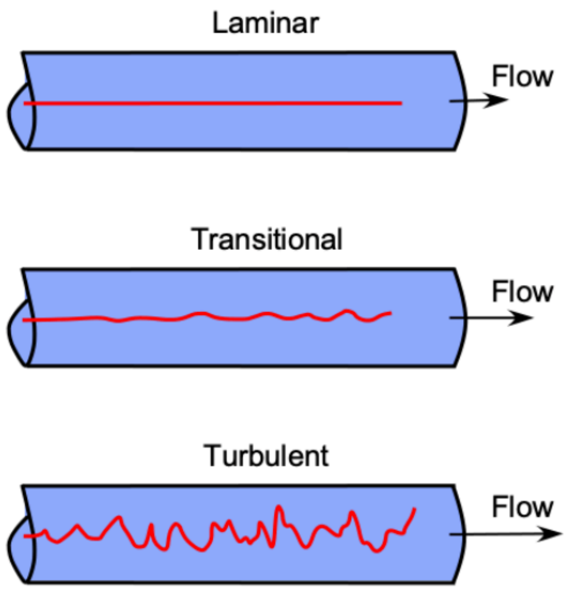

Figure 10: Different types of flow

Laminar Flow:

Occurs when the fluid flows in parallel layers, with minimal mixing between them. This type of flow is characterized by smooth, orderly motion and typically occurs at low velocities and with high-viscosity fluids.

Turbulent Flow:

Describes a chaotic fluid motion where eddies and swirls are present. This type of flow occurs at higher velocities and with low-viscosity fluids, leading to increased mixing and energy dissipation.

Transitional flow:
Transitional flow can be described as the type of flow of fluid experiences as it is changing from turbulent flow to laminar flow or vice versa. It can be approximated as a state of being in between laminar flow and turbulent flow(Sharma et al., 2022).

Reynolds Number:
A dimensionless number used to predict the flow regime in a pipe. It is defined as:

$$Re = \frac{\rho u D}{\mu}$$

where:

ρ is the fluid density,
u is the flow velocity,
D is the pipe diameter,
μ is the dynamic viscosity of the fluid.

Laminar flow typically occurs at Re<2000, while turbulent flow occurs at Re>4000Re>4000. The range between these values is known as the transition zone. Turbulent flow is the type of flow that dissipates the most amount of head.

ii. Head Loss:

Energy losses due to friction and other factors as the fluid flows through the pipe. The Darcy-Weisbach equation is commonly used to estimate head loss:

$$h_f = f \frac{L}{D} \frac{u^2}{2g}$$

where:

h_f is the head loss,
f is the Darcy friction factor,
L is the length of the pipe,
D is the pipe diameter,
u is the flow velocity,
g is the acceleration due to gravity.

Head loss due to fittings can be calculated using the formula:

$$h_m = \frac{ku^2}{2g}$$

where:

h_m is the head loss,
k is the friction loss coefficient
u is the flow velocity,
g is the acceleration due to gravity.

iii. Bernoulli's Equation

Bernoulli's Equation is a principle of fluid dynamics that describes the conservation of energy in a flowing fluid. It is derived from the conservation of energy and is applicable to incompressible, non-viscous fluids. The equation is given by:

$$P + \frac{1}{2}\rho u^2 + \rho g h = constant$$

where:

P is the static pressure,
ρ is the fluid density,
u is the flow velocity,
g is the acceleration due to gravity,
h is the elevation head.

Bernoulli's equation can be interpreted as the sum of the pressure energy (P), kinetic energy ($\frac{1}{2}pu^2$), and potential energy (ρgh) being constant for a given volume of water travelling down a conduit.

Bernoulli's equation may be used to calculate the amount of energy contained by a fluid travelling down a conduit(*SALA Manual for Water Reticulation Treatment Storage Zimbabwe*, 1970).

Combining Pipe Flow and Bernoulli's Equation

In practical applications, Bernoulli's equation is often combined with the principles of pipe flow to analyse and design fluid systems. For instance, the head loss due to friction in pipes can be incorporated into Bernoulli's equation to account for energy dissipation, leading to a modified form:

$$P_1 + \frac{1}{2}\rho u_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho u_2^2 + \rho g h_2 + h_f$$

Where P_1, u_1, h_1 refer to the initial and P_2, u_2, h_2 refer to the final conditions and h_f is the head loss due to friction. This modified equation helps engineers design efficient piping systems by balancing energy inputs and losses.

2.11 Effect of elevation on the amount of head in water flowing through a pipe:

Elevation plays a critical role in the flow of water through pipes, impacting both the pressure and the energy required to move water within a distribution network. Understanding how elevation affects water flow is essential for designing efficient and reliable water supply systems. Hydrostatic pressure is the pressure exerted by a fluid at equilibrium due to the force of gravity. In the context of water flow in pipes, the pressure increases with depth (or elevation decrease) and decreases with height (or elevation increase).

$$P = \rho g h$$

where:

P is the pressure,
ρ is the density of the water,
g is the acceleration due to gravity,
h is the height of the water column above a certain datum.

For a given water distribution system, higher elevation points will have lower pressure, and lower elevation points will have higher pressure, assuming no other external influences like pumps.

The difference in elevation between two points in a pipe network creates a static head. For example, if water needs to be pumped to a higher elevation, additional energy (pumping head) is required to overcome this elevation difference(Sharma et al., 2022).

$$h_s = z_2 - z_1$$

where:

h_s is the static head,
z_1 and z_2 are the elevations at points 2 and 1, respectively.

The static head must be considered in the design and operation of pumps. Pumps must provide sufficient pressure to overcome this head difference and maintain desired flow rates.

Topography of an area has a direct influence on the amount of head in a pipe. A sudden decrease in elevation results in increased head of the fluid that is flowing and vice versa. Too much head results in rapid deterioration of pipes and/or bursts of pipes. Too little head results in water not having enough energy to flow to the end user.

To manage pressure variations due to elevation changes, water distribution systems are often divided into pressure zones. Each zone is designed to maintain a specific pressure range, typically using pressure-reducing valves (PRVs) or booster pumps. These pressure zones ensure that consumers receive adequate water pressure regardless of their elevation. They help prevent excessively high pressures at lower elevations that could damage pipes and fixtures and ensure sufficient pressure at higher elevations.

2.12 Types of Water Distribution networks

Water reticulation systems are networks designed to distribute water from sources to consumers. These systems ensure that water is transported efficiently and reliably to meet demand. There are various types of water reticulation systems based on how energy is provided to deliver the fluid to the end user as well as the configuration of the various pipes and conduits that provide the channel/path for the water to reach the end user.

i. Gravity System

In a gravity system, water is transported from a higher elevation (such as a reservoir or water tower) to lower elevations using the force of gravity. This type of system is energy-efficient as it does not require pumps to move the water.(Sharma et al., 2022)

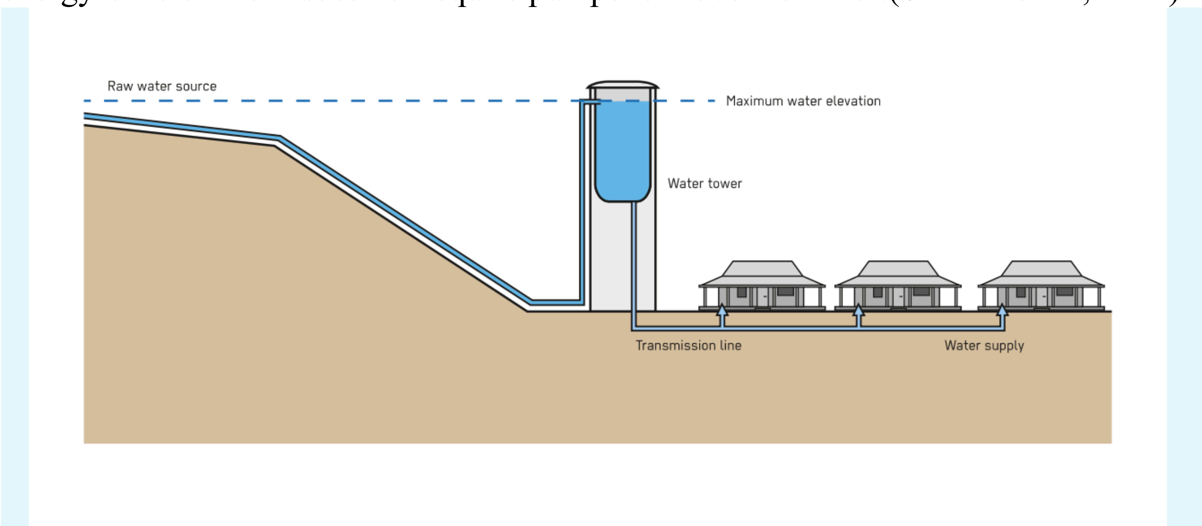

Figure 11: Gravity system showing above

- Advantages:
  - Low operational costs due to minimal energy requirements.
  - Simple design and maintenance.
  - Reliable during power outages.
  - Makes use of terrain to provide water of acceptable head to end users.

- Disadvantages:
  - Limited to areas with suitable topography.
  - Requires significant initial investment in infrastructure like reservoirs and water towers.

ii. Pump System

A pump system uses mechanical pumps to transport water through the network, allowing for water distribution regardless of the terrain. This system is often used in flat areas where gravity alone is insufficient.(Sharma et al., 2022)

- Advantages:
    - Can provide consistent water pressure.
    - Able to overcome challenges posed by unsuitable terrain.
    - Pump sizing allows for effective management of head. This may result in fewer bursts as well as cost savings from using smaller pipes.

- Disadvantages:
    - Higher operational costs due to energy consumption.
    - Requires regular maintenance of pumps and electrical components.
    - Vulnerable to power outages unless backup systems are in place.

iii. Combined (Hybrid) System

A combined or hybrid system utilizes both gravity and pumps. Water is initially pumped to a higher elevation, where it can then be distributed by gravity. This approach combines the advantages of both systems.(Sharma et al., 2022)

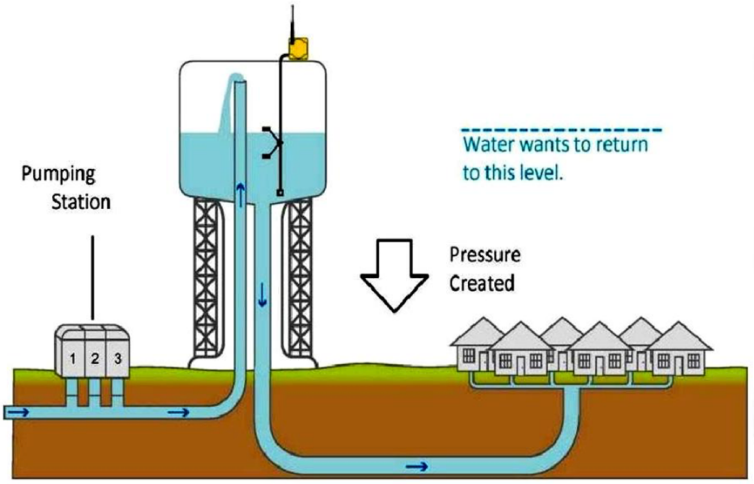

Figure 12Hybrid system shown above

- Advantages:
    - Balanced energy efficiency.
    - Flexibility to adapt to varied terrains.
    - Improved reliability with backup options.

- Disadvantages:
    - More complex design and higher initial costs.
    - Requires maintenance of both pumping stations and gravity-fed components.

iv. Pressurized or Closed Loop System

In a pressurized or closed loop system, water is continuously circulated through the network under constant pressure, maintained by pumps and pressure-regulating devices. This system is often used in commercial and industrial applications.(Sharma et al., 2022)

- Advantages:
    - Consistent water pressure throughout the network.

- Efficient for high-demand areas.
    - Provides multiple paths for water to flow. This mitigates risks associated with pipe bursts and downtime (maintenance).
    - Beneficial for users who are further down the reticulation network especially during peak demand times.

- Disadvantages:
    - High energy consumption.
    - Requires sophisticated control systems and regular maintenance.

v. Branched System

In a tree or branched system, the main pipeline branches out into smaller pipelines, resembling a tree structure. This is a common layout for residential water distribution(Sharma et al., 2022).

- Advantages:
    - Simple design and easy to expand.
    - Fewer cut off valves.
    - Cost-effective for small to medium-sized areas.

- Disadvantages:
    - Pressure can drop significantly at the extremities.
    - Difficult to isolate sections for maintenance without disrupting service.
    - There are many dead ends where water does not circulate but remains stagnant.
    - Sediments can accumulate in the dead end with potential bacterial growth. Drain valves at dead ends allow stagnant water to be drained out periodically, wasting a significant amount of water.

vi. Grid or Network System

A grid or network system features interconnected pipelines forming a grid pattern, ensuring multiple pathways for water distribution. This system is common in urban areas.

- Advantages:
    - High reliability and redundancy.
    - Easier to manage pressure and flow.
    - Sections can be isolated for maintenance with minimal disruption.
- Disadvantages:
    - Complex and costly to design and construct.
    - Requires advanced management and monitoring systems.

systems are more likely in the stabilisation and recovery phases.

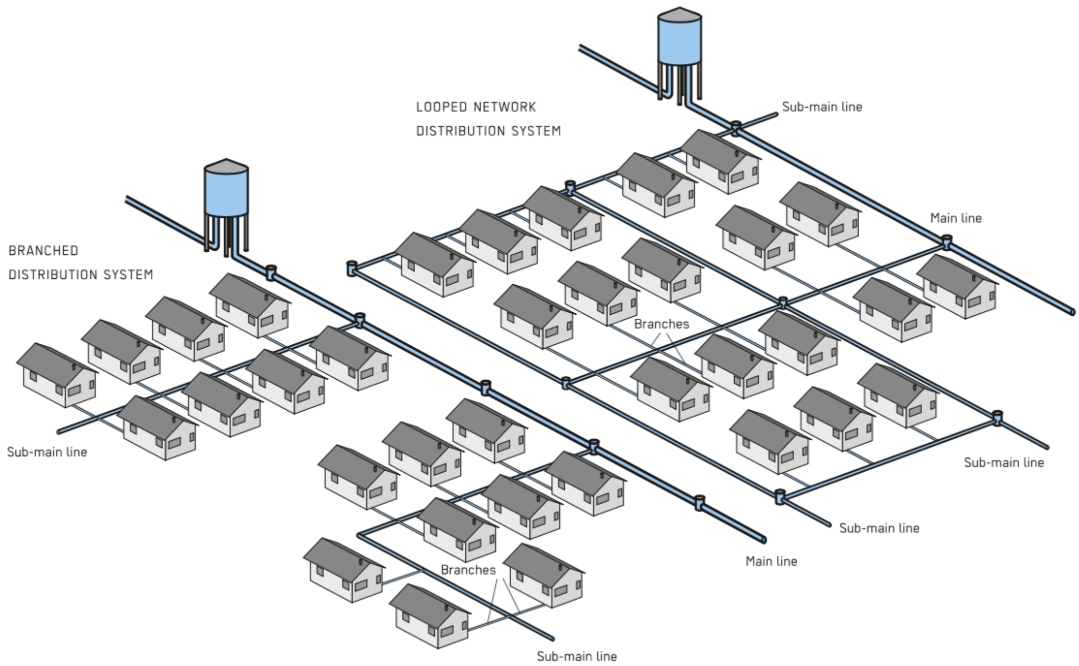

Figure 13:Image comparing a branch to a grid system

The choice of water reticulation system depends on various factors, including topography, population density, water demand, and budget constraints. Each system has its own set of advantages and disadvantages, making it important to select the most appropriate one based on specific needs and conditions(Sharma et al., 2022).

2.13 Population

Designing a water reticulation network involves several key considerations, one of the most important being the population it serves. The size, distribution, and growth of the population directly impact the design and operation of the water supply system. Assessing the current population is the first step in designing order to collision at work. This may be done using various methods including gathering data from census records as well as making use of local authorities and demographics Studies. Understanding how the population is distributed across the service area is crucial. This includes identifying high-density urban areas, suburban zones, and sparsely populated sections so as to ensure we have an understanding of the people we intend to provide WASH facilities to. In addition to determining the current population, designing of a network requires ensuring it is future-proof. This is done through forecasting the population growth of the area for a selected time horizon. Future population growth must be projected to ensure the network can accommodate increasing demand. This involves analysing historical growth trends, planned developments. For estimation of the population of the area to be served by the network the following formula will be used:

$$P = P_0 e^{rt}$$

Where

P is the expected population

P_0 is the starting population at the time of design

E is Euler's number (2.71)

R is the rate of population growth as a percentage (2.82% from the SALA manual for Zimbabwe)

T is the time in years

2.14 Water Demand Analysis

Estimating the average water consumption per person is essential. This can vary based on lifestyle, climate, and economic conditions. Calculate the total water demand by multiplying the per capita consumption by the current and projected population. This helps in determining the required capacity of the water reticulation network. (CF Schutte & WA Pretorious, 1997)

Level of living index	Water use (ℓ/c·d)								
	Drink/ cook	Dish wash	House wash	Clothes wash	Bath/ shower	Garden	Toilet	Pool	Total
Very low	3	2	1	3	15	0	0	0	24
Low	4	3	1	4	20	18	0	0	50
Moderate	4	4	2	4	40	26	0	0	80
High	4	10	3	6	92	100	30	5	250
Very high	4	15	5	8	163	200	40	15	450

Figure 14Domestic Water Use

	Units	Minimum	Maximum	Typical
Residential Suburbs				
High Density, 300 m2 stand area	l/Stand/d	600	1 300	850
Medium Density, 500 m2 stand area	l/Stand/d	700	1 300	900
Low Density, 1 000 m2 stand area	l/stand/d	1 000	2 000	1 200
2 000 m2 stand area	l/stand/d	1 500	3 000	2 000
Flats	l/unit/d	600 (bachelor)	1 200 (family)	900
Hotels	l/bed/d	500	1 500	800
Hospitals	l/bed/d	200	1 500	500
Clinics	1/100 m2 gross floor area/d	500	1 500	1 000
	l/patient/d (alternatively)			15
Dayschools	l/pupil/d	10	60	30
Boarding School	l/boarder/d	50	150	90
Business Zones (up to 2 storeys)	l/hectare/d	10 000	20 000	16 000
Industrial Zones Dry Industries	l/hectare/d	10 000	30 000	20 000
Offices and Shops	l/employee/d	20	40	30
Parks, Nurseries	l/hectare/d	10 000	30 000	20 000
RSS (Rural Standpipe System)	l/person/d	20	80	50

Figure 15: Estimated Daily Water usage patterns in urban areas (SALA Manual)

Provisions are made for commercial or industrial water usage as needed. This means that in addition to the population of an area, land use within the specified area is crucial to estimating the demands of the area. Variations of water usage throughout the day must also be accounted for. There is a need to Identify peak demand periods (e.g., morning and evening) to ensure the system can handle maximum load without compromising service quality.

$$Peak\ hour\ factor = 3 * Average\ Daily\ Demand$$

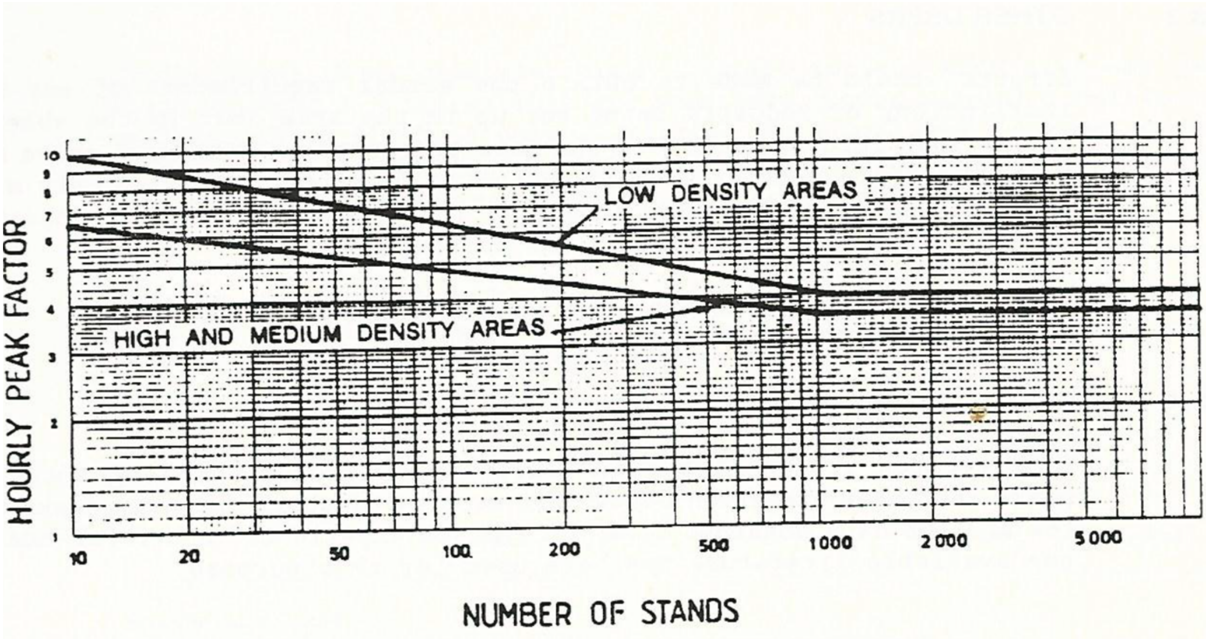

Figure 16: Peak hour factor obtained from the SALA Manual for Hopley using Number of Stands 2,000

	Mean	Standard Deviation
Peak Week Factor		
Zimbabwe cities	1,3	0,06
Zimbabwe towns	1,37	0,12
Peak Day Factor		
Zimbabwe cities	1,47	0,075
Zimbabwe towns	1,61	0,23

Figure 15Peak Daily Factors for Zimbabwe (SALA Manual)

2.15 Firefighting demands

A provision must been made in the design of water reticulation systems for firefighting demands. The SALA Manual stipulates the following Flowrates for urban areas:

- **Large Towns** (Population over 5 000)

Fire flow in outlying areas	7,5 l/s
Densely built areas	15,0 l/s
Minimum mains pressure	12 m
Business and Industrial Areas (Fire flow depending on risk which must be very carefully assessed)	10-40 l/s
Minimum mains pressure	12 m

No building more than 60 m along the street from a hydrant.

Figure 17: Firefighting demands as well as positioning of fire hydrants (SALA Manual)

This will be considered as guidelines for estimating the firefighting demands as well as placement of fire hydrants in the design off the network.

2.16 Residual head

The seller manual stipulates that residual head at the end user residual head at the end user be no less than 10 m for high density areas. The local municipality City of Harare advised that due to budget constraints as well as constraints in the water supply systems (shortages) 2m of head will be sufficient. This results in an overall decrease in cost of the reticulation system smaller pipes are able to be used to meet there is your head requirements.

2.17 Network Design Considerations

There is a need to ensure that water sources (e.g., reservoirs, wells) and storage facilities (e.g., water towers, tanks) are able to meet both current and future demands. Storage should also account for emergency reserves. pipelines must be designed so as to have the capacity to efficiently transport water from sources to consumers. Larger main pipelines distribute water to smaller branch lines. The layout should minimize head loss and ensure consistent pressure for all users regardless of distance from a water tower or pumping station. To aid in this usage of pressure reducing valves should be incorporated into the design of the system. Implementation of pressure zones to maintain adequate water pressure across the network, especially in areas with significant elevation differences. Pressure-reducing valves and booster stations may be required to mitigate the effects of a rapid change in elevation across the area to be served by the water network.(Sharma et al., 2022)

Designing a network with redundancy aids to ensure reliability. This may include looped systems that provide multiple pathways for water to reach consumers, reducing the impact of pipe failures or maintenance activities as well as the issues of stagnant water mentioned in **Section 2.11.**

Expansion Capability: Incorporate flexibility in the design to allow for future expansions. This includes provisions for additional pipeline branches, increased storage capacity, and upgraded pumping stations as well as population growth and emergence of economic activities within the area

2.18 Components of a water Distribution network

i. Isolating valves

Isolating valves (either gate valves or butterfly valves) should be installed to facilitate maintenance of the main and are generally located to suit the topography and isolate practical lengths of mains pipes. These valves may be of lesser diameter than the actual pipeline in order to reduce costs, but care should be taken to ensure that the velocity through the valve is not excessive.

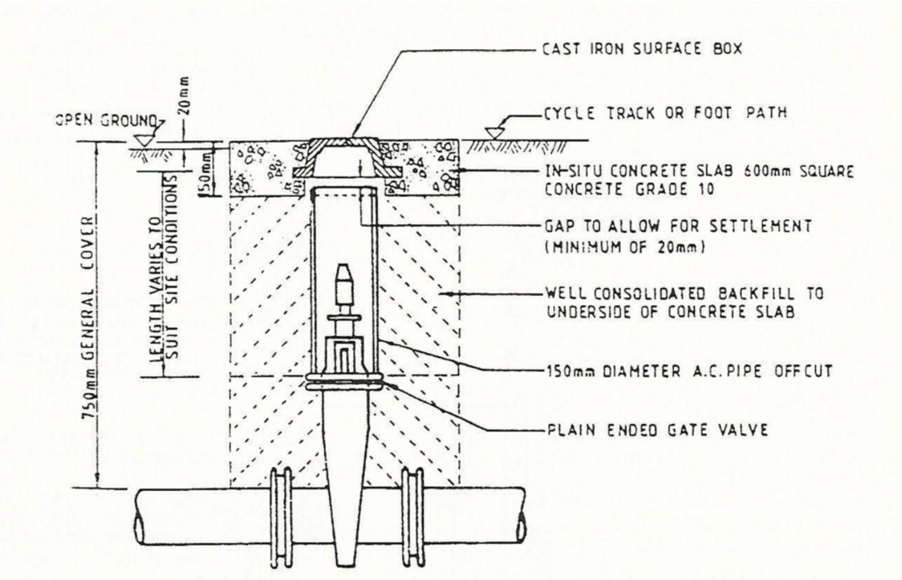

Figure 16: Isolating Valve

ii. Air Valves

Air valves should be provided to discharge air when the main is being filled, and to admit air when it is being emptied. This should also discharge air accumulated at any time. though this is not so important on gravity supplies as on rising mains from pumps. The solubility of air in water rises with the pressure and therefore the general tendency in gravity mains is for the imprisoned air to be dissolved. In rising mains however the tendency is for dissolved air to come out of solution enforcing the need for air valves.

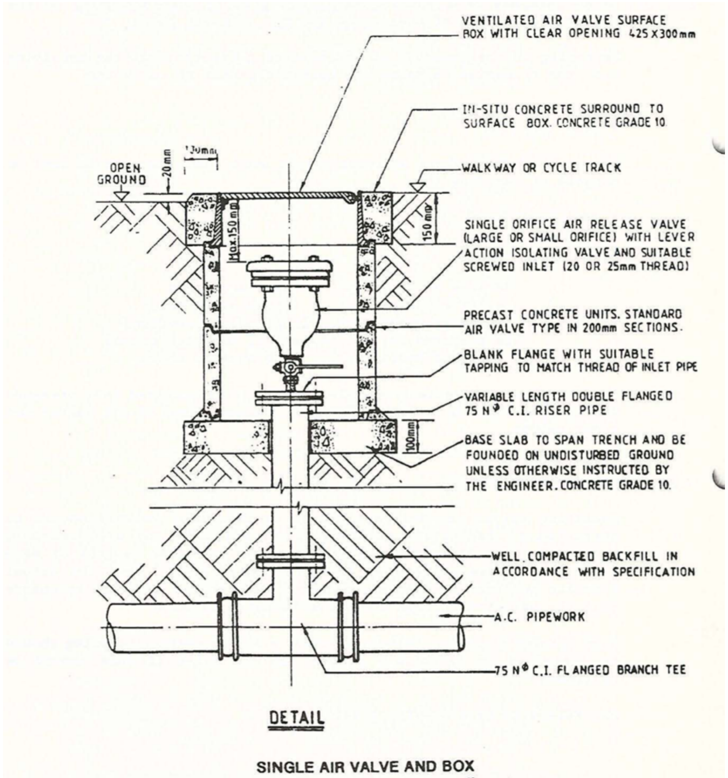

Figure 17:Air Release Valve

iii. Valve chambers

Chambers for isolating, air, and other valves, should provide sufficient working space to allow a spanner to be used on all bolts. Venting of air valve. chambers should allow for adequate air flow, and steps should be taken to prevent ingress of vermin. Roof slabs should be designed to allow for removal and replacement of the valves.

Valve chambers should where possible be finished proud of the finished ground level, and be designed as water retaining structures to remain dry throughout the year. The provision of a sump in one corner of the valve chamber is normally desirable to facilitate collection and removal of water by bucket or pump. Such chambers may be situated at points where smaller pipes branch from the mains pipe to allow for isolation of various sections of the network (which would be crucial in the event of a pipe burst or when scheduled maintenance is required.)

iv. Pressure Reducing Valves

Every effort should be made to design the system in such a way that it is not necessary to use pressure reducing valves. However, should it be necessary to utilise these valves, then the PRV should be provided with a pressure relief valve on the outlet side to prevent the possible built up of pressure which could result from a failure of the PRV to operate correctly.

The discharge from the relief valve should be conspicuous when it occurs. The installation should also be provided with the dirt box upstream of the PRV and a by-pass pipe around the PRV complete with an isolating valve protected against accidental opening.

v. Fire Hydrants

These are hydrants that are installed so as to allow firefighters access to high pressure water in the event of a fire outbreak. As stated above in **Section 2.14** they are to be located no more than 60m apart in urban areas

vi. Stand Connections

The stand connections and communication pipes for connection to dwelling house, These are the connections that allow residential units to connect to the water distribution network. Each household is to have its own stand connection.

vii. Pipes

Cement, steel and several types of plastic are the most commonly used materials for pressure pipelines in Zimbabwe. The suitability of a material for use on a particular pipeline must be taken into account. Internal and external corrosion protection systems for the pipes, joints, fittings and specials must be carefully considered. In selecting the best material, the following factors should be considered:

- The life cycle cost (initial capital plus maintenance costs).
- The chemical composition of the water distributed.
- For example, certain types of pipes may not be advisable for conveying water which has not been sufficient stabilised.
- The corrosion nature of the soil and the possible existence of stray electric currents.
- The structural strength of the pipes.

Cost of Pipe

- Plastic piping is cheaper in the smaller diameters (50 mm and less)
- AC is cheaper from 75 mm upwards
- In all cases steel tubing is the most expensive product

Strength of Pipe

Selection of the pipe with pressure ratings adequate to meet the operating conditions of the system is required. Should a pipe be laid exposed then plastic becomes unsuitable as it is easily damaged by impact forces as well as long term exposure to the sun. for a given diameter steel pipes are the strongest followed by cementious pipes followed by plastic pipes.

Type of Soil

In some instances soil conditions affect the choice of pipe material. For instance acidic soil has the potential to corrode galvanized steel tube, and very rocky soils may damage plastic pipes or cement pipes unless properly bedded in sand (*SALA Manual for Water Reticulation Treatment Storage Zimbabwe*, 1970).

Parameters	GS	PVC	BP	AC
Crushing strength versus superimposed load in trench	Excellent	Fair	Poor	Good
Bursting strength versus internal pressure	Excellent	Good	Good	Excellent
Resistance to corrosion	Poor	Excellent	Excellent	Good
Flow capacity	Fair	Excellent	Excellent	Good
Resistance to external mechanical injury	Excellent	Fair	Poor	Fair
Easy of instal-lation	Easy	Must be handled gently and should normally be buried		
Pipe cost	High	Fair	Fair	Fair
Cost per fitting	Low	High	High	Fair

Figure 18: comparison of pipes of different Materials)

viii. Fittings

These are components of the water distribution network that serve to connect pipes of different diameters, and are installed at junctions or other points where pipes converge or diverge.

3 Methodology

Designing a water reticulation network to serve a population requires a comprehensive approach that considers current and future demands, efficient distribution, reliable service, and sustainability. By integrating demographic data, advanced technologies, and best practices in network design, municipalities can ensure a robust and adaptable water supply system that meets the needs of their communities.

3.1 Data Collection Steps

3.1.1 Study Area

Maps of the study area are provided below.

Figure 19 Map showing positon of Zimbabwe (red) in the African Continent

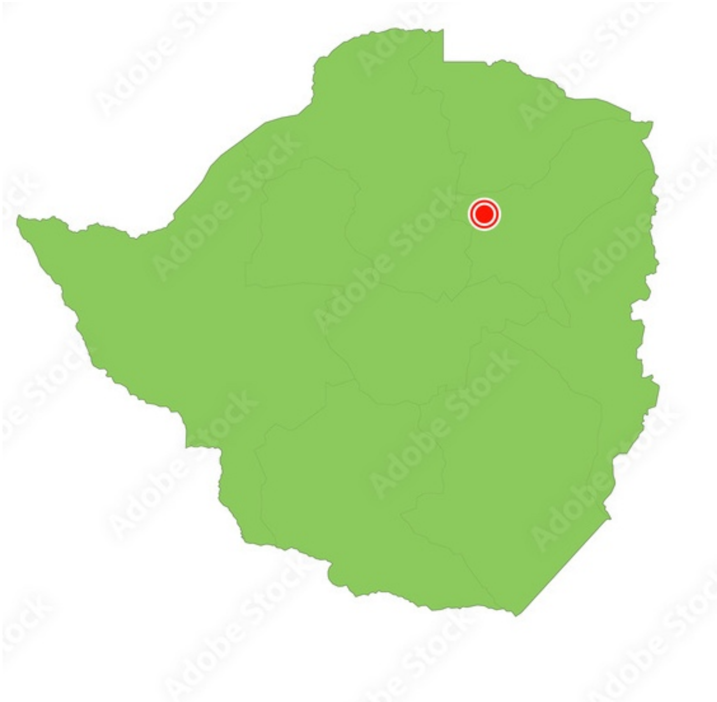

Figure 20 Map showing position of Harare (Red) within Zimbabwe

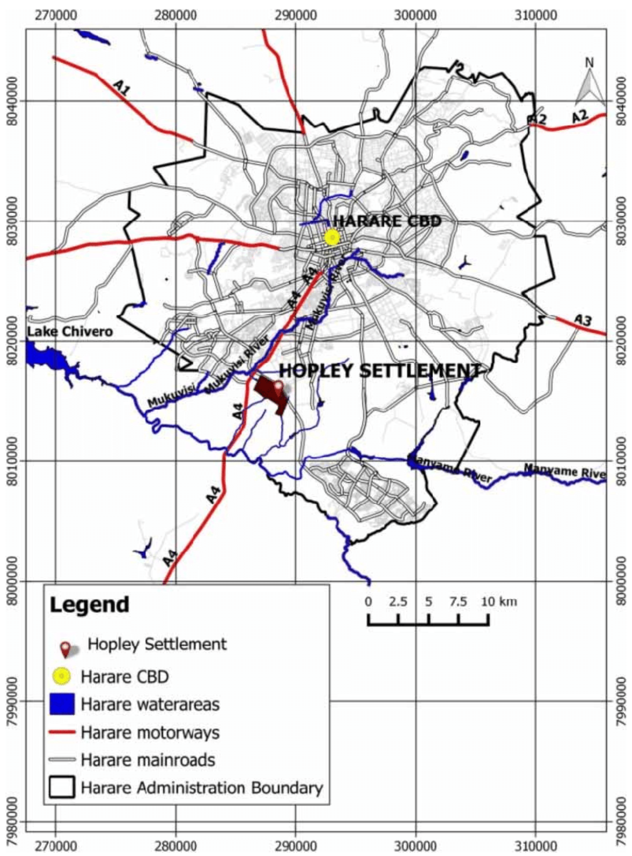

Figure 21 Map showing Hopley Settlement within Harare

3.1.2 Reconnaissance of the general area.

There was need to familiarise with the area. As such a site visit was conducted to gain a better understanding of the area as well. As to meet some of the residents of the suburb. Information concerning water use was also collected. Dissatisfaction with and expectations of the water system by the community were expressed by the residents.

Figure 22:Aerial view of a part of Hopley


Figure 23:Conducting Reconnaissance atop the Water Tower

3.1.3 Population Size of the area

According to data from the Dialogue on Shelter and the Zimbabwe Homeless People's Federation and survey Report the population size of Hopley is approximately 180,000. (Harare Water Department and VEI (Netherlands), 2019).

The scope of this project is to connect approximately 2000 households to municipality water. Data from the above study established an average of 6 residents per household. Design population is therefore

$$P = 2{,}000 * 6 = 12{,}000$$

3.1.4 Number of Households of the area

This was obtained using Data from City of Harare. Maps were available for the area showing stand layout and using QGIS the number of stands in the proposed area (Phase 2) was approximately 2,000.

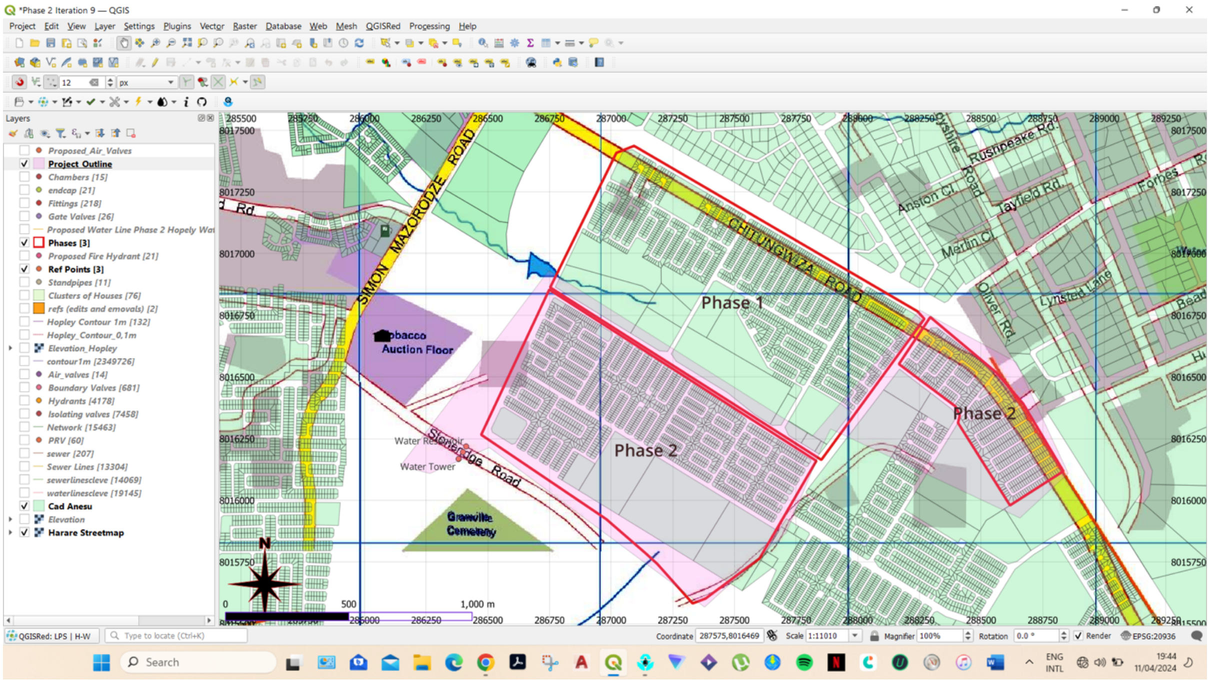

Figure 24QGIS Screenshot showing the Project scope area (PHASE 2 shown above) including the stand layout of the area

3.1.5 Distribution of stands

Stand layout and distribution was obtained from the files of the map of the area provided by City of Harare. Landuse was also available from the data shared by City of Harare. The area covered by the scope of the project was strictly residential use. No commercial or economic activities were sanctioned to take place in the area.

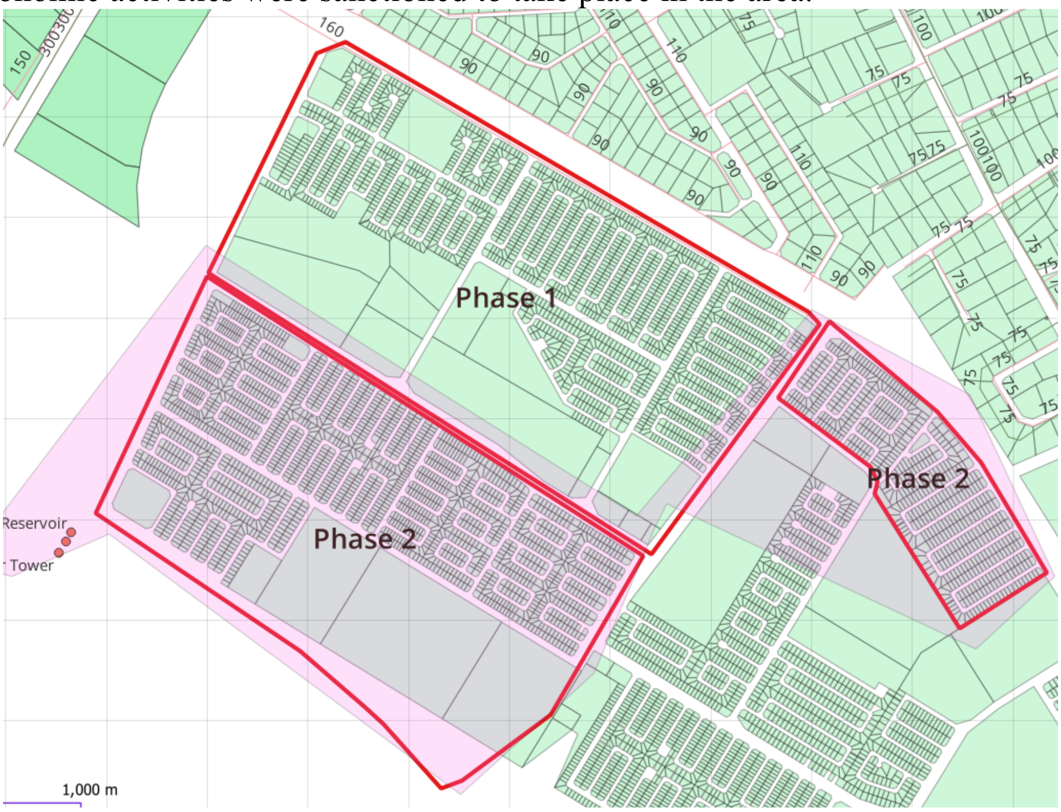

Figure 25: Phase 2 shown above. Stand distribution data obtained from City of Harare

Figure 26: Stands were aggregated into clusters for purpose of building the model

3.1.6 Available and existing infrastructure

Knowledge of the available infrastructure was critical in the design of this water reticulation network. This ensures one does not design for a system with components that are not available. During the visit to the area there is a recently installed Pump station, workshop and Water Tower was constructed by Fidelity Life Assurance which was handed over to City of Harare (the local municipality). The list below summarises the recently installed infrastructure in the area:

- 1ML Water Tower.
- 10ML Water Reservoir.
- Water Pumps x2 (37kW each).
- Diesel Generator (3 phase 200KVA).
- Workshop.
- Control unit for the pumps.
- Power factor correction unit.
- VSD starters x2.
- Spares and equipment stored in the warehouse.


Figure 27: left 1ML Water tower right: 10ML Water Reservoir

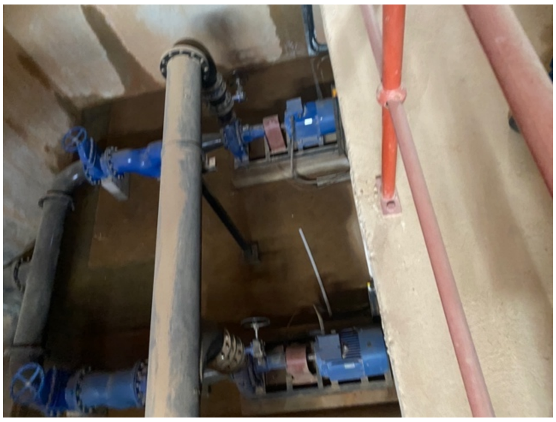

Figure 28: left 2 37kW pumps right : 200KVA generator

Figure 29: Pumps and pipes inside the Pumping Station

Further to this, another mains traversing the northern boundary of the project area were discovered using the QGIS data obtained from city of Harare. There exists a 150mm mains from which water can be abstracted for the northern region of the designed area.

3.1.7 Distances between points and Topography of the area

This was obtained using a Digital Elevation Model (DEM) satellite image provided by City of Harare. Using QGIS one is able to generate contours of the terrain with accuracy of 0,2cm. this elevation data was useful for creation of the model where accurate measurements of the elevation were needed for the reticulation system. Distances were also measured using QGIS

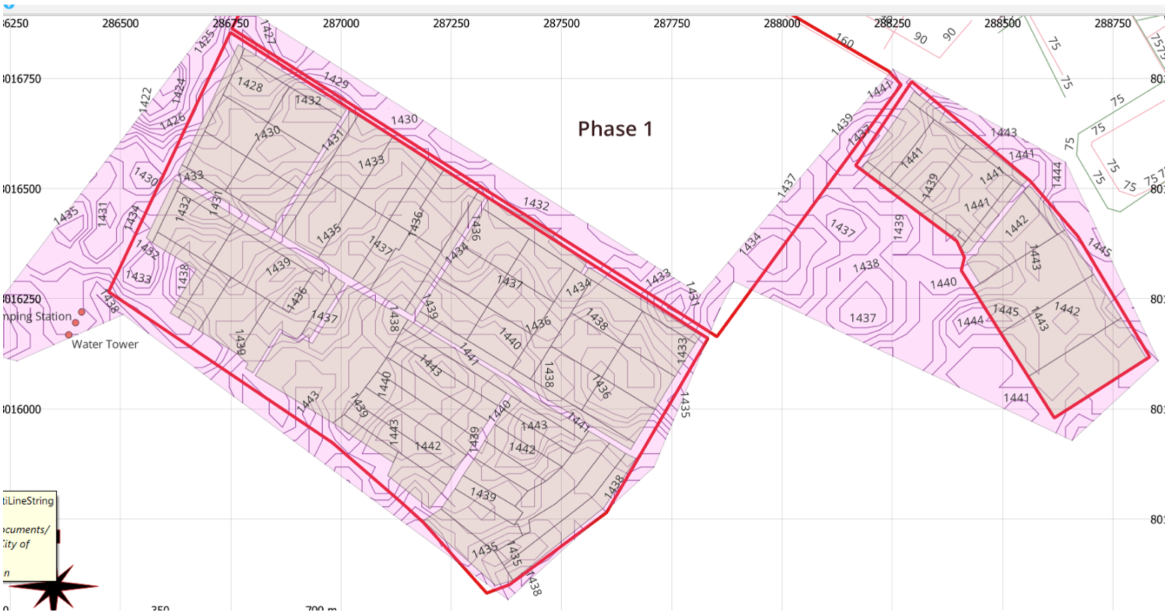

Figure 30: DEM for the project area obtained on QGIS

3.1.8 Selection of pipe materials

Materials the material choice for the project was PVC class 16. The selection was based on cost savings realised through use of the material. The cost of steel and galvanised iron pipes is prohibitive.

Upon request from ProPlastics PVC pipe diameters were provided. These are 90mm, 110mm, 160mm and 300mm PVC pipes. In the design of this reticulation network larger diameter pipes will serve to larger discharges while smaller diameters will serve the regions with smaller discharges. Roughness Coefficients were also provided for the pipes.

3.1.9 Fittings needed

School taps, fire hydrants, gate valves, tees, endcaps, standpipes, elbows, T's and reducers were all needed in the network system. These were placed on the QGIS diagram and included in the BOQ attached in **Appendix 2**

3.1.10 Best practices from COH Department of Water

Consultations with Engineer Kapeta, Engineer Charumbira and Engineer Gore of city of Harare yielded knowledge of the following sets of best practices:

- 90mm pipes were commonly adopted wherever suitable.
- Closed networks are generally preferred to maintain even pressure distribution in a given network.
- A combination of gravity and pumped network is preferred.
- Adopt as few branches from the large diameter as possible. This reduces potential points of weaknesses in a given reticulation system.
- Incorporate air release valve when a pipe suddenly changes direction (from rising to falling).

3.2 Data Analysis

Calculations for population were done on excel. The area was divided into clusters of 30 – 60 households depending on stand distribution on QGIS. The average number of residents per household was 6 (obtained from the Dialogue on Shelter survey on Hopley). To incorporate population growth into the demand the number of residents per household was inputted into the formula for population growth. A design time period of 10 years was used. The growth rate given in **Section 2.13** of 2.82%, thus the formula gave

$$P = P_0 e^{rt}$$

$$P = 6e^{0.0282*10}$$

$$P = 7.954$$

$$(take\ Population\ per\ household = 8\ adjusted\ for\ Population\ growth)$$

The figure of 8 was multiplied by the number of houses per cluster to give the number of residents per cluster (for example cluster 1 has 49 houses and 49 * 8 = 392 residents.

This number of residents per cluster needed to be converted to volumes of water used per day. To do this the number of residents per cluster is to be multiplied by the per capita usage from the SALA Manual. An estimate of 40l/c/d was used for the area from Figure 14 using a figure in-between the very low index of living and the low index of living 24 and 50 l/c/d respectively the average of these figures was 37 and an 8% increase was used to scale the figure closer to the one for the low level of living index of 50l/c/d.

Following the example the water usage adjusted for population growth in Cluster 1 becomes 392 * 40 = 15,680 l/d.

From the SALA Manual a peak hour factor of 3 was chosen (high density area with +2,000 residents). This results in the daily water demand of 47,040 l/d that the system needs to be designed for.

The SALA Manual stipulated a 60m radius for fire hydrants with each hydrant having a flow need of 15l/s. taking an estimate of 900s duration per day we have a firefighting demand of 13,500 l/d for cluster 1 (Cluster 1 has an approximately 60m radius.

The total demand for cluster 1 is the sum of the firefighting demand + usage demand = 60,540l/d capacity that our system must be able to supply. This figure is then converted to l/min by dividing by (60*24)

This process is repeated for all the clusters of the area as shown by an image of the excel sheet provided below:

Subdivision number	Number of houses (Counted on QGIS)	Valve to isoalte	Connected on Qgis	Number of Residents (adjusted for pop growth) = number of houses * 6 * e^0.0282*10	water usage by people = num residents * 40	including PHF = water usage *3	Firefighting Demand = 15 l/s * 900 s	total demand (usage by people + firefighting demand)	demand l/m = demand per day / (60 * 60 * 24)	Elevation inputted (obbtained from QGIS
1	56	y	y	448	17,920	53,760	13,500	67,260	47	1,427
2	49	y	y	392	15,680	47,040	13,500	60,540	41	1,430
3	46	y	y	368	14,720	44,160	13,500	57,660	38	1,430
4	57	y	y	456	18,240	54,720	13,500	68,220	48	1,433
5	57	y	y	456	18,240	54,720	13,500	68,220	48	1,430
6	57	y	y	456	18,240	54,720	13,500	68,220	48	1,432
7	34	y	y	272	10,880	32,640	13,500	46,140	28	1,432
8	65	y	y	520	20,800	62,400	13,500	75,900	54	1,436
9	65	y	y	520	20,800	62,400	13,500	75,900	54	1,434
10	65	y	y	520	20,800	62,400	13,500	75,900	54	1,434
11	65	y	y	520	20,800	62,400	13,500	75,900	54	1,437
12	32	y	y	256	10,240	30,720	13,500	44,220	27	1,437
13	62	y	y	496	19,840	59,520	13,500	73,020	52	1,436
14	32	y	y	256	10,240	30,720	13,500	44,220	27	1,438
15	63	y	y	504	20,160	60,480	13,500	73,980	53	1,439
16	35	y	y	280	11,200	33,600	13,500	47,100	29	1,440
17	26	y	y	208	8,320	24,960	13,500	38,460	22	1,434
18	54	y	y	432	17,280	51,840	13,500	65,340	45	1,436
19	55	y	y	440	17,600	52,800	13,500	66,300	46	1,437
20	56	y	y	448	17,920	53,760	13,500	67,260	47	1,439
21	56	y	y	448	17,920	53,760	13,500	67,260	47	1,440
22	44	y	y	352	14,080	42,240	13,500	55,740	37	1,440
23	44	y	y	352	14,080	42,240	13,500	55,740	37	1,440
24	44	y	y	352	14,080	42,240	13,500	55,740	37	1,440
25	26	y	y	208	8,320	24,960	13,500	38,460	22	1,435
26	44	y	y	352	14,080	42,240	13,500	55,740	37	1,438
27	46	y	y	368	14,720	44,160	13,500	57,660	38	1,438
28	48	y	y	384	15,360	46,080	13,500	59,580	40	1,439
29	52	y	y	416	16,640	49,920	13,500	63,420	43	1,437
30	53	y	y	424	16,960	50,880	13,500	64,380	44	1,437
31	54	y	y	432	17,280	51,840	13,500	65,340	45	1,439
32	43	y	y	344	13,760	41,280	13,500	54,780	36	1,440
33	32	y	y	256	10,240	30,720	13,500	44,220	27	1,432
34	22	n	y	176	7,040	21,120	13,500	34,620	18	1,431
35	27	y	y	216	8,640	25,920	13,500	39,420	23	1,435
36	13	y	y	104	4,160	12,480	13,500	25,980	11	1,434
37	57	y	y	456	18,240	54,720	13,500	68,220	48	1,436
38	36	y	y	288	11,520	34,560	13,500	48,060	30	1,439
39	74	y	y	592	23,680	71,040	13,500	84,540	62	1,440
40	26	y	y	208	8,320	24,960	13,500	38,460	22	1,440
41	27	y	y	216	8,640	25,920	13,500	39,420	23	1,438
42	53	y	y	424	16,960	50,880	13,500	64,380	44	1,439

44	13	y	y	104	4,160	12,480	13,500	25,980	11	1,437
45	37	y	y	296	11,840	35,520	13,500	49,020	31	1,442
46	50	y	y	400	16,000	48,000	13,500	61,500	42	1,443
47	50	y	y	400	16,000	48,000	13,500	61,500	42	1,443
48	50	y	y	400	16,000	48,000	13,500	61,500	42	1,442
49	50	y	y	400	16,000	48,000	13,500	61,500	42	1,442
50	50	y	y	400	16,000	48,000	13,500	61,500	42	1,443
51	50	y	y	400	16,000	48,000	13,500	61,500	42	1,443
52	36	y	y	288	11,520	34,560	13,500	48,060	30	1,443
53	36	y	y	288	11,520	34,560	13,500	48,060	30	1,443
54	34	y	y	272	10,880	32,640	13,500	46,140	28	1,443
55	34	y	y	272	10,880	32,640	13,500	46,140	28	1,441
56	26	y	y	208	8,320	24,960	13,500	38,460	22	1,439
57	34	y	y	272	10,880	32,640	13,500	46,140	28	1,439
58	62	y	y	496	19,840	59,520	13,500	73,020	52	1,440
59	62	y	y	496	19,840	59,520	13,500	73,020	52	1,440
60	59	y	y	472	18,880	56,640	13,500	70,140	49	1,440
61	50	y	y	400	16,000	48,000	13,500	61,500	42	1,439
62	49	y	y	392	15,680	47,040	13,500	60,540	41	1,437
63	34	y	y	272	10,880	32,640	13,500	46,140	28	1,441
64	19	y	y	152	6,080	18,240	13,500	31,740	16	1,443
65	229	y	y	1832	73,280	219,840	13,500	233,340	191	1,442

3.3 Designing the model

3.3.1 Design choices

- Hybrid system of gravity and pumped for the southern section and a pumped system for the northern section.
    - Hybrid offers reliability and adequate pressure. Pumped system chosen for northern section due to complexity of connecting to hybrid system.
    - Southern section to make use of water tower and pumping station facilities.
    - Northern section to make use of already available 150mm mains line running along Chitungwiza Road.
- Use of PVC class 16 pipes of 90, 110, 160 and 300mm diameter
    - PVC chosen due to corrosion. Resistance and cost savings.
    - Class 16 ensures no bursts from excessive pressure.
- Height of water tower was established to be 25m during reconnaissance.

- Demands were calculated for clusters as shown above with each cluster having a pipe that delivers water.
    - Simplifies modelling and allows efficient sizing of pipes.
- Least number of branches from main pipe.
    - Reduces possible points of failures in the system.
- Where there are no clearly defined stands estimations will be made to the number of stands the area may be divided into so as to ensure design capacity allows for future allocation of stands. Communal taps were incorporated into these areas.
- Pipes to be laid in-between houses so as to not disturb existing structures.

Microsoft excel was used to calculate demands.

3.3.2 Use of QGIS

QGIS was extensively used to sketch a preliminary network (not accounting for pipe diameters.) This was done to establish the paths taken by pipes as well as to ascertain the length of spans for pipes within the network. Location of various elements of the network was done using QGIS. The area was divided into two sections with the northern section being section A and the southern section being Section B.

Section A

- Draws its water from the recently installed elevated tower.
- 300mm PVC pipe serves as the main trunk (on the left).
- 110mm PVC pipes serve as larger lines supplying multiple sections.
    - Used as intermediary pipes (large enough diameter to reduce unit head losses while keeping costs reasonably low.
- 90 mm PVC serves to connect individual households and standpipes.
- Choice was made to keep costs relatively low while ensuring the pressure available is high enough.
- Fittings included T's, and elbows.
- Fire hydrants were placed approximately every 60m to enable firefighters regular access points.
- Isolating valves were placed to enable future maintenance on certain sections of the network while allowing the rest of the households to remain connected to water.
- Endcaps were placed at the end of pipes to seal off pipes.
- Individual house connections were placed to connect each stand to the nearest 90mm pipes.
- Choice was made so as to be able to connect phase 1 of Hopley to the water tower to increase water availability in the area.

Section B

- Draws its water from the recently upgraded 300mm main trunk running parallel to Chitungwiza Rd
- Design included a 300mm pipe to serve as the main. This provision enables the connection of the rest of Hopley to the 300mm pipe.

- No public water points as houses were clearly defined and settlements were approved by the municipality.
- Fire hydrants and fittings were installed following procedures identical to those outlined above (Section A)

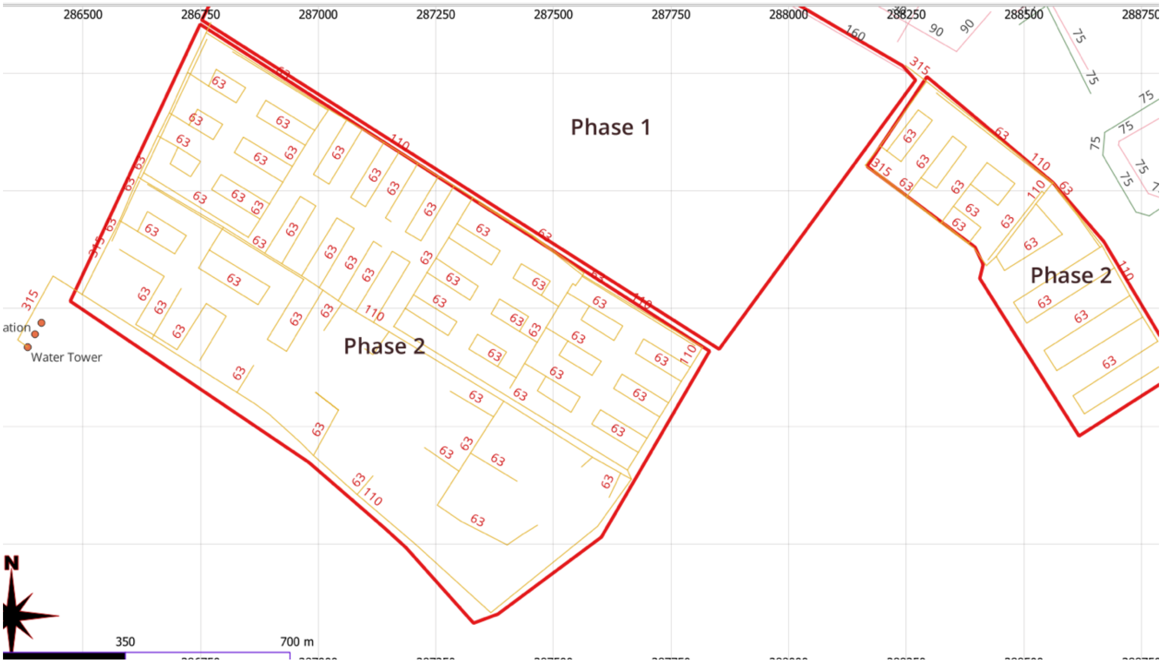

Figure 31: Proposed layout of the water reticulation network. Pipes shown

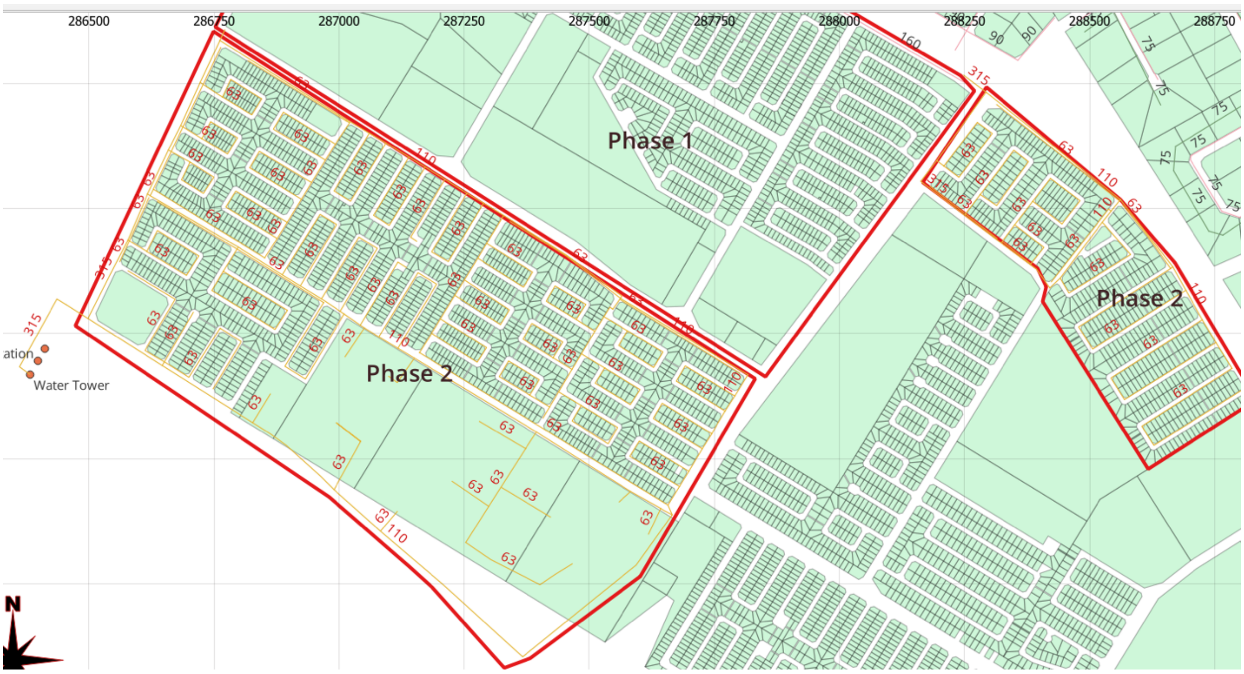

Figure 32: Proposed Pipe layout shown using QGIS.

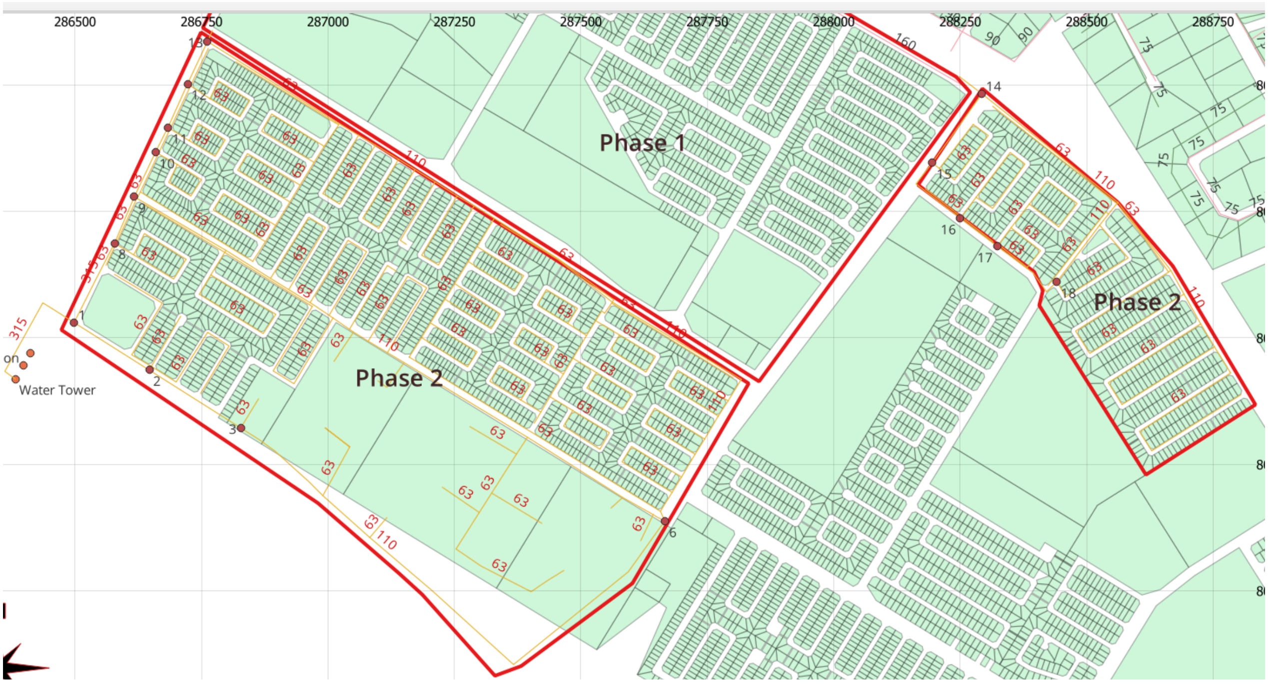

Figure 33: Incorporation of Chambers shown at points where branching of pipes occurs

Figure 34: Location of Endcaps within the Pipe network

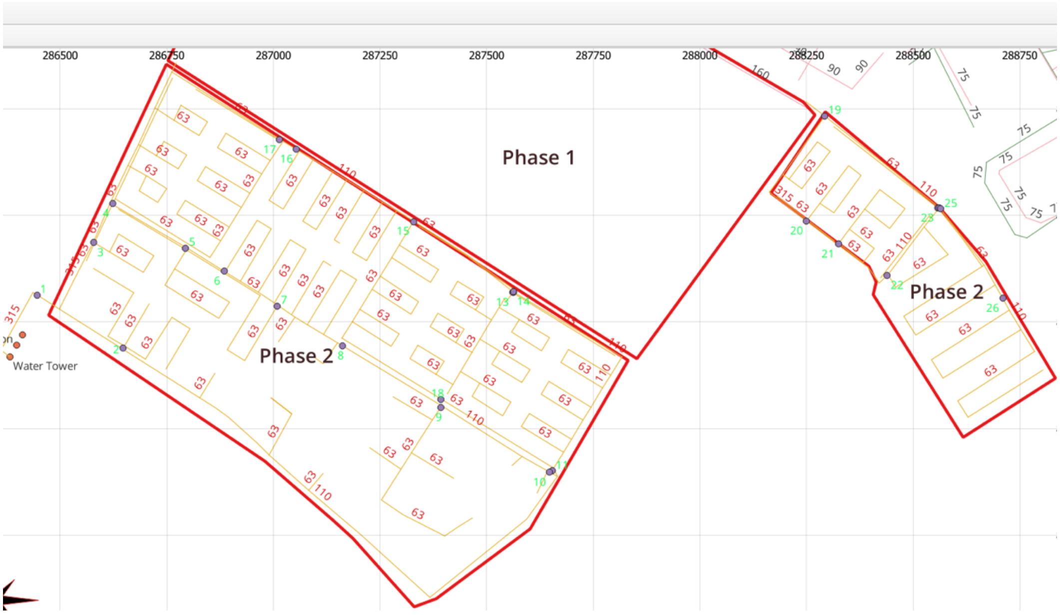

Figure 35: Positioning of Gate Valves within the network

Figure 36: Positioning of Fire Hydrants within the network

Figure 37:Positioning of Standpipes. these allow access to water in areas without formal allocation of stands in the networks

Figure 38:Location of fittings within the network. these include Tees, reducers, and elbows

Figure 39: Location of Air Release Valves. these are primarily located on larger diameter pipes.

3.3.3 Use of EPANET2

Hydraulic design of the model was done using EPANET 2. Data obtained from QGIS, Literature review, surveys, and city of Harare was all needed to create a hydraulic model of the network. This was done to ensure that the network would be able to meet the demands of the residents as well as to ensure adequate service delivery for all users within the scope of the project. Emphasis was on meeting the minimum head for all users while using the most cost-effective solution (smallest diameter pipes and shortest distances.)

EPANET2 required the following input parameters:

Table 2: Input Parameters for EPANET2 components

Component	Input	Output
Junction	• Elevation • Water Demand	• Hydraulic gradient • Pressure
Reservoir	• Hydraulic head	•
Tank	• Bottom elevation • Diameter • Max and min levels	• Hydraulic gradient over time
pipes	• Start and end nodes • Diameter • Length • Roughness coefficient • Status (closed or open)	• Flow rate • Velocity • Headloss • Darcy Weisbach friction factor • Flow rate • Head loss
Valve	• Start and end node • Diameter • status	• flow rate • head loss

The following steps highlight the procedure undertaken during the preliminary network design in EPANET:

i. Layout of pipe network was done using information from reconnaissance and QGIS proposed network layout
ii. Demand estimates had already been calculated incorporating population growth, peak hour factors and firefighting demands
iii. Distribution of demand was done using the clusters (aggregated stands from the QGIS layout).
iv. Demands were placed at end nodes
v. Pipe lengths were obtained from QGIS
vi. Pipe friction factors were obtained from ProPlastics
vii. Relative elevations were obtained from the contours generated on QGIS
viii. Demands were placed at end nodes. There was no demand placed for nodes at junctions as water was assumed to be consumed only at the end nodes.

A sketch of the network was produced in EPANET 2

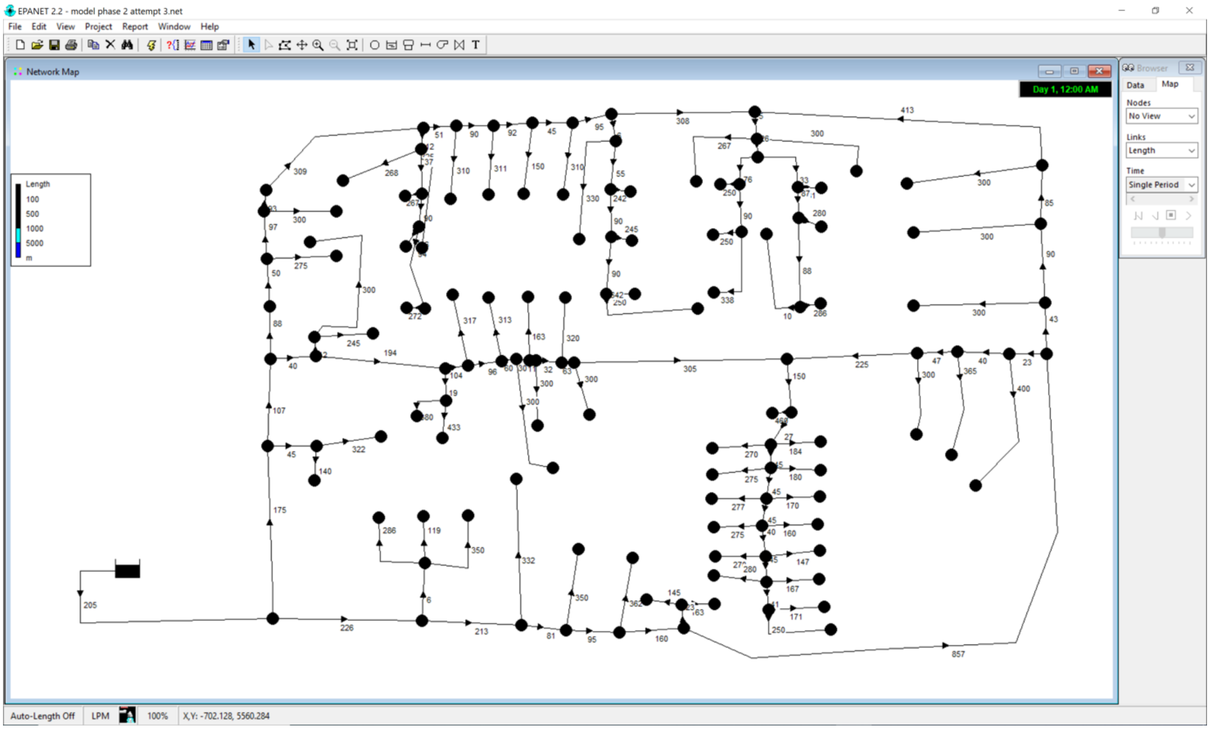

Figure 40:Pipes and their lengths (m) shown in the EPANET Network layout

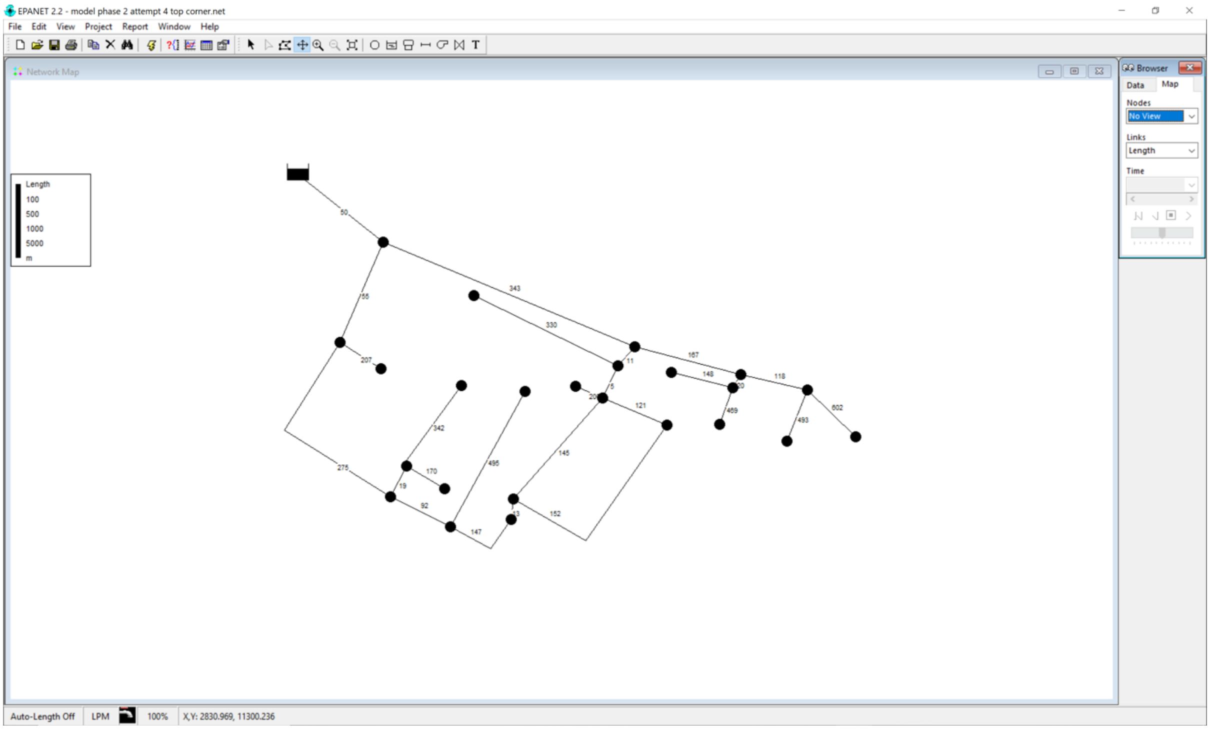

Figure 41: Pipes and their lengths (m) shown in the EPANET Network layout

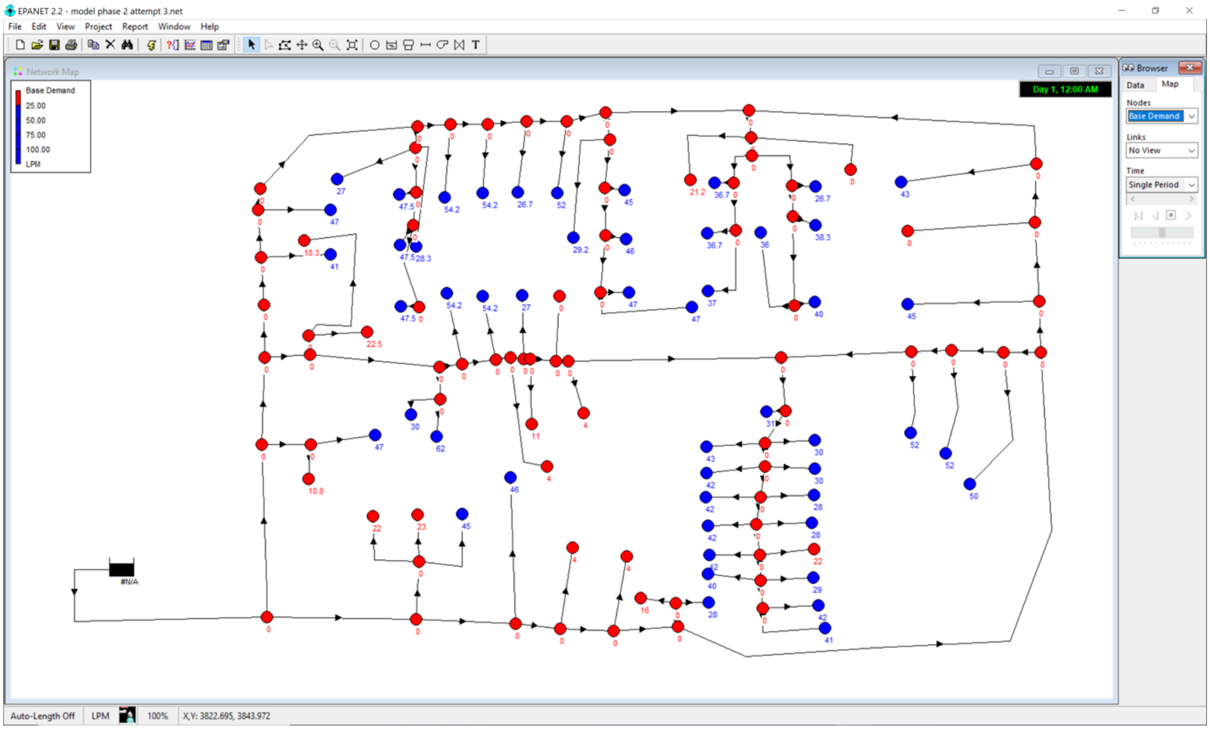

Figure 42: Nodes with their demands (l/min) shown in the EPANET Model

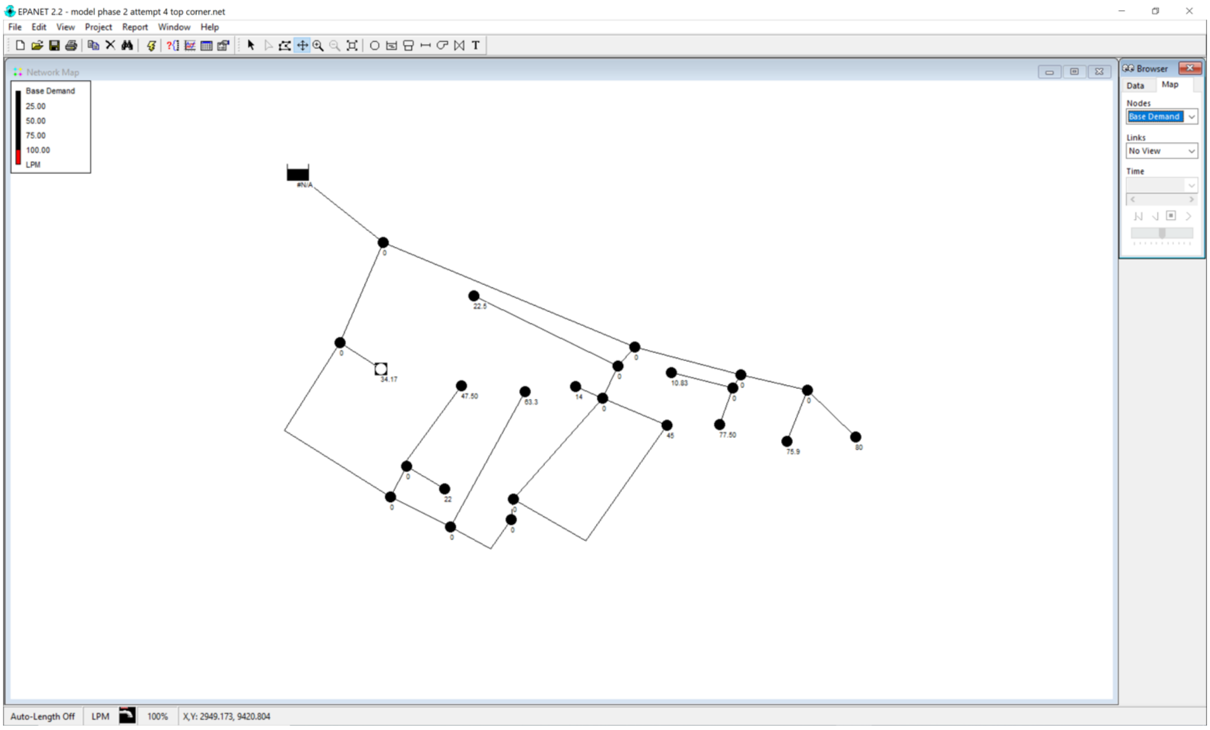

Figure 43: Nodes with their demands (l/min) shown in the EPANET Model

After the layout was drawn with preliminary diameters, hydraulic network simulation was conducted to determine if the network configuration was suitable and satisfactory. The most important parameters processed by the software were:

i. Head loss in each pipe (m)
ii. Rate of head loss (m/km)

iii. Velocities (m/s)

iv. Pressure at each node (m)

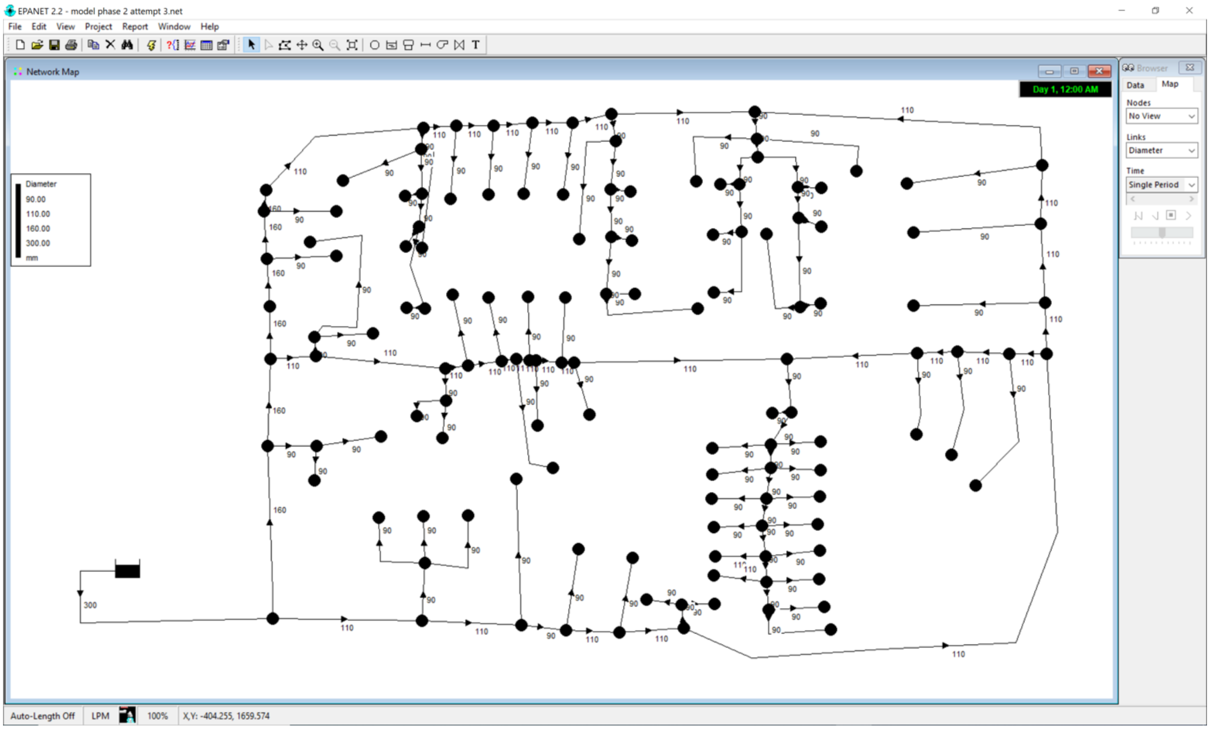

Figure 44: Pipes and their diameters (mm) shown in EPANET

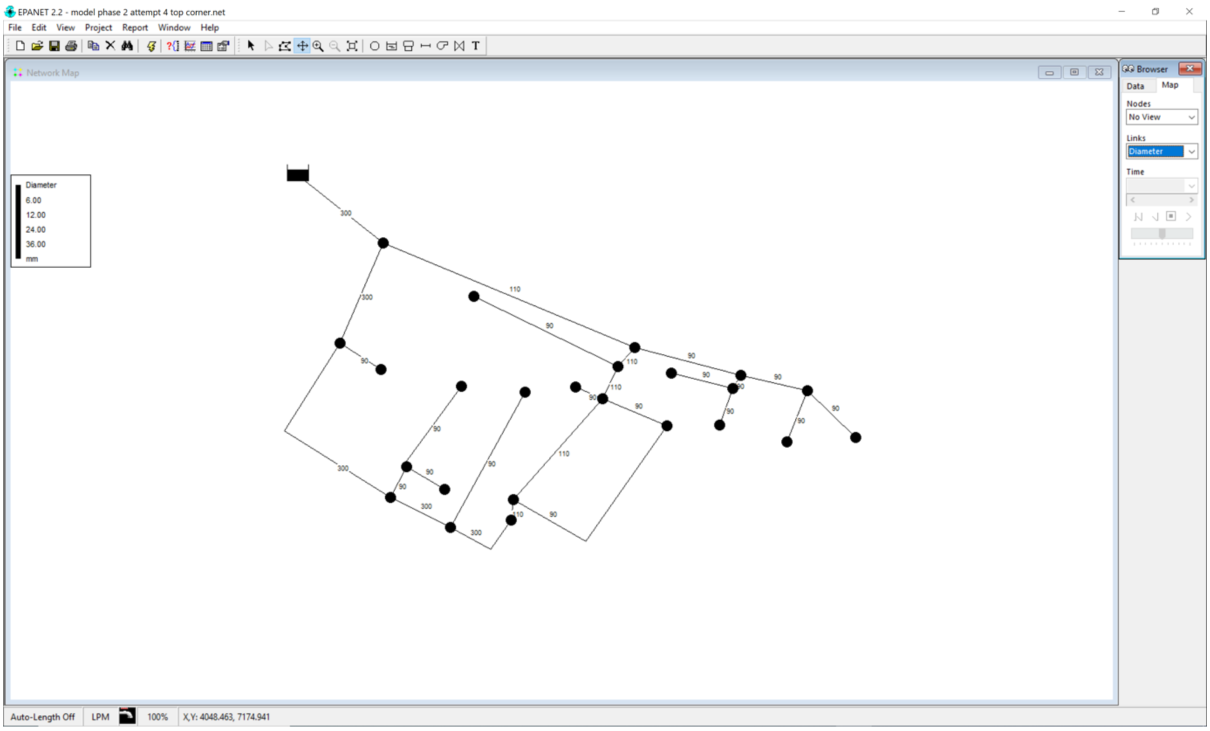

Figure 45: Pipes and their diameters (mm) shown in EPANET

The lines show the pipes. The circles show points of pipe intersection or endpoints at which demand for clusters was placed. It must be noted that the diagram is not to scale as pipe dimensions and roughness coefficients were manually entered for each pipe.

3.4 Bill of quantities

A detailed bill of quantities is required for the proposed network layout. All materials to be used need to be accounted for in their specifications. **Section 3.3.2** shows the various items needed in the reticulation network. Sizes were adjusted to comply with the pipe diameters from the successful hydraulic model from EPANET. In addition to pipes, valves and fittings, quantities of materials required for construction of chambers was also included in the BOQ. A detailed bill of quantities is provided in **Appendix 2.**

4 Results and Discussion

4.1 Results

Detailed results are attached in **Appendix 1.**

i. Section A Node Results are on page 62
ii. Section A Link results are on page 66
iii. Section B Node results are on page 70
iv. Section B Link Results are on page 71

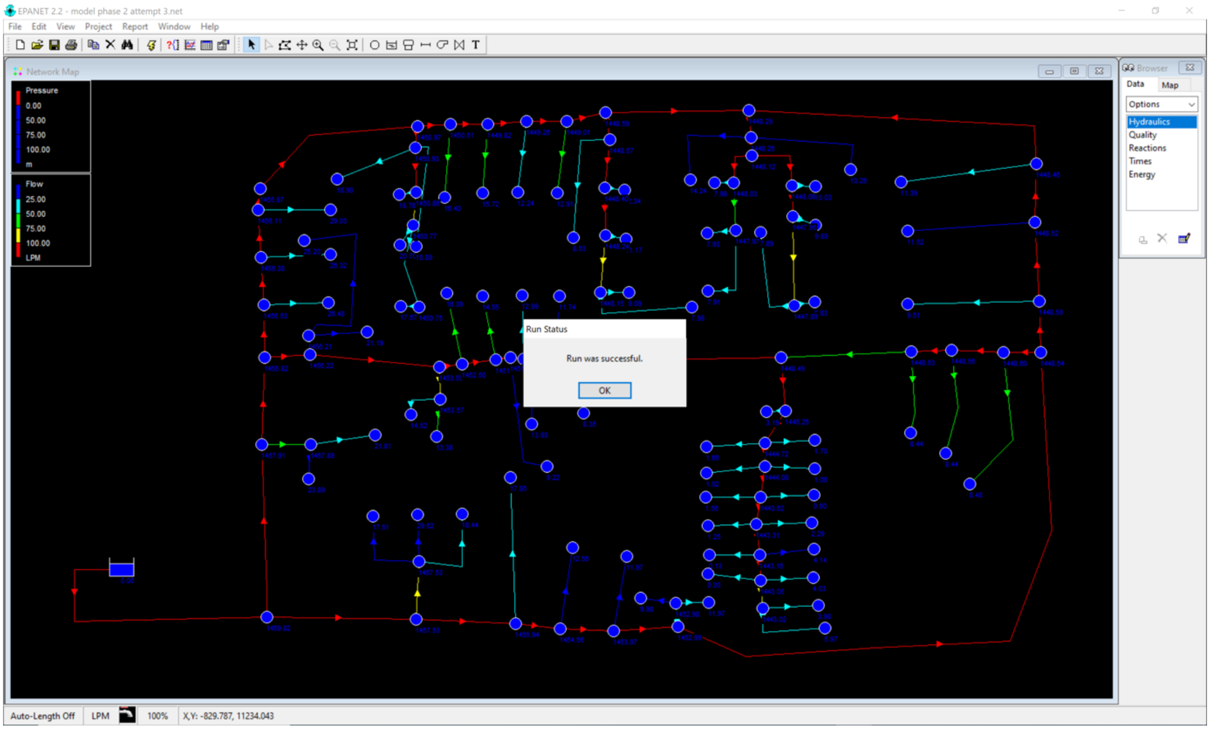

Figure 46: Successful run on EPANET

4.2 Discussion

Under initial conditions (all pipes with 110mm diameter) the hydraulic model failed to meet the nodal demands. Thus, pipe sizing became an iterative process of adjusting pipe diameter for each pipe until satisfactory results were obtained. The aim was to satisfy the demands utilising the smallest number of 300mm pipes to result in cost savings for the network design.

Examination of hydraulic run results was then performed. To be noted from the results were points outside the ranges below:

Parameter	minimum	Maximum
Pressure	7m	70m
Pipe friction head loss	0.5m/km	10m/km
Velocity	0.4m/s	1.5m/s

In addition to achieving a working hydraulic model there was need to ensure that the designed network utilised the least expensive combination of pipes. This meant emphasis was on utilising smaller pipes whenever possible while maintaining functionality of the network without compromising the resultant outputs at the end nodes.

5 Conclusion

This project provides and give access to potable water to at least 14.000 residents of the very low income are of Hopley in Zone 6. This area provides, if the project is implemented well, a huge opportunity for follow-up projects from the Government, City of Harare, Development agencies and NGOs. Moreover, the rest of the settlement including illegal settlers will get access from the 3 public standpipes that will be installed at the district office. It is envisaged that the project will cut out the water vendors and the residents will not have to walk for long distances to obtain water. Cases of water borne diseases are expected to decrease following the implementation of this project. This will result in a higher quality of life for the residents of the area as well as progressing towards the SDG's, MDG's and the City of Harare's aim to achieve a "World class city by 2025".

6 Recommendations

The reticulation network designed has a service life of 10 years, however it is advised to adopt an active maintenance policy. The network should be monitored using flow measuring sensors as well as pressure sensors. This will aid in identification of potential issues that may arise during the service life of the network. Use of ultrasonic flow and pressure sensors that send data from a remote location can be used to allow monitoring of the system from the offices. Periodic inspection of network components will also ensure potential faults are identified before they occur and disrupt the network.

The use of EIA (Environmental Impact Assessment) techniques is important before commencement of the project in order to establish communication with the people from the targeted area.

Need for Water Conservation:
Promotion of water conservation practices will aid to reduce demand and extend the service life of the network. This includes but is not limited to public awareness campaigns and incentives for using water-efficient appliances.

Water Quality & Quantity:
Water supply in Harare is currently under extreme stress with large areas receiving little to no water. From a technical point of view, it is possible to get water into Hopley as it is connected to and situated close to a large reservoir that receives water roughly 5 days per week, directly from the main pumping station. However, it means that implementation of this project less water will be available for other residents and water rationing will become tighter in other areas. From an equity point of view this not a reason to not supply water to the Hopley residents, as they are already for 14 years without a piped water supply making the area a high-risk area in terms of water born outbreaks.

Since the water supply of Harare is in a state of emergency several proposals have developed to increase the water production from the current 230 ML/day (or 230.000 m3/day) to about 450 ML/day through improvements in the water treatment, reduce physical losses and also reduce the risk of contamination of shallow wells. Amongst others a proposal to the Dutch government and the World Bank was submitted with a value of $2.6 million. (Harare Water Department and VEI (Netherlands), 2019)

Water is provided by the City of Harare and water quality is reported towards WHO and local standards. Harare Water carries out water tests at source and periodic reviews are done in the distribution system as well. Quality assurance tests also take place at the tap on a few selected households in the city. Harare Water Department will identify a household where periodic tests will be done to ensure that the residents are receiving good quality water all the time.

Sustainability:

Hopley is a district within Harare City Council boundaries and it has recently been awarded district status by the local authority management. This will greatly improve in the development of the area since all issues will be handled at local level. The scope of this project will not be able to provide all properties with water connections/sanitation, however, this project is viewed as an initial big step forward in terms of development in the area. For years, residents in Hopley have been relying on borehole water. No significant interventions have been made to improvements in the water and sanitation systems and this has left residents more reliant on underground water.

Financial Sustainability:
All of the 2.000 households are going to be provided with a water meter that will be been donated by the Harare Department of Water, which is not common as new customers normally pay for a new water meter and connection materials. The households are already registered on the customer database for City of Harare and they are currently receiving a bill for property charges of 9 Zimdollar (or USD 0,50) per month. The residents of Hopley have indicated in interviews conducted by Dialogue on Shelter (NGO) that they are willing and able to pay for water usage that is expected to be at 18 Zimbabwean dollar (=1 USD) per month, this is underlined by the fact that many have already subscribed for a water connection and are willing to pay for the connection fee. The city is developing a platform for low-income earners to periodically pay their bills within the billing month.

It is envisaged that the residents of Hopley will be able to pay for water usage and the local authority has devised a payment plan for the connection fees which is affordable. Expenditure figures in the area are showing that much of their income is used to buy food which gives an indication that wellness expenses are not compromised.(Harare Water Department and VEI (Netherlands), 2019)

Institutional Sustainability:
the Harare Water Department will integrate the new infrastructure into their asset database and assume responsibility for future maintenance. The City of Harare recently established a new district office in the project area so that residents can also make enquires and pay their bills, so that they are not forced to walk to other district offices.

Environmental Sustainability:
The reticulation network will follow the existing gravel road network so no resettlement of houses or shops is foreseen. Through investing in quality materials, the technical lifetime of assets will be longer and thus environmental impact lower.

The awareness activities will emphasize rational water use and safe water where possible. This will save costs and lower the water footprint.

The awareness campaigns will focus on the importance to construct lined pit latrines so that the wastewater cannot infiltrate to the ground water aquifer. The community will also be educated on water conservation, environmental sustainability and hygiene issues.

Technological Sustainability:
All materials will be procured according to the local procurement rules for which the South African SABS standard or equivalent (ISO norm) are used. This ensures a long technical lifetime and requires less maintenance (on e.g., the working of valves) and less repairs. Furthermore, Harare Water Department will get support on how to install materials according to the requirements (e.g., regarding minimum depth), to prevent any problems which are avoidable by good installation. Best practices in operation & maintenance will be demonstrated by VEI experts.

Social sustainability:
An important part of the proposed project is to stimulate social sustainability through awareness campaigns and community involvement to create awareness about hygiene, proper use of safe water and willingness to pay, stipulating the different payment modalities, as for example cash at the counter, mobile payments or other. This enables specifically the poor to access centrally supplied water, for example to pay in small parts. These campaigns specifically target the poor underserved and women, as they play a crucial role in decision-making and family management(Shoko Bartha, 2018).

Payment modalities, such as partial payments, will be introduced for residents in the project area to reduce the burden for the administrative connection fees. Also, three standpipes will be constructed for residents living outside the project area so that they at least get access to safe water from the piped water system.

7 Bibliography

Amnesty International. 2010. No Chance to Live: New-born Deaths at Hopley Settlement, Zimbabwe. London: Amnesty International.

Bendix, A. 2019. African Cities are Running out of Water, and the Continent Needs Almost R1 Trillion to Avoid a Crisis of Disease and Dehydration [Online]. 2020. https://www.businessinsider.co.za/african-cities-water- crisis-2019-3?r=US&IR=T

Anna Kahumulo Tibaijuka. (2007). Manual on the Right to Water and Sanitation. *Centre on Housing Rights and Evictions,* .

CF Schutte, & WA Pretorious. (1997). Water demand and pop forecasting. *Water South Africa*, *23*, 127–145.

Chenje M., Sola L., and Paleney D., (1996), The State of Environment Government of Zimbabwe Ministry of Mines, Environment and Tourism MET Report, Harare. Gary A, (1991), Conservation of Natural Resources, Klee Prentice Hall, Englewood Cliffs, New Jersey

City of Harare. 2012. City of Harare Strategic Plan 2012–2025. Harare: City of Harare.

City of Harare. 1999. Local Development Plan No. 31: Southern Incorporated Areas. Harare: City of Harare.

Dignity (UN Human Rights (UNHR)) www.chor.orgVENVissues/water.aspx-03-03-21

Government of Zimbabwe. 2013. Constitution of Zimbabwe Amendment (No 20). Harare: Government of Zimbabwe.

Harare Water Department and VEI (Netherlands). (2019). *Dialogue on Shelter and the Zimbabwe Homeless People's Federation Hopley Settlement Profile & Survey Draft Report*.

How the Urban Water Cycle Works. (n.d.). Retrieved March 8, 2024, from https://www.sehinc.com/news/how-urban-water-cycle-works

http://www.internationalcitiesofpeace.org/cities-listing/dangamvura-zimbabwe23-03-21, 2100hrs

Jacobsen et al. 2012 'Into the Water in African Cities: Why drinking Water?'

James. A. Christenson & Jerry. W. Robinson, Iowa State University, Community Development in perspective.

Jones Rachael. (2015). United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. *Sustainability for the 21st Century*, *22*, 4. https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

Joye, D.D., and B.C. Barrett, "The tank drainage problem revisited: do these equations actually work ? ," Can. J. Chem. Eng., 81, 1052 (2003)

Lewis A. Rossman, Water Supply and Water Resources Division, National Risk Management Research Laboratory (2000), EPANET 2 User's Manual

Mackenzie. L. Davis & David. A. Comwell (2013), Introduction to Environmental Engineering, 5' Edition, McGraw-Hill.

Manzungu E., (2002), Managing Common Property in an age of Globalisation: Zimbabwean Experiences, Harare, Weaver Press.

Mazbhelli. (2023). *UNFPA World Population*. https://www.unfpa.org/swp2023

Mazbhelli j, Jones, K., Rafagh, Q., & Smiranh, G. (n.d.). *THE 17 GOALS | Sustainable Development*. Retrieved March 8, 2024, from https://sdgs.un.org/goals

Mehta, B. E., & Dastur, A. (2008). Approaches to Urban Slums. In *World Bank Institute Resources*. The World Bank. https://doi.org/doi:10.1596/978-0-8213-7354-5

Mekambe, H., Janeku, U., Osima, F., & Moyes, A. (n.d.). *Millennium Development Goals (MDGs) | African Development Bank Group*. Retrieved March 8, 2024, from https://www.afdb.org/en/topics-and-sectors/topics/millennium-development-goals-mdgs#

Millennium Development Goals (MDGs) | African Development Bank Group. (n.d.). Retrieved 8 March 2024, from h9ps://www.afdb.org/en/topics-and-sectors/topics/millennium- development-goals-mdgs#

Nancy Phillips, Groundwater and Surface Water, Understanding the interaction, A guide for Watershed Partnerships, 2nd edition.

National Development Strategy 1 (2021-2025) | veritaszim. (n.d.). Retrieved March 8, 2024, from https://www.veritaszim.net/node/4583

Ncube I, & Manhu, A. (2017, January 1). *Zimbabwe Congress of Trade Unions, 2017*. http://www.zctu.co.zw/

Nicolini, M. & Zovatto, L. 2009 Optimal location and control of pressure reducing valves in water networks. Journal of Water Resources Planning and Management 135, 178-187

Puja s;, Rhamid, j;, & Smith, F. J. (1988). Environmental Manual for Vector Control Training and Information Materials. *Training and Information Material Series for the World Health Organisation*, *2*. https://iris.who.int/bitstream/handle/10665/69487/vectcont_2_eng.pdf?sequence=2&isAllowed=y

SALA Manual for Water Reticulation Treatment Storage Zimbabwe. (1970).

Savic, D. A. & Walters, G. A. 1997 Genetic algorithms for least cost design of water. Journal of Water Resources Planning and Management 123, 67-77.

Sharma, V., Tyagi, S., Rastogi, S., Kumar, K., Siddiqui, M. A., Kumar, M., & Supervisor,]. (2022). Comparison Review of Methods of Water Distribution System For Efficient Water Supply. *International Journal of Mechanical Engineering*, *7*(5), 974–5823.

Shoko Bartha. (2018). *UNFPA Zimbabwe | Hopley infrastructure project empowers young women*. https://zimbabwe.unfpa.org/en/news/hopley-infrastructure-project-empowers-young-women#

Tevera D.and Moyo S., (2000), Environmental Security in Southern Africa, SAPES Books,

THE 17 GOALS | Sustainable Development. (n.d.). Retrieved 8 March 2024, from h9ps://sdgs.un.org/goals

The Water Wheel, (2007), Institute of Water Management of Southern Africa, Volume 6, Number 3 May/June, South Africa.

United Nations General assembly 2021 (www.un.org.waterforlifedecade/_right_to_water.shtml13-03-21)

United Nations. 2018. Sustainable Development Goal 6 Synthesis Report 2018 on Water and Sanitation. New York: United Nations

WHO and UNICEF (World Health Organization and the United Nations Children's Fund). 2017. Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. Geneva: WHO and UNICEF.

United Nations Task Team. (2015). *United Nations: HABITAT III ISSUE PAPERS 22-INFORMAL SETTLEMENTS*.
http://mirror.unhabitat.org/downloads/docs/11991_1_594827.pdf

The right to water and sanitation toolkit, fact sheet No. 35 www.chor.org/EN/Issues/ESCR/Pages/water.aspx -03/03/21- 1500hrs, Zimbabwe National Water Policy. 2012.

Zimbabwe Report, 2010, Water Resource Management, Supply and Sanitation

8 Appendices

8.1 Appendix 1: EPANET Results

8.1.1 Section A

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**********************************************************************
*                          E P A N E T                               *
*                  Hydraulic and Water Quality                       *
*                  Analysis for Pipe Networks                        *
*                         Version 2.2                                *
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Input File: model phase 2 attempt 3.net

Project Summary
Summary of the Results obtained after successful run

Link - Node Table:

Link ID	Start Node	End Node	Length m	Diameter mm
Pipe-1	fit-67	fit-68	93	160
Pipe-2	fit-68	fit-69	97	160
Pipe-4	fit-70	fit-71	88	160
Pipe-5	fit-71	fit-72	107	160
Pipe-7	fit-72	fit-73	175	160
Pipe-8	fit-73	R-1	205	300
Pipe-9	J-1	fit-68	300	90
Pipe-10	J-2	fit-69	275	90
Pipe-11	fit-69	fit-70	50	160
Pipe-12	J-3	fit-70	257	90
Pipe-14	fit-75	J-35	245	90
Pipe-16	J-37	fit-74	322	90
Pipe-17	fit-74	fit-72	45	90
Pipe-18	fit-74	J-36	140	90
Pipe-19	J-38	fit-78	380	90
Pipe-20	fit-78	J-39	433	90
Pipe-21	fit-78	fit-79	19	90
Pipe-23	fit-77	fit-75	12	90
Pipe-24	fit-77	fit-79	194	110

Pipe-25	fit-79	fit-80	104	110
Pipe-26	J-8	fit-80	317	90
Pipe-27	J-11	fit-81	313	90
Pipe-28	fit-80	fit-81	96	110
Pipe-29	fit-81	fit-83	60	110
Pipe-30	fit-83	fit-82	30	110
Pipe-31	fit-82	J-14	163	90
Pipe-32	fit-85	J-15	320	90
Pipe-33	fit-82	fit-84	11	110
Pipe-34	fit-84	fit-85	32	110
Pipe-35	fit-85	fit-86	63	110
Pipe-36	fit-76	fit-90	23	110
Pipe-37	fit-90	fit-89	40	110
Pipe-38	fit-89	fit-88	47	110
Pipe-39	fit-88	fit-87	225	110
Pipe-40	fit-87	fit-86	305	110
Pipe-41	fit-88	J-58	300	90

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Link - Node Table: (continued)

Link ID	Start Node	End Node	Length m	Diameter mm
Pipe-42	fit-89	J-59	365	90
Pipe-43	fit-90	J-60	400	90
Pipe-44	fit-87	fit-91	150	90
Pipe-45	fit-91	J-45	460	90
Pipe-46	fit-91	fit-92	27	90
Pipe-47	fit-92	fit-93	45	90
Pipe-48	fit-93	fit-94	45	90
Pipe-49	fit-94	fit-95	45	90
Pipe-50	fit-95	fit-96	40	90
Pipe-51	fit-96	fit-97	45	90
Pipe-52	J-46	fit-92	270	90
Pipe-53	fit-92	J-52	184	90
Pipe-54	J-47	fit-93	275	90
Pipe-55	fit-93	J-53	180	90
Pipe-56	J-48	fit-94	277	90
Pipe-57	fit-94	J-54	170	90
Pipe-58	J-49	fit-95	275	90
Pipe-59	fit-95	J-55	160	90
Pipe-60	J-50	fit-96	270	110
Pipe-61	fit-96	J-56	147	90
Pipe-62	J-51	fit-97	280	110
Pipe-63	fit-97	J-57	167	90

Pipe-65	fit-100	fit-99	85	110
Pipe-66	fit-99	fit-98	90	110
Pipe-67	fit-98	fit-76	43	110
Pipe-68	J-31	fit-98	300	90
Pipe-69	J-30	fit-99	300	90
Pipe-70	J-29	fit-100	300	90
Pipe-72	J-6	fit-103	267	90
Pipe-73	fit-106	J-4	272	90
Pipe-74	fit-105	J-5	266	90
Pipe-75	fit-105	fit-106	94	90
Pipe-76	fit-105	fit-103	90	90
Pipe-80	fit-108	J-7	325	90
Pipe-81	fit-67	fit-109	309	110
Pipe-82	fit-109	fit-110	51	110
Pipe-83	fit-110	fit-111	90	110
Pipe-84	fit-111	fit-112	92	110
Pipe-85	fit-112	fit-113	45	110
Pipe-86	fit-110	J-9	310	90
Pipe-87	J-10	fit-111	311	90
Pipe-88	fit-112	J-12	150	90
Pipe-89	J-13	fit-113	310	90
Pipe-90	fit-113	fit-114	95	110
Pipe-91	J-16	fit-115	330	90
Pipe-92	fit-115	fit-114	6	90
Pipe-93	fit-116	fit-117	90	90

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Link - Node Table: (continued)

Link ID	Start Node	End Node	Length m	Diameter mm
Pipe-94	fit-117	fit-118	90	90
Pipe-95	fit-118	fit-115	55	90
Pipe-96	fit-118	J-18	242	90
Pipe-97	fit-117	J-19	245	90
Pipe-98	fit-116	J-20	250	90
Pipe-99	fit-116	J-21	642	90
Pipe-100	J-34	fit-75	300	90
Pipe-101	fit-114	fit-119	308	110
Pipe-104	fit-120	J-17	267	90
Pipe-105	fit-119	fit-120	5	90
Pipe-106	J-24	fit-122	250	90
Pipe-107	J-23	fit-123	250	90
Pipe-110	fit-123	fit-122	90	90
Pipe-111	fit-122	fit-121	76	90

Pipe-112	J-28	fit-125	286	90
Pipe-113	fit-126	J-27	280	90
Pipe-114	fit-127	J-26	281	90
Pipe-115	fit-125	J-32	10	90
Pipe-116	fit-125	fit-126	88	90
Pipe-117	fit-127	fit-126	87	90
Pipe-118	fit-127	fit-121	33	90
Pipe-119	fit-120	J-25	300	90
Pipe-121	J-61	fit-128	171	90
Pipe-122	fit-130	fit-76	857	110
Pipe-123	J-64	fit-131	145	90
Pipe-124	fit-131	J-63	163	90
Pipe-125	fit-131	fit-130	23	90
Pipe-127	J-40	fit-135	286	90
Pipe-128	J-41	fit-135	119	90
Pipe-129	J-42	fit-135	350	90
Pipe-130	fit-73	fit-136	226	110
Pipe-131	fit-136	fit-135	6	90
Pipe-132	fit-137	J-43	332	90
Pipe-133	fit-130	fit-139	160	110
Pipe-134	fit-139	fit-138	95	110
Pipe-135	fit-138	fit-137	81	90
Pipe-136	fit-137	fit-136	213	110
Pipe-137	fit-84	J-44	300	90
Pipe-138	fit-138	J65c	350	90
Pipe-139	fit-139	J65d	362	90
Pipe-140	fit-86	J65b	300	90
Pipe-141	fit-83	J65a	300	90
Pipe-143	fit-128	fit-97	41	90
Pipe-144	J-22	fit-123	338	90
Pipe-145	fit-108	fit-109	12	90
Pipe-146	J-33	fit-108	268	90
Pipe-147	fit-108	fit-103	37	90

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Link - Node Table: (continued)

Link ID	Start Node	End Node	Length m	Diameter mm
Pipe-148	fit-120	fit-121	26	90
Pipe-149	fit-119	fit-100	413	110
Pipe-150	fit-128	J-62	250	90
Pipe-3	fit-71	fit-77	40	110

8.1.1.1 Section A Node Results:

Node ID	Demand LPM	Head m	Pressure m	Quality
J-1	47.00	1456.03	29.03	0.00
J-2	41.00	1456.32	26.32	0.00
J-3	38.00	1456.48	26.48	0.00
J-4	47.50	1450.67	17.67	0.00
J-5	47.50	1450.70	20.70	0.00
J-6	47.50	1450.78	18.78	0.00
J-7	28.30	1450.89	18.89	0.00
J-8	54.20	1452.39	16.39	0.00
J-9	54.20	1450.40	16.40	0.00
J-10	54.20	1449.72	15.72	0.00
J-11	54.20	1451.55	14.55	0.00
J-12	26.70	1449.24	12.24	0.00
J-13	52.00	1448.91	12.91	0.00
J-14	27.00	1450.99	12.99	0.00
J-15	0.00	1450.74	11.74	0.00
J-16	29.20	1448.53	8.53	0.00
J-17	21.20	1448.24	14.24	0.00
J-18	45.00	1448.34	12.34	0.00
J-19	46.00	1448.17	11.17	0.00
J-20	47.00	1448.09	9.09	0.00
J-21	47.00	1447.98	7.98	0.00
J-22	37.00	1447.91	7.91	0.00
J-23	36.70	1447.93	7.93	0.00
J-24	36.70	1447.98	7.98	0.00
J-25	0.00	1448.26	13.26	0.00
J-26	26.70	1448.03	10.03	0.00
J-27	38.30	1447.89	9.89	0.00
J-28	40.00	1447.83	8.83	0.00
J-29	43.00	1448.39	11.39	0.00
J-30	0.00	1448.52	11.52	0.00
J-31	45.00	1448.51	9.51	0.00
J-32	36.00	1447.89	7.89	0.00
J-33	27.00	1450.90	18.90	0.00
J-34	18.30	1456.20	25.20	0.00
J-35	22.50	1456.19	21.19	0.00
J-36	10.80	1457.89	23.89	0.00
J-37	47.00	1457.81	21.81	0.00

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Node Results: (continued)

Node ID	Demand LPM	Head m	Pressure m	Quality
J-38	30.00	1453.52	14.52	0.00
J-39	62.00	1453.38	13.38	0.00
J-40	22.00	1457.51	17.51	0.00
J-41	23.00	1457.52	29.52	0.00
J-42	45.00	1457.44	18.44	0.00
J-43	46.00	1455.85	17.85	0.00
J-44	11.00	1450.93	13.93	0.00
J-45	31.00	1445.19	3.19	0.00
J-46	43.00	1444.66	1.66	0.00
J-47	42.00	1444.02	1.02	0.00
J-48	42.00	1443.56	1.56	0.00
J-49	42.00	1443.25	1.25	0.00
J-50	42.00	1443.13	0.13	0.00
J-51	40.00	1443.03	0.03	0.00
J-52	30.00	1444.70	1.70	0.00
J-53	30.00	1444.06	1.06	0.00
J-54	28.00	1443.60	0.60	0.00
J-55	28.00	1443.29	2.29	0.00
J-56	22.00	1443.14	4.14	0.00
J-57	29.00	1443.03	4.03	0.00
J-58	52.00	1448.44	8.44	0.00
J-59	52.00	1448.44	8.44	0.00
J-60	50.00	1448.48	8.48	0.00
J-61	42.00	1442.98	3.98	0.00
J-62	41.00	1442.97	5.97	0.00
J-63	28.00	1452.97	11.97	0.00
J-64	16.00	1452.98	9.98	0.00
fit-67	0.00	1455.87	1455.87	0.00
fit-68	0.00	1456.11	1456.11	0.00
fit-69	0.00	1456.38	1456.38	0.00
fit-70	0.00	1456.53	1456.53	0.00
fit-71	0.00	1456.82	1456.82	0.00
fit-72	0.00	1457.91	1457.91	0.00
fit-73	0.00	1459.82	1459.82	0.00
fit-74	0.00	1457.89	1457.89	0.00
fit-75	0.00	1456.21	1456.21	0.00
fit-76	0.00	1448.64	1448.64	0.00
fit-77	0.00	1456.22	1456.22	0.00
fit-78	0.00	1453.57	1453.57	0.00
fit-79	0.00	1453.59	1453.59	0.00
fit-80	0.00	1452.50	1452.50	0.00
fit-81	0.00	1451.66	1451.66	0.00
fit-82	0.00	1451.01	1451.01	0.00

fit-83	0.00	1451.22	1451.22	0.00
fit-84	0.00	1450.94	1450.94	0.00
fit-85	0.00	1450.74	1450.74	0.00
fit-86	0.00	1450.35	1450.35	0.00

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Node Results: (continued)

Node ID	Demand LPM	Head m	Pressure m	Quality
fit-87	0.00	1448.49	1448.49	0.00
fit-88	0.00	1448.53	1448.53	0.00
fit-89	0.00	1448.56	1448.56	0.00
fit-90	0.00	1448.60	1448.60	0.00
fit-91	0.00	1445.25	1445.25	0.00
fit-92	0.00	1444.72	1444.72	0.00
fit-93	0.00	1444.08	1444.08	0.00
fit-94	0.00	1443.62	1443.62	0.00
fit-95	0.00	1443.31	1443.31	0.00
fit-96	0.00	1443.15	1443.15	0.00
fit-97	0.00	1443.05	1443.05	0.00
fit-98	0.00	1448.59	1448.59	0.00
fit-99	0.00	1448.52	1448.52	0.00
fit-100	0.00	1448.46	1448.46	0.00
fit-103	0.00	1450.86	1450.86	0.00
fit-105	0.00	1450.77	1450.77	0.00
fit-106	0.00	1450.75	1450.75	0.00
fit-108	0.00	1450.93	1450.93	0.00
fit-109	0.00	1450.97	1450.97	0.00
fit-110	0.00	1450.51	1450.51	0.00
fit-111	0.00	1449.82	1449.82	0.00
fit-112	0.00	1449.26	1449.26	0.00
fit-113	0.00	1449.01	1449.01	0.00
fit-114	0.00	1448.59	1448.59	0.00
fit-115	0.00	1448.57	1448.57	0.00
fit-116	0.00	1448.15	1448.15	0.00
fit-117	0.00	1448.24	1448.24	0.00
fit-118	0.00	1448.40	1448.40	0.00
fit-119	0.00	1448.29	1448.29	0.00
fit-120	0.00	1448.26	1448.26	0.00
fit-121	0.00	1448.12	1448.12	0.00
fit-122	0.00	1448.03	1448.03	0.00
fit-123	0.00	1447.97	1447.97	0.00
fit-125	0.00	1447.89	1447.89	0.00
fit-126	0.00	1447.95	1447.95	0.00

fit-127	0.00	1448.06	1448.06	0.00
fit-128	0.00	1443.02	1443.02	0.00
fit-130	0.00	1452.99	1452.99	0.00
fit-131	0.00	1452.98	1452.98	0.00
fit-135	0.00	1457.53	1457.53	0.00
fit-136	0.00	1457.53	1457.53	0.00
fit-137	0.00	1455.94	1455.94	0.00
fit-138	0.00	1454.56	1454.56	0.00
fit-139	0.00	1453.97	1453.97	0.00
J65b	4.00	1450.35	8.35	0.00
J65c	4.00	1454.56	12.56	0.00
J65d	4.00	1453.97	11.97	0.00

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Node Results: (continued)

Node ID	Demand LPM	Head m	Pressure m	Quality	
J65a	4.00	1451.22	9.22	0.00	
R-1	-2304.70	1460.00	0.00	0.00	Reservoir

8.1.1.2 Section A Link Results:

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe-1	-768.88	0.64	2.49	Open
Pipe-2	-815.88	0.68	2.78	Open
Pipe-4	-894.88	0.74	3.30	Open
Pipe-5	-1642.29	1.36	10.23	Open
Pipe-7	-1700.09	1.41	10.92	Open
Pipe-8	-2304.70	0.54	0.86	Open
Pipe-9	-47.00	0.12	0.27	Open
Pipe-10	-41.00	0.11	0.21	Open
Pipe-11	-856.88	0.71	3.04	Open
Pipe-12	-38.00	0.10	0.18	Open
Pipe-14	22.50	0.06	0.07	Open
Pipe-16	-47.00	0.12	0.27	Open
Pipe-17	-57.80	0.15	0.38	Open
Pipe-18	10.80	0.03	0.01	Open
Pipe-19	-30.00	0.08	0.12	Open
Pipe-20	62.00	0.16	0.43	Open
Pipe-21	-92.00	0.24	0.87	Open
Pipe-23	40.80	0.11	0.21	Open
Pipe-24	706.61	1.24	13.55	Open

Pipe-25	614.61	1.08	10.44	Open
Pipe-26	-54.20	0.14	0.34	Open
Pipe-27	-54.20	0.14	0.34	Open
Pipe-28	560.41	0.98	8.79	Open
Pipe-29	506.21	0.89	7.28	Open
Pipe-30	502.21	0.88	7.17	Open
Pipe-31	27.00	0.07	0.10	Open
Pipe-32	0.00	0.00	0.00	Open
Pipe-33	475.21	0.83	6.48	Open
Pipe-34	464.21	0.81	6.19	Open
Pipe-35	464.21	0.81	6.20	Open
Pipe-36	225.79	0.40	1.66	Open
Pipe-37	175.79	0.31	1.05	Open
Pipe-38	123.79	0.22	0.56	Open
Pipe-39	71.79	0.13	0.21	Open
Pipe-40	-460.21	0.81	6.10	Open
Pipe-41	52.00	0.14	0.32	Open
Pipe-42	52.00	0.14	0.32	Open
Pipe-43	50.00	0.13	0.30	Open
Pipe-44	532.00	1.39	21.61	Open

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Link Results: (continued)

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe-45	31.00	0.08	0.13	Open
Pipe-46	501.00	1.31	19.30	Open
Pipe-47	428.00	1.12	14.38	Open
Pipe-48	356.00	0.93	10.21	Open
Pipe-49	286.00	0.75	6.81	Open
Pipe-50	216.00	0.57	4.07	Open
Pipe-51	152.00	0.40	2.15	Open
Pipe-52	-43.00	0.11	0.23	Open
Pipe-53	30.00	0.08	0.12	Open
Pipe-54	-42.00	0.11	0.22	Open
Pipe-55	30.00	0.08	0.12	Open
Pipe-56	-42.00	0.11	0.22	Open
Pipe-57	28.00	0.07	0.11	Open
Pipe-58	-42.00	0.11	0.22	Open
Pipe-59	28.00	0.07	0.11	Open
Pipe-60	-42.00	0.07	0.08	Open
Pipe-61	22.00	0.06	0.07	Open
Pipe-62	-40.00	0.07	0.08	Open
Pipe-63	29.00	0.08	0.12	Open

Pipe-65	-145.82	0.26	0.75	Open
Pipe-66	-145.82	0.26	0.75	Open
Pipe-67	-190.82	0.33	1.22	Open
Pipe-68	-45.00	0.12	0.25	Open
Pipe-69	0.00	0.00	0.00	Open
Pipe-70	-43.00	0.11	0.23	Open
Pipe-72	-47.50	0.12	0.27	Open
Pipe-73	47.50	0.12	0.27	Open
Pipe-74	47.50	0.12	0.27	Open
Pipe-75	47.50	0.12	0.27	Open
Pipe-76	-95.00	0.25	0.92	Open
Pipe-80	28.30	0.07	0.11	Open
Pipe-81	768.88	1.35	15.87	Open
Pipe-82	571.08	1.00	9.10	Open
Pipe-83	516.88	0.91	7.56	Open
Pipe-84	462.68	0.81	6.16	Open
Pipe-85	435.98	0.76	5.52	Open
Pipe-86	54.20	0.14	0.34	Open
Pipe-87	-54.20	0.14	0.34	Open
Pipe-88	26.70	0.07	0.10	Open
Pipe-89	-52.00	0.14	0.32	Open
Pipe-90	383.98	0.67	4.37	Open
Pipe-91	-29.20	0.08	0.12	Open
Pipe-92	-214.20	0.56	4.02	Open
Pipe-93	-94.00	0.25	0.91	Open
Pipe-94	-140.00	0.37	1.85	Open
Pipe-95	-185.00	0.48	3.07	Open
Pipe-96	45.00	0.12	0.25	Open

Link Results: (continued)

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe-97	46.00	0.12	0.26	Open
Pipe-98	47.00	0.12	0.27	Open
Pipe-99	47.00	0.12	0.27	Open
Pipe-100	-18.30	0.05	0.05	Open
Pipe-101	169.78	0.30	0.99	Open
Pipe-104	21.20	0.06	0.07	Open
Pipe-105	272.60	0.71	6.16	Open
Pipe-106	-36.70	0.10	0.17	Open
Pipe-107	-36.70	0.10	0.17	Open
Pipe-110	-73.70	0.19	0.59	Open
Pipe-111	-110.40	0.29	1.21	Open

Pipe-112	-40.00	0.10	0.20	Open
Pipe-113	38.30	0.10	0.19	Open
Pipe-114	26.70	0.07	0.10	Open
Pipe-115	36.00	0.09	0.16	Open
Pipe-116	-76.00	0.20	0.62	Open
Pipe-117	114.30	0.30	1.29	Open
Pipe-118	-141.00	0.37	1.88	Open
Pipe-119	0.00	0.00	0.00	Open
Pipe-121	-42.00	0.11	0.22	Open
Pipe-122	416.61	0.73	5.07	Open
Pipe-123	-16.00	0.04	0.04	Open
Pipe-124	28.00	0.07	0.11	Open
Pipe-125	-44.00	0.12	0.24	Open
Pipe-127	-22.00	0.06	0.07	Open
Pipe-128	-23.00	0.06	0.08	Open
Pipe-129	-45.00	0.12	0.25	Open
Pipe-130	604.61	1.06	10.12	Open
Pipe-131	90.00	0.24	0.82	Open
Pipe-132	46.00	0.12	0.26	Open
Pipe-133	-460.61	0.81	6.11	Open
Pipe-134	-464.61	0.81	6.21	Open
Pipe-135	-468.61	1.23	17.03	Open
Pipe-136	-514.61	0.90	7.50	Open
Pipe-137	11.00	0.03	0.01	Open
Pipe-138	4.00	0.01	0.00	Open
Pipe-139	4.00	0.01	0.00	Open
Pipe-140	4.00	0.01	0.00	Open
Pipe-141	4.00	0.01	0.00	Open
Pipe-143	-83.00	0.22	0.73	Open
Pipe-144	-37.00	0.10	0.18	Open
Pipe-145	-197.80	0.52	3.46	Open
Pipe-146	-27.00	0.07	0.10	Open
Pipe-147	142.50	0.37	1.91	Open
Pipe-148	251.40	0.66	5.37	Open
Pipe-149	-102.82	0.18	0.40	Open
Pipe-150	41.00	0.11	0.21	Open

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Link Results: (continued)

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe-3	747.41	1.31	15.05	Open

8.1.2 Section B

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* E P A N E T *
* Hydraulic and Water Quality *
* Analysis for Pipe Networks *
* Version 2.2 *

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Input File: model phase 2 attempt 4 top corner.net

Link - Node Table:

Link ID	Start Node	End Node	Length m	Diameter mm
Pipe-1	J-70	n-1	207	90
Pipe-2	n-1	n-2	55	300
Pipe-3	J-71	n-13	342	90
Pipe-4	n-13	J-73	170	90
Pipe-5	n-13	n-14	19	90
Pipe-6	n-14	n-1	275	300
Pipe-7	n-15	J-72	495	90
Pipe-8	n-14	n-15	92	300
Pipe-10	n-16	J-75	152	90
Pipe-11	n-16	n-17	145	110
Pipe-12	n-17	J-75	121	90
Pipe-13	n-17	J-80	200	90
Pipe-14	J-74	n-18	330	90
Pipe-15	n-17	n-18	5	110
Pipe-16	n-2	n-19	343	110
Pipe-17	n-19	n-18	11	110
Pipe-18	J-76	n-20	148	90
Pipe-19	n-20	J-77	469	90
Pipe-20	n-19	n-21	167	90
Pipe-21	n-21	n-20	20	90
Pipe-22	n-21	n-22	118	90
Pipe-23	n-22	J-78	493	90
Pipe-24	n-22	J-79	602	90
Pipe-25	n-2	R-1	50	300

Pipe-26	n-15	J-1	147	300
Pipe-27	J-1	n-16	13	110

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8.1.2.1 Section B Node Results:

Node ID	Demand LPM	Head m	Pressure m	Quality
J-70	34.17	1449.96	8.96	0.00
J-71	47.50	1449.88	6.88	0.00
J-72	63.30	1449.76	7.76	0.00
J-73	22.00	1449.97	7.97	0.00
J-74	22.50	1449.83	4.83	0.00
J-75	45.00	1449.87	6.87	0.00
J-76	10.83	1448.98	4.98	0.00
J-77	77.50	1448.68	3.68	0.00
J-78	75.90	1448.42	4.42	0.00
J-79	80.00	1448.32	6.32	0.00
J-80	14.00	1449.85	7.85	0.00
n-1	0.00	1450.00	1450.00	0.00
n-2	0.00	1450.00	1450.00	0.00
n-13	0.00	1449.98	1449.98	0.00
n-14	0.00	1449.99	1449.99	0.00
n-15	0.00	1449.99	1449.99	0.00
n-16	0.00	1449.96	1449.96	0.00
n-17	0.00	1449.86	1449.86	0.00
n-18	0.00	1449.85	1449.85	0.00
n-19	0.00	1449.85	1449.85	0.00
n-20	0.00	1448.98	1448.98	0.00
n-21	0.00	1449.00	1449.00	0.00
n-22	0.00	1448.73	1448.73	0.00
J-1	0.00	1449.98	1449.98	0.00
R-1	-492.70	1450.00	0.00	0.00 Reservoir

8.1.2.2 Section B Link Results

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe-1	-34.17	0.09	0.15	Open
Pipe-2	-384.78	0.09	0.03	Open
Pipe-3	-47.50	0.12	0.27	Open
Pipe-4	22.00	0.06	0.07	Open
Pipe-5	-69.50	0.18	0.53	Open
Pipe-6	-350.61	0.08	0.03	Open
Pipe-7	63.30	0.17	0.45	Open
Pipe-8	281.11	0.07	0.02	Open
Pipe-10	74.60	0.20	0.60	Open
Pipe-11	143.21	0.25	0.73	Open
Pipe-12	-29.60	0.08	0.12	Open
Pipe-13	14.00	0.04	0.03	Open
Pipe-14	-22.50	0.06	0.07	Open
Pipe-15	158.81	0.28	0.89	Open
Pipe-16	107.92	0.19	0.44	Open
Pipe-17	-136.31	0.24	0.66	Open

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Link Results: (continued)

Link ID	Flow LPM	Velocity m/s	Unit Headloss m/km	Status
Pipe-18	-10.83	0.03	0.01	Open
Pipe-19	77.50	0.20	0.64	Open
Pipe-20	244.23	0.64	5.09	Open
Pipe-21	88.33	0.23	0.81	Open
Pipe-22	155.90	0.41	2.25	Open
Pipe-23	75.90	0.20	0.62	Open
Pipe-24	80.00	0.21	0.68	Open
Pipe-25	-492.70	0.12	0.05	Open
Pipe-26	217.81	0.05	0.01	Open
Pipe-27	217.81	0.38	1.56	Open

Appendix 2: Bill Of Quantities

item	Specs	number of items	unit price	cost ($)	Contribution
Pipes (6m lengths)	90mm Pvc	3,073	$ 28.22	$ 86,720.06	15.53%
	110mm Pvc	952	$ 39.65	$ 37,746.80	6.76%
	160mm PVC	0	$ 84.83	$ -	
	300mm Pvc	258	$ 339.53	$ 87,598.74	15.69%
Taps (schools)	brass tap 20mm	160	$ 11.00	$ 1,760.00	0.32%
Fire Hydrants	80mm	20	$ 168.00	$ 3,360.00	0.60%
	110mm	0	$ -	$ -	0.00%
	300mm	0	$ -	$ -	0.00%
		0	$ -	$ -	0.00%
Valves	90mm	21	$ 106.00	$ 2,226.00	0.40%
	110mm	3	$ 134.00	$ 402.00	0.07%
	300mm	3	$ 850.00	$ 2,550.00	0.46%
	ARV150TD	3	$4,503.00	$ 13,509.00	2.42%
Elbows	90mm 90degree	105	$ 12.79	$ 1,342.95	0.24%
	110mm 90degree	10	$ 17.18	$ 171.80	0.03%
	300mm 30degree	0	$ 127.20	$ -	0.00%
	300mm 90degree	6	$ 224.51	$ 1,347.06	0.24%
T	90mm 90mm 90mm	30	$ 7.47	$ 224.10	0.04%
	110mm 110mm 110mm	37	$ 13.14	$ 486.18	0.09%
	160mm 160mm 160mm	0	$ 62.99		0.00%
	300mm 300mm 300mm	14	$ 541.00	$ 7,574.00	1.36%
Endcaps	90mm	56	$ 5.25	$ 294.00	0.05%
	110mm	0	$ 7.84		0.00%
	160mm ,	0	$ 11.74		0.00%
	300mm	1	$ 58.01	$ 58.01	0.01%
Standpipes	20 mm Barrel Nipple	11	$ 0.50	$ 5.50	0.00%
	32mm 90deg elbow\	33	$ 0.70	$ 23.10	0.00%
	32mm HDPE pipe (6m)	33	$ 5.76	$ 190.08	0.03%
	20mm brass tap	55	$ 11.00	$ 605.00	0.11%
Individual House Connections					
	20mm GI pipe (6m)	2,100	$ 57.60	$120,960.00	21.67%
	20 mm Barrell Nipples	7,350	$ 0.50	$ 3,675.00	0.66%
	20mm F elbow	8,400	$ 0.70	$ 5,880.00	1.05%
	20mm equal tee	1,050	$ 1.00	$ 1,050.00	0.19%
	20 mm Gate valve	2,100	$ 7.50	$ 15,750.00	2.82%
	15 mm water meter	2,100	$ 60.00	$126,000.00	22.57%
	20mm Malleable iron saddle	1,050	$ 5.00	$ 5,250.00	0.94%
				$ -	
Chamber	precast valve box (750 * 550 * 200) (items)	84	$ 15.00	$ 1,260.00	0.23%
	Valve lids (items)	21	$ 10.00	$ 210.00	0.04%
	cement (bags	120	$ 13.00	$ 1,560.00	0.28%
	19mm stones (cubic metres)	6	$ 45.00	$ 270.00	0.05%
	river sand (cubic metres)	6	$ 20.00	$ 120.00	0.02%
	pitsand (cubic metres)	50	$ 20.00	$ 1,000.00	0.18%
	bricks (no items)	26,100	$ 100.00	$ 2,610.00	0.47%
	Valve lids larger ones(items)			$ -	
Reducers	110mm to 90mm	32	$ 8.08	$ 258.56	0.05%
	300mm to 110mm	5	$ 107.82	$ 539.10	0.10%
	300mm to 90mm	7	$ 124.59	$ 872.13	0.16%
Miscellaneous	thrust blocks	100	$ 7.00	$ 700.00	0.13%
	solvent cement (500ml)	100	$ 3.00	$ 300.00	0.05%
	hacksaws	40	$ 10.00	$ 400.00	0.07%
	hammers	40	$ 10.00	$ 400.00	0.07%
	others (to be specified)	10	$1,000.00	$ 10,000.00	1.79%
	fuel	5000	$ 1.60	$ 8,000.00	1.43%
	airtime	400	$ 5.00	$ 2,000.00	0.36%
	signage "H"	20	$ 20.00	$ 400.00	0.07%
	signage "V"	29	$ 20.00	$ 580.00	0.10%
Subtotal				$558,239.17	
	20%				
Contingency				$111,647.83	
total				**$669,887.00**	