HYDRAULIC ANALYSIS OF WATER DISTRIBUTION SYSTEM NETWORKS USING EPANET SOFTWARE

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IN

THE DEPARTMENT OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY, NIGERIA

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PLAGIARISM

This work **HYDRAULIC ANALYSIS AND DESIGN OF WATER DISTRIBUTION NETWORKS USING EPANET SOFTWARE** by OBAZEE, Edosa Samuel with matriculation number ENG1704620 of the Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria has PASSED the PLAGIARISM TEST.

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DEDICATION

This work is dedicated to Almighty God, for His love and protection throughout my stay in the University of Benin.

ACKNOWLEDGEMENT

I wish to express my profound gratitude to Almighty God, the author and dispenser of knowledge and wisdom, for His protection throughout my stay in the University.

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ABSTRACT

The pressure exerted on a water distribution system due to population increase and aging of the system yields to routine assessment of its functionality. EPANET 2.2 software was used comparatively in evaluating/analyzing the serviceability of the water distribution system in University of Benin, Ugbowo campus.

A steady state analysis was also carried out to determine hydraulic parameters such as pressure, velocity, headloss and flow. The results from the design simulation shows that the pressure gotten at all nodes was suitable for the design and the pressure results indicated a high head within the system which resulted to (90%) of the nodes operating above the adopted system pressure of 10m while the remaining 10% of the pressure was operating below the pressure of 10m.

Also, (95%) of the system velocity was within range of 0.2 – 3 m/s adopted while 5% of the velocity was below the adopted velocity. The resultant effect of low velocities in the system would lead to delay in the flow of water through pipes network. Therefore, the system requires strengthen for optimum performance.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

Life is dependent on water. Water is essential to human life as it is to all other animal and plant life on the earth. We need water not only for our everyday survival—our bodies require it to function—but also for the production of our food, the production of our energy, and the operation of our industries. "On average, each person needs 70 litres of water per day." It also includes the requirement for water to uphold a minimal level of domestic and personal hygiene necessary to preserve health (Arjun et al., 2015).

Human need for water consumption rises along with his style of living (Arunkumar & Nethaji, 2011). As a result, there is a necessity to move and transport potable water inside a municipality from a source to the site of consumption. In concept, the system would need storage tanks or reservoirs, a network of pipelines, pumps, valves, and other appurtenances to reliably and continuously deliver water from a source to a consumer. The drinking water distribution system is the name given to all of this infrastructure (EPA, 2005).

For business and industry to function in a municipal setting, water supply is necessary. The requirement to supply water to fire hydrants that are strategically placed in order to effectively safeguard the public from fire is not less significant. Furthermore, municipal water systems could be required to supply water for specialized services like street cleaning, selling water to contractors for building construction, parks and recreation, and other applications (U.S. Fire Administration, 2008).

The main objective of all water utilities is to supply consumers with safe drinking water that is free of pathogenic and other undesired organisms (Gavin et al., 2006). Since major water quality variations can occur within drinking water distribution systems owing to contamination, drinking water utilities around the world have the issue of providing their customers with high-quality water (Roopali & Patel, 2015). After leaving the treatment facility, the quality of the treated water diminishes as it moves through a distribution system.

The prevention of the spread of waterborne infections and the achievement of this goal both depend on disinfection. Chlorine is utilized as a disinfectant residue in drinking water delivery systems all over the world to fight microbiological contamination and growth. However, when the water moves through the systems, the chlorine residual concentration degrades mostly as a result of its interactions with the organic matter present in the water naturally (bulk decay) and with the materials on the inside surfaces of the pipes (wall decay). For the water to be safe, the residual disinfectant concentration must be kept at levels that allow for the least possible production of disinfection byproducts (Monteiro et al., 2014).

In the distribution system, deterioration in water quality is also largely caused by water age. These changes will occur to a greater or lesser extent depending on the water flow rate, finished water quality, pipe materials, and deposited materials (such as sand, iron, and manganese) (U.S. Environmental Protection Agency, 2002).

Modeling is a continual process that involves creating models at the same time that knowledge and information about simulation systems become more and more available, becoming more and more suited to describing actual processes. Modeling is described as "the process of comparing the results of a model with field observations to, if necessary, adjust the data describing the system until the predicted behavior agrees reasonably with the behavior observed in reality for a wide range of operating conditions" by (Walski, et al., 2003). You can determine system pressures and flow rates under a variety of scenarios using hydraulic modeling of water distribution systems rather than going outside and physically monitoring your system.

1.2 Statement of Problem

Inconsistent water pressure, ineffective velocity, and the use of uneconomical pipe diameters, which raises operational expenses, are serious problems with the community's current water distribution system. Due to these issues, water supply to different parts of the neighbourhood is less than ideal. The lack of an effective water distribution system, which can reliably deliver sufficient water supply, appropriate pressure, and velocity to various areas of the community while optimising the choice of pipe diameters to reduce costs and improve sustainability, is thus the specific issue that needs to be addressed in this project.

The major aim of this study is to build an EPANET model and perform a hydraulic analysis of a fictitious water distribution system.

i. To construct an EPANET model and carryout a hydraulic analysis of the hypothetical water distribution network.

ii. To compare the software-generated values for flow, head, and pressure with those produced using the linear theory technique.

1.3 Aim and Objectives

The aim of this study is to use EPANET hydraulic modelling software to design a water distribution network for UNIBEN, Benin City. The objectives are to ensure that:

i. To determine the water demand within the research area.

ii. To create an efficient distribution system to provide water to different areas of the community at an appropriate pressure and velocity using economical pipe diameters.

iii. To determine the adequate source, the type of pumps and storage tanks sufficient to meet the demand.

1.4 Scope of Work

To use EPANET 2.2 to model the water distribution network consisting of pipes, nodes, pumps, valves and storage tanks for University of Benin, Ugbowo Campus, Edo state. Also to create a schematic diagram of the network and entered data for elements like pipe lengths, diameters, node elevations, tank levels, etc. Various flow conditions and demand patterns will be simulated to optimize pipe sizes.

The average daily demand (ADD) will be calculated based on the population to be served, per capita water consumption and transmission losses. The population was obtained from the University of Benin student affairs data and projected to the design year using a growth factor. Per capita demand was estimated considering residential and commercial/industrial needs. The ADD was calculated by multiplying average per capita demand with design population and adding losses.

1.5 Justification of Study

Around the world, a lot of money is spent on building new or improving existing piping systems for water supply. Even then, a sizable portion of the global population lacks access to safe piped water. Using rational approaches for constructing a water distribution system will result in significant savings because water transmission and the water distribution network account for close to 80% to 85% of the cost of a whole water supply system (Shwarme & Sharma, 2008).

An easier and quicker way to guarantee that a planned water distribution system is effectively designed for is through hydraulic modeling. It enhances distribution system performance and aids in planning and budgeting for capital improvements.

The assessment of water quality at the point of treatment and at the point of consumption is made possible by water quality modeling. Since the student population at UNIBEN Ugbowo Campus is expanding every year, water quality modeling is needed to verify that the water is fit for drinking and free of physical, chemical, and biological organisms at the point of consumption.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Importance of Water for Life's Existence

One of the most valuable resources in the planet is water. It is essential to both plant and animal life. Since the human body is composed of roughly 70% water, humanity cannot survive without it (Alkali, et al., 2014).

71% of the Earth's surface is covered in water. 96.5% of the water in the crust of the Earth is in seas and oceans, 1.7% is in groundwater, 1.7% is in glaciers and the ice caps of Antarctica and Greenland, a small portion is in other significant bodies of water, and 0.001% is in the atmosphere as vapour, clouds (which are made of ice and liquid water suspended in air), and precipitation (Gleick, 1993).

Water fit for human consumption is called **Drinking water or Potable water**.

2.2 History of Water Distribution

A brief historical review of public water systems is given in (Jepherson, 2001). Jepherson asserts that the concept of public water delivery systems dates back to 700 BC, when "qanats" (slightly slanted hillside tunnels) bringing water to Persia were constructed. Aqueduct construction by the Romans began around 312 BC. Ancient water supply systems' intricate technical designs were revealed by recently found spring-water gathering systems at Machu Pichu in Peru. The water supply systems in Machu Pichu have existed since 1450

AD. The City of Boston integrated its water works built to provide water for residential consumption and firefighting in 1652 AD, establishing the first public water system in the United States. Since that time, other public water delivery systems have been established. In former times, channels were constructed out of cut stone, brick, or debris. Most commonly, drilled stone, wood, clay, and lead were used to make pipes. Wooden pipes were replaced with cast iron pipes in the 18th century. Significant advancements in the creation of pipe joints that could withstand high pressures were made in the 19th century. In the early 20th century, the use of water delivery pipelines composed of steel, ductile iron, asbestos cement, and reinforced concrete increased. Accurate estimate of flows and pressures in various distribution system components was required due to the rising complexity of distribution systems. The single-pipe flow problem's solution was no longer sufficient. The field of water distribution network analysis, also known as pipe network analysis, was born out of the search for techniques that could analyze (solve for flows and pressures) the whole water distribution network.

2.3 Water Distribution Models

Within the water utility sector, water distribution system models are now commonly used as a method of simulating the hydraulic and water quality behavior of water distribution system networks. Software for modeling water distribution today is strong, complex, and easy to use. To make building models, storing model results, and displaying model results easier, GIS and Computer Aided Design (CAD) technology are incorporated into numerous software packages. Early network models could only simulate hydraulic behavior in steady state. The ability to model was enhanced in the 1970s with the addition of Extended Period Simulation (EPS) models, which could handle operations and demand that changed over time.

Researchers then started introducing the idea of water quality modeling in the early 1980s. Water quality simulation capabilities is now regularly included in the majority of software packages for modeling water distribution systems. In more recent times, transient models for tank mixing/aging and water hammer (a transient phenomenon) simulation have either been integrated into or added to models of water distribution systems. Users may now do probabilistic studies, model calibration, and design and operation optimization for water systems thanks to algorithms that have been created (EPA, 2005).

2.4 EPANET

A computer program called EPANET simulates hydraulic and water quality behavior over a long time period in pressurized pipe networks. A network is made up of pipes, nodes (joints in the pipes), pumps, valves, and reservoirs or storage tanks. During a simulation period made up of numerous time steps, EPANET monitors the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network.

It is possible to replicate not only chemical species but also water age and source tracing.

Our knowledge of the movement and destiny of drinking water elements within distribution networks will be improved by using EPANET as a research tool. It can be applied to a wide variety of distribution system analysis.

Designing sampling programs, calibrating hydraulic models, analyzing chlorine residuals, and determining consumer exposure are a few examples. Alternative management techniques for enhancing water quality throughout a system can be evaluated with the aid of EPANET.

These may consist of:

Changes to pumping and tank filling/emptying schedules, source usage within multiple source systems, use of satellite treatment, such as re-chlorination at storage tanks, and targeted pipe cleaning and replacement are just a few.

EPANET, which is a windows-based program, offers an integrated environment for altering network input data, executing hydraulic and water quality simulations, and viewing the results in various forms. These comprise data tables, time series graphs, color-coded network maps, and contour plots.

2.4.1 Steps In The Design of Networks

The steps involved in the analysis and design of water distribution network are: Preliminary layout, Skeletonization, Computation of loads, hydraulic analysis and Correction of pipe sizes (Davis and Sorenson, 1993).

A preliminary layout of all pipes including distribution reservoirs and elevated tanks is prepared on an appropriate map of the community and pipe sizes may then be assumed based on standard pipe sizes. Based on subsequent hydraulic computations, the sizes are checked or corrected.

The network is skeletonized by eliminating all the smaller pipes in which flow is negligible. The degree of skeletonization depends on the ultimate use of the modal but minimal skeletonization should include all pipes and features of major concern. Though most modern software packages place no limit on the size of the network model. Skeletonization is still frequently used in order to reduce modelling effort.

Loading points are taken as pipe junctions and the water demand at each junction/node is determined.

Pipe sizes/diameters are then adjusted if necessary to obtain the desired pressure at critical points in the network.

2.4.2 Hydraulics Analysis of Water Pipe Network

The hydraulic analysis of water distribution in pipe networks involves the determination of the system parameters such as the fluid flow in the pipes, velocity, pressure, water demand, roughness coefficient, energy losses etc. these parameters are measurable and standardize and they make for the uniqueness of the hydraulic system (Qasim et al. 2009).

When water flows in a pipe, it experiences some resistance to its motion, which leads to the reduction of the velocity and available energy (head) of the flow. Shear stresses develop between the water and pipe wall, which is as a result of friction or surface resistance and also at bends, connections and curves in the pipe network configuration, known as form resistance, Swamee and Sharma (2008).

There are therefore energy losses (also called head losses), which are generally the results of two mechanisms, namely:

a) Friction along the pipe wall (pipe friction)

b) Turbulence due to changes in streamlines through fittings and appurtenances

Three types of energy mainly associated with a fluid in a hydraulic system include the kinetic energy (or Velocity head), potential energy (or elevation head) and the internal pressure energy (or pressure head). The total energy associated with a fluid per unit weight of the fluid is called the Head (H) (Audu, 2010 and Gard, 2013). The total energy at any point in a hydraulic system is the sum of the velocity head, the elevation head and the pressure head.

This can be expressed mathematically as given by Swamee and Sharma (2008) in equation 2.0

$$H = Z + \frac{P}{\Upsilon} + \frac{2V^2}{2g} \qquad \textit{Equation 2.0}$$

Where,

H = Total Head

Z = Elevation Head, elevation above the datum

$\frac{P}{\Upsilon}$ = Pressure Head

$\frac{2V^2}{2g}$ = Velocity Head

P = Pressure (N/m^2)

g = Acceleration due to gravity (m/s^2)

γ = Fluid specific weight (N/m^3)

V = Flow velocity (m/s)

The loss of energy (head) in a water distribution network is classified into major loss and minor loss (Garg, 2013). The major loss of energy is due to turbulence within the bulk fluid in motion. Minor losses may occur as a result of sudden enlargement of the pipes, sudden contraction of pipes, bend of pipes, an obstruction in pipe, pipe fittings and water flow disturbances caused by valves, bends in the pipeline, and changes in pipes diameter.

Generally, there are three empirical relationships for the determination of the major energy loss (or head loss in a pipe network. These includes the Darcy-Weisbach equation, the Hazen Williams equation and Chezy-Manning equation.

2.4.3 Hydraulics Modelling Capabilities

Effective water quality modeling requires accurate and full-featured hydraulic modeling. The hydraulic analysis engine in EPANET is progressive and has the following capabilities:

i. limits the size of the network that can be analyzed in no way.

ii. uses the Hazen-Williams, Darcy-Weisbach, or Chezy Manning's formulas to calculate friction headloss.

iii. takes into account small head losses from bends, fittings, etc.

iv. types of pumps with constant or variable speeds.

v. computes the cost and energy of pumping.

vi. Models cutoff, check, pressure-regulating, and flow-control valves, among other sorts of valves.

vii. permits any design for storage tanks (height-dependent variations in diameter).

viii. takes into account a variety of demand types at nodes, each with a unique pattern of temporal variation.

ix. simulates the pressure-dependent flow emitted by emitters (sprinkler heads).

x. can base system operation on both simple tank level or timer controls and on complex rule-based controls.

2.4.4 Early Hydraulics/Modelling Methods

In the past, a variety of techniques have been employed to calculate flows in a network of pipes. The use of mathematical models is the last of these techniques, which also include the use of graphical tools and physical analogies. The following is a list of some of the more significant techniques:

i. The Hardy Cross Method

ii. The Simultaneous Node Method

iii. The Simultaneous Loop Method

iv. The Gradient Method (Simultaneous Network Method)

v. The Linear Method (Simultaneous Pipe Method), respectively, follow.

For the purpose of performing moment distribution assessments for statically determined structures, Hardy Cross, a structural engineering professor at the University of Illinois at Urbana-Champaign, created a mathematical procedure in 1936. Hardy Cross later discovered that the method created could also be used to calculate pressures or flows in closed loop water distribution systems and released a paper describing how the technique was used for that objective. In that paper, Hardy Cross presented two different approaches: one that iteratively applied a flow adjustment factor for each network loop to solve for flows in each pipe, and another that iteratively applied a grade adjustment factor to solve for hydraulic grades at each system node. Using a particular reference point (such as a tank or reservoir as a starting point) and the corresponding pipe headloss between adjacent nodes as calculated by using the Hazen-Williams equation, the related nodal grades were then produced in the former instance. The flows in each pipe were then determined in the latter scenario by directly solving the Hazen-Williams equation for discharge while using the variations in the resulting nearby nodal grades as a gauge of the pipe's headloss. The "loop" method required the specification of initial estimates of pipe flow for each pipe that initially satisfied flow continuity at each junction node. For each junction node, initial estimates of the nodal hydraulic grade required to be supplied when using the "node" approach (Ormsbee, 2006). As a result, the loop adjustment approach was more widely accepted by engineers and quickly earned the name **"Hardy Cross Method"** exclusively. The Hardy Cross method had to wait for several decades for the development of the computing hardware and software required for its full implementation, even though it was initially designed for use with a noncomputer based solution methodology. Nevertheless, the method's overall structure was clearly a candidate for such an application (Ormsbee, 2006).

The Gradient Method, which was put forth by Todini and Pilati (1987), is the last technique for consideration. In this formulation, the nodal heads and the individual pipe flows are simultaneously solved by combining the individual energy equations for each pipe with the individual nodal equations for each junction node. The nonlinear energy equations are first linearized using a Taylor Series expansion, just like the "simultaneous loop" and "linear method," respectively. However, in this instance, an effective recursive method is used to solve the equations by inverting the original coefficient matrix. The EPA has chosen to employ this technique in the creation of the program EPANET (Ormsbee, 2006).

In order to fully utilize the computing power of contemporary computers, more recent computer methods, such as the simultaneous node method, simultaneous loop method, linear method, and gradient method all use matrix formulations of the network issue (Ormsbee, 2006).

2.5 Methods of Distributing Water

At different sites, sufficient water pressure is necessary for an effective distribution system. The following methods may be used to force water into the distribution system, depending on the level of the source, the local geography, and other factors:

i. **Gravity system:** This works well if the source of supply is high enough. It is the most efficient and dependable distribution method. The consumer's water head is only need to the bare minimum. The frictional and other losses devour the remaining head.

ii. **Pumping system:** Without being stored, treated water is pushed immediately into the distribution mains. Another name for it is pumping without a storage system. Pumps with high lifts are necessary to implement this system. If power supply fails, there is complete stoppage of water supply. This method is not generally used.

iii. **Combined gravity and pumping system:** This is the most prevalent system, water that has been treated is pumped into an elevated distribution reservoir, where it is stored, and is subsequently delivered to the customer by gravity. Water that is in excess during times of low demand is stored in reservoirs and delivered at times of high need. It is the most affordable, effective, and trustworthy system.

2.6 Layout of Water Distribution System

The distribution pipes are generally laid below the road pavements, and as such their layouts generally follow the layouts of roads. There are, in general, four different types of pipe networks; any one of which either singly or in combinations, can be used for a place.

They are **Dead End Systems, Radial System, Grid Iron System, and Ring System.**

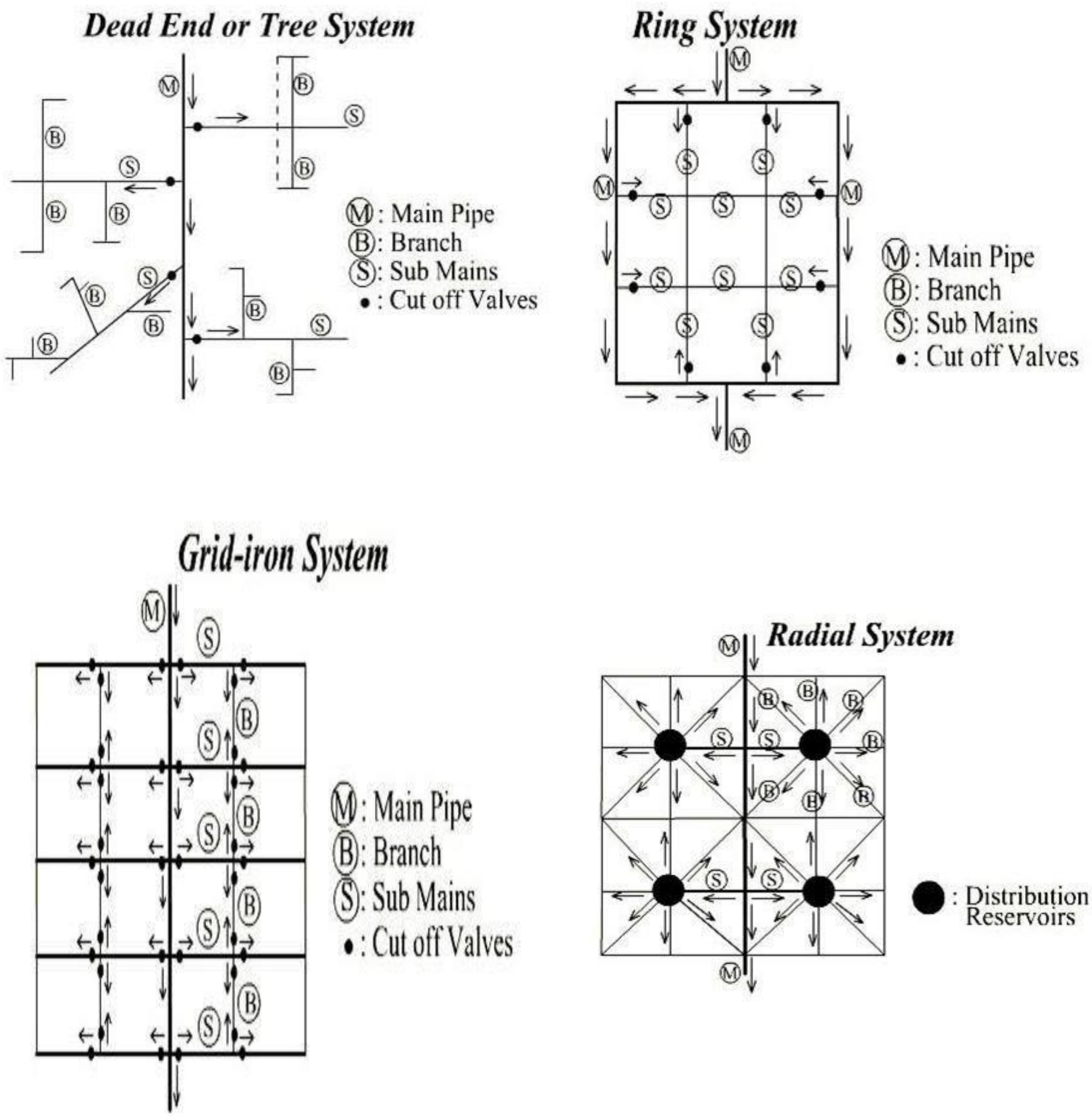

Figure 2.1: Layout of Water Distribution System

2.7 Theoretical Concepts Applied in Hydraulic Modelling

The fundamental underlying equations of hydraulic models—conservation of mass and conservation of energy—are represented as a collection of linear and nonlinear equations. Iterative solution techniques are frequently employed to numerically solve the set of equations because of the nonlinearity. The Newton-Raphson method is the most often used numerical technique (EPA, 2005).

2.8.1 Conservation of Mass

The sum of all mass flows in all pipes entering a junction must equal the sum of all mass flows in all pipes exiting the junction in order to comply with the conservation of mass principle for hydraulic analysis. If storage is involved, EPS includes a phrase to describe the buildup of water at those nodes. The idea can be expressed mathematically as follows:

$$\sum_{i=1}^{n}(Q\imath - U\imath) - \frac{dS}{dt} = 0$$

Equation 2.1

Where,

$Q\imath$ = inflow to node in i-th pipe in m^3/s

$U\imath$ = water used or leaving at the i^{th} pipe in m^3/s

$\frac{dS}{dt}$= change in storage in m^3/s

2.8.2 Conservation of Energy

According to the conservation of energy principle, the energy differential between any two places in a network must be constant regardless of the flow path. This principle can be expressed in terms of head as follows for hydraulic analysis:

$$Z_1 + \frac{P_1}{\gamma} + \frac{V_1}{2g} + \sum h_p = Z_2 + \frac{P_2}{\gamma} + \frac{V_2}{2g} + \sum h_l + \sum h_m$$ *Equation 2.2*

Where,

Z_{1and2} = elevation at point 1 and 2 respectively (m)

P_{1and2} = pressure at point 1 and 2 respectively (N/m)

γ = Fluid specific weight (N/m^3)

V_{1and2} = velocity at point 1 and 2 respectively (m/s)

g = acceleration due to gravity (m/s^2)

h_P = pumping head gain (m)

h_L = headloss in pipes (m)

h_M = headloss due to appurtenances (m)

2.8.3 Headlosses in Pipes

The loss of head (headloss) that occurs when a real fluid moves through a pipe is caused by a portion of the fluid's total energy being required to maintain the flow.

A pipe's headloss is divided into two groups, namely:

i. Friction-Related Headloss

ii. Appurtenance-Related Headloss

2.7.3.1 Headloss due to Friction

Three empirical formulas commonly used are **Darcy-Weisbach, Hazen-Williams and Chezy-Manning**. All three equations relate headloss in pipes to velocity, length of pipe, pipe diameter and pipe roughness.

i. DARCY-WEISBACH FORMULA

$$h_f = \frac{fLV^2}{2gD}$$ *Equation 2.3*

Where,

h_F = frictional headloss (m)

f = friction factor

L = length of pipe (m)

V = velocity of flow (m/s)

D = diameter of pipe (m)

ii. HAZEN-WILLIAMS FORMULA

The equation most commonly used in modelling software for computation of pipe-friction headloss is the Hazen-Williams equation represented as follows:

$$h_f = \frac{10.68LQ^{1.852}}{C^{1.852}D^{4.87}}$$ *Equation 2.4*

Where,

h_F = frictional headloss (m)

C = pipe carrying capacity factor

L = length of pipe (m)

Q = pipe flow rate (m^3/s)

D = diameter of pipe (m)

Table 2.1: Roughness Coefficients for New Pipe (Rossman, 2000)

Material	Hazen-Williams C (dimensionless)	Darcy- Weisbach f (feet x 10^{-3})	Manning's n (dimensionless)
Cast Iron	130-140	0.85	0.012-0.015
Concrete or Concrete lined	120-140	1.0-10	0.012-0.017
Galvanized Iron	120	0.5	0.015-0.017
Plastic	140-150	0.005	0.011-0.015
Steel	140-150	0.15	0.015-0.017
Vitrified Clay	110		0.013-0.015

iii. CHEZY-MANNING FORMULA

Another popular equation used in determining the headloss of a pipe network is the Chezy-Manning equation. It is more typically associated with open channel flow such as drains and channels and it is expressed as (Walski *et al*, 2003):

$$h_L = \frac{C_f L(nQ)^2}{D^{5.33}}$$ *Equation 2.5*

Where,

h_L = headloss in pipes (m)

C_f = Unit coversion factor to SI units

n = Manning roughness coefficient

Q = Pipe flow rate (m^3/s)

D = Diameter of pipe (m)

Table 2.2: Manning's Roughness Values (Garg, 2013)

Pipe Material	**Manning's Roughness Coefficient**
Asbestos Cement	0.011
Corrugated Metal	0.022
Concrete	0.015
Galvanized Iron	0.016
Cast Iron (new)	0.012
Steel (coal –tar enamel)	0.010
Steel (New unlined)	0.011
Steel (Riveted)	0.019
Wood stave	0.012

The head loss computed using Manning equation 2.5 is dependent on the pipe length and the diameter, the discharge or flow through the pipe, and roughness coefficient. A higher value for 'n' represents a higher internal pipe roughness. Table 2.2 provides typical Manning's roughness coefficients for commonly used pipe materials.

2.8.3.2 Headloss due to Appurtenance (Minor Loss)

The additional turbulence that develops at bends and fittings results in minor head losses (also known as local losses). The significance of integrating these losses relies on the network's design and the needed level of precision. By giving the pipe a modest loss coefficient, they can be explained. This coefficient and the velocity head of the pipe, or the minor headloss, are multiplied together.

$$h_L = K\frac{V^2}{2g}$$ *Equation 2.6*

Where,

h_L= minor losses

K = minor loss coefficient

V = flow velocity (m/s)

g = acceleration due to gravity (m/s^2)

Table 2.3: Minor Loss Coefficients for Selected Fittings (Rossman, 2000)

FITTING LOSS	COEFFICIENT
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Swing check valve, fully open	2.5
Gate valve, fully open	0.2

Short-radius elbow	0.9
Medium-radius elbow	0.8
Long-radius elbow	0.6
45-degree elbow	0.4
Closed return bend	2.2
Standard tee - flow through run	0.6
Standard tee - flow through branch	1.8
Square entrance	0.5
Exit	1.0

2.9 Physical Components of a Water Distribution Network

In a hydraulic model, a distribution system is depicted as a collection of linkages and nodes. Nodes, on the other hand, represent junctions, sources, tanks, and reservoirs, while links represent pipes. Depending on the particular software program, valves and pumps are either represented as nodes or as links.

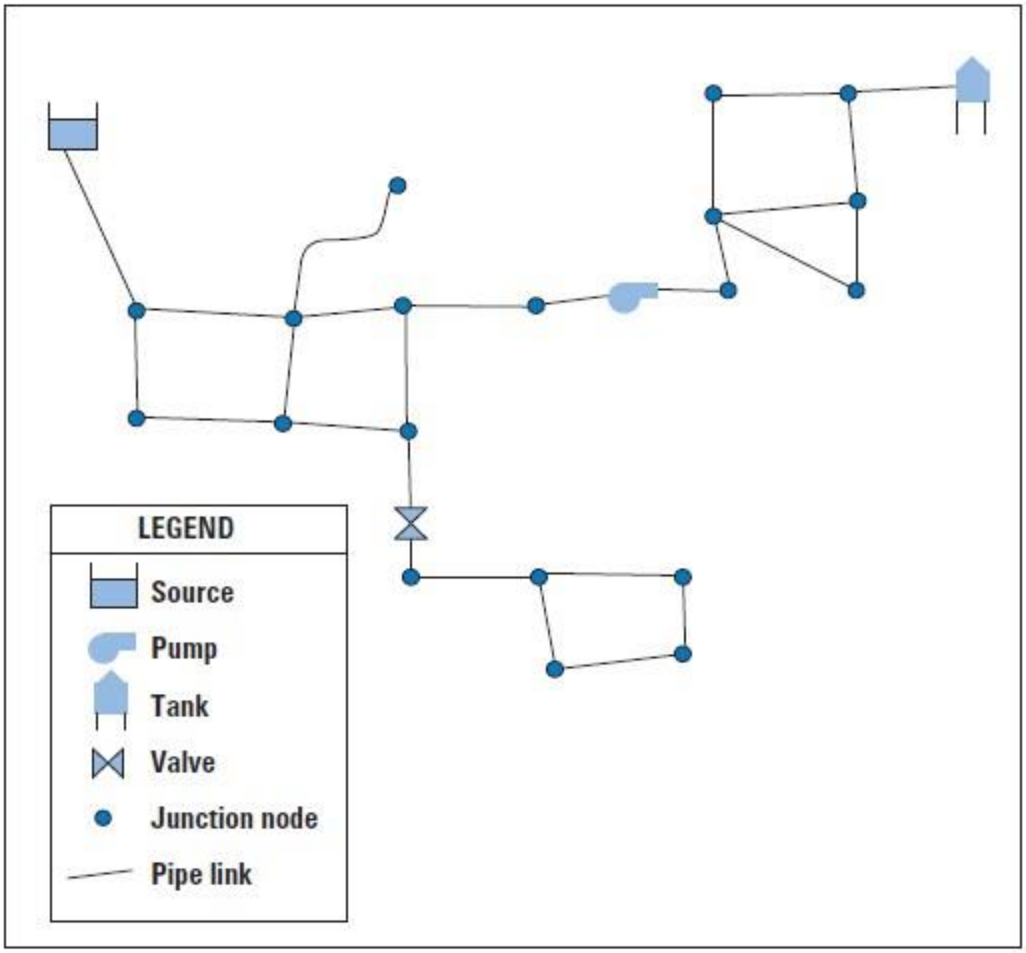

Figure 2.2: Link-Node Representation of a Water Distribution System (EPA, 2005)

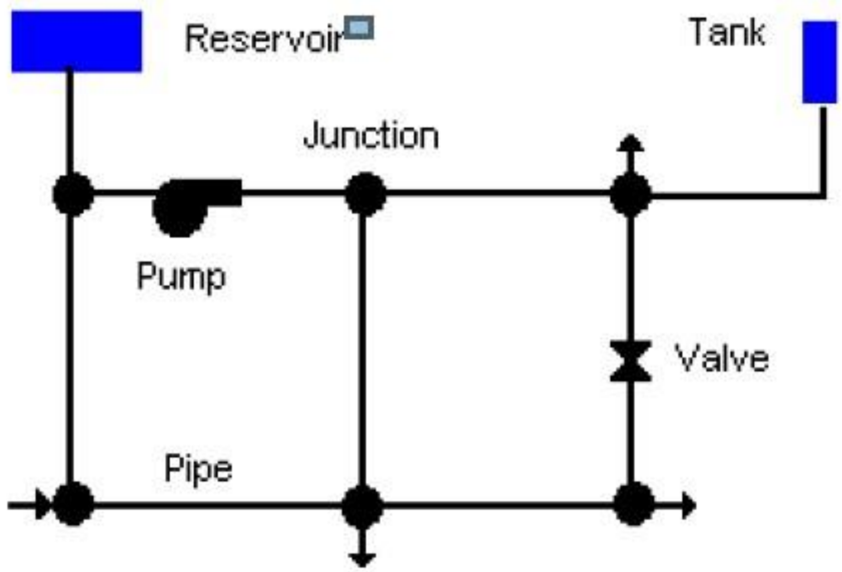

Figure 2.3: Physical Components using EPANET (Rossman, 2000)

2.9.1 Junctions

Junctions are places in a network where links join together and where water enters or exits. Elevation above a reference (often mean sea level), water demand (rate of network withdrawal), and operating water quality are the fundamental input data needed for junctions.

2.9.2 Reservoirs

Reservoirs are nodes that the network can use as an endless external source or drain of water. Modeling of things like lakes, rivers, groundwater aquifers, and connections to other systems are all done using them. Water quality source sites can also be reservoirs. The hydraulic head of a reservoir, which is equivalent to the water surface elevation if the reservoir is not under pressure, and its starting quality for water quality analysis are the two main input properties.

A reservoir's head and water quality cannot be impacted by network activity since it serves as a network's boundary point. It lacks computed output attributes as a result.

2.9.3 Tanks

Tanks are nodes with storage capacity, and throughout a simulation, the amount of water they can hold can change over time. The most important input factors for tanks are the bottom elevation (where the water level is zero), diameter, initial, minimum, and maximum water levels, and initial water quality. Hydraulic head (water surface height) and water quality are the main outcomes that are calculated over time. Tanks must function within their minimum and maximum ranges. When a tank reaches its minimum level or its maximum level, EPANET halts outflow and halts inflow, respectively. Tanks can be used as sources of high-quality water.

2.9.4 Pipes

Pipes are links that convey water from one point in the network to another. EPANET assumes that all pipes are full always. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head. The principal hydraulic input parameters for pipes are start and end nodes, diameter, length, roughness coefficient (for determining headloss), status (open, closed, or contains a check valve). The status parameter allows pipes to implicitly contain shutoff (gate) valves and check (non-return) valves (which allow flow in only one direction). The water quality inputs for pipes consist of bulk reaction coefficient and wall reaction coefficient. The most commonly used pipes today for water mains are ductile iron, pre-stressed concrete, polyvinyl chloride (PVC), reinforced plastic, and steel.

2.9.5 Pumps

Pumps are components that give a fluid energy, increasing its pressure or raising its hydraulic head as a result. The start and end nodes as well as the pump curve, or the sum of the heads and flows the pump is capable of producing, are the main input parameters for a pump.

Instead of a pump curve, the pump might be visualized as a constant energy device that delivers the fluid with the same amount of energy (horsepower or kilowatts) for all possible combinations of flow and head. Flow and head gain are the main output parameters. Pumps only allow one direction of flow, and EPANET won't permit a pump to operate outside the boundaries of its pump curve.

2.9.6 Valves

Valves are linkages in a network that control the flow or pressure at a particular location. Start and end nodes, diameter, setting, and status are some of the main input parameters for these systems. Flow rate and headloss are the computed outputs for a valve. The following valve types are among those found in EPANET:

i. Pressure Reducing Valve (PRV)

ii. Pressure Sustaining Valve (PSV)

iii. Pressure Breaker Valve (PBV)

iv. Flow Control Valve (FCV)

v. Throttle Control Valve (TCV)

vi. General Purpose Valve (GPV).

2.10 Non-Physical Components of a Water Distribution Network

In addition to physical components, EPANET uses three different types of informational items to represent the behavior and operational features of a distribution system: curves, patterns, and controls.

2.10.1 Curves

A relationship between two quantities is represented by data pairs that make up curves, which are objects. A curve may be shared by two or more objects. Pump curves, efficiency curves, volume curves, and head loss curves are among the curve types that can be used in EPANET models.

2.10.2 Time Patterns

When a quantity is to be allowed to change over time, a Time Pattern is a set of multipliers that can be used. It is possible for time patterns to be related with nodal needs, reservoir heads, pump schedules, and water quality source inputs. Each pattern employs the same fixed time interval. During this time frame, a quantity stays at a constant value that is equal to the sum of its nominal value and the pattern's multiplier for that time frame. While every time pattern must use the same time interval, there is no restriction on how many periods can be in a pattern. A pattern loops back to its first period when the simulation clock reaches the maximum number of periods in the pattern.

2.10.3 Controls

Controls are components that specify how the network will be run over time. At certain locations throughout the network, they define the state of chosen links as a function of time, tank water levels, and pressures. Useful controls fall into two categories: simple controls and rule-based controls.

2.11 Review on Previous Studies Done

Akodwaa-Boadi (2012) modelled free chlorine decay in the Kumasi Water Distribution Network using SynerGEE software. This was achieved by determining the bulk and wall chlorine decay coefficients of aged PVC, AC and Cast Iron pipes. By applying first order decay kinetics, he obtained the bulk coefficients to be $0.053hr^{-1}$ and wall coefficient to be 0.25, 0.19 and $0.38hr^{-1}$ for PVC, AC and Cast Iron pipes respectively.

Ogbeifun (2015) modelled chlorine residual in UNIBEN Ugbowo Campus Water Distribution System using EPANET software. He performed a bulk chlorine decay (Batch Test) on water samples from UNIBEN Ugbowo Campus using the HACN CN66 Chlorine Residual Kit to obtain the bulk chlorine coefficient of the water and found the value to be $0.039hr^{-1}$. His finding showed that residual chlorine of 0.3mg/L at the headwork work would leave a minimum of 0.22mg/L at the extreme nodes.

Omosigho (2017) carried out a hydraulic analysis system and a study for the improvement of the UNIBEN Ekehuan Campus water distribution using Water CAD software. It was found that the existing system is inadequate to meet the present and future water demand and suggested measures to improve the network to be able to meet the water need of the present and future. The suggested improvement measures include:

1. The existing elevated tank capacity increased from **58 m^3** to **200 m^3**.

2. The elevated tank height increased from the present **9.4m** to **15m**

3. Pumping hours of BH1 and BH2 increased from **4 hours** to **16 hours** each daily.

4. The transmission pipes (PI12 and PI13) increased from existing **75mm** diameter to **200mm** diameter.

5. The distribution pipes increased from existing **75mm** diameter to **100mm (**PI1, PI3, PI6, PI8, and PI9) **and 150mm** diameter (PI2, PI4, PI5, PI7, PI10 and PI11).

6. The discharge pipe **(**PI14**)** from the elevated tank increased from present **75mm** to **200 mm.**

Though Omosigho (2017) carried out hydraulic analysis of the existing water distribution network on the basis of an improved water distribution network was desgined, it only carried out a physico-chemical and biological analysis of water supplies without any water quality modelling of the network. This study will extend the existing study by conducting a water quality modelling of the water distribution system.

CHAPTER THREE

3.0 METHODOLOGY

3.1 UNIVERSITY OF BENIN WATER SUPPLY SCHEME

The distribution system in the University of Benin supply water to staff and students that are resident in the Ugbowo campus of the university. Some of the staff both in the senior and junior cadre are resident on campus while the others only stay during working hours (8am to 5pm). The major consumers of the water in University of Benin distribution network are the students, who reside in the halls of residence in the Ugbowo campus. These halls of residences are usually over crowded with the water facility highly prone to contamination from the activities of the students.

The Ugbowo campus of the University of Benin covers an area of 2,823 hectares and it is located between latitude 6º 23’ 15”N and 6º 24’ 30”N and longitude 5º 36’ 30”E and 5º 38’ 30”E. It is bounded in the west by the Benin Ore express way, in the north by Ekosodin community, in the east by Uteh community and in the south by the University of Benin Teaching Hospital (UBTH).

The University of Benin Ugbowo campus consists of site A in the western part of the campus with land area of 1,462 hectares and site B in the eastern part of the campus with a land area of 1,387 hectares. The two sites are separated by the Ikpoba River.

University of Benin Ugbowo Campus initially relied upon the State Urban water Board for its water supply which was taken from a 200mm diameter pumping mains along Benin – Ore road. The water supplied was unreliable which led the University to consider constructing its own boreholes and treatment plants, ground and elevated water storage reservoirs and distribution pipelines were laid along most roads and streets in the Ugbowo campus (Onaghinor, 2001). University of Benin water system supplies water to the entire campus in Ugbowo comprising all the faculties, senior and junior staff quarters, students' hostels (Halls), Administrative offices, libraries, cafeteria, Ekosodin community etc.

In order to reduce the stress on the water infrastructures and be able to meet the water demand of the increased population in the University, 75mm AC pipes were laid parallel to the existing ones which supply water from the borehole located at the back of postgraduate school to clinical hostel, students hostels (hall 1, hall 2 and hall 3). Futhermore, 150mm AC pipes were also laid parallel to the 200mm AC pipes along the road leading to the Capitol and supplied water to Vice Chancellor's lodge. Currently, these pipes have been replaced by 200mm diameter uPVC pipes.

The water delivered from the waterworks is distributed to the service area through a network of pipes ranging from 75mm to 300mm diameter with supply regulated by reinforced concrete elevated storage tanks, ground storage tank and booster pumps in the headwork. Figure 3.1 shows the layout map of the University of Benin. The elevated water storage tank and ground level storage reservoir in the waterworks are shown in Figure 3.3 and Figure 3.4 respectively. There is a gully erosion site which has affected the UNIBEN water supply scheme. Another end cap is located at capitol and near nursing hostel where the supply to UBTH was truncated.

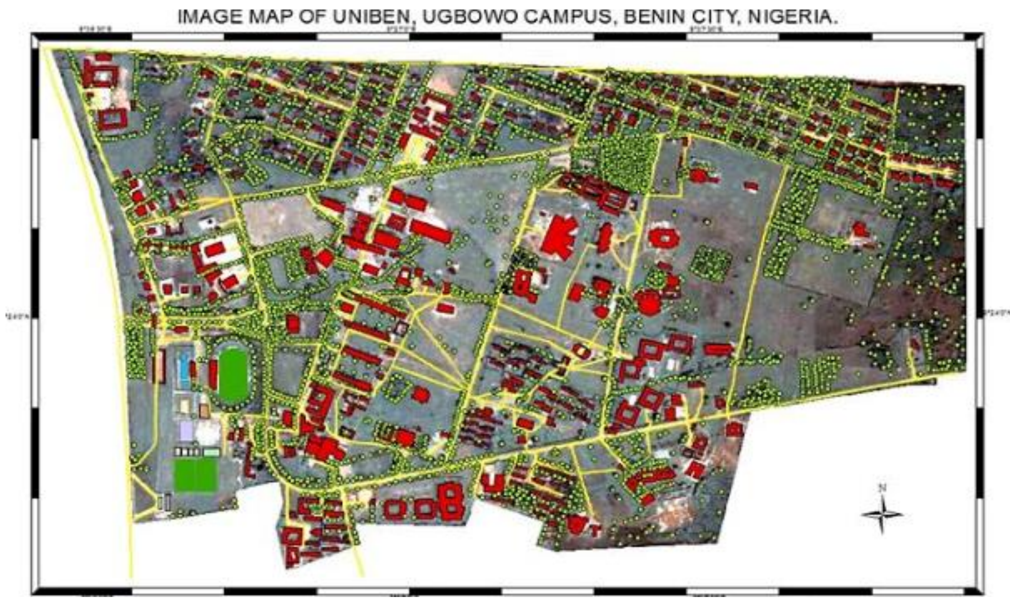

Figure 3.1: Digitized layout Map of Road Network in the University of Benin

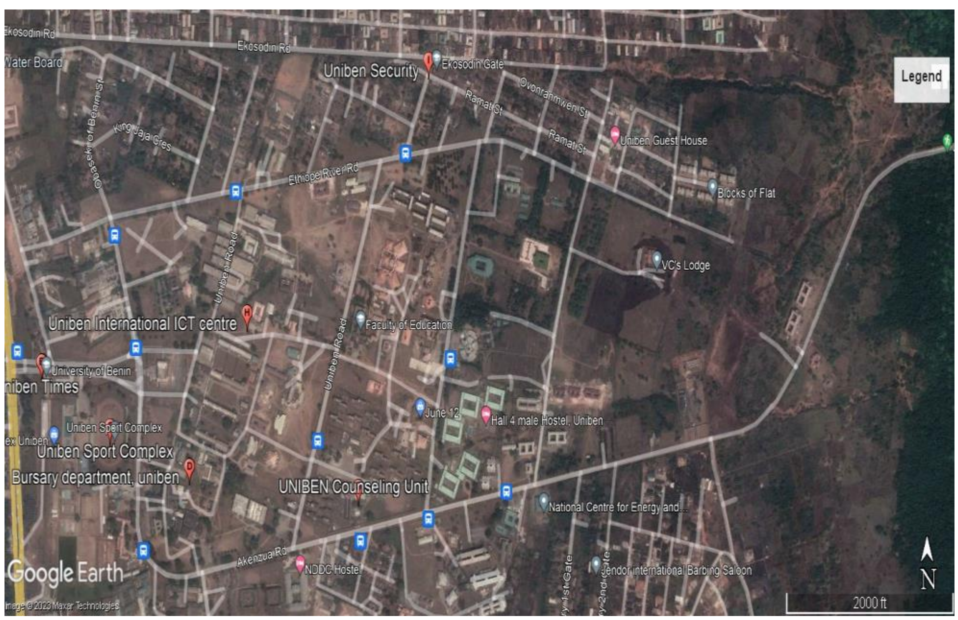

Figure 3.2: Google Earth Imagery of the University of Benin

Figure 3.3: Elevated Water Storage Tank in UNIBEN

Figure 3.4: Ground Level Storage Reservoir (GLSR) Uniben Waterworks

3.10 Procedures For Obtaining The Google Earth Image

i. Open the Google earth pro software and ensure a network connection has been established.

ii. From the sidebar use the search tab to locate the town.

iii. From the toolbar select the add placemark button and add four points enclosing the entire town and label these points i.e. pml, pm2, pm3 & pm4.

iv. Locate place tab on the sidebar were the four placemarks are listed right click pm1 and select properties and save the northing and easting.

v. Repeat step 4 above for pm2, pm3 & pm4

vi. Zoom the entire town to extend and click on the save image button on the toolbar.

vii. On clicking the save image button another bar would appear under the toolbar, simply select the map option and also set the resolution to maximum and click the save button after which the save as dialogue box appear select JPEG. Format and enter a file name and location.

3.10.1 Procedures For Obtaining Node Elevations

i. Open Google Earth Pro and search the study location.

ii. Locate tool bar and left click on add path.

iii. Select Style, color and increase width of the path to maybe 2.5.

iv. Select Altitude and ensure to use **Clamped to Ground.**

v. Select Measurement and set to **meters.**

vi. Click **OK** after selecting all possible nodal points according to the design on EPANET.

vii. Locate places on side bar and right click on the current path.

viii. Select save as and save file in kml format.

ix. Open Chrome Browser and search GPSvisualizer.com and left click convert to plain text.

x. Upload the kml file saved from Google Earth Pro.

xi. Left click on **Add Dem Elevation Data** dropdown and select best available source.

xii. Click on convert and note the elevation being displayed for each selected node in (6) above.

3.10.2 Procedures For Drawing The Network On EPANET

i. Open the EPANET software.

ii. Locate view tab and select backdrop.

iii. Then Load the Saved image that is in BMP format.

iv. Add Storage tank to the network and edit the properties.

v. Assign nodes to various Junctions according to the Google Earth Image

vi. Select the add pipe icon from the map toolbar and add pipes from node to node and edit the properties of each pipes.

3.11 Distribution Network Modelling in EPANET

This study involved hydraulic analysis and design of water distribution system using EPANET software. The input data required by EPANET for hydraulic simulation includes the pipes with the different diameters; node locations, elevation of nodal points, water demands, and patterns. The University of Benin water distribution is powered predominantly by gravity due to the correct location of the headworks. The schematic network and the modelled network of the University of Benin is presented in Figure 3.5 and Figure 3.6 . EPANET uses the Hardy Cross method for the hydraulic analysis of the distribution network.

Figure 3.5: Schematic network design on Google Earth

3.11.1 Nodal Water Demand

The nodal demand of water in the distribution system was computed by determining the total water demand of the University of benin Ugbowo campus. This comprises water of water use for flushing and cleaning in the administrative area as well as water for drinking and other domestic uses in the residential areas. The residential areas consist of the staff quarters and the hostels.

In determining the water demand for the university, the population of staff and students of the university was obtained. The students comprises graduated and postgraduate students of the University of Benin as well as pupils of Uniben staff nursery, primary and secondary schools. The number of students resident in the various hostels was also obtained from the office of the dean, students' affairs, University of Benin. A per capita water demand of 120lcpd demand was adopted for this study.

It is worthy of note that while the population of the students obtained included those at the Ekehuan campus of the university, the extra augmented for the population of non-students and staff who earn a livelihood in the University of Benin premise. These include those that work in the banks, in the shopping complex and contractors executing various projects.

3.11.2 Topographical Survey of University of Benin

Topograhical map of the project area was produced from a 10m contour-interval map of Benin City. The information obtained from the contour map were used to produce a 1m contour interval map for the University of Benin. Figure 3.6 shows the contour map of the University of Benin from which nodal elevation was extracted.

3.11.3 Pattern formulation

The University of Benin comprises staff who are either resident on campus or stay in the environment only during working hours and days. The implication of this is that water consumption is not static but fluctuates with the number of persons in the land area per time.

The consumption is even more drastically reduced in the weekend and holiday periods than in the working week days.

For this study, two patterns were formulated. The patterns were constructed for 24 hours period in the administrative area (WKI) as well as for the resident area (RESI). Figure 3.7 and 3.8 shows the pattern of water consumption for WKI and RES 1. The patterns were designed to reflect the patterns stated by Georgescu and Georgescu, (2012).

3.2 Population Projection

A demographic methodology called the geometric method for population projection uses a straightforward mathematical model to predict future population sizes. It is predicated on the idea that over a specific time frame, the population increases or decreases steadily. The approach operates as follows:

1. Initial Population: As a starting point, use the size of the current population.

2. Growth Rate: Establish the rate of annual growth. The annual percentage increase or reduction in population is represented by this rate.

3. Projection Period: Indicate the length of time you wish to project the population for.

4. Calculation: Repeatedly across the projection period, multiply the original population by the growth rate. This calculation's formula is:

Current Population + Growth Rate = Future Population Number

The population was projected using Equation 3.2

$$P_t = P_i(1+r)^n \qquad \text{Equation 3.2}$$

Where,

Pi = the initial population,

r = the annual growth rate,

n = the number of years,

Pt = the Projected population

Table 3.1 Design Standard For EPANET 2.2 Simulation

S/N	Description	Standards
	Demand	
1	Base demand/Average Daily Demand (ADD)	To be completed based on per capita of 300 litres per day for the total residential population
2	Maximum Daily Demand (MDD)	1.25-1.50
3	Peak Hour Demand (PHD)	1.50-3.00
	Head losses	
4	Head loss for pipe diameter of 100-300mm	1.0-3.0 m/km
5	Head loss for pipe diameter greater than 300mm	2.0-5.0 m/km
	Velocities	
6	Velocity of flow for pipe diameter of 100-150mm	0.3-1.0 m/s (optimum0.4 m/s)
7	Velocity of flow for pipe diameter of 200-300mm	0.4-1.5 m/s (optimum 0.5 m/s)
8	Velocity of flow for pipe diameter greater than 300mm	0.5-2.0 m/s (optimum 0.6 m/s)
	Pressure	
9	Pressure downstream of district meter area	15-40 m (minimum 12.5 m)
10	Pressure downstream of district meter area and mains	25-60 m (minimum 12.5 m)
	Pipe Material	
11	High Density Polyethylene (HDPE) pipes	100-600 mm
12	Ductile Iron	Greater than 600 mm
13	Domestic Connections (external diameter)	20, 25, 32, 40 and 50 mm

CHAPTER FOUR

4.0 PRESENTATION AND DISCUSSION OF RESULTS

4.1 Water Demand Computations

The population of the University of Benin, Ugbowo campus was computed to determine the water demand of the institution. Population values were obtained for the number of postgraduates, undergraduates, staff and pupils of the University of Benin staff school. Appropriate assumptions were made for other persons who one way or the other enter the university campus daily.

4.1.1 Staff Population of the University of Benin

The staff of the University of Benin is divided into academic and non-academic staff (see Table 4.1). The academic staff comprises staff of the various faculties of the University, while the non- academic staff comprises the administrative staff both at Ugbowo campus and Ekehuan campus of the University. The population of staff of the university at Ekehuan campus will augment the population in the Ugbowo campus who are not staff but depend on the university for their water needs. These groups of persons comprises those working in the food court, transport operators, shop/laundry operators, etc.

Table 4.1: Staff Strength of the University of Benin

Staff Group	Number
Academic staff	1896
Non-Academic staff	4393
TOTAL NUMBER OF STAFF	**6289**

4.1.2 Undergraduate Students Population

The population of undergraduate students in the University of Benin are as presented in the Table 4.2. The Figures comprises data obtained from fourteen (14) faculties in the University of Benin. It is estimated that about 45% of the population of Art students are in Ekehuan campus, comprising of Fine Art department, Music department, etc.

Table 4.2: Undergraduate Students in the various Department of the University of Benin

S/N	**Faculty**	**Population**
1	Agriculture	4009
2	Arts	12500
3	Basic Medical Sciences	4522
4	Dentistry	333
5	Education	15944
6	Engineering	8478
7	Environmental Sciences	280
8	Law	2032
9	Life Sciences	10512
10	Management Sciences	6455
11	Medicine	1604
12	Pharmacy	2078
13	Physical Sciences	7123
14	Social Sciences	6523
	TOTAL	**82393**

4.1.3 Post Graduate Students Population

The population of the post graduate students in the University of Benin was obtained from Central Processing Unit of the University of Benin **(see Table 4.3 below).** The number of students resident on campus was obtained from the students' Affairs division of the University of Benin.

Table 4.3: Post Graduate Students from 2021/2022 to 2022/2023 as at August 2023.

Faculty	**Total row**
Agriculture	334
Arts	540
Basic Medical Sciences	531
Education	1432
Engineering	1266
Environmental Sciences	176
Institute of Education	144
Institute of Public administration	138
Law	249
Life Sciences	866
Management Sciences	805
Medicine	303
Pharmacy	326
Physical Sciences	595
Social Sciences	717

TOTAL	8422

4.1.4 Population of Pupils and Contract Staff in Uniben Staff School

Population values were obtained from the management of the university staff secondary school and estimate were obtained for the nursery and primary school. The numbers of pupils are presented in Table 4.4.

Table 4.4: Population of Students in Uniben Staff School

Number of Pupils of Uniben Staff School	**Total**
Nursery and primary school pupils and board employed staff	1006
Secondary school pupils and board employed staff	1450
TOTAL	**2456**

4.1.5 Summary of Nodal Water Demand

For a per capita water demand of 120Lpcd, the amount of water consumed per resident per second is given as 0.00139L/c/s. The base water demand for each segment of the population of the university is given in Table 4.5. Since the population obtained is inclusive of number of students and staff at Ekehuan campus, this sufficiently accounts for the non-students and non-staff who are working in other areas of the campus such as the business centres, banks, Agric farms etc. The obtained total water demand was also used as the peak demand considering that the network being studied is already in existence and can only meet design population estimates.

Table 4.5: Summary of water Consumers in the University Campus

S/N	Water consumers	Total Population	Water demand (L/s)
1	Uniben staff	6289	8.742
2	Undergraduate students	82393	114.526
3	Post graduate students	8422	11.707
4	Uniben staff school/contract Teachers	2456	3.414
		TOTAL	**138.389**

4.2 Water Demand of Campus Residents

The senior staff quarters in the University of Benin comprises about 243 blocks of apartments consisting of several bungalows and duplexes. The bungalow consist of boys quarters which, more often than not, accommodate students. Assuming that each block of apartment is occupied by 10 persons comprising of a family of six (6) in the main building and four occupants in the 'boy quarters'. The total number of senior staff in the University of Benin was found to be **2430**.

The junior staff quarter which is situated to the west of hall 3 hostel comprises 52 apartments comprising of 3-bedroom and 2-bedroom flats. A maximum occupants of 8 persons was assumed as occupants of each of the block which amounted to 416 occupants.

Table 4.6: Population of Cleared students in the Halls of Residence

S/N	Hostels/quarters	Total Number of Cleared Bed Spaces
1	Queen Idia Hall (Hall 1)	1920
2	Tinubu Hall (Hall 2)	1920
3	Aminu Kano Hall (Hall 3)	1920
4	Hall 4	2000
5	Hall 5 (female)	120
6	Hall 5 (male)	120
7	Hall 6	150
8	Hall 7	150
9	NDDC (female)	388
10	NDDC (male)	308
11	Keystone Bank Hostel (PG)	204
12	Dr. Erastus Akingbola Hostel (PG)	92
13	Intercontinental Bank Hostel (PG)	61
14	Clinical Hostel	477
	TOTAL	**9830**
	Total population using a peak factor of 1.5	**14745**
15	Junior staff quarters	2430
16	Senior staff quarters	416
	TOTAL POPULATION	**17591**
water consumption @0.00139L/s		**24.451**

Table 4.6 present the number of students resident in the various hostels during the 2022/2023 academic session. A peak factor of 1.5 was used to determine the population of students in the hostels. This is predicated on the fact that the hostels are usually overcrowded due to students squatting with their friends in the halls of residence.

Table 4.7: Representation of the Links

Link ID	Start Node	End Node	Length m	Diameter mm
P1	J1	J2	222.16	400
P2	J2	J41	225.73	63
P3	J41	J3	196.8	63
P4	J3	J4	360.9	39
P5	J4	J5	444	30
P6	J5	J6	117.5	25
P7	J6	J7	164.84	25
P8	J7	J8	325.56	25
P9	J8	J9	476.7	25
P10	J9	J10	394	25
P11	J10	J11	469.5	25
P12	J8	J12	227.4	25
P13	J12	J13	300	21.56
P14	J13	J14	500	37.56
P15	J2	J42	180.53	100
P16	J42	J17	225.5	100
P17	J17	J16	252	75
P18	J16	J15	192.5	100
P19	J15	J20	133.5	100
P20	J20	J21	250	25
P21	J21	J19	270.5	12
P22	J20	J14	258.75	75
P23	J14	J18	90	75
P24	J18	J19	80.86	50
P25	J19	J28	136	50
P26	J18	J23	287.3	50
P27	J9	J22	274	25
P28	J22	J23	618.82	25
P29	J10	J24	613.7	50
P30	J24	J25	189.64	50
P31	J23	J26	176	50
P32	J23	J27	90	25
P33	J26	J25	202.9	50
P34	J25	J40	96	50
P35	J40	J34	208.5	50
P36	J28	J27	247.5	50
P37	J27	J29	93.2	39

P38	J29	J30	162.65	25
P39	J26	J31	61.2	25
P40	J27	J31	170	25
P41	J31	J32	203.5	25
P42	J25	J32	63.8	25
P43	J32	J33	91.4	20
P44	J40	J37	127	50
P45	J34	J36	123.92	25
P46	J36	J35	94.2	25
P47	J37	J38	86.1	25
P48	J33	J39	60	25
P49	J30	J33	204.5	25
P50	J3	J16	270.6	39
P51	J31	J30	93.5	25
P52	J37	J36	180	25

Table 4.8: Representation of the Nodes

Node ID	Demand LPS	Head m	Pressure m
J1	-4.50	128.40	14.20
J2	0.10	128.40	12.00
J3	0.10	127.30	14.30
J4	0.10	124.98	7.18
J5	0.10	118.19	4.99
J6	0.10	115.62	5.02
J7	0.10	115.20	5.70
J8	0.10	114.97	6.57
J9	0.10	115.43	16.93
J10	0.10	116.10	17.40
J11	0.10	115.78	23.88
J12	0.30	114.74	7.34
J13	0.30	119.69	13.79
J14	0.30	123.18	19.68
J15	0.00	125.53	13.13
J16	0.10	125.97	8.97
J17	0.10	127.86	12.16
J18	0.10	122.75	19.25
J19	0.10	122.18	17.98

J20	0.10	125.23	15.93
J21	0.10	123.80	13.70
J22	0.10	115.71	13.51
J23	0.10	119.76	19.76
J24	0.00	116.74	21.74
J25	0.10	116.94	20.94
J26	0.10	118.04	21.04
J27	0.10	120.02	20.12
J28	0.10	121.31	17.71
J29	0.10	119.76	20.76
J30	0.10	117.76	19.56
J31	0.10	117.84	19.44
J32	0.10	117.07	20.57
J33	0.10	117.09	20.69
J34	0.10	116.60	21.40
J35	0.10	116.44	24.14
J36	0.10	116.50	21.80
J37	0.10	116.60	23.10
J38	0.10	116.54	22.84
J39	0.10	117.05	21.75
J40	0.10	116.69	20.69
J41	0.10	127.76	13.26
J42	0.10	128.31	12.31

Table 4.9: Final Results for the Links

Link ID	Flow LPS	Velocity m/s	Unit Headloss m/km	Status
P1	4.50	0.04	0.00	Open
P2	1.14	0.37	2.82	Open
P3	1.04	0.33	2.38	Open
P4	0.50	0.42	6.42	Open
P5	0.40	0.57	15.28	Open
P6	0.30	0.62	21.90	Open
P7	0.20	0.41	2.54	Open
P8	0.10	0.21	0.72	Open
P9	-0.12	0.25	0.97	Open
P10	-0.16	0.33	1.70	Open
P11	0.10	0.20	0.69	Open
P12	0.12	0.25	1.02	Open
P13	-0.18	0.48	16.52	Open
P14	-0.48	0.43	6.97	Open
P15	3.26	0.42	0.51	Open
P16	3.16	0.40	1.97	Open
P17	3.06	0.69	7.53	Open
P18	3.40	0.43	2.25	Open
P19	3.40	0.43	2.25	Open
P20	0.15	0.30	5.72	Open
P21	0.05	0.41	5.99	Open
P22	3.15	0.71	7.94	Open
P23	2.37	0.54	4.70	Open
P24	1.02	0.52	7.07	Open
P25	0.97	0.49	6.40	Open
P26	1.26	0.64	10.42	Open
P27	-0.06	0.12	1.02	Open
P28	-0.16	0.32	6.55	Open
P29	-0.36	0.18	1.05	Open
P30	-0.36	0.18	1.05	Open
P31	1.21	0.62	9.79	Open
P32	-0.22	0.44	2.86	Open
P33	0.88	0.45	5.41	Open

P34	0.60	0.31	2.65	Open
P35	0.21	0.11	0.39	Open
P36	0.87	0.44	5.23	Open
P37	0.32	0.27	2.81	Open
P38	0.22	0.45	12.28	Open
P39	0.23	0.48	3.29	Open
P40	0.23	0.46	12.84	Open
P41	0.25	0.51	3.75	Open
P42	-0.18	0.37	2.08	Open
P43	-0.03	0.10	0.24	Open
P44	0.29	0.15	0.68	Open
P45	0.11	0.23	0.84	Open
P46	0.10	0.20	0.69	Open
P47	0.10	0.20	0.69	Open
P48	0.10	0.20	0.69	Open
P49	0.23	0.47	3.25	Open
P50	0.44	0.36	4.92	Open
P51	0.11	0.22	0.82	Open
P52	0.09	0.18	0.54	Open

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

1. EPANET is a satisfactory for the hydraulic analysis and water quality modelling of water distribution networks.
2. The result obtained by use of EPANET compared favourably with those obtained by using linear theory method in the analysis of the Jeppson network.
3. Results obtained by using EPANET 2.2 for the hydraulic analysis of UNIBEN Ugbowo campus water distribution network are in close agreement and can thus be utilized interchangeably.

5.1 CONCLUSION

The following conclusions are drawn based on the findings from this study;

1. The values obtained from EPANET 2.2 are reliable and satisfactory for hydraulic simulations as it is a faster, accurate and an easy means of carrying out hydraulic computations.

2. EPANET hydraulic simulating softwares give comparable results in analysis.

3. The results from the simulation in the proposed water distribution system proves to more be efficient and sufficient to supply water to various destinations than the existing distribution system.

5.2 RECOMMENDATIONS

EPANET 2.2 has proved to be an efficient software for hydraulic and water quality modelling. Hence, it is recommended to be adopted for these purposes especially for designing a proposed water distribution system to ensure an economic design is obtained.

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APPENDIX

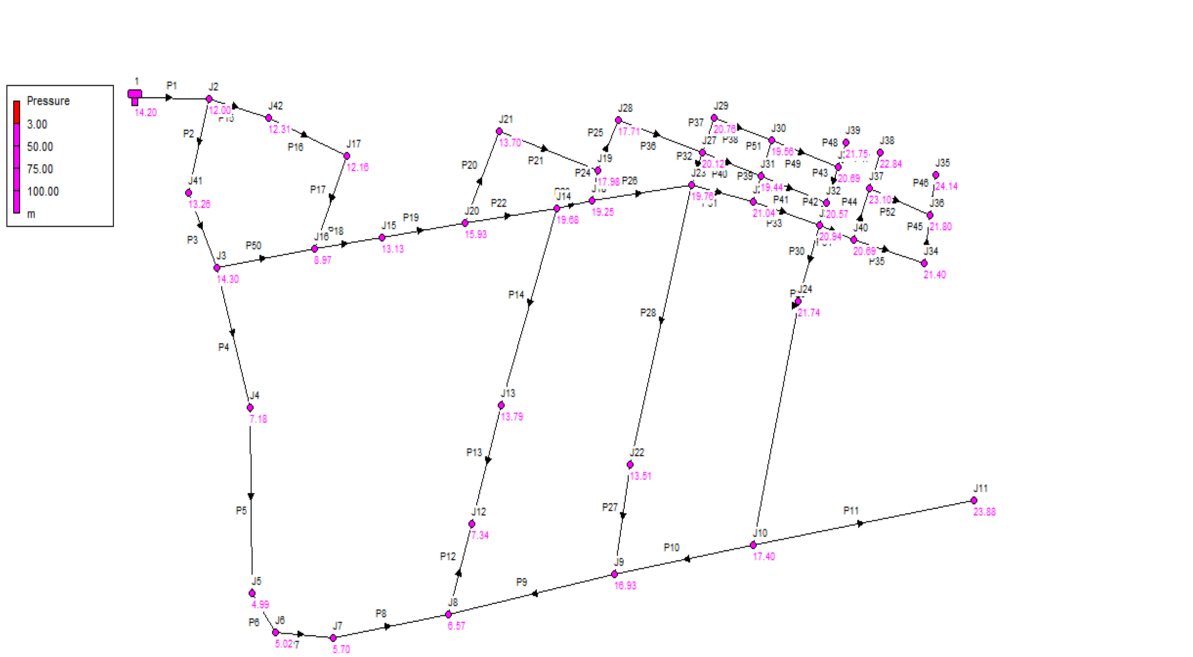

Figure A1: Pressure at Nodes of Hypothetical Network

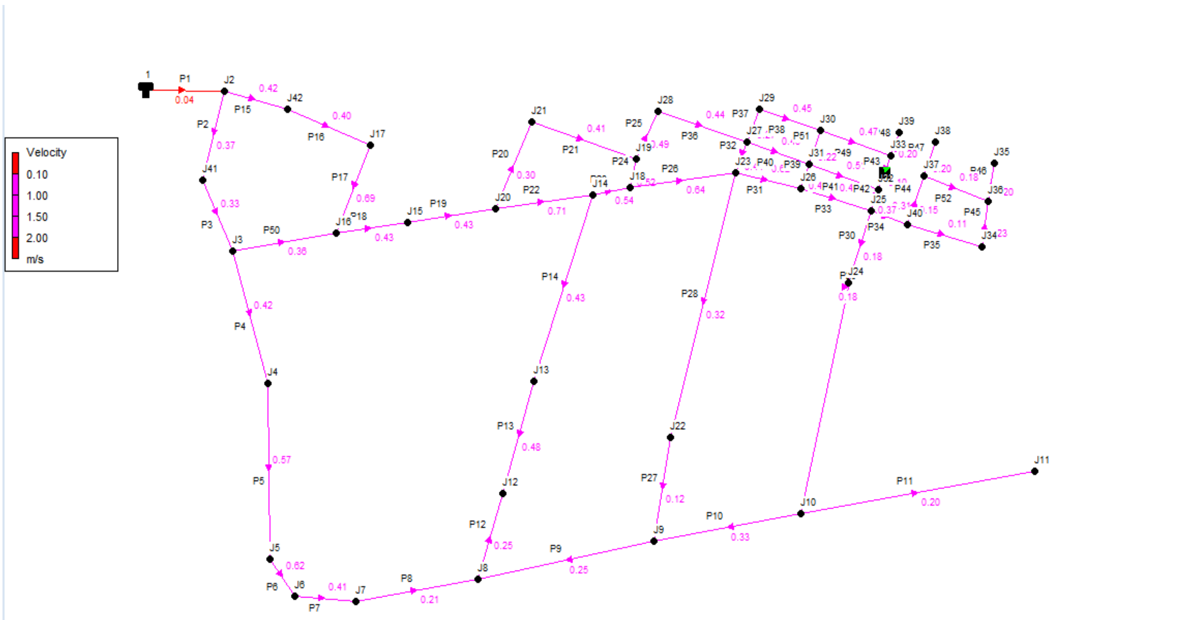

Figure A2: Velocity in Pipes of Hypothetical Network

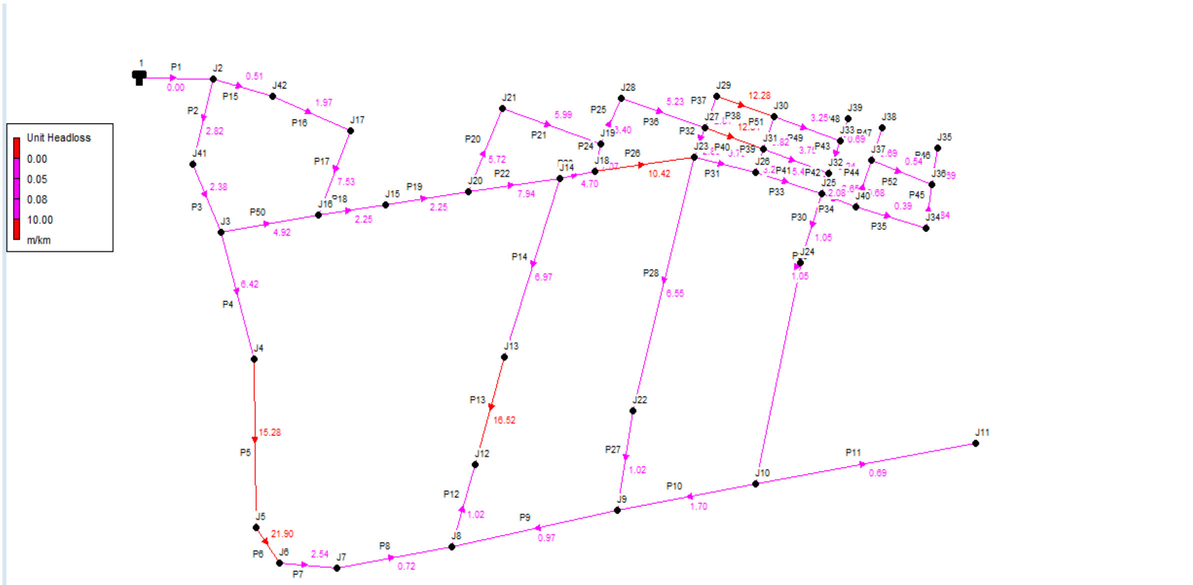

Figure A3: Headloss in Pipes of Hypothetical Network

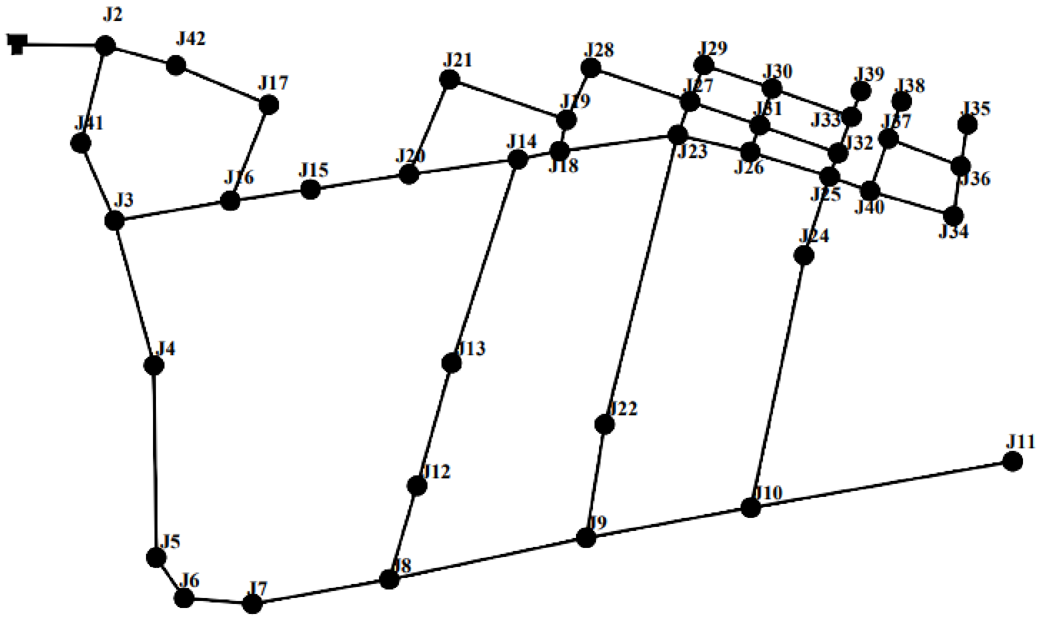

Figure A4: AUTOCAD REPRESENTATION OF ALL NODES

JUNCTIONS	**LANE**	**DESCRIPTION**
J2 J41 J3 J4 J5	1	Saint Albert Catholic Church
J6 J7 J8 J9 J10 J11	2	NDDC Hostel (Akenzua Road)
J8 J12 J13 J14	3	Education Field
J9 J22 J23 J27 J29	4	Faculty of Law
J10 J24 J25 J32 J33	5	Keystone Hostel

J39		
J3 J16 J15 J20 J14 J18 J23 J26 J25 J40 J34	6	Senior Staff Quarters Axis
J2 J42 J17 J16	7	Uniben Water Board
J20 J21 J19	8	Back gate leading to Ekosodin
J18 J19 J28	9	Back gate leading to Ekosodin

J28 J27 J31 J32	10	Blocks Of Flats Axis
J29 J30 J33	11	Uniben Guest House
J40 J37 J38	12	VC lodge
J34 J36 J35	13	VC lodge