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UTILIZATION OF EPANET FOR THE DESIGN OF INSTITUTIONAL PIPE NETWORK

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ABSTRACT

Sustainable facility design has been established as one of the most important practices for achieving sustainability. Efforts to enhance the progress on access to drinking water, sanitation and hygiene in institution's environments, attain 17 United Nations' Sustainable Development Goals, environmental and cost performances of a product require innovative design. This innovative facility design requires new design concepts and engineering specifications. In this paper, pipe network analysis of Elizade University (EU), Ilara- Mokin was conducted as a way to attain a sustainable product. The population of the institution between 2011 and 2018 was collected and projected to 2026 using the geometrical progression technic. Water demand at each of the nodes was computed using standard methods. The network was drawn and analysed using EPANET software. The study revealed that the pipeline was open loops, a mixture of both surface and underground layouts. It has an overhead tank, 43 pipes of two diameters (50 mm and 150 mm) and 44 nodes. 50 mm diameter pipes accounted for 54.51 % and 150 mm accounted for 45.49 %. The water demands at the nodes were between 30l/s and 480l/s, flows in the pipes were from 20 l/s to 3545l/s, and the velocity of flow in the pipe was in the range of 1.13 m/s to 1805 m/s and the friction factor of these pipes ranged between 0.012 and 0.016. Analysis of the Variance of the effects of the diameters on the outputs of the analysis revealed that the diameter of the pipe has an effect on the flow or discharge and the velocity of flow or discharge in the pipe, and the friction factor of these pipes, but not a significant a factor at 95 % confidence level ($F_{1,10}$= 0.034; p = 0.858). It was concluded that the pipeline and pipe layout at the EU is mainly open loops, consisting of 50 millimetres and 150 millimetres diameter pipes and the size of the pipe (diameter) is a function of the flow rate, the velocity of flow and the friction factor through it.

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1. Introduction

Water is one of the natural resources that are essential for the nourishment of life, and ecological and environmental systems (Oyebode and Igbi, 2018). Potable water is a vital resource for communities' economic and social development. Federal, State and local governments, industries, privates, and several organizations (both international and national) worldwide have executed water schemes to encourage safe water production and supply to institutions and communities over the years (Oyebode and Igbi, 2018). Water quality and quantity are essential to sustainable development. An adequate water supply is precious for healthy ecosystems, socioeconomic development and for human survival.

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An adequate water supply is precious for healthy ecosystems, socioeconomic development and for human survival. Adequate water distribution and supply (quantity and quality) is critical in reducing the global burden of waterborne and water-related diseases and enhancing the welfare, health, and productivity of populations (Oyebode and Igbi, 2018). Figure 1 presents a Piktochart of 17 (seventeen) United Nations' Sustainable Development Goals and a Venn illustration of the three (3) pillars (economy, society and environment) of sustainable development. The present worldwide population growth rate in the institutions and higher standards of living will remain to create demand for clean, safe and potable institutional, municipal, communal and industrial water. The literature establishes that there is a perfect and good relationship between the availability of safe and adequate water, sanitation, health, hygiene and sustainability development (Oke *et al.,* 2016; Sikka *et al.,* 2022; Alam *et al.,* 2022). Figure 2 shows the global coverage of drinking water services in schools between 2015 and 2021 and the regional coverage of drinking water services in schools from 2015 to 2021 (JMP, 2022). In municipal, institutional and industrial water supply schemes, the collection, treatment, production, storage, distribution and supply of treated water and potable water are the key and major elements that affect the quantity and quality of the potable and treated water distribution, supply and availability to the consumers or communities. Water collection, treatment, production and storage are continuous processes that can be improved easily at any period of time, due to fluctuations in quantity and quality, while treated water distribution and availability to the community are fixed processes or strategies that cannot be rehabilitated easily due to costs and techniques involvement (Oke *et al.,* 2016). Water distribution and availability are conducted through pipelines, pipe networks and pipe layouts (Oke et al., 2016). There are several factors that involve in the selection of a pipe network and pipeline. The key procedural factors are ground conditions, length of pipes, long-term material changes, durability aspects, resistance to environmental and chemical attacks, and initial and operational costs (Hang et al., 2013, Oke *et al.,* 2016). More previous studies on pipe network analysis can be found in the literature such as Oke (2007); Babatola *et al.* (2008), Swamee and Sharma (2008), Oke (2010), Adeniran and Oyelowo (2013), Oyebode and Igbi (2018) and Abdulsamad and Abdulrazzaq (2023). The literature such as Gupta and Bhave (2007), Ge *et al.* (2010), Giustolisi (2010). Adeniran and Oyelowo (2013), Oyebode and Igbi (2018), and Abdulsamad and Abdulrazzaq (2023) reported that there are several computer programs running on personal computers for pipe network analysis. These water resources and management programs such as UNWB-LOOP, EPANET, WADISO, MODPATH, WATERGEM, MODFLOW, MODFLOW-USG, MT3DMS, SEAWAT, RT3D, PHT3D, U of K KYPIPE and MODFLOW-LGR had been developed, completed and available for utilization in the pipe network analysis. These collections of software are available for pipe network analysis but require advanced knowledge, skills and training as well as additional expenses such as purchasing costs. With reference to Brkic (2018) and advances in technology and the development of various computer systems, there is a need to utilize EPANET (which is available at no additional cost and is simple in application) in pipe network analysis. The focal aim of this research is to apply EPANET in the pipe network analysis of an institution and evaluate the flows and velocity calculated statistically using water demand at the nodes, with a critical aim of attaining sustainable development goals SDGs 3 (virtuous health and well-being), SDGs 6 (clean and potable water, and sanitation); and SDGs 15 (life on land).

MATERIALS AND METHODS

Pipeline and pipe layouts in Elizade University were identified. Elizade University (EU) is one of the private Universities in Nigeria. The University is located in Ilara-Mokin, a mini-city in Ondo State, Southwest, Nigeria (Figure 3). EU has an increasing population of 3,150 people, including students and staff members. EU is one of the promising private Universities in Nigeria.

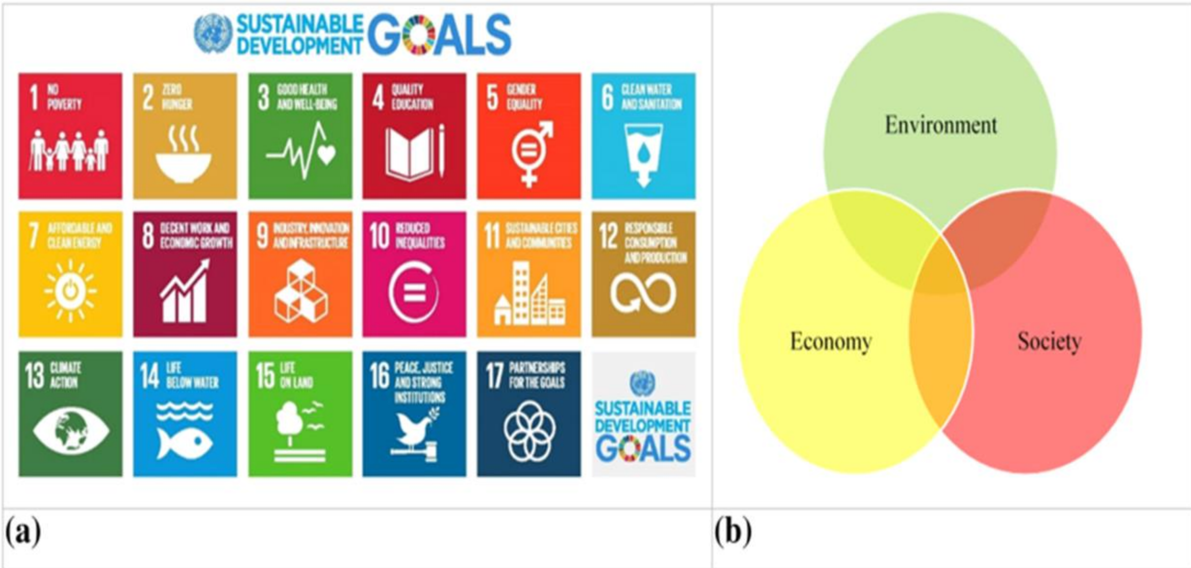

Figure 1 (a) Piktochart of 17 United Nations' Sustainable Development Goals. (b) Venn chart of the three main pillars of sustainable development (Source: Dalampira and Nastis, 2019)

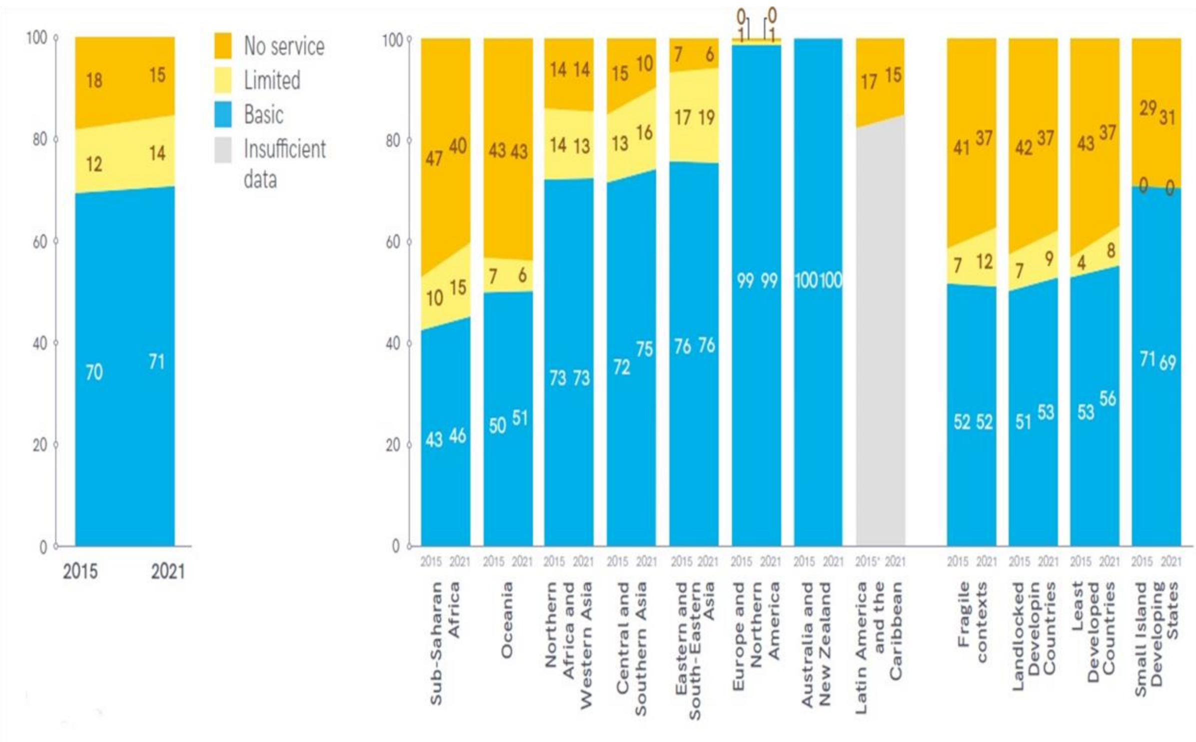

Figure 2 the global coverage of drinking water services in schools from 2015 - 2021 and the regional report of potable water services in institutions or schools from 2015 to 2021 (JMP, 2022).

Node and valves in these pipelines and pipe layouts were marked. Pipe length, pipe's diameter, and elevations at each marked node were measured using Garmin GPS 72H. The population of the institution was collected from 2011 to 2018. The growth rate of the population was identified and computed. The population was projected from 2019 to 2026 (based on the strategic plan of the University Management) by using geometrical progression as follows:

$$G_t = G_0(1+g_r)^p \quad (1)$$

Where; G_t is the EU's projected population; G_0 is the EU's population at the base year, g_r is the EU's population growth rate and p is the life span of the network. Water demands at all the nodes were computed using the projected population at the node and water demand per capita per day as follows:

$$Q_{wd} = G_t q \quad (2)$$

Where; Q_{wd} is the water demand per node and q is the water demand per capita per day 75 l/p.d for students at the hostel, 150 l/p.d for staff members at the staff's quarter and 40 l/p.d for all the population at the academic areas.

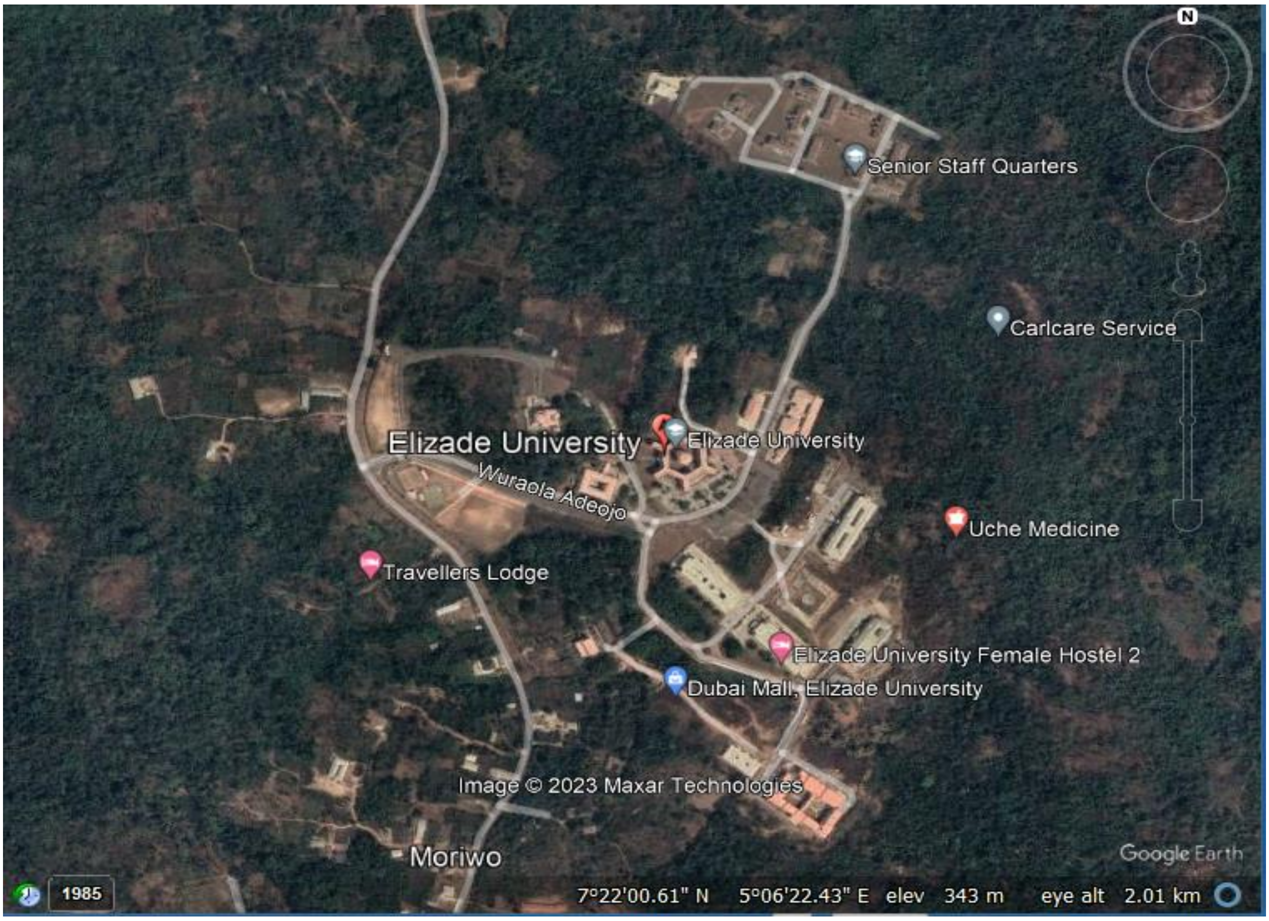

Figure 3: Location of EU and an aerial view of the University environment

The Pipeline and pipe layout were drawn as a pipe network using AutoCAD software (Figure 4). Software EPANET 2.2 (EPANET) is a software application utilised worldwide to model water quality and distribution systems. EPANET software (software package) is a public and free access website or domain, for water quality, pipe network analysis and water distribution modelling developed and made available by the United States Environmental Protection Agency's Water Supply and Water Resources Division) was downloaded from https://www.epa.gov/water-research/epanet and installed. EPANET 2.2 was utilised to analyse the drawn pipe network. Figure 5 presents the detailed procedures for utilizing EPANET 2.2 in a single period. Relationships between the diameter of the pipe and analysis (flow rate, velocity and friction factor) were established and evaluated statistically.

RESULTS AND DISCUSSION

The findings, results and outputs of the study and research are presented, summarised and discussed in the following categories as follows:

a. **Pipeline and pipe layout:** The pipeline and pipe layout in the EU are mainly open loops. It contains neither a closed loop nor a pseudo loop (Figure 6), which indicated that it will be difficult to conduct pipe network analysis using either Hardy Cross, Linear Theory or Newton Raphson techniques. The three techniques required the second axiom of pipe network analysis, which include closed-loop equations. The figure revealed that the pipeline and pipe layout in the EU consists of a tank (overhead), 44 nodes and various elevations, and 43 pipes. The pipeline and pipe layout in the EU is of two folds (surface and underground), which can be attributed to the geological features in the environment (rocky environment). In addition, there are two main types of pipe diameters (50 mm and 150 mm). Figure 6a presents the pipeline and pipe layout and the Label (Nodes and Pipes numbers). Figure 6b provides the pipeline and pipe layout and the diameter of the pipes. Table 1 presents the total length, average flows, average velocity and friction factors in each of the diameters. The table revealed that 54.51 % of the total length belongs to 50 mm diameter pipes and 45.59 % of the total length belongs to 150 mm diameter pipes. A higher proportion of the total length of pipe to 50 mm diameter pipe can be attributed to the initial cost and profit-making principle of the contractor and consultant not based on water demand or any hydraulic principle.

Table 1: A summary information on the pipe’s diameters

Diameters	Length	Percentage	Flow	Velocity	Friction Factor
50	2005.11	54.51	456.61	232.55	0.016
150	1673.3	45.49	1308.93	102.75	0.012

b.

Figure 6c shows the pipeline and pipe layout and the elevation at nodes. The figure revealed that the highest elevation was 390m at the overhead tank and the lowest elevation on the pipeline and pipe layout was 339.1 m at the node 34. The difference between the highest and the lowest provided hydraulic head of 50.9 m this support the distribution or supply of treated and stored water by gravity easily. Figure 6d provides the pipeline and pipe layout and the length of the pipes. The figure revealed that the length of these pipes was between 10 m at the tank to node 2 and 120 m at the node 27. This result shows that the length of pipes in this pipeline and pipe layout is a function of bend or intersection. Figure 6e provides the pipeline and pipe layout and the water demand at the nodes. The figure unveiled that the lowest treated water demand was 0.0 l/s at nodes where there were no population and the highest at node 42 with a water demand of 460 l/s at the point with hostels (male and female students).

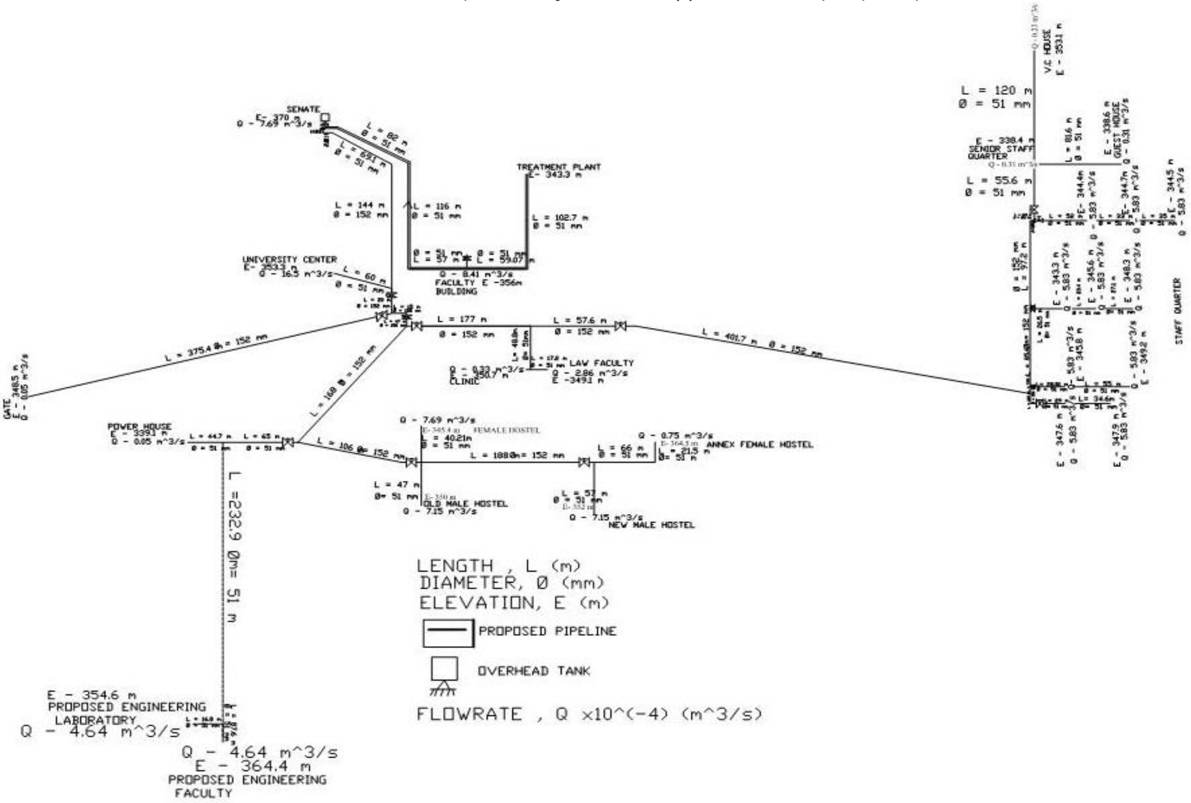

Figure 4: Pipeline and pipe layout drew as a pipe network using AutoCAD software

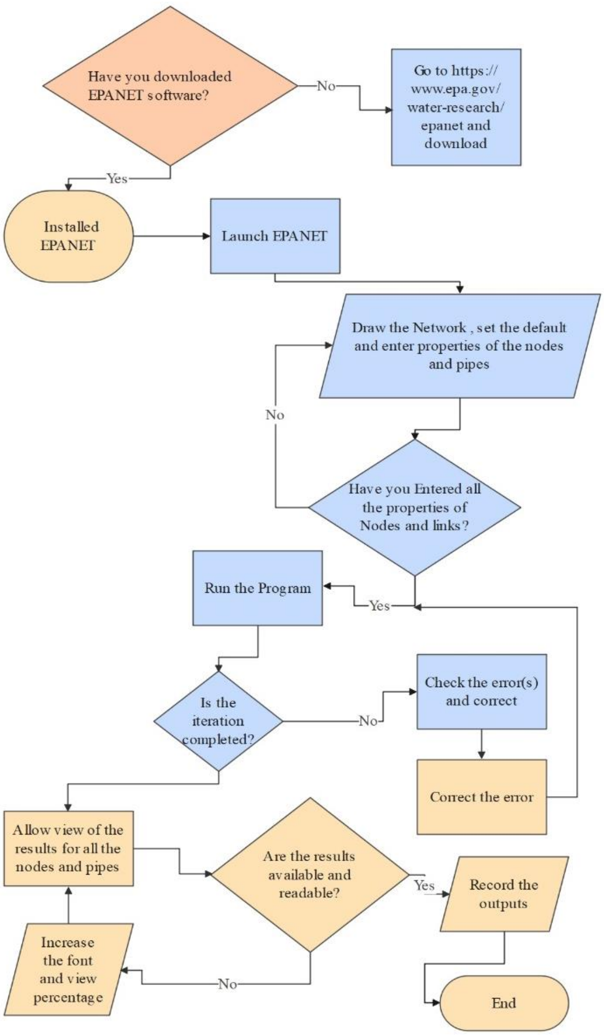

Figure 5: Flow Chart for the utilization of EPANET

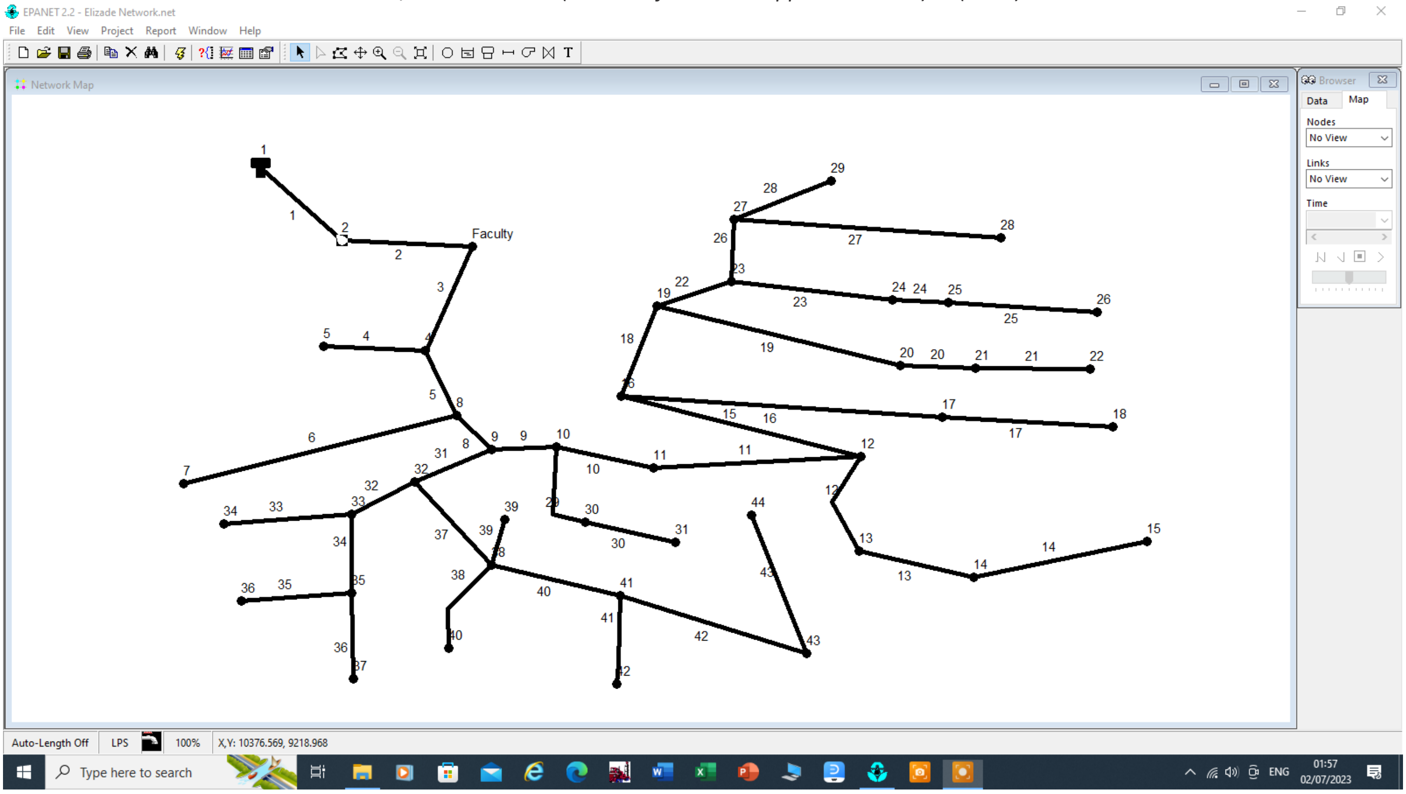

Figure 6a: the pipeline and pipe layout and the Label (Nodes and Pipes numbers).

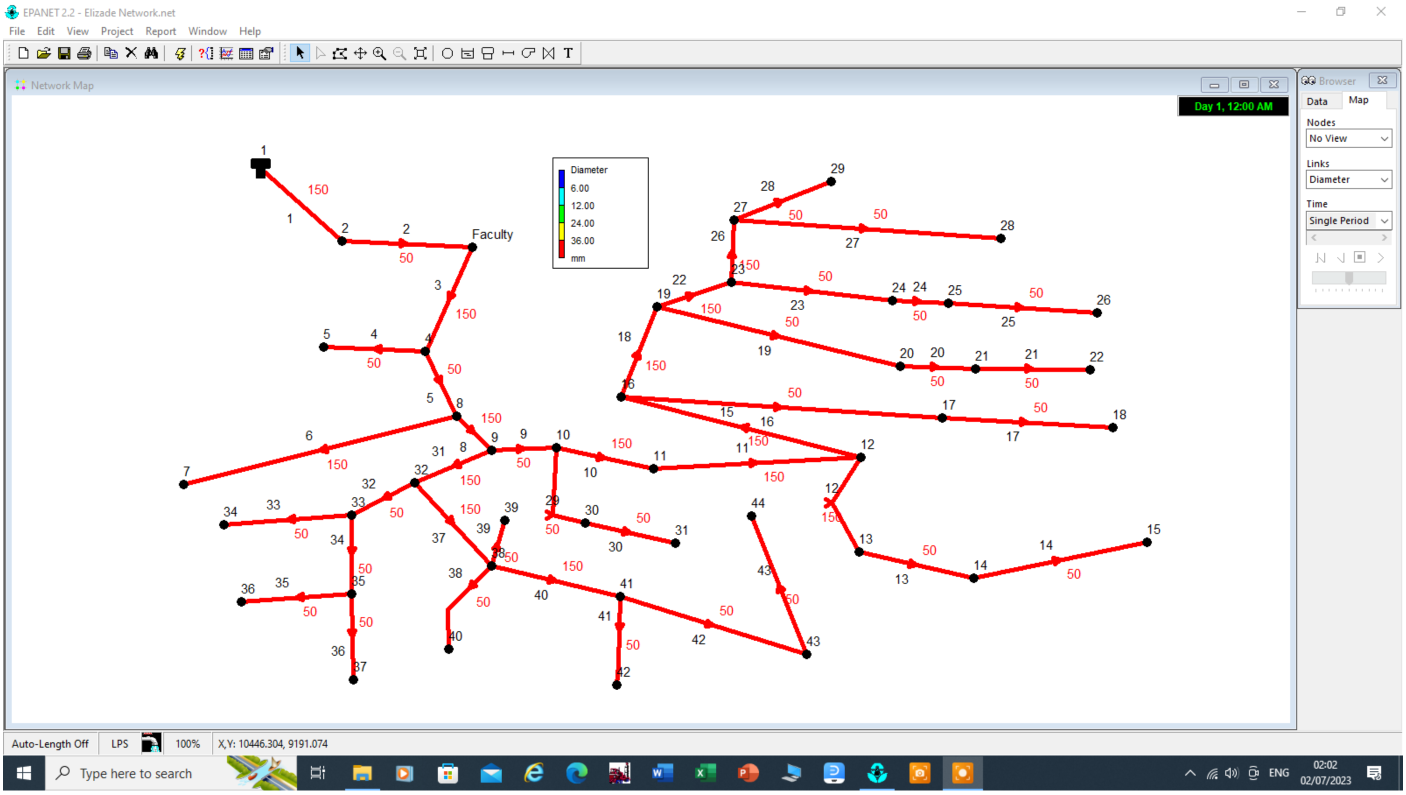

Figure 6b: the pipeline and pipe layout and the diameter of the pipes.

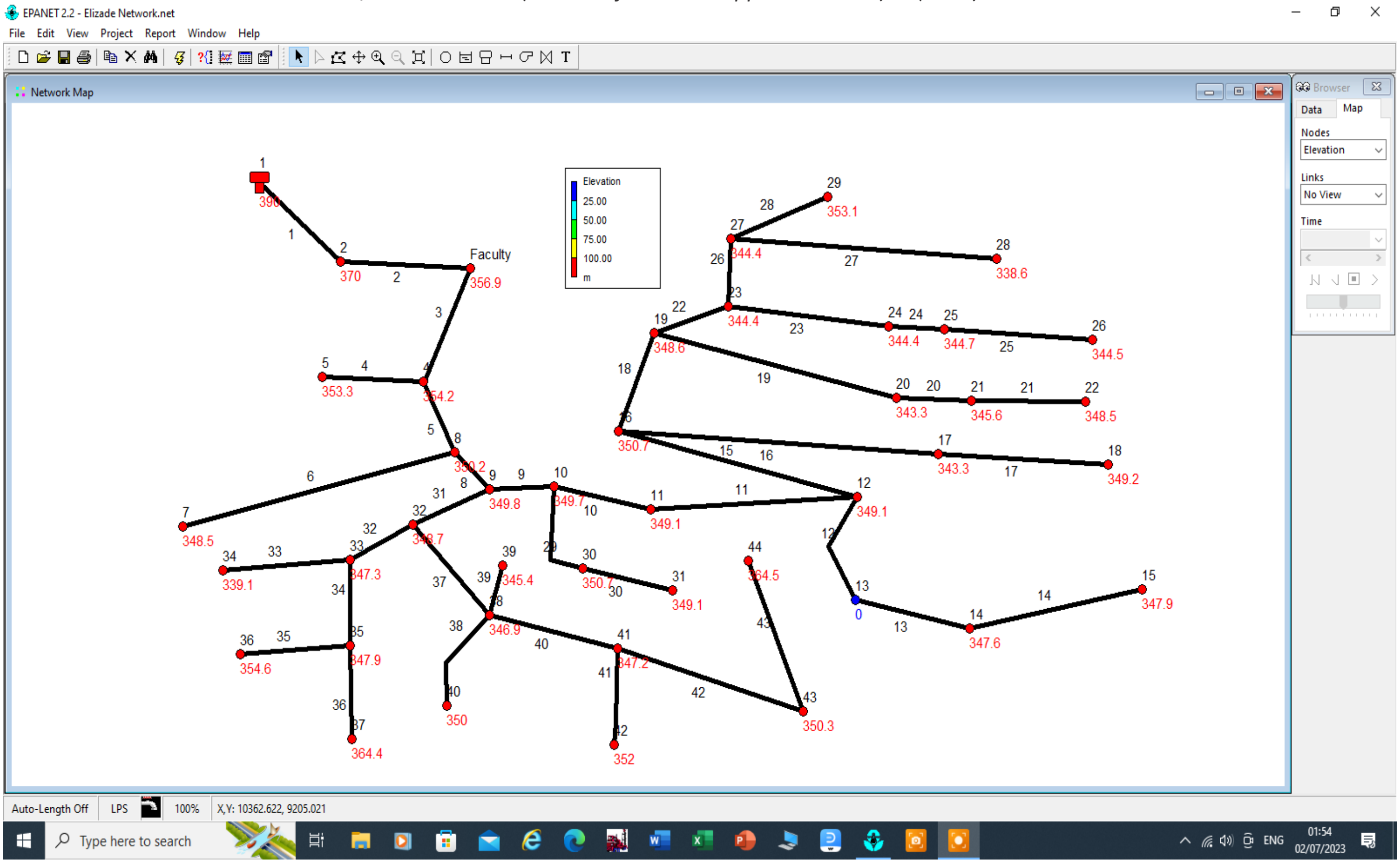

Figure 6c the pipeline and pipe layout and the elevation at nodes

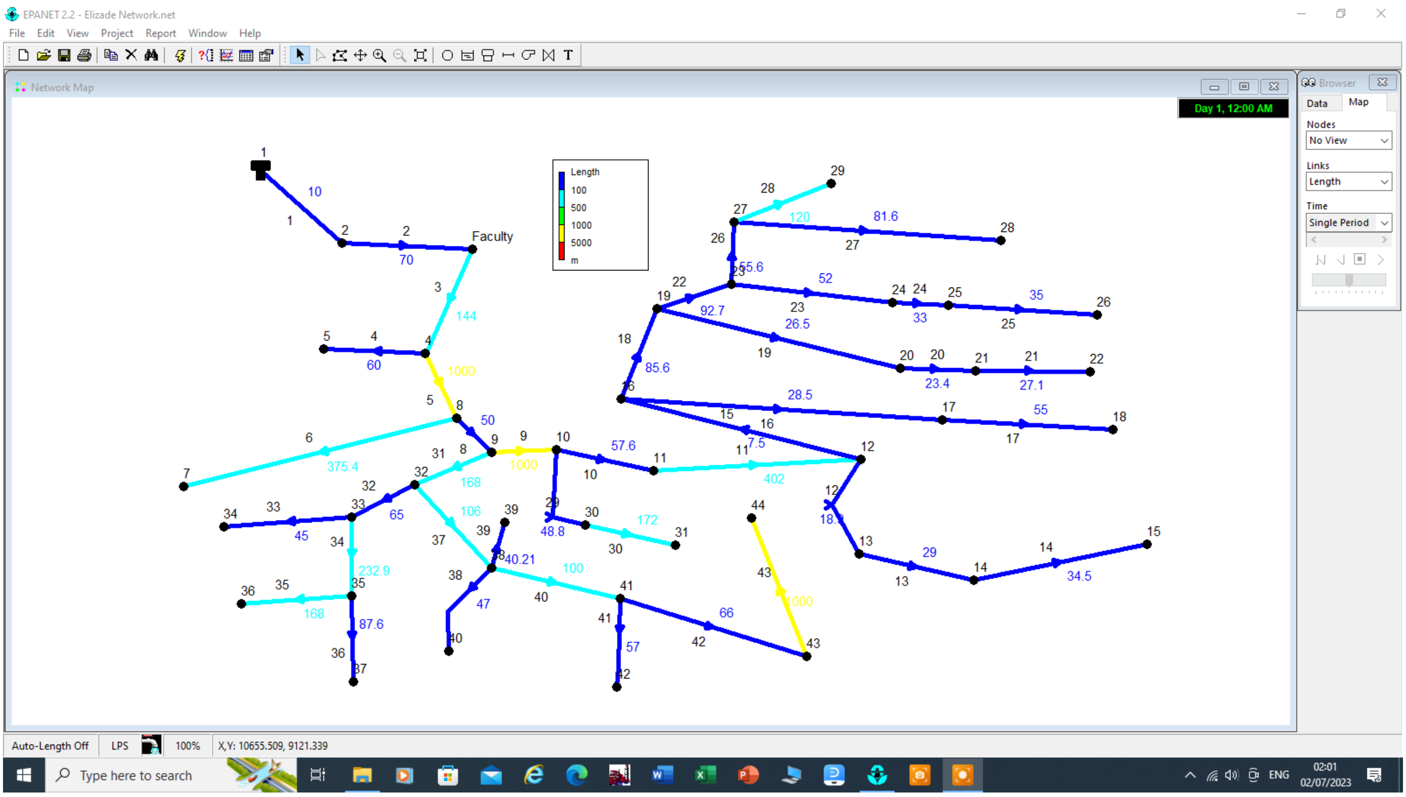

Figure 6d: the pipeline and pipe layout and the length of the pipes.

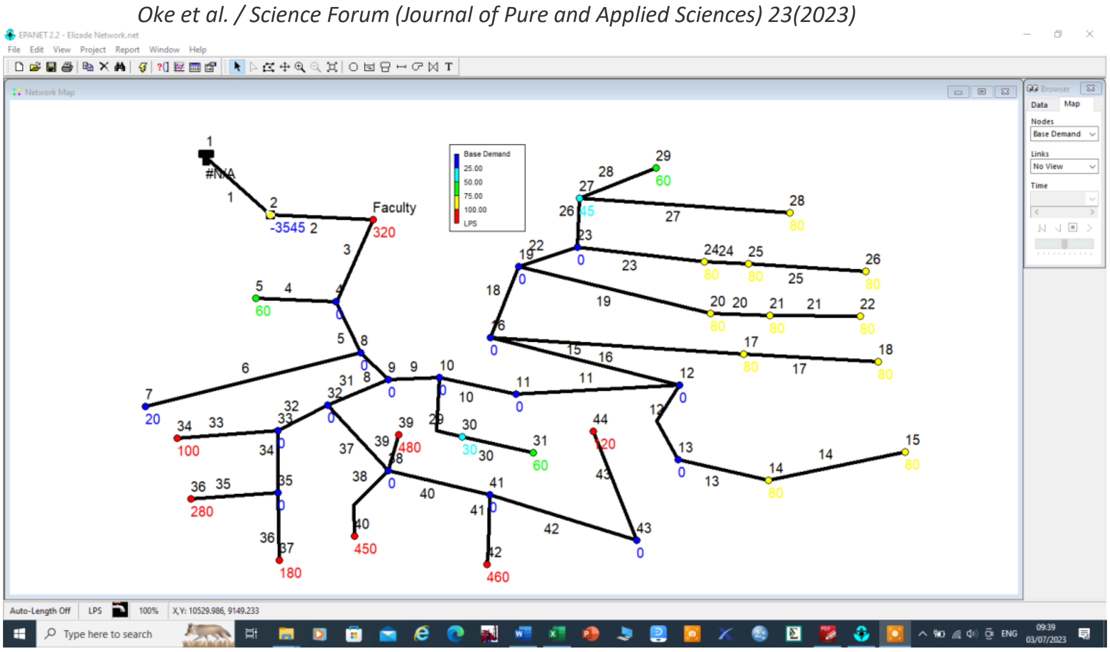

Figure 6e: the pipeline and pipe layout and the water demand at the nodes.

b. Pipe Network Analysis: The analysis was conducted using EPANET 2.2. The results are presented as shown in Figure 7. Figure 7a exhibited the pipeline and pipe layout and the direction of flow, which established that water flows from higher elevations to lower elevations. Figure 7b brings home the pipeline and pipe layout and the flows in the pipes and direction, which revealed that the highest flow was 3545 l/s within pipe 2(the primary pipe from the tank) and the lowest flow within pipe 6 was 20 l/s. This result established there are primary pipe (which channels water from the major source), and secondary pipe (which acquits water from the primary) and tertiary pipe (which conveys water to the consumers). The study revealed that secondary pipes are missing the network, the pipeline and the pipe layout, which can be attributed to the cost saving and profit making by both management and contractor respectively. Figure 7c presents the pipeline and pipe layout and the elevation and flows. Figure 7d shows the pipeline and pipe layout and the water demand and diameter of pipes. Figure 7e provides the pipeline and pipe layout and water demand and diameters. Figure 7f shows the pipeline and pipe layout and the water demand and friction factors. Figure 7g presents the pipeline and pipe layout and the water demand and length. Figure 7h offers the pipeline and pipe layout and the water demand and velocity. The summary of revelation from figures 7c to 7h is that flow and velocity of water in the pipe is a function of water demand at the node and the diameter of the pipe. The friction factor of the pipe is not a constant, function of the diameter of the pipe, flow and velocity of the pipe. This agreed with the comment and observations made in the literature by Brikc (2018).

c. **Statistical Relationship Between Pipe's Diameter and the Outputs**

Figure 8 presents the relationship and correlation between the diameter of the pipe and the outputs (friction factor of the pipe, flow and velocity of the pipe). The figure revealed that the pipe's diameter is inversely proportional to the friction factor of the pipe and the velocity of discharge or flow in the pipe, and directly proportional to the flow in the pipe (Table 1). Table 2 provides and summarized the results of the analysis of the variance. The Table showed that the diameter of the pipe has an effect on these outputs, but the effect was not a significant factor at a 95% confidence level ($F_{1,10} = 0.034$ and $p = 0.858$)

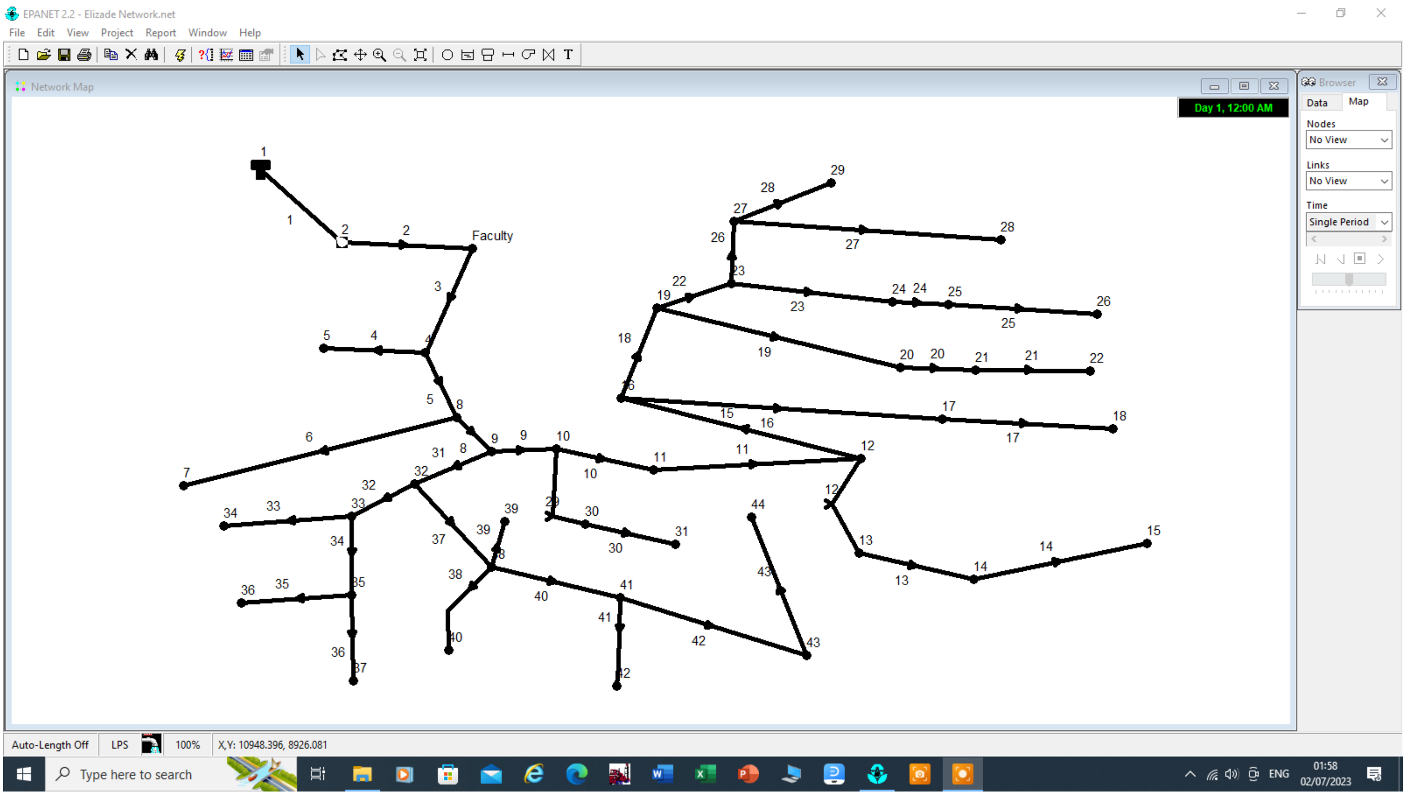

Figure 7a the pipeline and pipe layout and the Direction of Flow

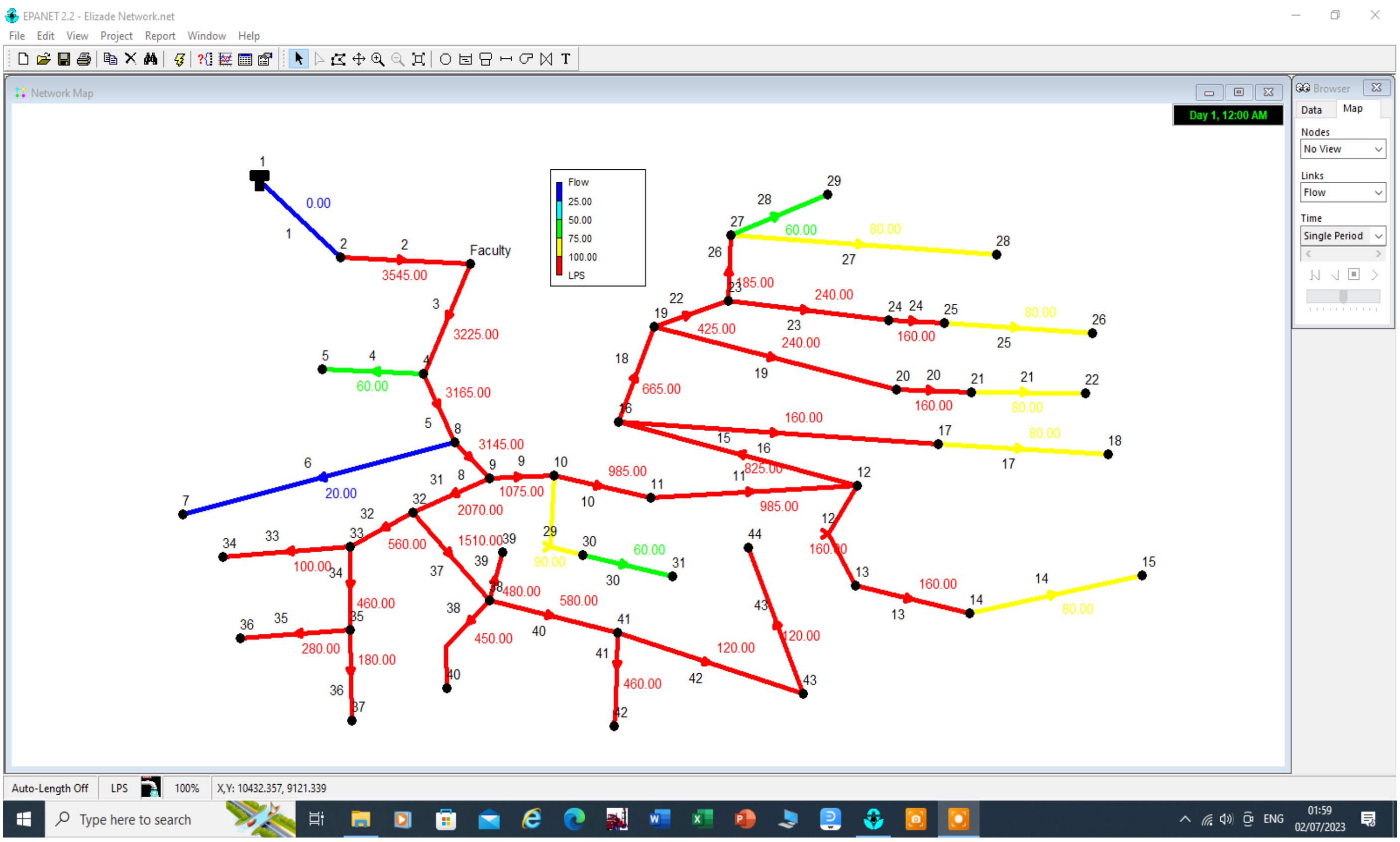

Figure 7b the pipeline and pipe layout and the Flows in the pipes and direction

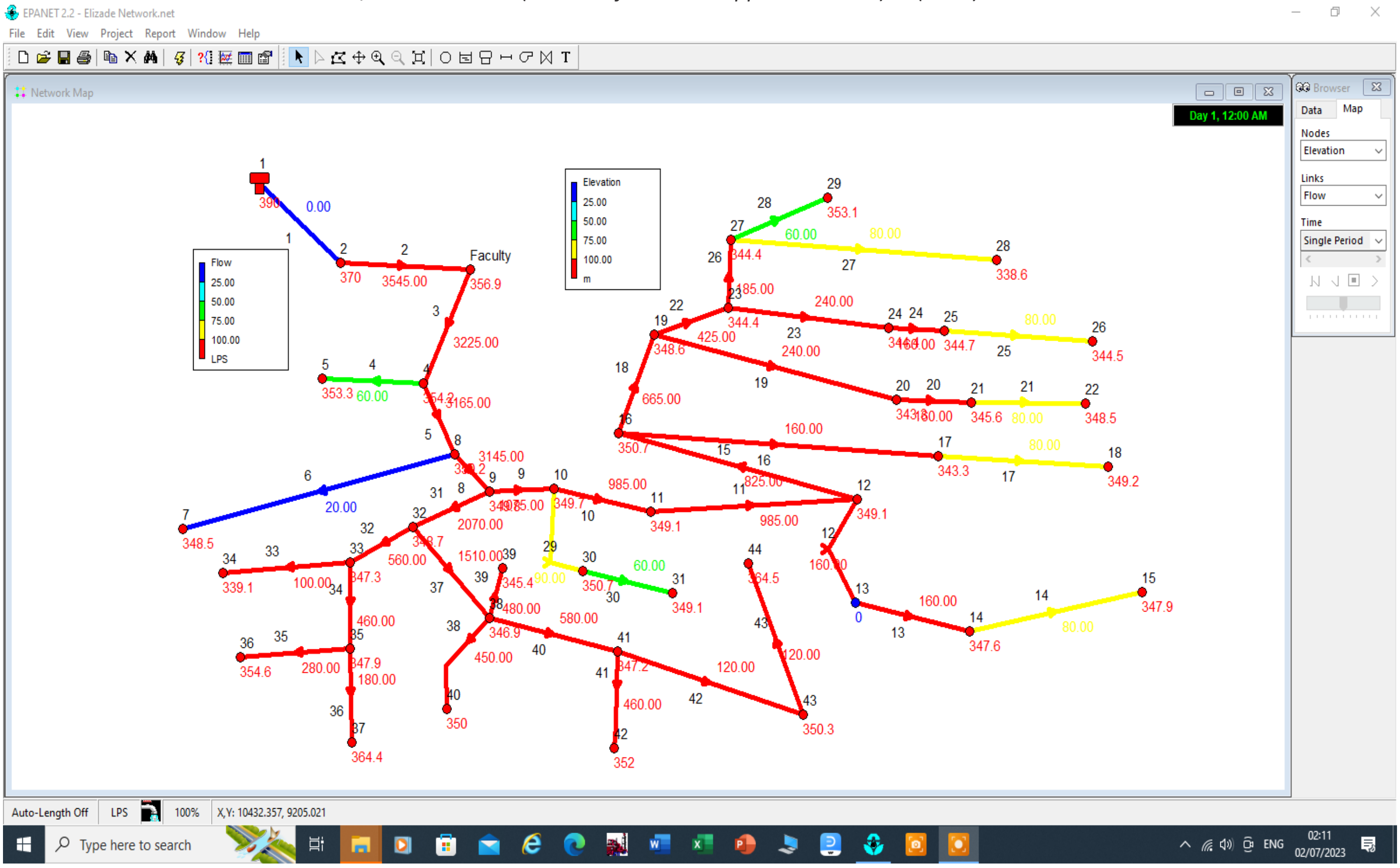

Figure 7c the pipeline and pipe layout and the Elevation and Flows

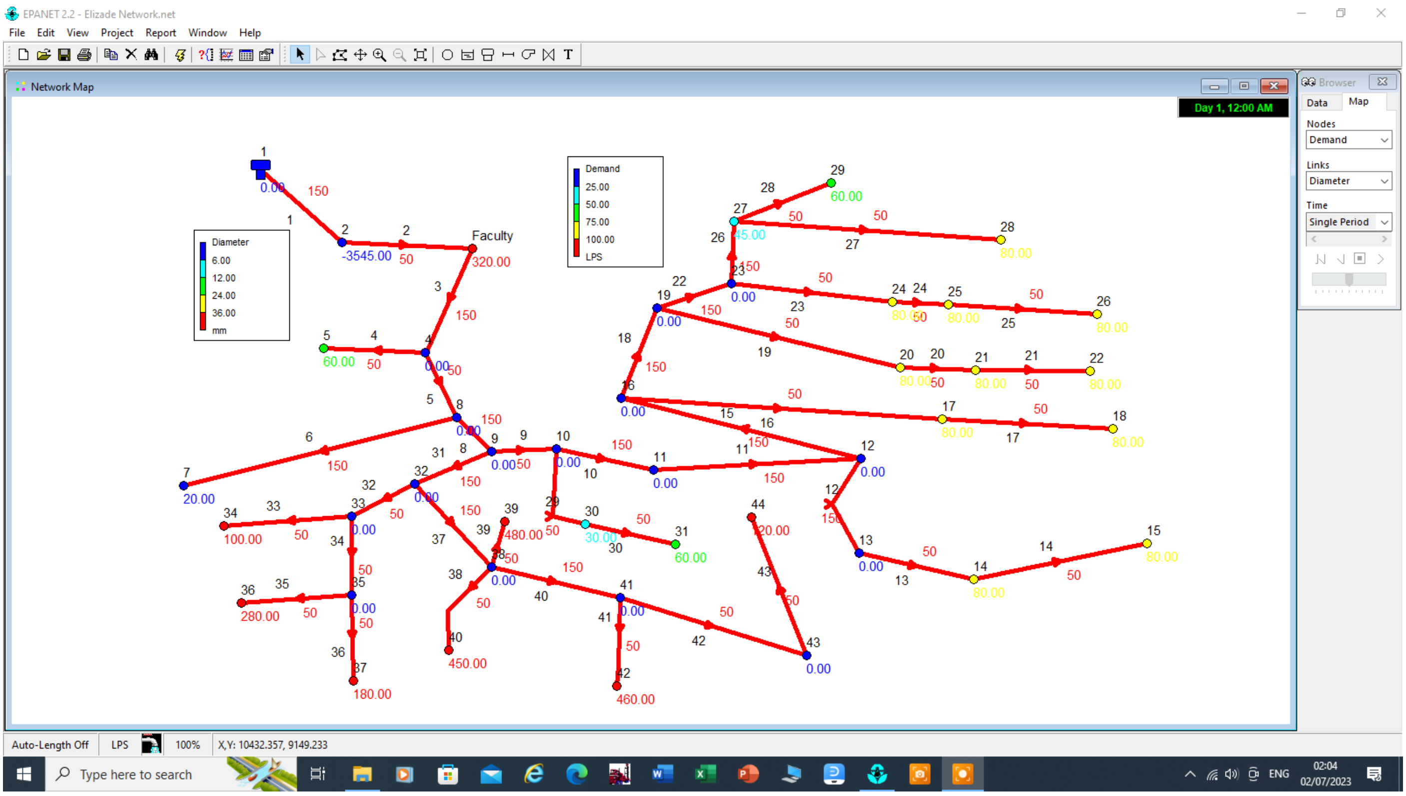

Figure 7d the pipeline and pipe layout and the Water Demand and Diameter of Pipes

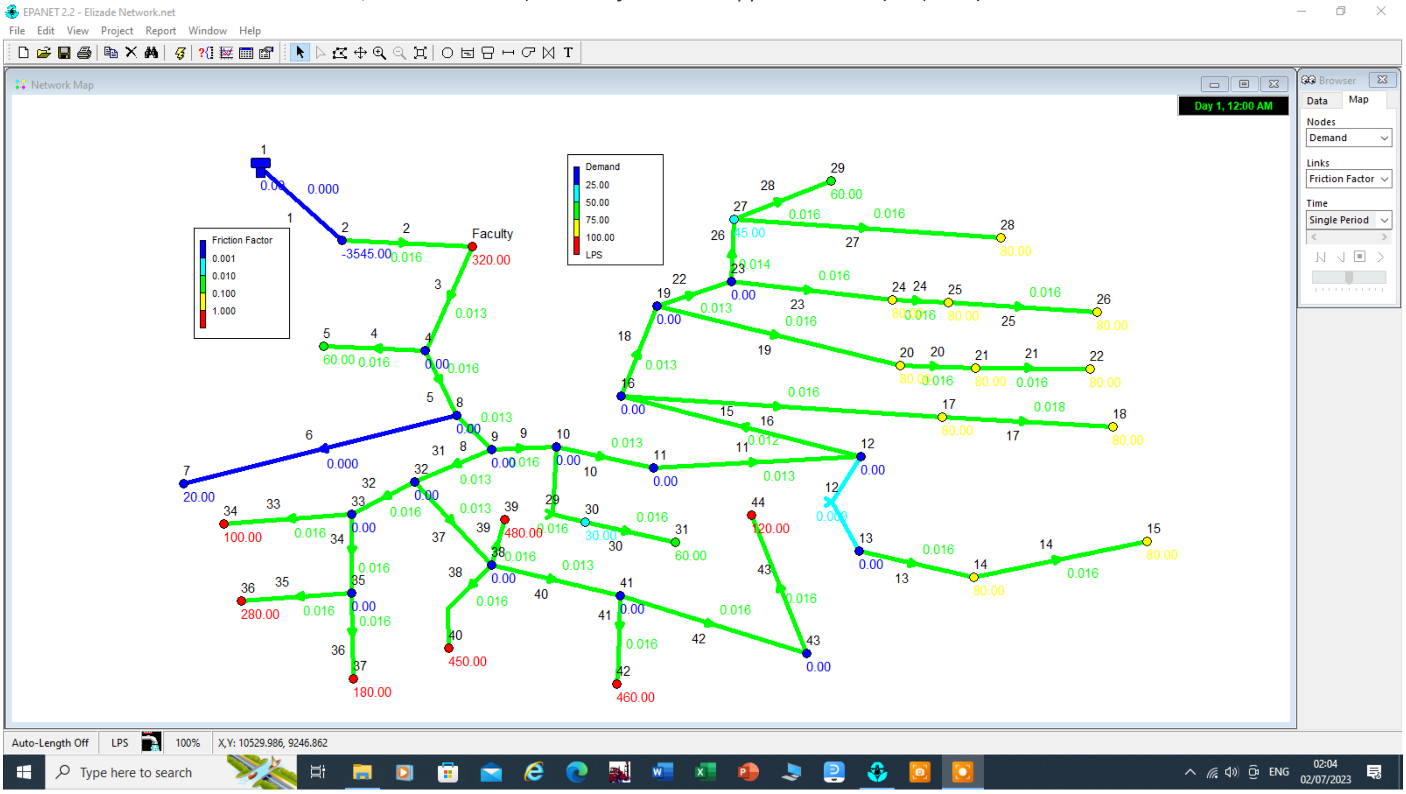

Figure 7e the pipeline and pipe layout and the Water Demand and Friction factors

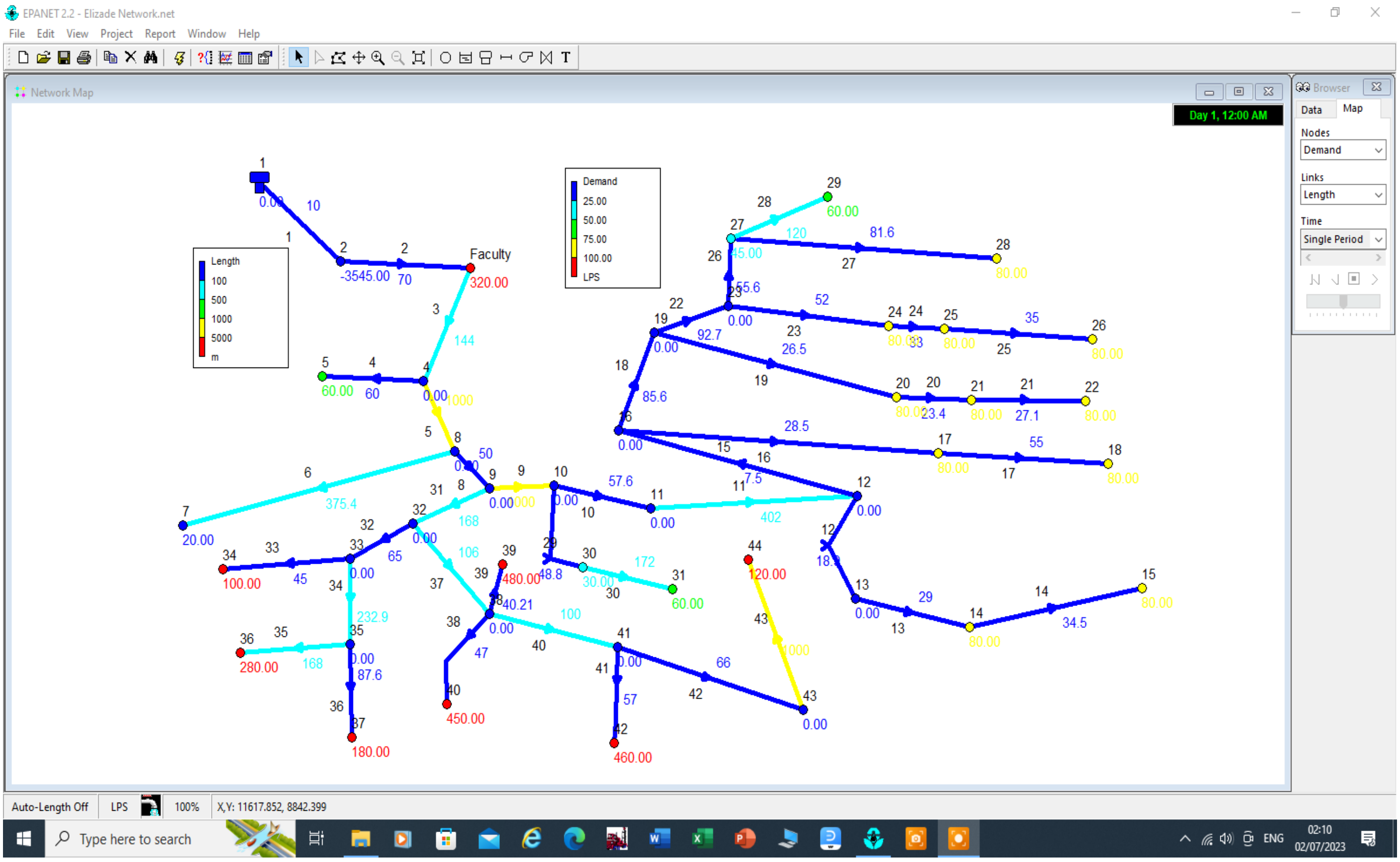

Figure 7g the pipeline and pipe layout and the Water Demand and Length.

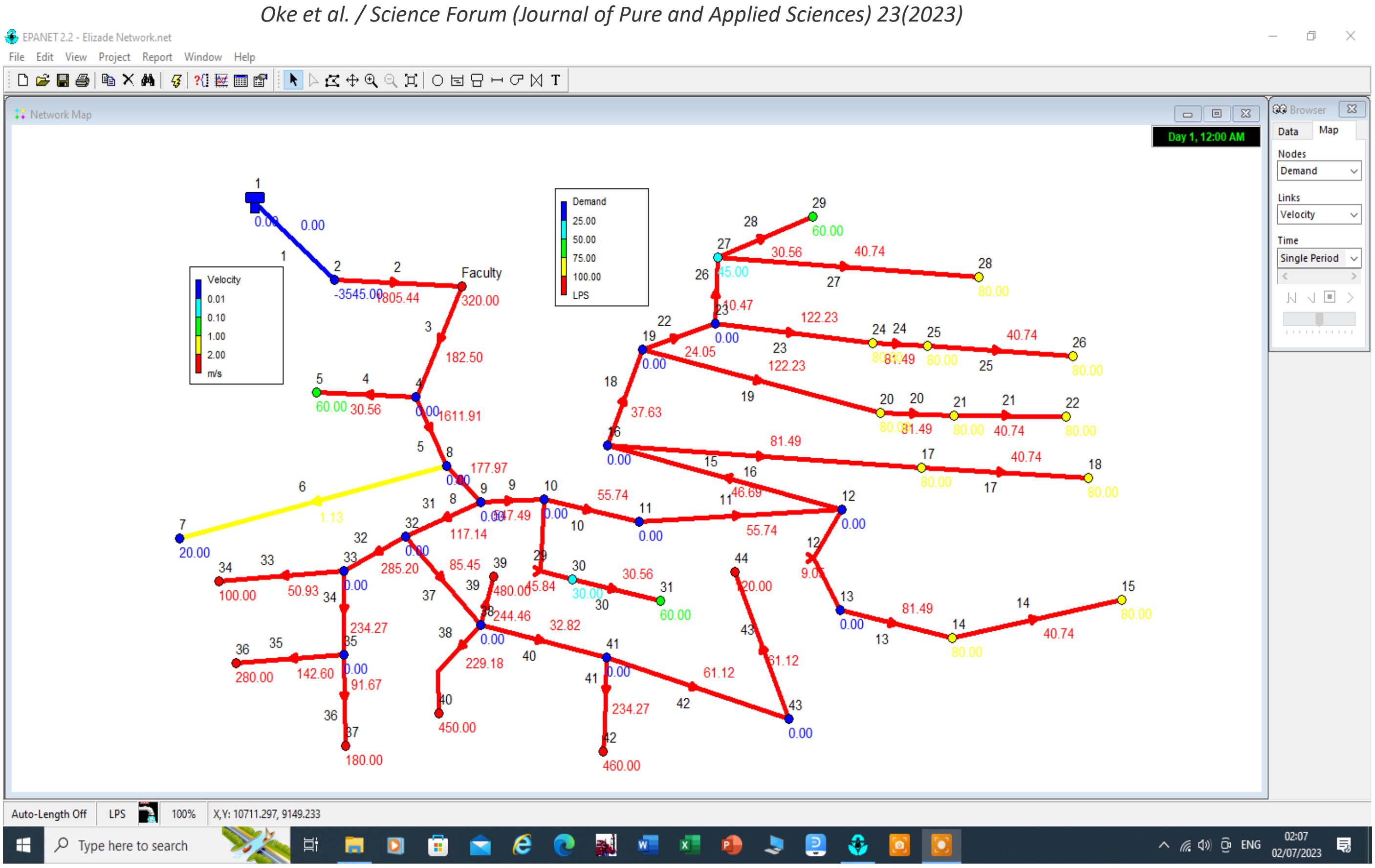

Figure 7h the pipeline and pipe layout and the Water Demand and Velocity.

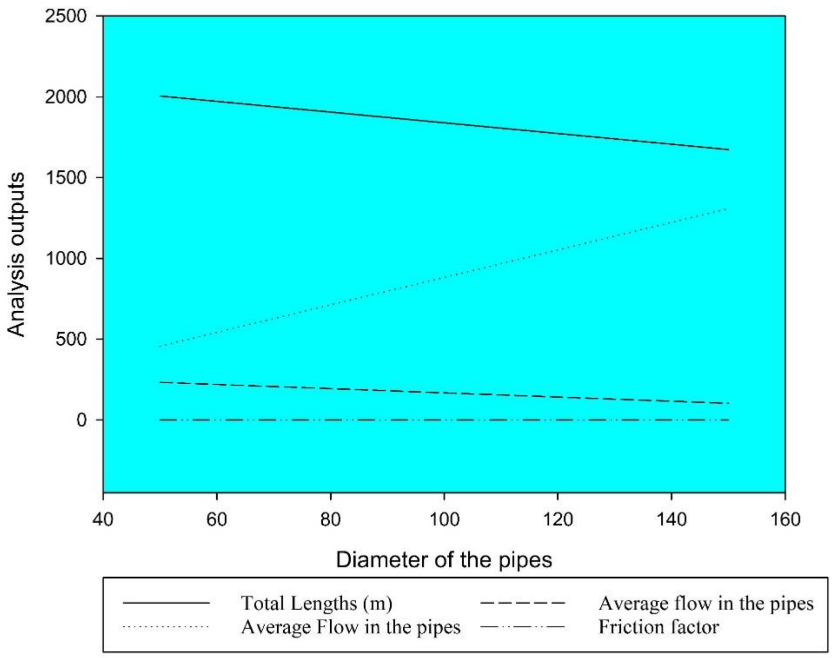

Figure 8: Relationship between pipe's diameter, the friction factor of the pipe, flow and velocity of flow of water in the pipe

Table 2: Results of analysis of the variance

Source of Variation	*Sum of Square*	*Degree of freedom*	*Mean Sum of Square*	*F-Value*	*P-value*
Between diameters	19335.46	1	19335.46	0.034	0.858
Within diameters	5737730	10	573773		
Total	5757065	11			

CONCLUSION

It was concluded that the pipeline and pipe layout at the EU is mainly open loops, consisting of 50 millimetres and 150 millimetres diameter pipes only and the size (diameter) of the pipe is a positive function of the flow rate, negative function of the velocity of flow and the friction factor through it. The diameter of the pipe has an effect on these outputs, but the effect was not a significant factor at a 95% confidence level ($F_{1,10}$ = 0.034 and p = 0.858)

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