Analysis and Design of Water Distribution Network Using EPANET: A Case Study of HSTU Campus of Dinajpur, Bangladesh

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Abstract: This paper represents the analysis and design of the Water Distribution Network (WDN) system using EPANET for Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh. Supply of water is essentially required for academic, administrative, student hostel and residential buildings according to their occupancies. Water supply system with sufficient pressure head and technical sustainability is nowadays a challenging task for the researcher, respected authority and government tackling the crisis in provided safe water due to the rapid increase in population. EPANET is a public domain software developed by the US Environmental Protection Agency (EPA) which is used widely to design and analysis of water supply network system with reference to technical sustainability. HSTU is a renowned public university located at northern part of Bangladesh having 89 acres campus area and population around Ten Thousand (2020) including teachers, students and staffs. Present Water Distribution System in HSTU campus has been found inadequate to cover the total campus and most the building has individual suction pump. In recent future such types of water distribution network system in HSTU may or may not be suitable. Hence, this study is all about the analysis and design of a new water distribution network and provide conclusion about the suitability of the network for recent future. Various public demands, quantities of inflows and out flows of the over-head reservoir are taken into consideration during the analysis. Study materials are to be used for this study include HSTU campus plan, network parameters such as block wise population, and water demand, elevations, pipe length and EPANET software. An extended period simulation of water distribution network system is carried out during the analysis using EPANET. This study is carried to provide the knowledge about various demands, pressure head, pipe flow and diameter, head losses and a new network of supply will make aware of the new demands. Water distribution network system design using EPANET will provide an overall improvement over the existing network and evaluate the supply network for future.

Keywords: EPANET, Water Distribution Network, Population, Water Demand, Hydraulic Simulation

1. Introduction

Water is an inorganic and transparent chemical substance that is nearly tasteless, colorless and odorless. It is the main component of the of the hydrosphere strata of the earth and compulsory for all living organisms. Providing adequate amount of clean water is utmost necessary and has been considered as one of the most important task in human history. Greater portion of primitive civilizations rise near water sources. Around 3500 years ago human began transporting water through pipes [1]. It is therefore expected that early civilizations arisen around river valleys such as those of the Nile in Egypt, Indus in India, Hwangho in China and Euphrates and Tigris in ancient Mesopotamia [2]. Primitive people used to deliver water over long distance using channel for daily use. Safety, reliability, affordability, and accessibility of fresh water is prime requirements for good health. Water is a critical resource that supports human life and culture,
ecological functions and economic activities. With progressive population growth the needs, the incremental water supply demand substantially increased day by day. This is leading to a crisis of water management in many locations which is acknowledged in various international declaration [3].

Water covers 71% of the total area of Earth’s surface, most of them are present in seas and oceans. Little portion of water can be found as groundwater (1.7%), another 1.7% is presents in the form of glaciers and ice caps of North and South pole, and percentage of water presents in air vapor and clouds and precipitation is (0.001%) [4]. It has been estimated that a minimum of 7.5 litres of water per person per day is required in the home for drinking, preparing food, and personal hygiene, the most basic requirements for water; at least 50 litres per person per day is needed to ensure all personal hygiene, food hygiene, domestic cleaning, and laundry needs [5]. In 2010, about 85% of the global population (6.74 billion people) had access to piped water supply through house connections [6, 7].

The aim of this study is to analysis and design of a water distribution network system using EPANET for HSTU campus in Dinajpur, Bangladesh. A water distribution system is a hydraulic infrastructure which consists of pipes, tanks, reservoirs, pumps, and valves that convey water to the consumers from source or a centralized treatment plant or wells in order to satisfy residential, commercial, industrial and firefighting requirements [8, 9]. World Health Organization (WHO) defines the water distribution system as a tree-like structure consists of pipes and nodes that carry water from sources to the consumers [10]. The most important concern in designing a water distribution system is to gratify consumers demand during the entire lifetime for the desired demand conditions under the limit of quantity and quality concern. Hence, it is necessary to plan and construct a suitable water distribution network system for continuously growing populations of HSTU in order to provide sufficient and uniform quantity of water through the designed network of pipes. Water distribution network is one of the main components of water supply system that needs to design and handle carefully because of cost involved and its purpose. Construction cost of a large water distribution network is higher although in the long run it saves a lot of money and life, but at primary stage a large investment is to be required. Nearly 80% to 85% of the total cost of whole water supply system expended into the water transmission and the water distribution network [11, 12]. Despite this, the function of these supply systems often goes unobserved until there is a major breakage or operational failure. As failure events are likely unavoidable and often dramatic and costly, so a proper water distribution system is required to avoid such unexpected hazards. WDN system also entails great social, economic, and environmental burdens. The most common challenges in WDN include water quality degradation, capacity shortages, infrastructure aging and deterioration, demand increases, and their ever-increasing energy consumption coupled to the global energy crisis. In water utility systems, a great amount of water is loss as leakage while in transport from source up to consumers. Water loss represents inadequacy in water delivery and measurement operations in distribution networks. By acquiring a continuous water supply, cities in the developing world must ensure that their water systems become more efficient and effective by reducing water losses, gradually increasing tax of water, enhancing staff productivity, increasing revenue Collection, and ensuring safe and reliable water supplies. When the productivity will increase, then investments in new infrastructure will lead to more feasible and workable water services [13].

In this particular study analysis and hydraulic simulation of distribution network system is done by the EPANET 2.0 software. The analysis of pipe networks has long been one of the most computationally complex problems which hydraulic engineers have to contend with [14]. EPANET is a software application used throughout the world that performs extended period simulation of hydraulic and water quality behavior within pressurized water supply pipe networks. It has the capabilities to analyzed unlimited number of pipes and User Manuals for better understanding the software can also be downloaded free [15]. EPANET has the capability of tracking the pressure and demand in each nodes, flow, velocities and head losses in each pipes, height of water in each tank and concentration of chlorine species throughout the network during the extended period simulation. It also traces the water age and source in addition to chemical species [16]. EPANET is specially designed as a simulation tool for better realization of the movement and fate of drinking water components within distribution systems. It can be applied in several ways such as in distribution systems analysis. Sampling programs design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment [16, 17].

Objectives of the study:
To analyze and design a WDN for HSTU campus and assess the present water demand and predict the future demand.
To determine all the hydraulic parameters of distribution system.
To provide equitable and constant water supply.

2. Study Area

This particular study was conducted in Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh. HSTU is a government- financed renowned public Science and Technology University at Dinajpur Sadar upazila in Rangpur Division, Bangladesh. The HSTU campus is located at 9 km from Dinajpur city on Dinajpur-Rangpur highway (NH 5), and around 10 km from Dinajpur railway station. The university is geographically situated at latitudes of 25.6987° North and longitudes of 88.6562° East. This university campus spread over an area of 89 acres of land with ample greenery and having populations around Ten Thousand including students, teachers and other academic or administrative staffs. Due to the rapid increase in population in the last few years, the current water supply system is failing to meet the water needs of the consumers. So
the purpose of this study is to design a sustainable water supply system for HSTU campus. Total campus is divided into two zones having two separate distribution networks with individual elevated storage tank and pumping system. Campus profile of HSTU are given in “Table 1”.

| Types of Building     | No. of Building |
|-----------------------|-----------------|
| Academic Building     | 9               |
| Hostel Building       | 11              |
| Quarter Building      | 23              |
| TSC                   | 1               |
| Auditorium            | 2               |
| Firm                  | 2               |
| Medical Center        | 1               |
| Guest House           | 2               |
| Employe Club          | 1               |
| VC Banglow            | 1               |
| Gymnasium             | 1               |
| Office Building       | 3               |
| Mosque                | 2               |
| Vaterinary Clinic     | 1               |
| Fire Hydrants         | 6               |
| Storage Tank          | 2               |

Satellite view of HSTU campus as shown in “Figure 1”.

3. Methodology

3.1. Materials

The materials used in this study consists of HSTU campus plan, water distribution parameters such as population and water demand etc. Distribution network parameters like nodal elevation, demand and pipe length, diameter etc. and EPANET software.

3.2. Layout of Distribution Network

Landscape of HSTU campus was firstly collected from Engineering Section of HSTU. After conducting several surveys on HSTU campus the Landscape of HSTU was upgraded using AutoCAD version 17. Landscape displays the layout of all the road and the permanent features. The distribution network was drawn up after completion of the preparation of landscape of HSTU. This university campus has the irregular pattern of roads and other permanent features that’s why the dead end system was selected. Intermittent supply system was considered for HSTU campus to bring economy in the design of the distribution system. Water should be supplied twice a day for 3 hours, once at night and once a day. Pumping and storage supply system is best suited for this purpose. Total campus area was divided into two zones having two individual supply network under an elevated storage tank for each network. Tank 1 serves zone 1 called Old Agricultural college campus situated into northern portion of the campus. Zone 2 including the southern old Veterinary College Campus and central portion of the campus is being served by Tank 2.

3.3. Leveling Work

Leveling was done to determine elevation of the campus at selected point which is subjected to the elements of the water distribution network. Points were selected according to the layout of the distribution network and the elevation was recorded by using Google Earth with respect to a selected point called datum. Depth of water table was selected as datum and elevation of all the points were measured with respect to datum in meter. Depth of node or supply pipe line was considered 2 meter below the ground surface.

3.4. Population and Demand Calculation

Population of campus was calculated from the number of buildings and their occupancies. Future population was calculated in terms of academic, student hostel, residential and other types of building and their capacity that could be constructed in the near future. After calculating population of the campus quantity of water required to supply can be calculated from the provision stated in Bangladesh National Building Code (BNBC). BNBC code provide minimum standards for the design, installation and maintenance of water supply and distribution system within a building and its premises. It also provides the demand of different types of the building according to their occupancies. Liter per Capita per Day (LPCD) demand as per BNBC code shown in “Table 2”.

| Types of Consumption          | Demand in LPCD |
|-------------------------------|----------------|
| Single Family                 | 135            |
| Single Family (full facilities)| 400            |
| Mess, Hostels,                | 70             |
| Educational Facilities        | 45             |
| Normal Medical Facilities     | 225            |
| Offices (full facilities)     | 45             |
| Offices                       | 30             |
| Low Fire Risk Storage         | 6              |
| Private Garage                | 5              |
| Small assembly                | 5              |
| lodge or hotel                | 135            |
| Sport facilities              | 5              |

3.5. EPANET Input

Elevation of the node were provided into EPANET as
calculated before in step 3.3. Selected Water supply system for HSTU campus is intermittent type and water has to be supplied twice a day for 3 hours at once. Litter per Second (LPS) was selected as flow units for EPANET. So the demand has to be calculated in LPS for 3hour×2= 6hour supply. At first stage it has been supplied from 12 AM to 3 AM and in the second stage from 12 PM to 3 PM. Pipes or links were drawn in the EPANET software by connecting two nodes. Landscape of HSTU (.wmf) file was used as a backdrop map.

Co-ordinates of the backdrop map were provided in such a way that the actual length of pipe can be obtain from the EPANET software while drawing pipe or link using auto-length. Diameter of the pipes were provided in millimeter. Correction of the diameter might be required and correction was provided in trial and error method. In this particular study Hazen-williams equation was used as head loss formula. So the pipes roughness co-efficient was used 140 [19]. Elevated storage reservoirs were provided with sufficient capacity to serve the water requirements throughout the day. Pump data was provided as pump curve which express the capacity of the pump in terms of discharge and total head. Here total head represents the summation of static, velocity and frictional head loss. Surface water source like river of large lake are not presently available so underground water has to be used as a source of water. In our study depth of submersible pump 300ft was considered as datum so the head of both reservoirs are considered as zero.

3.6. Hydraulic Simulation

After a water distribution network has been described suitably, it’s hydraulic and water quality behavior were analyzed. The hydraulic simulation was done for a period of 24 hours and report time starts from 12 AM. During the simulation period the pressure, demand of each node and flow, velocity of each pipe were noticed [16, 20].

4. Results and Discussions

EPANET results were obtained after completing successful simulation. Water distribution network system in HSTU campus consists of 112 nodes or junctions, 112 cast iron links or pipes of varying diameter, 2 pumps, 2 elevated storage tanks and underground water as source reservoirs. An extended period simulation of WDN system using EPANET was conducted and changes in the hydraulic parameter like nodal demand, pressure and pipe flow, velocity, head loss were observed at each hydraulic time steps. 24 hour simulation period was selected within which water was supplied twice from 12 AM to 3 AM and 12PM to 3 PM. Total water demand per day for zone 1 and zone 2 were 435.24 and 633.55 cubic meter respectively. Total quantity of water to be supplied into the networks were 1068.79 cubic meter per day. Reporting start time of hydraulic simulation was set as 13:00 hour or 1 PM because demand of water was highest then.

4.1. Nodes Result

Water Distribution Network of HSTU campus has 112 nodes. The elementary input data for nodes are elevation, base demand and demand pattern. Hydraulic head and pressure are the output results computed from EPANET at 13 hours are shown in “Table 3”.

| Node ID | Elevation m | Demand LPS | Head m | Pressure m |
|---------|-------------|------------|--------|------------|
| June 1  | 87.002      | 0          | 108.62 | 21.61      |
| June 2  | 87.306      | 0          | 108.38 | 21.07      |
| June 3  | 87.306      | 0          | 108.27 | 20.96      |
| June 4  | 87.306      | 0.685      | 108.23 | 20.92      |
| June 5  | 87.306      | 0.261      | 107.90 | 20.60      |
| June 6  | 87.306      | 0.359      | 107.48 | 20.18      |
| June 7  | 87.002      | 0          | 107.66 | 20.66      |
| June 8  | 87.002      | 0          | 107.11 | 21.11      |
| June 9  | 87.002      | 0.08       | 107.97 | 20.97      |
| June 10 | 86.697      | 0          | 108.01 | 21.32      |
| June 11 | 86.697      | 0.016      | 108.00 | 21.30      |
| June 12 | 86.697      | 0.359      | 107.40 | 20.70      |
| June 13 | 86.087      | 0.216      | 105.18 | 19.09      |
| June 14 | 87.002      | 0.014      | 108.05 | 21.05      |
| June 15 | 87.002      | 0          | 107.77 | 20.76      |
| June 16 | 86.697      | 0          | 106.01 | 19.32      |
| June 17 | 86.697      | 0.626      | 105.91 | 19.21      |
| June 18 | 86.697      | 0.604      | 105.94 | 19.24      |
| June 19 | 86.697      | 0          | 105.70 | 19.00      |
| June 20 | 86.697      | 0.615      | 105.63 | 18.94      |
| June 21 | 86.697      | 0.144      | 105.28 | 18.58      |
| June 22 | 87.002      | 0.767      | 107.64 | 20.64      |
| June 23 | 87.306      | 0          | 107.50 | 20.20      |
| June 24 | 87.611      | 2.396      | 106.85 | 19.23      |
| June 25 | 87.306      | 0          | 107.45 | 19.01      |
| June 26 | 87.306      | 0.067      | 107.43 | 20.12      |
| June 27 | 87.002      | 0          | 106.35 | 19.35      |
| Node ID | Elevation m | Demand LPS | Head m | Pressure m |
|---------|-------------|------------|--------|------------|
| June 28 | 87.002      | 0.013      | 106.35 | 19.34      |
| June 29 | 87.002      | 0.048      | 105.68 | 18.68      |
| June 30 | 87.002      | 0.447      | 108.22 | 21.22      |
| June 31 | 87.002      | 0          | 108.34 | 21.34      |
| June 32 | 87.002      | 1.863      | 107.99 | 20.99      |
| June 33 | 87.002      | 0          | 107.61 | 20.60      |
| June 34 | 87.002      | 0.745      | 107.50 | 20.50      |
| June 35 | 87.002      | 0.186      | 107.81 | 21.42      |
| June 36 | 86.392      | 0          | 106.85 | 20.15      |
| June 37 | 86.697      | 0.345      | 106.30 | 19.60      |
| June 38 | 86.697      | 0          | 106.85 | 20.15      |
| June 39 | 86.697      | 0.374      | 106.58 | 19.89      |
| June 40 | 87.002      | 0.359      | 105.46 | 18.46      |
| June 41 | 86.392      | 0.411      | 107.52 | 21.12      |
| June 42 | 87.002      | 0          | 107.51 | 20.51      |
| June 43 | 87.002      | 0          | 107.38 | 20.38      |
| June 44 | 87.002      | 0          | 107.06 | 20.05      |
| June 45 | 87.002      | 0.288      | 106.26 | 18.96      |
| June 46 | 87.002      | 0.072      | 106.88 | 19.88      |
| June 47 | 86.392      | 0          | 107.12 | 20.73      |
| June 48 | 86.392      | 0.288      | 106.66 | 20.27      |
| June 49 | 87.002      | 0.403      | 106.14 | 19.13      |
| June 50 | 87.002      | 0.381      | 102.77 | 15.77      |
| June 51 | 87.002      | 0          | 105.15 | 18.15      |
| June 52 | 87.002      | 0          | 103.14 | 16.13      |
| June 53 | 87.002      | 0.054      | 103.08 | 16.99      |
| June 54 | 85.782      | 0.319      | 106.78 | 21.00      |
| June 55 | 86.697      | 0          | 103.87 | 17.17      |
| June 56 | 86.697      | 0          | 103.78 | 17.08      |
| June 57 | 86.697      | 0.359      | 103.55 | 16.85      |
| June 58 | 86.697      | 0.374      | 103.52 | 16.82      |
| June 59 | 86.697      | 0.431      | 105.52 | 18.83      |
| June 60 | 86.697      | 0          | 101.79 | 15.09      |
| June 61 | 86.697      | 0          | 101.56 | 14.86      |
| June 62 | 86.697      | 0.388      | 101.35 | 14.65      |
| June 63 | 86.697      | 0.41       | 101.33 | 14.63      |
| June 64 | 87.002      | 0.273      | 98.74  | 11.44      |
| June 65 | 87.002      | 0          | 106.61 | 19.61      |
| June 66 | 87.002      | 0          | 106.13 | 19.13      |
| June 67 | 86.697      | 0.431      | 105.52 | 18.83      |
| June 68 | 87.002      | 0.359      | 105.86 | 18.85      |
| June 69 | 87.002      | 0.417      | 105.08 | 18.07      |
| June 70 | 87.002      | 0          | 106.36 | 19.36      |
| June 71 | 87.002      | 0.374      | 105.60 | 18.6      |
| June 72 | 85.782      | 2.981      | 106.26 | 20.48      |
| June 73 | 86.392      | 0          | 108.00 | 21.61      |
| June 74 | 87.002      | 0          | 107.62 | 20.31      |
| June 75 | 87.002      | 0          | 107.55 | 20.24      |
| June 76 | 86.392      | 0.479      | 105.82 | 19.43      |
| June 77 | 87.002      | 4.792      | 107.36 | 20.06      |
| June 78 | 87.002      | 2.023      | 107.43 | 20.12      |
| June 79 | 87.002      | 9.583      | 107.11 | 20.1       |
| June 80 | 86.392      | 0          | 107.02 | 20.63      |
| June 81 | 86.392      | 0          | 106.71 | 20.32      |
| June 82 | 87.002      | 0          | 105.46 | 18.46      |
| June 83 | 87.002      | 0          | 105.32 | 18.32      |
| June 84 | 87.002      | 0.359      | 104.67 | 17.67      |
| June 85 | 87.002      | 0.338      | 105.01 | 18.01      |
| June 86 | 87.002      | 0          | 104.44 | 17.44      |
| June 87 | 87.002      | 1.118      | 104.17 | 17.16      |
| June 88 | 86.087      | 0.180      | 103.71 | 17.62      |
| June 89 | 86.392      | 0          | 104.59 | 18.19      |
| June 90 | 86.392      | 1.162      | 104.07 | 17.68      |
| June 91 | 86.392      | 0.072      | 104.43 | 18.04      |
| June 92 | 86.392      | 0.072      | 104.30 | 17.91      |
| June 93 | 86.392      | 0.404      | 106.82 | 20.42      |
| June 94 | 86.392      | 0          | 106.15 | 19.76      |
The above “Table 3” shows during simulation at 13.00 hours the highest pressure generated at junction 1 and 73 is 21.61m and lowest pressure generated at junction 64 is 11.44m.

4.2. Links Result

This supply network has 112 links and the Direction of flow depends upon the hydraulic head and considered that pipe allows full flow at all the time. The elementary input data for pipes are diameter, length and roughness coefficient. Flow rates, velocity and head loss are the output results obtained from EPANET at 13 hours are shown in “Table 4”.

| Link ID | Length m | Diameter mm | Flow LPS | Velocity m/s | Unit Head-loss m/km |
|---------|-----------|-------------|----------|--------------|---------------------|
| Pipe 1  | 9.32      | 175         | 20.151   | 0.838        | 3.98                |
| Pipe 2  | 76.81     | 125         | 7.270    | 0.592        | 3.10                |
| Pipe 3  | 44.94     | 80          | 1.990    | 0.396        | 2.48                |
| Pipe 4  | 3.89      | 40          | 0.685    | 0.545        | 10.06               |
| Pipe 5  | 43.58     | 40          | 0.620    | 0.493        | 8.36                |
| Pipe 6  | 8.48      | 20          | 0.261    | 0.831        | 49.28               |
| Pipe 7  | 7.88      | 25          | 0.359    | 0.731        | 30.00               |
| Pipe 8  | 44.52     | 50          | 0.685    | 0.349        | 3.39                |
| Pipe 9  | 6.39      | 15          | 0.080    | 0.453        | 22.40               |
| Pipe 10 | 13.11     | 40          | 0.591    | 0.487        | 8.65                |
| Pipe 11 | 10.88     | 15          | 0.016    | 0.091        | 1.14                |
| Pipe 12 | 20.51     | 25          | 0.359    | 0.731        | 30.00               |
| Pipe 13 | 81.65     | 20          | 0.216    | 0.688        | 34.71               |
| Pipe 14 | 70.93     | 15          | 0.014    | 0.079        | 0.89                |
| Pipe 15 | 119.9     | 100         | 5.280    | 0.672        | 5.09                |
| Pipe 16 | 71.78     | 50          | 1.989    | 1.013        | 24.42               |
| Pipe 17 | 12.64     | 40          | 0.626    | 0.498        | 8.51                |
| Pipe 18 | 9.05      | 40          | 0.604    | 0.481        | 7.97                |
| Pipe 19 | 25.71     | 40          | 0.759    | 0.604        | 12.16               |
| Pipe 20 | 8.02      | 40          | 0.615    | 0.489        | 8.24                |
| Pipe 21 | 25.97     | 20          | 0.144    | 0.458        | 16.38               |
| Pipe 22 | 10.04     | 40          | 0.767    | 0.61         | 12.40               |
| Pipe 23 | 68.42     | 80          | 2.524    | 0.502        | 3.85                |
| Pipe 24 | 19.09     | 50          | 2.396    | 1.22         | 34.48               |
| Pipe 25 | 12.74     | 25          | 0.128    | 0.261        | 4.44                |
| Pipe 26 | 5.15      | 20          | 0.067    | 0.213        | 3.97                |
| Pipe 27 | 80.64     | 15          | 0.061    | 0.345        | 13.55               |
| Pipe 28 | 10.34     | 15          | 0.013    | 0.074        | 0.77                |
| Pipe 29 | 77.5      | 15          | 0.048    | 0.272        | 8.70                |
| Pipe 30 | 8.79      | 25          | 0.447    | 0.911        | 45.02               |
| Pipe 31 | 59.17     | 80          | 2.794    | 0.556        | 4.64                |
| Pipe 32 | 16.06     | 50          | 1.863    | 0.949        | 21.63               |
| Pipe 33 | 41.43     | 40          | 0.931    | 0.741        | 17.75               |
| Link ID  | Length m | Diameter mm | Flow LPS | Velocity m/s | Unit Head-loss m/km |
|---------|----------|-------------|----------|--------------|---------------------|
| Pipe 34 | 8.78     | 40          | 0.745    | 0.593        | 11.75              |
| Pipe 35 | 19.58    | 20          | 0.186    | 0.592        | 26.32              |
| Pipe 36 | 154.4    | 125         | 9.864    | 0.886        | 5.23               |
| Pipe 37 | 41.03    | 40          | 1.078    | 0.858        | 23.29              |
| Pipe 38 | 19.89    | 25          | 0.345    | 0.703        | 27.87              |
| Pipe 39 | 15.34    | 100         | 0.733    | 0.093        | 0.13               |
| Pipe 40 | 8.23     | 25          | 0.374    | 0.762        | 32.36              |
| Pipe 41 | 46.25    | 25          | 0.359    | 0.731        | 30.00              |
| Pipe 42 | 7.56     | 25          | 0.411    | 0.837        | 38.54              |
| Pipe 43 | 39.65    | 80          | 3.589    | 0.714        | 7.38               |
| Pipe 44 | 17.53    | 50          | 1.051    | 0.555        | 7.49               |
| Pipe 45 | 10.85    | 25          | 0.360    | 0.733        | 30.15              |
| Pipe 46 | 13.43    | 20          | 0.288    | 0.917        | 59.14              |
| Pipe 47 | 9.56     | 15          | 0.072    | 0.407        | 18.43              |
| Pipe 48 | 25.84    | 40          | 0.691    | 0.55         | 10.22              |
| Pipe 49 | 7.75     | 20          | 0.288    | 0.917        | 59.14              |
| Pipe 50 | 26.43    | 25          | 0.403    | 0.821        | 37.16              |
| Pipe 51 | 78.98    | 50          | 2.219    | 1.13         | 29.91              |
| Pipe 52 | 51.37    | 25          | 0.415    | 0.845        | 39.23              |
| Pipe 53 | 10.85    | 25          | 0.381    | 0.776        | 33.49              |
| Pipe 54 | 12.4     | 15          | 0.034    | 0.192        | 4.59               |
| Pipe 55 | 30.48    | 25          | 0.319    | 0.65         | 24.10              |
| Pipe 56 | 62.81    | 50          | 1.804    | 0.919        | 20.38              |
| Pipe 57 | 8.26     | 40          | 0.733    | 0.583        | 11.40              |
| Pipe 58 | 7.61     | 25          | 0.359    | 0.731        | 30.00              |
| Pipe 59 | 8.09     | 25          | 0.374    | 0.762        | 32.36              |
| Pipe 60 | 90.49    | 40          | 1.071    | 0.852        | 23.01              |
| Pipe 61 | 17.45    | 40          | 0.798    | 0.85         | 13.34              |
| Pipe 62 | 6.03     | 25          | 0.388    | 0.79         | 34.64              |
| Pipe 63 | 6.03     | 25          | 0.410    | 0.835        | 38.36              |
| Pipe 64 | 56.88    | 20          | 0.273    | 0.869        | 53.56              |
| Pipe 65 | 104      | 80          | 4.562    | 0.908        | 11.51              |
| Pipe 66 | 16.65    | 40          | 1.207    | 0.96         | 28.71              |
| Pipe 67 | 14.47    | 25          | 0.431    | 0.878        | 42.08              |
| Pipe 68 | 9.14     | 25          | 0.359    | 0.731        | 30.00              |
| Pipe 69 | 26.65    | 25          | 0.417    | 0.85         | 39.58              |
| Pipe 70 | 38.69    | 80          | 3.355    | 0.667        | 6.52               |
| Pipe 71 | 23.35    | 25          | 0.374    | 0.762        | 32.36              |
| Pipe 72 | 18.78    | 80          | 2.981    | 0.593        | 5.24               |
| Pipe 73 | 15.55    | 200         | 29.332   | 0.934        | 4.17               |
| Pipe 74 | 90.24    | 175         | 20.831   | 0.866        | 4.23               |
| Pipe 75 | 14.19    | 150         | 14.854   | 0.841        | 4.80               |
| Pipe 76 | 33.78    | 25          | 0.479    | 0.976        | 51.17              |
| Pipe 77 | 14.44    | 80          | 4.792    | 0.953        | 12.61              |
| Pipe 78 | 7.51     | 50          | 2.023    | 1.03         | 25.20              |
| Pipe 79 | 85.24    | 125         | 9.583    | 0.781        | 5.18               |
| Pipe 80 | 67.61    | 80          | 3.954    | 0.787        | 8.83               |
| Pipe 81 | 50.64    | 80          | 3.229    | 0.642        | 6.07               |
| Pipe 82 | 54.43    | 50          | 1.923    | 0.979        | 22.94              |
| Pipe 83 | 13.81    | 40          | 0.697    | 0.555        | 10.39              |
| Pipe 84 | 21.65    | 25          | 0.359    | 0.731        | 30.00              |
| Pipe 85 | 11.6     | 25          | 0.338    | 0.689        | 26.83              |
| Pipe 86 | 34.52    | 40          | 1.226    | 0.786        | 29.56              |
| Pipe 87 | 11.04    | 40          | 1.118    | 0.89         | 24.92              |
| Pipe 88 | 18.79    | 15          | 0.108    | 0.611        | 39.04              |
| Pipe 89 | 63.93    | 40          | 1.306    | 1.039        | 33.23              |
| Pipe 90 | 19.27    | 40          | 1.162    | 0.925        | 26.76              |
| Pipe 91 | 8.48     | 15          | 0.072    | 0.407        | 18.43              |
| Pipe 92 | 15.42    | 15          | 0.072    | 0.407        | 18.43              |
| Pipe 93 | 5.4      | 25          | 0.404    | 0.823        | 37.33              |
| Pipe 94 | 35.47    | 25          | 0.321    | 0.786        | 24.38              |
| Pipe 95 | 38.21    | 20          | 0.048    | 0.153        | 2.14               |
| Pipe 96 | 14.1     | 15          | 0.008    | 0.045        | 0.31               |
| Pipe 97 | 12.67    | 15          | 0.040    | 0.226        | 6.20               |
| Pipe 98 | 48.64    | 20          | 0.273    | 0.869        | 53.56              |
| Pipe 99 | 22.89    | 15          | 0.064    | 0.362        | 14.82              |
| Pipe 100| 8.99     | 15          | 0.108    | 0.611        | 39.04              |
The above “Table 4” shows during simulation at 13.00 hours the highest flow or discharge generated through the pipe 73 is 29.332 LPS and lowest flow generated through the pipe 28 is 0.013 LPS.

4.3. Results in Color-coded Map

“Figure 2” illustrate the color-coded map for node demand and link flow of water distribution network at 13 hours.

| Link ID | Length m | Diameter mm | Flow LPS | Velocity m/s | Unit Head-loss m/km |
|---------|----------|-------------|----------|--------------|---------------------|
| Pipe 101 | 14.05 | 15 | 0.101 | 0.572 | 34.49 |
| Pipe 102 | 89.06 | 125 | 8.501 | 0.693 | 4.15 |
| Pipe 103 | 5.07 | 40 | 1.041 | 0.828 | 21.83 |
| Pipe 104 | 7.1 | 15 | 0.072 | 0.407 | 18.43 |
| Pipe 105 | 6.59 | 40 | 0.969 | 0.771 | 19.12 |
| Pipe 106 | 84.93 | 125 | 7.460 | 0.608 | 3.26 |
| Pipe 107 | 10.5 | 40 | 0.853 | 0.679 | 15.10 |
| Pipe 108 | 39.38 | 80 | 3.466 | 0.69 | 6.92 |
| Pipe 109 | 149 | 50 | 1.677 | 0.854 | 17.81 |
| Pipe 110 | 91.8 | 50 | 1.464 | 0.746 | 13.85 |
| Pipe 111 | 35.15 | 40 | 1.198 | 0.953 | 28.32 |
| Pipe 112 | 129.4 | 20 | 0.366 | 0.847 | 51.05 |
| Pump Pu1 | #N/A | #N/A | 31.281 | 0 | -108.65 |
| Pump Pu2 | #N/A | #N/A | 45.778 | 0 | -108.06 |

![Figure 2. Color-coded map for node demand and link flow.](image-url)
In the color coded map, the node having demand less than 0 LPS is in blue color, node having demand within the range of 0 to 0.25 LPS is in mint green color, node having demand within the range of 0.25 to 0.5 LPS is in green color, node having demand within the range of 0.5 to 1 LPS is in yellow color and finally node having demand more than 1 LPS is in red color. The link having flow less than 0.5 LPS is in blue color, link having flow within the range of 0.5 to 1 LPS is in mint green color, link having flow within the range of 1 to 2 LPS is in green color, link having flow within the range of 2 to 4 LPS is in yellow color and finally link having flow more than 4 LPS is in red color.

“Figure 3” illustrate the color-coded map for node pressure and link velocity of water distribution network at 13 hours.

Figure 3. Color-coded map for node pressure and link velocity.

In the color coded map, the node having pressure less than 17 m is in blue color, node having pressure within the range of 17 to 18 m is in mint green color, node having pressure within the range of 18 to 19 m is in green color, node having pressure within the range of 19 to 20 m is in yellow color and finally node having pressure more than 20 m is in red color. The link having velocity less than 0.60 m/s is in blue color, link having velocity within the range of 0.60 to 0.70 m/s is in mint green color, link having velocity within the range of 0.70 to 0.80 m/s is in green color, link having flow within the range of 0.80 to 0.90 m/s is in yellow color and finally link having velocity more than 0.90 m/s is in red color.

4.4. Results in Graph

“Figure 4” illustrate the graphical representation of node
pressure distribution at 13 hours.

In the above “Figure 4” X axis represents the nodal pressure or water head in meter and Y axis represents the total percentage of nodes having pressure less than that particular water pressure. This graph demonstrates that maximum number of nodes having pressure within the range of 17 to 21.5 m.

“Figure 5” illustrate the graphical representation of link flow distribution at 13 hours.
In the above “Figure 5” X axis represents the link or pipe flow in LPS and Y axis represents the total percentage of links having flow less than that particular flow. This graph demonstrates that maximum number of link having flow within the range of 0 to 3 LPS. “Figure 6” illustrate the graphical representation of link velocity distribution at 13 hours.

In the above “Figure 6” X axis represents the link or pipe velocity in m/s and Y axis represents the total percentage of links having velocity less than that particular velocity. This graph demonstrates that maximum number of link having velocity within the range of 0.5 to 1 m/s.

5. Conclusion

The prime consideration of this study was to analyze and design of a water distribution network for HSTU campus. Total number of 112 nodes, 112 links, 2 elevated storage tanks and 2 pumps are provided in distribution network to meet the water requirement. The evaluation tools have been explored throughout the case study to identify the poor performance, network expansion points, nodes demand requirement [21]. Highest and lowest pressure for node is generated within the range from 11.44 m to 21.61 m which is much higher than the 10 m or 1 bar required to maintain service standard of water supply. About 45.5% nodes having pressure above 20 m, percentage of node having pressure within 15 m to 20 m is 50% and 4.5% nodes having pressure below 15 m. Flow through the pipes ranges from 0.013 LPS to 29.332 LPS. Percentage of the number of pipes having velocity above 1 m/s is 4.5%, 71.5% pipes having velocity within the range between 0.5 m/s to 1 meter per second and rest of the 24% pipes having velocity below 0.5 m/s. For this particular study velocity through the pipe in the design network is much lower than the scouring limit 3 m/s. Largest and smallest diameter are provided 200 mm and 15 mm respectively. Simulation was carried out during the peak hour, pressure of water presents in the network is adequate enough to meet the water requirement by storing water into the individual underground storage tank of each building and there is no negative pressure in any node. Velocity of water through the pipes of this particular water distribution networks remained much lower than the scouring limit and the networks will be reliable in near future to meet the additional demand of water.

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