DESIGN OF GRAVITY FLOW WATER SUPPLY NETWORK BY WATERGEMS: CASE STUDY OF PANCHRA GRAM-PANCHAYAT IN BIRBHUM DISTRICT, WEST BENGAL

A thesis submitted towards partial fulfillment of the requirements for the degree of

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Declaration of Originality and Compliance of Academic Ethics

I hereby declare that this thesis contains a literature survey and original research work by the undersigned candidate, as part of my **Master of Engineering** in **Water Resources & Hydraulic Engineering (6 Semester)** under the Faculty Council of Interdisciplinary Studies, Law and management in Jadavpur University during academic session 2019-22.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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Certificate of Recommendation

This is to certify that the thesis entitled "**Design of Gravity Flow Water Supply Networks by WaterGEMS Software: Case Study of Panchra in the district of Birbhum, West Bengal**" is a bonafide work carried out by Mr. Soham Adak under my supervision and guidance for partial fulfillment of the requirement for the Post Graduate Degree of Master of Engineering in Water Resources & Hydraulic Engineering (6 Semester) during the academic session 2019-2022.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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Final Examination
for the evaluation
of the thesis

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ABSTRACT

The people of Panchra G.P under Khoyrasole block in Birbhum district are deprived of drinking water supply or receive very poor quantum of drinking water due to ground water of the habitations is found to be scarce and insufficient. Presently no piped water supply facility / sustainable drinking water supply system exists within the scheme jurisdiction & people of the area are using hand pump tube well as source of potable water most of which became dry during summer seasons. Water borne diseases like diarrhoea/ Amibiosis / typhoid etc. are common within the command area. To combat this situation, Public Health Engineering Directorate, under the Government of West Bengal has proposed a new piped water supply scheme for this area. It will be a sub-surface water scheme. Source of intake will be Ajay river.

The Panchra Piped Water Supply Scheme covers 40 (Forty) nos. of habitations in 25 (Twenty Five) nos. of mouzas of Block Khoyrasole, P.S. Khoyrasole under Birbhum District in the state of West Bengal. The total area covered under the scheme is about 4642.054 hectare with a total population of 19957 as per 2011censusand average population density of 4.30 persons per hectare.

WaterGEMS software has been used for design and analysis for the above mention water distribution network. WATERGEMS software developed by Bentley Systems, USA. As per the data received the inputs were done and accordingly the results were interpreted in graphical format. The whole network of service area consists about 459 pipes and 449 junctions. Hence detailed reports are represented in graphical form.

Key Words: Hydraulic Parameters, junctions, pipes, Panchra G.P, WaterGEMS.

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CHAPTER 1- INTRODUCTION

1.1 Background of the study:

One of the most important issues in human history has been providing sufficient water of appropriate quality and quantity. A reliable source of water for drinking and agriculture is given to the inhabitants by a river. Fishing, fertile of soil due to annual flooding and ease of transportation include as additional benefits. The first great civilizations, such as those in Mesopotamia and Egypt, all grew up in river valleys but it became difficult to meet users demand of water as population grew day by day.

Water transportation from various sources to individual households for drinking and other purposes began. For example, the aqueducts to deliver water from distant sources to their communities were constructed by Romans.

A water supply system or water supply network is a system of engineered hydrologic and hydraulic components which provide supply. Public utilities of the water industry run water supply networks. The majority of assets of a water utility is usually represented by water supply network. All the activities related to provision of potable water are covered by a sustainable urban water supply network. Water supply from sustainable perspective is improved by incorporating innovative water technologies into water supply system. The development of innovative water technologies provides flexibility to the water supply system, generating a fundamental and effective means of sustainability based on an integrated real options approach. For human existence, water is an essential natural resource. Every industrial and natural process need Water, for example, oil refining, cooling, steel industry and even in food processing also. Adaptation of new approach is very necessary to design urban water supply networks. New sources of water are needed to be developed to achieve a sustainable water supply network and to reduce environmental pollution. The action must be taken to prevent leakage of pipeline because the price of water is increasing, so less water must be wasted. The fresh water consumption rate and the waste water generation rate must be maintained by a sustainable water supply network.

Modelling hydraulic network can be very useful in managing the system and for making decision about system rehabilitation or a major expansion. One of the most important problems concerning the use of mathematic simulators is determining how well they can represent the physical system. A simulator model must be calibrated before its result can be reliably used for any purpose. Although a variety of reasons may cause the discrepancy between simulated and measured values one stands out prominently the approximate knowledge of some input data. The input data are design parameter such as pipe roughness and nodal demands. After period of network complexity like aging of pipes, roughness values are uncertain and not directly measurable. Calibration of computer models for network analysis is a regular component of the model building process. The process generally first involves a series of field test during which pressure and flows are recorded at strategic location in the system. This is followed by desk exercise during which adjustments are made to the roughness values and used in modelling the system and are used in modelling the system and a satisfactory match identity obtained between modelled and observed values several methodologies were proposed to assist the modeller in the derivation of good calibrated network. So, calibration is the process of adjusting uncertain model input data (parameters) in order as obtained the predicted model nodes and pipe flows (output) that are in a reasonable agreement with field observations.

It is crucial to provide water to the consumers. It is so much needed to deliver water to the individual consumer in the required quantity and under a satisfactory pressure by water distribution system. Elements such as pipes, tanks, pumps and valves etc are the integral parts of a hydraulic infrastructure which is known as water distribution system. Those individuals who are involved with designs, construction and maintenance of public water distribution system are very much interested in computation of flows and pressures in network pipes. The purpose of this study is performing the hydraulic analysis of Khayrasole Block in the district of Birbhum, water distribution network using WaterGEMS V8i Software.

1.2 Study area:

Panchra is a Gram Panchayat, which falls under Block Khoyrasole, Sub-Division Suri Sadar, District Birbhum and 9 km away from Block Head Quarter, 36 km away from Sub-Division Head Quarter, 36 km away from District Head Quarter and is connected with Road/ Rail networks. Nearest Railway Station is Sainthia Junction 34 km and nearest Airport is Andal 72 km away from the Headworks site of the proposed command area. The area falls within dry and arid region of the state.

Panchra G.P consists of 25nos of mouzas. Presently there are 41nos. habitations. As per census 2011 total no. of population is 19967 out of which 10942 & 46 are SC & ST population respectively. Total command area is 4642.054 hectares. Average population density works out to be 4.30 persons per Ha.

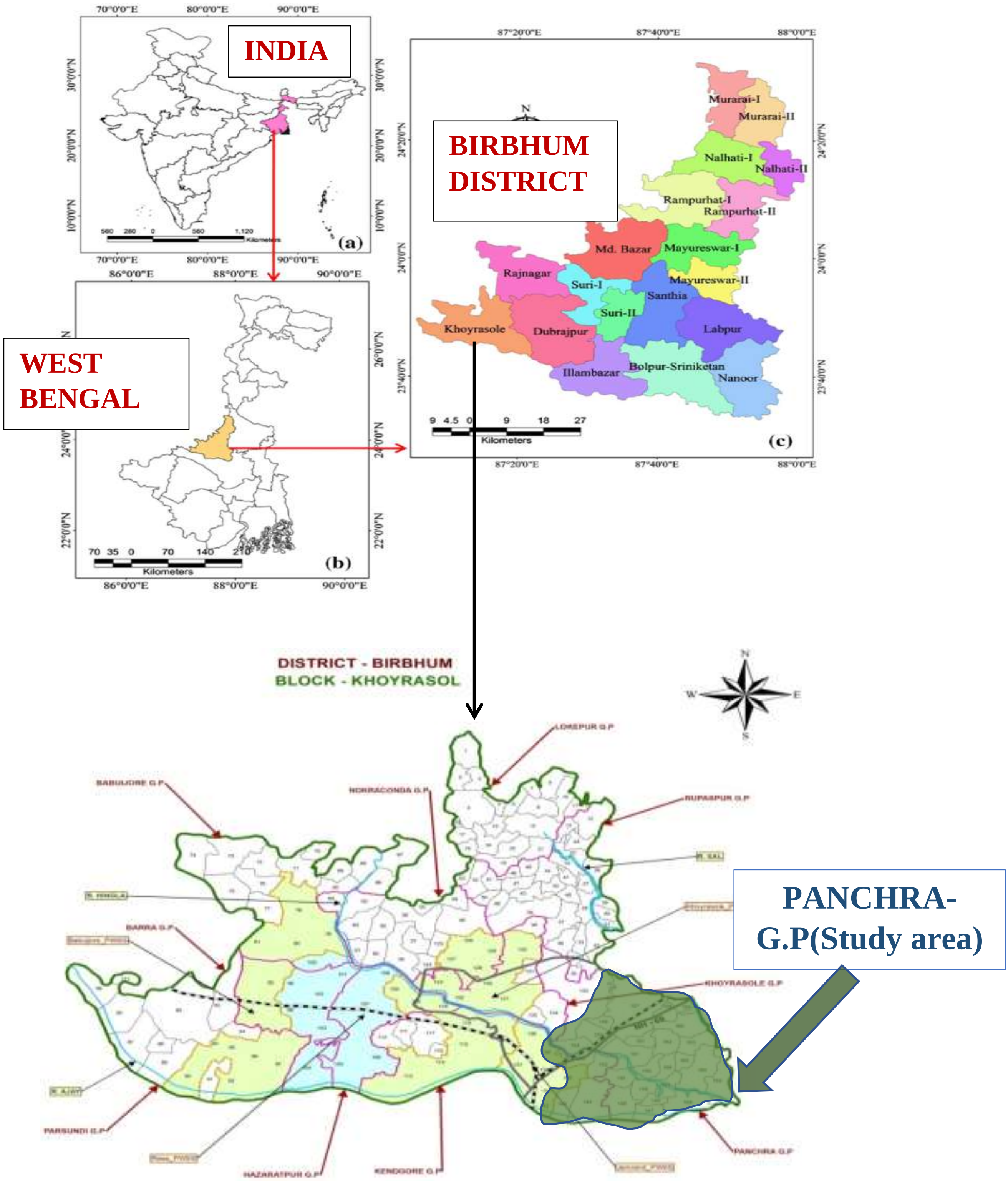

Figure 1 : Index Map of Study Area

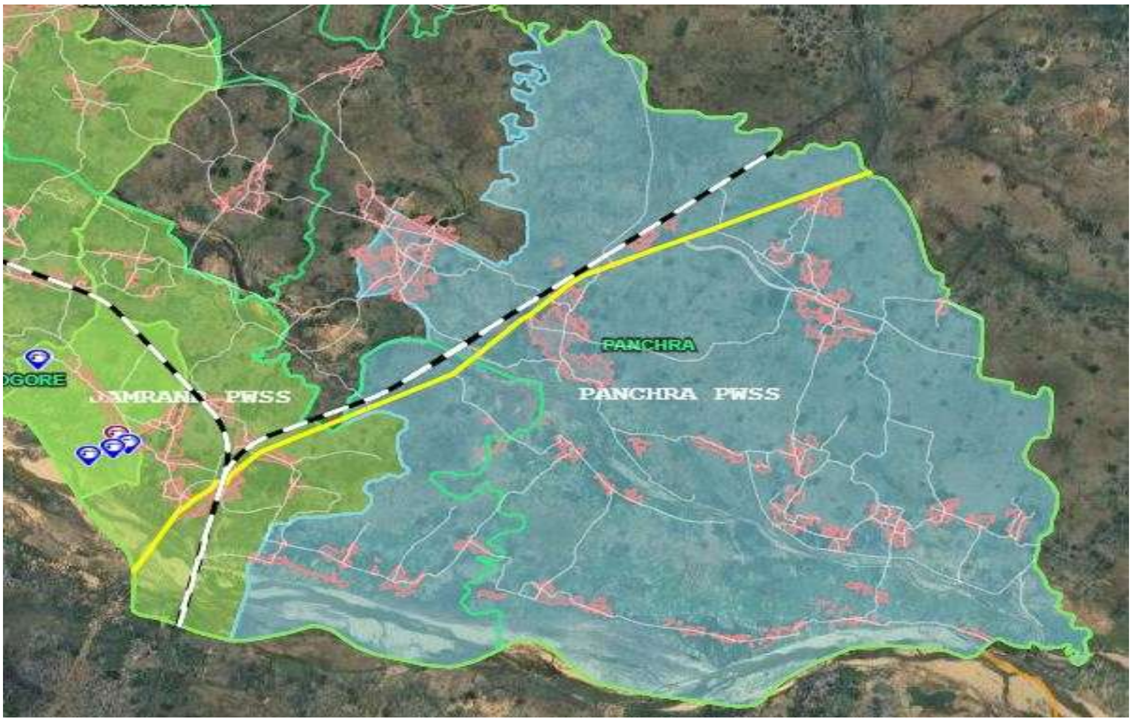

Figure 2 : Map of Panchra PWSS(Source PHED website)

1.3 Objective(s) of study:

The main objective of the study is to develop hydraulic model of water supply network using Water GEMS software for sustainable rural drinking water supply at Panchra Gram Panchayet in the district of Birbhum, West Bengal.

1.4 Brief Methodology of the study:

Methodology is the systematic, theoretical analysis of the methods applied to a field of study. It comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge. Typically, it encompasses concepts such as paradigm, theoretical model, phases and quantitative or qualitative techniques methodology does not set out to provide solutions – it is, therefore, not the same as a method. Instead, a methodology offers the theoretical underpinning for understanding which method, set of methods, or best practices can be applied to specific case, for example, to calculate a specific result.

For this study, the layout map for the pipeline network in connection to Panchra G.P, Khoyrasole block in Birbhum District of West Bengal was analysed. The design data was derived from the existing topographical survey of the study area.

The model was created by giving the appropriate input parameters to the various elements, such as Input variables for the pipes include length, trial diameter (based on observation and engineering judgement), and the Hazen-Williams Constant/Roughness coefficient. The connections have been assigned input parameters such as base demand and elevation.The model was estimated and validated against the applicable CPHEEO provisions.

1.5 Proposed outcome:

- To design the distribution network considering the increase in the future population for 30 year.
- To develop a model of a gravity flow pipeline distribution network from the reservoir to the consumer end using WaterGEMS software.
- To determine the velocity, flow, head loss of different pipes and pressure, hydraulic grade, pressure head at different nodes of the pipeline distribution network using the software.
- To evaluate the model efficacy for minimize the leakage, and to optimize the water availability to consumers.

1.6 Outline of Thesis:

- The thesis is divided into 8 chapters. Chapter 2 offers a review of the literature. The 3rd chapter depicts the research topic and technique. The 4th chapter shows the governing equations as well as the significance of the numerical model WaterGEMS for the design and analysis of the distribution network. In the chapter 5 the detailed study about the area is described. The data analysis and methodology are presented in Chapter 6 .The outcome and discussion of the research study is presented in chapter 7. Finally the in the form of conclusions and the future scope of the study is discussed in chapter 8 . The dissertation concludes with a list of references.

CHAPTER 2- LITERATURE REVIEW

2.1 National and International literature review:

The literature review shows that in the case of simple water distribution systems, optimization is extensively used. The design of large-scale water networks has some important features like the increasing population and the topography. Some papers focus on the details of a particular master planning study or actual water distribution systems.

Halhal et al. studied the optimization of a town in Morocco. The network consisted of 115 nodes, 158 existing pipes to be rehabilitated, and nine new pipelines to be designed (orsized) for the system. Murphy et al. applied the GA optimization model to the Jamestown System expansion plan composed of about 350 pipes and 4 major regulating valves separating the transmission system from the distribution network and isolating the distribution network into 2 pressure zones.

Shau et al. selected the Ruey-Fang water supply system in Taipei County to illustrate the practical application of the GA. There are 26 pipelines, 20 nodes, and 2 water intake points. One of intake is water treatment plant; the other is the Kung- Liao system support.

Wu et al. studied a water distribution system supplying about 18.3 million gallon of water for a peak day demand. The hydraulic network model contains 2018 pipes, 1371 nodes, 3 pumps, 1 reservoir, 9 elevated storage tanks and 20 wells. They performed optimization runs for optimizing improvement solutions for four scenarios: satisfying full demand growth; determining sustainable demand growth; maximizing water production; and prioritizing phase-in capital improvement.

Ulanicki et al. (2000) studied open and closed-loop pressure control for leakage reduction as the UK water industry was addressing a major challenge of reducing leakage from the water supply and distribution network. They attempted to formulate investigation methods for planning and implementation of online control strategies of predictive and feedback control for areas with many pressure-reducing valves and target points. The considered methods were supposed to take into account a leakage model and the results were applied to an area with three pressure-reducing valves and two target points.

Das (2006) carried out a pipe network analysis for a water treatment plant. As a case study, the total schematic drawing of the rising main for South 24 Parganas Water Supply Scheme under Public Health Engineering Department (PHED), Government of West Bengal was considered. The network consisted of a Clear Water Reservoir (CWR) from which two pumps are supplying water to twenty-four (24) numbers of Zonal Overhead Reservoirs (OHR) and two Ground Level Reservoirs (GLR) (BS-I & BS-II for feeding 27 more overhead reservoirs) through the rising main. It was observed that the time required for filling the OHR s at different levels was not the same which was needed to be maintained by adjusting the Flow Control Valves (FCV). After modelling the network by EPANET 2.0 software it was observed that the time requirements of 24 overhead reservoirs were almost the same. Then optimum head losses in pipes and valves were also achieved during the operation.

Das et al. (2008) analysed the pipe flow and headloss of a modelled network based on EPANET in a water treatment plant in Raipur. The study was carried out in two phases in the first phases a pipeline network was designed using EPANET software in such a way that the model flow data for different zonal overhead reservoirs takes almost the same time by adjusting the Flow Control Valve (FCV) and by changing other parameters such as flow parameters of the FCVs, loss coefficient of the throttle control valve TCV's, etc. To achieve the desired inflow to the Zonal OHRs a lot of modifications were done by adjusting different parameters of TCV, Pressure Reducing Valve (PRV) and FCV for optimising the head losses in the pipes and valves in the modelled system. From the result, it was observed that 60% and more reduction losses occurred in the pipelines and valves. The validation model also revealed 92.31% success.

Liana et al. (2008) studied mathematical modelling and computer simulation which may become one of the most important tools for water companies in their attempt to provide their high-quality service economically for both development and operations. The available sophisticated and accessible models permit the proper evaluation of network behaviour under normal and abnormal conditions and it allows these goals to be realized more fully than ever before. The result was obtained using two softwares EPANET and INFOWORKS WS. The results were compared among each other. The obtained results were similar to the optimal design model for water distribution systems, considering the water quality aspect reported by Vuta and Popa (2006).

Izquierdo et al. (2008) discussed the sensitivity analysis to assess the relative importance of pipes in water distribution networks. The information regarding the recognition of the sundry and relative importance of the different pipes in a water distribution network, in turn, will be helpful in the different aspects of a water distribution network make-up, namely design, planning, control and management. A methodology was proposed, to determine the relative importance of the pipes in a water distribution network based on the quantification of the uncertainty of the data using an error limit analysis performed using sensitivity analysis. By making use of the mathematical model of the network, the estimated steady-state together with uncertainty levels, a fuzzy estimated steady state of the network can be obtained.

Koppel et al. (2009) studied the calibration of a model of an operational distribution network system containing pipes of different ages. The objective of their work was to describe that whether the Levenberg-Marquardt algorithm can give successful results when operational distribution systems are calibrated with proper parameter increment selection for the calculation of partial derivative. The functional dependence of pipe roughness on age calibration was proposed for the calibration of a model of a water distribution system containing pipes of different ages. From the results, it was observed that the combination of the Levenberg-Marquardt algorithm with the response surface obtained by the trial and error method facilitated calibration significantly.

Arunkumar et al. (2011) carried out a study on water demand analysis of municipal water supply using EPANET software. The main objective was to provide effective planning, development and operation of water supply and distribution networks which is one of the most important parts of urban infrastructure. The study delineated the areas within a municipality which were un-served or underserved by the Municipality. Using EPANET 2.0 water model software, the demand for the Underserved and Unserved area was calculated. From the results, it was observed that PRV and SV were needed to maintain the even pressure at all nodes throughout the supply line and pressure above the threshold value as per the CPHEEO (Central Public Health and Environmental Engineering Organisation) manual at the tail ends of the network.

Chandramouli et al. (2011) studied the reliability-based optimal design of a water distribution network for municipal water supply. The objective of the study was to develop a new parameter to evaluate the overall network reliability using fuzzy logic concepts based on the excess pressures available at the demand nodes and to incorporate those developed parameters in a two objective optimization model for the design of a water distribution network using the combination of Genetic Algorithms and EPANET tool kit in the MATLAB environment. The proposed methodology was applied on a two-loop gravity network. Total 54 numbers of optimal solutions were identified for the network. The results were compared with the results of the previous researches in respect of different parameters like the Network Reliability Parameter (NRP), Cost Reliability Ration (CRR) and Cost per Unit Reliability and Unit Length (CURUL). It was found that comparing with the results of the previous research the present study shows better results.

Das et al. (2013) studied on analysed a hammerhead increase demand of water in an urban area as became necessary to increase the capacity of the water pipeline networks by keeping the pipes and valves elements unchanged as it was very difficult to work to change those in an urban area due to inaccessibility. This paper presents a study on the characteristics of hammerhead at increased flow demand at different points of a network using HAMMER software. According to the layout of the distribution network of the Dhapa water treatment plant, Kolkata Municipal Corporation (KMC), West Bengal, India, all the parameters of the pipes, junctions and other elements were inserted in the above software. The flow capacity had been increased to 50%, 75%, 100% more than the existing flow capacity of the above network and the transient analysis was done accordingly. From the results, the increasing flow demands can be observed for all zones which satisfy the basic equation of Water Hammer theoretically.

Moreira et al. (2013) found that the majority of the life cycle cost of a pump is related to being energy used in pumping and the rest were related to the purchase and maintenance of the equipments. Any optimizations in the energy efficiency of the pump cause a considerable reduction in total operational cost. The Fatima water supply system in Portugal was analyzed to reduce its operational’ energy costs. To achieve the most efficient and economic point, different pump characteristics were analysed and modelled. The genetic algorithm embedded in the modelling software was considered along with the manual override approach to determine the best quality pumping.

Mukherjee et al. (2013) carried out a comparative study between hydraulic analysis outputs of pipeline network between softwares EPANET and HAMMER. The main objective here was to design a pipeline of water distribution networks and insert the required input in both the software accordingly. The outputs which were considered for the above study were hydraulic grade line and pressure at junctions and flow and unit head loss for pipes. The comparative study was carried out with the help of statistical regression analysis by finding out correlation coefficient and probable error coefficient.

Sarkar (2014) worked on the real-life operation of Garfa Boosting Station, Garfa, under Borough XII of KMC which served mainly four KMC wards that are ward numbers 103, 104, 106 and 109 having population above one lakhs including floating ones, to solve the different problem regarding low pressure of the flow of water at various areas. An extended period simulation in which an application of Water gems and Hammer software was carried out in this study worked similarly as real-life scheduled three operation shifts. The result from the extended period simulation suggests 98% accuracy with the field data received in the case of Ward number 98 and the rest of the other wards it depends upon valve operation and perhaps these results can be more prominent if it was furnished with those valve data also.

Wu et al. (2014) worked on the optimization of a parallel pump system for energy saving and long service life. Experiments were carried out between two identical pumps. Theoretical solution based on the Lagrange multiples method was proved by the developed optimised model employing a genetic algorithm. The presented model gives optimal input data for the pumps' rotational speed and valve positions. From the results, it was seen that control valves are especially helpful for the improvement of a single pump's efficiency and reliability and the optimization model provides a proper balance between efficiency and reliability by offering a suitable operating mode.

Mukherjee et al. (2015) worked on the transient analysis of pipeline network for drinking purposes in Assam, India which is linked between intake well at Brahmaputra river to Jalukbari water treatment plant (WTP) to study the temporal behaviour of the proposed raw water pipeline for drinking purpose. Hammer analysis tests were carried out using HAMMER software in relation to the basic transient equation and the number of waterhammer protection devices was suggested accordingly. From the result, it was observed that increasing the number of water hammer protection devices does not reduce the maximum head proportionately.

Ganguly (2016) studied the usage of flow control valves (FCVs) to control the flow in order to meet the demand in a drinking water pipeline network system through simulation by EPANET software. From the result of the pressures and hydraulic grades of the total pipe network system along with few geographical undulations, it was observed that usage of air valves was very much necessary in this case to meet the demand.

Halder (2016) studied a closed pipe network at Brindabanchak Gram Panchayat at Panskura-II block of East Medinipur district under the raw water supply from River Rupnarayan to estimate various hydraulic parameters such as hydraulic grade, pressure, flow, velocity and unit head loss whole piped network using EPANET software. As per the data received the inputs were inserted into the software and accordingly the outcomes were represented in graphical format. The whole network consisted of 364 pipes and 337 junctions. The results were also compared with a popular pipeline designing software LOOP. The result obtained from the pipe network system using EPANET and LOOP software had a similarity of 96% which suggests that by using any one of the software, these results could be adjusted.

Saha (2016) performed a transient analysis of pipe networks using HAMMER software at the Mukutmanipur area of the Purulia piped water supply scheme. Sudden power failure, pump failure, valve failure were the main reasons behind the hydraulic transient in a water supply line. This work described the generation, propagation and reflection of pressure waves in liquid-filled pipe systems causing surge and waterhammer. The hydraulic modelling of the clear water transmission main of the study area was first done and followed by the steady-state analysis of the same by WaterGEMS software. Finally, the maximum transient pressured developed in the network and the factor of safety of the pipe experiencing the maximum transient pressure was checked as per Indian standards and American Water Work Association standards, respectively.

Sarkar (2016) estimated the energy required in different processes in Garden Reach Water Works (GRWW), a conventional waterworks that were used to supply transmit of potable treated water to the southern portion of the Kolkata Municipal Corporation (KMC) area and many other municipalities in West Bengal, India. Estimation of energy required in transmitting water to the four booster pumping stations (BPS) fed from GRWW through Calcutta City (CC) Grid was also analysed in the study.

D.j Mehta et al. (2017) studied the existing Water Distribution Network at Punagam Area of Surat City Using WATERGEMS Software. The objective of this study was to analyze the existing water distribution network of Punagam area using WATERGEMS V8i and to recommend some measures if present network does not fulfil the present and future demand. At the end of the study it was found that the flow computed using WATERGEMS is nearly equal to the actual flow, the velocity computed using WATERGEMS is nearly equal to the actual velocity, the head loss computed using WATERGEMS is nearly equal to the actual head loss. But in some of the pipes there is variation in the flow, velocity and headloss due to improper base demand, less diameter pipe used and pressure fluctuation.

Shinde et al.(2018) studied the hydraulic analysis of Shivaji Nagar territory of Panvel city, Maharashtra. Steady state analysis has been carried out for calculation of hydraulic parameter such as head pressure and flow rate. The result obtained verified that the pressure at all junction and the flows with their velocities at all pipes are feasible enough to provide adequate water to the network of study area.

Debnath (2019) studied the water distribution network of Bhogpur gram panchayat at Panskura-II block in West Bengal by using WaterCAD software. The design and analyses of the water distribution network for Surface Water Based Water Supply Scheme at Panskura- II (also referred to as Kolaghat Block), Zone-III (Bhogpur Gram Panchayet) of Purba Medinipur district using WaterCAD software was discussed in this study. At the end of the analysis, it was found that the resulting pressures at all the nodes and the links velocities were satisfied enough to provide water to the study area.

Maity (2019) simulated on clear water rising main network of Adityapur Municipality in Jharkhand using WaterGEMS software. The objective of the study was to determine the parameters like flow, velocity, headloss, and pressure in clear water rising main pipelines.

In addition to this, a comparative study was presented for total cost variation due to a change in diameter of the pipe in relation to energy cost against this water supply scheme. The inputs of the water distribution system which consist of 37 pipes and 10 junctions were inserted into the software and the outputs were reflected in tabular and graphical format for steady-state simulations and in addition to this extended period simulation was also carried out to compute the time of filling of all the OHRs according to their water demands.

Berhani et al.(2020) optimized an existing piped water supply network which consists of 117 pipes (40.67 km), 99 demand nodes (equivalent to 50480 end users) that are spread across a hilly area over a 1989 m to 2046 m elevation gradient at Wukro Town, Ethiopia using the Darwin Designer in WaterGEMS software. It was applied to the particular piped water supply network to obtain optimal pipe diameter which supplies an adequate quantity of water at satisfactory pressures to the end-users. In the WaterGEMS model, the Darwin Scheduler of daily pumping operations tools was also used for optimal control and operation of pump systems. From the results it was observed that the maximum pressure before the optimization was 31.1 m and after optimization increased to 38.1m, the minimum pressure on the former was 7.9 m and 16 m later during peak hour demand. Comparing the results it was observed that the optimized networks reduce the cost by 9.6% than those of before optimization networks by traditional hydraulic.

Ebsa et al.(2020) studied on hydraulic performance analysis of a water supply distribution network using WaterGEMS software. In this study the junction pressure and the velocity in pipes were analysed and the overall supply of water did not satisfy the total demand of the command area. From the results it was observed that about 14 % of the total number of nodes analyzed had negative pressures while 68 % of the nodes had pressures less than the adopted pressure for the analysis which signifies that there is inadequate head within the distribution network for water supply and 85.6 % of flow velocities in the pipes were within the adopted velocity while around 14.4 % of the velocities exceeded the adopted velocity which indicates that the performance of the water distribution system of under current demand is inefficient.

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CHAPTER 3- WATER DISTRIBUTION NETWORK

3.1 Population Forecasting:

The design population will have to be calculated considering some factors governing the future growth and development of the project area in the industrial, commercial, educational social and administrative spheres. Special factors causing certain emigration or influx of population should also be foreseen to the extent possible.

A judgment based on this factor would help in selecting the most suitable method of deriving the probable trend of population growth in the area or areas in the project from out of the following methods, graphically interpreted where necessary.

3.1.1 Demographic method of population projection:

Population change can occur only in three ways (i) By Birth (ii) By Death (iii) Migration. Population forecasts are frequently obtained by preparing and summing up separate but related projections of natural increases and net migration and are expressed below.

The net effect of births and deaths on population is termed as a natural increase (natural decrease if death exceeds birth).

Migration also affects the number of birth and death in an area and so, projections of the net migration are prepared before the projection of natural increase.

This method thus takes into account the prevailing and anticipated birth rate and death rate of the region and city for the period under consideration. An estimate is also made of the emigration from and immigration to the city, growth of the city area wise and the net increase of population calculated accordingly considering all these factors, by arithmetical balancing.

3.1.2 Arithmetic Increase Method:

This method is generally applicable to large and old cities. In this method, the average increase in population per decade is calculated from the past records and added to the present population to find out the population in the next decade. This method gives low value and is suitable for well-settled and established communities. This method is given in equation number (4.1).

$$P_n = \left[P_0 + n\bar{x} \right] \qquad \text{……(3.1)}$$

where,

P_n = Prospective or forecasted population after n decades.

P_0= Population at present.

n = Number of decades between now and the future.

$\bar{x}$ = Average (arithmetic mean) of population increases in the known decades.

3.1.3 Incremental Increase Method:

In this method, the increment in arithmetical increase is determined from the past decade and the average of that increment is added to the average increase. This method increases the figures obtained by the arithmetic increase method. This method is given in equation number (4.2).

$$P_n = P_0 + n\bar{x} + \left[\frac{n(n+1)}{2}\right]\bar{y} \qquad \text{……(3.2)}$$

where,

$\bar{x}$ = Average increase of population of known decades.

$\bar{y}$ = Average incremental increases of the known decades.

3.1.4 Geometrical Increase method:

In this method percentage increase is assumed to be the rate of growth and the average of the percentage increases is used to find out future increments in population. This method gives much higher value and is mostly applicable for growing towns and cities having vast scope for expansion. This method is given in equation no (4.3).

$$P_n = P_0\left(1 + \frac{r}{100}\right)^n \qquad \text{……(3.3)}$$

where,

r = Assumed growth rate (%).

3.1.5 Decreasing Rate of growth method:

In this method, it is assumed that the rate of percentage of increase and the average decrease in the rate of growth is calculated. Then the percentage increase is modified by deducting the decrease in the rate of growth. This method is applicable only in such cases where the rate of growth of the population shows a downward trend.

3.1.6 Graphical Method:

In this approach, there are two methods. In one, only the city in question is considered and in the second, other similar cities are also taken into account.

a) Graphical Method based on Single City:

In this method, the population curve of the city is smoothly extended for getting future value. This extension has to be done carefully and it requires vast experience and good judgment. The line of best fit may be obtained by the method of least squares.

b) Graphical Method based on cities with similar growth pattern:

In this method, the city in question is compared with other cities which have already undergone the same phases of development that the city in question is likely to undergo and based on this comparison a graph between populations and decades is plotted.

3.1.7 Logistic Method:

The S-shaped logistic curve for any city gives a complete trend of growth of the city right from beginning to saturation limit of the population of the city.

3.1.8 Method of density:

In this approach, the trend in the rate of density increase of population for each sector of a city is found out and population forecast is done for each sector based on the above approach. The addition of sector-wise population gives the population of the city.

3.1.9 Per capita supply:

3.1.9.1 Basic needs:

Pipe water supplies for communities should provide adequately for the following as applicable:

a. Domestic needs such as drinking, cooking, bathing, washing, flushing of toilets, gardening and individual air conditioning.
b. Industrial Needs.
c. Public purpose such as street washing or watering, flushing of sewers, watering of public parks.
d. Industrial and commercial uses including central air conditioning.
e. Fire fighting.
f. Requirements of livestock; and
g. Minimum permissible "unaccounted for water (UFW)"

3.1.9.2 Factors affecting consumption:

a. Size of the city

The per capita demand for big cities is generally large as compared to the smaller towns as the larger cities, required huge quantities of water for maintaining clean and healthy environments.

b. Characteristics of population and standard of living:

Rich and upper-class communities generally consume more water to their affluent living standards than poor or middle-class communities. The habit of the persons also affects consumption.

c. Industrial and Commerce:

The type and number of different industries also affect consumption. Commercial consumption is that of retail and wholesale mercantile houses and office buildings.

d. Climatic Condition:

In hot weather, the consumption of water is more compared to that during cold weather.

e. Metering:

The consumption of water when supply is metered is less compared to that when the water charges are on a flat rate basis.

3.1.9.3 Recommendations:

The Environmental Hygiene Committee suggested certain optimum service levels for communities based on population groups. In the code of Basin Requirements of Water Supply, Drainage and Sanitation (IS 1172-1983) as well as the National Building Code, a minimum of 135 lpcd has been recommended for all residents provided with a full flushing system for excreta disposal. Through the manual on sewerage and sewage treatment recommends a supply of 150 lpcd wherever sewage exists/ is contemplated, intending to conserve water, a minimum of 135 lpcd is now recommended.

It is well recognised that minimum water requirements for domestic and other essential beneficial uses should be met through the public water supply. Other needs of water including industries etc may have to be supplemented from other systems depending upon the constraints imposed by the availability of capital finances and the proximity of water sources having adequate quantities of acceptable quality which can be economically utilized for pubic water supplies.

Based on the objectives of full coverage of urban communities with easy access to portable drinking water in quantities recommended to meet the domestic and other essential non-domestic needs, the following recommendations are made.

a) Domestic and non-domestic needs:

The recommended values for domestic and non-domestic purposes are given in Table 2 (CPHEEO Manual, 1999).

Table 1: Recommended Per Capita water supply levels for designing schemes

Serial number	Classifications of Towns / Cities	Recommended maximum water supply level (lpcd)
1	Towns provided with piped water supply but without a sewerage system	70
2.	Cities provided with piped water supply where sewerage system is existing/contemplated	135
3	Metropolitan and megacities provided with piped water supply where sewerage system is existing/contemplated.	150

i. In urban areas, where water is provided through public stand posts, 40 lpcd should be considered.

ii. Figures exclude “unaccounted for water (UFW)” which should be limited to 15%. as per the CPHEEO manual (1999).

iii. Figures include requirements of water for commercial, institutional and minor industries.

However, the bulk supply to each establishment should be assessed separately with proper justification.

b) Institutional needs:

The water requirements for the institution should be provided in addition to the provisions indicated above, where required, if they are of considerable magnitude and not covered in the provisions already made. The individual requirements are mentioned in the following Table 3 (CPHEEO manual, 1999).

Table 2: Institutional demand.

Serial Number	Institutions	Litres Per head per day
1	Hospital (including Laundry)	
	a. Number of beds exceeding 100 b. Number of beds not exceeding 100	450 (per bed) 340 (per bed)
2	Hotels	180 (per bed)
3	Hostel	135
4	Nurses homes and medical quarters	135
5	Boarding School / Colleges	135
6	Restaurants	70 per seat
7	Airports and Seaports	70
8	Junction Station and intermediate stations where mail or express stoppage (Both Railway and Bus stations) is provided.	70
9	Terminal Stations	45
10	Intermediate Stations (excluding mail and express stops)	45
11	Day school / Colleges	45
12	Office	45
13	Factories	45
14	Cinema, Concert hall and theatre	15

3.1.9.4 Fire fighting demand:

It is usually to provide for firefighting demand as a coincident draft on the distribution system along with the normal supply to the consumers as assumed. A provision in kilo litres/day based on the formula of $100\sqrt{P}$ where P= Populations in thousands may be adopted for communities larger than 50,000. It is desirable that 1/3rd of the fire fighting requirements from part of the service storage the balance requirement may be distributed in several static tanks at strategic points. These static tanks may be filled from the nearby ponds stream or canals by water tankers wherever feasible. The high-rise building should be provided with adequate fire storage from the protected water supply distribution.

3.1.9.5 Industrial needs:

While the per capita rates of supply recommended will ordinarily include the requirement of small industries (other than factories) distributed within a town, separate provisions will have to be included for meeting the demands likely to be made by specific industries within the urban areas. The forecast of this demand will be based on the nature and magnitude of each such industry and the quantity of water required per unit of production. The potential for industrial expansion should be carefully investigated so that the availability of adequate water supply may attract such industries and add to the economic prosperity of the community as can be seen from the tabulation the quantities of water used by industry vary widely. They are also affected by many factors such as cost and availability of water, waste disposal problems, management and the types of processes involved. Individual studies of the water requirement of a specific industry should therefore be made for each location, the values given below serve only as guidelines. In the context of the reuse of water in several industries, the requirement for freshwater is getting reduced considerably. All the water requirement in Kiloliters per unit is defined in Table 4 (CPHEEO manual, 1999).

Table 3: Industrial demand

Industry	Unit of Production	Water requirement in Kiloliters per unit
Automobile	Vehicle	40
Distillery	Kilolitre alcohol	122-170
Fertiliser	Ton	80-200
Leather	100 kg (Tanned)	4
Paper	Tonne	200-400
Special Quality paper	Tonne	400-1000
Straw Board	Tonne	75-100
Petroleum Refinery	Tonne (Crude)	1-2
Steel	Tonne	200-250
Sugar	Tonne (Cane Crushed)	1-5
Textile	100 kg (Goods)	8-14

3.1.9.6 Pressure Requirements:

Piped water supplies should be designed on a continuous 24 hrs basis to distribute water to the consumer at adequate pressure at all points. Intermittent Supplies are neither desirable from the public health point of view nor economical for towns where one-storied buildings are common and for supply to the ground level storage tanks in multi-storied buildings, the minimum residual pressure at ferrule point should be 7 m for direct supply. Where two-storied buildings are common, it may be 12 m and where 3 storied buildings are prevalent 17 m or as stipulated by local bye-laws. The pressure required for firefighting would have to be boosted by the fire engines.

3.2 Design Period:

Water Supply projects may be designed normally to meet the requirements over thirty years after their completion. The time lag between design and completion of the project should be taken into account which should not exceed two years to five years depending on the size of the project. The thirty years may however be modified in regard to certain components of the project depending on useful life or the facility for carrying out extension when required and rate of interest so that expenditure far ahead of utility is avoided. Necessary land for future expansion/duplication of components should be acquired at the beginning itself. Where expensive tunnels and large aqueducts are involved entailing large capital outlay for duplication, they may be designed for ultimate project requirements. Where failure such as the collapse of steel pipes under vacuum put the pipeline out of commission for a long time or the pipe location presents special hazards such as floods, ice, and mining, etc., duplicate lines may necessary.

Project components may be designed to meet the requirements of the following design period.

The design period of different structures is mentioned in the following Table 4.4 (CPHEEO manual, 1999). In this study we have considered 30 years design period of the distribution system as mentioned in the below Table 4.4.

Table 4: Design Period of different components.

Serial number	Item	Design period (in years)
1	Storage by Dam	50
2	Infiltration works	30
3	Pumping	
4	i) Pump House	30
5	ii) Electric Motor and pump	15
6	Water Treatment unit	15
7	Pipe Connection to several treatment unit	30
8	Raw water and clear water conveying main	30
9	Clearwater reservoir at the headwork, balancing tank and	15
10	Distribution System	30

3.3 Methods of Distribution:

The prime objective of a water distribution system design is to provide an adequate amount of pressure (as per CPHEEO guidelines) at the consumer end. Depending upon the elevation of the reservoir (water source) and that of the city or village, the topography of the area and other local conditions and considerations, the water may be supplied through the distribution system in the following three ways

a) Gravitational System.
b) Pumping System.
c) By combined gravity and pumping system.

These systems are described below:

a) **Gravitational System:** In this system, the water is supplied from the water source which is situated at a higher elevation than the distribution area (consumers) with comparatively lower elevation, by the actions of gravity without any use of pump. For proper functioning of this system, sufficient difference of head between source and the distribution area (consumers), is required to maintain adequate pressure at the consumer end after considering frictional and other loss.

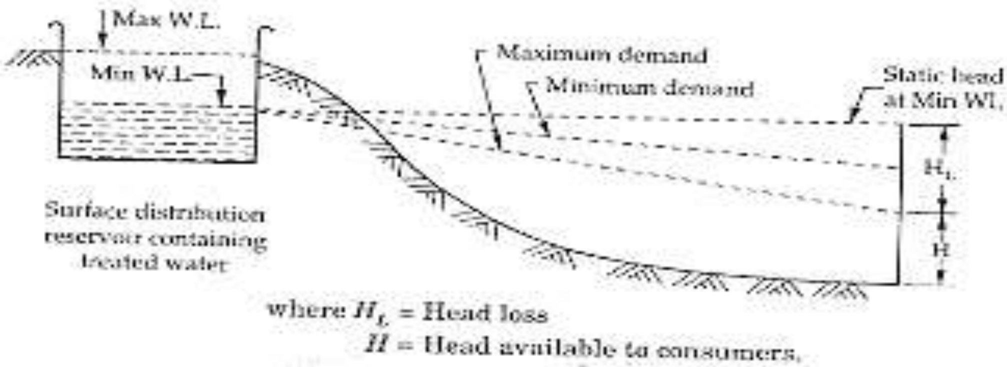

Figure 3:Gravitational System (Source: book of Garg, 2015)

Advantages of Gravity system:

- This method is the most economical and reliable method as no pumping is required at any stage
- Pressure does not change suddenly.
- The maintenance cost is very low.
- This will keep the leakages and the wastages to be minimum.

b) **Pumping System:** In the pumping system, treated water is directly pumped into the distribution mains without storing it anywhere. High lift pumps are required in these systems which have to operate at variable speeds to meet the variable demand of water. This type of system is generally used where the elevation of the source is lower than the elevation of the distribution area (consumers). The pumps are used to improve the required pressure head to distribute the water to the consumers and storage reservoir. This type of system is very useful during fires as it can force a large volume of water under high pressure in the required direction.

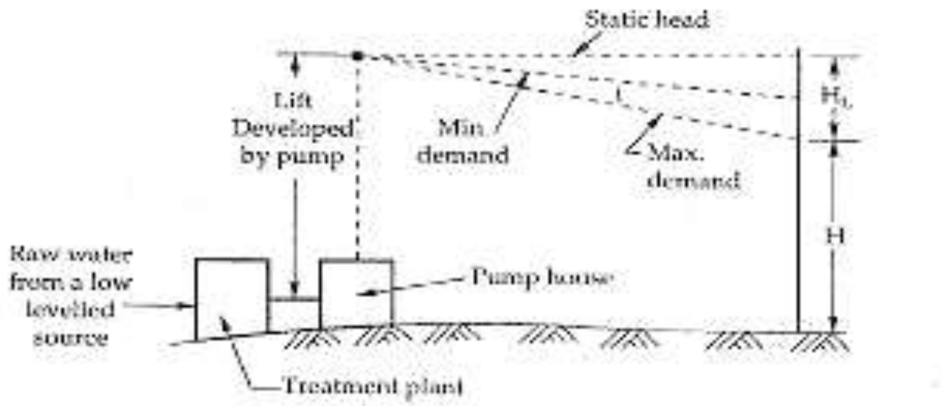

Figure 4:Pumping System (Source: book of Garg, 2015)

Disadvantages of pumping system:

- Continuous power supply and monitoring are needed at the pumping station, to provide the desired flow in the distribution system.
- This pumping system depends on the power supply if the power supply fails, there will be a complete stoppage of the water supply.

c) Combined gravity and pumping system: In this system, the treated water is pumped out at a constant rate and stored into an overhead reservoir, from where it is distributed to the consumer by the actions of gravity. Sometimes the entire water is first of all pumped into the distribution reservoir, and many a time, it is pumped into the distribution main and distribution reservoir simultaneously. During low demand periods the reservoir stores the excess water and during high demand periods it supplies to the consumers. This system is very productive, economical and dependable.

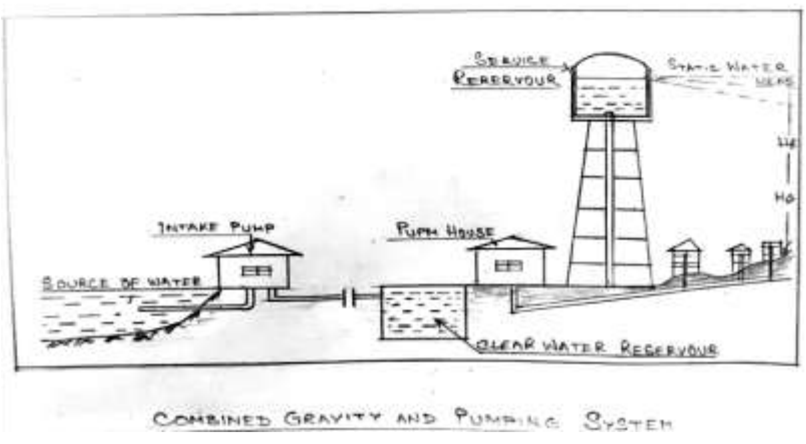

Figure 5: Combined gravity and pumping system(google)

3.4 Distribution Systems (Network Configurations)

The distribution pipes are generally laid below the road pavements so both of their layouts are the same. Depending upon the local conditions and orientation of roads the network systems are divided into four different types. They are:

i) Dead End System (Tree)
ii) Radial System
iii) Grid Iron System (Loop)
iv) Ring System

3.4.1 Dead End System

In the dead-end system, which is also sometimes called the Tree system, there is one pipe, from which a number of sub-main pipes (generally right angle) originate.

Each sub-main then divides into several branch pipes, called laterals. From the laterals service, connections are given to the consumers.

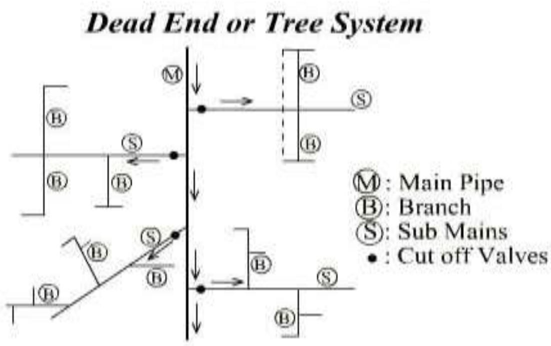

Figure 6:Dead End System (Source: book of Garg,2015)

This type of layout may have to be adopted for older towns that have developed haphazardly without properly planned roads.

Advantages of this system are :

a) The design and building of this system are very simple. The distribution network can be solved very easily.
b) Very few cut-off valves (i.e. sluice valves) are required in this system.
c) Laying the pipe is very easy, shorter pipe lengths are needed.

Disadvantages of this system are:

a) Any repair or damage in any pipeline will completely stop the water supply in the area being fed by the pipe as in this method water can reach a particular point only through one route.
b) There are many numbers of dead ends in this system that prevents the free circulation of water and the quality of water gets decreased due to stagnation of water.

3.4.2 Grid-iron System

In this system, the main pipes, sub-main pipes, branch pipes are connected to each other. This type of system is mainly designed for a well-planned city or town where the roads are generally developed in a grid-iron pattern.

Advantages of this system are:

a) The friction loss and the diameter of the pipe are reduced as the water reaches different places through more than one route.

b) In the time of repair and maintenance, a small area will be devoid of complete supply as some suppliers will be reaching at the point from some another route.

Water remains in continuous circulation as all the pipes are interconnected and there is no dead-end hence the quality does not get reduced.

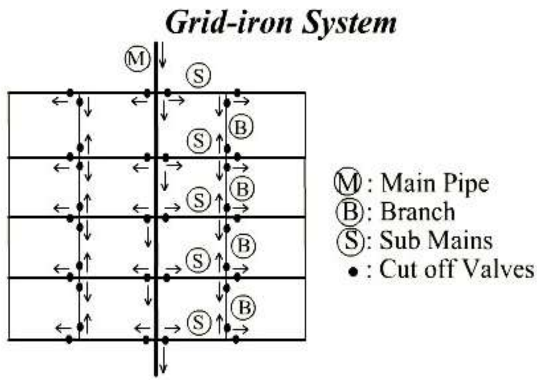

Figure 7:Grid Iron System (Source: book of Garg,2015)

Disadvantages of this system are:

a) Its construction is costlier.
b) The design is difficult and costlier.
c) The system requires more length of pipelines and a larger number of sluice valves.

3.4.3 Ring System:

In this system, a closed ring, either circular or rectangular, of the main pipe is formed around the area to be served. The distribution area is divided into rectangular or circular blocks, and main water pipes are laid on the periphery of these blocks. These types of systems are ideal for cities having well-planned roads.

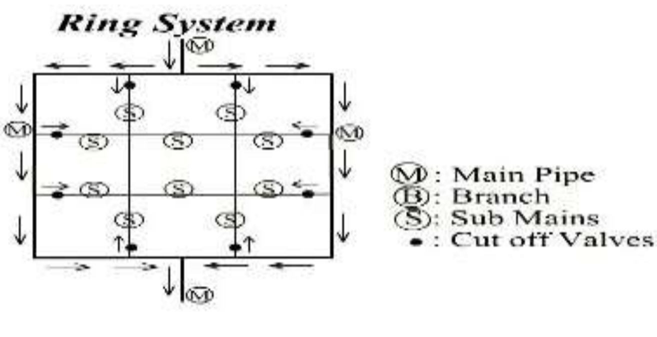

Figure 8:Ring System (Source: book of Garg,2015)

Advantages of this system are:

a) As the water is continuously circulating so water does not get stagnant.
b) Repair works can be done without affecting the other part of the network.
c) A large quantity of water is available for fire fighting.

Disadvantages of this system are:

a) A longer length and large diameter pipes are required.
b) More cut-off valves are necessary.
c) Skilled manpower is necessary while laying pipes.

3.4.4 Radial System:

In this system, water is supplied from the water main pipe to the distribution reservoir through pumping and then the water is supplied through the radially laid distribution pipes to the consumers. This type of system is designed for those towns having a system of radial roads from different centres, where the pipelines can be laid in a radial method by placing the distribution reservoir at the centres.

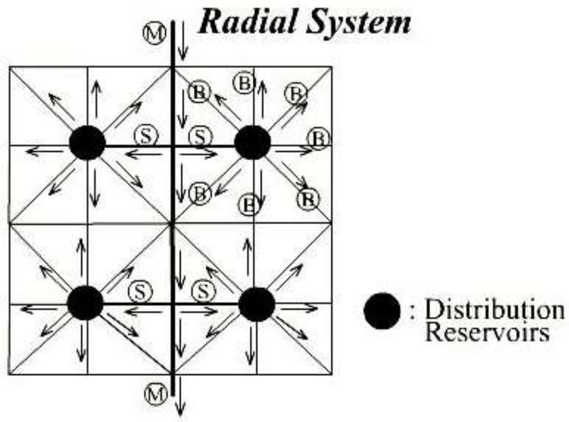

Figure 9:Radial System (Source: book of Garg, 2015)

Advantages of this system are:

a) This system ensures adequate pressure and efficient water distribution
b) It is very easy to calculate pipe sizes.
c) Head loss is very small because of quick discharge.

Disadvantages of this system are:

a) The cost of the project is more because of the number of individual distribution reservoirs.
b) A fault on the single feeder or distributor causes an interruption in the supply to all the users connected to that distributor.

3.5 Hydraulics of network systems:

Pipeline networks include series pipes, parallel pipes, and branching pipes. These simple networks can be converted to an equivalent pipe, which helps simplify and analyse these networks. The equivalent pipes are those pipes when more than one pipe delivers the same rate of flow.

3.5.1 Series Pipes:

For a system with two or more pipes in series, the total head loss is,

$$h_{Le} = \sum h_{Li}$$

or

$$K_e Q^n = \sum K_i Q^{ni} = K_1 Q^{n1} + K_2 Q^{n2} + \ldots\ldots\ldots\ldots$$

where K_e is the pipe coefficient for the equivalent pipe. When using Hazen-Williams equation, all n=1.85 and when using Darcy-Weisbach equation, n=2 for rough pipes and n=1.75 for smooth pipes for fully turbulent flow: therefore K_e simplifies to

$$K_e = K_1 + K_2 + \ldots\ldots\ldots = \sum K_i$$

For Darcy-Weisbach equation

$$K = \frac{8fL}{\pi^2 g D^5} \qquad \ldots\ldots(3.4)$$

h_L is the head loss in m, L is the pipe length in m, Q is the flow rate in m^3/s, D is the pipe diameter in m, and g is the acceleration due to gravity, 9.81 m/s^2.

For Hazen-Williams equation

$$K = \frac{\phi L}{C^{1.85} D^{4.87}} \qquad \ldots\ldots(3.5)$$

where ϕ =4.73 for U.S customary units and ϕ = 10.66 for SI units. The head loss h_L is in m: L is the pipe length in Q is the flow rate in m^3/s, D is the pipe diameter in m.

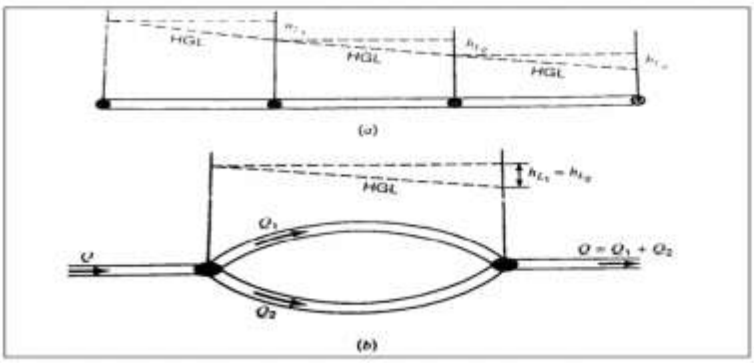

Figure 10:(a) Series Pipe System (b) Parallel Pipe System

3.5.2 Parallel Pipes:

The Concept of an equivalent pipe can be applied to two or more pipes that are parallel then the head loss of each pipe between junctions must be equal:

$$h_L = h_{L1} = h_{L2} = h_{L3} = h_{L4}..........$$

The total flow rate is the sum of individual flows in each pipe and is given as

$$Q = Q_1 + Q_2 + Q_3 + ... = \sum Q_i$$

Substituting $Q = \left(\frac{h_L}{K_e} \right)^{\frac{1}{n_e}}$, from $h_L = KQ^n$, into equations yields.

$$\left(\frac{h_L}{K_e} \right)^{\frac{1}{n_e}} = \left(\frac{h_L}{K_1} \right)^{\frac{1}{n_1}} + \left(\frac{h_L}{K_2} \right)^{\frac{1}{n_2}} + \left(\frac{h_L}{K_3} \right)^{\frac{1}{n_3}} + ... = \sum \left(\frac{h_L}{K_i} \right)^{\frac{1}{n_i}} \qquad ……(3.6)$$

When using the Hazen-Williams Equation, all the exponents n_i are equal: when using the Darcy-Weisbach equation, it is customary to assume n_i equal for all pipes(i.e., fully turbulent, n=2) for rough pipes. Then the equation number (4.6) is reduced to,

$$\left(\frac{1}{K_e} \right)^{\frac{1}{n}} = \left(\frac{1}{K_1} \right)^{\frac{1}{n}} + \left(\frac{1}{K_2} \right)^{\frac{1}{n}} + \left(\frac{1}{K_3} \right)^{\frac{1}{n}} + ... = \sum \left(\frac{1}{K_i} \right)^{\frac{1}{n}} \qquad ……(3.7)$$

3.5.3 Branching Pipe Flow:

The flow distribution in branching systems can be determined by applying the continuity and energy equations.

3.5.3.1 Flow Continuity Equation:

The sum of inflows entering the junction equals the sum of flows leaving the junction.

$$\sum \text{Inflow} = \sum \text{Outflow}$$

When the junction J is considered as shown in Fig.4.10 where five pipes are interconnected and there is an outflow demand. The directions of flows Q_1, Q_2 and Q_4 are entering the junction, while the directions of flows Q_3, Q_5 and Q_6 are leaving the junction. By common sense, the total flow entering the junction should be equal to the total flow leaving the junction because it neither creates nor stores any flow inside, and thus, the Figure represents it. $Q_1 + Q_2 + Q_4 = Q_3 + Q_5 + Q_6$

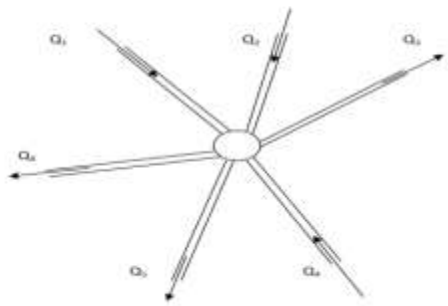

Figure 11: Flow across a junction

3.5.3.2 Energy Equation:

The difference in hydraulic head between any two junctions within any pipe system equals the net head losses between junctions are represented in equation number (3.8).

$$[P_a + Z_a] - [P_b + Z_b] = h_1 - h_p \qquad \ldots\ldots(3.8)$$

The piezometric head $\left(\frac{p}{\gamma} + Z\right)$ of the water, the pressure head added to water by a pump (h_p), the kinematic head of water $\frac{V^2}{2g}$ and the total head losses (h_l) lost from water by friction and fitting minor losses when moves inside pipes from the point of the higher head (hydraulic pressure) to the point of the lower head with mean velocity (V) and flow rate (Q) To relate all above pressure head together, let's take the pipe in Fig. 4.11.

Assume that the flow direction in the pipe is from the junction (a) to (b) and its value is Q, the pressure and elevation head and the mean velocity at (a) are P_a , Z_a and V_a respectively, the total pressure, elevation head and mean velocity at (b) are P_b, Z_b and V_b respectively, the total friction and fitting head losses from (a) to (b) are h_l , the pump's head is h_p , all heads in are in m. for this system.

$$P_a + Z_a + \frac{V_a^{\ 2}}{2g} + h_p = P_b + Z_b + \frac{V_b^{\ 2}}{2g} + h_l \qquad \ldots\ldots(3.9)$$

The combination of the flow continuity equation and energy equation results in a system of non–linear equations that are solved by trial and error/hand computations or by using computer software that solves such equations.

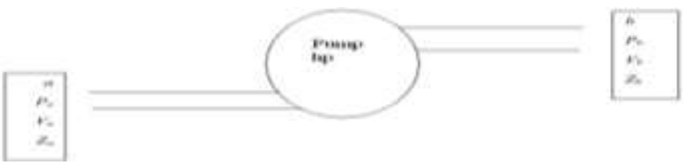

Figure 12: Flow through the pump.

3.5.4 Gradient Method:

With the advent of computer hardware algorithms were developed aimed to solve water networks increasing in size and complexity. One of the most widely used algorithms, even nowadays, was proposed by Todini and Pilati (1987) and is called the gradient method. This method is another application of the Newton-Raphson technique. Although it takes into account, both, nodal heads and pipe flows to simultaneously solve the equations of conservation of mass and energy. The nonlinear energy equations are first linearised using the Taylor series expansion to produce the overall system of linear equations.

$$\begin{pmatrix} A_{11} & A_{12} \\ A_{21} & 0 \end{pmatrix} \begin{pmatrix} q \\ h \end{pmatrix} = \begin{pmatrix} -A_{10} & h_0 \\ d & \end{pmatrix}$$

……(3.10)

where A_{11} is the diagonal matrix containing the linearisation coefficients $R|q|^{\beta-1}$, $A_{12} = A_{21}{}^{T}$ is the unknown nodes incidence matrix, A_{10} is the fixed head nodes incidence matrix, d is the nodal demands and h_0 are the fixed nodal head.

Next, the Newton-Raphson iterative technique can be obtained by differentiating both sides of equation number (4.10).

$$\begin{pmatrix} \beta A_{11} & A_{12} \\ A_{21} & 0 \end{pmatrix} \begin{pmatrix} d\mathrm{q} \\ d\mathrm{h} \end{pmatrix} = \begin{pmatrix} d\mathrm{E} \\ d\mathrm{d} \end{pmatrix}$$

……(3.11)

where

$$d\mathrm{E} = A_{11} q^k + A_{12} h^k + A_{10} h_0$$

$$d\mathrm{d} = A_{21} q^k - d$$

are the residuals to be iteratively evaluated for flows and heads h_k at iteration k; and βA_{11} is the diagonal matrix of the exponents of the pipe equations.

Subsequent updates to $q_{k+1} = q_k + dq$ and $h_{k+1} = h_k + dh$ continue until convergence is achieved; i.e. the residuals d**E** and d**d** are reduced to zero.

Although the gradient algorithm requires a larger set of equations to be solved than the Hardy Cross or Linear theory methods, it is robust and computationally efficient (Mays, 1999; Todini, 2006).

3.5.5 Theory of correlation:

Calculation of *r*: Correlation coefficient (r) is unaffected by the choice of origin and scale of one or both the variables.

$$r = r_{xy} = \frac{\mathrm{COV}(x, y)}{\sigma_x . \sigma_y} \qquad \text{……(3.12)}$$

where

$$\sigma_x^{\,2} = \frac{\sum x^2}{n} - \left(\frac{\sum x}{n} \right)^2$$

$$\sigma_y^{\,2} = \frac{\sum y^2}{n} - \left(\frac{\sum y}{n} \right)^2 \qquad \text{………(3.13)}$$

$$\mathrm{COV}(x, y) = \frac{\sum x.y}{n} - \left(\frac{\sum x}{n} \right)\left(\frac{\sum y}{n} \right) \qquad \text{……(3.14)}$$

where x= Output obtained from WaterGEMS (Here output indicates pressure, hydraulic grade for junctions and flow, velocity, headloss, for pipes.

y= Output obtained from EPANET (Here output indicates pressure, hydraulic grade for junctions and flow, velocity, headloss, for pipes)

σ_x = Standard Deviation of x

σ_y = Standard Deviation of y

values x and y, the two standard deviations and covariance σ_x, σ_y and COV(x,y) respectively are calculated, and finally the correlation coefficient r or r_{xy} between them. $\sigma_x^{\,2}$, $\sigma_y^{\,2}$ are the variance of x and y

CHAPTER 4: APPLICATION OF WATERGEMS SOFTWARE

4.1 Overview of WaterGEMS software:

WaterGEMS from Bentley Systems helps engineers to model, design and analyze complex pressurized piping systems. This software has a powerful graphical interface (both in Stand-Alone and AutoCAD mode) makes it easy to quickly layout a complex network of pipes, tanks, pumps, and more.

In industries, this network simulation software is used to

a) Perform steady-state analyses of water distribution systems with pumps, tanks, and control valves.
b) Perform extended period simulations to determine the piping system's response in varying supply and demand schedules.
c) Perform water quality simulations to determine the water source and age, or track the growth or decay of a chemical constituent throughout the network.
d) Perform Fire Flow Analysis on the system to determine how your system will behave under extreme conditions.
e) Create multiple sets of hydraulic, physical property, operational, initial setting, fire flow, cost, and water quality alternatives.
f) Calibrate our design manually or with the assistance of the Darwin Calibrator, which utilizes the power of Genetic Algorithms.

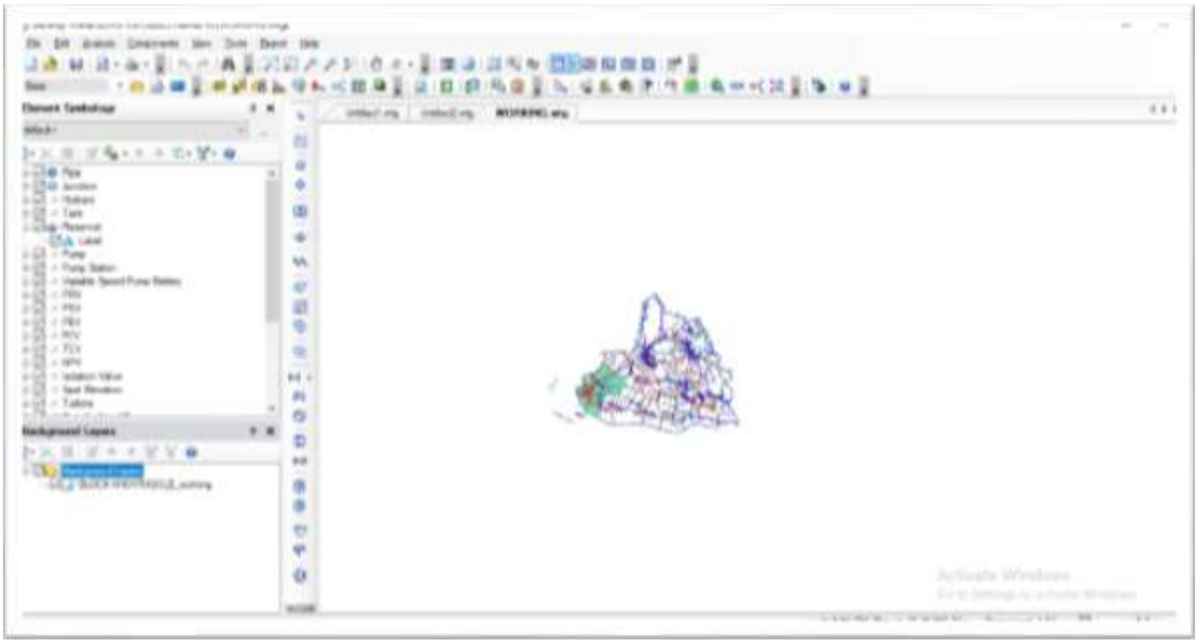

Figure 13: WaterGEMS V8i Home screen

4.1.1 Hydraulic Model Capabilities:

a) This network simulation software perform steady-state, extended period and water quality simulations
b) This network simulation software reduces time wasted on preparing the bill of quantities, thus it helps the civil engineer in estimating construction costs.
c) It helps the civil engineer to determine water sources and age at any element in the system. Model cylindrical and non-cylindrical tanks and constant hydraulic grade source nodes.
d) This network simulation software will help us to design multiple time-variable demands at any junction node. This software provides solutions to model flow valves, pressure-reducing valves, pressure sustaining valves, pressure breaking valves and throttle control valves.
e) This network simulation software can track conservative and non-conservative chemical constituents present in water.

4.2 Physical Components of the software :

The basic physical components of the software is junction , pipe, reservoir , tank, pump. A brief description of all the components is narrated below.

4.2.1 Junctions:

Junctions are points in the network where links join together and where water enters or leaves the network. The basic input data required for junctions are:

- Elevation above some reference level.
- Water demand i.e. the rate of withdrawal from the network.
- Initial water quality.

The output results computed for junctions are

- Hydraulic head (internal energy per unit weight of water)
- Pressure
- Water quality.

Junctions can also:

- Have their demand vary with time.
- Have multiple categories of demands assign to them.

4.2.2 Reservoir:

Reservoirs are nodes that represent an infinite external source or sink of water to the network. They are used to model such things as lakes, rivers, groundwater aquifers, and tie-ins to other systems. The primary input properties for a reservoir are its hydraulic head (equal to the water surface elevation if the reservoir is not under pressure) and its initial quality for water quality analysis. Because a reservoir is a boundary point to a network, its head and water quality cannot be affected by what happens within the network. Therefore it has no computed output properties.

4.2.3 Tanks:

Tanks are nodes with storage capacity, where the volume of stored water can vary with time during a simulation. The primary input properties for tanks are:

- Elevation (Base).
- Elevation / Level (Minimum)
- Elevation / Level (Initial)
- Elevation / Level (Maximum)
- Elevation (in the Physical section of tank properties).
- Diameter (or shape if non-cylindrical)

The principal computed outputs are:

- Total head (water surface elevation
- Flow output

Tanks can also be used as water quality source points.

4.2.4 Pipes:

Pipes are link elements that connect junction nodes, pumps, valves, tanks, and reservoirs. 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).

Computed outputs for pipes include

- flow rate
- velocity
- headloss

The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas:

i. Hazen-Williams formula
ii. Darcy-Weisbach formula
iii. Chezy-Manning formula

The Hazen-Williams formula is the most commonly used headloss formula in the US. It cannot be used for liquids other than water and was originally developed for turbulent flow only. The Darcy-Weisbach formula is the most theoretically correct. It applies to all flow regimes and to all liquids. The Chezy-Manning formula is more commonly used for open channel flow. Each formula uses the following equation to compute headloss between the start and end node of the pipe.In this study Hazen Williams formula is considered during hydraulic analysis using WaterGEMS, EPANET software.

Table 5: Pipe headloss formulas for full flow

Pipe Head Loss Formula name	Pipe Head Loss Formula
Hazen-Williams formula	$h_L = \frac{10.67 L Q^{1.85}}{C^{1.85} d^{4.87}}$
Darcy-Weisbach formula	$h_L = \frac{8 f L Q^2}{\pi^2 g d^5}$
Chezy-Manning formula	$h_L = \frac{n^2 L Q^2}{0.0972 D^5}$

where, C = Hazen-Williams roughness coefficient
f = Darcy-Weisbach friction factor [f is a function of Reynolds number and relative roughness]
ε = Darcy-Weisbach roughness coefficient
n = Chezy-Manning roughness coefficient
d = pipe diameter (m)
L= Pipe length (m)
Q = flow rate (m^3/s)

Table 6: Roughness coefficients for new pipes

Material	Hazen-Williams, C (unit less)	Darcy-Weisbach, ε (m × 10^{-3})	Chezy-Manning, N (unit less)
Cast Iron	130-140	0.259	0.012-0.015
Concrete lined	120-140	0.3-3.0	0.012-0.017
Galvanized Iron	120	0.152	0.015-0.017
Plastic	145	0.002	0.011-0.015
Steel	140-150	0.046	0.015-0.017
Vitrified clay	110		0.013-0.015

Choosing a pipe material, pipes can be assigned a material type chosen from an engineering library. Each material type is associated with various pipe properties, such as roughness coefficient and roughness height. When a material is selected, these properties are automatically assigned to the pipe.

4.2.4.1 Minor Loss Type:

Minor head losses (also called local losses) are caused by the added turbulence that occurs at bends and fittings. The importance of including such losses depends on the layout of the network and the degree of accuracy required. They can be accounted for by assigning the pipe a minor loss coefficient. The minor head loss becomes the product of this coefficient and the velocity head of the pipe ,

i.e. $h_L = K \frac{v^2}{2g}$

where K is minor loss coefficient, v is flow velocity (length/time) and is the acceleration of gravity (length/time^2).

4.2.5 Valves:

A valve is a node element that opens, throttles, or closes to satisfy a condition you specify. The following valve types are available in the softwares :
Their principal input parameters include:-

- start and end nodes
- diameters settings
- status

The computed outputs for a valve are flow rate and head loss.

4.2.5.1 Valve Type Description

- **Pressure Reducing Valve (PRV):** PRVs throttle to prevent the downstream hydraulic grade from exceeding a set value. If the downstream grade rises above the set value, the PRV will close. If the head upstream is lower than the valve setting, the valve will open fully.
- **Pressure Sustaining Valve (PSV**): A Pressure Sustaining Valve (PSV) is used to maintain a set pressure at a specific point in the pipe network. The valve can be in one of three states:

- **Partially opened (i.e., active)** to maintain its pressure setting on its upstream side when the downstream pressure is below this value
- **Fully open** if the downstream pressure is above the setting
- **Closed** if the pressure on the downstream side exceeds that on the upstream side (i.e., reverse flow is not allowed).

- **Pressure Breaker Valve (PBV**) PBVs are used to force a specified pressure (head) drop across the valve. These valves do not automatically check the flow and will actually boost the pressure in the direction of reverse flow to achieve a downstream grade that is lower than the upstream grade by a set amount.

4.2.6 Pumps:

Pumps are links that impart energy to a fluid thereby raising its hydraulic head. The principal input parameters for a pump are its start and end nodes and its pump curve (the combination of heads and flows that the pump can produce). In lieu of a pump curve, the pump could be represented as a constant energy device, one that supplies a constant amount of energy (horsepower or kilowatts) to the fluid for all combinations of flow and head. The principal output parameters are flow and head gain.

4.2.7 The WaterGEMS workspace consist of the following elements:

i. Standard Toolbar
ii. Edit Toolbar
iii. Analysis Toolbar
iv. Scenarios Toolbar
v. Compute Toolbar
vi. View Toolbar
vii. Help Toolbar
viii. Layout Toolbar
ix. Tools Toolbar
x. Zoom Toolbar
xi. Customizing WaterGEMS Toolbars and Buttons
xii. WaterGEMS Dynamic Manager Display.

i) Standard Toolbar:

The Standard toolbar contains controls for opening, closing, saving, and printing of projects which are simulated by the above software. Commands and usages of this toolbar.

a. **New:** Select File to Create dialog box opens, allowing us to define a name and directory location for the new project.

b. **Open:** To allow us to browse the project to be opened.

c. **Close:** To close the currently open project.

d. **Close all:** To close all the projects that are opened.

e. **Save:** To Save the current project.

f. **Save as:** To save all the projects that are opened.

g. **Print Preview:** To Open the Print Preview window, displaying the current view of the network as it will be printed.

h. **Print:** To print the current view of the network.

ii) Edit Toolbar:

The Edit toolbar contains controls for deleting, finding, undoing, and redoing actions in the above mentioned software. Commands and usages of this toolbar.

a. Undo: To Cancel our most recent action.
b. Redo: To Re-do the last cancelled action.
c. Delete: To Delete the currently selected element(s) from the network.
d. Clear Highlight: To Remove the highlighting that can be applied using the Network Navigator.

e. Find Element: To Find a specific element by choosing it from a menu containing all elements in the current model.

iii) Analysis Toolbar:

The Analysis toolbar contains controls for analyzing WaterGEMS projects: Commands and usages of this toolbar.

a. **Totalizing Flow Meters:** To allow us to view, edit, and create flow meter definitions.

b. Hydrant Flow Curves: To allow us to view, edit, and create hydrant flow definitions.
c. **System Head Curves** To allow us to view, edit, and create system head definitions
d. Post Calculation Processor: Here we can perform statistical analysis for an element or elements on various results obtained during an extended period simulation calculation.
e. Energy Costs: Here we can view, edit, and create energy cost scenarios.
f. Darwin Calibrator: Here we can view, edit, and create calibration studies.
g. Darwin Designer: Here we can view, edit, and create designer studies.
h. Darwin Scheduler: Here we can view, edit, and create Scheduler studies.
i. Criticality: Here we can view, edit, and create Criticality studies.

j. **Pressure Zone** Here we can view, edit, and create Pressure Zone studies.

iv) Scenarios Toolbar

The Scenarios toolbar contains controls for creating scenarios in WaterGEMS V8i projects. Commands and usages of this toolbar.

a. **Scenario List Box**: It helps us to change the current scenario.
b. **Scenarios:** We can create, view, and manage project scenarios.
c. **Alternatives:** Here we can create, view, and manage project alternatives.
d. **Calculation Options**: Here we can create different profiles for different calculation settings.

v) Compute Toolbar:

The Compute toolbar contains controls for computing WaterGEMS projects. Commands and usages of this toolbar.

a) **Validate:** Run a diagnostic check on the network data to alert us to possible problems that may be encountered during calculation.

b) **Compute:** It is used to calculate the water distribution network as per the input inserted and determine the output values.

c) **EPS Results Browser**: To manipulate the currently displayed time step and to animate the drawing pane

d) Fire Flow Results Browser:
e) Flushing Results Browser:
f) **Calculation Summary:**
g) User Notifications:

(d–g) To open the respective dialogue boxes.

vi) View Toolbar:

The View toolbar contains controls for viewing WaterGEMS projects. Commands and usages of this toolbar.

a) **Element Symbology** To create, view, and manage the element symbol settings for the project.

b) Background Layers To create, view, and manage the background layers associated with the project

c) Network Navigator To Open the Network Navigator dialog box

d) Selection Sets. To Open the Selection Sets Manager, allowing you to create, view, and modify the selection sets associated with the project.

e) Queries To Opens the Query Manager.

f) Prototypes To Opens the Prototypes Manager.
g) **Flex Tables** To create, view, and manage the tabular reports for the project.
h) Graphs To create, view, and manage the graphs for the project.
i) Profiles To create, view, and manage the profiles for the project.
j) Contours We can create, view, and manage named views
k) Named Views Here we can create, view, and manage named views.
l) **Aerial View** Here we can zoom to can zoom to different elements in the project.
m) Properties To open the property editor**.**
n) Customizations To open the customization manager

vii) Layout Toolbar :

The Layout toolbar is used to layout a model in the WaterGEMS V8i drawing pane. Commands and usages of this toolbar.

a) **Select**: To Change our mouse cursor into a select. When this tool is active, click on the drawing pane to place the element.

b) Pipe: To Change our mouse cursor into a pipe. When this tool is active, click on the drawing pane to place the element.

c) Junction: To Change our mouse cursor into a junction. When this tool is active, click on the drawing pane to place the element.

d) Hydrant: To Change our mouse cursor into a hydrant. When this tool is active, click on the drawing pane to place the element.

e) Tank: To Change our mouse cursor into a tank. When this tool is active, click on the drawing pane to place the element.

f) **Reservoir:** To Change our mouse cursor into a Reservoir. When this tool is active, click on the drawing pane to place the element.

g) **Pump** To Change our mouse cursor into a pump. When this tool is active, click on the drawing pane to place the element.

h) **Variable Speed Pump Battery:** To Change our mouse cursor into a variable speed pump battery. When this tool is active, click on the drawing pane to place the element.

i) **Isolation Valve:** To Change our mouse cursor into an Isolation Valve. When this tool is active, click on the drawing pane to place the element.

j) **Spot Elevation:** To Change our mouse cursor into a Spot Elevation. When this tool is active, click on the drawing pane to place the element.

k) **Turbine:** To Change our mouse cursor into a turbine. When this tool is active, click on the drawing pane to place the element.

l) **Periodic Head flow:** To Change our mouse cursor into a periodic head flow. When this tool is active, click on the drawing pane to place the element.

m) **Air Valve:** To Change our mouse cursor into an air valve. When this tool is active, click on the drawing pane to place the element.

n) **Hydro pneumatic Tank:** To Change our mouse cursor into a hydropneumatic tank. When this tool is active, click on the drawing pane to place the element.

o) **Surge Valve:** To Change our mouse cursor into a Surge Valve. When this tool is active, click on the drawing pane to place the element.

p) **Check Valve:** To Change our mouse cursor into a check valve. When this tool is active, click on the drawing pane to place the element.

q) **Rupture Disk:** To Change our mouse cursor into a rupture disk. When this tool is active, click on the drawing pane to place the element.

r) **Discharge to Atmosphere:** To Change our mouse cursor into a discharge to the atmosphere. When this tool is active, click on the drawing pane to place the element.

s) **Orifice between Pipes:** To Change our mouse cursor into an orifice between pipes. When this tool is active, click on the drawing pane to place the element.

t) **Valve with Linear Area Change:** To Change our mouse cursor into a valve with linear area change. When this tool is active, click on the drawing pane to place the element.

u) **Surge Tank:** To Change our mouse cursor into a surge tank. When this tool is active, click on the drawing pane to place the element.

v) **Border:** To Change our mouse cursor into a border. When this tool is active, click on the drawing pane to place the element.

w) **Text:** To Change our mouse cursor into a text. When this tool is active, click on the drawing pane to place the element.

x) **Line:** To Change our mouse cursor into a line. When this tool is active, click on the drawing pane to place the element.

viii)Tools Toolbar

The Tools toolbar provides quick access to the same commands that are available in the Tools menu. Commands and usages of this toolbar.

a) **Active Topology Selection**: To open a Select dialog to select areas in the drawing.

b) **Model Builder**: We can create, edit, and manage Model Builder connections to be used in the model-building/model synchronising process.

c) **Trex:** We can select the data source type, set the elevation dataset, choose the model and features.

d) **SCADA Connect:** Using this tool we can add or edit signals.
e) **Skelebrator Skeletonizer**: It is used to define how to skeletonise our network.
f) **Load Builder**: After opening this tool we can create a manage load builder template.

g) **Thiessen Polygon**: It is used to create thissen polygon
h) **Demand Control Center:** Here we can add new demands, delete existing demands, or modify existing demands
i) **Unit Demand Control Center**: Here we can add new unit demands, delete existing unit demands, or modify existing unit demands
j) **Hyperlinks:** Associate external files, such as pictures or movie files, with elements
k) **User Data Extensions:** To add and define custom data fields. For example, you can add new fields such as the pipe installation date.

l) **Compact Database:** To eliminate the empty data records, thereby defragmenting the data store and improving the performance of the file.

m) **Synchronize Drawing:** To Synchronize the current model drawing with the project database.

n) **Update Database Cache:** It Ensures consistency between the database and the model by recalculating and updating certain cached information.

o) **Update Results from Project Directory:** This command copies the model result files (if any) from the project directory (the directory where the project .mdb file is saved) to the custom result file directory

p) **Copy Results to Project Directory:** This command copies the result files that are currently being used by the model to the project directory.

q) **Assign Isolation Valves to Pipes:** Here we can find the nearest pipe for each selected isolation and assign the valve to that pipe.

r) **Batch Pipe Split:** To open the Batch Pipe Split dialog

s) **Customize:** To open the external tool dialog box

t) **Options:** To open the Options dialog box, which allows us to change Global settings, Drawing, Units, Labelling, and project-wise.

ix) Zoom Toolbar:

The Zoom toolbar provides access to the zooming and panning tools. Command and usage of this toolbar.

a) **Zoom Extents**: To set the view so that the entire model is visible in the drawing pane.

b) **Zoom Window**: To activate the manual zoom tool, where you can specify a portion of the drawing to enlarge.

c) **Zoom In**: To magnify the current view in the drawing pane

d) **Zoom Out:** To reduce the current view in the drawing pane.

e) **Zoom Real-time**: It allows us to zoom in and out by moving the mouse while the left mouse button is depressed.

f) **Zoom Center:** Here we can set X and Y coordinates and the percentage of Zoom.

g) **Zoom Selection**: It enables us to zoom to specific elements in the drawing.

h) **Zoom Previous**: Return the zoom level to the most recent previous setting.

i) **Zoom Next**: To reset the zoom level to the setting that was active before a Zoom Previous command was executed.

j) **Pan**: It allows us to move the model within the drawing pane.

k) **Refresh Drawing**: To update the main window view according to the latest information contained in the Bentley WaterGEMS V8i data store.

CHAPTER 5: DETAILS OF STUDY AREA

5.1 Study Area:

The Panchra Piped Water Supply Scheme covers 40 (Forty) nos. of habitations in 25 (Twenty Five) nos. of mouzas of Block Khoyrasole, P.S. Khoyrasole under Birbhum District in the state of West Bengal. The total area covered under the scheme is about 4642.054 hectare with a total population of 19957 as per 2011censusand average population density of 4.30 persons per hectare. The area is predominantly habited by SC, total percentage being of 55.06 % of total population.

Ground water of the habitations is found to be scarce and insufficient. Presently no piped water supply facility / sustainable drinking water supply system exists within the scheme jurisdiction& people of the area are using hand pump tube well as source of potable water most of which became dry during summer seasons. Water borne diseases like diarrhoea/ Amibiosis / typhoid etc. are common within the command area.

Considering the sufferings of the people Panchra Piped Water Supply System was initiated.

NRDWP guideline recommends for supply of water up to household level through pipe line. Therefore, water demand for every household including connections to schools/Anganwadis/Health Centres etc. through Community Tank are also considered in this project.

Figure 14: Map of Panchra G.P with Mouza boundary

5.2 Salient Features:

Table 7:Salient Features of Panchra G.P

1	Name of the scheme	Panchra piped water supply scheme Block: khoyrasole, District: Birbhum
2	Name of the District	Birbhum
3	Location	The proposed command area falls under Block Khoyrasole, Sub-Division Suri Sadar, District Birbhum and 9 km away from Bloc Head Quarter, 36 km away from Sub-Division Head Quarter, 36 km away from District Head Quarter and is connected with Road/ Rail networks. Nearest Railway Station is Sainthia Junction 34 km and nearest Airport is Andal 72 km away from the Headworks site of the proposed command area. The area falls within dry and arid region of the state.
4	Name of the Block	Khoyrasole
5	Number of Mouzas (As per Census 2001)	25
6	Number of habitation	41
7	Number of Population (2011)	19967
8	Command area	4642.054 hectares
10	Per Capita Service Level	70 lpcd
11	Source of Water	Sub-Surface Water from river Ajay
12	Number of tubewells	7(Working)+ 4(Standby)

Table 8: Details of Mouzas within the study area

Sl. No.	Name of the Village/ Mouza	J.L. No.	2011 Census			Considered under the	
			Total	**SC**	**ST**	**Population**	**Area (Ha)**
1.	Rajanpur	143	702	138	0	702	109.27
2.	Rasidpur	144	1474	758	0	1474	294.61
3.	Dherobazar	145	935	115	0	935	103.5
4.	Balta	146	629	199	0	629	172.4
5.	Parulbana	147	330	7	0	330	91.46
6.	Singdanga	148	0	0	0	0	49.98
7.	Lohanagar	149	150	0	0	150	91.57
8.	Majura	150	561	385	0	561	103.22
9.	Panchra	151	3412	1093	1	3412	207.2
10.	Simjuri	152	213	86	0	213	110.31
11.	ChakDerola	153	0	0	0	0	59.51
12.	Ranipathar	155	376	146	0	376	13.977
13.	Barakuri	157	943	397	2	943	262.16
14.	Rayhosenpur	158	113	26	0	113	67.53
15.	Idilpur	159	777	0	0	777	47.57
16.	Pursunda	160	2297	1120	0	2297	200.52
17.	Bibharpur	161	263	259	0	263	71.57
18.	Maheshpur	162	292	134	0	292	128.2
19.	Paigara	163	607	149	43	607	125.12
20.	Bahadurpur	164	2000	445	0	2000	269.68
21.	Labarhsol	165	702	594	0	702	60.75
22.	Nanna	166	381	227	0	381	80.82
23.	Junidpur	167	1067	628	0	1067	92.03
24.	Chapla	168	665	654	0	665	182.92
25.	Bharara	169	1068	455	0	1068	239.17
	Total =		**19957**	**10942**	**46**	**19957**	**4642.054**
						Total SC / ST Population	10988
						Percentage of SC / ST Population	55.06 %
						Population Density (persons/Ha)	4.30

Table 9: Details of Sub-surface Tubewells (Proposed)

Sl. No.	**Ultimate Demand**	**Pumping Hours**	**Expected yield of the proposed tubewell**	**Nos. of tubewell proposed**	**Details of the River Bed tubewell with length of the strainer**
	kLD	Hr	m3/Hr		
1	2605	16	23.26	7(Working)+ 4(Standby)	200 mm Diameter x Depth 22m Housing: Dia 200 mm length 11 m VerticalStrainer : Dia 200 mm length 9 m

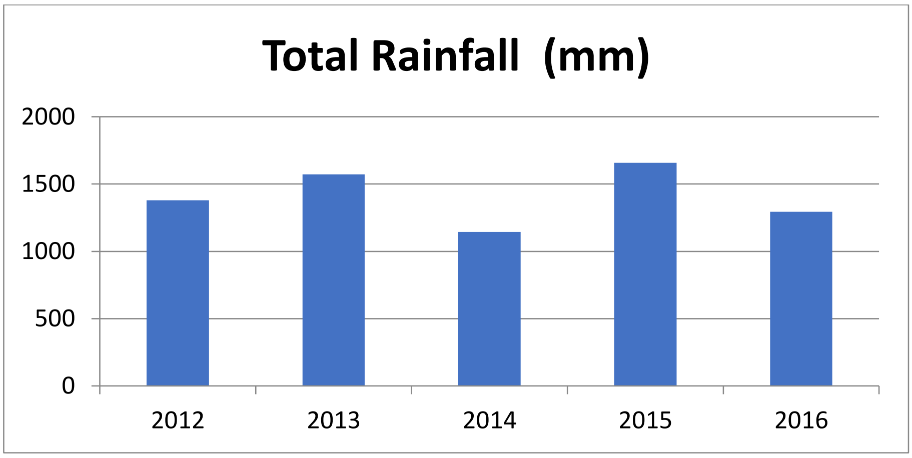

Figure 15: Rainfall Data of Birbhum District

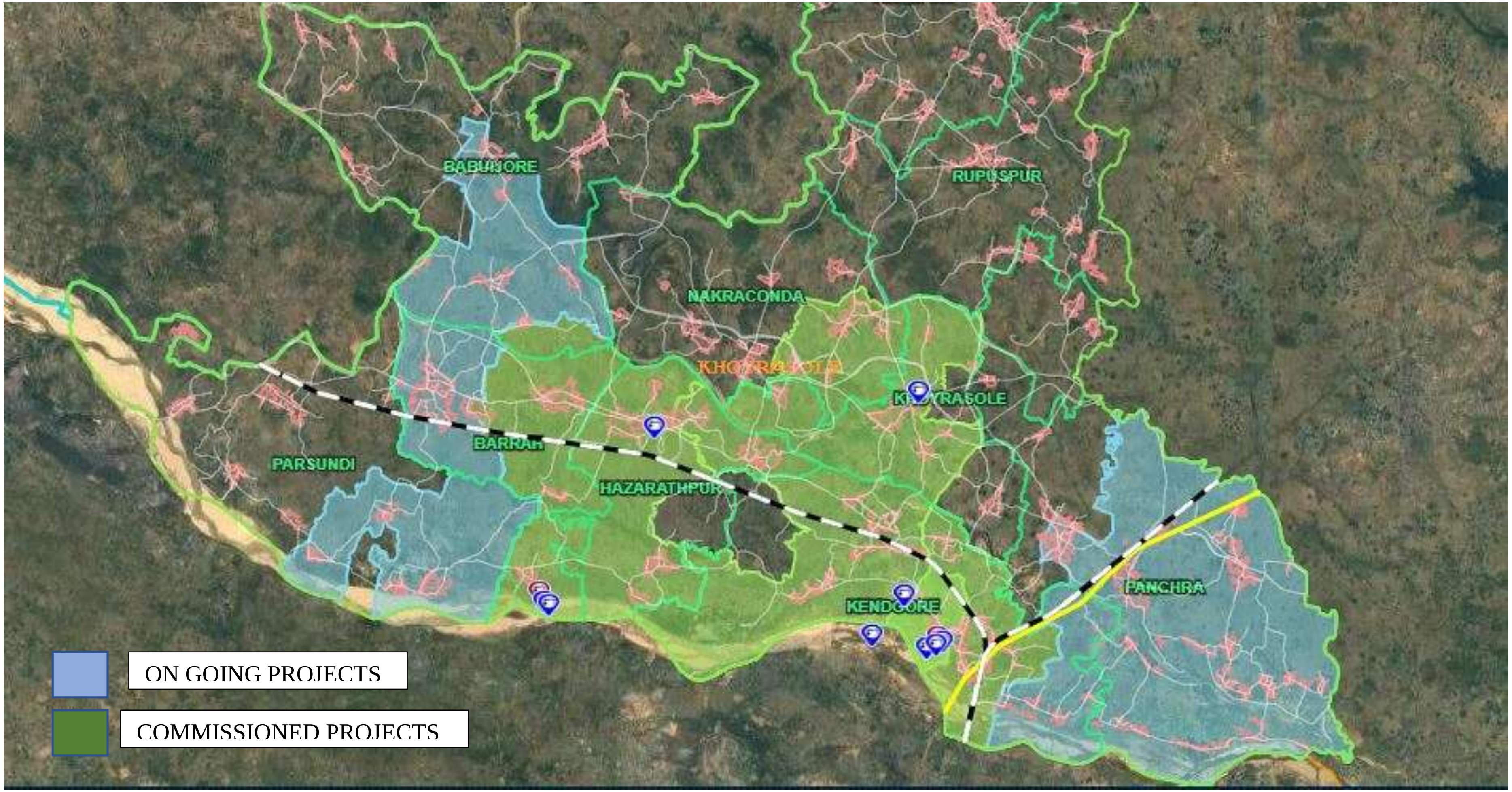

Figure 16: Map showing PWSS under Khoyrasole block (Source: West Bengal PHED Website)

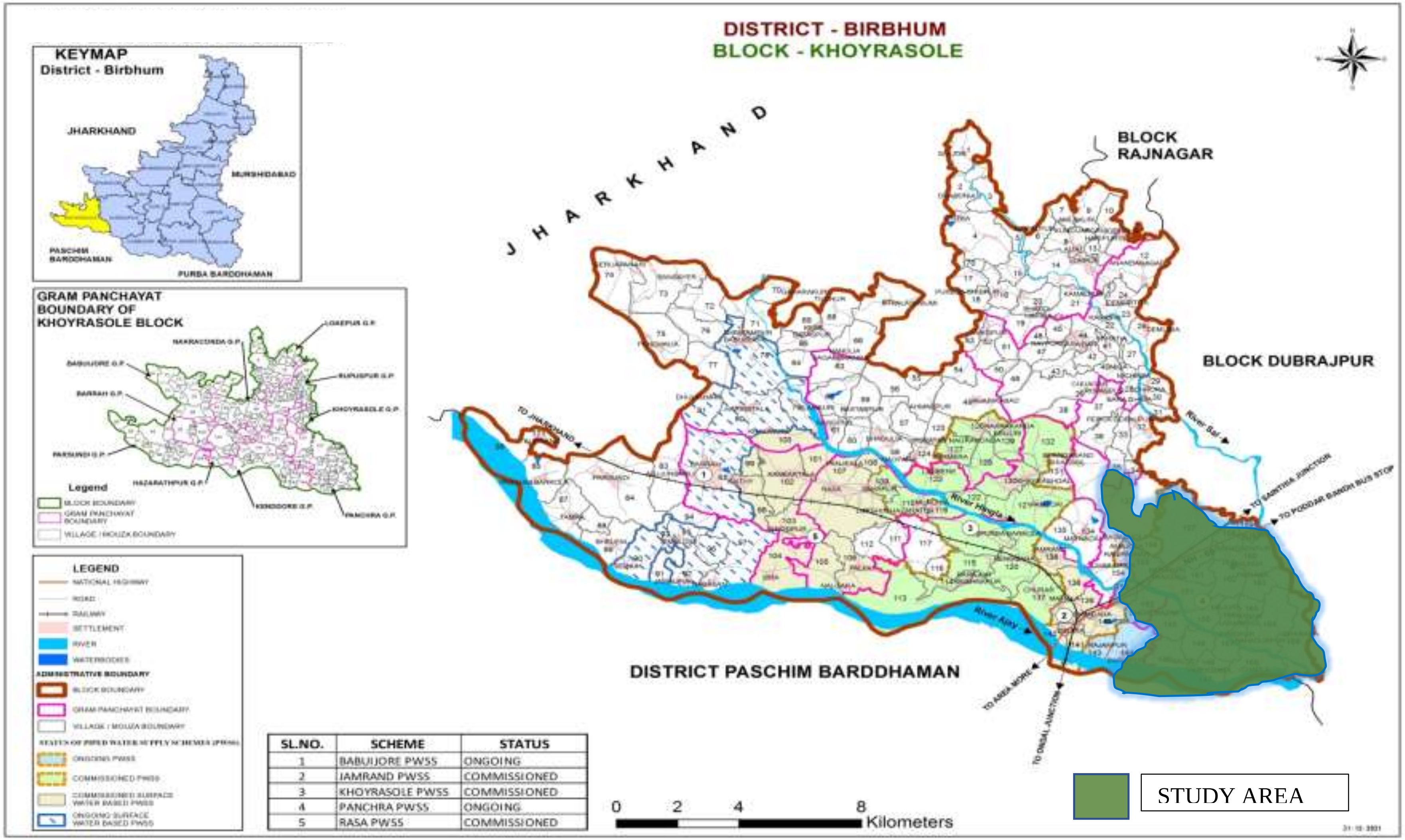

Figure 17:Map of the study area within Khoyrasole block

CHAPTER 6 : METHODOLOGY

6.1 Methodology flow chart:

The steps involved to address the specific objective of this study are as follows.

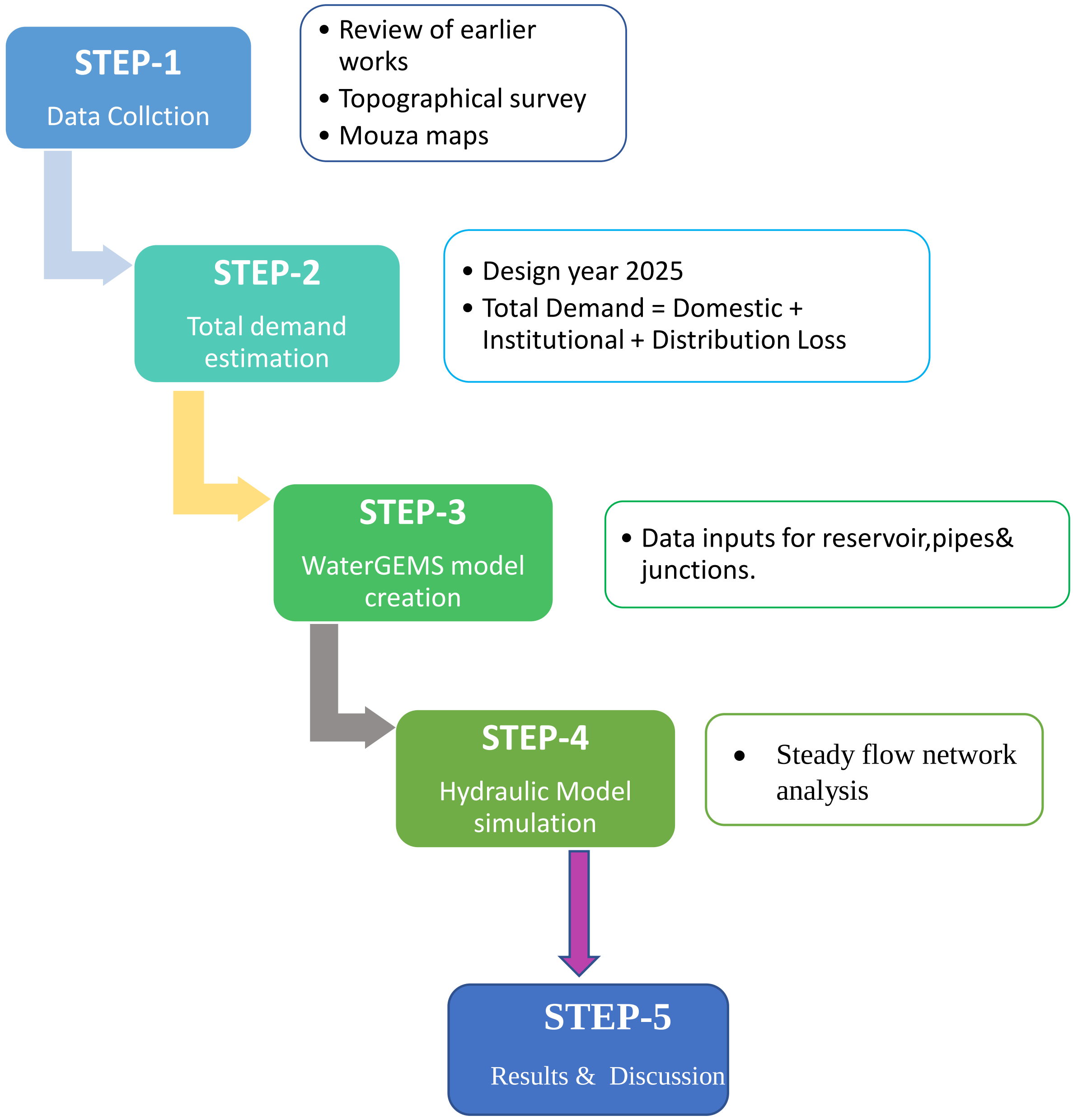

Figure 18: Methodology flow chart

Step 1 Data collection:

Earlier paper works were reviewed which helped to procced with this study.The study needed for the implementation of the water distribution network shall relate to conducting / authenticating the properties survey results for all inhabitants within the study area, along with topographic survey along roadways, paths, and the planned pipe alignments. Topographical survey data in form of autoCAD drawing was collected from WBPHED office. Along with this the details of mouzas of Panchra G.P was also collected from their website.

Step 2 Estimation of total demand:

The ultimate design population of the study area has been calculated using the Geometrical Increase Method which was described in section 4.1.4. This method is used as this method gives a higher value than other population forecasting methods, which is more acceptable in design for the safety point of view. At first, the geometric mean of the decadal growth rate of the past five decades of this district is calculated. Then using the formula mentioned in equation no 4.3 and considering 30 years design year the projected population on 2052 is determined from the population of 2011 census which was collected and the projected population of each Mouza are given in Column 1 of Table 7.1(b). The Domestic demand of the study area is determined by multiplying the values of column 1 by 70 as mentioned in Table 4.1. Column 3 consists of institutional demand which is determined by considering 5% of domestic demand (5% of Column 1). In column 4 the distribution loss is determined considering 10% of domestic demand and institutional demand . In column 6 the total demand is determined considering 3 as the peak factor as per the CPHEEO manual. The design demand is determined considering total demand.

All the calculations have been made as per CPHEEO Manual 1999 and WBPHED Schedule (2013).

The Details are mentioned in tables 7.1(a),7.1(b). **(**Source: District Census Handbook Birbhum 2011)

Table 10: Decadal Growth Rate of Birbhum

Year span	Geometric Mean of All Decadal Growth (*r*)
1961-71	16.15
1971-81	
1981-91	
1991-2001	
2001-11	

Table 11: Demand Calculation of the study area.

Panchra G.P								As per Geometric Mean Mathod Pn=Po(1+r/100)^n (r= Geometric Mean of All Decadal Growth , n=No of Decades)					
Name of the Village/ Mouza	J.L No.	2011 Census Population			Considered under the scheme		*r*	Projected population on 2052 (considering design period as 30 years) (P)	Domestic demand in KLD (@70 lpcd)	Institutional Demand in KLD(5% of column 2)	Distribution loss in KLD (10% of column 2+ column 3)	Total Demand in KLD {3*(column2+ column 3) + column 4)}	Factored Demand(l/s)
		Total	SC	ST	Population	Area (Ha)		1	2	3	4	6	10
Rajanpur	143	702	125	16	702	109.27		1167	82	4.1	8.61	94.71	3.33
Rasidpur	144	1474	167	17	1474	294.61		2451	172	8.6	18.06	198.66	6.96
Dherobaar	145	935	115	12	935	103.5		1555	109	5.45	11.45	125.9	4.41
Balta	146	629	199	10	629	172.4		1046	73	3.65	7.67	84.32	2.97
Parulbana	147	330	7	9	330	91.46		549	38	1.9	3.99	43.89	1.53
Lohanagar	149	150	0	11	150	91.57		250	18	0.9	1.89	20.79	0.72
Majura	150	561	385	14	561	103.22		933	65	3.25	6.83	75.08	2.64
Panchra	151	3412	1093	13	3412	207.2		5672	397	19.85	41.69	458.54	16.08
Simjuri	152	213	86	15	213	110.31		355	25	1.25	2.63	28.88	1.02
Ranipathar	155	376	146	18	376	13.977		625	44	2.2	4.62	50.82	1.77
Barakuri	157	943	397	19	943	262.16	16.15	1568	110	5.5	11.55	127.05	4.47
Rayhosenpr	158	113	26	2	113	67.53		188	13	0.65	1.37	15.02	0.54
Idilpur	159	777	0	1	777	47.57		1292	90	4.5	9.45	103.95	3.66
Pursunda	160	2297	1120	3	2297	200.5		3818	267	13.35	28.04	308.39	10.83
Bibharpur	161	263	259		263	71.57		438	31	1.55	3.26	35.81	1.26
Maheshpur	162	292	134	4	292	128.2		486	34	1.7	3.57	39.27	1.38
Paigara	163	607	149	7	607	125.1		1009	71	3.55	7.46	82.01	2.88
Bahadurpur	164	2000	445	8	2000	269.6		3341	234	11.7	24.57	270.27	9.48
Labarhsol	165	702	594		702	60.75		1167	82	4.1	8.61	94.71	3.33
Nanna	166	381	227	20	381	80.82		634	44	2.2	4.62	50.82	1.77
Junidpur	167	1067	628	21	1067	92.03		1774	124	6.2	13.02	143.22	5.01
Chapla	168	665	654	6	665	182.9		1106	77	3.85	8.09	88.94	3.12
Bharara	169	1068	455	5	1068	239.1		1776	124	6.2	13.02	143.22	5.01
TOTAL	**Population 19967**				**Area** 4642.054ha.		**Projected Population 33200**		**2324**	**116.2**	**244.07**	**2684.3**	**94.17** *3(peak factor)

Step 3 WaterGEMS model creation:

The Mouza Map of the Study area was collected from the WBPHED website and keeping its AutoCAD drawing in the background, the pipeline distribution system was drawn using a network simulation software WaterGEMS. The pipelines were drawn along the road embankment.

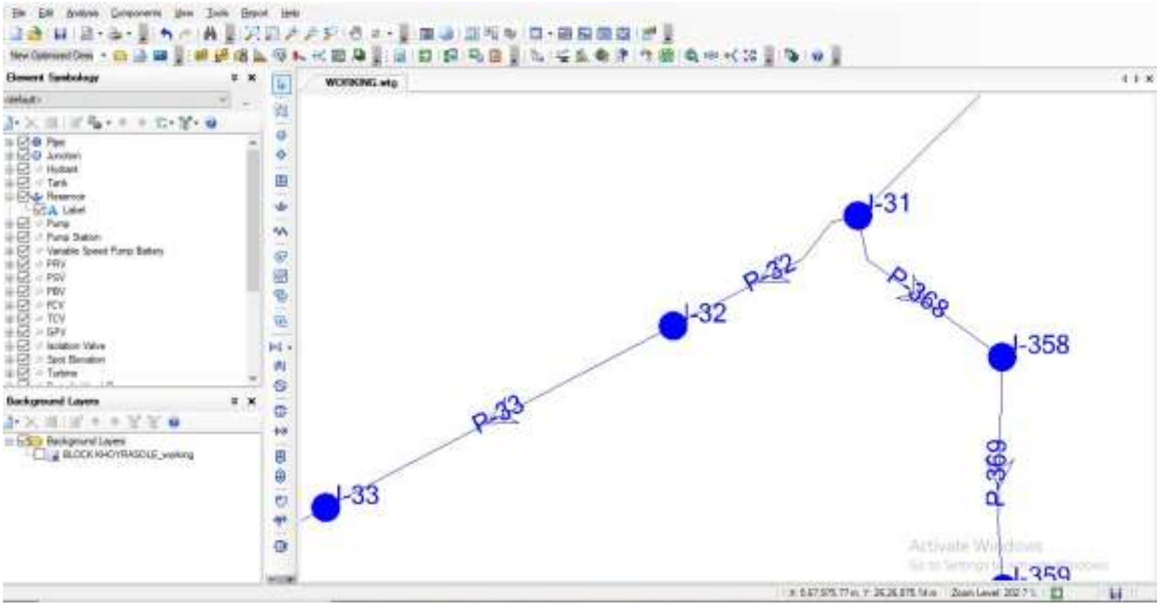

Figure 19: Drawing network in WaterGEMS V8i

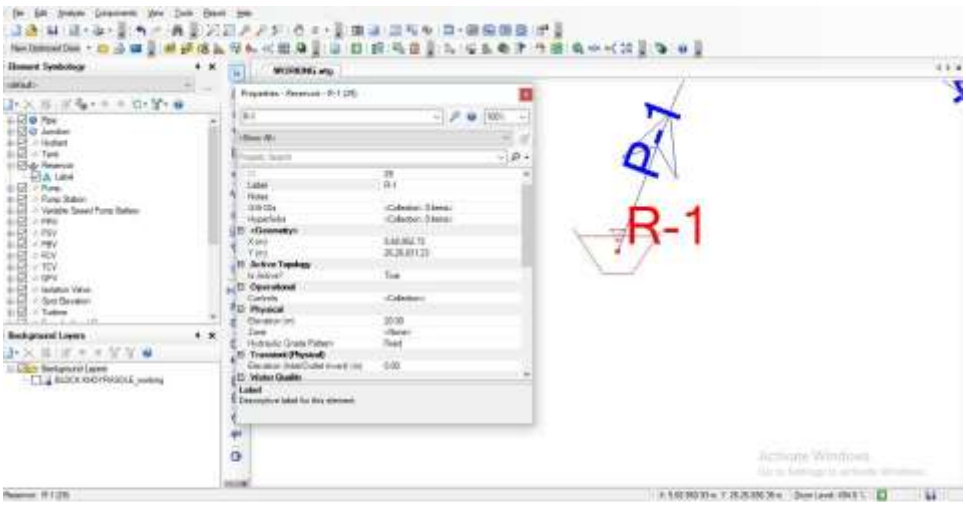

Figure 20: Property editor for reservoir in WaterGEMS V8i

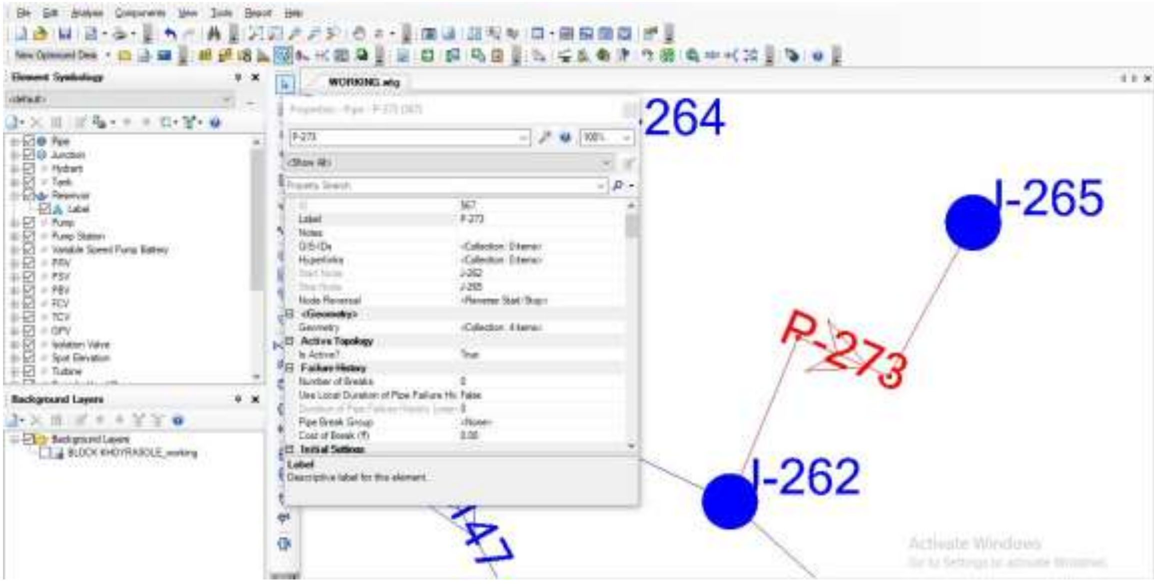

Figure 21: Property editor for pipeline in WaterGEMS V8i

Most of the hydraulic analysis software has common input data requirements. These data are grouped into pipe data and node data. Pipe data are the assigned pipe number, pipe diameter (mm), Hazen-Williams C-value, length (m) and diameter (mm). Node data are assigned node number, elevation (m) and water demand (lps). Pump curve data are the assigned head (m) and flow (lps).

In this network, there are 462 junctions and 463 pipes. The Input parameters for Junctions and pipes which are used during the hydraulic analysis are mentioned below in table 8.1 where J, P , T indicates Junction, Pipe , Tank respectively and the suffix of J, P, T represents its number. The topography is almost plain and the elevation is 75m. Here we have used one type of pipe ie PVC pipe. The Hazen William constant is considered 145 for PVC pipes

Table 12: Input data of junctions and pipes.

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-1	0.423	77	R-1	J-1	293.6	PVC	145
P-2	0.603	68	J-1	J-2	293.6	PVC	145
P-3	0.146	116	J-1	J-3	83.8	PVC	145
P-4	0.479	84	J-2	J-4	293.6	PVC	145
Detailed Input data of junctions and pipes is attached to Annexure -1							

Step 4 Hydraulic Model Simulations:

In the case of the steady-state mechanism by clicking validates option the network can be validated. If there is some problem it will show to the bottom dialogue box otherwise "No Problem" message is shown in the dialogue box. After that to compute and get the result we have to click compute button under the analysis tab. The software computes pressure (kPa), pressure head (m) at each junction and the flow (l/s), velocity (m/s), head losses, the rate of head loss (m/m) in each pipe

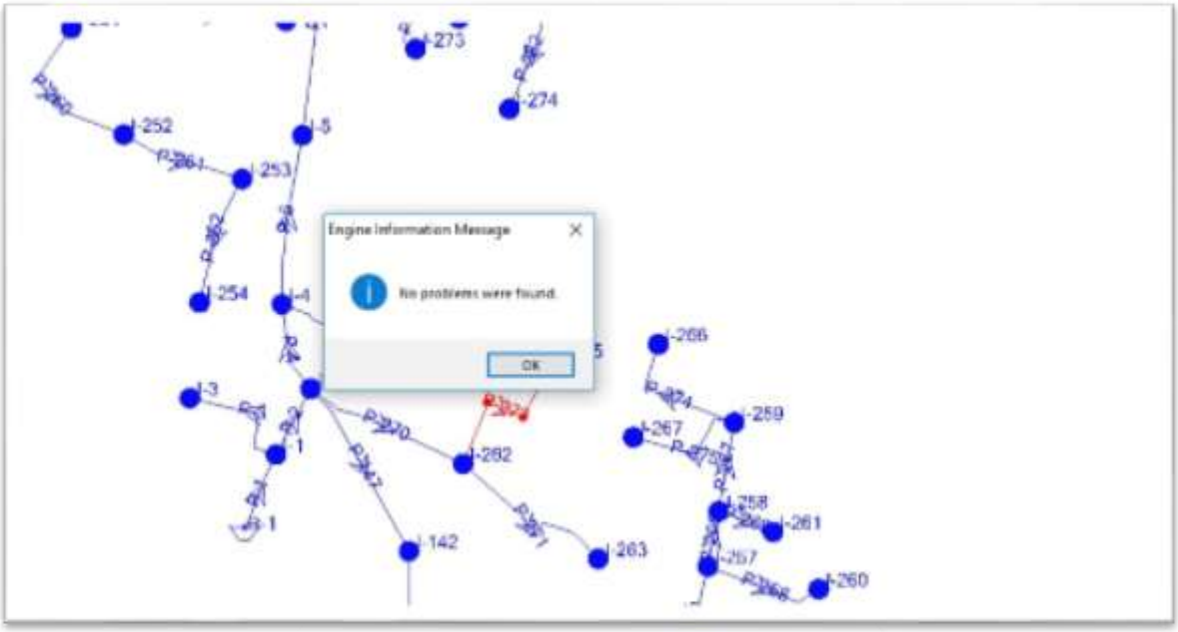

Figure 22:Network validated

Step 5 Results and Analysis:

The result generated by the software can be seen in the flex table. The pipe diameter has to be optimized repeatedly to get the calculated output value as per the CPHEEO guidelines.

Both the results generated by the two network simulation software respectively can be copied to excel files and to analyze the network parameters the different graphs generated by the software itself were used. The software-generated graphs are shown in Chapter 9.

CHAPTER 7: RESULTS AND DISCUSSIONS

7.1Output:

The output parameters obtained from the above mentioned software are elevation, hydraulic grade, pressure, pressure head for each junctions and flow, velocity, headloss gradient and headloss for each pipe. Here the hydraulic grade is defined as the same as the piezometric head $\left(\frac{p}{\gamma}+Z\right)$ of the water where the datum head Z signifies the elevation of each junctions. Pressure head is $\frac{p}{\gamma}$ where p is the pressure obtained in a particular junction and $\gamma = \rho g$ is the unit weight of water. The headloss of each pipe is determined using Hazen Williams Equation as mentioned in Table 5.1. The output obtained from the WaterGEMS software is mentioned in Table 9.1 .

Table 13: Output obtained from WaterGEMS software

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)
P-1	R-1	J-1	293.6	PVC	145	87.04	1.29	0.005	0.35
P-2	J-1	J-2	293.6	PVC	145	86.471	1.28	0.004	0.3
P-3	J-1	J-3	83.8	PVC	145	0.146	0.03	0	0
P-4	J-2	J-4	293.6	PVC	145	53.707	0.79	0.002	0.15

Detailed Input data of junctions and pipes is attached to Annexure -2

7.2 Results and discussion :

Table 14: Maximum and minimum values of each output parameter

Junction:

Parameter	Maximum/Minimum	Value	Junction Number
Pressure (kPa)	Maximum	196.20	J-1
	Minimum	70.54	J-443,J-444,
Pressure Head (m)	Maximum	20	J-1
	Minimum	7.19	J-443,J-444,

Pipe:

Parameter	Maximum/Minimum	Value	Pipe Number	Diameter	Material
Flow	Maximum (l/s)	87.04	P-1	293.6	PVC
	Minimum (l/s)	0.005	P-74	83.8	PVC
Velocity	Maximum (m/s)	1.29	P-1	293.6	PVC
	Minimum (m/s)	0.01	P-77, P-134, P-135,P-136, P-139,P-141,	83.8	PVC
Headloss	Maximum (m)	0.78	P-152	209.4	PVC
	Minimum (m)	0	P-453, P-454, P-456	83.8	PVC

From Table 7.2, it has been observed that the pressure was maximum at J-1 with a magnitude of 196.20 kPa, 20m respectively and minimum at J-443, J-444, J-445, with a magnitude of 68.67 kPa,7.07 m respectively. The pressure and pressure head are maximum at J-1 because its elevation is much less than the elevation of the overhead reservoir, and minimum at J-443, J-444, J-445 as it is at a distant point from the overhead reservoir.

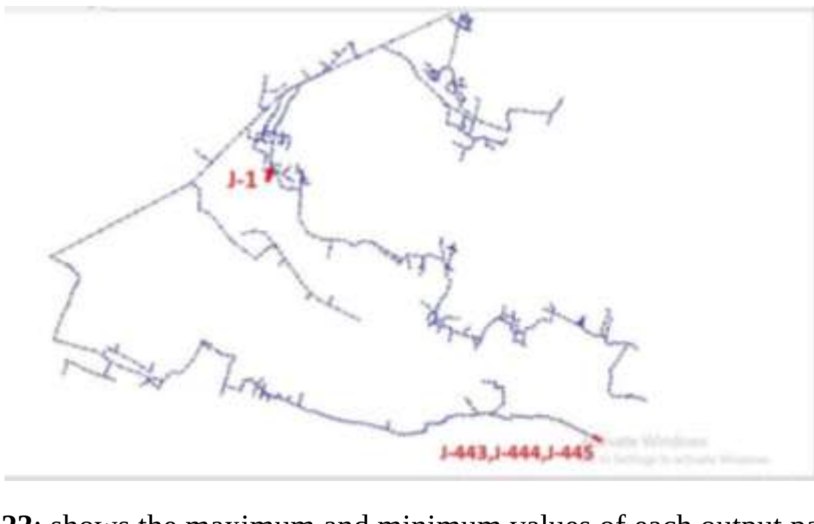

Figure 23: shows the maximum and minimum values of each output parameter

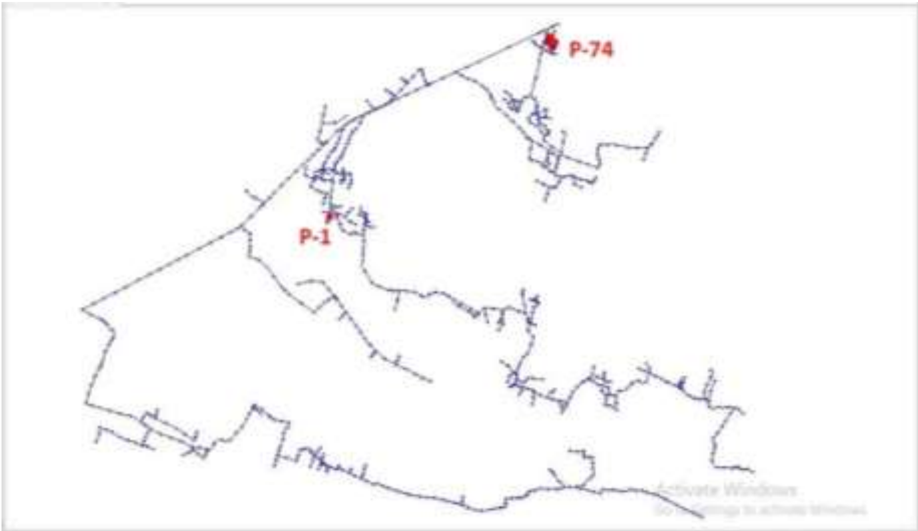

Figure 24: Pipes showing maximum and minimum flow

In case of pipes the flow is maximum at P-1 with a magnitude of 87.04 l/s as the pipe is connected to the overhead reservoir which is the source of the network similarly minimum at P-74 with a magnitude of 0.005 l/s as the demand is very less at the junction connecting that particular pipe .

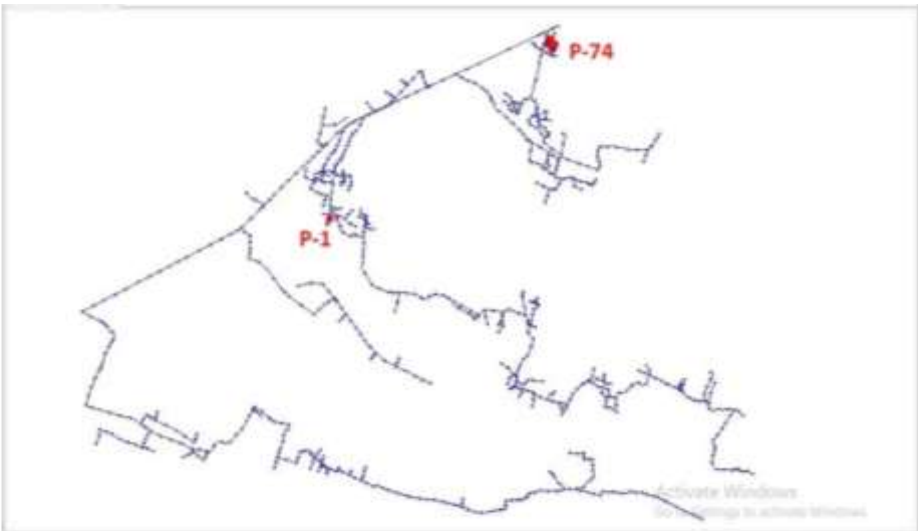

Figure 25: Pipes showing maximum and minimum velocity

The velocity is maximum at P-1 with a magnitude of 1.29 m/s as this is a pipe which is originated directly from the main pipe having a very high amount of flow and a diameter of 293.6 mm. The velocity is minimum at P-77, P-134, P-135,P-136, P-139,P-141 with a magnitude of 0.01 m/s

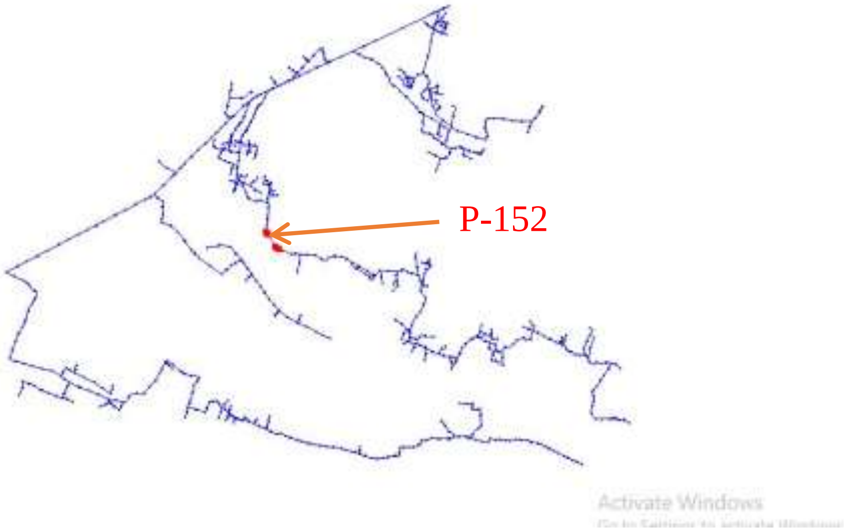

Figure 26: Pipes highlighted in RED showing maximum and minimum headloss

The headloss is maximum at P-152 with a magnitude of 0.78 m. As per Hazen Williams formula mentioned in Table 4.1. The headloss is minimum at P-453,P-454,P-456, with a magnitude of 0 m.

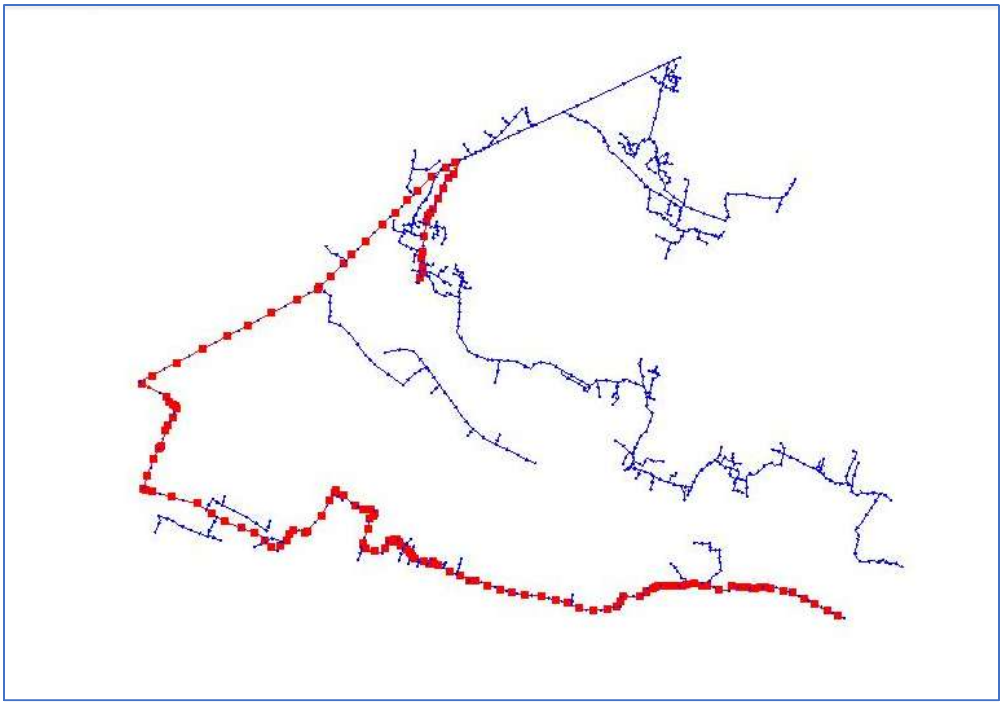

Figure 27: Longest path of the water supply network highlighted in red

The longest path is a path which is originated from the overhead reservoir R-1 ended at an extreme consumer end of Junction J-448. The length of the longest path is 14890 m. This path is originated from the overhead reservoir (R-1) and moves towards north east directions upto J-13 then it turned and moves towards south west direction through J-20, upto J-39. Then this path changes its direction and moves towards east direction upto J-313. Then it continues its journey in south direction upto J-319. After that it changes its direction and moves towards east again upto J-327. Then it moves towards the north direction till J-333 then its changes its direction to east and moves upto the extreme point ie J-445.

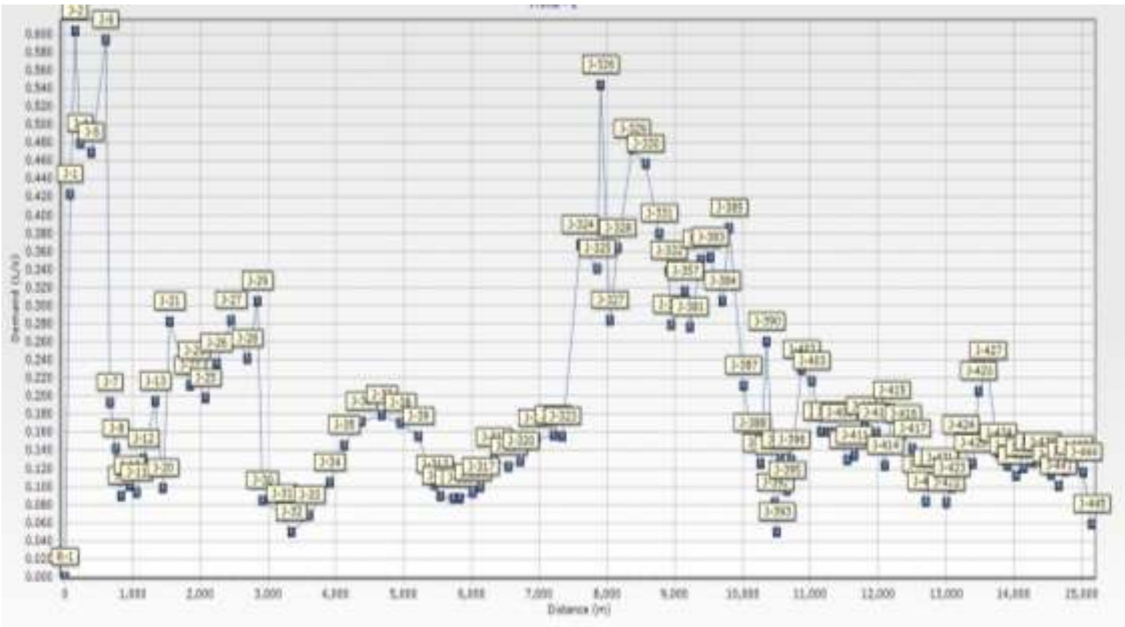

Figure 28: Profile of Demand of different junctions located on the longest path

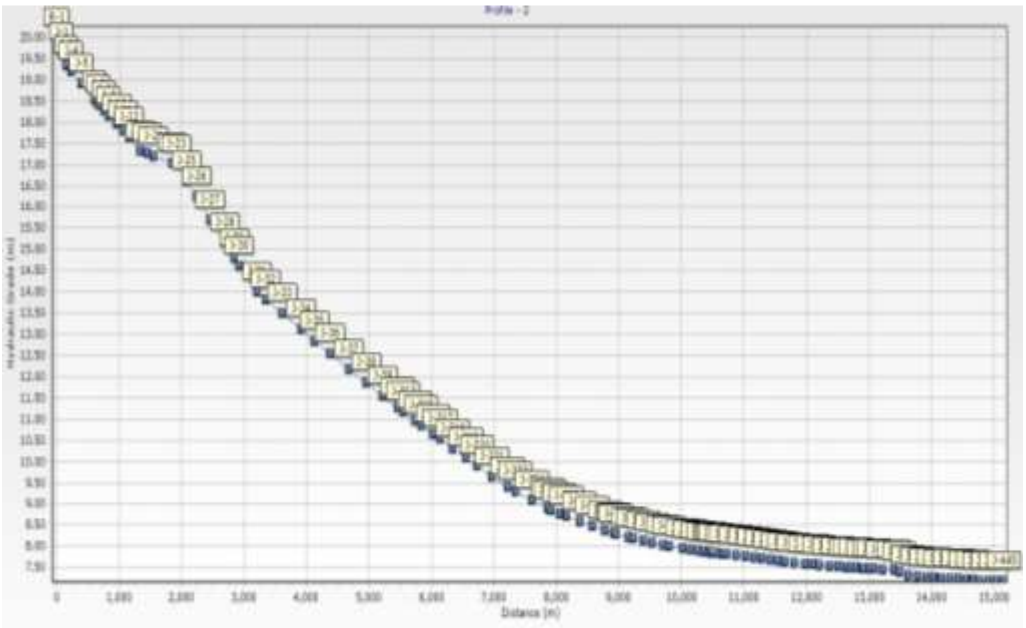

Figure 29: Profile of Pressure of different junctions located on the longest path.

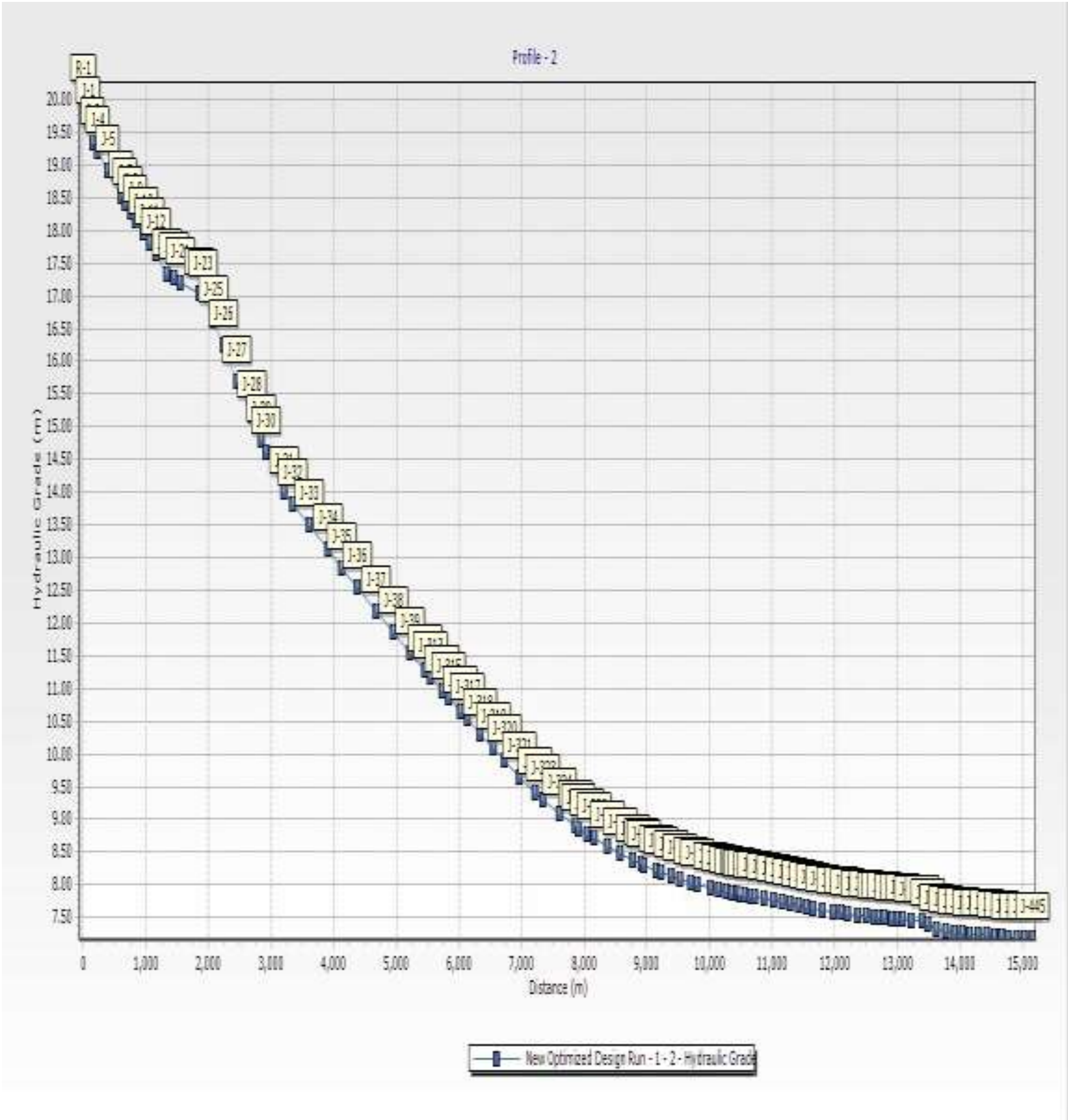

Figure 30: Profile of Hydraulic Grade of different junctions located on the longest path

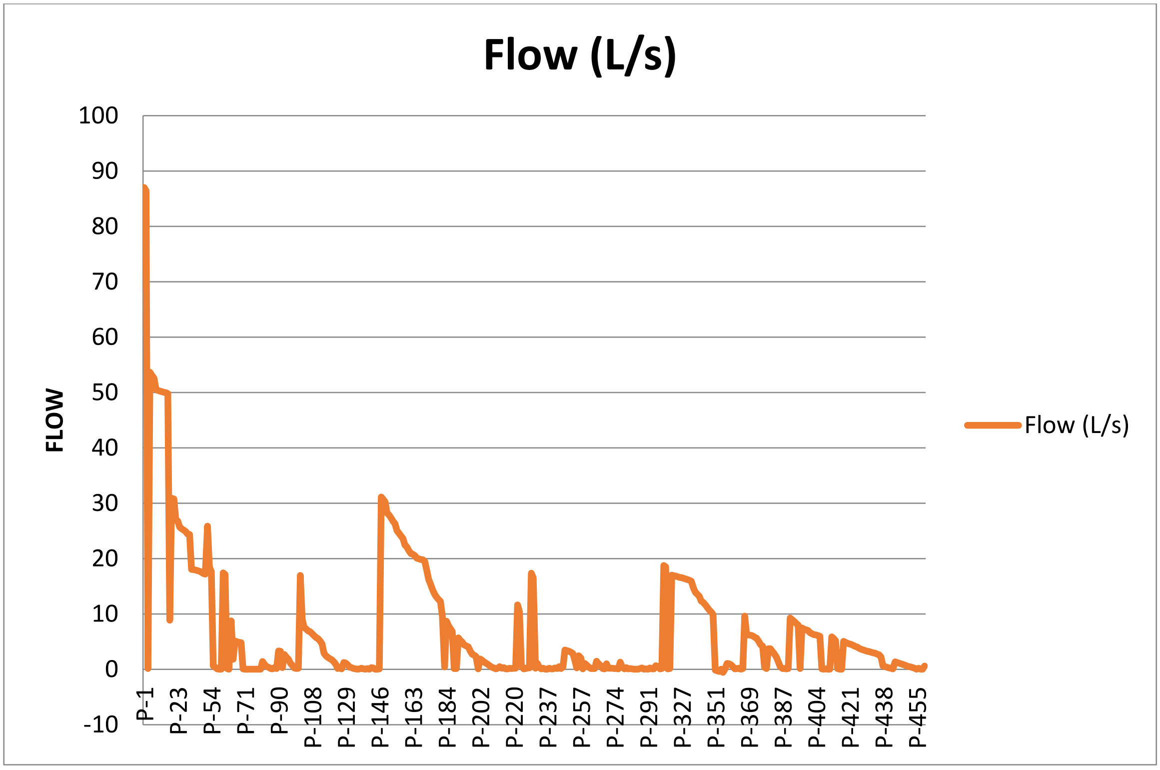

Figure 31: Profile of flow of different pipes

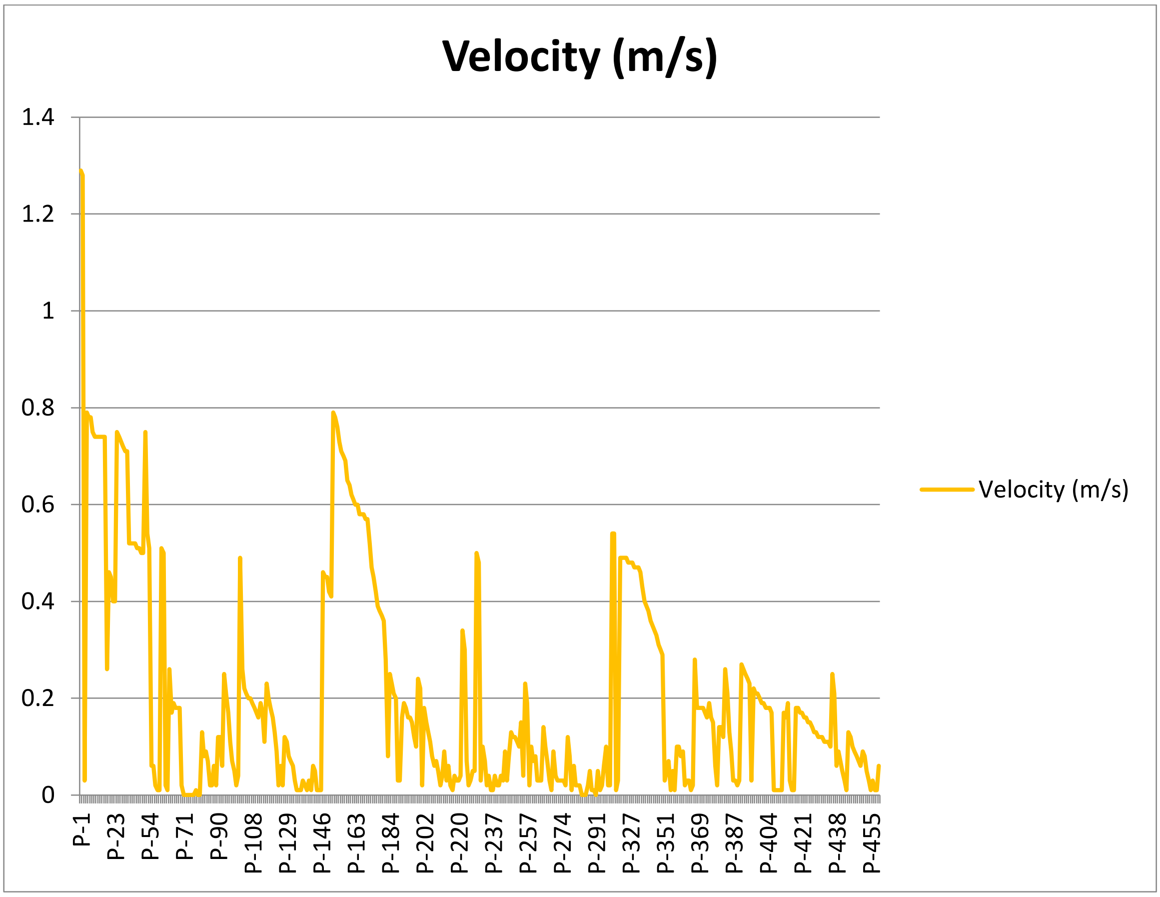

Figure 32: Profile of Velocity of different pipes

CHAPTER 8: CONCLUSION AND FUTURE SCOPES OF STUDY

Conclusions:

WaterGEMS, computer-based modelling software for water distribution networks, was used in this study to conduct an empirical analysis of the water distribution system in Panchra G.P region of Khoyrasole block in the district of Birbhum.

The main view of this work is to analyse the water distribution network and lookout the Deficiencies (if any) in it is analysis, establishment and its usage. At the end of the analysis it was found that the resulting minimum pressures at all the nodes and the links velocities are satisfy enough to provide water to the study area. The model results shows value of minimum pressure is 7.19m of H_2O which is within the limit as per CEEPHO manual.

So our model has a good efficacy.

Future Scopes of Study:

This study consists a huge number of elements more actual data on this might give the accurate results and further problem solving work may be done on this network based on the results. Along with there are various software which deal with the pipeline analysis. More detailed data are required to have an accurate study of stress analysis at the bends and the supports to the joints of the pipeline. CAESAR software is perfect match to that study. CAESAR is an advanced personal computer based tool for the engineer who designs or analysis piping system. QGIS data base model are available then complicated network analysis can also be processed.

The hydraulic analysis of this gravity type network may be done again considering the loss which will occur if we use of pressure reducing valve to reduce the pressure at different points of lower elevation level and air relief valve to release the air entrapped in pipes at the highest elevation points in this gravity flow network.

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REFERENCES:

CPHEEO (1999) “Manual on Water Supply and Treatment” published by Central Public Health and Environmental Engineering, New Delhi, India

Census of India (2011),West Bengal “ District Census Handbook Birbhum Village and town rectory” , Published by Directorate of Census Operations, West Bengal.

Garg,S.K.(2015) Water Supply Engineering ,28th Edition, Khanna Publishers.

Ulanicki, B., Bounds, P.L.M., Rance, J.P. and Reynolds, L. (2000). Open and closed loop pressure control for leakage reduction. Urban Water, 2(2), pp. 105-114.

Das, S. (2006). Study of pipeline network system and temporal decay of chlorine for the water treatment plant at Dakshin Raipur, West Bengal. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Das, S., Roy, P.K. and Mazumdar, A. (2008). Analysis of pipe flow and headloss of a modeled network based on EPANET in a water treatment plant at Raipur, West Bengal. Journal of the Institution of Public Health Engineers, India, 2008-09(3), pp. 21-28.

Izquierdo, J., Montalvo, I., Perez, R. and Herrera, M. (2008). Sensitivity analysis to assess the relative importance of pipes in water distribution networks. Mathematical and Computer Modelling, 48(1-2), pp. 268–278.

Liana, V. and Vlad, P. (2008). INFOWORKS WS and EPANET V2- Modelling the water distribution networks, UPB Scientific Bulletin, Series D, 70(4), pp. 91-102.

Koppel, T. and Vassiljev, A. (2009). Calibration of a model of an operational water distribution system containing pipes of different age. Advances in Engineering Software, 40(8), pp. 659– 664.

Saha, S. (2010). Analysis of pipeline alignment of a Thermal power plant based on pipeline identification with help of Geoinformatics tools (PIGMI) and HAMMER. M.E. Thesis.School of Water Resources Engineering, Jadavpur University: Kolkata, India.

Arunkumar, M. and Nethaji, M.V.E. (2011). Water Demand Analysis of Municipal Water Supply using EPANET Software. International Journal of Applied Bioengineering, 5(1), pp. 9-19.

Chandramouli, S. and Malleswararao, P. (2011). Reliability based optimal design of a water distribution network for Municipal water supply. International Journal of Engineering andTechnology, 3(1), pp. 9-19.

Chatterjee, B. (2011). Pipeline transient analysis of Mejia Thermal Power Station, DVC by HAMMER Software. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Jaman, H. (2011). Modification of Hunter’s Curve in the Perspective of Water and Energy Conservation. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Mukherjee, B. (2012). Pipeline design and analysis of distribution network of Dhapa water treatment plant, KMC by EPANET and HAMMER software. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Mukherjee, B., Das, S. and Mazumdar, A. (2012). Comparison of Pipeline Hydraulic Analysis between EPANET and HAMMER softwares. International Journal of Advances in Science and Technology, 4(6), pp. 52-63.

Das, S., Mukherjee, B. and Mazumdar, A. (2013). Analysis of Hammer Head at Increased Flow Demand in Pipe Networks: A Case Study. International Review of Mechanical Engineering, 7(4), pp. 757-766.

Sarkar, P.K. (2014). Extended Period Simulations of Pipeline Distribution Network of Garfa Boosting Station by Hammer and WaterGEMS Softwares. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Wu, P., Lai, Z., Wu, D. and Wang, L. (2014). Optimization Research of Parallel Pump System for Improving Energy Efficiency. Journal of Water Resources Planning and Management, 141(8), pp. 04014094 (1-8).

Mukherjee, B., Das, S., Mazumdar, A. and Sarkar, P. (2015a). Management in Real time Operation of Drinking Water pipeline Distribution Network: A case study. 47th IWWA Annual Convention, pp. 298-303.

Mukherjee, B., Das, S. and Mazumdar, A. (2015b). Transient Analysis of a Pipeline Network for Drinking Purpose in Assam, India. Journal of the Institution of Public Health Engineers, India, 2014-15 (4), pp. 26-32.

Mandal, S. (2015). Pipeline analysis of ash slurry disposal system of (2×520) MW Thermal Power Station by HAMMER software. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Das, M. (2015). Design of Landscape Irrigation System by AutoCAD Software and Simulations of Pipeline Distribution Network of a proposed site by Hammer and WaterGEMS Softwares. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Mukherjee, B., Das, S. and Mondal, S. (2016). Behaviour of Stresses in Steam Pipelines of a Captive Power Plant under Various Loading Conditions: A Case Study. 103rd Indian Science Congress Conference, ISCA, University of Mysore, India.

Ganguly, S. (2016). Hydraulic Analysis for a Composite Piped Water Supply Network using EPANET Software: A Case Study. M.E. Thesis. School of Water Resources Engineering,Jadavpur University, Kolkata: India.

Saha, B.K. (2016). Transient Analysis of Purulia Piped Water Supply Line using HAMMER Software. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Sarkar, K. (2016). Energy Estimation of Garden Reach Water Works and Its Water Transmission for Calcutta City Grid. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Halder, K. (2016). Comparison between EPANET and LOOP Softwares using a Gravity Flow Water Supply Network. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

Mukherjee, B., Das, S. and Mazumdar, A. (2017). Stress analysis of smart support system for a steam pipeline of Sagardighi Thermal Power Plant, West Bengal, India. International Journal of Innovative and Emerging Research in Engineering, 4(1), pp. 137-146..

Debnath, K.(2019). Study of Water Distribution Network of Bhogpur G.P at Panskura in West Bengal by WATERCAD Software. M.E. Thesis. School of Water Resources Engineering, Jadavpur University, Kolkata: India.

ANNEXURE-1

Input Parameters for hydraulic analysis.

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-1	0.423	77	R-1	J-1	293.6	PVC	145
P-2	0.603	68	J-1	J-2	293.6	PVC	145
P-3	0.146	116	J-1	J-3	83.8	PVC	145
P-4	0.479	84	J-2	J-4	293.6	PVC	145
P-5	0.469	155	J-4	J-5	293.6	PVC	145
P-6	0.594	219	J-5	J-6	293.6	PVC	145
P-7	0.193	69	J-6	J-7	293.6	PVC	145
P-8	0.142	85	J-7	J-8	293.6	PVC	145
P-9	0.089	76	J-8	J-9	293.6	PVC	145
P-10	0.101	116	J-9	J-10	293.6	PVC	145
P-11	0.093	102	J-10	J-11	293.6	PVC	145
P-12	0.131	99	J-11	J-12	293.6	PVC	145
P-13	0.194	183	J-12	J-13	293.6	PVC	145
P-18	0.087	740	J-17	J-18	209.4	PVC	145
P-20	0.217	115	J-13	J-20	293.6	PVC	145
P-21	0.165	96	J-20	J-21	293.6	PVC	145
P-22	0.207	309	J-21	J-22	293.6	PVC	145
P-23	0.084	63	J-22	J-23	293.6	PVC	145
P-26	1.83	157	J-25	J-26	209.4	PVC	145
P-27	0.098	221	J-26	J-27	209.4	PVC	145
P-28	0.282	233	J-27	J-28	209.4	PVC	145
P-29	0.212	154	J-28	J-29	209.4	PVC	145
P-30	0.228	81	J-29	J-30	209.4	PVC	145
P-31	0.197	277	J-30	J-31	209.4	PVC	145
P-32	0.236	145	J-31	J-32	209.4	PVC	145
P-33	0.284	258	J-32	J-33	209.4	PVC	145
P-34	0.242	301	J-33	J-34	209.4	PVC	145
P-35	0.304	218	J-34	J-35	209.4	PVC	145
P-36	0.085	252	J-35	J-36	209.4	PVC	145
P-37	0.069	298	J-36	J-37	209.4	PVC	145
P-38	0.05	277	J-37	J-38	209.4	PVC	145
P-39	0.069	272	J-38	J-39	209.4	PVC	145
P-52	0.105	159	J-23	J-25	209.4	PVC	145
P-53	0.146	84	J-14	J-52	209.4	PVC	145
P-54	0.171	216	J-52	J-15	209.4	PVC	145
P-55	0.179	103	J-52	J-53	116.4	PVC	145
P-56	0.171	199	J-53	J-54	83.8	PVC	145
P-57	0.156	199	J-54	J-55	83.8	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-58	0.187	82	J-54	J-56	83.8	PVC	145
P-59	0.195	116	J-53	J-57	83.8	PVC	145
P-60	0.223	251	J-15	J-58	209.4	PVC	145
P-61	0.093	54	J-58	J-16	209.4	PVC	145
P-62	0.038	113	J-58	J-59	83.8	PVC	145
P-63	0.054	79	J-59	J-60	83.8	PVC	145
P-64	0.195	112	J-18	J-61	209.4	PVC	145
P-65	0.089	124	J-61	J-19	116.4	PVC	145
P-66	0.037	132	J-61	J-62	186.4	PVC	145
P-67	1.854	88	J-62	J-63	186.4	PVC	145
P-68	0.024	155	J-63	J-64	186.4	PVC	145
P-69	0.041	399	J-64	J-65	186.4	PVC	145
P-70	0.054	27	J-62	J-66	83.8	PVC	145
P-71	0.066	120	J-66	J-67	83.8	PVC	145
P-72	0.041	148	J-66	J-68	83.8	PVC	145
P-73	0.012	119	J-66	J-69	83.8	PVC	145
P-74	0.015	49	J-69	J-70	83.8	PVC	145
P-75	0.017	76	J-63	J-71	83.8	PVC	145
P-76	0.005	67	J-71	J-72	83.8	PVC	145
P-77	0.014	95	J-63	J-73	83.8	PVC	145
P-78	0.007	74	J-73	J-74	83.8	PVC	145
P-79	0.024	75	J-73	J-75	83.8	PVC	145
P-81	0.007	141	J-65	J-77	116.4	PVC	145
P-82	0.007	81	J-77	J-78	116.4	PVC	145
P-83	0.227	42	J-78	J-79	83.8	PVC	145
P-84	0.231	144	J-77	J-80	83.8	PVC	145
P-85	0.121	126	J-80	J-81	83.8	PVC	145
P-86	0.256	121	J-78	J-82	83.8	PVC	145
P-88	0.119	86	J-79	J-84	83.8	PVC	145
P-89	0.115	142	J-84	J-85	83.8	PVC	145
P-90	0.215	129	J-65	J-86	186.4	PVC	145
P-91	0.134	84	J-86	J-87	186.4	PVC	145
P-92	0.092	116	J-87	J-88	83.8	PVC	145
P-93	0.219	32	J-87	J-89	116.4	PVC	145
P-94	0.224	34	J-89	J-90	116.4	PVC	145
P-95	0.288	68	J-90	J-91	116.4	PVC	145
P-96	0.227	207	J-91	J-92	116.4	PVC	145
P-98	0.413	235	J-92	J-94	116.4	PVC	145
P-99	0.417	269	J-94	J-95	83.8	PVC	145
P-100	0.476	138	J-90	J-96	83.8	PVC	145
P-101	0.254	239	J-89	J-97	83.8	PVC	145
P-102	0.13	301	J-16	J-98	209.4	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-103	0.225	289	J-98	J-17	209.4	PVC	145
P-104	0.346	155	J-98	J-99	209.4	PVC	145
P-105	0.245	183	J-99	J-100	209.4	PVC	145
P-106	0.301	136	J-100	J-101	209.4	PVC	145
P-107	0.221	99	J-101	J-102	209.4	PVC	145
P-108	0.299	219	J-102	J-103	209.4	PVC	145
P-109	0.398	203	J-103	J-104	209.4	PVC	145
P-110	0.321	136	J-104	J-105	209.4	PVC	145
P-111	0.188	62	J-105	J-106	209.4	PVC	145
P-112	0.351	234	J-106	J-107	186.4	PVC	145
P-113	0.424	126	J-107	J-108	186.4	PVC	145
P-114	0.427	251	J-108	J-109	186.4	PVC	145
P-115	0.447	222	J-109	J-110	116.4	PVC	145
P-116	0.309	105	J-110	J-111	116.4	PVC	145
P-117	0.214	122	J-111	J-112	116.4	PVC	145
P-118	0.244	137	J-112	J-113	116.4	PVC	145
P-119	0.351	235	J-113	J-114	116.4	PVC	145
P-120	0.433	224	J-114	J-115	116.4	PVC	145
P-124	0.466	141	J-115	J-119	83.8	PVC	145
P-126	0.133	129	J-115	J-121	83.8	PVC	145
P-127	0.214	97	J-121	J-122	83.8	PVC	145
P-128	0.092	74	J-108	J-123	116.4	PVC	145
P-129	0.107	105	J-123	J-124	116.4	PVC	145
P-130	0.115	106	J-124	J-125	116.4	PVC	145
P-131	0.123	118	J-125	J-126	83.8	PVC	145
P-132	0.061	53	J-126	J-127	83.8	PVC	145
P-133	0.129	138	J-127	J-128	83.8	PVC	145
P-134	0.071	62	J-128	J-129	83.8	PVC	145
P-135	0.05	78	J-129	J-130	83.8	PVC	145
P-136	0.028	173	J-127	J-131	83.8	PVC	145
P-137	0.061	113	J-124	J-132	83.8	PVC	145
P-138	0.071	87	J-132	J-133	83.8	PVC	145
P-139	0.072	117	J-133	J-134	83.8	PVC	145
P-140	0.041	88	J-107	J-135	83.8	PVC	145
P-141	0.113	82	J-135	J-136	83.8	PVC	145
P-142	0.029	123	J-125	J-137	83.8	PVC	145
P-143	0.071	77	J-137	J-138	83.8	PVC	145
P-144	0.139	157	J-138	J-139	83.8	PVC	145
P-145	0.056	158	J-138	J-140	83.8	PVC	145
P-146	0.056	200	J-106	J-141	83.8	PVC	145
P-147	0.071	174	J-2	J-142	293.6	PVC	145
P-148	0.453	188	J-142	J-143	293.6	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-149	0.446	168	J-143	J-144	293.6	PVC	145
P-150	0.536	148	J-144	J-145	293.6	PVC	145
P-151	0.36	139	J-145	J-146	293.6	PVC	145
P-152	0.53	284	J-146	J-147	209.4	PVC	145
P-153	0.617	208	J-147	J-148	209.4	PVC	145
P-154	0.4	111	J-148	J-149	209.4	PVC	145
P-155	0.823	178	J-149	J-150	209.4	PVC	145
P-156	0.475	201	J-150	J-151	209.4	PVC	145
P-157	0.465	170	J-151	J-152	209.4	PVC	145
P-158	0.493	135	J-152	J-153	209.4	PVC	145
P-159	0.649	219	J-153	J-154	209.4	PVC	145
P-160	0.329	185	J-154	J-155	209.4	PVC	145
P-161	0.525	213	J-155	J-156	209.4	PVC	145
P-162	0.314	134	J-156	J-157	209.4	PVC	145
P-163	0.086	138	J-157	J-158	209.4	PVC	145
P-164	0.16	162	J-158	J-159	209.4	PVC	145
P-165	0.177	177	J-159	J-160	209.4	PVC	145
P-166	0.119	198	J-160	J-161	209.4	PVC	145
P-167	0.108	144	J-161	J-162	209.4	PVC	145
P-168	0.082	116	J-162	J-163	209.4	PVC	145
P-169	0.071	67	J-163	J-164	209.4	PVC	145
P-170	0.463	75	J-164	J-165	209.4	PVC	145
P-172	0.47	30	J-166	J-167	209.4	PVC	145
P-173	0.277	163	J-167	J-168	209.4	PVC	145
P-174	0.646	130	J-168	J-169	209.4	PVC	145
P-175	0.789	100	J-169	J-170	209.4	PVC	145
P-176	0.527	131	J-170	J-171	209.4	PVC	145
P-177	0.437	151	J-171	J-172	209.4	PVC	145
P-178	0.392	85	J-172	J-173	209.4	PVC	145
P-180	0.328	151	J-174	J-175	209.4	PVC	145
P-181	0.425	130	J-175	J-176	83.8	PVC	145
P-184	0.591	90	J-175	J-179	209.4	PVC	145
P-185	0.515	185	J-179	J-180	209.4	PVC	145
P-186	0.319	170	J-180	J-181	209.4	PVC	145
P-187	0.599	213	J-181	J-182	209.4	PVC	145
P-188	0.492	122	J-182	J-183	83.8	PVC	145
P-190	0.531	116	J-182	J-185	83.8	PVC	145
P-191	0.837	152	J-182	J-186	209.4	PVC	145
P-192	0.169	164	J-186	J-187	186.4	PVC	145
P-193	0.162	75	J-187	J-188	186.4	PVC	145
P-194	0.439	103	J-188	J-189	186.4	PVC	145
P-195	0.291	101	J-189	J-190	186.4	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-196	0.174	120	J-190	J-191	186.4	PVC	145
P-197	0.171	54	J-191	J-192	186.4	PVC	145
P-198	0.185	113	J-192	J-193	186.4	PVC	145
P-199	0.282	109	J-193	J-194	116.4	PVC	145
P-200	0.35	130	J-194	J-195	116.4	PVC	145
P-201	0.186	129	J-195	J-196	83.8	PVC	145
P-202	0.201	163	J-195	J-197	116.4	PVC	145
P-203	0.354	167	J-197	J-198	116.4	PVC	145
P-204	0.108	155	J-198	J-199	116.4	PVC	145
P-205	0.277	108	J-199	J-200	116.4	PVC	145
P-206	0.27	181	J-200	J-201	116.4	PVC	145
P-207	0.221	177	J-201	J-202	116.4	PVC	145
P-208	0.242	60	J-202	J-203	83.8	PVC	145
P-209	0.3	76	J-203	J-204	83.8	PVC	145
P-210	0.199	130	J-204	J-205	83.8	PVC	145
P-211	0.115	250	J-192	J-206	83.8	PVC	145
P-212	0.173	162	J-191	J-207	83.8	PVC	145
P-213	0.109	210	J-207	J-208	83.8	PVC	145
P-215	0.21	29	J-188	J-210	83.8	PVC	145
P-216	0.312	103	J-210	J-211	83.8	PVC	145
P-217	0.176	81	J-210	J-212	83.8	PVC	145
P-218	0.179	157	J-179	J-213	83.8	PVC	145
P-219	0.086	100	J-176	J-214	83.8	PVC	145
P-220	0.068	136	J-174	J-215	83.8	PVC	145
P-221	0.218	160	J-173	J-216	83.8	PVC	145
P-222	0.138	62	J-173	J-217	209.4	PVC	145
P-223	0.189	138	J-217	J-174	209.4	PVC	145
P-224	0.222	162	J-217	J-218	116.4	PVC	145
P-225	0.503	75	J-218	J-219	83.8	PVC	145
P-226	0.469	101	J-218	J-220	83.8	PVC	145
P-227	0.104	148	J-168	J-221	83.8	PVC	145
P-228	0.14	137	J-167	J-222	83.8	PVC	145
P-229	0.289	108	J-165	J-223	209.4	PVC	145
P-230	0.267	111	J-223	J-166	209.4	PVC	145
P-231	0.616	96	J-223	J-224	83.8	PVC	145
P-232	0.188	151	J-164	J-225	116.4	PVC	145
P-233	0.695	205	J-225	J-226	83.8	PVC	145
P-234	0.4	58	J-165	J-227	83.8	PVC	145
P-235	0.113	42	J-163	J-228	83.8	PVC	145
P-236	0.111	179	J-228	J-229	83.8	PVC	145
P-237	0.057	130	J-228	J-230	83.8	PVC	145
P-238	0.041	150	J-169	J-231	83.8	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-239	0.208	83	J-170	J-232	83.8	PVC	145
P-240	0.116	206	J-158	J-233	83.8	PVC	145
P-241	0.085	142	J-159	J-234	83.8	PVC	145
P-242	0.088	137	J-234	J-235	83.8	PVC	145
P-244	0.059	235	J-153	J-237	83.8	PVC	145
P-245	0.019	182	J-237	J-238	83.8	PVC	145
P-246	0.34	223	J-149	J-239	83.8	PVC	145
P-248	0.148	202	J-21	J-241	186.4	PVC	145
P-249	0.461	119	J-241	J-242	186.4	PVC	145
P-250	0.149	66	J-242	J-243	186.4	PVC	145
P-251	0.086	124	J-243	J-244	186.4	PVC	145
P-252	0.186	51	J-244	J-245	186.4	PVC	145
P-254	0.219	110	J-246	J-247	116.4	PVC	145
P-255	0.282	192	J-247	J-248	83.8	PVC	145
P-256	0.257	60	J-245	J-249	116.4	PVC	145
P-257	0.323	77	J-249	J-246	116.4	PVC	145
P-258	0.241	91	J-249	J-250	83.8	PVC	145
P-259	0.286	65	J-247	J-251	116.4	PVC	145
P-260	0.114	154	J-251	J-252	116.4	PVC	145
P-261	0.274	116	J-252	J-253	83.8	PVC	145
P-262	0.338	120	J-253	J-254	83.8	PVC	145
P-263	0.295	128	J-246	J-255	83.8	PVC	145
P-264	0.15	114	J-245	J-256	83.8	PVC	145
P-265	0.16	112	J-144	J-257	116.4	PVC	145
P-266	0.143	51	J-257	J-258	116.4	PVC	145
P-267	0.344	82	J-258	J-259	116.4	PVC	145
P-268	0.233	111	J-257	J-260	83.8	PVC	145
P-269	0.408	53	J-258	J-261	83.8	PVC	145
P-270	0.139	155	J-2	J-262	116.4	PVC	145
P-271	0.066	168	J-262	J-263	83.8	PVC	145
P-272	0.597	143	J-4	J-264	83.8	PVC	145
P-273	0.211	153	J-262	J-265	83.8	PVC	145
P-274	0.179	129	J-259	J-266	83.8	PVC	145
P-275	0.192	115	J-259	J-267	83.8	PVC	145
P-276	0.162	67	J-6	J-268	83.8	PVC	145
P-277	0.144	118	J-6	J-269	116.4	PVC	145
P-278	0.085	148	J-269	J-270	83.8	PVC	145
P-279	0.5	57	J-269	J-271	83.8	PVC	145
P-280	0.31	76	J-269	J-272	83.8	PVC	145
P-281	0.072	84	J-272	J-273	83.8	PVC	145
P-282	0.201	99	J-270	J-274	83.8	PVC	145
P-283	0.106	50	J-235	J-275	83.8	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-284	0.124	61	J-275	J-236	83.8	PVC	145
P-285	0.053	56	J-275	J-276	83.8	PVC	145
P-286	0.018	62	J-233	J-277	83.8	PVC	145
P-287	0.02	165	J-155	J-278	83.8	PVC	145
P-288	0.134	100	J-156	J-279	83.8	PVC	145
P-289	0.15	144	J-279	J-280	83.8	PVC	145
P-290	0.046	64	J-279	J-281	83.8	PVC	145
P-291	0.073	79	J-159	J-282	83.8	PVC	145
P-292	0.025	162	J-91	J-283	83.8	PVC	145
P-293	0.213	64	J-283	J-284	83.8	PVC	145
P-295	0.061	121	J-88	J-286	83.8	PVC	145
P-296	0.114	97	J-23	J-287	116.4	PVC	145
P-297	0.152	196	J-287	J-288	83.8	PVC	145
P-298	0.311	182	J-288	J-289	83.8	PVC	145
P-299	0.084	292	J-288	J-290	83.8	PVC	145
P-300	0.136	119	J-13	J-291	209.4	PVC	145
P-301	0.164	103	J-291	J-14	209.4	PVC	145
P-302	0.061	131	J-291	J-292	83.8	PVC	145
P-303	0.157	252	J-29	J-293	83.8	PVC	145
P-322	0.102	229	J-39	J-312	209.4	PVC	145
P-323	0.089	100	J-312	J-313	209.4	PVC	145
P-324	0.087	187	J-313	J-314	209.4	PVC	145
P-325	0.087	93	J-314	J-315	209.4	PVC	145
P-326	0.093	186	J-315	J-316	209.4	PVC	145
P-327	0.099	113	J-316	J-317	209.4	PVC	145
P-328	0.131	206	J-317	J-318	209.4	PVC	145
P-329	0.122	216	J-318	J-319	209.4	PVC	145
P-330	0.128	175	J-319	J-320	209.4	PVC	145
P-331	0.153	237	J-320	J-321	209.4	PVC	145
P-332	0.157	255	J-321	J-322	209.4	PVC	145
P-333	0.155	125	J-322	J-323	209.4	PVC	145
P-334	0.368	263	J-323	J-324	209.4	PVC	145
P-335	0.34	251	J-324	J-325	209.4	PVC	145
P-336	0.544	48	J-325	J-326	209.4	PVC	145
P-337	0.284	139	J-326	J-327	209.4	PVC	145
P-338	0.363	110	J-327	J-328	209.4	PVC	145
P-339	0.473	209	J-328	J-329	209.4	PVC	145
P-340	0.457	206	J-329	J-330	209.4	PVC	145
P-341	0.379	195	J-330	J-331	209.4	PVC	145
P-342	0.339	138	J-331	J-332	209.4	PVC	145
P-343	0.278	41	J-332	J-333	209.4	PVC	145
P-351	0.102	152	J-340	J-341	83.8	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-352	0.108	196	J-341	J-342	83.8	PVC	145
P-353	0.115	173	J-342	J-343	83.8	PVC	145
P-354	0.129	175	J-340	J-344	83.8	PVC	145
P-355	0.055	99	J-343	J-345	116.4	PVC	145
P-356	0.065	143	J-343	J-346	83.8	PVC	145
P-357	0.045	123	J-322	J-347	116.4	PVC	145
P-358	0.072	108	J-347	J-348	116.4	PVC	145
P-359	0.147	272	J-348	J-349	116.4	PVC	145
P-360	0.35	233	J-349	J-350	83.8	PVC	145
P-361	0.379	100	J-350	J-351	83.8	PVC	145
P-362	0.114	130	J-326	J-352	83.8	PVC	145
P-363	0.147	160	J-326	J-353	83.8	PVC	145
P-364	0.183	93	J-348	J-354	83.8	PVC	145
P-366	0.029	119	J-332	J-356	83.8	PVC	145
P-367	0.135	204	J-333	J-357	209.4	PVC	145
P-368	0.316	139	J-31	J-358	209.4	PVC	145
P-369	0.036	153	J-358	J-359	209.4	PVC	145
P-370	0.032	108	J-359	J-360	209.4	PVC	145
P-371	0.117	226	J-360	J-361	209.4	PVC	145
P-372	0.229	276	J-361	J-362	209.4	PVC	145
P-373	0.183	125	J-362	J-363	209.4	PVC	145
P-375	0.52	340	J-363	J-365	186.4	PVC	145
P-376	0.685	163	J-365	J-366	186.4	PVC	145
P-377	0.222	129	J-366	J-367	186.4	PVC	145
P-378	0.091	200	J-367	J-368	83.8	PVC	145
P-379	0.224	290	J-368	J-369	83.8	PVC	145
P-380	0.132	52	J-367	J-370	186.4	PVC	145
P-381	0	173	J-370	J-371	186.4	PVC	145
P-382	0.395	185	J-371	J-372	186.4	PVC	145
P-383	0.495	178	J-372	J-373	116.4	PVC	145
P-384	0.492	183	J-373	J-374	116.4	PVC	145
P-385	0.736	275	J-374	J-375	116.4	PVC	145
P-386	0.722	241	J-375	J-376	83.8	PVC	145
P-387	0.36	189	J-376	J-377	83.8	PVC	145
P-388	0.158	105	J-371	J-378	83.8	PVC	145
P-389	0.143	83	J-374	J-379	83.8	PVC	145
P-390	0.113	107	J-375	J-380	83.8	PVC	145
P-391	0.146	73	J-357	J-381	209.4	PVC	145
P-392	0.276	169	J-381	J-382	209.4	PVC	145
P-393	0.351	139	J-382	J-383	209.4	PVC	145
P-394	0.353	171	J-383	J-384	209.4	PVC	145
P-395	0.304	96	J-384	J-385	209.4	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-396	0.385	125	J-385	J-386	83.8	PVC	145
P-397	0.142	220	J-385	J-387	209.4	PVC	145
P-398	0.212	128	J-387	J-388	209.4	PVC	145
P-399	0.148	116	J-388	J-389	209.4	PVC	145
P-400	0.126	91	J-389	J-390	209.4	PVC	145
P-401	0.26	96	J-390	J-391	209.4	PVC	145
P-402	0.123	30	J-391	J-392	209.4	PVC	145
P-403	0.082	28	J-392	J-393	209.4	PVC	145
P-404	0.05	54	J-393	J-394	209.4	PVC	145
P-405	0.129	92	J-394	J-395	209.4	PVC	145
P-406	0.096	65	J-395	J-396	209.4	PVC	145
P-407	0.129	111	J-390	J-397	83.8	PVC	145
P-408	0.067	77	J-391	J-398	83.8	PVC	145
P-409	0.047	131	J-390	J-399	83.8	PVC	145
P-410	0.08	77	J-392	J-400	83.8	PVC	145
P-411	0.047	66	J-394	J-401	83.8	PVC	145
P-412	0.04	147	J-396	J-402	209.4	PVC	145
P-413	0.229	151	J-402	J-403	209.4	PVC	145
P-414	0.217	143	J-403	J-404	186.4	PVC	145
P-415	0.161	63	J-403	J-405	83.8	PVC	145
P-416	0.095	94	J-405	J-406	83.8	PVC	145
P-417	0.057	80	J-402	J-407	83.8	PVC	145
P-418	0.048	121	J-404	J-408	186.4	PVC	145
P-419	0.16	143	J-408	J-409	186.4	PVC	145
P-420	0.159	119	J-409	J-410	186.4	PVC	145
P-421	0.129	108	J-410	J-411	186.4	PVC	145
P-422	0.134	148	J-411	J-412	186.4	PVC	145
P-423	0.167	171	J-412	J-413	186.4	PVC	145
P-424	0.159	133	J-413	J-414	186.4	PVC	145
P-425	0.123	101	J-414	J-415	186.4	PVC	145
P-426	0.184	155	J-415	J-416	186.4	PVC	145
P-427	0.158	146	J-416	J-417	186.4	PVC	145
P-428	0.142	124	J-417	J-418	186.4	PVC	145
P-429	0.102	71	J-418	J-419	186.4	PVC	145
P-430	0.083	87	J-419	J-420	186.4	PVC	145
P-431	0.109	122	J-420	J-421	186.4	PVC	145
P-432	0.109	97	J-421	J-422	186.4	PVC	145
P-433	0.083	78	J-422	J-423	186.4	PVC	145
P-434	0.098	130	J-423	J-424	186.4	PVC	145
P-435	0.145	178	J-424	J-425	186.4	PVC	145
P-436	0.125	87	J-425	J-426	116.4	PVC	145
P-437	0.206	147	J-426	J-427	116.4	PVC	145

Label	Demand (L/s)	Length (Scaled) (m)	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C
P-438	0.227	190	J-427	J-428	116.4	PVC	145
P-439	0.152	131	J-428	J-429	83.8	PVC	145
P-440	0.121	125	J-429	J-430	83.8	PVC	145
P-441	0.103	93	J-430	J-431	83.8	PVC	145
P-442	0.078	71	J-431	J-432	83.8	PVC	145
P-443	0.108	157	J-432	J-433	83.8	PVC	145
P-444	0.074	145	J-427	J-434	116.4	PVC	145
P-445	0.137	145	J-434	J-435	116.4	PVC	145
P-446	0.123	116	J-435	J-436	116.4	PVC	145
P-447	0.112	122	J-436	J-437	116.4	PVC	145
P-448	0.121	134	J-437	J-438	116.4	PVC	145
P-449	0.126	133	J-438	J-439	116.4	PVC	145
P-450	0.127	135	J-439	J-440	116.4	PVC	145
P-451	0.113	104	J-440	J-441	83.8	PVC	145
P-452	0.101	109	J-441	J-442	83.8	PVC	145
P-453	0.117	139	J-442	J-443	83.8	PVC	145
P-454	0.124	122	J-443	J-444	83.8	PVC	145
P-455	0.116	124	J-444	J-445	83.8	PVC	145
P-456	0.058	201	J-426	J-446	83.8	PVC	145
P-457	0.138	90	J-446	J-447	83.8	PVC	145
P-458	0.043	93	J-415	J-448	83.8	PVC	145
P-463	0.049	111	J-323	J-345	116.4	PVC	145

ANNEXURE-2

Output Parameters for hydraulic analysis.

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-1	R-1	J-1	293.6	PVC	145	87.04	1.29	0.005	0.35	19.65
P-2	J-1	J-2	293.6	PVC	145	86.471	1.28	0.004	0.3	19.35
P-3	J-1	J-3	83.8	PVC	145	0.146	0.03	0	0	19.65
P-4	J-2	J-4	293.6	PVC	145	53.707	0.79	0.002	0.15	19.2
P-5	J-4	J-5	293.6	PVC	145	53.049	0.78	0.002	0.28	18.92
P-6	J-5	J-6	293.6	PVC	145	52.58	0.78	0.002	0.39	18.53
P-7	J-6	J-7	293.6	PVC	145	50.59	0.75	0.002	0.11	18.41
P-8	J-7	J-8	293.6	PVC	145	50.396	0.74	0.002	0.14	18.27
P-9	J-8	J-9	293.6	PVC	145	50.254	0.74	0.002	0.12	18.15
P-10	J-9	J-10	293.6	PVC	145	50.165	0.74	0.002	0.19	17.96
P-11	J-10	J-11	293.6	PVC	145	50.064	0.74	0.002	0.17	17.8
P-12	J-11	J-12	293.6	PVC	145	49.97	0.74	0.002	0.16	17.64
P-13	J-12	J-13	293.6	PVC	145	49.839	0.74	0.002	0.29	17.34
P-18	J-17	J-18	209.4	PVC	145	8.87	0.26	0	0.25	15.61
P-20	J-13	J-20	293.6	PVC	145	30.878	0.46	0.001	0.08	17.27
P-21	J-20	J-21	293.6	PVC	145	30.78	0.45	0.001	0.06	17.21
P-22	J-21	J-22	293.6	PVC	145	26.994	0.4	0.001	0.16	17.05
P-23	J-22	J-23	293.6	PVC	145	26.782	0.4	0.001	0.03	17.01
P-26	J-25	J-26	209.4	PVC	145	25.674	0.75	0.002	0.38	16.24
P-27	J-26	J-27	209.4	PVC	145	25.438	0.74	0.002	0.53	15.71
P-28	J-27	J-28	209.4	PVC	145	25.154	0.73	0.002	0.55	15.16
P-29	J-28	J-29	209.4	PVC	145	24.913	0.72	0.002	0.36	14.81
P-30	J-29	J-30	209.4	PVC	145	24.451	0.71	0.002	0.18	14.62
P-31	J-30	J-31	209.4	PVC	145	24.366	0.71	0.002	0.61	14.01
P-32	J-31	J-32	209.4	PVC	145	18.065	0.52	0.001	0.18	13.83
P-33	J-32	J-33	209.4	PVC	145	18.016	0.52	0.001	0.33	13.5
P-34	J-33	J-34	209.4	PVC	145	17.947	0.52	0.001	0.38	13.12
P-35	J-34	J-35	209.4	PVC	145	17.842	0.52	0.001	0.27	12.85
P-36	J-35	J-36	209.4	PVC	145	17.696	0.51	0.001	0.31	12.54
P-37	J-36	J-37	209.4	PVC	145	17.525	0.51	0.001	0.36	12.19
P-38	J-37	J-38	209.4	PVC	145	17.346	0.5	0.001	0.33	11.86
P-39	J-38	J-39	209.4	PVC	145	17.175	0.5	0.001	0.32	11.54
P-52	J-23	J-25	209.4	PVC	145	25.872	0.75	0.002	0.39	16.62
P-53	J-14	J-52	209.4	PVC	145	18.456	0.54	0.001	0.11	16.93
P-54	J-52	J-15	209.4	PVC	145	17.666	0.51	0.001	0.26	16.67
P-55	J-52	J-53	116.4	PVC	145	0.603	0.06	0	0	16.93
P-56	J-53	J-54	83.8	PVC	145	0.354	0.06	0	0.02	16.91

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-57	J-54	J-55	83.8	PVC	145	0.093	0.02	0	0	16.91
P-58	J-54	J-56	83.8	PVC	145	0.038	0.01	0	0	16.91
P-59	J-53	J-57	83.8	PVC	145	0.054	0.01	0	0	16.93
P-60	J-15	J-58	209.4	PVC	145	17.449	0.51	0.001	0.3	16.37
P-61	J-58	J-16	209.4	PVC	145	17.128	0.5	0.001	0.06	16.31
P-62	J-58	J-59	83.8	PVC	145	0.126	0.02	0	0	16.37
P-63	J-59	J-60	83.8	PVC	145	0.037	0.01	0	0	16.37
P-64	J-18	J-61	209.4	PVC	145	8.786	0.26	0	0.04	15.57
P-65	J-61	J-19	116.4	PVC	145	1.83	0.17	0	0.04	15.53
P-66	J-61	J-62	186.4	PVC	145	5.102	0.19	0	0.03	15.55
P-67	J-62	J-63	186.4	PVC	145	4.99	0.18	0	0.02	15.53
P-68	J-63	J-64	186.4	PVC	145	4.89	0.18	0	0.03	15.5
P-69	J-64	J-65	186.4	PVC	145	4.835	0.18	0	0.08	15.42
P-70	J-62	J-66	83.8	PVC	145	0.088	0.02	0	0	15.55
P-71	J-66	J-67	83.8	PVC	145	0.012	0	0	0	15.55
P-72	J-66	J-68	83.8	PVC	145	0.015	0	0	0	15.55
P-73	J-66	J-69	83.8	PVC	145	0.021	0	0	0	15.55
P-74	J-69	J-70	83.8	PVC	145	0.005	0	0	0	15.55
P-75	J-63	J-71	83.8	PVC	145	0.021	0	0	0	15.53
P-76	J-71	J-72	83.8	PVC	145	0.007	0	0	0	15.53
P-77	J-63	J-73	83.8	PVC	145	0.039	0.01	0	0	15.53
P-78	J-73	J-74	83.8	PVC	145	0.007	0	0	0	15.53
P-79	J-73	J-75	83.8	PVC	145	0.007	0	0	0	15.53
P-81	J-65	J-77	116.4	PVC	145	1.416	0.13	0	0.03	15.39
P-82	J-77	J-78	116.4	PVC	145	0.815	0.08	0	0.01	15.38
P-83	J-78	J-79	83.8	PVC	145	0.469	0.09	0	0.01	15.38
P-84	J-77	J-80	83.8	PVC	145	0.375	0.07	0	0.01	15.38
P-85	J-80	J-81	83.8	PVC	145	0.119	0.02	0	0	15.38
P-86	J-78	J-82	83.8	PVC	145	0.115	0.02	0	0	15.38
P-88	J-79	J-84	83.8	PVC	145	0.348	0.06	0	0.01	15.37
P-89	J-84	J-85	83.8	PVC	145	0.134	0.02	0	0	15.37
P-90	J-65	J-86	186.4	PVC	145	3.353	0.12	0	0.01	15.41
P-91	J-86	J-87	186.4	PVC	145	3.261	0.12	0	0.01	15.4
P-92	J-87	J-88	83.8	PVC	145	0.338	0.06	0	0.01	15.39
P-93	J-87	J-89	116.4	PVC	145	2.704	0.25	0.001	0.02	15.38
P-94	J-89	J-90	116.4	PVC	145	2.19	0.21	0	0.02	15.36
P-95	J-90	J-91	116.4	PVC	145	1.834	0.17	0	0.02	15.34
P-96	J-91	J-92	116.4	PVC	145	1.147	0.11	0	0.03	15.31
P-98	J-92	J-94	116.4	PVC	145	0.73	0.07	0	0.01	15.3
P-99	J-94	J-95	83.8	PVC	145	0.254	0.05	0	0.01	15.29
P-100	J-90	J-96	83.8	PVC	145	0.13	0.02	0	0	15.36
P-101	J-89	J-97	83.8	PVC	145	0.225	0.04	0	0.01	15.37

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-102	J-16	J-98	209.4	PVC	145	16.963	0.49	0.001	0.34	15.97
P-103	J-98	J-17	209.4	PVC	145	9.077	0.26	0	0.1	15.86
P-104	J-98	J-99	209.4	PVC	145	7.539	0.22	0	0.04	15.93
P-105	J-99	J-100	209.4	PVC	145	7.295	0.21	0	0.04	15.88
P-106	J-100	J-101	209.4	PVC	145	6.994	0.2	0	0.03	15.85
P-107	J-101	J-102	209.4	PVC	145	6.773	0.2	0	0.02	15.83
P-108	J-102	J-103	209.4	PVC	145	6.473	0.19	0	0.04	15.79
P-109	J-103	J-104	209.4	PVC	145	6.075	0.18	0	0.03	15.76
P-110	J-104	J-105	209.4	PVC	145	5.754	0.17	0	0.02	15.74
P-111	J-105	J-106	209.4	PVC	145	5.567	0.16	0	0.01	15.73
P-112	J-106	J-107	186.4	PVC	145	5.145	0.19	0	0.05	15.68
P-113	J-107	J-108	186.4	PVC	145	4.58	0.17	0	0.02	15.65
P-114	J-108	J-109	186.4	PVC	145	2.903	0.11	0	0.02	15.64
P-115	J-109	J-110	116.4	PVC	145	2.456	0.23	0.001	0.12	15.51
P-116	J-110	J-111	116.4	PVC	145	2.147	0.2	0	0.05	15.47
P-117	J-111	J-112	116.4	PVC	145	1.933	0.18	0	0.04	15.42
P-118	J-112	J-113	116.4	PVC	145	1.689	0.16	0	0.04	15.39
P-119	J-113	J-114	116.4	PVC	145	1.338	0.13	0	0.04	15.34
P-120	J-114	J-115	116.4	PVC	145	0.905	0.09	0	0.02	15.33
P-124	J-115	J-119	83.8	PVC	145	0.133	0.02	0	0	15.32
P-126	J-115	J-121	83.8	PVC	145	0.306	0.06	0	0.01	15.32
P-127	J-121	J-122	83.8	PVC	145	0.092	0.02	0	0	15.32
P-128	J-108	J-123	116.4	PVC	145	1.251	0.12	0	0.01	15.64
P-129	J-123	J-124	116.4	PVC	145	1.143	0.11	0	0.01	15.63
P-130	J-124	J-125	116.4	PVC	145	0.845	0.08	0	0.01	15.62
P-131	J-125	J-126	83.8	PVC	145	0.4	0.07	0	0.01	15.61
P-132	J-126	J-127	83.8	PVC	145	0.339	0.06	0	0	15.61
P-133	J-127	J-128	83.8	PVC	145	0.149	0.03	0	0	15.6
P-134	J-128	J-129	83.8	PVC	145	0.077	0.01	0	0	15.6
P-135	J-129	J-130	83.8	PVC	145	0.028	0.01	0	0	15.6
P-136	J-127	J-131	83.8	PVC	145	0.061	0.01	0	0	15.61
P-137	J-124	J-132	83.8	PVC	145	0.184	0.03	0	0	15.63
P-138	J-132	J-133	83.8	PVC	145	0.113	0.02	0	0	15.63
P-139	J-133	J-134	83.8	PVC	145	0.041	0.01	0	0	15.63
P-140	J-107	J-135	83.8	PVC	145	0.142	0.03	0	0	15.68
P-141	J-135	J-136	83.8	PVC	145	0.029	0.01	0	0	15.68
P-142	J-125	J-137	83.8	PVC	145	0.322	0.06	0	0.01	15.61
P-143	J-137	J-138	83.8	PVC	145	0.251	0.05	0	0	15.61
P-144	J-138	J-139	83.8	PVC	145	0.056	0.01	0	0	15.61
P-145	J-138	J-140	83.8	PVC	145	0.056	0.01	0	0	15.61
P-146	J-106	J-141	83.8	PVC	145	0.071	0.01	0	0	15.73
P-147	J-2	J-142	293.6	PVC	145	31.16	0.46	0.001	0.12	19.23

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-148	J-142	J-143	293.6	PVC	145	30.707	0.45	0.001	0.12	19.11
P-149	J-143	J-144	293.6	PVC	145	30.261	0.45	0.001	0.11	19
P-150	J-144	J-145	293.6	PVC	145	28.229	0.42	0.001	0.08	18.92
P-151	J-145	J-146	293.6	PVC	145	27.87	0.41	0.001	0.08	18.84
P-152	J-146	J-147	209.4	PVC	145	27.339	0.79	0.003	0.78	18.07
P-153	J-147	J-148	209.4	PVC	145	26.723	0.78	0.003	0.55	17.52
P-154	J-148	J-149	209.4	PVC	145	26.323	0.76	0.003	0.28	17.24
P-155	J-149	J-150	209.4	PVC	145	25.038	0.73	0.002	0.41	16.82
P-156	J-150	J-151	209.4	PVC	145	24.564	0.71	0.002	0.45	16.37
P-157	J-151	J-152	209.4	PVC	145	24.099	0.7	0.002	0.37	16
P-158	J-152	J-153	209.4	PVC	145	23.606	0.69	0.002	0.28	15.72
P-159	J-153	J-154	209.4	PVC	145	22.469	0.65	0.002	0.42	15.31
P-160	J-154	J-155	209.4	PVC	145	22.14	0.64	0.002	0.34	14.96
P-161	J-155	J-156	209.4	PVC	145	21.481	0.62	0.002	0.37	14.59
P-162	J-156	J-157	209.4	PVC	145	20.898	0.61	0.002	0.22	14.37
P-163	J-157	J-158	209.4	PVC	145	20.813	0.6	0.002	0.23	14.14
P-164	J-158	J-159	209.4	PVC	145	20.548	0.6	0.002	0.26	13.88
P-165	J-159	J-160	209.4	PVC	145	20.11	0.58	0.002	0.27	13.6
P-166	J-160	J-161	209.4	PVC	145	19.991	0.58	0.002	0.3	13.3
P-167	J-161	J-162	209.4	PVC	145	19.883	0.58	0.002	0.22	13.08
P-168	J-162	J-163	209.4	PVC	145	19.801	0.57	0.002	0.18	12.9
P-169	J-163	J-164	209.4	PVC	145	19.521	0.57	0.001	0.1	12.81
P-170	J-164	J-165	209.4	PVC	145	17.964	0.52	0.001	0.09	12.71
P-172	J-166	J-167	209.4	PVC	145	16.3	0.47	0.001	0.03	12.43
P-173	J-167	J-168	209.4	PVC	145	15.387	0.45	0.001	0.15	12.28
P-174	J-168	J-169	209.4	PVC	145	14.309	0.42	0.001	0.11	12.17
P-175	J-169	J-170	209.4	PVC	145	13.574	0.39	0.001	0.07	12.1
P-176	J-170	J-171	209.4	PVC	145	13.021	0.38	0.001	0.09	12
P-177	J-171	J-172	209.4	PVC	145	12.629	0.37	0.001	0.1	11.91
P-178	J-172	J-173	209.4	PVC	145	12.301	0.36	0.001	0.05	11.85
P-180	J-174	J-175	209.4	PVC	145	9.657	0.28	0	0.06	11.69
P-181	J-175	J-176	83.8	PVC	145	0.457	0.08	0	0.02	11.68
P-184	J-175	J-179	209.4	PVC	145	8.685	0.25	0	0.03	11.66
P-185	J-179	J-180	209.4	PVC	145	7.867	0.23	0	0.05	11.61
P-186	J-180	J-181	209.4	PVC	145	7.375	0.21	0	0.04	11.57
P-187	J-181	J-182	209.4	PVC	145	6.844	0.2	0	0.04	11.53
P-188	J-182	J-183	83.8	PVC	145	0.169	0.03	0	0	11.53
P-190	J-182	J-185	83.8	PVC	145	0.162	0.03	0	0	11.53
P-191	J-182	J-186	209.4	PVC	145	5.676	0.16	0	0.02	11.51
P-192	J-186	J-187	186.4	PVC	145	5.238	0.19	0	0.04	11.47
P-193	J-187	J-188	186.4	PVC	145	4.947	0.18	0	0.02	11.45
P-194	J-188	J-189	186.4	PVC	145	4.44	0.16	0	0.02	11.44

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-195	J-189	J-190	186.4	PVC	145	4.269	0.16	0	0.02	11.42
P-196	J-190	J-191	186.4	PVC	145	4.084	0.15	0	0.02	11.4
P-197	J-191	J-192	186.4	PVC	145	3.314	0.12	0	0.01	11.4
P-198	J-192	J-193	186.4	PVC	145	2.754	0.1	0	0.01	11.39
P-199	J-193	J-194	116.4	PVC	145	2.568	0.24	0.001	0.07	11.32
P-200	J-194	J-195	116.4	PVC	145	2.367	0.22	0.001	0.07	11.26
P-201	J-195	J-196	83.8	PVC	145	0.108	0.02	0	0	11.26
P-202	J-195	J-197	116.4	PVC	145	1.905	0.18	0	0.06	11.2
P-203	J-197	J-198	116.4	PVC	145	1.628	0.15	0	0.04	11.16
P-204	J-198	J-199	116.4	PVC	145	1.358	0.13	0	0.03	11.13
P-205	J-199	J-200	116.4	PVC	145	1.137	0.11	0	0.01	11.12
P-206	J-200	J-201	116.4	PVC	145	0.895	0.08	0	0.02	11.1
P-207	J-201	J-202	116.4	PVC	145	0.595	0.06	0	0.01	11.09
P-208	J-202	J-203	83.8	PVC	145	0.397	0.07	0	0.01	11.09
P-209	J-203	J-204	83.8	PVC	145	0.282	0.05	0	0	11.08
P-210	J-204	J-205	83.8	PVC	145	0.109	0.02	0	0	11.08
P-211	J-192	J-206	83.8	PVC	145	0.21	0.04	0	0.01	11.39
P-212	J-191	J-207	83.8	PVC	145	0.488	0.09	0	0.02	11.38
P-213	J-207	J-208	83.8	PVC	145	0.176	0.03	0	0	11.38
P-215	J-188	J-210	83.8	PVC	145	0.333	0.06	0	0	11.45
P-216	J-210	J-211	83.8	PVC	145	0.086	0.02	0	0	11.45
P-217	J-210	J-212	83.8	PVC	145	0.068	0.01	0	0	11.45
P-218	J-179	J-213	83.8	PVC	145	0.218	0.04	0	0	11.66
P-219	J-176	J-214	83.8	PVC	145	0.138	0.03	0	0	11.68
P-220	J-174	J-215	83.8	PVC	145	0.189	0.03	0	0	11.75
P-221	J-173	J-216	83.8	PVC	145	0.222	0.04	0	0.01	11.85
P-222	J-173	J-217	209.4	PVC	145	11.654	0.34	0.001	0.04	11.82
P-223	J-217	J-174	209.4	PVC	145	10.437	0.3	0	0.06	11.75
P-224	J-217	J-218	116.4	PVC	145	0.714	0.07	0	0.01	11.81
P-225	J-218	J-219	83.8	PVC	145	0.104	0.02	0	0	11.81
P-226	J-218	J-220	83.8	PVC	145	0.14	0.03	0	0	11.81
P-227	J-168	J-221	83.8	PVC	145	0.289	0.05	0	0.01	12.27
P-228	J-167	J-222	83.8	PVC	145	0.267	0.05	0	0.01	12.43
P-229	J-165	J-223	209.4	PVC	145	17.38	0.5	0.001	0.13	12.58
P-230	J-223	J-166	209.4	PVC	145	16.577	0.48	0.001	0.12	12.46
P-231	J-223	J-224	83.8	PVC	145	0.188	0.03	0	0	12.58
P-232	J-164	J-225	116.4	PVC	145	1.095	0.1	0	0.02	12.79
P-233	J-225	J-226	83.8	PVC	145	0.4	0.07	0	0.02	12.77
P-234	J-165	J-227	83.8	PVC	145	0.113	0.02	0	0	12.71
P-235	J-163	J-228	83.8	PVC	145	0.209	0.04	0	0	12.9
P-236	J-228	J-229	83.8	PVC	145	0.057	0.01	0	0	12.9
P-237	J-228	J-230	83.8	PVC	145	0.041	0.01	0	0	12.9

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-238	J-169	J-231	83.8	PVC	145	0.208	0.04	0	0	12.17
P-239	J-170	J-232	83.8	PVC	145	0.116	0.02	0	0	12.09
P-240	J-158	J-233	83.8	PVC	145	0.104	0.02	0	0	14.14
P-241	J-159	J-234	83.8	PVC	145	0.237	0.04	0	0.01	13.87
P-242	J-234	J-235	83.8	PVC	145	0.148	0.03	0	0	13.87
P-244	J-153	J-237	83.8	PVC	145	0.488	0.09	0	0.03	15.69
P-245	J-237	J-238	83.8	PVC	145	0.148	0.03	0	0	15.69
P-246	J-149	J-239	83.8	PVC	145	0.461	0.08	0	0.03	17.21
P-248	J-21	J-241	186.4	PVC	145	3.504	0.13	0	0.02	17.18
P-249	J-241	J-242	186.4	PVC	145	3.356	0.12	0	0.01	17.17
P-250	J-242	J-243	186.4	PVC	145	3.27	0.12	0	0.01	17.17
P-251	J-243	J-244	186.4	PVC	145	3.084	0.11	0	0.01	17.15
P-252	J-244	J-245	186.4	PVC	145	2.864	0.1	0	0	17.15
P-254	J-246	J-247	116.4	PVC	145	1.621	0.15	0	0.03	17.06
P-255	J-247	J-248	83.8	PVC	145	0.241	0.04	0	0.01	17.05
P-256	J-245	J-249	116.4	PVC	145	2.439	0.23	0.001	0.03	17.12
P-257	J-249	J-246	116.4	PVC	145	2.039	0.19	0	0.03	17.09
P-258	J-249	J-250	83.8	PVC	145	0.114	0.02	0	0	17.12
P-259	J-247	J-251	116.4	PVC	145	1.057	0.1	0	0.01	17.05
P-260	J-251	J-252	116.4	PVC	145	0.783	0.07	0	0.01	17.04
P-261	J-252	J-253	83.8	PVC	145	0.445	0.08	0	0.01	17.03
P-262	J-253	J-254	83.8	PVC	145	0.15	0.03	0	0	17.03
P-263	J-246	J-255	83.8	PVC	145	0.16	0.03	0	0	17.09
P-264	J-245	J-256	83.8	PVC	145	0.143	0.03	0	0	17.15
P-265	J-144	J-257	116.4	PVC	145	1.495	0.14	0	0.02	18.98
P-266	J-257	J-258	116.4	PVC	145	1.013	0.1	0	0.01	18.97
P-267	J-258	J-259	116.4	PVC	145	0.714	0.07	0	0	18.97
P-268	J-257	J-260	83.8	PVC	145	0.139	0.03	0	0	18.98
P-269	J-258	J-261	83.8	PVC	145	0.066	0.01	0	0	18.97
P-270	J-2	J-262	116.4	PVC	145	1	0.09	0	0.02	19.33
P-271	J-262	J-263	83.8	PVC	145	0.211	0.04	0	0	19.33
P-272	J-4	J-264	83.8	PVC	145	0.179	0.03	0	0	19.19
P-273	J-262	J-265	83.8	PVC	145	0.192	0.03	0	0	19.33
P-274	J-259	J-266	83.8	PVC	145	0.162	0.03	0	0	18.97
P-275	J-259	J-267	83.8	PVC	145	0.144	0.03	0	0	18.97
P-276	J-6	J-268	83.8	PVC	145	0.085	0.02	0	0	18.53
P-277	J-6	J-269	116.4	PVC	145	1.313	0.12	0	0.02	18.51
P-278	J-269	J-270	83.8	PVC	145	0.434	0.08	0	0.02	18.49
P-279	J-269	J-271	83.8	PVC	145	0.072	0.01	0	0	18.51
P-280	J-269	J-272	83.8	PVC	145	0.307	0.06	0	0	18.5
P-281	J-272	J-273	83.8	PVC	145	0.106	0.02	0	0	18.5
P-282	J-270	J-274	83.8	PVC	145	0.124	0.02	0	0	18.49

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-283	J-235	J-275	83.8	PVC	145	0.089	0.02	0	0	13.87
P-284	J-275	J-236	83.8	PVC	145	0.019	0	0	0	13.87
P-285	J-275	J-276	83.8	PVC	145	0.018	0	0	0	13.87
P-286	J-233	J-277	83.8	PVC	145	0.02	0	0	0	14.14
P-287	J-155	J-278	83.8	PVC	145	0.134	0.02	0	0	14.96
P-288	J-156	J-279	83.8	PVC	145	0.268	0.05	0	0	14.58
P-289	J-279	J-280	83.8	PVC	145	0.046	0.01	0	0	14.58
P-290	J-279	J-281	83.8	PVC	145	0.073	0.01	0	0	14.58
P-291	J-159	J-282	83.8	PVC	145	0.025	0	0	0	13.88
P-292	J-91	J-283	83.8	PVC	145	0.274	0.05	0	0.01	15.33
P-293	J-283	J-284	83.8	PVC	145	0.061	0.01	0	0	15.33
P-295	J-88	J-286	83.8	PVC	145	0.114	0.02	0	0	15.39
P-296	J-23	J-287	116.4	PVC	145	0.683	0.06	0	0	17.01
P-297	J-287	J-288	83.8	PVC	145	0.531	0.1	0	0.03	16.98
P-298	J-288	J-289	83.8	PVC	145	0.084	0.02	0	0	16.98
P-299	J-288	J-290	83.8	PVC	145	0.136	0.02	0	0	16.97
P-300	J-13	J-291	209.4	PVC	145	18.768	0.54	0.001	0.16	17.18
P-301	J-291	J-14	209.4	PVC	145	18.542	0.54	0.001	0.14	17.04
P-302	J-291	J-292	83.8	PVC	145	0.061	0.01	0	0	17.18
P-303	J-29	J-293	83.8	PVC	145	0.157	0.03	0	0	14.8
P-322	J-39	J-312	209.4	PVC	145	17.019	0.49	0.001	0.26	11.28
P-323	J-312	J-313	209.4	PVC	145	16.917	0.49	0.001	0.11	11.17
P-324	J-313	J-314	209.4	PVC	145	16.827	0.49	0.001	0.21	10.96
P-325	J-314	J-315	209.4	PVC	145	16.74	0.49	0.001	0.1	10.86
P-326	J-315	J-316	209.4	PVC	145	16.653	0.48	0.001	0.2	10.65
P-327	J-316	J-317	209.4	PVC	145	16.56	0.48	0.001	0.12	10.53
P-328	J-317	J-318	209.4	PVC	145	16.461	0.48	0.001	0.22	10.31
P-329	J-318	J-319	209.4	PVC	145	16.329	0.47	0.001	0.23	10.08
P-330	J-319	J-320	209.4	PVC	145	16.207	0.47	0.001	0.18	9.9
P-331	J-320	J-321	209.4	PVC	145	16.079	0.47	0.001	0.24	9.66
P-332	J-321	J-322	209.4	PVC	145	15.926	0.46	0.001	0.26	9.4
P-333	J-322	J-323	209.4	PVC	145	14.677	0.43	0.001	0.11	9.29
P-334	J-323	J-324	209.4	PVC	145	13.903	0.4	0.001	0.21	9.09
P-335	J-324	J-325	209.4	PVC	145	13.536	0.39	0.001	0.19	8.9
P-336	J-325	J-326	209.4	PVC	145	13.195	0.38	0.001	0.03	8.87
P-337	J-326	J-327	209.4	PVC	145	12.321	0.36	0.001	0.09	8.78
P-338	J-327	J-328	209.4	PVC	145	12.038	0.35	0.001	0.07	8.71
P-339	J-328	J-329	209.4	PVC	145	11.675	0.34	0.001	0.12	8.59
P-340	J-329	J-330	209.4	PVC	145	11.202	0.33	0.001	0.11	8.49
P-341	J-330	J-331	209.4	PVC	145	10.745	0.31	0	0.09	8.39
P-342	J-331	J-332	209.4	PVC	145	10.365	0.3	0	0.06	8.33
P-343	J-332	J-333	209.4	PVC	145	9.891	0.29	0	0.02	8.31

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-351	J-340	J-341	83.8	PVC	145	-0.156	0.03	0	0	9.26
P-352	J-341	J-342	83.8	PVC	145	-0.265	0.05	0	0.01	9.27
P-353	J-342	J-343	83.8	PVC	145	-0.38	0.07	0	0.01	9.28
P-354	J-340	J-344	83.8	PVC	145	0.055	0.01	0	0	9.26
P-355	J-343	J-345	116.4	PVC	145	-0.553	0.05	0	0	9.29
P-356	J-343	J-346	83.8	PVC	145	0.045	0.01	0	0	9.28
P-357	J-322	J-347	116.4	PVC	145	1.092	0.1	0	0.02	9.39
P-358	J-347	J-348	116.4	PVC	145	1.02	0.1	0	0.01	9.37
P-359	J-348	J-349	116.4	PVC	145	0.844	0.08	0	0.02	9.35
P-360	J-349	J-350	83.8	PVC	145	0.494	0.09	0	0.03	9.32
P-361	J-350	J-351	83.8	PVC	145	0.114	0.02	0	0	9.32
P-362	J-326	J-352	83.8	PVC	145	0.147	0.03	0	0	8.86
P-363	J-326	J-353	83.8	PVC	145	0.183	0.03	0	0	8.86
P-364	J-348	J-354	83.8	PVC	145	0.029	0.01	0	0	9.37
P-366	J-332	J-356	83.8	PVC	145	0.135	0.02	0	0	8.33
P-367	J-333	J-357	209.4	PVC	145	9.613	0.28	0	0.08	8.23
P-368	J-31	J-358	209.4	PVC	145	6.231	0.18	0	0.02	13.99
P-369	J-358	J-359	209.4	PVC	145	6.195	0.18	0	0.03	13.96
P-370	J-359	J-360	209.4	PVC	145	6.163	0.18	0	0.02	13.94
P-371	J-360	J-361	209.4	PVC	145	6.047	0.18	0	0.04	13.9
P-372	J-361	J-362	209.4	PVC	145	5.817	0.17	0	0.04	13.86
P-373	J-362	J-363	209.4	PVC	145	5.634	0.16	0	0.02	13.84
P-375	J-363	J-365	186.4	PVC	145	5.114	0.19	0	0.07	13.77
P-376	J-365	J-366	186.4	PVC	145	4.429	0.16	0	0.03	13.74
P-377	J-366	J-367	186.4	PVC	145	4.207	0.15	0	0.02	13.72
P-378	J-367	J-368	83.8	PVC	145	0.356	0.06	0	0.02	13.71
P-379	J-368	J-369	83.8	PVC	145	0.132	0.02	0	0	13.7
P-380	J-367	J-370	186.4	PVC	145	3.759	0.14	0	0.01	13.71
P-381	J-370	J-371	186.4	PVC	145	3.759	0.14	0	0.02	13.69
P-382	J-371	J-372	186.4	PVC	145	3.222	0.12	0	0.02	13.68
P-383	J-372	J-373	116.4	PVC	145	2.727	0.26	0.001	0.12	13.56
P-384	J-373	J-374	116.4	PVC	145	2.235	0.21	0	0.08	13.47
P-385	J-374	J-375	116.4	PVC	145	1.386	0.13	0	0.05	13.42
P-386	J-375	J-376	83.8	PVC	145	0.518	0.09	0	0.04	13.38
P-387	J-376	J-377	83.8	PVC	145	0.158	0.03	0	0	13.38
P-388	J-371	J-378	83.8	PVC	145	0.143	0.03	0	0	13.69
P-389	J-374	J-379	83.8	PVC	145	0.113	0.02	0	0	13.47
P-390	J-375	J-380	83.8	PVC	145	0.146	0.03	0	0	13.42
P-391	J-357	J-381	209.4	PVC	145	9.297	0.27	0	0.03	8.2
P-392	J-381	J-382	209.4	PVC	145	9.021	0.26	0	0.06	8.14
P-393	J-382	J-383	209.4	PVC	145	8.671	0.25	0	0.05	8.1
P-394	J-383	J-384	209.4	PVC	145	8.318	0.24	0	0.05	8.05

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-395	J-384	J-385	209.4	PVC	145	8.014	0.23	0	0.03	8.02
P-396	J-385	J-386	83.8	PVC	145	0.142	0.03	0	0	8.02
P-397	J-385	J-387	209.4	PVC	145	7.486	0.22	0	0.05	7.96
P-398	J-387	J-388	209.4	PVC	145	7.275	0.21	0	0.03	7.93
P-399	J-388	J-389	209.4	PVC	145	7.126	0.21	0	0.03	7.91
P-400	J-389	J-390	209.4	PVC	145	7	0.2	0	0.02	7.89
P-401	J-390	J-391	209.4	PVC	145	6.593	0.19	0	0.02	7.87
P-402	J-391	J-392	209.4	PVC	145	6.423	0.19	0	0.01	7.86
P-403	J-392	J-393	209.4	PVC	145	6.294	0.18	0	0.01	7.86
P-404	J-393	J-394	209.4	PVC	145	6.244	0.18	0	0.01	7.85
P-405	J-394	J-395	209.4	PVC	145	6.075	0.18	0	0.02	7.83
P-406	J-395	J-396	209.4	PVC	145	5.979	0.17	0	0.01	7.82
P-407	J-390	J-397	83.8	PVC	145	0.067	0.01	0	0	7.89
P-408	J-391	J-398	83.8	PVC	145	0.047	0.01	0	0	7.87
P-409	J-390	J-399	83.8	PVC	145	0.08	0.01	0	0	7.89
P-410	J-392	J-400	83.8	PVC	145	0.047	0.01	0	0	7.86
P-411	J-394	J-401	83.8	PVC	145	0.04	0.01	0	0	7.85
P-412	J-396	J-402	209.4	PVC	145	5.85	0.17	0	0.02	7.8
P-413	J-402	J-403	209.4	PVC	145	5.572	0.16	0	0.02	7.78
P-414	J-403	J-404	186.4	PVC	145	5.203	0.19	0	0.03	7.75
P-415	J-403	J-405	83.8	PVC	145	0.152	0.03	0	0	7.78
P-416	J-405	J-406	83.8	PVC	145	0.057	0.01	0	0	7.78
P-417	J-402	J-407	83.8	PVC	145	0.048	0.01	0	0	7.8
P-418	J-404	J-408	186.4	PVC	145	5.042	0.18	0	0.03	7.72
P-419	J-408	J-409	186.4	PVC	145	4.882	0.18	0	0.03	7.69
P-420	J-409	J-410	186.4	PVC	145	4.722	0.17	0	0.02	7.67
P-421	J-410	J-411	186.4	PVC	145	4.594	0.17	0	0.02	7.65
P-422	J-411	J-412	186.4	PVC	145	4.459	0.16	0	0.02	7.63
P-423	J-412	J-413	186.4	PVC	145	4.292	0.16	0	0.03	7.6
P-424	J-413	J-414	186.4	PVC	145	4.133	0.15	0	0.02	7.58
P-425	J-414	J-415	186.4	PVC	145	4.01	0.15	0	0.01	7.57
P-426	J-415	J-416	186.4	PVC	145	3.778	0.14	0	0.02	7.55
P-427	J-416	J-417	186.4	PVC	145	3.62	0.13	0	0.02	7.53
P-428	J-417	J-418	186.4	PVC	145	3.478	0.13	0	0.01	7.52
P-429	J-418	J-419	186.4	PVC	145	3.376	0.12	0	0.01	7.51
P-430	J-419	J-420	186.4	PVC	145	3.293	0.12	0	0.01	7.5
P-431	J-420	J-421	186.4	PVC	145	3.184	0.12	0	0.01	7.49
P-432	J-421	J-422	186.4	PVC	145	3.074	0.11	0	0.01	7.48
P-433	J-422	J-423	186.4	PVC	145	2.992	0.11	0	0.01	7.48
P-434	J-423	J-424	186.4	PVC	145	2.894	0.11	0	0.01	7.47
P-435	J-424	J-425	186.4	PVC	145	2.748	0.1	0	0.01	7.45
P-436	J-425	J-426	116.4	PVC	145	2.623	0.25	0.001	0.05	7.4

Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen-Williams C	Flow (m/s)	Velocity (m/s)	Headloss Gradient (m/m)	Headloss (m)	Pressure (m)
P-437	J-426	J-427	116.4	PVC	145	2.238	0.21	0	0.07	7.33
P-438	J-427	J-428	116.4	PVC	145	0.635	0.06	0	0.01	7.32
P-439	J-428	J-429	83.8	PVC	145	0.483	0.09	0	0.02	7.3
P-440	J-429	J-430	83.8	PVC	145	0.362	0.07	0	0.01	7.29
P-441	J-430	J-431	83.8	PVC	145	0.259	0.05	0	0	7.29
P-442	J-431	J-432	83.8	PVC	145	0.182	0.03	0	0	7.29
P-443	J-432	J-433	83.8	PVC	145	0.074	0.01	0	0	7.29
P-444	J-427	J-434	116.4	PVC	145	1.375	0.13	0	0.03	7.3
P-445	J-434	J-435	116.4	PVC	145	1.238	0.12	0	0.02	7.28
P-446	J-435	J-436	116.4	PVC	145	1.115	0.1	0	0.01	7.27
P-447	J-436	J-437	116.4	PVC	145	1.003	0.09	0	0.01	7.25
P-448	J-437	J-438	116.4	PVC	145	0.882	0.08	0	0.01	7.24
P-449	J-438	J-439	116.4	PVC	145	0.756	0.07	0	0.01	7.23
P-450	J-439	J-440	116.4	PVC	145	0.629	0.06	0	0.01	7.23
P-451	J-440	J-441	83.8	PVC	145	0.516	0.09	0	0.02	7.21
P-452	J-441	J-442	83.8	PVC	145	0.415	0.08	0	0.01	7.2
P-453	J-442	J-443	83.8	PVC	145	0.298	0.05	0	0.01	7.19
P-454	J-443	J-444	83.8	PVC	145	0.175	0.03	0	0	7.19
P-455	J-444	J-445	83.8	PVC	145	0.058	0.01	0	0	7.19
P-456	J-426	J-446	83.8	PVC	145	0.18	0.03	0	0	7.39
P-457	J-446	J-447	83.8	PVC	145	0.043	0.01	0	0	7.39
P-458	J-415	J-448	83.8	PVC	145	0.049	0.01	0	0	7.57
P-463	J-323	J-345	116.4	PVC	145	0.619	0.06	0	0	9.29