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Potential of Greywater reuse and its effects on potable water demand management and downstream sewer network

Muhammad Ashfaque Rajput Abdul Hameed

United Arab Emirates University

College of Engineering

Department of Civil and Environmental Engineering

POTENTIAL OF GREYWATER REUSE AND ITS EFFECTS ON POTABLE WATER DEMAND MANAGEMENT AND DOWNSTREAM SEWER NETWORK

Muhammad Ashfaque Rajput Abdul Hameed

This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

Under the Supervision of Dr. Rezaul K. Chowdhury

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Declaration of Original Work

I, Muhammad Ashfaque Rajput, the undersigned, a graduate student at the United Arab Emirates University (UAEU) and the author of the thesis entitled *"Potential of Greywater Reuse and its Effects on Potable Water Demand Management and Downstream Sewer Network",* hereby, solemnly declare that this thesis is an original research work that has been done and prepared by me under the supervision of Dr. Rezaul K. Chowdhury, in the College of Engineering at UAEU. This work has not been previously formed as the basis for the award of any degree, diploma or similar title at this or any other university. The materials borrowed from other sources and included in my thesis have been properly cited and acknowledged.

Student's Signature ________________ Date ________________

Approval of the Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor (Committee Chair): Dr. Rezaul K. Chowdhury
   Title: Assistant Professor
   Department of Civil and Environmental Engineering
   College of Engineering

   Signature ____________ Date ____________

2) Member: Dr. Munjed Maraqa
   Title: Associate Professor
   Department of Civil and Environmental Engineering
   College of Engineering

   Signature ____________ Date ____________

3) Member (External Examiner): Professor Patrick Willems
   Title: Professor
   Department of Civil Engineering
   Faculty of Engineering, Katholieke Universiteit Leuven, Belgium
   Signature …………………………… Date 7/5./2015……………

This Master Thesis is accepted by:

Dean of the College of Engineering: Professor Mohsen Sherif

Signature ________________   Date ________________

Dean of the College of the Graduate Studies: Professor Nagi Wakim

Signature ________________   Date ________________

Abstract

The UAE's water demand is rapidly increasing because of population growth, infrastructure development, expansion of agricultural practices and for the desert greening policies. These circumstances force the country to depend on expansive desalinated water and made the country second largest desalination water producer in the world. It is essential to reduce the current water consumption rates by using efficient methods and conservation techniques. Greywater reuse is an effective and promising alternate to cope with this challenge. The study aimed to reduce the water consumption in the Emirate of Abu Dhabi by investigating the potential of greywater reuse. A field survey was carried out in a case study area in Al Ain which comprises of 100 traditional villa type houses. Each house occupies a plot area of 2050 m^2 and approximately two thirds of each plot is used for gardening and plantation. It was found that about 94% of residents in the comprises are using municipal water for home gardening. Analyses of water consumption data showed that about 80% of supplied water is used for outdoor activities and only 20% for indoor uses that goes to the sewer network. Statistical analysis of water consumption explored that the consumption is independent of family size. The EPANET software was used for hydraulic modelling of the existing water network. The simulation results specified that the recapture of greywater has positive impacts on the hydraulic performances of the water network. It was shown that greywater reuse has several advantages such as reduction of water demand by 10%, reduction in desalination plants' operation and maintenance cost, reduction in emission of greenhouse gases and energy uses. On the contrary, in addition to health risks from greywater, recapture of greywater may reduce the sewer flow and thereby increase the retention time of sludge in the sewer line. Outcomes of the study support that the Abu Dhabi Emirate has a great potential of greywater reuse and about 86% of residents were agreed to reuse it for their home gardens. However, for the installation of greywater scheme, residents expressed their interest on financial rebate from the government.

Keywords: Water consumption, greywater, hydraulic modeling, data analysis.

Title and Abstract (in Arabic)

إمكانية إعادة استخدام المياه الرمادية وآثارها المترتبة على المياه الصالحة للشرب وشبكة المياه

الطلب على المياه الصالحة للشرب في دولة الإمارات العربية المتحدة يتزايد بشكل متسارع وذلك بسبب الزيادة في الكثافة السكانية، وتطور البنية التحتية، و الزيادة في السلوكيات الزراعية و سياسات تخضير الصحراء. هذه الظروف أجبرت دولة الإمارات العربية المتحدة على التوسع في إنتاج المياه المحلاة وجعلتها من ضمن ثاني أكبر دولة في العالم من حيث إنتاج المياه المحلاة. ونتيجة لذلك يجب أن يحد من معدلات استهلاك المياه الحالية باستخدام أساليب فعالة و محافظة. وإن إعادة استخدام المياه الرمادية يعد من الأساليب الفعالة والواعدة للتعامل مع هذا التحدي. تهدف هذه الدراسة الى الحد من استهلاك المياه في إمارة أبوظبي من خلال التحقق من إمكانية إعادة استخدام المياه الرمادية. كبداية تم إجراء مسح ميداني لمئة منزل من نوع الفلل في مدينة العين. وقد وجد أن كل منزل يحتل مساحه 2050 متر مربع و مايقارب ثلثي هذه المساحة تستخدم للأغراض الزراعة و البستنة. فقد وجد أن 94 بالمئة من سكان المنطقة التي شملتها الدراسة يستخدمون المياه الصالحة للشرب لري الحدائق المنزلية. أظهرت تحليلات البيانات الاستهلاكية للمياه أن حوالي 80 بالمئة من مياه الشرب تستخدم للنشاطات الخارجية و 20 بالمئة فقط تستخدم في الأنشطة الداخلية التي تستخرج بواسطة أنابيب الصرف الصحي. إن من خلال التحليل الإحصائي لاستهلاك المياه وجد أن استهلاك المياه لا يعتمد على أعداد الأفراد بالأسرة الواحدة. فقد تم استخدام برنامج EPANET لتمثيل النموذج الهيدروليكي لشبكة المياه الحالية. نتائج المحاكاة أوضحت أن فصل المياه الرمادية عن شبكة المياه لها اثار إيجابية على الأداء الهيدروليكي للشبكة. فقد تبين أن إعادة استخدام المياه الرمادية لها العديد من المزايا الإيجابية مثل: الحد من الطلب على المياه بنسبة 10 بالمئة، تخفيض تكلفة تشغيل وصيانة محطات تحلية المياه، والحد من استهلاكات الطاقة و الغازات المسببة للاحتباس الحراري. بالإضافة للمخاطر الصحية الناجمة عن المياه الرمادية، فصل المياه الرمادية عن شبكة الصرف الصحي قد يؤدي لتقليل التدفق في الشبكة ومما يؤدي لزيادة وقت الاحتفاظ بالحمأة في خط الصرف الصحي. نتائج البحث قد دلت أن إمارة أبوظبي لديها إمكانيات كبيرة في مجال إعادة استخدام المياه الرمادية وحوالي 86 بالمئة من السكان قد أكدوا موافقتهم على إعادة استخدام المياه الرمادية لري حدائقهم المنزلية. وقد أعرب السكان عن اهتمامهم بالخصم المالي المقدم من الحكومة من أجل تركيب نظام معالجة المياه الرمادية.

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My special thanks to all my family members for their encouragement and moral supports throughout my career. I have no word to express my gratitude to them. I wish to thank the UAE University, the College of Engineering and Graduate Studies, Department of Civil and Environmental Engineering and the coordinator of the Civil Engineering Master Program for providing me the necessary facilities and supports throughout this research.

Finally, I would like to acknowledge that the thesis is completed with financial supports from the UAEU-NRF Research Project (31N135) awarded to my supervisor.

Dedication

To my beloved parents and family members

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List of Abbreviations

AADC: Al Ain Distribution Company

ADDC: Abu Dhabi Distribution Company

ADWEC: Abu Dhabi Water and Electricity Company

BOD: Biochemical Oxygen Demand

COD: Chemical Oxygen Demand

DAM: District Area Meter

EAD: Environment Agency Abu Dhabi

FOG: Fat, Oil and Grease

GHG: Greenhouse gas

GIS: Geographical Information System

L/day: Liters per day

Lpcd: Liters per capita per day

m: Meter

m/s: Meter Per Second

MG/day: Million Gallon per day

RSB: Regulation and Supervision Bureau

TSE: Treated Sewage Effluent

TSS: Total Suspended Solids

UAE: United Arab Emirates

UAEU: United Arab Emirates University

Chapter 1: Introduction

1.1 Background

Greywater is the domestic wastewater originates from shower tub, wash basin, ablution and laundry excluding toilet and kitchen sources. The reuse of greywater is increasing worldwide to curb the increasing water consumption because after appropriate treatments it is suitable for reuse for non-potable purposes. Greywater reuse has several economical and environmental benefits. Previous studies estimated that about 50% to 80% of domestic wastewater is greywater (Jamrah *et al.*, 2008). Treated greywater can be reused for several purposes such as lawn watering, agriculture and garden irrigation, groundwater recharging and toilet flushing. Therefore, greywater reuse approach can decrease the pressure on authorities for the production of costly desalinated water and the development of associated new infrastructures.

Greywater reuse has many advantages such as reduction of municipal water consumption, reduction of the need to construct large wastewater treatment plants and it helps to reduce the amount of discharged wastewater into the sea that is beneficial for aquatic environments. It can also save the operation and maintenance cost of the expensive desalination plants and the water distribution systems, but it has some drawbacks. If sewer lines are not properly designed to accommodate the reduction of sewer flows from greywater extraction, sewer pipelines experience dense sludge contents leading to solid deposition and sewer blockage and may create an overloading problem with the existing treatment plants. Further to this, there is also possibility of health issues of reuse of untreated greywater.

The United Arab Emirates (UAE) is located in the extreme arid zone and most parts of UAE landscape are desert, where water is a precious and scarce resource. The water resources have significant economic and social importance to the prosperity of any country. Despite challenges of water stress, water consumption statistics in UAE show that the municipal water consumption is more than triples the world average of 200 liter/capita/day (EAD, 2014). This provides a challenge to researchers and authorities to introduce water efficient management strategies and water conservation approaches to overcome this water consumption in the UAE.

The Abu Dhabi Emirate is located in the southern part of the Arabian Gulf and its territory area is about 67,340 km^2, which is about 80% of total UAE and its population is about 1.3 million (based on 2006 census). The location of Abu Dhabi Emirate is shown in Figure 1.1. In order to meet the increasing water consumption in Abu Dhabi, development of additional conventional and unconventional water resources and their effective management are of great concern to the authorities (EAD, 2008a).

1.2 Problem Statement

1.2.1 Water Resources in Abu Dhabi Emirate

The available groundwater resources in the Abu Dhabi Emirate are estimated to be 640 km^3 and fresh water is only less than 3% of it. Correspondingly, the groundwater recharge rate is less than 4% of its total annual water consumption (EAD, 2008b). Further, if the current water extraction rate continues, both fresh and brackish reserves will be depleted within 50 years because it was reported that the water table drops about 5 meters a year in the Abu Dhabi Emirate (EAD, 2014). The climate of Abu Dhabi Emirate is also bi-seasonal Mediterranean type with high temperature and low rainfall. The monthly minimum and maximum temperatures in Abu Dhabi (Al Ain) are shown in Figure 1.2.

Figure 1.1: Location of Abu Dhabi Emirate (source: www.ead.ae)

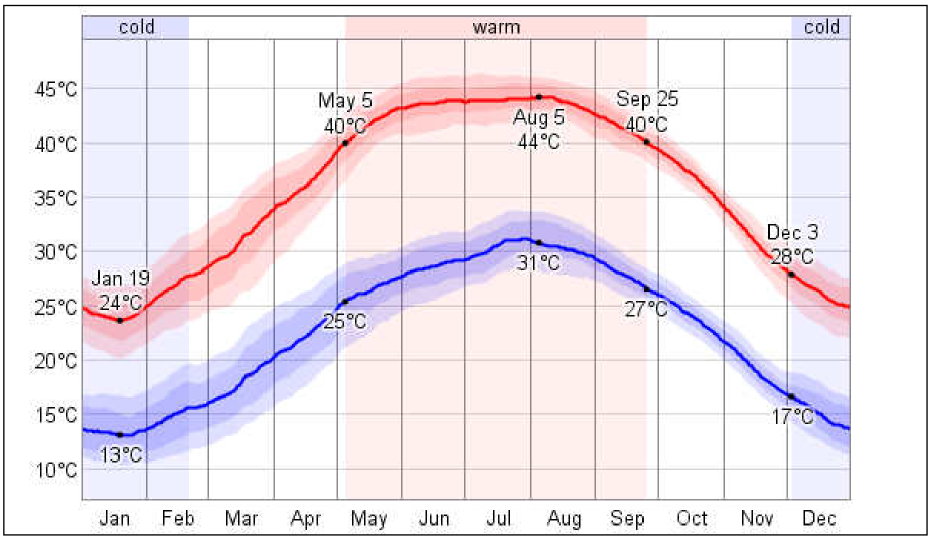

Figure 1.2: Monthly maximum and minimum temperatures in Al Ain

(Source: https://weatherspark.com/averages/32854/Al-Ain-Abu-Dhabi-United-Arab-Emirates)

The summer (May to October) is very warm and during the day time temperatures normally exceed 40°C. Occasional rainfall in the UAE occurs during winter (November to April) with an average rainfall of less than 100 mm/year (EAD, 2008b). The average monthly rainfall and rainfall days in the Abu Dhabi Emirate (Al Ain station) are shown in Figure 1.3.

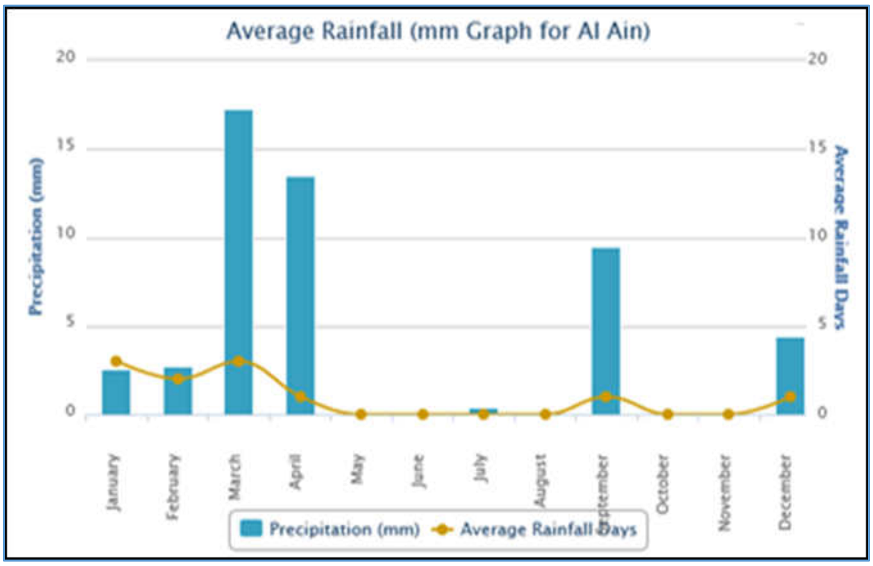

Figure 1.3: Average monthly rainfall and rainfall days in Al Ain

(source: http://www.worldweatheronline.com/Al-Ain-weather-averages/Abu-Dhabi/AE.aspx)

The Abu Dhabi Emirate receives about 65% of its total water from the conventional source of groundwater, and about 31% from non-traditional or unconventional sources of desalination plants. This is because conventional water resources are unable to meet the demand for fresh water and now desalination of sea water is the main source of municipal water in the Emirate. The other 4% of total water comes from another unconventional source of treated sewage effluent (TSE) (EAD, 2014).

1.2.2 Depletion of Groundwater in Abu Dhabi Emirate

In earlier days, domestic water demand in some parts of Abu Dhabi and all of Al Ain city was fulfilled by the groundwater wells, but over extraction of groundwater not only declined the water table in the region but also increased the salinity intrusion of ground water. The main reasons of over extraction of groundwater resources were increased in water consumption from rapid economic development in the region, an increase in population and expansion of agricultural sector during the last few decades (EAD, 2008b). The reduction of groundwater table causes numerous impacts on the environment, including the shutdown of some wells due to deteriorating water quality, dryness and declination of the water table. This creates a huge gap between the available water resources and increase of municipal water consumption. The depletion trend of groundwater in Abu Dhabi is shown in Figure 1.4.

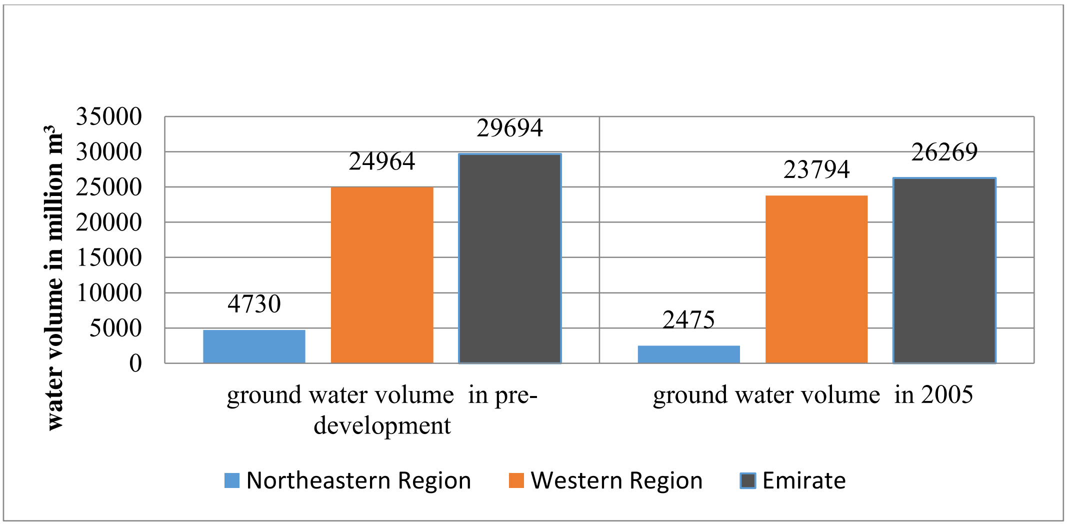

Figure 1.4: Groundwater depletion trend in Abu Dhabi (source: EAD, 2008b)

1.2.3 Projected Population Growth in Abu Dhabi Emirate

It is projected that the population of Abu Dhabi Emirate will be more than four millions in the next 25 years. Table 1.1 shows the estimated population growth in Abu Dhabi at the current growth rate (3.7%), at the medium projected growth rate (5.8%) and at the highest projected growth rate (7.9%) (EAD, 2008b). The municipal water consumption in Abu Dhabi is increasing due to population growth, urbanization and rapid expansion of economic activities. Therefore, it is necessary to find alternative water sources and to conserve the existing water resources to meet the increasing water demand and to reduce the pressure of developing more infrastructures.

Table 1.1: Projected population of Abu Dhabi Emirate (EAD, 2008b)

Year	Projected population at different growth rates		
	Low (3.7%)	Medium (5.8%)	High (7.9%)
2010	1,594,230	1,618,994	1,751,412
2015	1,791,890	2,146,216	2,561,507
2020	2,148,845	2,845,128	3,746,302
2025	2,576,908	3,771,640	5,479,109
2030	3,090,243	4,999,868	8,013,407

1.2.4 Projected Future Water Demand in Abu Dhabi Emirate

The water demand in Abu Dhabi is expected to increase more than 30% by 2030 (EAD, 2014). Several years' water demand forecast for Abu Dhabi have been produced by the ADWEC based on the current water consumption and estimated population growth. Table 1.2 shows the forecasted water demand in the Abu Dhabi Emirate (EAD, 2008b).

Table 1.2: Projected water demand in the Abu Dhabi Emirate (EAD, 2008b)

Year	Available water capacity (MG/day)	Water demand (MG/day)	Required water capacity (MG/day)	Water deficit (MG/day)
2016	830	960	1,007	-177
2017	830	987	1,030	-200
2018	827	1,013	1,066	-239
2019	826	1,039	1,090	-264
2020	825	1,065	1,113	-288
2021	830	1091	1136	-261
2022	850	1117	1159	-267
2023	850	1143	1182	-293
2024	850	1169	1205	-319
2025	850	1195	1228	-345
2026	850	1221	1251	-371
2027	850	1247	1274	-397
2028	850	1273	1297	-423
2029	850	1299	1320	-449
2030	850	1325	1343	-475

The projected water demand in Table 1.2 shows that there will be significant growth in municipal water demand during the period from 2016 to 2030 in the Abu Dhabi Emirate. The ADWEC estimation indicates that if new water resources will not be constructed, there will be about 475 million gallons per day (MG/day) water deficit in the Abu Dhabi Emirate by 2030 that is more than 60% of the current water consumption and this prediction force the authorities rely on the unconventional water resources, such as desalination and treated sewage effluent, as well as to adopt mechanisms for water consumption reduction. Therefore, a comprehensive water management plan is required in order to develop more water resources (ie., to diversify water sources). Greywater reuse is one of the alternatives to diversify water sources and to minimize the water consumption in the region (Chowdhury *et al.*, 2014).

1.2.5 Desalinated Water in Abu Dhabi Emirate

Increasing pollution in groundwater quality due to over exploitation of the available water resources and unreliable surface water, and widened water supply and demand gap stressed the UAE to become the second largest desalinated water producer in the world. The desalinated water is not only an expensive source, but it is also an unsustainable solution to overcome the increasing municipal water consumption. It has significant economic and environmental effects, but depletion of groundwater resources leads the authorities to produce desalinated water in order to meet the municipal water demand despite of its economic and environmental concerns.

The desalination plants require huge energy and generate over 30 million tones of greenhouse gas (GHG) emission (CO_2 equivalent) per year, which is 31% of the total GHG emissions in 2010 produced by power and water sector in Abu Dhabi Emirate (EAD, 2014). If this trend continues, further increase in the emission of GHGs can exacerbate the climate change by contributing to increase in temperature, decrease of precipitation and the rise of sea level (EAD, 2014). On the other hand, desalination process is one of the major sources of marine pollution because they discharge the heated brine water into the sea (Arabian Gulf). These affect sea water salinity level by increasing the salt concentration and alter the seawater temperature. The occurrence of these phenomena threatens the water security in the Arabian Gulf and causes numerous effects on sea environment, aquatic life and endangered marine biodiversity (EAD, 2014).

The brine water discharge into the sea (Arabian Gulf) intensifies the impacts on marine ecosystems and reduces the local fisheries by killing the native intolerable species. Fishing in the region is not only an employment and income opportunities for centuries, but also it contributes to food security and symbol of the rich heritage of the UAE (EAD, 2014).

The construction of desalination plant requires huge capital investment in the early stage. In the operational stage, these plants need bulk fuel and regular maintenance. Regardless of all these construction, operational and maintenance costs, there is a big difference in production and selling cost of the expensive desalinated water in the UAE. The gap is filled by the government subsidies. Currently the Abu Dhabi Government subsidies about AED 217 billion that will be incurred in next 20 years, under the assumption that the traffic remains same and inflation remains unchanged (EAD, 2014). The Regulation and Supervision Bureau (RSB) in Abu Dhabi (www.rsb.gove.ae) reported that the water cost per cubic meter was about AED 10.43 in 2011. Before 2015, the non-UAE nationals (expatriate) paid AED 2.20 and the UAE nationals got desalinated water free of cost. The rate has changed from January 2015. The Government subsidies in water tariff are a great burden on the economy of the country. In addition to this, if desalination activities continue, the Arabian gulf pollution will be a serious issue in the near future and will have huge environmental cost and their mitigation will also be very expensive (EAD, 2014).

1.2.6 Rational of Greywater Reuse and the Vision 2030

Despite a water scarce nation, water consumption rate in the Abu Dhabi Emirate is highest in the world. The municipal water consumption rate in 2008 was between 565 and 920 liters per capita per day, as compared to the developed countries' average range of between 160 and 220 liters per capita per day (EAD, 2014). The most obvious reason behind this huge difference is related to the water supply oriented strategy in the Emirate (ie., subsidized water tariff) and the use of municipal water for outdoor purposes such as irrigation for home garden, plantation and car wash etc.

The Abu Dhabi Environment Vision 2030 aims to mitigate the environmental impacts in the region, since the Emirate is facing an environmental sustainability challenge from the lack of water resources. Therefore, efficient management and conservation of water resources is one of the top prioritized areas of the Vision 2030. It emphasizes for the collective responsibilities for sustainable water solutions and for the development of a water conservation strategy to reduce the water consumption in the Emirate. The high water consumption in Abu Dhabi produces bulk amounts of wastewater which provides us the opportunity to reuse the domestic greywater for home garden irrigations and to reduce the overall municipal water consumption in the Emirate.

In 2012, the agriculture, forestry and public parks sectors were used about 70.7% of the total water in the Abu Dhabi Emirate, whereas 16.1% was used by domestic, 8.2% by Government departments, 4.3% by commercial and 0.5% by industrial consumers (EAD, 2014). The agriculture and forestry sector is the only sector that used about 5.3% of recycled water and remaining 94.7% was supplied from groundwater during the year 2010, whereas other sectors (domestic, commercial and industrial) are still not using the recycled water and they depend on expensive desalinated water (SCAD, 2012).

In the traditional villa type houses in UAE, significantly high amount of municipal water is used for the irrigation to home gardens and plantation. Therefore, the current practice to use high quality desalinated water for non-domestic purposes should be abolished, because of the energy, cost and environmental consequences of desalinated water. Hence, it is hypothesized that the reuse of domestic greywater can provide a long term solution to curb this water shortage. Rather than draining the available greywater into the sewer system, they can be reused for watering the house lawns and for other non-domestic purposes (toilet flush, car washing etc.).

1.3 Purpose of Study

The purpose of this research is to estimate the potential of greywater reuse for non-domestic purposes (irrigation for gardens and plants) and to assess their impacts in reducing water consumption and associated consequences on water network. The study also highlights the current water consumption practices in the region and provides the future outlook to manage this valuable resource in the Emirate of Abu Dhabi.

1.4 Scope of Study

The study will focus on the potential of available domestic greywater and hydraulic analyses of the existing water network through the hydraulic modeling and based on the estimated greywater quantities .

A case study area named "Al Faqa New Village" located in Al Ain was considered in this study. Further to hydraulic analysis of reduced wastewater impacts on water network, the study also assessed the social attitudes to reuse greywater in or around the residential houses. The project was conducted as part of the UAE-NRF research project (31N135) entitled "*Assessment of decentralized greywater harvesting and reuse opportunity in Al Ain*".

1.5 Objectives of Study

The aim of the study is to identify the potential of greywater reuse and to assess its impacts on water consumption and water network. The objectives of the study are to:

- Estimate the total municipal water consumption and greywater generation in the study area
- Identify the social acceptability of greywater reuse scheme
- Conduct hydraulic modeling of the exiting water network based on the estimated quantity of greywater reuse
- Utilize water network hydraulic modeling's results to improve supply efficiency and the use of 'surplus' water, from low water demand areas to water deficit districts, where water is not supplied 24 hours currently, and
- Review the physical, chemical and biological characteristics of greywater and impacts of greywater reuse on water network.

1.6 Selection of Study Area

The study area "Al Faqa New Village" in Al Ain is shown in the Figure 1.5. The reason to select this area is the availability of digital water meter records at every house and the District Area Meter at the inlet water branch. The residential compound comprises of more than 100 villa type traditional UAE homes and it is located in the Northern Region of Al Ain in the Abu Dhabi Emirate.

The inhabitants in the complex are Emirati or UAE national. The total population in the area is about one thousand and every house has an outdoor plantation site and more than 90% houses have their own home gardens irrigated by municipal water. The municipal water is desalinated water produced at the Fujjrah Desalination Plant and supplied to the area by the Al Ain Distribution Company (AADC).

1.7 Methodology

The one year municipal water consumption data was collected from door to door visits after getting the approval from the AADC and the UAEU (approval letter is attached in the Appendix –B). The data consisted of 100 houses at the Al Faqa New Village and the collected data were compared with the AADC data to verify the consumption figures.

Figure 1.5: Areal view of the study area “Al Faqa New Village”

(source: Google Earth)

The social, demographic and greywater reuse acceptance data were collected through a structured questionnaire survey. The questionnaire design was based on the information needed to estimate greywater quantity available in every household. The data were gathered from various answers given by the respondents. The information included number of occupants, frequency of water uses, irrigation practices and other relevant factors that affect water consumption. The questionnaire survey was approved by the UAEU Ethics Committee, which is attached in the Appendix-C.

After collection of consumption data, the hydraulic modeling software (EPANET) was used to analyze the hydraulic effects on the existing water network due to reduction of estimated greywater quantities. For this purpose, the water distribution network's GIS data was collected from the AADC. The historical records of water inflow data for the study area, residential water meter readings, distribution pipe diameters and elevation were used for the modeling. Different greywater reuse or reduction scenarios were performed based on the desktop hydraulic modeling.

The greywater characteristics were reviewed for physical (pH, turbidity, TDS, conductivity, etc.), chemical (COD, ions, salinity, heavy metals, etc.) and biological (coliform bacteria) parameters from the previous studies in order to examine the greywater characteristics for their possible end uses for lawns/gardens and for non-domestic consumptions such as toilet flushing.

1.8 Need of Resources

The following resources were needed to conduct the study:

- Water consumption data from water meters in the study area (approval required from the AADC)
- A residential questionnaire survey in the study area (approval required from the UAEU Ethics Committee)
- Greywater sample collection bottles (purchased from the UAEU-NRF 31N135 budget)

- Portable multi-parameter water quality meter (available from the UAEU-NRF 31N135 project)
- Use of CEED laboratory for greywater sample analyses
- Chemicals for laboratory tests (purchased from the UAEU-NRF 31N135 project budget)
- A hydraulic modeling software (EPANET), freely available
- GIS software (ArcInfo or ArcView) (available in the COE college, UAEU)
- Statistical software (MiniTab) (available in the COE college, UAEU)
- A desktop computer (available in the COE college, UAEU)

1.9 Expected Outcomes of the Study

The expected outcomes from this study are listed below:

- Quantify the water consumption at different villas in the study area
- Quantify the amount of available greywater at the study area
- Identify the factors affecting greywater reuse
- Effects of greywater reuse on municipal water consumption
- Effects of greywater reuse on water network (sedimentation, clogging, change of strength and large scale sludge)
- Provide recommendations to implement the efficient use of greywater and water consumption management without affecting the pressure and velocity requirements of the existing water network, and
- Estimation of greywater reuse potential that should be evaluated prior to designing the greywater reuse schemes.

1.10 Study Limitation

The thesis is conducted for 100 houses in the Al Faqa New Village where the residents are only Emariti/UAE national. The water network hydraulic modeling was conducted based on the reduced consumption scenarios representing 0%, 5%, and 10% reduction in water use. The study did not consider the impacts of other water consumption measures (increase of water tariff, implication of smart water appliances, government restriction on water uses etc.) on water network.

1.11 Thesis Layout

The Chapter-2 presents the literature review of greywater background, benefits of greywater reuse, worldwide practices of greywater reuse, estimated greywater quantity, quality and treatments of greywater and the possible factors affecting the greywater reuse application. The Chapter-3 describes the selection of the study area, the various methods used to collect the data from the field and statistical analysis of the results in addition to use of hydraulic modeling. The Chapter-4 includes the water consumption estimation and calibration, discussion on seasonal and monthly water consumption, statistical analysis water computation, description of survey responses and the calculation of greywater quantity. The hydraulic modeling of the existing water network by means of the EPANET software and use of different scenarios based on the estimated greywater quantity and their results are discussed in the Chapter-5. In Chapter-6, the potential of greywater reuse in Abu Dhabi Emirate, their economic and environmental benefits are described in addition to the greywater quality review. Finally, the conclusion and recommendation are presented in Chapter-7, followed by the bibliography and appendices.

Chapter 2: Literature Review

2.1 Background

The depletion of fresh water resources and deterioration of water quality is one of the serious growing problems globally. The living standards and population growth are escalating the municipal water consumption continuously. Previous studies identified that in the developed countries more than 30% of their total water consumption is used for outdoor activities (gardens, car wash), in spite of their urbanization and industrial growth. Therefore, it is obvious that providing adequate municipal water will be the major issue in future. The aim of this chapter is to review the relevant literatures and previous studies in order to understand the application of greywater reuse for non-domestic uses and to assess their sources of generation, characteristics and benefits as an alternative option.

2.2 Greywater

The domestic wastewater collected from all sources excluding that generates from the toilet is called greywater. In some definition, the kitchen wastewater is not considered as part of greywater (Mourad *et al.*, 2011). Therefore, sources of greywater are wash basin, shower and bath tub, washing machine, ablution basin and sinks. The wastewater discharged from toilets is considered as black water and are not included in greywater. Kitchen wastewater is also excluded from greywater because of their high organic contents (food waste, oil and fat, etc.) (Aljaradin and Selim, 2011; Al Wabel, 2011; Kime *et al.*, 2009).

The domestic wastewater can be divided into two main categories. Firstly, greywater that is generated from household sources, except toilet and kitchen and it is estimated about 60 to 70% of total household water consumption. Secondly, the black water that is estimated to be about 30 to 40% originated from the toilet and kitchen (Kim *et al.*, 2009). Because of the low level of organic matters, greywater is generally less polluted and suitable for non-domestic water uses such as irrigation, toilet flushing, dust control, soil compaction and construction work after appropriate treatments (Khatun and Amin, 2011). In a recent study, Chowdhury *et al.* (2014) estimated greywater generation rate of 192 liters per capita per day in the city of Al Ain in UAE. The quantity was found sufficient enough for toilet flushing requirements.

2.3 Benefit of Greywater Reuse

Greywater reuse is an attractive option to reduce the municipal water consumption and it has many advantages such as savings on consumers' water bills, decrease the cost of municipal water production, and decrease the cost of wastewater treatment and construction of supply and storage facilities (Mah *et al.*, 2008). On-site reuse of greywater has two distinct advantages, it saves municipal water without affecting the lifestyle of consumers and it saves huge maintenance and energy consumption cost of municipal water production (Friedler and Hadari, 2006). The benefits of greywater reuse are described below in more details.

2.3.1 Decrease of Municipal Water Consumption

The greywater reuse application can provide the solution to manage the growing municipal water consumption and greywater may be reused as treated or un-treated for different non-domestic purposes (Nitivattananon and Sa-nguanduan, 2013). The domestic greywater is a sustainable water source and it can be reused for irrigation of palm trees and plantation around the houses in order to deal with water shortages. Many countries are practicing to reuse greywater because it is very cost effective and sustainable (Al Wabel, 2011). In previous studies it was estimated that about 30% of municipal water can be saved by reusing greywater for non-domestic activities (Mourad, 2011). However, in traditional villas in Abu Dhabi, such study was not conducted. In a recent study, Chowdhury et al. (2014) estimated that the greywater generation rate is about 192 liters per capita per day in traditional villas in the city of Al Ain in UAE.

2.3.2 Economic Benefit of Greywater Reuse

The construction of additional infrastructure and water supply facilities to meet the increasing water consumption requires huge cost for the development, operation and maintenance of water supply infrastructures (Friedler and Hadari, 2006). The on-site reuse of domestic greywater has economic benefits for householders and the authorities, because it saves the water bills for householders and on the other hand, it lessens the load on the treatment plants and sewer systems, but most importantly, it can save the additional investment in construction of water supply networks, water treatment plants and repair and replacement of defective pipe lines (Li *et al.*, 2010). In some typical conditions, greywater reuse provides an economical and environmentally sustainable option to reduce the overall urban water consumption, for example, the collected greywater from schools and mosques can be reused for toilet flushing, car washing and fire fighting (Kim *et al.*, 2009).

2.3.3 Manage of Water Shortage

The water shortages and increasing municipal water consumption are of major concern in many arid and semi-arid regions including the UAE. The reuse of domestic wastewater/greywater is an alternative source that can help to manage the deficiency of available water (Nitivattananon and Sa-nguanduan, 2013). Lowering the municipal water consumption has become an essential issue for water authorities, and different measures and combination of methods are being under investigation for the efficient use of water resources. Greywater reuse has been considered one of the most appropriate options that can play a significant role to overcome this increasing water consumption problem. Previous studies showed that greywater reuse for toilet flushing can save about 40 to 60 Liters per capita per day from every household, and other non-domestic uses (garden irrigation, car washing, etc.) can save plenty of municipal water (Friedlerand and Hadari, 2006).

2.3.4 Increase of Plantation Area

One of the main reasons for increasing the municipal water consumption in the UAE is practice of landscape and home garden irrigation. Therefore, greywater reuse is an alternative source to irrigate the home gardens and plantation, which can reduce the municipal water demand sufficiently (Aljaradin and Selim, 2011). The agricultural activities can be increased by adopting the reuse of domestic greywater for irrigation, but all related factors and aspects should be considered by doing the engineering evaluation and social assessment prior to implement of the greywater reuse schemes (McNeill *et al.*, 2009). The microbial risk assessment has to be conducted prior to reuse of greywater for agricultural practices.

2.3.5 Energy Saving and Environmental Sustainability

The higher consumption of municipal water and its use for home gardening and irrigation practices puts tremendous pressure on the authorities to produce more desalinated water. Production of more desalinated water requires more energy and they generate more greenhouse gases in the atmosphere that increase the pollution level and have adverse effects on the environment (Kotwicki and Al-Otaibi, 2011).

On the other hand, discharge of desalination plants' waste and brine water into the marine water (Arabian Gulf in UAE) significantly affects the marine ecology. Therefore, reuse of greywater for non-domestic purposes is getting popularity in many countries to conserve the expensive and scarce water resources (Mourad *et el.*, 2011), and particularly in the UAE, they can save energy and can reduce GHGs by downscaling desalination plants.

2.4 Practices of Greywater Reuse

During the last few decades, many industrial and developed countries, including the European, USA, Japan and Australia have been reusing greywater for non-potable purposes (Khatun and Amin, 2011). The greywater reuse has been identified as one of the most economic and feasible options to manage fresh water shortages and to cope with increasing water consumption due to rapid population growth (Friedler and Hadari, 2006). The reuse of greywater provides an alternative source to irrigate the garden and use for other non-potable purposes that are helping to lower the municipal water consumption (Kotwicki and Al-Otaibi, 2011).

Nowadays, it is not only common to reuse greywater for irrigation and groundwater recharge in arid and water scarce regions, but it is also practiced in many countries where fresh water availability is adequate such as Germany and Japan. There are several reasons to adopt the domestic wastewater reuse practice, for example, water shortage forces Australia to reuse wastewater, Japan is practicing due to high water consumption for public use and Germany and France considered wastewater reuse practices for economic and environmental reasons (Nitivattananon and Sa-nguanduan, 2013).

Almost all Middle Eastern countries are facing scarcity of water, but greywater reuse is not yet common here and the most obvious reasons are the lack of awareness on the water shortage issue, cultural issues and the lack of proper regulation and required standards. Few studies were carried out on the reuse of greywater in the region. Mourad *et al.* (2011) showed that about 84% of survey respondents in the Sultanate of Oman were agreed to reuse the treated greywater for irrigation. Chowdhury *et al.* (2014) conducted a study in the city of Al Ain, UAE where they showed that about 70% survey respondents were agreed to reuse greywater for irrigation purposes. Greywater reuse is an economical and additional source that can reduce the increasing water consumption and able solve the water shortage issue sufficiently in the arid region (Halalsheh *et al.,* 2008).

2.5 Potential Quantity of Greywater

The reuse of domestic wastewater/greywater for non-potable purposes has great potential to reduce the consumption of supply water (Naji and Lustig, 2006) and every house has potential to produce greywater with almost the same quantity throughout the years (Mah *et al.*, 2008). Greywater can be collected without much effort (Li *et al.*, 2010) and each house can produce about 55 to 65% of greywater of their total domestic wastewater (Khatun and Amin, 2011).

According to Jamrah et al. (2008), residential areas have high potential to produce greywater and most households can produce about 50 to 80% of greywater from their total fresh water consumption, but it needs to be collected separately from the black water. A typical household in the Sultanate of Oman generates about 80 to 83% of greywater from its total municipal water consumption and it was estimated that about 55 to 57% of greywater generates from showers and bath, about 28 to 33%

from the kitchen sink, about 6 to 9% from clothes washing and about 5 to 7% from the wash basins (Jamrah *et al.*, 2008). In developing countries, domestic water consumption normally varies between 100 and 180 liters per capita per day that is about 30 to 70% of the total urban water consumption, but most of this water transforms into wastewater. This wastewater comprises of 60 to 70% of greywater and the remaining is black water (Friedler and Hadari, 2006).

2.6 Greywater Quality and Characteristics

Greywater quality varies from house to house and it depends on the sources of generation, such as shower, washbasin and kitchen, etc., lifestyles and cultural habits of the householders (Khatun and Amin, 2011). The contamination level of greywater is much lower than the wastewater generated from the kitchen and toilets (Aljaradin and Selim, 2011). This is because greywater do not contain much organic matters, food waste and FOGs (fat, oil and grease). Greywater has different chemical and biological characteristic; the low per capita consumption houses has a high organic load and concentration of total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) as compared to the high water consumption households. Presence of pathogens or Ecoli in greywater mainly depends on the sources of greywater (Halalsheh *et al.*, 2008). Chowdhury *et al.* (2014) observed presence of coliform bacteria in ablution greywater in the city of Al Ain, UAE. High sodium content in greywater is also observed in previous studies (Chowdhury *et al.*, 2014). Presence of high sodium ions and its accumulation in the soil is a hazard for plants and soil fertility which may be raised from its long use for irrigation without appropriate treatments (Mourad *et al.*, 2011).

It is recommended to treat the greywater to meet the minimum standards and to make it acceptable by the householders to use for gardening and plantation (Kotwicki and Al-Otaibi, 2011). Kim *et al.* (2009) recommended that application of proper disinfection is necessary for safe use of greywater for watering the home gardens and toilet flushing, but it is necessary to separate the greywater from the black water (Halalsheh *et al.*, 2008) and proper quality monitoring has to be done to evaluate their toxic effects before reusing for gardening and toilet flushing (Mah *et al.*, 2008). It is important to use advanced technologies and modern treatment methods to remove the pollutants and pathogens from greywater and to improve their quality. Appropriate treatment of greywater will help to increase the public acceptance for greywater reuse (Nitivattananon and Sa-nguanduan, 2013).

2.7 Greywater Treatment Methods

A satisfactory treatment and disinfection of greywater improves its aesthetic quality and public acceptance for different non-potable uses. Since greywater is most preferably be used for watering the home gardens and indoor toilet flushing, selection of treatment methods is important which is based on greywater specific characteristics, sources and their collection systems. This may include different combinations of sand and gravel filters, water collection and storage tanks, pumps, fabric filter and disinfection (Aljaradin and Selim, 2011).

2.7.1 Disinfection of Greywater

Presence of microorganisms in greywater has risk to spread out and can affect the human health. Therefore, the greywater treatment with chlorine disinfection helps to remove the microorganisms and make it safe for non-potable uses. Although, it is observed that the presence of colloidal matters, soap and bacteria decay the residual chlorine so fast, increasing ammonia concentration can slow down the residual decay process and greywater can remain safe for longer duration (March and Gual, 2009). Disinfection process is applied to improve the biological quality of greywater. Some filters (slow sand filter, bioretention basin) were found to reduce coliform bacteria counts in greywater. The pasteurization method was used in previous studies for treatment against E. coli and other pathogenic bacteria (Li *et al.*, 2010).

2.7.2 Greywater Treatment Systems

There are several on-site greywater treatment technologies that have been introduced during the last decade (Nitivattananon and Sa-nguanduan, 2013). Different countries are using different technologies for greywater treatment that depend on their greywater quality based on organic and bacterial pollutants, greywater reuse purposes, public acceptance, health and environment risks. Therefore, primary consideration to select the proper type of treatment system should depend on their quality, quantity and end uses (Khatun and Amin, 2011). Some of these technologies are briefly described below.

2.7.2.1 Sand bed Filter Method

Greywater can be filtered through the natural sand bed, this method has the ability to remove the majority of organic and suspended matter that will result low consumption of chlorine for disinfection of greywater (Mourad *et al.*, 2011). But, practice shows that the sand filter method cannot remove the organic matter, in most of the cases.

2.7.2.2 Membrane Technologies

Membrane technologies are very easy and economical, and suitable to implement for small and large greywater reuse schemes (Nitivattananon and Sanguanduan, 2013). The pollutant removal efficiency of membrane technologies is significantly higher.

2.7.2.3 Activated Carbon Technologies

The activated carbon filter adheres with the ultra violet unit (for disinfection) was observed to remove all impurities and pathogens of ablution greywater received from a mosque and the test results were found almost same as the tap water (Al-Wabel, 2011).

2.7.2.4 Septic Tank with Sand Filter

The septic tanks with sand filter or wetland are the simple and efficient choice for on-site treatment of greywater, this method allows the suspended particles to settle down and cleanse off any biological hazards prior to reuse the greywater to irrigate the plants (Halalsheh *et al.*, 2008).

2.7.2.5 Microfiltration Membrane Method

The microfiltration membrane is the most effective method for greywater treatment; this method is very effective and has good capacity to improve the aesthetic problem such as color and turbidity, removal of COD, suspended solids, E. coli, total coliform, Salmonella and Staphylococcus bacteria from the raw wastewater, but the treatment is very cost intensive (Kim *et al.*, 2009).

2.7.2.6 Oxidation Process Method

The oxidation process is also an effective method for greywater treatment and it has the ability to remove color, turbidity, COD, suspended solids, E. coli, total coliform, Salmonella and Staphylococcus bacteria from the domestic wastewater/greywater, but disinfection is required. The process is also a cost intensive method (Kim *et al.*, 2009). The method is simple to operate and their maintenance costs are low, but the treatment efficiency is high (Li *et al.*, 2010).

2.8 Factors Affecting Greywater Reuse

Reuse of greywater is restricted in many countries primarily because of their technical, social and economical factors; similarly lack of awareness, benefit, cost, government supports and regulations are also main hurdles. The statistics show that economic and social conditions of a country have significant impact on the greywater reuse practice. So, greywater reuse practices are more common in the high income countries such as in the USA and Australia because of public awareness. Some developing countries such as Vietnam and Thailand have limited practice on reuse of domestic wastewater. In the last decade, many countries have been started to reuse greywater for non-domestic purposes, primarily for outdoor irrigation to landscape plantation, parks and golf courses etc. But, still there are many challenges to widen this practice. Some of these challenges are lack of public awareness, public perception, unavailability of regulation and standards, and lack of social and political willingness (Khatun and Amin, 2011).

2.8.1 Social Factors Affecting Greywater Reuse

Greywater has low quality in comparison with municipal water, so there are many social challenges to reuse it on-site (McNeill *et al.*, 2009). The social acceptance to reuse domestic greywater is the primary factor to utilize this unconventional resource. Without public acceptance, reuse of greywater is not possible to go step forward (Nitivattananon and Sa-nguanduan, 2013). In order to promote the reuse of treated greywater, awareness and training are necessary. Awareness can provide a sense of safety and training can make the users able to control, organize and maintain the reuse system safely and effectively. This approach will increase confidence levels for people to reuse greywater and to manage the system. This will result an enhanced greywater reuse practice and thereby decrease the water shortage problem. However, it is necessary to ensure the public and environment protection by minimizing the potential risks in the reuse of domestic wastewater/greywater (Naji and Lustig, 2006). The social attitude has great importance to reuse the greywater because in some countries water and wastewater has religious values as well.

2.8.2 Cultural Factors Affecting Greywater Reuse

A study in the Palestian showed that about 75% residents of the West Bank were not agreed to accept the reuse of treated wastewater for irrigation due to their local cultural values (Halalsheh *et al.*, 2008). On the other hand, in Jordan, more than 50% farmers agreed to reuse the wastewater for irrigation purposes (Halalsheh *et al.*, 2008). Local cultural and religious issues are significantly important in the reuse of greywater. A comprehensive greywater reuse education and awareness plan can raise the participation and acceptable level of consumers (McNeill *et al.*, 2009).

2.8.3 Economic Factors of Greywater Reuse

The use of treated greywater is safer than the raw greywater, but the cost of treatment is normally high and it is one of the main barriers to accept greywater reuse for the public. Actually, the cost of greywater treatment varies according to their utilization and the type of treatment selection. The economic analysis to install the greywater system is very essential to implement greywater reuse strategy, because financial factors always govern to implement any sustainable system (Mourad *et al.*, 2011). It is one of the most restricted factors in promoting the greywater reuse scheme, but the associated cost of greywater reuse can be overcome by reducing cost of construction of water mains and sewer lines and by improving the effectiveness of existing water and sewer system (Naji and Lustig, 2006). The payback period of greywater treatment systems depends on the volume of treated greywater and the savings from municipal water charges (Li et al., 2010). Usually the greywater treatment system used for irrigation has a shorter payback period.

2.8.4 Irrigation Methods

The selection of proper irrigation method is very important to reuse treated greywater safely for plantation and crops. It can be done by providing proper technical training, awareness and education to the users (McNeill *et al.*, 2009). Spray and drip types of irrigation methods are commonly used and the spray irrigation is more likely to be in contact with people. As a result, regulations for spray irrigation water requirements are comparatively much stricter than the drip irrigation system. The use of advanced technologies and implementation of quality control standards for greywater can help to remove the potential hazards of the greywater (Nitivattananon and Sa-nguanduan, 2013).

2.8.5 Greywater Reuse Impacts on Sewer Network

The reuse of domestic wastewater/greywater may affect the wastewater inflow into the sewer lines and the sewer system may be affected by a reduction of sewer flow (Kim *et al.*, 2009). Less flow in the sewer system may produce dense sludge, but it depends on the concentration of pollutants and sources of wastewater.

2.8.6 Greywater Reuse Policy and Planning

The government can play a significant role to develop the understanding and acceptance of greywater reuse by informing the public and by reducing social and economic hurdles. Government rebate to install on-site greywater treatment system can be an effective mechanism to motivate people. Public involvement in this regards can help to accept the reuse of greywater and can improve the performance of water conservation and management plan (Li *et al.*, 2010). It is so important to introduce the clear policy to promote the reuse of greywater and to address all concerns to achieve the sustainability in water management by linking them through a policy and proper planning for water reuse infrastructures. The environmental and social benefit assessment is necessary. In fact, greywater is a more reliable and continuous source than rainwater. A water conservation strategy requires proper planning and regulatory frameworks and cooperation among different government and non-government organizations (Naji and Lustig, 2006).

2.8.7 Regulations and Guidelines of Greywater Reuse

The guidelines and regulations to reuse greywater are significantly important to examine and assess the impacts on public health and the environment. Therefore, social, environmental and economic concerns should be introduced by proper guidelines and regulations (Naji and Lustig, 2006). Most countries have the potential of greywater reuse, but majority of countries does not have effective regulations or guidelines to reuse the greywater safely for non-domestic purposes (Kim *et al.*, 2009). It is necessary to monitor the performance of regulation and guidelines periodically in order to ensure the safety of the environment and public health (Naji and Lustig, 2006). Though guidelines and regulations are available in UAE for treated sewage effluent, specific guidelines for greywater reuse is not available yet.

Chapter 3: Data and Methodology

3.1 Introduction

This chapter describes the different methods used in this thesis from collection of primary field data directly from each house in the study area, door to door survey to gather water meter reading data from every house, analysis of current water consumptions in the study area and the potential of greywater reuse by means of hydraulic modeling. The results were compared with local standards and regulations. The hydraulic modeling of the existing water network was carried out considering different water consumption scenarios in order to observe the effects of greywater reuse on the existing water network.

3.2 Study Area

The selection of appropriate study area was an important step in this thesis in order to meet the study objectives and to examine different usage of municipal water and the opportunity for greywater reuse. Therefore, the study area was selected based on the highest water consumption community in the Al Ain region, which has home gardens and amenity plantation zones. The RSB water supply regulation (2009) estimated that the villas (locally known as *Shabiat*) of Emirati national have the highest per capita municipal water consumption rate. This research shows that the most probable reason behind this high consumption of water is their traditional passion to have a plantation and home garden in the villas. Therefore, several communities were visited to select a suitable study area for this thesis in the Al Ain Region. Many areas do not get continuous (24 hours) water supply and some areas do not have water meters for all houses. Other constraints were to get the large number of community demographic structure and water consumption data within a limited time and resources.

Accordingly, the "*Al Faqa New Village*" was selected as the study area, which meets the objectives to perform the project activities for this thesis. The complex occupies 100 detached villas, two commercial houses and one Mosque and all villas receive water from a single source provided by the Abu Dhabi Distribution Company (ADDC). However, the demographic and municipal water consumption data were not available at the beginning of this study. The municipal water is supplied in the study area by the Al Ain Distribution Company (AADC) and the village has a single supply source from the Al-Shuwaib North pumping station of ADDC. The study area has a water network consists of ductile iron pipes and all houses have a municipal water connection with a wall mounted electromagnetic water meter. Figures 3.1a and 3.1b show the location map of the housing complex.

3.2.1 Geographic Feature of the Study Area

The *Al Faqa New Village* is located in the Northern Region of Al Ain city, approximately 60 km from the Al Ain city center towards Dubai at the latitude (easting): 359715 and longitude (northing): 2730645, along the Al Ain - Dubai highway. The village occupies 100 typical residential villas; the plot size for each villa is 45m x 45m (2025 m^2) as shown in the Figure 3.1. Every villa has a double storied building (townhouse) with five bedrooms. The building area is about 20% of the plot size (roughly estimated at the Google Pro) and the rest 80% area is kept open yard. The villas were constructed by the government and only the Emirati nationals are living in the village. The open space in every villa is occupied by amenity plantations and gardening.

Figure 3.1a: Areal map of the study area (left) and an enlarged block view (right) (source: Google pro image)

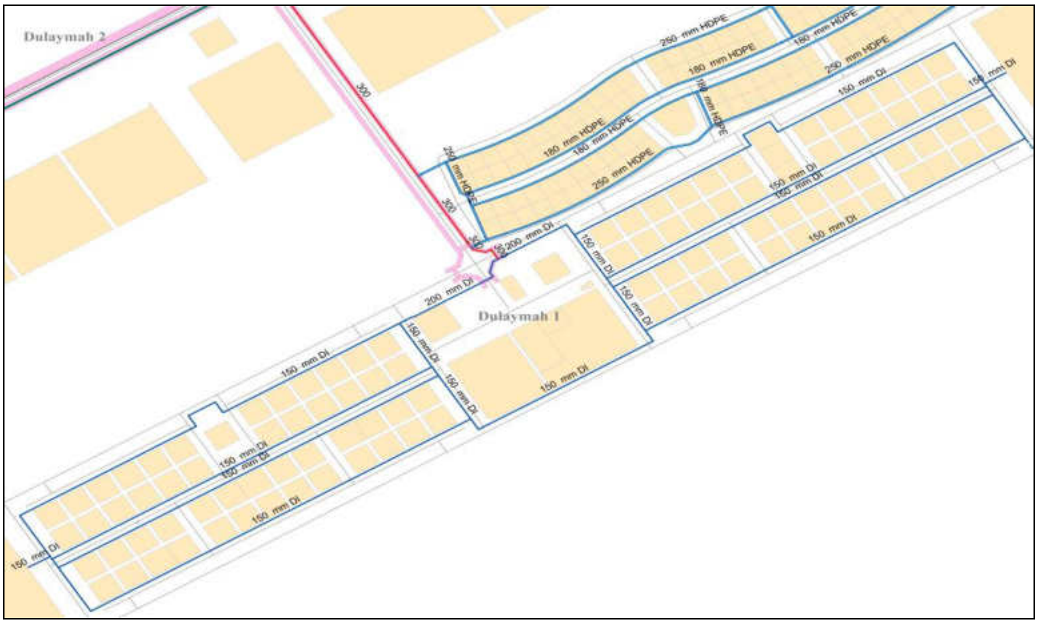

Figure 3.1b: Study area with water network and plot layout details

(source: AADC)

3.3 Survey Data Collection

Two surveys were conducted in the study area. Firstly, a door to door questionnaire survey was conducted by interviewing the householders regarding municipal water uses for different purposes, family size and their willingness for water conservation and greywater reuse. The questionnaire was approved by the UAEU Ethics Committee. A total of 35 villas' residents were participated in the questionnaire survey. The questionnaire and its ethics approval are attached in the Appendix – A and C, respectively. Secondly, water consumption data were collected from water meter readings for all houses ("house" and "villa" are interchangeably used in this thesis). The monthly water consumption data for 100 houses was collected for a year (February 2013 to January 2014). Since AADC is responsible for the operation and maintenance of the water meters in the area, appropriate permission was taken from the AADC before collection of water meter readings. The collected water meter reading data reflect the actual facts for 12 months of consumers' water consumption, which will facilitate to examine the seasonal variations and the trend of water consumption.

3.4 Water Consumption Data Collection

The water meters in the study area are the properties of the AADC and the meters are enclosed and locked in a GRP wall mounted box. To open the GRP box and to collect data, it was important to get formal approval from the relevant authority, so the approval was obtained from the Al Ain Distribution Company's Managing Director Office (refer the Appendix –B) to collect the consumption data independently, prior to start getting the existing meter reading records for each house in the selected study area. Figure 3.2 shows the photograph of a water meter in a villa in the study area. The meter operates with a long life (10 years) battery and has a data storage capacity for 12 months in the cubic meter (m^3) unit, which is needed in this thesis.

3.5 Coding of Houses in the Study Area

There is a total of 100 residential villas, a mosque and a co-operative market in the selected study area, and all of them have water meters provided by the AADC.

Since this water meter reading belongs to individual resident's privacy, therefore, a un-anonymous coding of house numbers were used in order to keep the customers unidentifiable and preserve their privacy issues.

Figure 3.2: Water meter connected in houses in the study area

(source: AADC)

After getting the authorization to collect consumption data from the AADC, the GIS drawing of the study area was obtained and the study area was divided into different blocks and the houses were coded as shown in the Figure 3.3. The divided blocks were marked as Block-A (12 houses), Block-B (12 houses), Block-C (8 houses), Block-D (10 houses), Block-E (8 houses), Block-F (12 houses), Block-G (10 houses), Block-H (12 houses), Block-J (8 houses), Block-M (8 houses) and Block-N has 3 connections (2 commercial and 1 Mosque).

Figure 3.3: The un-anonymous coding of houses (villas) in the study area

(these coding are not related to the actual property IDs)

3.6 Calibration of Water Consumption Field Data

After collection of water consumption data from all houses independently, it was important to verify the gathered data. The water supply source line in the study area is installed with a District Area Meter (DAM) with an electromagnetic flow meter and an RTU as data recorder (Figure 3.3). Therefore, the secondary data of monthly DAM water consumption record in the study area were also obtained from the AADC Northern Regional Office in order to compare and verify the collected meter readings from individual houses. Conceptually summation of water meter readings from all buildings in the study area should be equal to the supplied water in the study area collected from the DAM's reading.

3.7 Methodology of Questionnaire Survey

There are several options to conduct a questionnaire survey, such as the door-to-door survey using printed questionnaire, mail or courier survey, telephone survey and gathering survey information during a social event. The selection of survey type depends on the purpose of study and the ease of analyzing the results. Since there were only 100 houses in the study area, the survey methodology adopted in this study was based on primary data and information collected directly from every house (door to door) and by interviewing the residents of the houses. Since Arabic is the native language of the residents, the researcher (surveyor) was accompanied by a native Arab speaker during the survey.

A questionnaire having a total of ten questions was used in the survey in order to obtain the required information of municipal water consumption and greywater reuse. A survey was carried out by personal interview of the residents of the houses in the study area. To get the specific information of the study area, particular importance was given to build the questionnaire format, layout and type of questions, to include the study area residents' social, cultural and ethical values and the customs of participants. The questionnaire design and format reflects the different water uses and overall consumption. So, the asked questions were designed as closed questions, values with multiple choice answers, and questions have independent choices that took minimum time and were scored easily.

The survey questionnaire (Appendix-A) included 10 multiple choice questions in simple English and Arabic languages. The questionnaire included basic questions related to the water availability, uses of municipal water for drinking and home lawn irrigation, awareness of water shortage, use of greywater uses to measure the level of acceptance of greywater reuse and information about total numbers of family members. The questions were written in a series that provided a valid and reliable opinion of participants through specified multiple choice answers. The answers of participants can be analyzed statistically to assess the individual house's municipal water consumption activities, acceptance of greywater reuse for home garden irrigation and calculation of population for the study area. The questions provided in the survey are listed below. The actual survey questions are provided in the Appendix D.

- Do you receive enough water for uses from the water network?
- Do you use municipal water for drinking purposes?
- Do you use municipal water for home garden irrigation?
- How many times a day do you need water for irrigation?
- Do you believe water conservation is an important issue in Al Ain?
- Do you know how important individual action is to meet water demand?

- Do you have a plan to take any action in this year to lower your water use?
- Do you agree to reuse laundry, washing and shower water for home garden irrigation?
- If greywater system cost will between AED 1000 to AED 4000, then do you prefer to install it?
- How many total numbers of family members in your house?

Prior to start the questionnaire survey, a formal approval was obtained from the UAEU Ethics Approval Committee (Appendix- C). After getting the approval from the concern authorities, the door to door survey was started in random order for all 100 houses. All 100 houses were approached, however, there was chance of many residents may hesitate to participate or the house head may not be available during survey time. Therefore, it was decided to visit each block to carry out the survey. The field visit was started from 25 April 2014 to 17 May 2014. Before starting the survey, a brief introduction about the survey and work was explained to the respondents, then the 10 specified questions were asked and the answers were recorded to analyze the collected information to draw a conclusion.

3.8 Analysis of Results

To develop the result in a tabulated or graphical form, several arithmetic calculations and comparisons were done. It was very important for the thesis to calculate the actual per capita water consumption of the study area. So, to estimate the municipal water consumption for each house, the customers' meter data were collected for 12 months and the demographic data were collected from the questionnaire survey. The one year's whole consumed water volume was divided by the estimated population of the village and the numbers of days per year to the get the per capita per day water consumption as shown in the formula:

$$\text{Average per capita per day consumption} = \frac{\text{Total consumed water (liters)}}{\text{Total population x 365}}$$

This equation was used to calculate the average per capita per day consumption by replacing the whole population in the denominator with the total numbers of residents in different houses in the study area. It is very important to compare the calculated real consumption from each house with the local regulations and Vision 2030, in order to identify any deviation from the recommended municipal water consumption limit.

Tables 3.1 and 3.2 were used for comparison, partially extracted from the EAD and RSB. The detailed calculations are described in the next chapter and will be used to compare with the actual consumption of the study area. The Vision 2030 sets the priority threshold target for water consumption (liter per capita per day) for domestic use as mentioned in the Table 3.1 and this threshold was used in this thesis for calculating the greywater quantity and the hydraulic simulation of the existing water network.

The Regulation and Supervision Bureau (RSB) is an independent body, which supervise the water quality and supply standard in the Abu Dhabi Emirate. They provide the water demand and sizing criteria to the all water distribution companies in the Emirates for daily demand rate of various residential and commercial premises as mentioned in the Table 3.2.

Table 3.1: Recommended water consumption guidelines according to the Abu Dhabi Environment Vision 2030 (Source: EAD, 2012) which provide guideline to preserve environment and water resources in the Emirate

Priority Area	Priority	Outcome	Measure	Baseline 2010	Threshold 2030
PA 3 Efficient management and conservation of water resources	P3.1 Integrated and efficient use of water resources	3.1.1 Moderate Average domestic water Consumption	Domestic water consumption in L/capita/day	586	Less than 340
		3.1.2 Moderate average daily domestic outdoor water use in villas and shabiyyat	Domestic outdoor water consumption (villa and shabiyyat) in L/capita/day	756	Less than 340
		3.1.3 Maximum use of recycled water for amenities plantation	% of total water consumed for amenities plantation	35%	67%

Table 3.2: Water demand and sizing criteria according to the RSB (RSB, 2009)

Type of premises and consumption categories	Description	Estimates of daily consumption rate (Imperial gallons)	Estimates of daily consumption rate (liters)
Villa and Shabiat	Per capita	77	350
Villa and Shabiat[2]	General services	250/450	1100/2000
Villa and Shabiat[3]	Per bedroom	110	500
Villa and Shabiat	Pool / m^2	6.6	30

[2]*General services mean water used for internal gardening and general cleaning purposes for a standard-sized shabiat and villa. It may increase or decrease according to the type and size of villa. However, the estimated rate of consumption for calculating additional quantities shall be between 1 and 1.5 gallons per square meter per day.*

[3]*For the shabiat and villa category, a reduction factor may be applied for every additional bedroom, according to the Distribution Company's own criteria.*

3.9 Statistical Analysis of Water Consumptions

The water consumption data from every house were statistically analyzed using the computer software called “Minitab” version - 17 (license available at UAEU). Statistical distributions of monthly water consumptions were conducted, and correlation and linear regression were conducted between water consumption and family size, different statistical parameters like mean, median, minimum, maximum, and standard deviation were estimated. The results of this study are presented in tabulated and graphical forms in the next Chapter 4.

3.10 Water Network Modeling

The hydraulic modeling was carried out using the EPANET software. The water network pipes and their characteristics were collected from the AADC GIS layers. Several water reduction scenarios were performed in order to estimate the potential of greywater available in the study area and to analyze the effects of greywater reuse on the pipe network, so that adequate quantities of municipal water can be conserved and overall water consumption can be reduced. The Chapter 5 discusses the detailed methodology and hydraulic modeling simulation of the existing water network of the study area. The software is freely available at the link www.epa.gov. It is widely used in many studies due to its user-friendly applications.

3.10.1 Description of Modeling Scenarios

To evaluate the greywater reuse potential, several studies applied hydraulic modeling on the existing pipelines by adopting different hypothetical scenarios with respect to the current municipal water supply consumption, in order to find a suitable approach for greywater reuse (Mah *et al.*, 2008).

Three supply scenarios were considered in this study, which are based on greywater quantity estimated in Chapter 4. The first scenario was created based on actual current water consumptions calculated from the field and other two scenarios were 5% and 10% reduction in current consumptions, respectively. It was estimated in Chapter 4 that the indoor water consumption is only 15% of the total water consumption in the study area. Theoretically, it was shown that a maximum of 8% of municipal water can be saved at the greywater generation rate of 192 liters/capita/day. Table 3.3 shows the water consumption reduction scenarios adopted in the hydraulic modeling simulation. The adopted water consumption scenarios of the existing municipal water distribution network will check any effect of greywater reuse on the existing water distribution network operation and performance including pressure and velocity.

Table 3.3: Description of water consumption scenarios

Scenario	Actual yearly consumption (m^3)	% Reduction	Annual consumption (m^3) used for modeling
1^{st}	867,434	0%	867,434
2^{nd}		5%	824,062
3^{rd}		10%	780,691

3.10.2 Water Consumption Calculation Methodology

The actual water consumption data recorded from water meters were used in the hydraulic modeling in order to determine the real flow conditions of the water system. The total water consumption of 86, 7434 m^3/year was calculated in the next

Chapter 4 in section 4.2.1 describe the detail of water consumption estimation for each block and the whole study area.

Chapter 4: Water Consumption

4.1. Introduction

This chapter includes the results of water consumption data analysis and the results of questionnaire survey interviews. Accordingly, the tables, charts and graphs are used to describe the summary of results. Statistical analyses of water consumption data for 100 villa type houses were conducted and included in this chapter. This chapter discovers the quantity and nature of water consumptions in the study area.

4.2. Municipal Water Consumption

The water meter reading data for 12 months were collected from all houses in the study area, as mentioned in the methodology section. There were 100 villa type detached houses of size 45 m by 45 m, built by the Government of Abu Dhabi. In addition, there were a private villa, a mosque and a co-operative shopping market in the study area. All houses are connected to the water distribution pipe of diameter ¾ inches, but only three houses consist of two connections with same size (¾ inch) water mains. The private villa, mosque and the co-operative shopping market are connected with a 1½ inch size water distribution pipe.

The water meter readings from February 2013 to January 2014 were recorded for every house. Figure 3.3 in Chapter 3 shows the layout of houses in different blocks in the study area. For the purposes of analyses, the study area was divided into 11 blocks and their alphabetic names are shown in Figure 3.3 (Chapter 3) and also in Table 4.1. Only the Block-N has a 1½ inch size water distribution pipe connection and all other blocks have a ¾ inch water connection. The total yearly consumption was calculated for each block and then the summation of all blocks' consumption was completed to find the accumulated consumption of the whole study area as shown in the Table 4.1. Moreover, numbers of villas in each block were also recorded and zero consumption houses were called as empty house as shown in the Table 4.1.

Table 4.1: Municipal water consumption in the study area

Block	Number of houses	Number of empty houses	Annual water consumption (m^3)	Water consumption per block (% of total)	Average consumption per house (m^3 /year)
Block-A	12	4	99,169	11.43%	1,418
Block-B	12	0	119,191	13.74%	1,370
Block-C	8	0	80,498	9.28%	934
Block-D	10	0	85,143	9.82%	834
Block-E	8	0	104,445	12.04%	1,577
Block-F	12	0	126,752	14.61%	1,546
Block-G	10	3	50,147	5.78%	416
Block-H	12	0	102,389	11.80%	1,003
Block-J	8	1	41,838	4.82%	288
Block-M	8	1	54,978	6.34%	500
Block-N	3	0	2,884	0.33%	3
All Blocks	103*	9	867,434	100%	

*There are 100 villas, but the Block-N occupies two commercial buildings and a mosque

Table 4.1 shows that, except for Block-N, average water consumption per house varies from 288.7 m^3 to 1577 m^3 per year. Dividing by 365 days, it becomes 790 L/day/house to 4321 L/day/house. Very low water consumption in Block-N is because the construction of these houses is not completed yet and there are some occasional inhabitants. A total of nine houses was found empty, and they are not included in the analyses.

4.2.1. Comparison of Water Consumption between Field and AADC Record

In order to verify the field data collected from consumer's water meter, the AADC water consumption details of the study area was obtained for the same period. Table 4.2 shows the comparison between monthly data collected from water meters during this study with the AADC monthly record available at the water supply operation office.

The results provided in Table 4.2 show that the field data collected from houses are closely matched with the AADC consumption record supplied to the distribution network of the study area. The AADC supplied data are approximately 5% more than the accumulated water consumption meter readings from all houses. This 5% additional supplied water is generally used for network flushing, fire demand and lines losses. Therefore, the collected water consumption data from all houses can be considered for subsequent analyses.

4.2.2. Monthly and Seasonal Water Consumption Pattern

The monthly water consumption in the study area is shown in Figure 4.1. It shows that water consumption decreased in winter season (December – February).

The monthly water consumption as a % of total water use is also shown in Figure 4.1. It shows that monthly water consumption varies between 7% to 9% of total water use in the study area. It is evident from the Figure 4.1 that winter season (November-January) water consumption is approximately 2% less than the other seasons.

Table 4.2: Comparison of collected field data with the AADC water supply record

S.No	Months	Accumulated field meters' consumption (m^3)	AADC DMA meter consumption (m^3)	Data difference (m^3)	Data difference (%)
1	February 2013	69,473	74,932	5,459	7.29%
2	March	78,071	81,257	3,186	3.92%
3	April	73,429	75,918	2,489	3.28%
4	May	76,701	79,592	2,891	3.63%
5	June	74,433	77,100	2,667	3.46%
6	July	75,342	78,169	2,827	3.62%
7	August	73,916	76,708	2,792	3.64%
8	September	73,363	76,873	3,510	4.57%
9	October	75,964	79,965	4,001	5.00%
10	November	69,491	75,519	6,028	7.98%
11	December	66,020	71,996	5,976	8.30%
12	January 2014	61,231	64,701	3,470	5.36%
Total Yearly / Avg:		867,434	912,730	45,296	4.96%

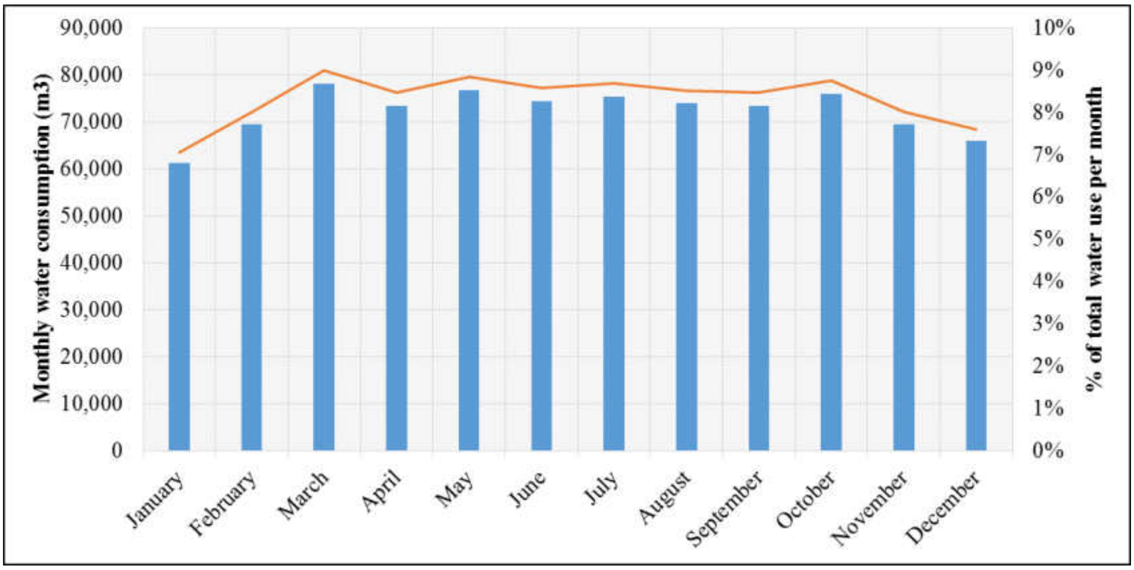

Figure 4.1: Monthly water consumption pattern at the study area

The Figure 4.2 shows the distribution of monthly water consumption among the different houses in the study area. A total of nine houses was emptied and have zero water consumption. From the Figure 4.2, it is clear that water consumption mostly varies between 200 to 1400 m^3/month. Extremely high water consumption is observed in three houses only (1400 to 1800 m^3/month) and only nine houses exhibit low water consumptions (less than 200 m^3/month). The median water consumption of 800 to 1000 m^3/month is observed in 19 houses.

4.3. Per Capita Water Consumption

To calculate the per capita per day water consumption is one the focal points in this study, the equation mentioned in Chapter 3 (Section 3.5.4) was used to determine the per capita per day water consumption. Average population of 10 persons per family (house) was considered based on the survey of population for 35 houses and for rest of houses same average was considered to calculate the per capita water consumption.

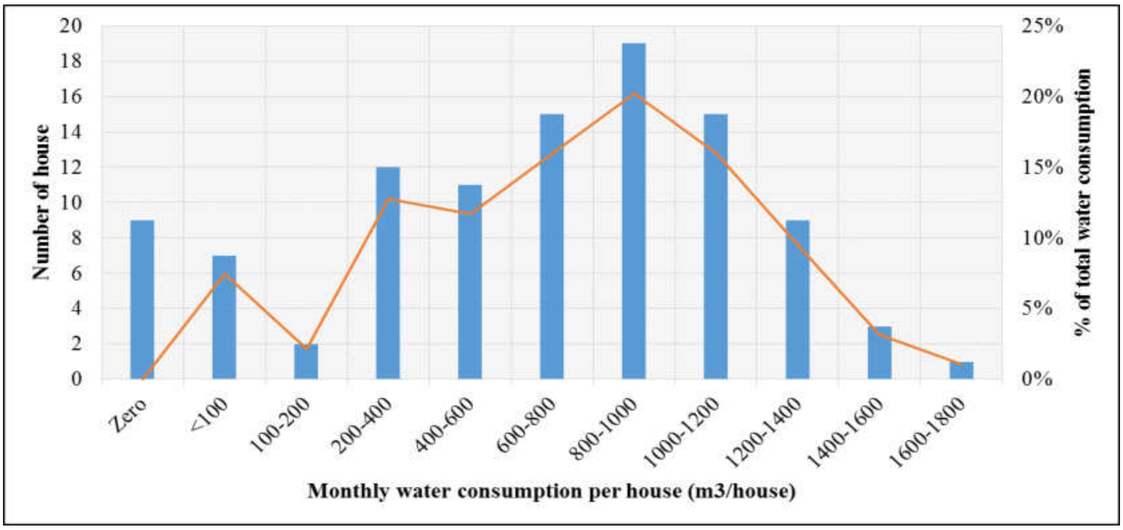

Figure 4.2: Water consumption pattern in different houses at the study area (bar indicates number of house and solid line indicates the % of total water use)

The Table 4.3 describes the per capita per day water consumption for different blocks in the study area as mentioned in Figure 3.3. Three houses in the Block-N was not fully occupied during the study year and therefore omitted in the estimation of average per capita water consumption. After accumulation of overall consumption for a year, the average per capita per day consumption was found equal to 2,577 liters/capita/day (standard deviation of 613) (except block-N), which is significantly larger than the recommended value by RSB regulation laws. Further, the actual consumption of 35 surveyed houses is described in the Figure 4.3, which shows the actual numbers of family members and their daily municipal water consumption in liters.

Table 4.3: Calculation of per capita water consumption

Block ID	Number of occupied houses	Population (survey result)	Annual water consumption (m^3)	Water consumption (m^3/capita/day)	Water consumption (liter/capita/day)
Block-A	8	80	99,169	3.4	3,396
Block-B	12	120	119,191	2.7	2,721
Block-C	8	80	80,498	2.8	2,757
Block-D	10	100	85,143	2.3	2,333
Block-E	8	80	104,445	3.6	3,577
Block-F	12	120	126,752	2.9	2,894
Block-G	7	70	50,147	2.0	1,963
Block-H	12	120	102,389	2.3	2,338
Block-J	7	70	41,838	1.6	1,637
Block-M	7	70	54,978	2.2	2,152
Block-N	3	30	2,884	0.3	263
All Blocks	94	940	867,434	2.5	2,577 *

**except Block-N, because it has two commercial and a mosque connection*

4.4 Statistical Analysis of Water Consumption

4.4.1 Statistical Analysis of Monthly Water Consumption

The statistical analysis of monthly water consumption among the different houses is shown in Table 4.4. Different statistical parameters like mean, median, minimum, maximum, standard deviation, skewness and kurtosis coefficients were estimated and shown in Table 4.4. It shows that significant variations are observed among monthly water consumptions in different houses. Higher standard deviation exhibits this variation. Minimum water consumptions are approximately near to 100 m^3 and maximum consumptions are approximately 2000 m3. A negatively skewed distribution is observed for the months of May to October. This indicates that monthly water consumption exhibits positively skewed distribution in winter season, whereas negative kurtosis coefficients are observed for all months.

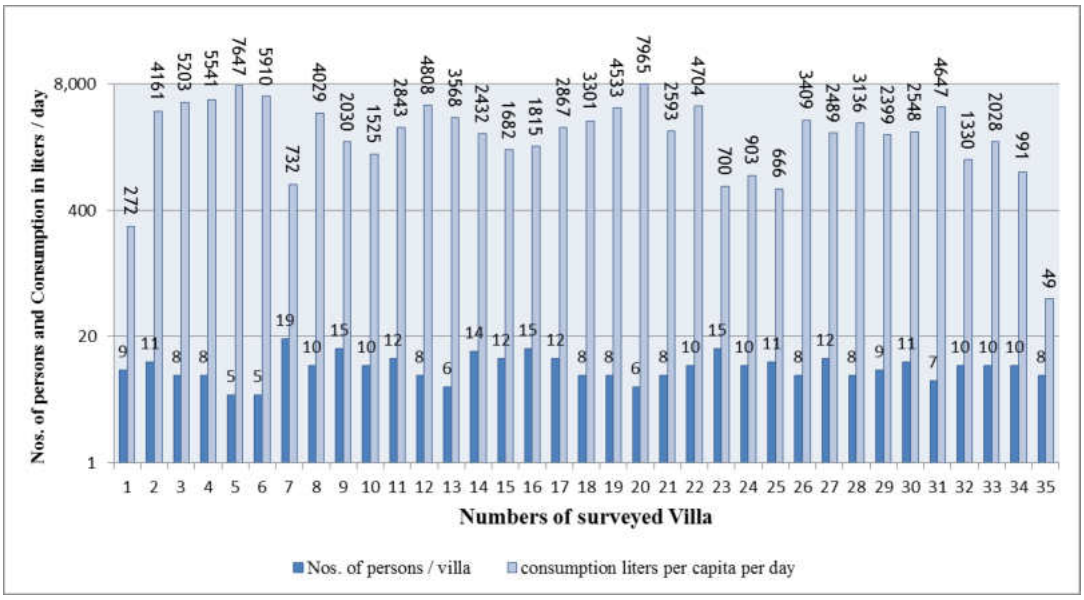

Figure 4.3: Details of water consumption and family size in surveyed 35 villas

Table 4.4 Summary of statistical analysis of monthly water consumption of different houses in the study area

Month	Mean (m^3)	Standard deviation (m^3)	Minimum (m^3)	Median (m^3)	Maximum (m^3)	Skewness	Kurtosis	Total consumption (m^3/month)
February 2013	841	532	100	757	2,102	0.59	-0.63	69,473
March	897	495	102	858	2,017	0.30	-0.75	78,071
April	837	434	123	815	1,844	0.35	-0.65	73,429
May	845	399	122	859	1,753	-0.06	-0.78	76,701
June	821	385	127	850	1,627	-0.13	-0.96	74,433
July	833	363	135	848	1,637	-0.13	-0.72	75,342
August	817	359	111	832	1,539	-0.23	-0.83	73,916
September	810	368	127	859	1,621	-0.21	-0.87	73,363
October	853	373	127	887	1,765	-0.16	-0.56	75,964
November	803	399	109	814	1,796	0.10	-0.52	69,491
December	762	432	103	769	1,862	0.39	-0.52	66,020
January 2014	731	474	103	639	1,992	0.62	-0.59	61,231

4.4.2 Statistical Distribution of Water Consumption

The Minitab version-17 was used to perform the statistical distribution of collected water consumption data. Figures 4.4 to 4.7 show the probability graphs and histogram charts of water consumption (monthly) for 100 houses, which indicate that monthly water consumption follows a normal distribution during January, February and September and May, June and July. The August, October and November are following the Gamma distribution, but March, April and December are the month, which are following Lognormal distribution. The histogram charts show that majority of consumption lies between 500 m^3 to 1500 m^3 monthly as indicated by the distribution curve, which mean the majority of houses are using high water consumption. Further, the appropriate fitted distribution values were selected after comparison of the probability distribution analysis as shown in the Table 4.5.

Figures 4.4 to 4.7 show that water consumptions in the months of Janaury, February and September are best fitted by normal probability distribution at the 95% confidence interval and water consumptions in the months of March, April and December are are best fitted by lognormal probability distribution at the 95% confidence interval. Further, the water consumptions in the months of May, June, July, August, October and November are best fitted by the Gamma distribution at the 95% significance level.

Table 4.5: Comparison of probability distribution for Monthly Water Consumption

Months	Comparison of probability distribution			
	Normal	Gamma	Weibull	Lognormal
January	P<0.005	P=0.022	P=0.023	P<0.005
February	P<0.005	P=0.249	P>0.250	P=0.006
March	P=0.140	P=0.026	P>0.250	P<0.005
April	P=0.114	P=0.149	P>0.250	P<0.005
May	P=0.113	P<0.005	P<0.010	P<0.005
June	P=0.024	P<0.005	P<0.010	P<0.005
July	P=0.153	P<0.005	P=0.014	P<0.005
August	P=0.018	P<0.005	P<0.010	P<0.005
September	P<0.005	P<0.005	P<0.010	P<0.005
October	P=0.023	P<0.005	P<0.010	P<0.005
November	P=0.182	P<0.005	P<0.010	P<0.005
December	P=0.067	P=0.008	P=0.080	P<0.005

Moreover, the distribution graphs show that the consumption rates are relatively high in summer months compared to the winter months. The variation in the number of houses (N) is due to remove of outliers in order to refine of unnecessary water consumption data and to build an adequate input model for appropriate statistical analysis and observations.

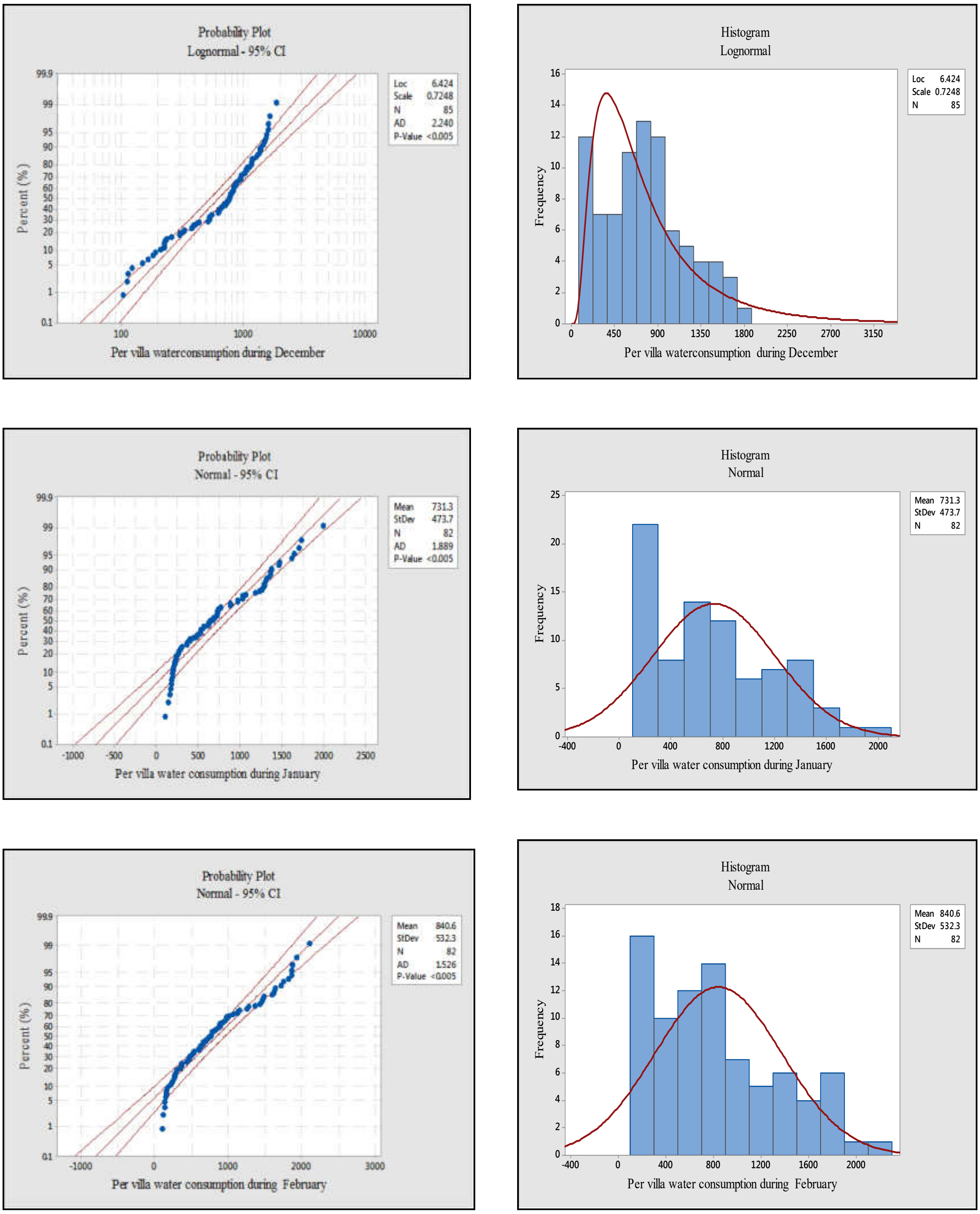

Figure 4.4 Statistical distribution of monthly water consumption for Winter

(December – February)

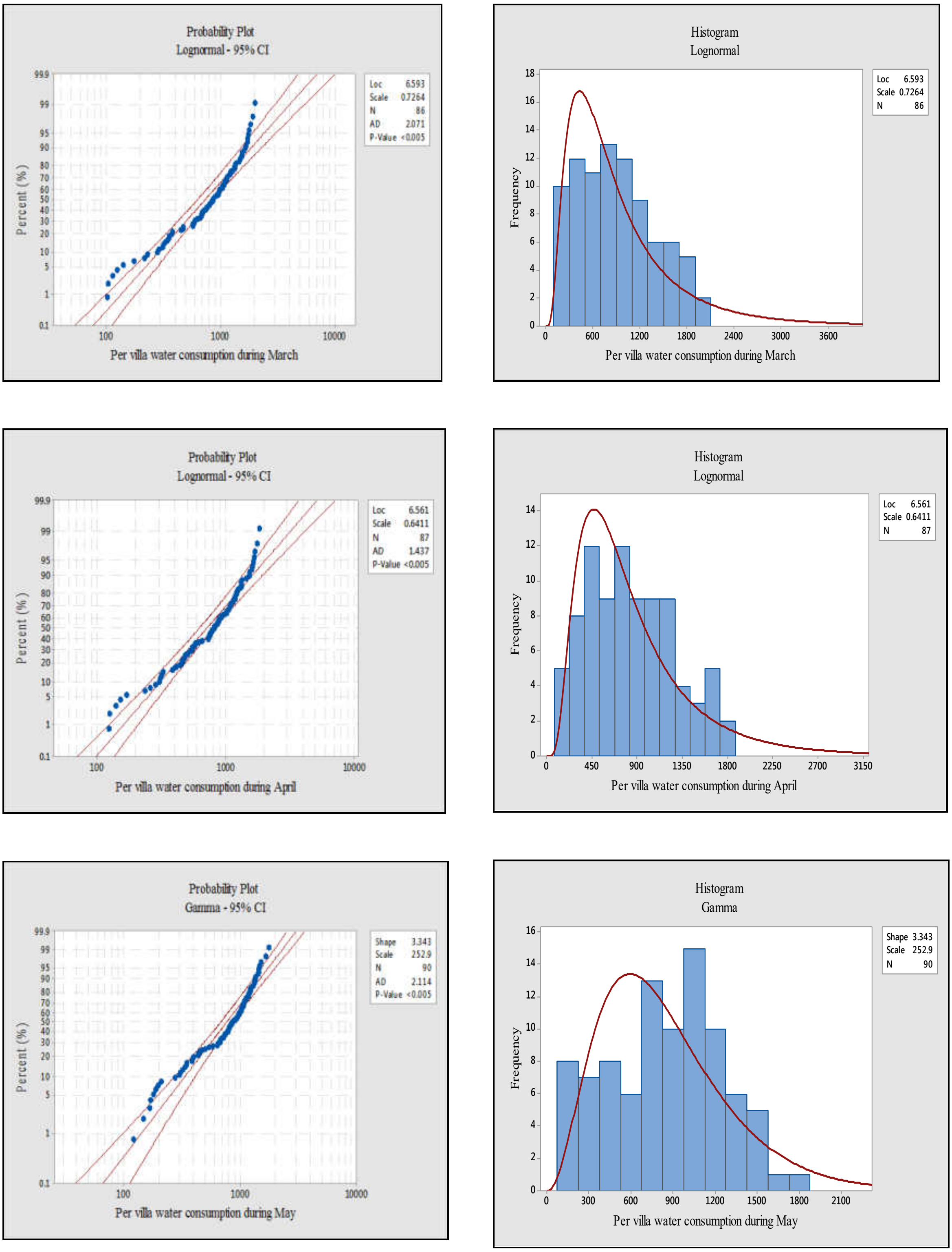

Figure 4.5: Statistical distribution of monthly water consumption for Spring

(March – May)

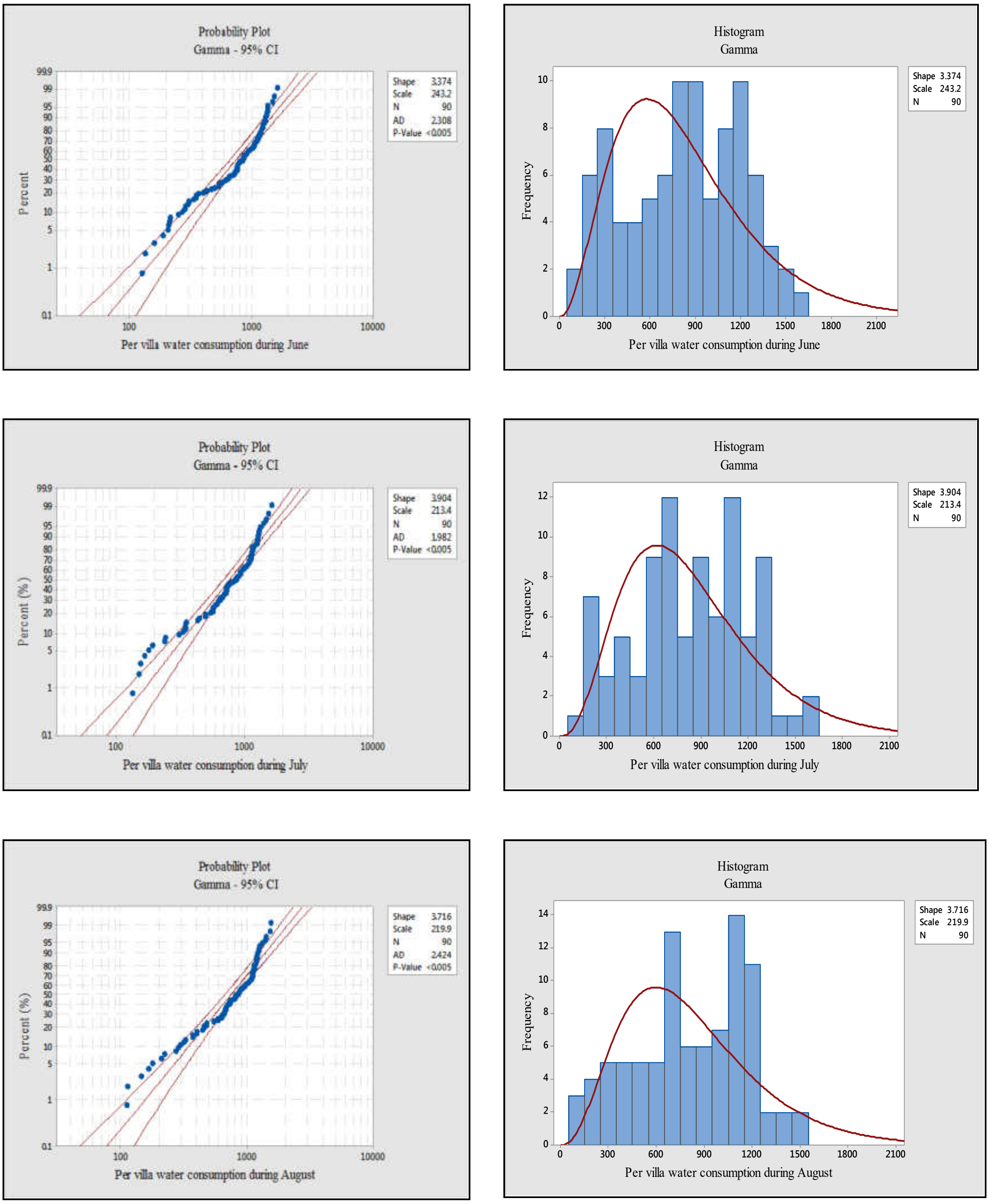

Figure 4.6: Statistical distribution of monthly water consumption for Summer

(June – August)

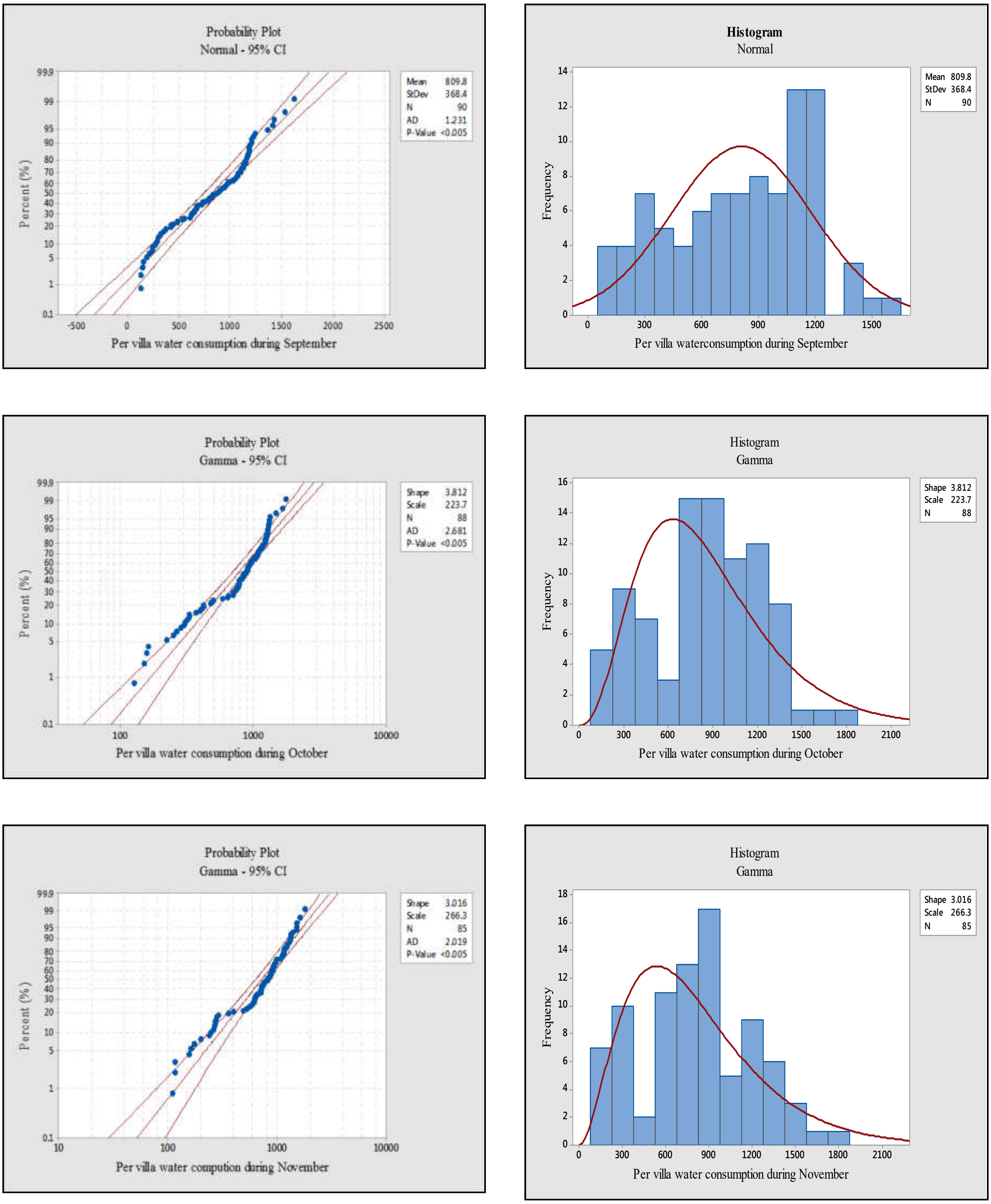

Figure 4.7: Statistical distribution of monthly water consumption for Autumn (September – November)

4.4.3 Statistical Analysis of Number of Persons vs. Water Consumption

The statistical analysis was done to find out the effects of numbers of persons on each house's water consumption, so the number of persons was considered as the factor and the water consumption was considered as the response to develop the statistical model of the ANOVA.

The statistical analysis done through Mini-tab and graphical results are shown in Figure 4.8. That indicates that collected water consumption data is satisfactory, and the normality plot shows that the distribution of consumption is normal, and the residual plot shows that the observation of water consumption is equally distrusted.

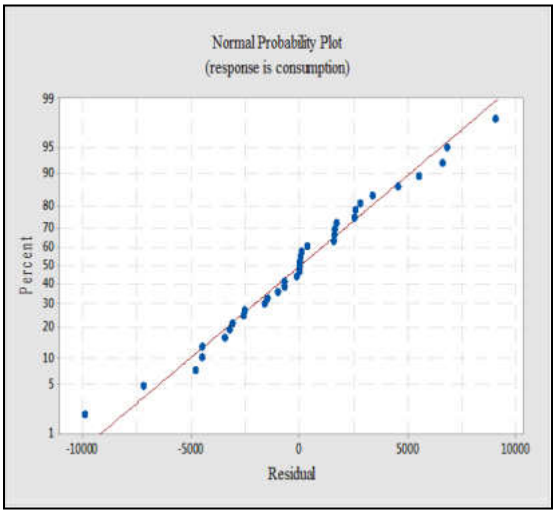

Figure4.8 (a): Probability plot of data

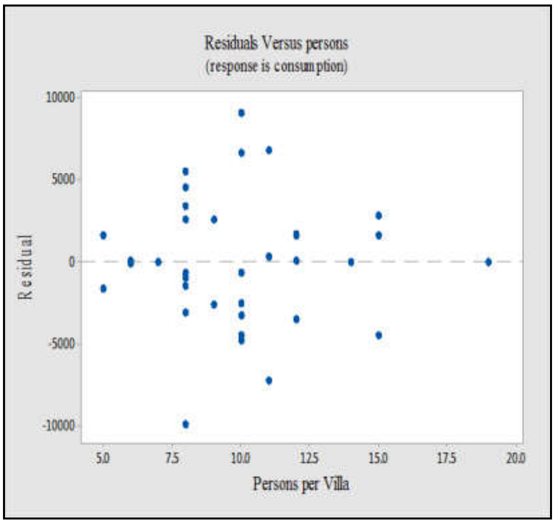

Figure4.8 (b): Residual Plot of data

Figure 4.8(a – b): Probability and residual plot for number of people vs. water consumption (Source: Table 4.7)

The Figure 4.9 shows that the order plot of water consumption in 35 houses and the order plot indicate that the water consumption order is independent for each house, which mean that each house's water using activities vary from each other due to the garden area and numbers of plants. It shows that the observation of residuals has an independent order.

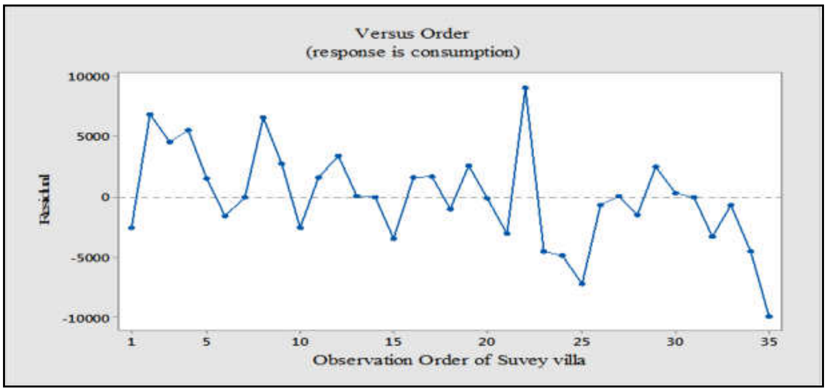

Figure 4.9: Dependent Order plot for consumption (Source: Table 4.7)

The main effect plot (Figure 4.10) of the relation between water consumption and the number of persons per family provides the clearest indication that the number of family members is not playing a significant role to escalate the water consumption.

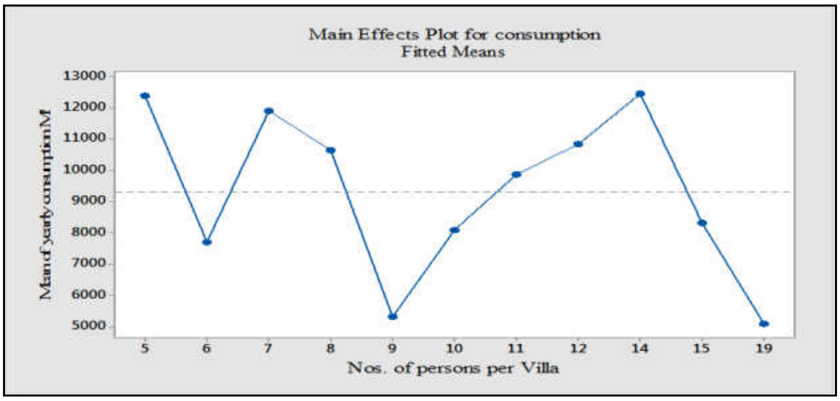

Figure 4.10: Effect plot, number of family member Vs water consumption

(Source: Table 4.7)

An example is that a five persons' villa has the highest consumption, whereas a nineteen persons' villa has the lowest consumption. Therefore, it is clear that the outdoor water consumption has the significant role in total water consumption in the study area.

4.5 Discussion on Water Consumption

The calculated results demonstrate that the average water consumption of more than 2,500 liters/capita/day is five times higher than the ADWEC and RSB estimated average consumption rate of 500 l/p/d in the region. It is noticed that the large size (1½ inch) water connections have 263 l/p/d consumption, which is about 12 times lower consumption compare to the villas connected with connection pipe of ¾ inch. The villas in the study area exhibit high water consumptions throughout the whole year and a slightly higher consumption is summer months. This indicates water consumption increased with higher temperatures in the summer season. The population density in the study area was found relatively low (based on surveyed family size). Therefore, the most possible reason for high water consumption is due outdoor water uses for plantation and home garden activities. During the field visits in the study area, it was observed that most villas are fitted with a modern drip irrigation system for watering the plants or fitted with fold irrigation as shown in the Figure 4.11.

Statistical analyses performed in the study also confirmed that the population does not have a significant effect on water consumption. The results show that the municipal water is not only used for domestic purposes (indoor), but the most obvious reason for the high water consumption rate is their use for outdoor activities. The questionnaire survey conducted (details are in the next section) in the study also confirmed that about 94% of houses are using municipal water for home garden irrigation and plants watering.

Figure 4.11: Photos of plantations and gardens in the study area

4.6 Results of Questionnaire Survey

There is a total of 100 villas, two commercial and a mosque in the study area. Out of them, nine houses were found empty and there is a mosque and a shopping market in the study area. Therefore, a total of 91 villas was visited randomly for the questionnaire survey. Sufficient responses were received from the villa residents to participate in the survey questionnaire and about 38% of villa residents (35 villas out of 91) were responded; some residents did not participate in the survey because of social barrier and personnel hesitation. The survey respondents were from all blocks in the study area. The outcomes of the survey from 35 villas can be considered sufficient enough for this study because the residents in all villas are Emirati national having similar socio-cultural tradition and water usage activities. There were 10 multiple choice questions in the questionnaire, the respondents' responses are summarized in Table 4.6.

Table 4.6 shows the tabulated results of the survey questionnaire. There are 100 residential villas dwelled by UAE nationals in the study area. All houses are receiving 24 hours municipal water from AADC without any interruption.

- The responses in question 1 show that only 69% of residents were satisfied with the current water supply quantity, but 31% resident were not satisfied with their current consumption of water quantities because all open areas are covered with green plantations and gardens. The reason behind dissatisfaction of current supply is that these residents have smaller diameter connection size ¾" but they have vegetation on large area inside and outside of the villa.
- The question 2 survey results indicate that 97% of residents are using municipal water for drinking purposes and only 3% are not using, most probably they use supplied bottled water for drinking purposes.
- The question 3 survey results indicate that 94% of residents are using municipal water for irrigation to home gardens and plantation. This indicates that the consumption is mainly dominated by the outdoor activities and most of these houses have gardens and plantation in their premises.

Table 4.6 Summary of survey questions and respondents’ responses

Question's statement	**Response**					
	Yes (%)	**No (%)**	**I don't know (%)**	**2 times**	**3 times**	**Other times**
Do you receive enough water for uses from the water network?	69%	31%	0%			
Do you use municipal water for drinking purposes?	97%	3%	0%			
Do you use municipal water for home garden irrigation?	94%	6%	0%			
How many times a day, do you need water for irrigation?	-	-	-	86.6%	8.6%	2.9%
Do you believe water conservation is an important issue in Al Ain?	100%	0%	0%			
Do you believe how importance is individual action to meet water demand?	97%	3%	0%			
Do you plan to take any action in this year to lower your water use?	86%	11%	3%			
Do you agree to reuse laundry, washing and shower water for home garden irrigation?	86%	3%	11%			

- The question 4 survey results indicate that more than 86% of residents give water to their garden and plants more than 2 times a day and more than 8% respondents give more than 3 times. This is very logical for the harsh weather and for non-native plants.
- The question 5 survey results show that 100% of respondents are aware that water conservation is very important for the Al Ain region.
- The question 6 results indicate that 97% of respondents know that individual action to save water is important and only 3% of them think that individual action does not affect water conservation. This is very interesting that people are aware of the conservation.
- The question 7 results show that 86% of respondents have intended to save water, but 11% of them did not have any plan to save water and 3% are not confident about their plan.
- The question 8 was one of the key questions for this study and the results show that 86% of respondents were agreed and have the intention to reuse greywater for plantation and home garden, but 3% of them were not agreed to reuse greywater and 11% of them were not sure about this.
- The question 9 was specific to judge the residents' opinion to bear the cost of greywater on-site filtration system, the results show that 71% of respondents agreed to install the filtration system, if the government bear the cost; about 26% of respondents were not sure about any clear opinion and only 3% of them were agreed to share the cost of on-site greywater filtration system. This indicates that any on-site greywater reuse scheme requires subsidies from the Government sector.

- The question 10 was the focal point in this survey about the estimation of study area population, the 35 houses were surveyed to get the information about family members and to estimate the whole village population. Based on the family size information from 35 houses, an average family size of 10 was estimated and then averaged over the whole study area, which provided a total population of 994 in the study area. Further, during the survey, it was found that 94% (33 out of 35) houses were occupied by Emiratis. Only 6% houses were on rent, which were occupied by other national (expats). The Table 4.7 shows the recorded family sizes of the study area houses. There were two age groups in the survey, below and above (and equal) 15 years of age. Total family size is the summation of both age groups. The houses were selected from all residential blocks to get a realistic reflection of the population.

However, the survey results confirmed that the majority of residents is using municipal water for watering the plants and home garden and it is the real cause of the high rate of per capita per day water consumption. It was a positive finding that about 86% of respondents were agreed to support the greywater reuse in their home garden irrigation.

Table 4.7* Actual population of 35 houses and consumption in study area collected during the survey

S.N.	House ID	Age and number of people			Yearly consumption m³
		≤ 15	≥ 15	Total	
1	A-7	4	5	9	2,743
2	A-8	3	8	11	16,705
3	A-11	0	8	8	15,192
4	B-1	4	4	8	16,179
5	B-5	3	2	5	13,956
6	B-11	1	4	5	10,785
7	C-2	9	10	19	5,078
8	C-3	5	5	10	14,705
9	C-4	0	15	15	11,115
10	C-6	0	10	10	5,567
11	C-7	5	7	12	12,452
12	C-8	4	4	8	14,038
13	D-2	2	4	6	7,813
14	D-5	2	12	14	12,428
15	E-1	4	8	12	7,368
16	E-2	2	15	15	9,939
17	E-4	4	8	12	12,559
18	F-1	4	4	8	9,639

S.N.	House ID	Age and number of people			Yearly consumption m³
		≤ 15	≥ 15	Total	
19	F-3	6	2	8	13,236
20	F-4	4	2	6	7,572
21	F-8	2	6	8	7,570
22	G-1	6	4	10	17,171
23	G-3	6	9	15	3,835
24	G-5	5	5	10	3,297
25	G-10	6	5	11	2,675
26	H-2	5	3	8	9,953
27	H-3	4	8	12	10,904
28	H-4	5	3	8	9,157
29	H-5	2	7	9	7,880
30	J-7	1	10	11	10,231
31	M-1	0	7	7	11,874
32	M-2	6	4	10	4,856
33	M-5	4	6	10	7,403
34	M-7	6	4	10	3,616
35	N-1	4	4	8	742

*table used to calculate main effect plot person vs water consumption

4.7 Greywater Generation Assessment and Calculation

The calculation of greywater generation is one of the main purposes of this study. Estimation of greywater generated at shower, wash basin, laundry and bathroom are the main sources of greywater generation at every house. Greywater can be reused for home garden irrigation to reduce the overall municipal water consumption. A schematic view of greywater reuse scheme is shown in Figure 4.12.

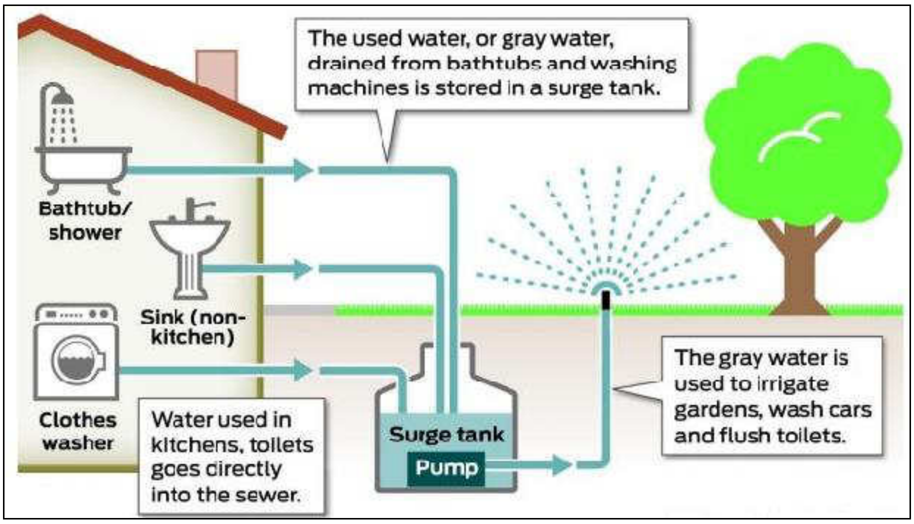

Figure 4.12: A schematic view of greywater generation and their reuse at houses

(Source: http://secure.waternow.org/index.php?cmd=focus_urban, December 2014)

Therefore, in order to estimate the actual generation of greywater at study area, the average wastewater quantity (sewer flow) generated from February 2013 to January 2014 (181,616 m^3) at the study area was obtained from the AADC (personal communication). The amount of water used for indoor activities is calculated as the difference of municipal water supplied to the area and the wastewater received at the sewer treatment plant. Table 4.8 shows the average monthly wastewater flow volume (sewer flow) from the study area.

Table 4.8: Monthly average wastewater flow (in m^3) from the study area

(Al Faqa New and Old Village) (source: ADSSC, Personnel Communication)

January	February	March	April	May	June
15221	15540	17639	17940	18290	14370
July	August	September	October	November	December
14787	13516	12630	13764	13380	14539

Table 4.8 shows the data of wastewater flow volume for two villages (new and old Al Faqa), therefore, in order to calculate wastewater volume from the study area (new village), the water supply data were obtained from the AADC pumping station to identify the percentage of wastewater share by each village. The data are shown in Table 4.9.

Table 4.9: AADC water supply distribution for both villages

(source: AADC)

Month	Total water supplied (m^3)	Al Faqa New Village (Study Area)		Al Faqa Old Village	
		Consumption m^3	% of consumption	Consumption M^3	% of consumption
May-14	122,054	84,417	69%	36,434	30%
Jun-14	124,281	87,510	70%	40,312	32%

Table 4.9 shows that the study area (Al Faqa new village) has about 70% of supplied water, therefore wastewater generation share was also same. Considering the

70% of wastewater generated from the study area, a total of 127,131 m^3/year wastewater generation can be considered from the study area. Table 4.10 shows the estimated wastewater generation (sewer flow) from the study area.

Table 4.10: Estimated wastewater generation (sewer flow) (in m^3) from the study area

January	February	March	April	May	June
10654	10878	12347	12558	12803	10059
July	August	September	October	November	December
10351	9461	8841	9635	9366	10177

An estimation of 127,131 m^3/year of wastewater (sewer) flow indicates that the indoor water consumption in the study area is 127,131 m^3/year (15% of total water consumption) and the rest of 85% (867,434 – 127,131 = 740,303 m^3/year) is used for outdoor activities. Considering a total population of 994 (family size of 10 per house) in the study area, it can be shown that indoor water consumption is about 350 liters per capita per day in the study area. The estimated outdoor water consumption rate is about 2040 liters per capita per day.

This assessment results indicate that there is more than 80% difference in the municipal water consumption and wastewater production in the study area. This huge difference in quantity is generally due to use of municipal water for outdoor activities such as plantation, home garden irrigation and car washing in the villas. This opinion can be validated, since each house has an 2,025 m^2 area and the building exist only in

740 m^2 (estimated in the Google earth pro), which indicates that 40% area is used for building and 60% area is used for home garden and parking.

Greywater in the UAE does not include toilet and kitchen wastewater. A recent study in the Al Ain city considering villa type houses (similar housing pattern in this study) estimated greywater generation rate of 192 liters/capita/day (Chowdhury *et al.*, 2014). Considering a similar greywater generation rate and an indoor water consumption of 350 liters/capita/day in the study area; greywater generation rate is about 55% of the indoor water use. Therefore, conceptually if 100% greywater will be reused for irrigation, only 8% of total water will be saved in the study area and this is because about 85% of water consumption is used for outdoor activities. But extraction of all greywater will reduce the generation of wastewater (from 350 lpcd to 158 lpcd, if all greywater is extracted) and may negatively affect the water/sewer network. This research question is covered in the next Chapter 5 for hydraulic modeling.

Chapter 5: Hydraulic Modeling of Water Network

5.1 Introduction

The water network hydraulic simulation and modeling is a technique, which is used for planning, design and operational applications to analyze the effectiveness of water supply system at different supply scenarios or conditions. The modeling work is generally pursued before implementation of a proposed water supply plan in order to determine the network performance. The hydraulic simulation is usually done by developing a model, based on the topographical condition and local requirements by using a suitable computer modeling software. This chapter describes the hydraulic modeling of existing water network in the study area using the EPANET software. The objectives of this chapter is to compare the results of different scenarios of water consumption reduction by greywater reuse in the water network in order to identify the optimal condition of greywater reuse for home garden irrigation.

5.2 Background of Hydraulic Modeling

Generally computer software is used to analyze the water distribution systems or network for flow and pressure. The softwares widely used for hydraulic modeling of water networks are EPANET, WADISO and WATERCAD. The simulation of any existing or new water network is very important to determine the hydraulic performance of a water distribution system. In order to obtain the satisfactory results from hydraulic modeling of different water reduction scenarios (to meet the minimum pressure and velocity requirements in the water network), accurate input data in the software play a significant role.

5.3 Purpose of Hydraulic Modeling

The primary purpose to perform the hydraulic modeling of the existing water network in the study area is to identify the effects of estimated greywater reuse, as reduction in total water consumption and change in water flow rate. Accordingly, the modeling result will guide to reuse the available greywater extraction, since after reduction in consumption; the water network is maintaining the optimum pressure and velocity requirement without modification of the water system.

The reuse of greywater and thereby to reduce water consumption in the study area are the main objectives of this study and it is expected that the reduction in current water supply will affect the existing water network system in terms of flow velocity and pressure. Therefore, it is necessary to analyze the effects of forecasted reduced municipal water quantity on the existing water network by using the hydraulic model.

5.3.1 Water Supply Scenario's Consumption Estimation

Three water reduction scenarios were considered in this study. The first scenario was based on the actual water consumption of 867,434 m^3 (no reduction), which was estimated at the consumers' connection points from the water distribution linearly converted into flow rate of 27.51 L/s.

The total wastewater produced by indoor water activities was estimated 127,131 m^3 annually as described in the Table 4.10, which is 15% of total (867,434 m^3) municipal water consumption. In the literature, it was found that about 69% of wastewater are greywater (Chowdhury *et al.*, 2014), but their rate of generation is about 192 liters/capita/day. Therefore, considering the generation rate of 192 liters/capita/day, maximum possible water saving target of 8% of total water consumption (indoor + outdoor) and considering the 69% of wastewater is greywater, a maximum of 10.11% of total water can be saved. Hence, the other two scenarios assumed in this study were reduction of total water consumptions by 5% and 10%. Table 5.1 shows the reduced water consumption and subsequent flow rates in liters/second. These reductions are considered for the total municipal water consumption in the study area (both for indoor and outdoor activities). The water consumptions in flow rate (L/s) are used as input data into the hydraulic model of the EPANET.

Table 5.1: Description of scenario and water consumption

Scenario	Actual yearly consumption (m^3)	% Reduction	Reduced yearly consumption (m^3)	Demand (L/sec)
1st	867,434	0%	867,434	27.51
2nd		5%	824,062	26.13
3rd		10%	780,690	24.76

5.4 Description of Modeling Parameters

To simulate the hydraulic model for the existing water network, several hydraulic and physical parameters are required to input in the model, such as water flow rate, pipe size and slope, pipe material and operational condition of the existing water supply system. These parameters are obtained through field data and from the AADC.

5.4.1 Water Network Layout

The details of the water mains layout plan of the existing water network are an important input into the model. The water network in the study area was obtained from the AADC. Figure 5.1 shows the water distribution mains in the study area.

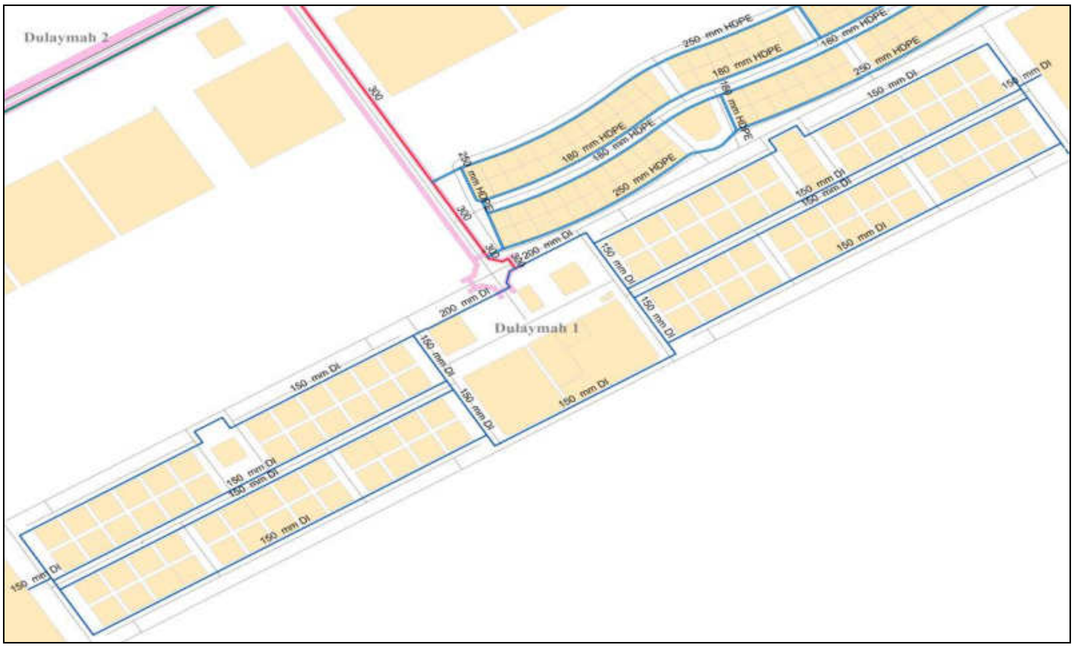

Figure 5.1: Layout of water distribution network in the study area (source: AADC)

5.4.2 Details of Water Network Pipes

The pipe lengths and pipe sizes are very important information for adequate simulation of the existing water distribution network. Therefore, the detail water network layout drawing was collected from the AADC and each pipe segment was marked with an ID, as shown in Figure 5.2. The total pipe lengths of existing water network were calculated to be 8,042.23 meters. The distribution network (DN) pipe of size 150 mm has a total length of 7,539.95 meters, DN 200 mm pipe has a length of 422.8 meters and DN 300 mm pipe has a length of 79.48 meters. The ductile iron pipes were used in the distribution network. Table 5.2 shows the different distribution network pipe segments (pipe ID as shown in Figure 5.2) and their corresponding sizes and lengths.

Table 5.2: Details of pipe size, length and material (Source: AADC)

S.No.	Pipe ID	Length (m)	Size (mm)	Pipe Material
1	P-1	100.00	300	Ductile Iron
2	P-2	232.04	200	Ductile Iron
3	P-3	9.98	200	Ductile Iron
4	P-4	160.26	200	Ductile Iron
5	P-5	2.38	150	Ductile Iron
6	P-6	354.92	150	Ductile Iron
7	P-7	105.30	150	Ductile Iron
8	P-8	354.91	150	Ductile Iron
9	P-9	105.97	150	Ductile Iron
10	P-10	21.00	150	Ductile Iron
11	P-11	105.97	150	Ductile Iron
12	P-12	763.81	150	Ductile Iron
13	P-13	764.00	150	Ductile Iron
14	P-14	764.00	150	Ductile Iron
15	P-15	25.67	150	Ductile Iron
16	P-16	105.97	150	Ductile Iron
17	P-17	21.00	150	Ductile Iron
18	P-18	105.97	150	Ductile Iron
19	P-19	350.93	150	Ductile Iron
20	P-20	25.67	150	Ductile Iron
21	P-21	105.97	150	Ductile Iron
22	P-22	21.00	150	Ductile Iron
23	P-23	105.97	150	Ductile Iron
24	P-24	344.95	150	Ductile Iron
25	P-25	105.20	150	Ductile Iron
26	P-26	354.91	150	Ductile Iron
27	P-27	105.97	150	Ductile Iron
28	P-28	21.00	150	Ductile Iron
29	P-29	105.97	150	Ductile Iron
30	P-30	763.85	150	Ductile Iron
31	P-31	763.85	150	Ductile Iron
32	P-32	763.81	150	Ductile Iron

5.4.3 Detail of Water Network Junctions and Elevation

Similar to the pipe length, the elevation data of existing pipelines were also collected from the AADC as built profile drawings. The laid pipelines' elevation details at each junction was recorded and marked with a unique junction ID (Figure 5.2) in order to use in the hydraulic modeling of the existing water distribution network. Table 5.3 shows the details of pipe and junction elevations along with their flow rate scenarios.

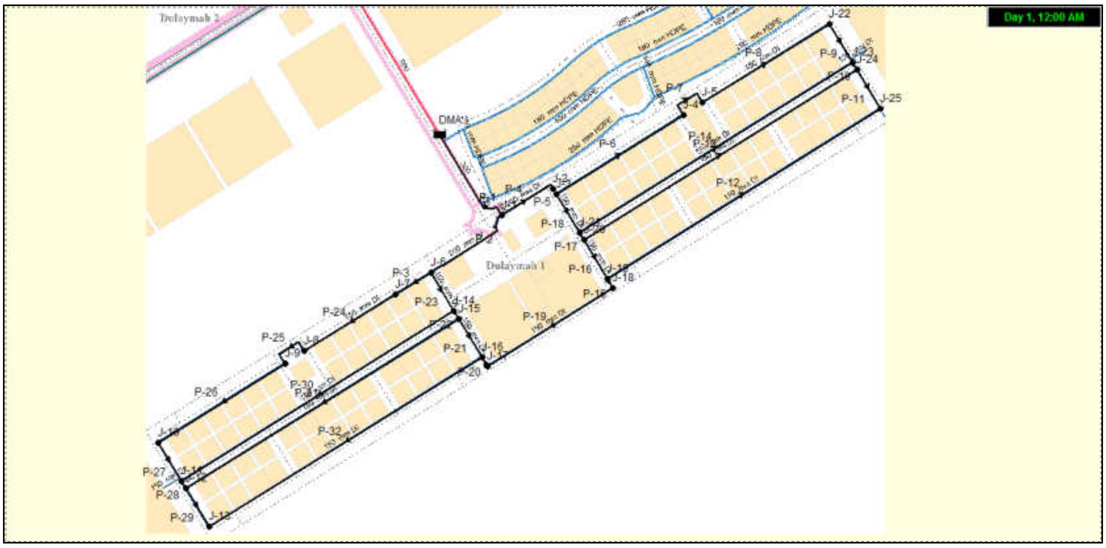

Figure 5.2: Layout of EPANET junctions and pipes

5.5 Hydraulic Modeling of Existing Water Network

To perform the hydraulic simulation of the existing water network, the junctions in the as built drawing are considered as the nodes and each node is identified by a unique ID. The nodes' elevation is obtained from the AADC lines profile drawings as mentioned in Table 5.3, theses elevations are used to input data in the EPANET. Further, the whole year's actual water consumption is converted into l/sec and used as water consumption by dividing at each node equally, except the nodes used for tee, elbow, reducer and network boundary as described in Table 5.3.

Table 5.3: Details of pipes, their ID and junction's elevation (source: AADC)

Node ID	Elevation (m)	Junction Demand (L/sec)			Remarks
		Scenario-1	Scenario-2	Scenario-3	
DMA	241.232	0.000	0.000	0.000	Boundary Node
J-1	241.525	0.000	0.000	0.000	T - Junction
J-2	242.522	0.000	0.000	0.000	Reducer 200x150
J-3	242.533	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-4	243.459	0.000	0.000	0.000	Elbow
J-5	243.751	0.000	0.000	0.000	Elbow
J-6	240.845	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-7	240.839	0.000	0.000	0.000	Reducer 200x150
J-8	239.261	0.000	0.000	0.000	Elbow
J-9	238.716	0.000	0.000	0.000	Elbow
J-10	237.496	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-11	237.810	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-12	237.881	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-13	238.330	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-14	241.174	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-15	241.174	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-16	241.431	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-17	241.471	0.000	0.000	0.000	Elbow
J-18	242.765	0.000	0.000	0.000	Elbow
J-19	243.165	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-20	242.790	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-21	242.700	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-22	245.508	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-23	245.618	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-24	245.618	1.72 L/sec	1.63 L/sec	1.55 L/sec	
J-25	242.199	1.72 L/sec	1.63 L/sec	1.55 L/sec	

5.5.1 The EPANET Software

The EPANET software is easy to use and widely used for water network and system's hydraulic analysis and performance evaluation. It was developed by the U.S. Environmental Protection Agency's National Risk Management Research Laboratory and freely available at the US EPA web site (www.epa.gov). The software can compute flow, pressure, residual chlorine and water age by simulating the hydraulic conditions of the water network. The EPANET Version 2 was used in this study.

5.5.2 Selection of Head Losses Equations

The Hazen–Williams equation was used in the EPANET software for water network modeling because it provides an empirical formula that is easy to calculate the flow friction loss due to pipe physical properties. The equation simply shows the relation between mean velocity of water in a pipe and the geometric properties of the pipe and slope of the energy line.

$$V=kCR^{0.63}S^{0.54} \qquad (5.1)$$

Where *V* is velocity (m/sec), *k* is a conversion factor (k = 0.849 for SI units), *C* is a roughness coefficient, *R* is the hydraulic radius in meter and *S* is the slope of the energy line (head loss per length of pipe or h_f/L).

The Manning's formula was also used to estimate the average flow velocity in a conduit/pipe.

$$V= (k/n)\, R^{2/3}S^{1/2} \qquad (5.2)$$

Where *V* is the cross-sectional average velocity (L/T; ft/s, m/s), *n* is Manning coefficient, *R* is the hydraulic radius (L; ft, m), *S* is the slope of the hydraulic grade

($S = h_f/L$) and k is a conversion factor between SI and English units. k=1 for SI units, and k = 1.49 for English units.

The Darcy–Weisbach equation was used to calculate the pipe head losses due to friction along a given length over the average flow velocity of the fluid. This equation has a dimensionless friction factor, which is known as Darcy friction factor and calculated by using the Moody diagram.

$$h_f=f_D(L/D)*(V^2/2g) \tag{5.3}$$

where h_f is the head loss due to friction (SI units: m), L is the length of the pipe (m), D is the hydraulic diameter of the pipe (m), V is the average flow velocity (m/s), g is the local acceleration due to gravity (m/s^2) and f_D is a dimensionless coefficient called the Darcy friction factor.

5.5.3 Water Consumption Pattern

The water consumption pattern is one of the essential input data requirements for time series analysis in the EPANET software. The hourly consumption pattern provides the water requirement at each node at any time during the day, which help to manage the operation of water distribution system. The hourly water consumption pattern (shown in Table 5.4) was collected from the historical water consumption data and was available at the AADC pumping station for the month of August 2013. The reason to choose the month of August consumption is that data were available for that month and significant variations among different months are not generally observed for diurnal variation of water consumption.

Table 5.4: Diurnal pattern of water consumption and pressure record

(source: AADC)

Date and time	Set pressure at the pumping station (bar)	Actual flow (100m³/h)	Consumption pattern (at 100 m³/h set flow)
8/12/13 1:00 PM	1.5	104	1.04
8/12/13 2:00 PM	1.5	105	1.04
8/12/13 3:00 PM	1.5	103	1.03
8/12/13 4:00 PM	1.5	104	1.04
8/12/13 5:00 PM	1.5	106	1.06
8/12/13 6:00 PM	1.5	92	0.92
8/12/13 7:00 PM	1.5	93	0.93
8/12/13 8:00 PM	1.5	88	0.88
8/12/13 9:00 PM	1.5	95	0.95
8/12/13 10:00 PM	1.5	96	0.96
8/12/13 11:00 PM	1.5	97	0.97
8/13/13 12:00 AM	1.5	98	0.98
8/13/13 1:00 AM	1.5	98	0.98
8/13/13 2:00 AM	1.5	97	0.97
8/13/13 3:00 AM	1.5	95	0.95
8/13/13 4:00 AM	1.5	96	0.96
8/13/13 5:00 AM	1.5	97	0.97
8/13/13 6:00 AM	1.5	108	1.08
8/13/13 7:00 AM	1.5	106	1.06
8/13/13 8:00 AM	1.5	104	1.04
8/13/13 9:00 AM	1.5	106	1.06
8/13/13 10:00 AM	1.5	105	1.05
8/13/13 11:00 AM	1.5	104	1.04
8/13/13 12:00 Noon	1.5	105	1.05

Table 5.4 shows the actual consumption pattern and pressure, which was used to analysis the real time demand of water distribution network and to understand any hydraulic complexity. Table 5.4 shows two distinct diurnal pattern of water consumption, from 6:00 AM to 5:00 PM the average hourly flow is 105 m^3 whereas from 6:00 PM to 5:00 AM the average hourly flow is 95 m^3. This indicates that water consumption in daytime is about 11% higher than the consumption at night.

5.5.4 EPANET Modeling Methodology

The EPANET software usually works based on the pipes, nodes or junctions and reservoirs, but it can provide adequate analysis and result of hydraulic model for different scenarios or conditions. The hydraulic model used for this study was developed on the existing water network that makes the data input for possible reduction in consumption and save the municipal water by using the following steps:

Step # 1: The EPANET program was opened, the length and elevation, flow and pressure units were selected in liter per second and meter pressure respectively.

Step # 2: The water network map was imported as a background and the distribution pipeline network was drawn to represent the actual pipes and junction layout.

Step # 3: The Hazen-Williams equation was selected for hydraulic simulation and the Hazen-Williams co-efficient for pipe roughness of 130 was used for ductile iron new pipes in the study area.

Step # 4: The length, diameter and roughness coefficient of all pipe segments were entered according to the data obtained from the AADC as built drawings.

Step # 5: The existing pressure of 1.5 bar at the source was entered in the Fixed Grade Node or boundary node in addition to the elevation.

Step # 6: The elevation of all junctions was entered according to the AADC as built profile drawings and the demand for every junction was entered according to section 5.4.4.

Step # 7: The water network operation method was described by choosing the steady state and time extend period conditions and the model hydraulic analysis option was selected. After completion of the above steps 1 to 7, the input data were rechecked for any missing data.

Step # 8: The model was run for hydraulic simulation. After successful run the model, time series graphs for pressure and flow velocity were drawn. The tabulated results were also prepared for evaluation of optimal selection.

The system control valves were not included in the EPANET layout for simulation, this is because the consumption was calculated at customer receiving point and hydraulic head and line losses were excluded.

5.6 Hydraulic Modeling Results

The water consumption scenarios mentioned in Table 5.3 were used for the hydraulic modeling simulation to identify the optimum water consumption quantity and to analyze the flow in each pipe and pressure at each junction for the water distribution network. The elevation differences of the water distribution network are presented graphically in Figure 5.3.

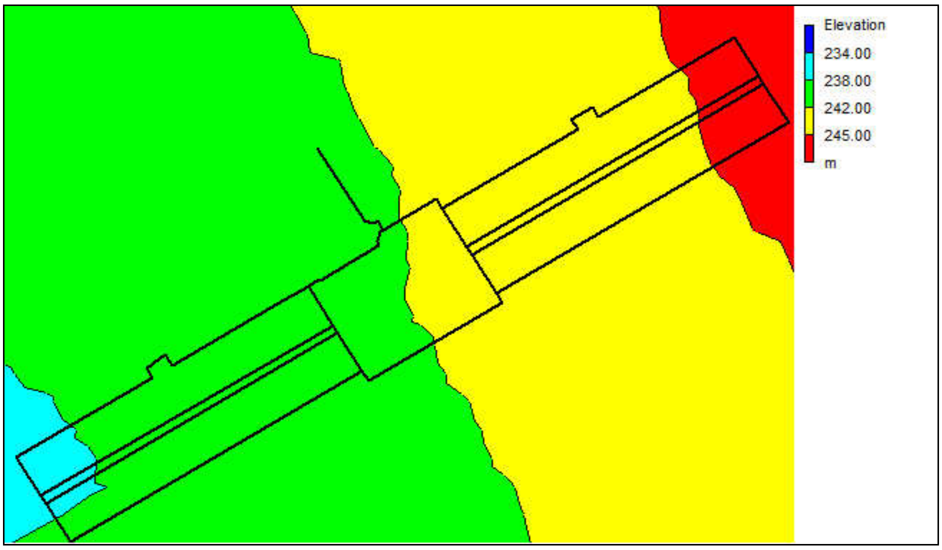

Figure 5.3: Elevations of water distribution network in the EPANET

The hydraulic simulation identified the flow conditions in every pipe and pressure at every node for different scenarios of water consumption management. Minor head losses in pipe segments are ignored in developing the model because the demand is calculated from the customer meter and head losses due to fittings and valves are already calculated to be about 5% as mentioned in Chapter 4, section 4.2.

5.6.1 Simulation Results of Scenario No.1

The scenario-1 is the current water consumption and the current water demand, and other model parameters (elevation, pipe size, length) are as mentioned in the above tables Table 5.2 and Table 5.3, in order to obtain the nodal pressure and pipe flow velocities. The graphical results are shown in Figures 5.4 to 5.7 (a – c) and tabulated in Appendix – D, which shows that Node J-24 has the lowest pressure of 9.96 meters at 5:00 am and the highest pressure of 18.28 meters at 7:00 pm for the node J-10. Further, the pipe segment P-15 has the lowest velocity of 0.02 m/s at 12:00 am and the highest velocity of 0.87 m/s in P-5 at 5:00 am. For all nodes, it is observed that pressure starts to drop at about 4 am and start to increase at 4 pm. This is because the water flow velocity increased during this time period (day time) and flow velocity and pressure are inversely related.

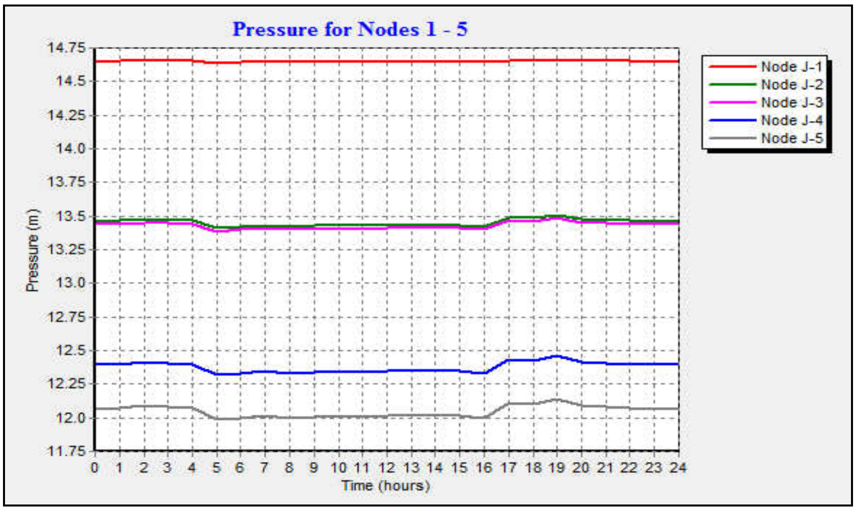

Figure 5.4: Scenaro – 1 pressure (m) details at nodes J-1 to J-5 during 24 hours

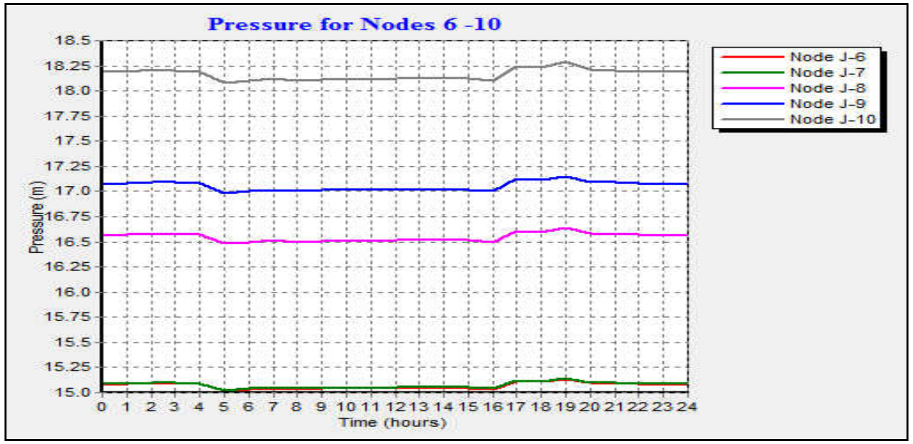

Figure 5.5(a): Pressure (meter) at nodes J-6 to J-10

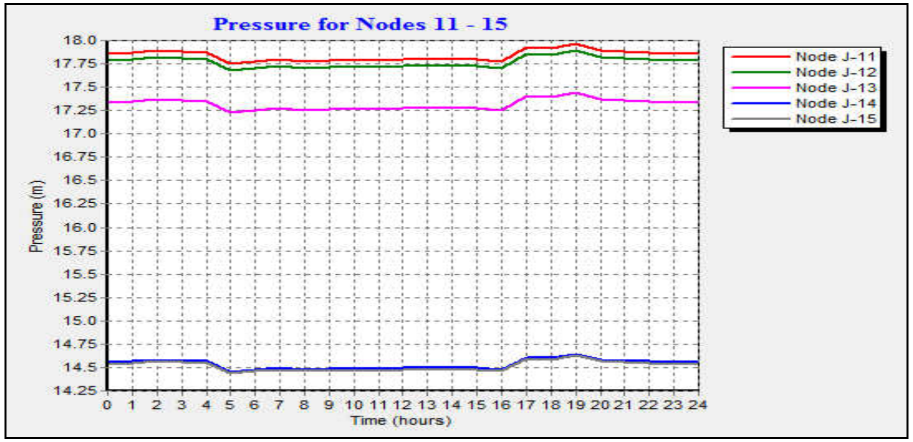

Figure 5.5(b): Pressure (meter) at nodes J-11 to J-15

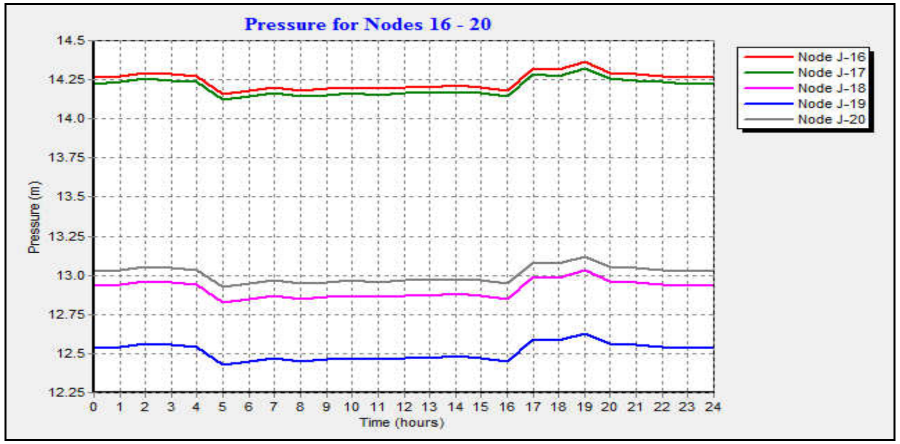

Figure 5.5(c): Pressure (meter) at nodes J-16 to J-20

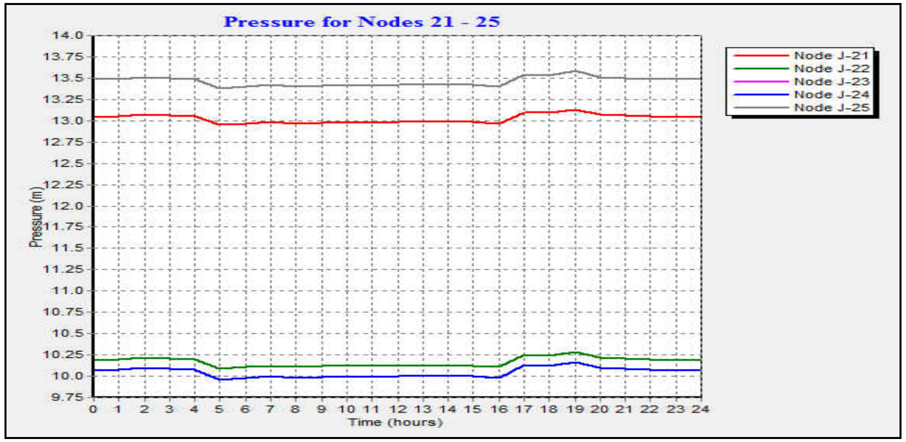

Figure 5.5(d): Pressure (meter) at nodes J-21 to J-25

Figure 5.5 (a – d): Scenario – 1 pressure (m) details at nodes J-6 to J-25 during 24 hours

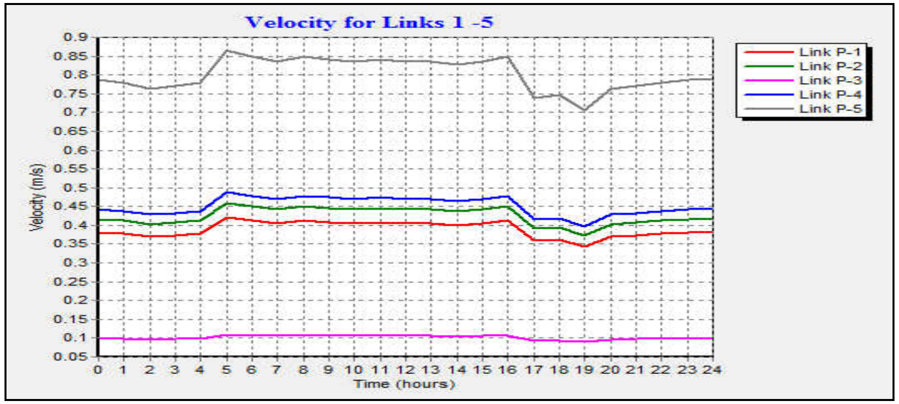

Figure 5.6(a): velocity (m/s) detail at Pipe P-1 to P-5

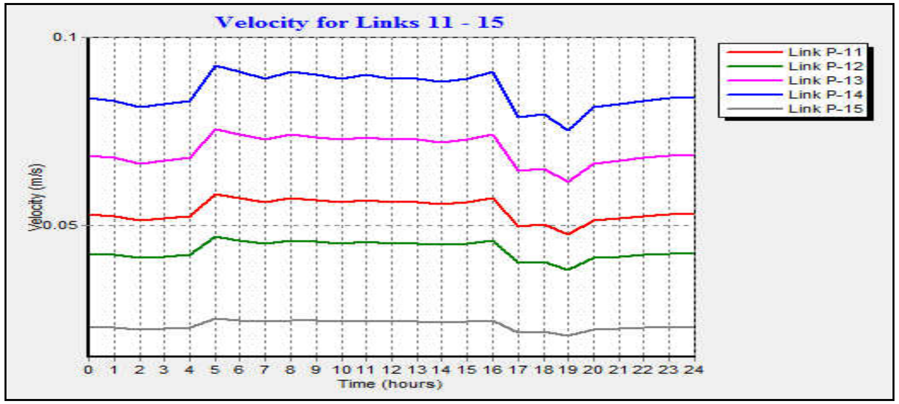

Figure 5.6(c): velocity (m/s) detail at Pipe P-11 to P-15

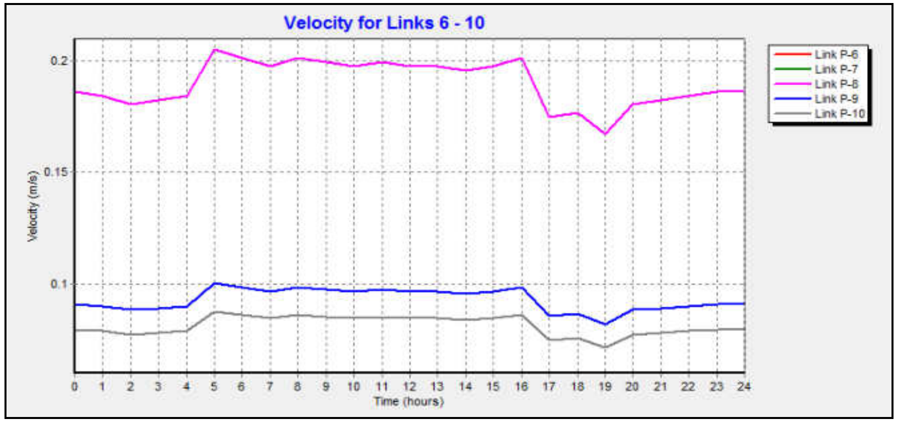

Figure 5.6(b): velocity (m/s) detail at Pipe P-6 to P-10

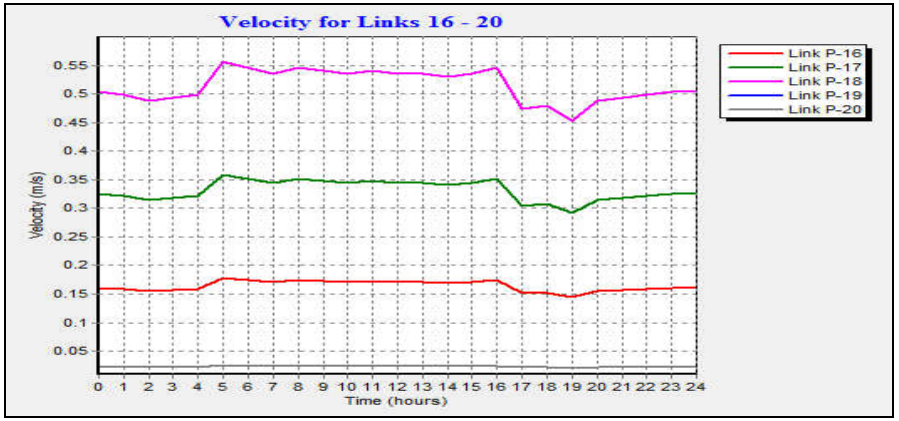

Figure 5.6(d): velocity (m/s) detail at Pipe P-16 to P-20

Figure 5.6(a – d): Scenario – 1 velocity (m/s) detail at Pipe P-1 to P-20 during 24 hours

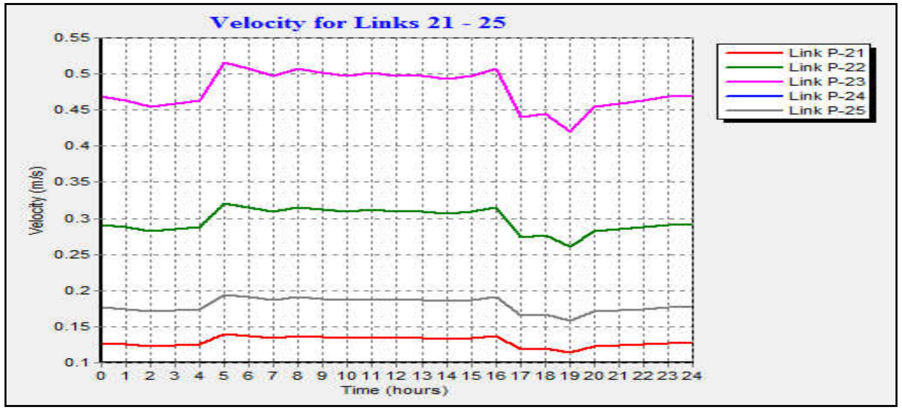

Figure 5.7(a): velocity (m/s) detail at Pipe P-21 to P-25

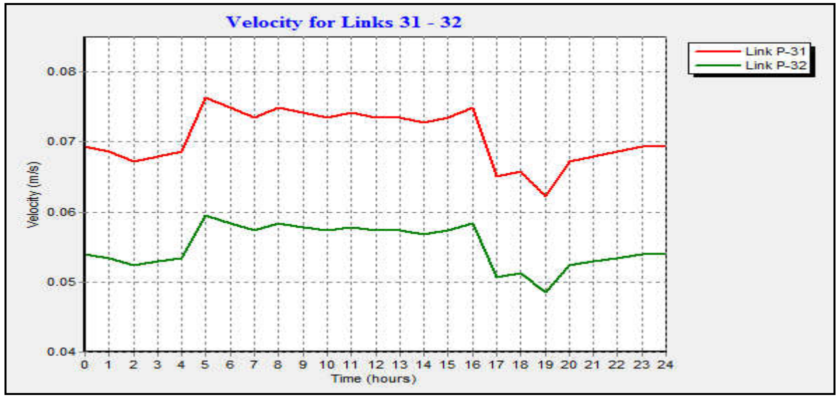

Figure 5.7(c): velocity (m/s) detail at Pipe P-31 to P-32

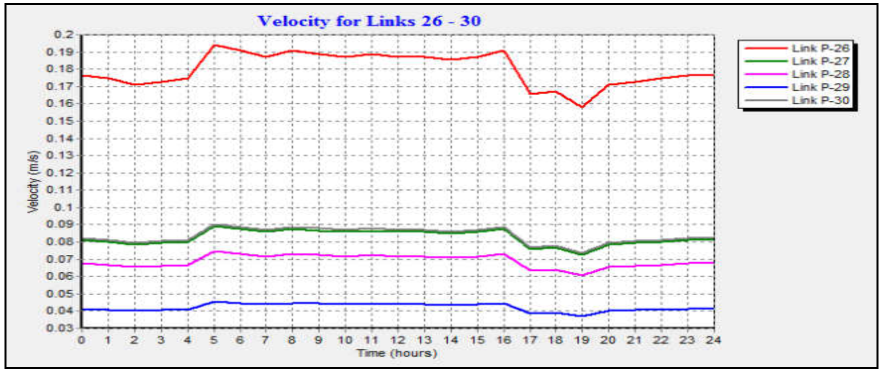

Figure 5.7(b): velocity (m/s) detail at Pipe P-26 to P-30

Figure 5.7(a – c): Scenario – 1 velocity (m/s) details at pipe P-21 to P-32 during 24 hours

5.6.2 Simulation Results of Scenario No.2

The scenario-2 is simulated based on the 5% reduction in the current water consumption or 35% of the indoor water consumption for every villa. The elevation, pipe size, length and material roughness were used as mentioned in chapter 4. The purpose is to understand the changes in nodal pressure and pipe velocities in comparison to the current water consumptions. The results are graphically presented in Figures 5.8 to 5.11 (a – c) and tabulated in the Appendix- D. The nodal pressures and pipe velocities show that Node J-24 has the lowest pressure of 10.02 meters at 5:00 am and the highest pressure of 18.29 meters occurred at 5:00pm for the node J-10. The pipe segment P-15 has the velocity of 0.02 m/s at 12:00 am and the highest velocity of 0.82 m/s occurred at 5:00 am for the pipe segment of P-5.

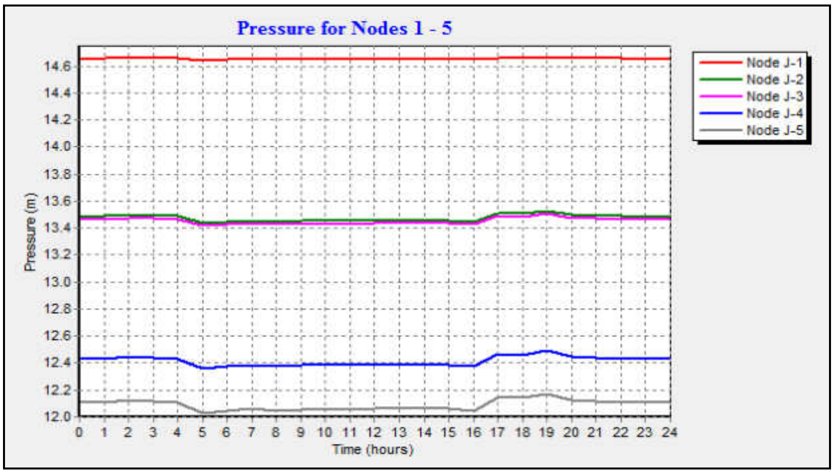

Figure 5.8: Scenario – 2 pressure (m) detail at node J-1 to J-5 during 24 hours

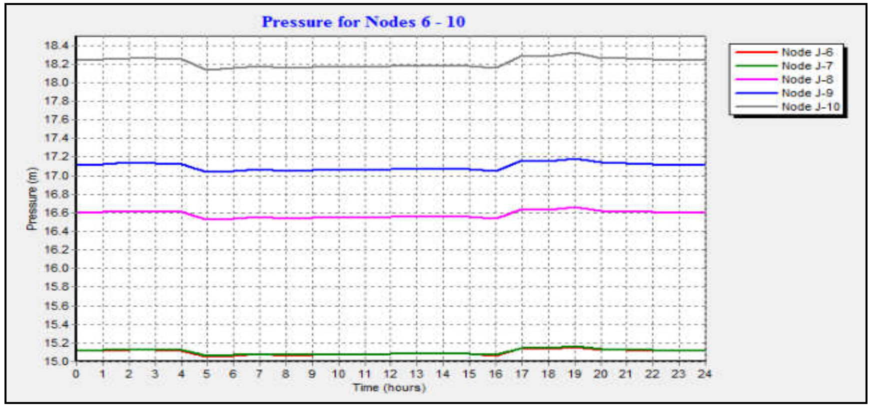

Figure 5.9 (a): Pressure (m) detail at node J-6 to J-10

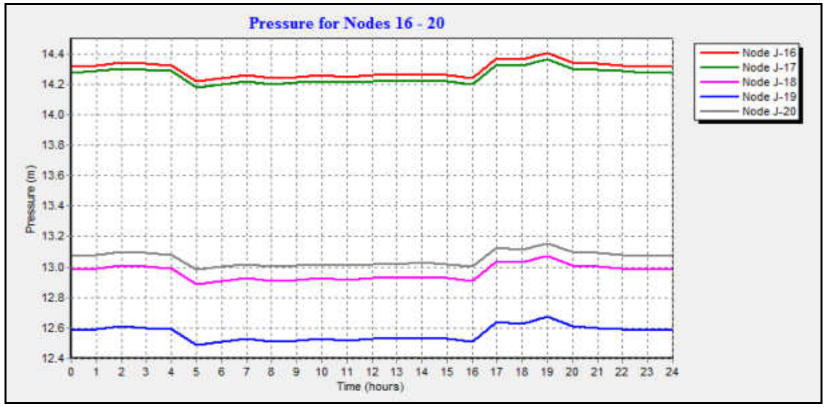

Figure 5.9 (c): Pressure (m) detail at node J-16 to J-20

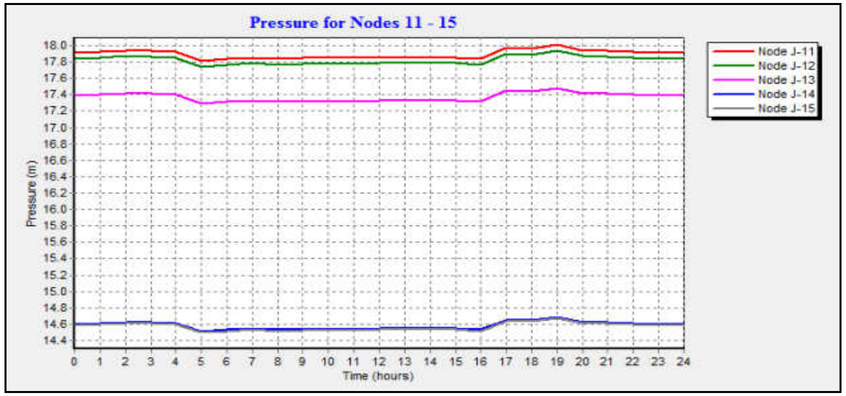

Figure 5.9 (b): Pressure (m detail at node J-11 to J-15

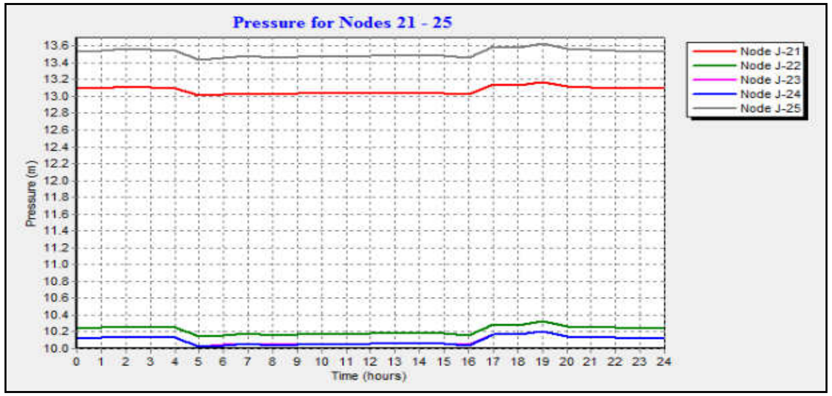

Figure 5.9 (d): Pressure (m) detail at node J-21 to J-25

Figure 5.9 (a - d): Scenario – 2 pressure (m) detail at node J-6 to J-25 during 24 hours

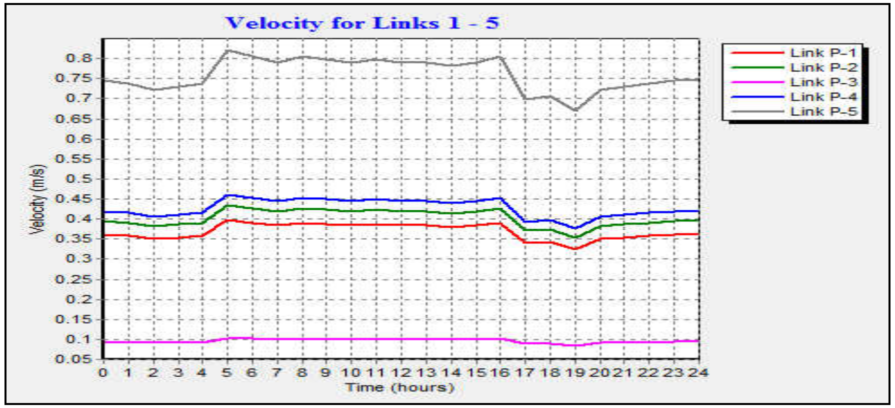

Figure 5.10(a): velocity (m/s) detail at Pipe P-1 to P-5

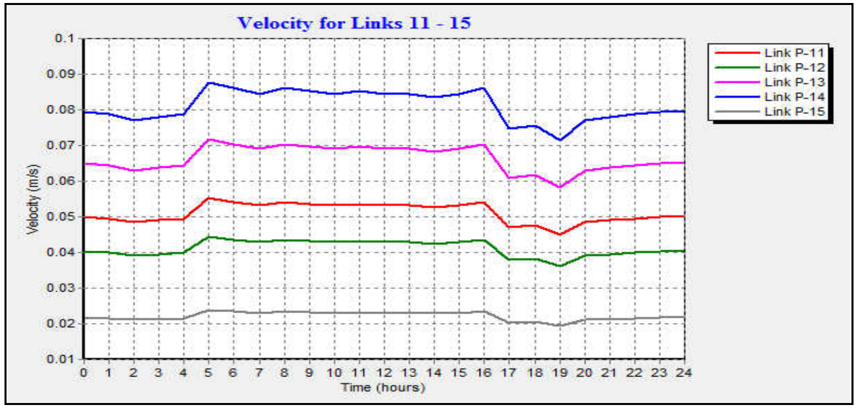

Figure 5.10(c): velocity (m/s) detail at Pipe P-11 to P-15

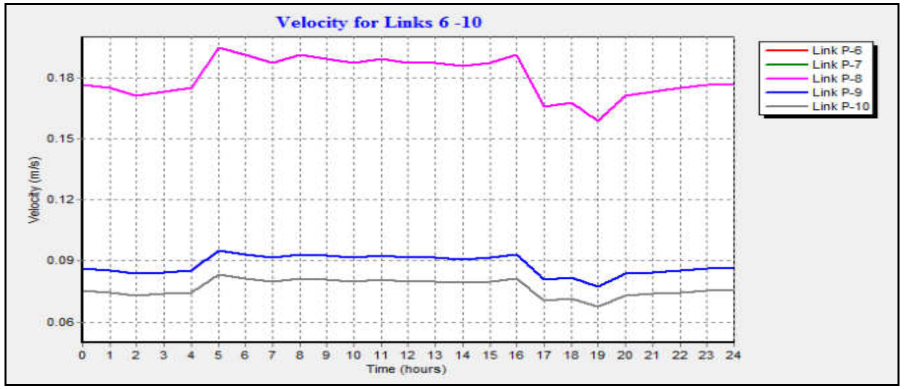

Figure 5.10(b): velocity (m/s) detail at Pipe P-6 to P-10

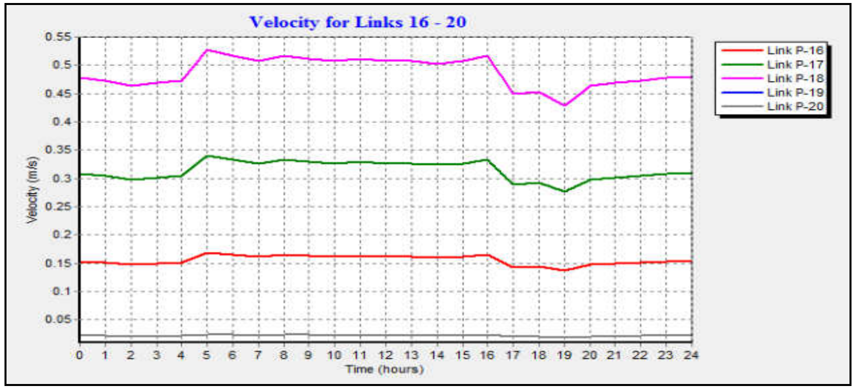

Figure 5.10(d): velocity (m/s) detail at Pipe P-16 to P-20

Figure 5.10 (a - d): Scenario – 2 velocity (m/s) detail at Pipe P-1 to P-20 during 24 hours

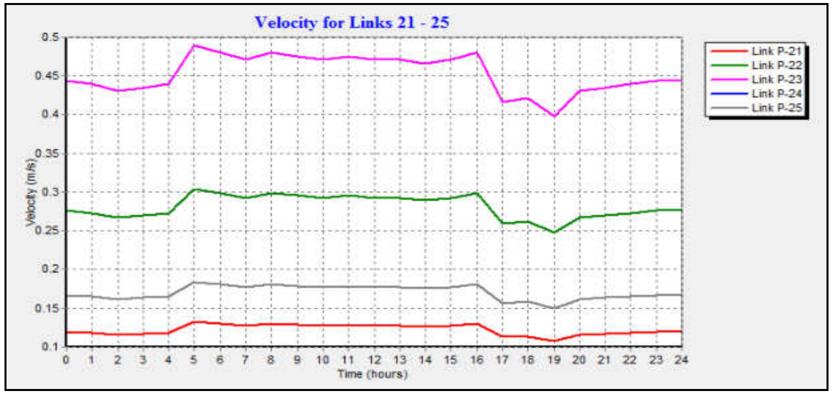

Figure 5.11(a): velocity (m/s) detail at Pipe P-21 to P-25

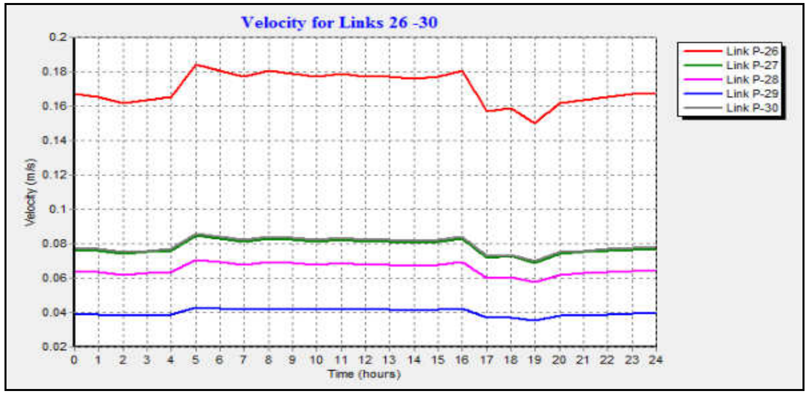

Figure 5.11(b): velocity (m/s) detail at Pipe P-26 to P-30

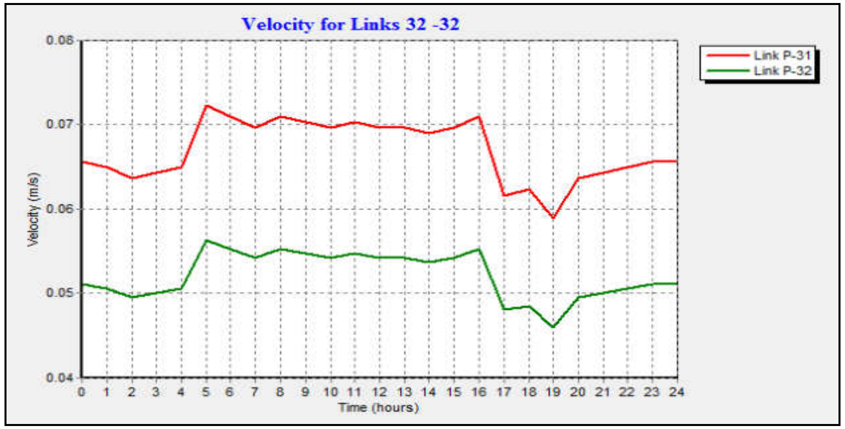

Figure 5.11(c): velocity (m/s) detail at Pipe P-31 to P-32

Figure 5.11(a - c): Scenario – 2 velocity (m/s) detail at Pipe P-21 to P-32 during 24 hours

5.6.3 Simulation Results of Scenario No.3

The scenario-3 is simulated based on the 10% reduction in the current water consumption or 69% reduction of the indoor water consumption for every villa (which is equivalent to 100% reuse of generated greywater). The elevation, pipe size, length and roughness coefficient were used as same as scenario 1. The results are graphically presented in Figures 5.12 to 5.15 (a - c) and tabulated in Appendix- D for nodes and pipes. The results show that the node J-24 has the lowest pressure of 10.07 meters at 5:00 am and the highest pressure of 18.36 meters occurred at 7:00 pm for the segment J-10. The Pipe P-15 exhibited a velocity of 0.02 m/s at 12:00 am and the highest velocity of 0.78 m/s at 5:00 am for the pipe segment of P-5.

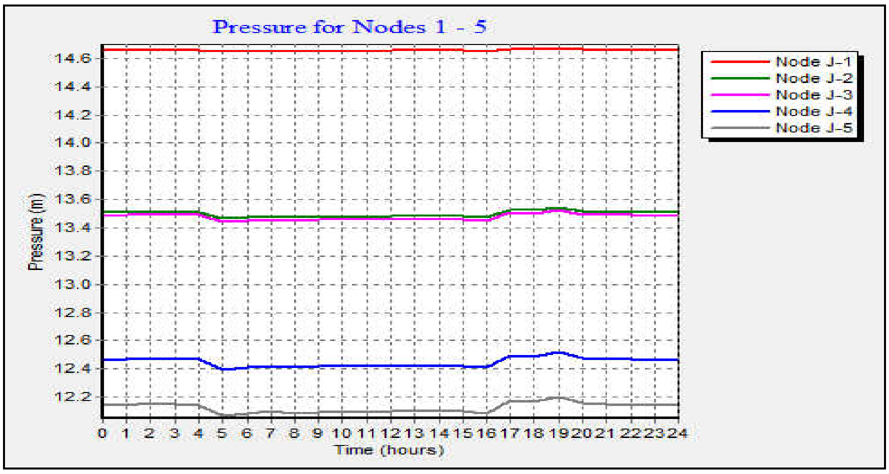

Figure 5.12: Scenario – 3 pressure (m) detail at node J-1 to J-5 during 24 hours

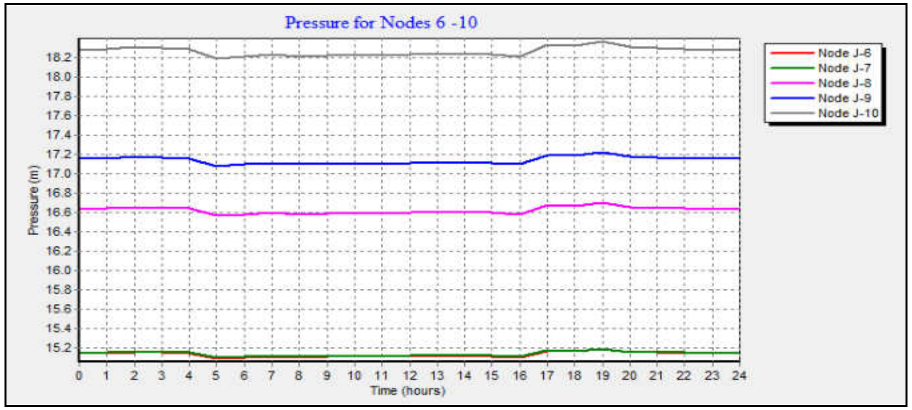

Figure 5.13 (a): Pressure (m) detail at node J-6 to J-10

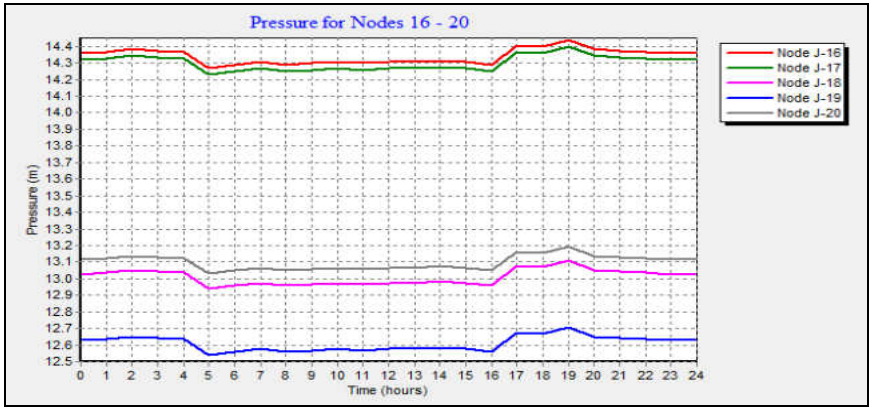

Figure 5.13 (c): Pressure (m) detail at node J-16 to J-20

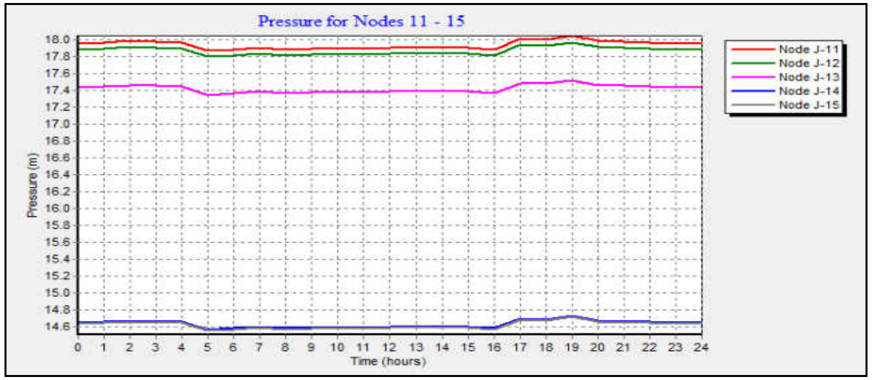

Figure 5.13(b): Pressure (m detail at node J-11 to J-15

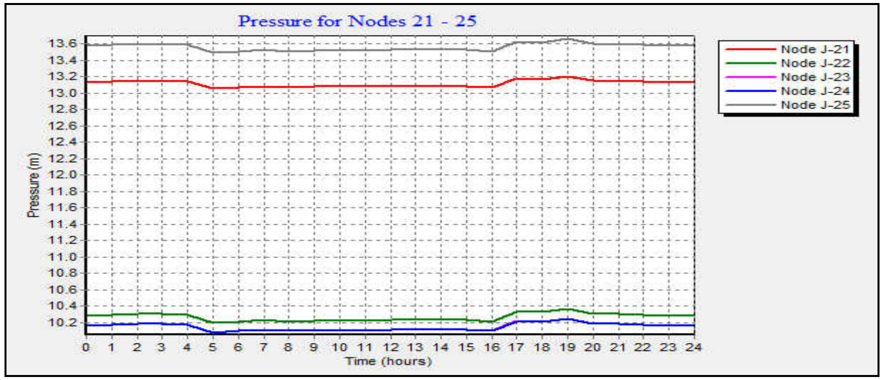

Figure 5.13 (d): Pressure (m) detail at node J-21 to J-25

Figure 5.13 (a – d): Scenario – 3 pressure (m) detail at node J-6 to J-25 during 24 hours

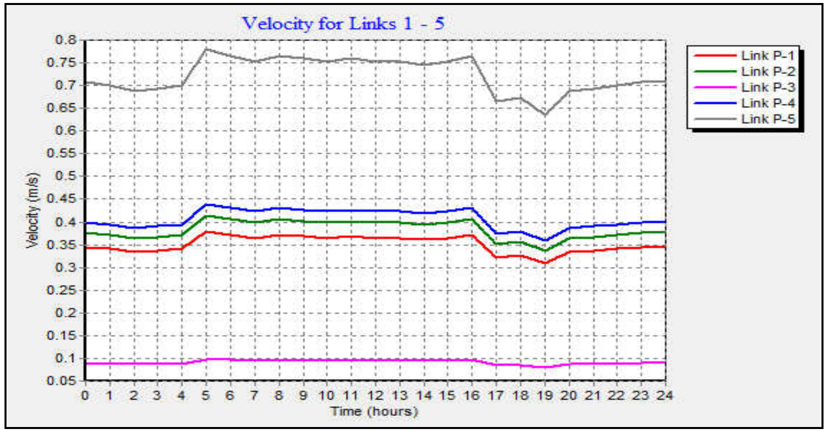

Figure 5.14(a): velocity (m/s) detail at Pipe P-1 to P-5

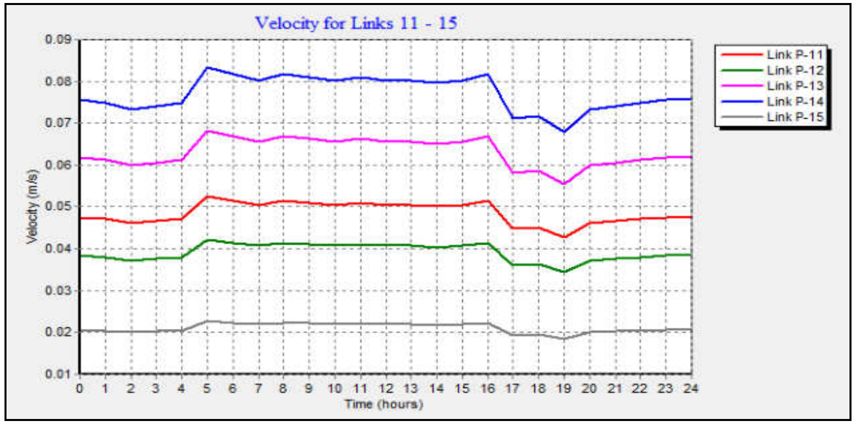

Figure 5.14(c): velocity (m/s) detail at Pipe P-11 to P-15

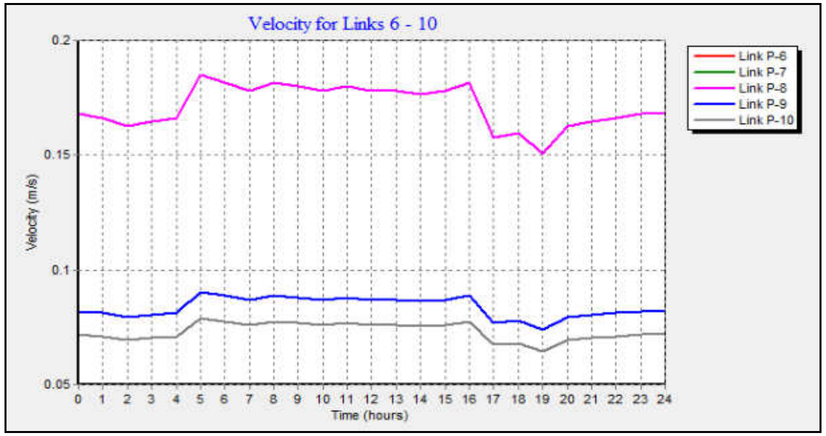

Figure 5.14(b): velocity (m/s) detail at Pipe P-6 to P-10

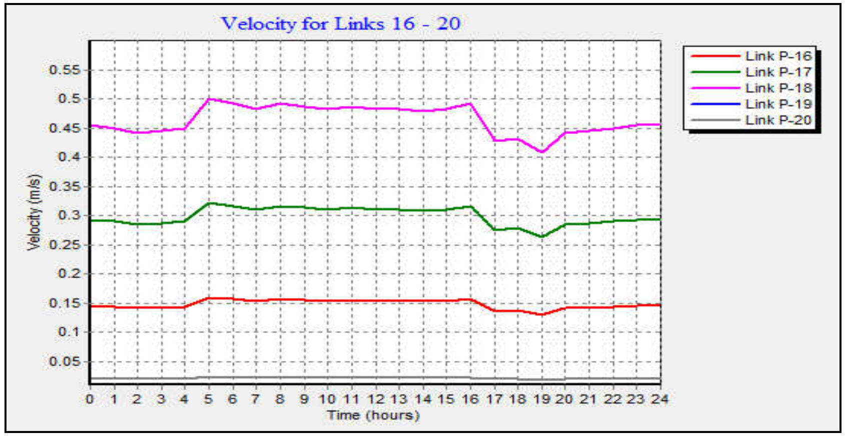

Figure 5.14(d): velocity (m/s) detail at Pipe P-16 to P-20

Figure 5.14 (a – d): Scenario – 3 velocity (m/s) detail at Pipe P-1 to P-20 during 24 hours

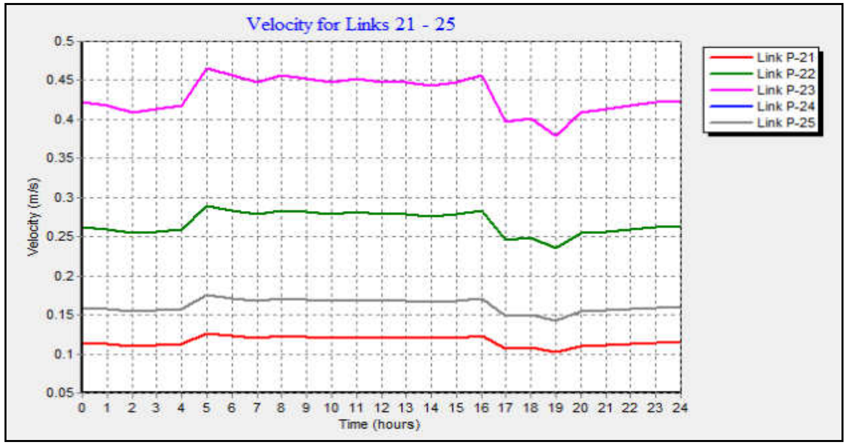

Figure 5.15(a): velocity (m/s) detail at Pipe P-21 to P-25

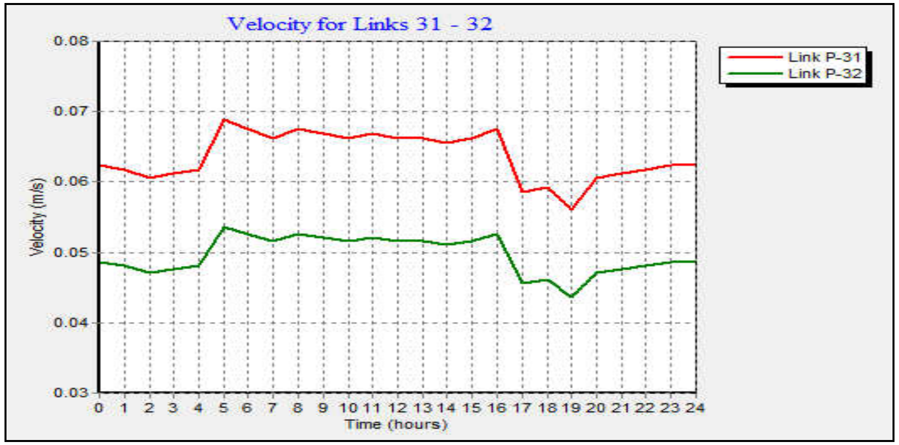

Figure 5.15(c): velocity (m/s) detail at Pipe P-31 to P-32

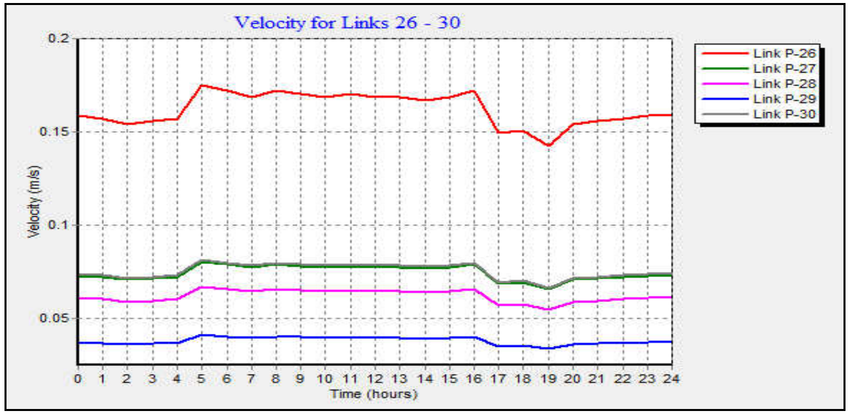

Figure 5.15(b): velocity (m/s) detail at Pipe P-26 to P-30

Figure 5.15 (a – c): Scenario – 3 velocity (m/s) detail at Pipe P-21 to P-32 during 24 hours

5.7 Conclusion

The modeling results indicate that reducing water consumption reduces the pressure in the water network as presented in Figure 5.16 and the maximum velocity also reduced, but lowest velocity remained the same as presented in Figure 5.17. After 5% reduction (Scenario-2), the current consumption pressure was improved to 0.60 % at the minimum location (J-24) and to 0.055% at the maximum pressure location (J-10). Further, when 10% of water consumption reduction (scenario-3) was used, the pressure was improved by 1.11% at the same low pressure point and 0.44% at the same maximum pressure node. Moreover, it is to be noted that the increase in water network pressure due to usage of greywater will not affect the water line strength because AADC service lines have 100 meters design pressure and distribution lines and fittings have 1600 meters of design pressure.

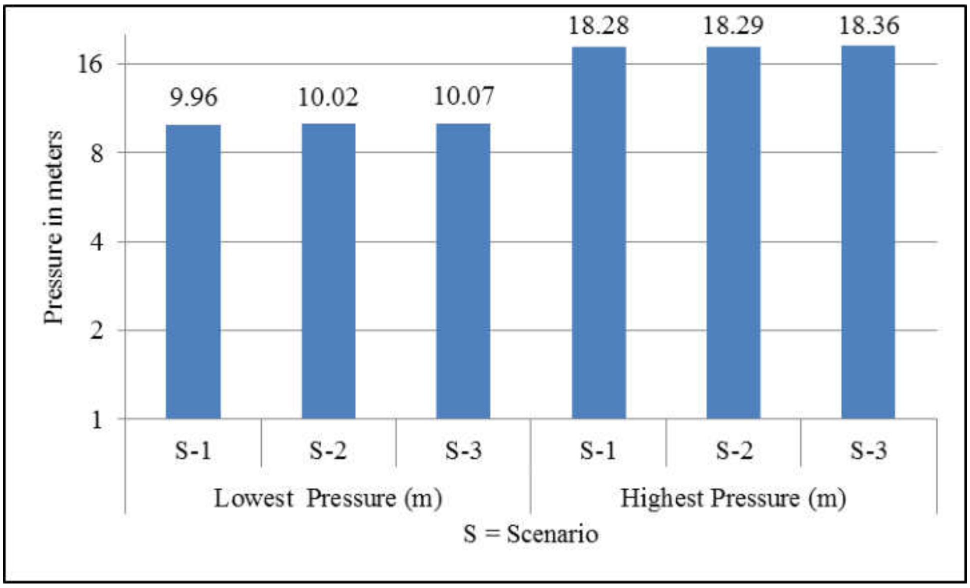

Figure 5.16: Node pressure improvement detail for different Scenarios

Similarly, the velocity was reduced by 5.75% at maximum point (P-5) and lowest velocity remained the same (P-15). Correspondingly, when 10% of water consumption reduction (scenario-3) was used, flow velocity at the maximum flow pipe (P-5) was reduced by 10.4%, but the lowest velocity was not found affected.

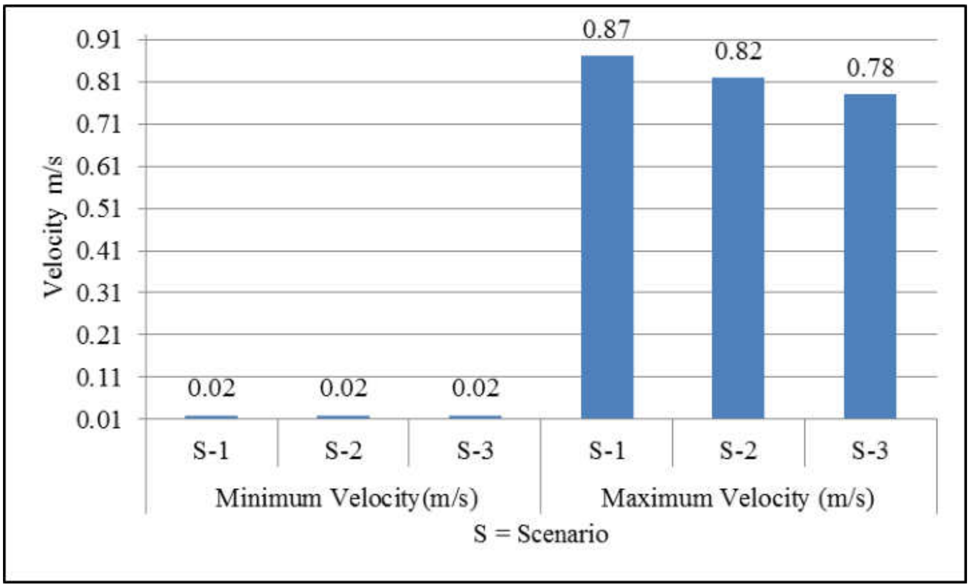

Figure 5.17: Flow velocity detail for different scenarios

The modeling results indicate that the reduction in municipal water consumption due to reuse of greywater for home garden irrigation has positive impacts on the water distribution network, such as the improved pressure will help to detect the water leakage and decline in high velocity will lessen the erosion of pipe linings and improve the water quality. Further, this approach will improve the minimum residual pressure and maintain the RSB recommended pressure of 12.5 m in the network, in addition to save the municipal water, which can be used in the water deficit area in the region or to meet the future demand.

Chapter 6: Greywater Reuse Potential and Effects

6.1 Introduction

The primary aim of this research was to estimate the quantity of available greywater at the study area and its potential to reuse for plantation and irrigation for home gardens. Therefore, the actual consumption of municipal water was measured directly from the household water meters to identify the water uses for indoor and outdoor activities and to estimate the quantity of wastewater from bath, sink and showers (greywater). The greywater can be recaptured for outdoor uses, which can reduce the overall water consumption that lead to meet the limit set by the RSB guidelines that the each villa's consumption should be not more than 5000 gallons per day or 20 cubic meters per day. The Abu Dhabi Environment Vision 2030 for sustainable use of municipal water has also set the same consumption limit.

6.2 Potential of Greywater Reuse in Abu Dhabi

The Environment Agency Abu Dhabi estimated that the per capita per day average water consumption is more than 500 liter in the Emirate and can vary from 220 to more than 1700 liter/capita/day (EAD, 2009). Results from this study show that the standard villa exists in the shabiyat at the study area has water consumptions between 263 to 3,577 liters/capita/day (Table 4.5). Further, this study estimated that only 15 to 20% of the total supplied water by the AADC return back to the sewerage treatment plant. A recent study done by Chowdhury *et al.* (2014) calculated that 69% of indoor consumed water can be collected as greywater from every house. Similarly, the RSB reported that there are about 40 to 60% of greywater available in indoor domestic water consumption that can be reused at home garden and plantation in the Emirate (RSB, 2013).

Results from this study show that if all greywater produced from the shower, bathtubs, ablution, wash basin and laundry recaptured and reused for home garden irrigation, a maximum of 10% of the total water consumption can be reduced throughout the year without interrupt the tradition and living style of the resident and without affecting the existing water networks' hydraulic performances. Similarly, if half of greywater be reused, about 5% of total water consumption can be decreased. As far as the public acceptance is concerned, the survey results indicate that about 86% of residents are agreed to reuse the greywater for their home garden subject to the condition that the greywater does not have any "*najees*" substances (not acceptable from a religious point of view) which means particles of black water (faeces) and it is less polluted.

Greywater reuse is an economical and environmental friendly alternative option for home garden irrigation. This study evaluated that Abu Dhabi Emirate has substantial potential of greywater reuse, since UAE national have a passion and love to have home garden and to grow plantation around their houses. And the reuse of greywater can play an important part to fulfill the threshold for municipal water reduction requirements of the Environment Vision 2030, which aims to reduce about half of current domestic water consumption by 2030. However, only greywater reuse is not sufficient enough to achieve this target. This is because about 80% of water is used for outdoor activities in typical villa type houses. Another alternative option is to reuse treated sewage effluent (TSE) for home irrigation, but this requires the establishment of extensive pipe networks.

6.3 Quantification of Greywater Reuse Benefits in Abu Dhabi

6.3.1 Economic Benefits in Abu Dhabi

The greywater is reused in many parts of the world because each domestic consumer has a considerable amount of greywater, which can be reused for non-domestic purposes at houses. The utilization of greywater lessens the pressure to build up new water systems to meet the water demand (Li *et al.*, 2010). The Abu Dhabi emirate depends on the expensive desalinated water due to the depleting water resources and increasing water demand. In such circumstances, greywater reuse for plantation and home gardens can provide an opportunity to reduce the overall water consumption without affecting the life style and routine water uses activities and extraction of greywater from water network will not affect the hydraulic performances of existing water pipes.

Previous studies indicated that greywater reuse reduces the domestic consumption and thereby can save water bills to customers. Reuse of greywater can improve the water supply system by reducing water treatment costs and water line leakage due to high pressure during off peak period (Li *et al.*, 2010). In Chapter-5, it is shown that up to 10% of total supplied municipal water can be saved from greywater reuse scheme for home garden irrigation. The quantity of municipal water consumption saving by reuse of greywater is shown in Table 6.1.

Table 6.1: Quantification of greywater reuse benefits

Al Ain water demand forecast by ADWEC[*1]			Saving of municipal water by reusing the greywater (liter)		Nos. of people can be served with saved water based on 500 l/p/c/d		Saving of electricity due to greywater reuse based on 2.3kWh[*2] per m³ of water (kWh)		Nos. of houses can be served with saved electricity based on 120 kWh daily	
Year	Water Quantity		Scenario -2 (5% reduction)	Scenario -3 (10% reduction)	Scenario - 2	Scenario - 3	Scenario - 2	Scenario -3	Scenario - 2	Scenario - 3
	MIGD	Liters / day								
2015	351	1,593,540,000	79,677,000	159,354,000	159,354	318,708	183,257	366,514	1,527	3,054
2016	358	1,625,320,000	81,266,000	162,532,000	162,532	325,064	186,912	373,824	1,558	3,115
2017	365	1,657,100,000	82,855,000	165,710,000	165,710	331,420	190,567	381133	1,588	3,176
2018	371	1,684,340,000	84,217,000	168,434,000	168,434	336,868	193,699	387,398	1,614	3,228
2019	378	1,716,120,000	85,806,000	171,612,000	171,612	343,224	197,354	394,708	1,645	3,289
2020	381	1,729,740,000	86,487,000	172,974,000	172,974	345,948	198,920	397,840	1,658	3,315

MIGD = Million Imperial gallons per day

*[*1] ADWEC Statement of Future Capacity Requirements 2008 – 2030*

*[*2]Dawoud and Al Mulla (2012)*

The forecasted demand by ADWEC based on the most likely trend for Al Ain (ADWEC, 2008) is used in Table 6.1 to calculate municipal water savings by implementation of the scenario-2 (extraction of 50% greywater) and scenario-3 (extraction of 100% greywater), described in the Chapter-5. The above results demonstrate that scenario-2, which is projected based on to implement 50% available greywater reuse for home garden irrigation can save about 79 million liters of municipal water, which is sufficient for additional more than 159,000 people at the rate of 500 liters per person per day. Moreover, it will also save the 180,000 kWh electricity daily, which is sufficient to serve the additional 1,500 typical standard villas in the Al Ain. Similarly, implementation of scenario-3 doubles this water and electricity benefits in Al Ain.

6.3.2 Environmental Benefits in Abu Dhabi

The municipal water consumption was significantly increased during the last few decades in the UAE due to rapid population growth and increase of visitors, expansion of industries, agricultural expansion and desert greening policies. In order to overcome the water shortage problems, the UAE is primarily dependent on expensive desalination projects to achieve the current and future water demand. It is estimated that UAE occupies the world's 35% of desalination projects that are not only expensive but also have adverse effects on the environment (Dawoud and Al Mulla, 2012).

The desalinated water production requires huge amount of energy to operate its plant and pumps. It was estimated that the lowest amount of energy required to produce 1 m^3 of municipal water is about 2 to 2.3 KWh, which pollute the air through emission of CO_2 (Dawoud and Al Mulla, 2012).

There is about 2 m^3 of brine water generates from the production of 1 m^3 of desalinated municipal water. The brine water is discharged into the sea (Arabian Gulf) that not only increases the average salinity level of sea water from 45 ppm up to 55 ppm, but raises the normal temperature from 35 °C up to 42 °C. On the other hand, heavy metals such as copper, nickel and other alloy concentrations in the sea water may increase from about 0.1 μg/L to 15 μg/L, which are used in the heat exchanger in the distillation plants (Dawoud and Al Mulla, 2012).

Therefore, reuse of greywater can reduce adequate amount of energy and maintenance expenditure of desalination plants. It was shown that if greywater reuse scenarios 2 and 3 (5% and 10% of total water consumption savings) are applied in the Emirate, the environmental problems associated with desalination plants would be reduced significantly. This will be a valuable gain towards sustainability and to stabilize the increasing water consumption in the UAE.

6.4 Greywater Quality

The greywater quality varies from house to house, which depends on lifestyle or hygienic habits and chemicals such as detergents and bath soaps used. Generally the requirements of water quality depend on their uses and the irrigation water does not require high quality standard as drinking water. Kitchen wastewater which contains oil, fats and grease, and food waste is excluded from greywater in UAE in order to reduce the biological risks. Residential wastewater sourced from baths, showers, wash basins, laundry and ablution are considered as greywater in UAE.

Generally, the aesthetic look of greywater is objectionable due to high levels of dissolved substances. The impurities or pollutants present in greywater makes them unsafe for using without treatment, particularly the health risks and environmental hazards associated with their reuse without treatment. However, the proper storage tank and suitable on-site treatment system can improve their quality and acceptance level (Friedler and Hadari, 2006). The treated greywater can provide the confidence to the users to utilize its potential (Li *et al.*, 2010).

A comparative quality review of greywater is presented in Table 6.2 and 6.3 in order to check whether the greywater is compliance with the quality standards. The purpose is to provide this information about quality parameters, which can satisfy the users to utilize it in home gardens. Thus, a research results on greywater quality from Omani houses is compared with the RSB and Dubai municipality treated wastewater reuse regulation.

Table 6.2: Chemical and physical quality comparison of Greywater

Quality Parameter	Unit	RSB drinking water quality[*1]	RSB treated wastewater quality[*2]	Recycle water limit for irrigation use[*3]		Greywater quality in Omani houses[*4]			Sample[*5] results
				Drip	Spray	Shower	Laundry	Sink	
pH		7.0 - 9.2	6 - 9	6.0 - 8.0	6.0 - 8.0	7.3	8.5	7.2	8.4
DO (Dissolved Oxygen)	mg/l		≥ 3			3.6	3.4	4	
EC (Electric Conductivity)	mS/m					2	3.5	1.4	
Alkalinity	mg/l					13.3	32.7	14.4	80
NO_3 (Nitrate)	mg/l	50	40	50	30	23.6	16.2	10.2	
TS	mg/l					520	2384	679	
TSS	mg/l		50	50	10	242	244	318	59
TDS	mg/l	100 - 1000	1500	1500	1000	279	2140	361	176
TFS	mg/l					174	1221	281	
TVS	mg/l					346	649	397	
Turbidity	NTU	4	75			346	328	211	48.25
BOD_5	mg/l		50	20	10	380	296	100	
COD	mg/l		100	100	50	375	471	110	86.6
TOC	mg/l		75			66	170	63	
Ca	mg/l					15.7	18.7	19.7	
Na (Sodium)	mg/l	150		500	200	184.5	667	148.9	
K (Potassium)	mg/l	12				43.1	23.4	5.5	

Table 6.3: Biological and heavy metal quality comparison of Greywater

Quality Parameter	Unit	RSB limit for drinking water*1	RSB treated wastewater quality*2	Recycle water limit for irrigation use*3		Greywater quality at Omani houses*4			Sample*5 results
				Drip	Spray	Shower	Laundry	Sink	
Mg (Magnesium)	mg/l	30		100	100	56.1	60.8	21	8
Zn (Zinc)	mg/l	0.5	0.5	0.5	0.2	2.4	0.14	0.04	
Al(Aluminum)	mg/l	0.2	20	2	2	0.014	0.08	0.01	
Pb (lead)	mg/l	0.1	0.1	0.5	0.5	0.1	0.08	0.06	
Cu (Copper)	mg/l	1	0.5	0.2	0.2	0.01	0.01	-	
Ni (Nickel)	mg/l	0.1	10	0.2	0.2	0.035	0.12	0.04	
Total Coli form	MPN/100ml	0	1000			≥ 200	≥ 200	≥ 200	59
Faceal Coli form	MPN/100ml	0	1000	20	0	≥ 200	≥ 200	≥ 200	

**1, Source: Water Quality Regulation 2013*

**2, Source: Recycled water and Bio-solids Regulation 2010*

**3, Source: Water Environmental Regulations; Environmental Regulation No.: EN/002; 1st Edition July 2010, (EHS) DIVISION*

**4, Source: Overcoming constraints in treated greywater reuse in Oman; Desalination 186 (2005) 177–186*

**5, A greywater sample (mixture of bath, sink and laundry water) was taken from the study area and tested at UAEU Lab*

Tables 6.2 and 6.3 show three water quality standards in UAE and greywater quality results from previous studies in Oman and a sample mixed greywater quality result. Due to limitations of the thesis scope, detailed greywater quality analyses were not performed, but one bulk sample of greywater, which was consisted of equal proportions of bath, wash basin and laundry wastewater mixture, was collected from the study area and the available quality tests were performed in the UAE University laboratory and results are mentioned in the Tables 6.2 and 6.3. Further, It is observed from the table 6.3 that greywater quality is acceptable with regard to the heavy metals, but exceeded the coli form limit. Table 6.2 shows that the majority of chemical and physical quality parameters of greywater is within the acceptable limit for their reuse in home gardens. The parameters that exceed the limit need to be controlled by appropriate treatment mechanisms. Previous studies informed that suspended particles and organic matters in greywater can be removed through filtration and chlorine dose is required for disinfection of microorganisms (Li *et al.*, 2010). However, it can be noticed from the comparison results of UAE and Oman greywater, these results indicate that the quality of greywater in the UAE is much better than Oman, most obvious reasons of greywater quality in the UAE is better because of better infrastructure of water supply system and high standard of municipal water quality.

Therefore, it is recommended to install on-site treatment system for greywater reuse scheme and the question related to bearing the cost of treatment system was included in the questionnaire survey, which shows that about 71% of respondents would like to install the greywater treatment system by the government at their houses. Therefore, some sort of government rebates to villa owner can be an effective option to encourage them to install greywater scheme.

6.5 Effects of Greywater Reuse on Downstream Sewer

The domestic wastewater is the main source of sewer flow. Sewer flow comes from indoor water consumption and it was found in the study that about only 15 to 20% of the total water is used in indoor activities. It is obvious that the application of greywater on-site reuse will reduce the municipal water consumption for each house, which will not only help to decrease the water consumption but also alleviate the sewer load on treatment plants (Al Wabel, 2011). On the other hand, this decline in wastewater discharge may affect the sewer flow and can increase the risk of sewer lines clogging. Similarly, wastewater treatment plant may experience to deal with dense sewer loads that require frequent removal of sludges (Friedler and Hadari, 2006).

The main purpose to assess the effects of greywater reuse on the sewer lines and treatment plant is to review different aspects of flow reduction and build up of dense sludge. Therefore, the ADSSC wastewater treatment plant was visited in the study area in order to obtain the required information and to discuss with the plant operation engineer to evaluate these effects on the sewer line.

After extraction of greywater, the sewerage treatment plant will receive a similar load with more concentrated substances due to less flow, the bowler will consume the same amount of electricity because the same load needs the same amount of oxygen. But hydraulic retention time (HRT) in the aeration tanks will be more than usual. Further, some equipment may become oversize due to reduction in the load and ascended speed in the settlement tank. Similarly, sewer line's hydraulic retention time (HRT) will also increase and sewer water solid contents may settle due to long retention time and less sewer water portion. Moreover, prolonged HRT is suitable for anaerobic bacteria growth and more time trigger the anaerobic process, which can produce odor in the gravity line.

Further, the effect of greywater reuse can be evaluated by estimating the average daily Blackwater and Kitchen wastewater volume generated during a 24 hour period and enter into the sewer system. The recent study done by the UAE University estimated that average daily water consumption by each person for toilet flush is 39 liters and for dishwashing the municipal water consumption in 44 liters per person daily in Al Ain (Chowdhury *et al.*, 2014). Which indicate that each person produce the 83 liters daily of wastewater that discharge in the sewer lines except the greywater. On the other hand, the Abu Dhabi Sewer Service Company (DSSC) guidelines for design of sewer lines recommend the design criteria is 180 liters per head sewer inflow for low cost residential houses (ADSSC, Design Guidelines, 2008) . Hence, it can be concluded that if 100% available greywater utilize then the average daily sewer flow rate will be 50% (83≈90 liters/head) of the design flow rate, which is 180 liters/head daily. Therefore, 100% recapturing of greywater, which is 192 liters per head per day (Chowdhury *et al.*, 2014), can lead to effect the sewer line flow, but half of this available greywater in the study area can be utilized without altering the existing system.

In addition to these, there is a possibility of odor and build up of dense sewer due to recapture of greywater and these effects can be minimized by proper operation and maintenance of sewer network and treatment plant. It was noticed that the majority of sewer flow is acceptable close to their design capacity in the Emirate and the ADSSC statistic shows that only 56.3% treated water is used for landscaping and 43.7% of treated sewer water is disposed to the sea (Arabian Gulf) in the Abu Dhabi Emirate (EAD, 2009). So, it can be presumed that reduction of sewer flow due to greywater reuse will not affect the sewer system, but a detail study should be done to find out the specific facts.

Chapter 7: Conclusion and Recommendation

7.1 Conclusion

The aim of this study was to evaluate the greywater reuse potential for home garden irrigation, which can reduce the increasing municipal water consumption in the Emirate of Abu Dhabi. The Abu Dhabi Emirate is located in arid zone, it has less than 100 mm of annual rainfall and a very limited surface and ground water resources, which force the authorities to depend on expensive desalinated water. In contrary, the per capita municipal water consumption in UAE is one of the highest in the world.

The reason behind such a high consumption is the use of municipal water for outdoor activities and it was identified in the study area that about 97% of residential villas are using municipal water for home garden irrigation. Water consumption pattern of 100 houses (villa type) was analyzed in this study. By comparing the actual water consumption of every house and the wastewater received at the sewer treatment plant, it was found that about 20% of the total municipal water returned back to the downstream sewer system (which indicates that indoor water consumption is approximately 20%) and the remaining 80% of the total water is used for outdoor activities. Statistical analyses of water consumption data and the number of family members in each house were conducted, which indicates that high water consumption in traditional UAE villa type houses is not dependents on the number of family members at the house rather it is connected to the outdoor water consumptions for gardening and plantation. In the study area, the sizes of every plot and actual building area are 2050 m^2 and 700

m^2, respectively. This indicates that about $2/3^{rd}$ of each plot is occupied with plantation and garden and consumes almost 80% of total supplied water.

Considering the circumstances of huge water consumption and less availability of water resources in UAE, water consumption management and augmentation of supply sources are of particular interest in the UAE. Greywater, the residential wastewater except toilet and kitchen sources, has been investigated in many water scarce countries as an alternative water sources for non-domestic consumptions such as gardening and toilet flushing. Consequently, this study investigated the potential of greywater harvesting in traditional UAE villas in order to curb the high water consumption and to achieve the sustainability according to the Abu Dhabi Environmental Vision 2030.

The hydraulic simulation of the water network in the study area comprises of 100 villa type houses was conducted using the EPANET modeling software. Three scenarios of greywater extraction were considered in the study, they were scenario -1 (no extraction of greywater), scenario-2 (50% extraction of greywater which will reduce total water consumption by 5%) and scenario-3 (100% greywater extraction which will reduce total water consumption by 10%). For both scenarios 2 and 3, modeling outcomes show positive effects and support the assumption of water consumption reduced by reusing greywater. The modeling results indicate that there will be sufficient improvement in the network hydraulics, when scenario-2 was applied by reducing the 5% of the total current water consumption (which means utilization of only 50% of available greywater or 35% of the indoor domestic wastewater), the pressure in the network was improved by 0.60% pressure at low pressure nodes (J-24) and velocity was decreased by 0.055% at high flow zones (P-5). Similarly, when scenario-3 was applied (which considered that about 100% of available greywater or 69% of indoor domestic wastewater was utilized that can decrease the current water consumption about 10%), the hydraulic parameters of water network were improved twice of the scenario-2 in the area.

The Abu Dhabi Emirate has a great potential to reuse the greywater for home garden irrigation and it was estimated that 79 million liters of municipal water can be saved daily according to the current water consumption in the Al Ain, if half of available greywater was extracted and reused for irrigation to home garden at Al Ain, which was estimated to be sufficient for additional 159,000 persons at the rate of 500 liters per person per day, and the figure can become double under the scenario -3 (100% greywater extraction and reuse). Moreover, it was shown that greywater reuse has many economic and environmental advantages such pumping station energy savings to supply municipal water and approximately 180,000 kWh electricity can be saved and the treatment plant operation, maintenance and cost can also be saved, even just reuse of 50% of available greywater.

7.2 Recommendation

This study shows that urban water management is a major challenge in the Abu Dhabi Emirate. Therefore, in order to promote the better use of water, it is necessary to educate the people to change their attitude/behavior of water uses because majority of residents does not realize that municipal water production by desalination plants is very expensive in the Emirates. One of the main reasons is that they receive desalinated water at very low price (subsidized by the government). Recently from January 2015, the water tariff has been increased from

AED 1.70 to 1.89 per 1000 liters for nationals and from 5.95 to 9.90 per 1000 liters for expats (RSB, 2015) and its impacts on water consumption will be a research question. The reuse of greywater is the one of the most economical options, which does not need expensive technology to reuse it, but it can provide a continuous solution for the water shortage problem and to reduce the water consumption without affecting the lifestyle and plantation habits of the residents in the Emirate.

Greywater reuse should be considered as a solution to manage the water shortage and reduce the stress on the authorities to develop the new infrastructure for water supply. However, to encourage the community to reuse treated greywater, a proper regulation and defined guidelines are needed, so that residents can accept this option. Despite their impacts on water saving, this research shows that greywater also has potential quality risk and there is a possibility of human contact during their reuse. Therefore, it is recommended to use the treated greywater, which will not only provide the confidence to the users, but also will make it safe for human and for the environment. There are several greywater treatment technologies are available and it is recommended to have a detail quality analysis for the Emirates houses greywater and based on the quality results the treatment system should be selected.

Greywater extraction reduces the sewer flow, that may dense the sludge and increase the bacterial growth which can cause clogging of sewer. In the Emirates, the sewer lines flow with their full design capacity and more than 40% of treated water is just disposed to the sea, so such problem will exist rarely, but is recommended to do frequent flushing of the sewer lines to avoid such problem and a detail study should be done in future. Another important observation was found during the questionnaire survey. Most of the residents expressed that they would like that the authority will establish the on-site greywater systems. Therefore, some form of rebate for the installation of greywater system is recommended.

In order to implement greywater reuse scheme and make this approach successful to reduce water consumption in the Emirate, it is equally important to involve all concern stakeholders with respect to their social and cultural values in addition to the technical issues described below:

- A priority should be given by the government to reuse the greywater for home irrigation by providing the safety standards and regulations and by introducing appropriate regulation and greywater quality monitoring system.
- The awareness and education program for greywater reuse should be launched to provide the required information, economic benefit and training to reuse and minimize the potential hazards, which will enhance the acceptance of greywater reuse.
- The reliable and efficient method should be adopted for greywater collection and reuse, because an inefficient approach to reuse the greywater can affect the human and environmental health.
- It is recommended to carry out a separate study to analyze the environmental impact on the soil and human health of a greywater reuse area.

The above recommendations will increase the confidence of the residents to reuse greywater for home lawn watering and will provide a cost effective opportunity to reduce the municipal water consumption and can decrease the desalination plants' load in the Abu Dhabi Emirate.

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List of Publications

Chowdhury, R.K and Rajput, M. A. (2015, submitted) Will Greywater Reuse Really Affect the Sewer Flow? Experience of a Residential Complex in Al Ain, UAE. Submitted to the LESAM 2015 Strategic Asset Management of Water and Wastewater Infrastructures, 17-19 November, Yokohama, Japan.

Chowdhury, R.K. and Rajput, M. A. (abstract accepted) Water Consumption Pattern in Traditional Villa Type Houses in Abu Dhabi, MODSIM 2015 Conference, Gold Coast, Australia, December 2015.

Chowdhury, R.K. and Rajput, M. A. (in preparation) Hydraulic Performances of Water Distribution Network Under Greywater Extraction Scenarios, Journal of Water Management, UK.

Appendix – A: Questionnaire Survey

Water User's Survey Questionnaire
استبيان المسح لاستهلاك المياه

Q.1: Do you receive enough water for your uses, from the water network system?
هل تتلقى ما يكفي من المياه للاستخدامات الخاصة بك من نظام شبكة المياه.

☐ Yes (نعم) ☐ No (لا)

Q.2: Do you use the potable water for drinking purpose? هل استخدام المياه لأغراض الشرب/

☐ Yes (نعم) ☐ No (لا)

Q.3: Do you use the potable water for home garden irrigation?
هل تستخدم مياه الشرب لأغراض ري حديقة البيت

☐ Yes (نعم) ☐ No (لا)

Q.4: How many times a day, do you need water for irrigation?
كم مرة التي تحتاج المياه للري فاليوم

☐ 1–2 ☐ 2–3 ☐ 3–4 ☐ 5–6 ☐ Others ( )

Q.5: Do you believe water conservation is an important issue in Al Ain?
هل تعتقد بأن المحافظة على المياه هي قضية هامة في العين

☐ Yes (نعم) ☐ No (لا) ☐ I don't know (لا أعرف)

Q.6: Do you believe how important are individual actions to meet future water demand?
هل تؤمن بأهمية السلوكيات الفردية لتلبية الطلب على المياه في المستقبل

☐ Important / مهم ☐ Not important/ ليس مهمًا ☐ I don't know (لا أعرف)

Q.7: Do you plan to take any action in the next year to lower your water use?
هل تخطط لاتخاذ أي إجراء في العام المقبل لخفض استخدام المياه الخاصة بك

☐ Yes (نعم) ☐ No (لا) ☐ I don't know(لا أعرف)

Q.8: Do you agree to reuse laundry, washing & shower water for Lawn irrigation?
هل توافق على إعادة استخدام مياه الاستحمام و الغسل لري الحديقة

☐ Agree (أوافق) ☐ Not agree (لا أوافق) ☐ I don't know (لا أعرف)

Q.9: If grey water system cost will 1000 to 4000 AED. Do you prefer to install it by?
إذا كانت تكلفة نظام المياه الرمادية بين 1000-4000 درهم،أتفضل بتركيبها

☐ Yourself (بنفسك) ☐ Department (بجهة مختصة) ☐ Share / تشترك ☐ I don't know (لا أعرف)

Q.10: Total number of family members at this house? إجمالي عدد أفراد الأسرة البيت

☐ Less than 15 years / أقل من 15 عاما ( ) ☐ Above than 15 years/أكثر من 15 عاما ( )

Appendix - B: Authorization of AADC Data Collection

شـركـة العيـن للتـوزيـع
Al Ain Distribution Company

Ref. : AADC/
Date : December, 2013

To : United Arab Emirates University,
College of Engineering,
Al Ain – U.A.E.

Atten: Prof. Amr El-Dieb,
Dean, College of Engineering,
UAEU.

Subject: **Request for Data for MSc Thesis**

With reference to the attached UAEU letter ref; CoB (23B/1054) -13 dated 10th December 2013, kindly be advised that we have no objection to authorize our employee, Eng. Muhammad Ashfaque Rajput (AADC ID # 123640 & UAEU Student ID # 201370040) to collect the required data for his research work.

Please make sure to submit to us a copy of the thesis, once the study is completed.

Regards,

Mohammed Salem Al Shamsi
Managing Director

شـركـة العيـن للتـوزيـع
Al Ain Distribution Company

c.c.to:

- Director - Water O&M
- Manager – Business Planning & Performance Department,
- File

AMM

UAEU College of Engineering

جامعة الإمارات العربيـة المتحدة
United Arab Emirates University

CoE (23B/ 1054)-13
December 10th, 2013

H.E. Mohammed Salem bin Omair Al-Shamsi
Manager
AlAin Distribution Company (AADC)

Subject: Request for data for MSc thesis

Dear Mr. Al Shamsi

The College of Engineering at United Arab Emirates University extends its warmest regards, and would like to inform your Excellency that M.Sc. student **Mr. Muhammad Ashfaque Rajput** (Student ID: 201370040) from Civil Engineering Department, has been enrolled into his Research Thesis entitled *"Potential of Greywater Reuse and its Effects on Potable Water Demand Management and Downstream Sewer Network"* as part of the UAEU-NRF (31N135) research under the supervision of Dr. Rezaul Chowdhury, Assistant Professor, UAEU. To pursue his research work, Mr. Muhammad has selected the "Al Faqaa New Village" as his study area and he will conduct a hydraulic modeling work at the study area. The following data are necessary for his research work:

1. Observed water consumption data (meter reading) of villas at the study area for the last two years
2. Details of water distribution network at the study area (GIS layout, pipe size, pipe materials, slope, pressure etc.) and
3. Observed water quality data at the study area for the last two years.

The provided data will only be utilized for academic research and research publication purposes. A copy of the thesis will be provided to the AADC.

Your collaboration and continuous support are very much appreciated with regards.

10/12/2013

Prof. Amr El-Dieb
Dean, College of Engineering
UAEU

DEAN COLLEGE OF ENGINEERING U.A.E UNIVERSITY

Cc.:

- Chair, CEE Department
- Dr. Chowdhury

Appendix - C: UAEU Ethics Approval for Questionnaire Survey

UAEU

جامعة الإمارات العربية المتحدة
United Arab Emirates University

No: DVCRGS/ 240/2014
21/04/2014

To: Dr. Muhammad Ashfaque Rajput

Subject: *Potential of Greywater Reuse and its Effects on Potable Water Demand Management and Downstream Sewer Network*

Dear Dr. Rajput,

Please be advised that the UAEU Scientific Research Ethics Committee, in its meeting No. 44 on April 20, 2014, reviewed the ethical principles involved in your submission.

The decision reached is:

[√] Approved as is

On behalf of the Committee, I wish you every success with your study.

Sincerely,

Prof. Reyadh Al Mehaideb
Deputy Vice Chancellor for Research and Graduate Studies

Deputy Vice Chancellor for
Research and Graduate Studies
PO BOX 15551, Al Ain, UAE
T +971 3 713 5900 F +971 3 713 4910
vprgs.office@uaeu.ac.ae www.uaeu.ac.ae

نائب مدير الجامعة
للدراسات العليا والبحث العلمي
ص.ب 15551، العين، الإمارات العربية المتحدة
ت +971 3 713 5900 ف +971 3 713 4910
vprgs.office@uaeu.ac.ae www.uaeu.ac.ae

Appendix - D

Hydraulic Simulation Results

Scenario -1

Tabulated Presentation of Nodal (Junction) Time Series

Results

1). Junction - 1 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	256.18	14.65
1:00	0	256.18	14.65
2:00	0	256.18	14.65
3:00	0	256.18	14.65
4:00	0	256.18	14.65
5:00	0	256.16	14.64
6:00	0	256.17	14.64
7:00	0	256.17	14.64
8:00	0	256.17	14.64
9:00	0	256.17	14.64
10:00	0	256.17	14.64
11:00	0	256.17	14.64
12:00	0	256.17	14.64
13:00	0	256.17	14.64
14:00	0	256.17	14.64
15:00	0	256.17	14.64
16:00	0	256.17	14.64
17:00	0	256.18	14.66
18:00	0	256.18	14.66
19:00	0	256.19	14.66
20:00	0	256.18	14.65
21:00	0	256.18	14.65
22:00	0	256.18	14.65
23:00	0	256.18	14.65
24:00:00	0	256.18	14.65

* T-Junction

2). Junction - 2 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.98	13.46
1:00	0	255.99	13.47
2:00	0	256.00	13.48
3:00	0	255.99	13.47
4:00	0	255.99	13.47
5:00	0	255.93	13.41
6:00	0	255.94	13.42
7:00	0	255.95	13.43
8:00	0	255.94	13.42
9:00	0	255.95	13.43
10:00	0	255.95	13.43
11:00	0	255.95	13.43
12:00	0	255.95	13.43
13:00	0	255.95	13.43
14:00	0	255.96	13.44
15:00	0	255.95	13.43
16:00	0	255.94	13.42
17:00	0	256.01	13.49
18:00	0	256.01	13.48
19:00	0	256.03	13.51
20:00	0	256.00	13.48
21:00	0	255.99	13.47
22:00	0	255.99	13.47
23:00	0	255.98	13.46
24:00:00	0	255.98	13.46

* Reducer 200mmx150mm

3). Junction - 3 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.97	13.44
1:00	1.67	255.98	13.44
2:00	1.63	255.99	13.45
3:00	1.65	255.98	13.45
4:00	1.67	255.98	13.44
5:00	1.86	255.92	13.39
6:00	1.82	255.93	13.40
7:00	1.79	255.94	13.41
8:00	1.82	255.93	13.40
9:00	1.81	255.94	13.40
10:00	1.79	255.94	13.41
11:00	1.81	255.94	13.40
12:00	1.79	255.94	13.41
13:00	1.79	255.94	13.41
14:00	1.77	255.95	13.41
15:00	1.79	255.94	13.41
16:00	1.82	255.93	13.40
17:00	1.58	256.00	13.47
18:00	1.60	256.00	13.46
19:00	1.51	256.02	13.49
20:00	1.63	255.99	13.45
21:00	1.65	255.98	13.45
22:00	1.67	255.98	13.44
23:00	1.69	255.97	13.44
24:00:00	1.69	255.97	13.44

4). Junction - 4 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.85	12.39
1:00	0	255.86	12.40
2:00	0	255.87	12.41
3:00	0	255.87	12.41
4:00	0	255.86	12.40
5:00	0	255.78	12.32
6:00	0	255.79	12.33
7:00	0	255.81	12.35
8:00	0	255.79	12.33
9:00	0	255.80	12.34
10:00	0	255.81	12.35
11:00	0	255.80	12.34
12:00	0	255.81	12.35
13:00	0	255.81	12.35
14:00	0	255.82	12.36
15:00	0	255.81	12.35
16:00	0	255.79	12.33
17:00	0	255.89	12.43
18:00	0	255.89	12.43
19:00	0	255.92	12.46
20:00	0	255.87	12.41
21:00	0	255.87	12.41
22:00	0	255.86	12.40
23:00	0	255.85	12.39
24:00:00	0	255.85	12.39

* Elbow

5). Junction - 5 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.82	12.07
1:00	0	255.82	12.07
2:00	0	255.84	12.09
3:00	0	255.83	12.08
4:00	0	255.82	12.07
5:00	0	255.73	11.98
6:00	0	255.75	12.00
7:00	0	255.77	12.02
8:00	0	255.75	12.00
9:00	0	255.76	12.01
10:00	0	255.77	12.02
11:00	0	255.76	12.01
12:00	0	255.77	12.02
13:00	0	255.77	12.02
14:00	0	255.78	12.03
15:00	0	255.77	12.02
16:00	0	255.75	12.00
17:00	0	255.86	12.11
18:00	0	255.85	12.10
19:00	0	255.89	12.14
20:00	0	255.84	12.09
21:00	0	255.83	12.08
22:00	0	255.82	12.07
23:00	0	255.82	12.07
24:00:00	0	255.82	12.07

* Elbow

6). Junction - 6 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.93	15.08
1:00	1.67	255.93	15.09
2:00	1.63	255.94	15.10
3:00	1.65	255.94	15.09
4:00	1.67	255.93	15.09
5:00	1.86	255.87	15.02
6:00	1.82	255.88	15.03
7:00	1.79	255.89	15.05
8:00	1.82	255.88	15.03
9:00	1.81	255.89	15.04
10:00	1.79	255.89	15.05
11:00	1.81	255.89	15.04
12:00	1.79	255.89	15.05
13:00	1.79	255.89	15.05
14:00	1.77	255.90	15.05
15:00	1.79	255.89	15.05
16:00	1.82	255.88	15.03
17:00	1.58	255.96	15.12
18:00	1.60	255.96	15.11
19:00	1.51	255.98	15.14
20:00	1.63	255.94	15.10
21:00	1.65	255.94	15.09
22:00	1.67	255.93	15.09
23:00	1.69	255.93	15.08
24:00:00	1.69	255.93	15.08

7). Junction - 7 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.93	15.09
1:00	0	255.93	15.09
2:00	0	255.94	15.10
3:00	0	255.94	15.10
4:00	0	255.93	15.09
5:00	0	255.87	15.03
6:00	0	255.88	15.04
7:00	0	255.89	15.05
8:00	0	255.88	15.04
9:00	0	255.88	15.05
10:00	0	255.89	15.05
11:00	0	255.88	15.05
12:00	0	255.89	15.05
13:00	0	255.89	15.05
14:00	0	255.9	15.06
15:00	0	255.89	15.05
16:00	0	255.88	15.04
17:00	0	255.96	15.12
18:00	0	255.95	15.12
19:00	0	255.98	15.14
20:00	0	255.94	15.10
21:00	0	255.94	15.10
22:00	0	255.93	15.09
23:00	0	255.93	15.09
24:00:00	0	255.93	15.09

* Reducer 200mmx150mm

8). Junction - 8 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.82	16.56
1:00	0	255.83	16.57
2:00	0	255.84	16.58
3:00	0	255.84	16.58
4:00	0	255.83	16.57
5:00	0	255.74	16.48
6:00	0	255.76	16.50
7:00	0	255.77	16.51
8:00	0	255.76	16.50
9:00	0	255.76	16.50
10:00	0	255.77	16.51
11:00	0	255.76	16.50
12:00	0	255.77	16.51
13:00	0	255.77	16.51
14:00	0	255.78	16.52
15:00	0	255.77	16.51
16:00	0	255.76	16.50
17:00	0	255.87	16.61
18:00	0	255.86	16.60
19:00	0	255.90	16.63
20:00	0	255.84	16.58
21:00	0	255.84	16.58
22:00	0	255.83	16.57
23:00	0	255.82	16.56
24:00:00	0	255.82	16.56

* Elbow

9). Junction - 9 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.79	17.07
1:00	0	255.80	17.08
2:00	0	255.81	17.10
3:00	0	255.81	17.09
4:00	0	255.80	17.08
5:00	0	255.70	16.99
6:00	0	255.72	17.00
7:00	0	255.74	17.02
8:00	0	255.72	17.00
9:00	0	255.73	17.01
10:00	0	255.74	17.02
11:00	0	255.73	17.01
12:00	0	255.74	17.02
13:00	0	255.74	17.02
14:00	0	255.75	17.03
15:00	0	255.74	17.02
16:00	0	255.72	17.00
17:00	0	255.84	17.12
18:00	0	255.83	17.11
19:00	0	255.87	17.15
20:00	0	255.81	17.10
21:00	0	255.81	17.09
22:00	0	255.80	17.08
23:00	0	255.79	17.07
24:00:00	0	255.79	17.07

* Elbow

10). Junction - 10 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.68	18.18
1:00	1.67	255.69	18.19
2:00	1.63	255.71	18.22
3:00	1.65	255.70	18.21
4:00	1.67	255.69	18.19
5:00	1.86	255.57	18.08
6:00	1.82	255.59	18.10
7:00	1.79	255.62	18.12
8:00	1.82	255.59	18.10
9:00	1.81	255.61	18.11
10:00	1.79	255.62	18.12
11:00	1.81	255.61	18.11
12:00	1.79	255.62	18.12
13:00	1.79	255.62	18.12
14:00	1.77	255.63	18.13
15:00	1.79	255.62	18.12
16:00	1.82	255.59	18.10
17:00	1.58	255.74	18.25
18:00	1.06	255.73	18.24
19:00	1.51	255.78	18.28
20:00	1.63	255.71	18.22
21:00	1.65	255.70	18.21
22:00	1.67	255.69	18.19
23:00	1.69	255.68	18.18
24:00:00	1.69	255.68	18.18

11). Junction - 11 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.67	17.86
1:00	1.67	255.68	17.87
2:00	1.63	255.7	17.89
3:00	1.65	255.69	17.88
4:00	1.67	255.68	17.87
5:00	1.86	255.56	17.75
6:00	1.82	255.59	17.78
7:00	1.79	255.61	17.80
8:00	1.82	255.59	17.78
9:00	1.81	255.6	17.79
10:00	1.79	255.61	17.80
11:00	1.81	255.6	17.79
12:00	1.79	255.61	17.80
13:00	1.79	255.61	17.80
14:00	1.77	255.62	17.81
15:00	1.79	255.61	17.80
16:00	1.82	255.59	17.78
17:00	1.58	255.73	17.92
18:00	1.60	255.72	17.91
19:00	1.51	255.77	17.96
20:00	1.63	255.7	17.89
21:00	1.65	255.69	17.88
22:00	1.67	255.68	17.87
23:00	1.69	255.67	17.86
24:00:00	1.69	255.67	17.86

12). Junction - 12 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.67	17.79
1:00	1.67	255.68	17.80
2:00	1.63	255.7	17.82
3:00	1.65	255.69	17.81
4:00	1.67	255.68	17.80
5:00	1.86	255.56	17.68
6:00	1.82	255.58	17.70
7:00	1.79	255.61	17.73
8:00	1.82	255.58	17.70
9:00	1.81	255.6	17.71
10:00	1.79	255.61	17.73
11:00	1.81	255.6	17.71
12:00	1.79	255.61	17.73
13:00	1.79	255.61	17.73
14:00	1.77	255.62	17.74
15:00	1.79	255.61	17.73
16:00	1.82	255.58	17.70
17:00	1.58	255.73	17.85
18:00	1.60	255.72	17.84
19:00	1.51	255.77	17.89
20:00	1.63	255.7	17.82
21:00	1.65	255.69	17.81
22:00	1.67	255.68	17.80
23:00	1.69	255.67	17.79
24:00:00	1.69	255.67	17.79

13). Junction - 13 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.67	17.34
1:00	1.67	255.68	17.35
2:00	1.63	255.70	17.37
3:00	1.65	255.69	17.36
4:00	1.67	255.68	17.35
5:00	1.86	255.56	17.23
6:00	1.82	255.58	17.25
7:00	1.79	255.60	17.27
8:00	1.82	255.58	17.25
9:00	1.81	255.59	17.26
10:00	1.79	255.60	17.27
11:00	1.81	255.59	17.26
12:00	1.79	255.60	17.27
13:00	1.79	255.60	17.27
14:00	1.77	255.62	17.29
15:00	1.79	255.60	17.27
16:00	1.82	255.58	17.25
17:00	1.58	255.73	17.40
18:00	1.60	255.72	17.39
19:00	1.51	255.77	17.44
20:00	1.63	255.70	17.37
21:00	1.65	255.69	17.36
22:00	1.67	255.68	17.35
23:00	1.69	255.67	17.34
24:00:00	1.69	255.67	17.34

14). Junction - 14 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.73	14.56
1:00	1.67	255.74	14.56
2:00	1.63	255.76	14.58
3:00	1.65	255.75	14.57
4:00	1.67	255.74	14.56
5:00	1.86	255.63	14.46
6:00	1.82	255.65	14.48
7:00	1.79	255.67	14.50
8:00	1.82	255.65	14.48
9:00	1.81	255.66	14.49
10:00	1.79	255.67	14.50
11:00	1.81	255.66	14.49
12:00	1.79	255.67	14.50
13:00	1.79	255.67	14.50
14:00	1.77	255.68	14.51
15:00	1.79	255.67	14.50
16:00	1.82	255.65	14.48
17:00	1.58	255.78	14.61
18:00	1.60	255.78	14.60
19:00	1.51	255.82	14.65
20:00	1.63	255.76	14.58
21:00	1.65	255.75	14.57
22:00	1.67	255.74	14.56
23:00	1.69	255.73	14.56
24:00:00	1.69	255.73	14.56

15). Junction - 15 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.71	14.54
1:00	1.67	255.72	14.55
2:00	1.63	255.74	14.57
3:00	1.65	255.73	14.56
4:00	1.67	255.72	14.55
5:00	1.86	255.61	14.44
6:00	1.82	255.63	14.46
7:00	1.79	255.65	14.48
8:00	1.82	255.63	14.46
9:00	1.81	255.64	14.47
10:00	1.79	255.65	14.48
11:00	1.81	255.64	14.47
12:00	1.79	255.65	14.48
13:00	1.79	255.65	14.48
14:00	1.77	255.66	14.49
15:00	1.79	255.65	14.48
16:00	1.82	255.63	14.46
17:00	1.58	255.77	14.60
18:00	1.60	255.76	14.59
19:00	1.51	255.81	14.63
20:00	1.63	255.74	14.57
21:00	1.65	255.73	14.56
22:00	1.67	255.72	14.55
23:00	1.69	255.71	14.54
24:00:00	1.69	255.71	14.54

16). Junction - 16 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.70	14.26
1:00	1.67	255.71	14.27
2:00	1.63	255.73	14.29
3:00	1.65	255.72	14.28
4:00	1.67	255.71	14.27
5:00	1.86	255.59	14.16
6:00	1.82	255.61	14.18
7:00	1.79	255.63	14.20
8:00	1.82	255.61	14.18
9:00	1.81	255.62	14.19
10:00	1.79	255.63	14.20
11:00	1.81	255.62	14.19
12:00	1.79	255.63	14.20
13:00	1.79	255.63	14.20
14:00	1.77	255.64	14.21
15:00	1.79	255.63	14.20
16:00	1.82	255.61	14.18
17:00	1.58	255.75	14.32
18:00	1.60	255.75	14.31
19:00	1.51	255.79	14.36
20:00	1.63	255.73	14.29
21:00	1.65	255.72	14.28
22:00	1.67	255.71	14.27
23:00	1.69	255.70	14.26
24:00:00	1.69	255.70	14.26

17). Junction - 17 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.70	14.22
1:00	0	255.71	14.23
2:00	0	255.73	14.25
3:00	0	255.72	14.24
4:00	0	255.71	14.23
5:00	0	255.59	14.12
6:00	0	255.61	14.14
7:00	0	255.63	14.16
8:00	0	255.61	14.14
9:00	0	255.62	14.15
10:00	0	255.63	14.16
11:00	0	255.62	14.15
12:00	0	255.63	14.16
13:00	0	255.63	14.16
14:00	0	255.64	14.17
15:00	0	255.63	14.16
16:00	0	255.61	14.14
17:00	0	255.76	14.28
18:00	0	255.75	14.27
19:00	0	255.79	14.32
20:00	0	255.73	14.25
21:00	0	255.72	14.24
22:00	0	255.71	14.23
23:00	0	255.70	14.22
24:00:00	0	255.70	14.22

* Elbow

18). Junction - 18 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.70	12.93
1:00	0	255.71	12.94
2:00	0	255.73	12.96
3:00	0	255.72	12.95
4:00	0	255.71	12.94
5:00	0	255.59	12.83
6:00	0	255.61	12.85
7:00	0	255.64	12.87
8:00	0	255.61	12.85
9:00	0	255.63	12.86
10:00	0	255.64	12.87
11:00	0	255.63	12.86
12:00	0	255.64	12.87
13:00	0	255.64	12.87
14:00	0	255.65	12.88
15:00	0	255.64	12.87
16:00	0	255.61	12.85
17:00	0	255.76	12.99
18:00	0	255.75	12.98
19:00	0	255.79	13.03
20:00	0	255.73	12.96
21:00	0	255.72	12.95
22:00	0	255.71	12.94
23:00	0	255.70	12.93
24:00:00	0	255.70	12.93

* Elbow

19). Junction - 19 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.70	12.53
1:00	1.67	255.71	12.54
2:00	1.63	255.73	12.56
3:00	1.65	255.72	12.55
4:00	1.67	255.71	12.54
5:00	1.86	255.59	12.43
6:00	1.82	255.62	12.45
7:00	1.79	255.64	12.47
8:00	1.82	255.62	12.45
9:00	1.81	255.63	12.46
10:00	1.79	255.64	12.47
11:00	1.81	255.63	12.46
12:00	1.79	255.64	12.47
13:00	1.79	255.64	12.47
14:00	1.77	255.65	12.48
15:00	1.79	255.64	12.47
16:00	1.82	255.62	12.45
17:00	1.58	255.76	12.59
18:00	1.60	255.75	12.58
19:00	1.51	255.79	12.63
20:00	1.63	255.73	12.56
21:00	1.65	255.72	12.55
22:00	1.67	255.71	12.54
23:00	1.69	255.70	12.53
24:00:00	1.69	255.70	12.53

20). Junction - 20 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.73	13.03
1:00	1.67	255.74	13.04
2:00	1.63	255.75	13.05
3:00	1.65	255.74	13.04
4:00	1.67	255.74	13.04
5:00	1.86	255.63	12.93
6:00	1.82	255.65	12.95
7:00	1.79	255.67	12.97
8:00	1.82	255.65	12.95
9:00	1.81	255.66	12.96
10:00	1.79	255.67	12.97
11:00	1.81	255.66	12.96
12:00	1.79	255.67	12.97
13:00	1.79	255.67	12.97
14:00	1.77	255.68	12.98
15:00	1.79	255.67	12.97
16:00	1.82	255.65	12.95
17:00	1.58	255.78	13.08
18:00	1.60	255.77	13.07
19:00	1.51	255.82	13.12
20:00	1.63	255.75	13.05
21:00	1.65	255.74	13.04
22:00	1.67	255.74	13.04
23:00	1.69	255.73	13.03
24:00:00	1.69	255.73	13.03

21). Junction - 21 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.75	13.05
1:00	1.67	255.75	13.05
2:00	1.63	255.77	13.07
3:00	1.65	255.76	13.06
4:00	1.67	255.75	13.05
5:00	1.86	255.65	12.95
6:00	1.82	255.67	12.97
7:00	1.79	255.69	12.99
8:00	1.82	255.67	12.97
9:00	1.81	255.68	12.98
10:00	1.79	255.69	12.99
11:00	1.81	255.68	12.98
12:00	1.79	255.69	12.99
13:00	1.79	255.69	12.99
14:00	1.77	255.70	13.00
15:00	1.79	255.69	12.99
16:00	1.82	255.67	12.97
17:00	1.58	255.80	13.10
18:00	1.60	255.79	13.09
19:00	1.51	255.83	13.13
20:00	1.63	255.77	13.07
21:00	1.65	255.76	13.06
22:00	1.67	255.75	13.05
23:00	1.69	255.75	13.05
24:00:00	1.69	255.75	13.05

22). Junction - 22 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.70	10.19
1:00	1.67	255.71	10.20
2:00	1.63	255.73	10.22
3:00	1.65	255.72	10.21
4:00	1.67	255.71	10.20
5:00	1.86	255.59	10.08
6:00	1.82	255.61	10.10
7:00	1.79	255.63	10.13
8:00	1.82	255.61	10.10
9:00	1.81	255.62	10.12
10:00	1.79	255.63	10.13
11:00	1.81	255.62	10.12
12:00	1.79	255.63	10.13
13:00	1.79	255.63	10.13
14:00	1.77	255.64	10.14
15:00	1.79	255.63	10.13
16:00	1.82	255.61	10.10
17:00	1.58	255.76	10.25
18:00	1.60	255.75	10.24
19:00	1.51	255.79	10.29
20:00	1.63	255.73	10.22
21:00	1.65	255.72	10.21
22:00	1.67	255.71	10.20
23:00	1.69	255.70	10.19
24:00:00	1.69	255.70	10.19

23). Junction - 23 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.69	10.07
1:00	1.67	255.70	10.08
2:00	1.63	255.72	10.10
3:00	1.65	255.71	10.09
4:00	1.67	255.70	10.08
5:00	1.86	255.58	9.96
6:00	1.82	255.60	9.98
7:00	1.79	255.62	10.01
8:00	1.82	255.60	9.98
9:00	1.81	255.61	9.99
10:00	1.79	255.62	10.01
11:00	1.81	255.61	9.99
12:00	1.79	255.62	10.01
13:00	1.79	255.62	10.01
14:00	1.77	255.63	10.02
15:00	1.79	255.62	10.01
16:00	1.82	255.6	9.98
17:00	1.58	255.75	10.13
18:00	1.60	255.74	10.12
19:00	1.51	255.79	10.17
20:00	1.63	255.72	10.10
21:00	1.65	255.71	10.09
22:00	1.67	255.7	10.08
23:00	1.69	255.69	10.07
24:00:00	1.69	255.69	10.07

24). Junction - 24 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.69	10.07
1:00	1.67	255.70	10.08
2:00	1.63	255.72	10.10
3:00	1.65	255.71	10.09
4:00	1.67	255.70	10.08
5:00	1.86	255.58	9.96
6:00	1.82	255.60	9.98
7:00	1.79	255.62	10.00
8:00	1.82	255.60	9.98
9:00	1.81	255.61	9.99
10:00	1.79	255.62	10.00
11:00	1.81	255.61	9.99
12:00	1.79	255.62	10.00
13:00	1.79	255.62	10.00
14:00	1.77	255.63	10.01
15:00	1.79	255.62	10.00
16:00	1.82	255.60	9.98
17:00	1.58	255.75	10.13
18:00	1.60	255.74	10.12
19:00	1.51	255.78	10.17
20:00	1.63	255.72	10.10
21:00	1.65	255.71	10.09
22:00	1.67	255.70	10.08
23:00	1.69	255.69	10.07
24:00:00	1.69	255.69	10.07

25). Junction - 25 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.69	255.68	13.48
1:00	1.67	255.69	13.49
2:00	1.63	255.71	13.51
3:00	1.65	255.70	13.50
4:00	1.67	255.69	13.49
5:00	1.86	255.57	13.37
6:00	1.82	255.60	13.40
7:00	1.79	255.62	13.42
8:00	1.82	255.60	13.40
9:00	1.81	255.61	13.41
10:00	1.79	255.62	13.42
11:00	1.81	255.61	13.41
12:00	1.79	255.62	13.42
13:00	1.79	255.62	13.42
14:00	1.77	255.63	13.43
15:00	1.79	255.62	13.42
16:00	1.82	255.60	13.40
17:00	1.58	255.74	13.54
18:00	1.60	255.73	13.53
19:00	1.51	255.78	13.58
20:00	1.63	255.71	13.51
21:00	1.65	255.70	13.50
22:00	1.67	255.69	13.49
23:00	1.69	255.68	13.48
24:00:00	1.69	255.68	13.48

26). DMA (District Meter)- Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	26.97	256.23	0
1:00	26.69	256.23	0
2:00	26.14	256.23	0
3:00	26.42	256.23	0
4:00	26.69	256.23	0
5:00	29.72	256.23	0
6:00	29.17	256.23	0
7:00	28.62	256.23	0
8:00	29.17	256.23	0
9:00	28.90	256.23	0
10:00	28.62	256.23	0
11:00	28.90	256.23	0
12:00	28.62	256.23	0
13:00	28.62	256.23	0
14:00	28.35	256.23	0
15:00	28.62	256.23	0
16:00	29.17	256.23	0
17:00	25.32	256.23	0
18:00	25.59	256.23	0
19:00	24.22	256.23	0
20:00	26.14	256.23	0
21:00	26.42	256.23	0
22:00	26.69	256.23	0
23:00	26.97	256.23	0
24:00:00	26.97	256.23	0

Scenario -1

Tabulated Presentation of Pipes Time Series

Results

1). Pipe P-1 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	100	300	130	26.97	0.38
1:00	100	300	130	26.69	0.38
2:00	100	300	130	26.14	0.37
3:00	100	300	130	26.42	0.37
4:00	100	300	130	26.69	0.38
5:00	100	300	130	29.72	0.42
6:00	100	300	130	29.17	0.41
7:00	100	300	130	28.62	0.4
8:00	100	300	130	29.17	0.41
9:00	100	300	130	28.90	0.41
10:00	100	300	130	28.62	0.4
11:00	100	300	130	28.90	0.41
12:00	100	300	130	28.62	0.40
13:00	100	300	130	28.62	0.40
14:00	100	300	130	28.35	0.40
15:00	100	300	130	28.62	0.40
16:00	100	300	130	29.17	0.41
17:00	100	300	130	25.32	0.36
18:00	100	300	130	25.59	0.36
19:00	100	300	130	24.22	0.34
20:00	100	300	130	26.14	0.37
21:00	100	300	130	26.42	0.37
22:00	100	300	130	26.69	0.38
23:00	100	300	130	26.97	0.38
24:00	100	300	130	26.97	0.38

2). Pipe P-2 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	232.038	200	130	13.08	0.42
1:00	232.038	200	130	12.95	0.41
2:00	232.038	200	130	12.68	0.40
3:00	232.038	200	130	12.81	0.41
4:00	232.038	200	130	12.95	0.41
5:00	232.038	200	130	14.41	0.46
6:00	232.038	200	130	14.15	0.45
7:00	232.038	200	130	13.88	0.44
8:00	232.038	200	130	14.15	0.45
9:00	232.038	200	130	14.01	0.45
10:00	232.038	200	130	13.88	0.44
11:00	232.038	200	130	14.01	0.45
12:00	232.038	200	130	13.88	0.44
13:00	232.038	200	130	13.88	0.44
14:00	232.038	200	130	13.75	0.44
15:00	232.038	200	130	13.88	0.44
16:00	232.038	200	130	14.15	0.45
17:00	232.038	200	130	12.28	0.39
18:00	232.038	200	130	12.41	0.40
19:00	232.038	200	130	11.74	0.37
20:00	232.038	200	130	12.68	0.40
21:00	232.038	200	130	12.81	0.41
22:00	232.038	200	130	12.95	0.41
23:00	232.038	200	130	13.08	0.42
24:00	232.038	200	130	13.08	0.42

3). Pipe P-3 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	9.975	200	130	3.12	0.10
1:00	9.975	200	130	3.08	0.10
2:00	9.975	200	130	3.02	0.10
3:00	9.975	200	130	3.05	0.10
4:00	9.975	200	130	3.08	0.10
5:00	9.975	200	130	3.43	0.11
6:00	9.975	200	130	3.37	0.11
7:00	9.975	200	130	3.31	0.11
8:00	9.975	200	130	3.37	0.11
9:00	9.975	200	130	3.34	0.11
10:00	9.975	200	130	3.31	0.11
11:00	9.975	200	130	3.34	0.11
12:00	9.975	200	130	3.31	0.11
13:00	9.975	200	130	3.31	0.11
14:00	9.975	200	130	3.27	0.10
15:00	9.975	200	130	3.31	0.11
16:00	9.975	200	130	3.37	0.11
17:00	9.975	200	130	2.92	0.09
18:00	9.975	200	130	2.96	0.09
19:00	9.975	200	130	2.80	0.09
20:00	9.975	200	130	3.02	0.10
21:00	9.975	200	130	3.05	0.10
22:00	9.975	200	130	3.08	0.10
23:00	9.975	200	130	3.12	0.10
24:00	9.975	200	130	3.12	0.10

4). Pipe P-4 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	160.264	200	130	13.89	0.44
1:00	160.264	200	130	13.75	0.44
2:00	160.264	200	130	13.46	0.43
3:00	160.264	200	130	13.61	0.43
4:00	160.264	200	130	13.75	0.44
5:00	160.264	200	130	15.31	0.49
6:00	160.264	200	130	15.02	0.48
7:00	160.264	200	130	14.74	0.47
8:00	160.264	200	130	15.02	0.48
9:00	160.264	200	130	14.88	0.47
10:00	160.264	200	130	14.74	0.47
11:00	160.264	200	130	14.88	0.47
12:00	160.264	200	130	14.74	0.47
13:00	160.264	200	130	14.74	0.47
14:00	160.264	200	130	14.60	0.46
15:00	160.264	200	130	14.74	0.47
16:00	160.264	200	130	15.02	0.48
17:00	160.264	200	130	13.04	0.42
18:00	160.264	200	130	13.18	0.42
19:00	160.264	200	130	12.47	0.40
20:00	160.264	200	130	13.46	0.43
21:00	160.264	200	130	13.61	0.43
22:00	160.264	200	130	13.75	0.44
23:00	160.264	200	130	13.89	0.44
24:00	160.264	200	130	13.89	0.44

5). Pipe P-5 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	2.38	150	130	13.89	0.79
1:00	2.38	150	130	13.75	0.78
2:00	2.38	150	130	13.46	0.76
3:00	2.38	150	130	13.61	0.77
4:00	2.38	150	130	13.75	0.78
5:00	2.38	150	130	15.31	0.87
6:00	2.38	150	130	15.02	0.85
7:00	2.38	150	130	14.74	0.83
8:00	2.38	150	130	15.02	0.85
9:00	2.38	150	130	14.88	0.84
10:00	2.38	150	130	14.74	0.83
11:00	2.38	150	130	14.88	0.84
12:00	2.38	150	130	14.74	0.83
13:00	2.38	150	130	14.74	0.83
14:00	2.38	150	130	14.6	0.83
15:00	2.38	150	130	14.74	0.83
16:00	2.38	150	130	15.02	0.85
17:00	2.38	150	130	13.04	0.74
18:00	2.38	150	130	13.18	0.75
19:00	2.38	150	130	12.47	0.71
20:00	2.38	150	130	13.46	0.76
21:00	2.38	150	130	13.61	0.77
22:00	2.38	150	130	13.75	0.78
23:00	2.38	150	130	13.89	0.79
24:00	2.38	150	130	13.89	0.79

6). Pipe P-6 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.92	150	130	3.29	0.19
1:00	354.92	150	130	3.26	0.18
2:00	354.92	150	130	3.19	0.18
3:00	354.92	150	130	3.23	0.18
4:00	354.92	150	130	3.26	0.18
5:00	354.92	150	130	3.63	0.21
6:00	354.92	150	130	3.56	0.2
7:00	354.92	150	130	3.5	0.2
8:00	354.92	150	130	3.56	0.2
9:00	354.92	150	130	3.53	0.2
10:00	354.92	150	130	3.5	0.2
11:00	354.92	150	130	3.53	0.2
12:00	354.92	150	130	3.5	0.2
13:00	354.92	150	130	3.5	0.2
14:00	354.92	150	130	3.46	0.2
15:00	354.92	150	130	3.5	0.2
16:00	354.92	150	130	3.56	0.2
17:00	354.92	150	130	3.09	0.18
18:00	354.92	150	130	3.13	0.18
19:00	354.92	150	130	2.96	0.17
20:00	354.92	150	130	3.19	0.18
21:00	354.92	150	130	3.23	0.18
22:00	354.92	150	130	3.26	0.18
23:00	354.92	150	130	3.29	0.19
24:00	354.92	150	130	3.29	0.19

7). Pipe P-7 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.3	150	130	3.29	0.19
1:00	105.3	150	130	3.26	0.18
2:00	105.3	150	130	3.19	0.18
3:00	105.3	150	130	3.23	0.18
4:00	105.3	150	130	3.26	0.18
5:00	105.3	150	130	3.63	0.21
6:00	105.3	150	130	3.56	0.2
7:00	105.3	150	130	3.5	0.2
8:00	105.3	150	130	3.56	0.2
9:00	105.3	150	130	3.53	0.2
10:00	105.3	150	130	3.5	0.2
11:00	105.3	150	130	3.53	0.2
12:00	105.3	150	130	3.5	0.2
13:00	105.3	150	130	3.5	0.2
14:00	105.3	150	130	3.46	0.2
15:00	105.3	150	130	3.5	0.2
16:00	105.3	150	130	3.56	0.2
17:00	105.3	150	130	3.09	0.18
18:00	105.3	150	130	3.13	0.18
19:00	105.3	150	130	2.96	0.17
20:00	105.3	150	130	3.19	0.18
21:00	105.3	150	130	3.23	0.18
22:00	105.3	150	130	3.26	0.18
23:00	105.3	150	130	3.29	0.19
24:00	105.3	150	130	3.29	0.19

8). Pipe P-8 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.91	150	130	3.29	0.19
1:00	354.91	150	130	3.26	0.18
2:00	354.91	150	130	3.19	0.18
3:00	354.91	150	130	3.23	0.18
4:00	354.91	150	130	3.26	0.18
5:00	354.91	150	130	3.63	0.21
6:00	354.91	150	130	3.56	0.2
7:00	354.91	150	130	3.5	0.2
8:00	354.91	150	130	3.56	0.2
9:00	354.91	150	130	3.53	0.2
10:00	354.91	150	130	3.5	0.2
11:00	354.91	150	130	3.53	0.2
12:00	354.91	150	130	3.5	0.2
13:00	354.91	150	130	3.5	0.2
14:00	354.91	150	130	3.46	0.2
15:00	354.91	150	130	3.5	0.2
16:00	354.91	150	130	3.56	0.2
17:00	354.91	150	130	3.09	0.18
18:00	354.91	150	130	3.13	0.18
19:00	354.91	150	130	2.96	0.17
20:00	354.91	150	130	3.19	0.18
21:00	354.91	150	130	3.23	0.18
22:00	354.91	150	130	3.26	0.18
23:00	354.91	150	130	3.29	0.19
24:00	354.91	150	130	3.29	0.19

9). Pipe P-9 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	1.61	0.09
1:00	105.97	150	130	1.59	0.09
2:00	105.97	150	130	1.56	0.09
3:00	105.97	150	130	1.58	0.09
4:00	105.97	150	130	1.59	0.09
5:00	105.97	150	130	1.77	0.1
6:00	105.97	150	130	1.74	0.1
7:00	105.97	150	130	1.71	0.1
8:00	105.97	150	130	1.74	0.1
9:00	105.97	150	130	1.72	0.1
10:00	105.97	150	130	1.71	0.1
11:00	105.97	150	130	1.72	0.1
12:00	105.97	150	130	1.71	0.1
13:00	105.97	150	130	1.71	0.1
14:00	105.97	150	130	1.69	0.1
15:00	105.97	150	130	1.71	0.1
16:00	105.97	150	130	1.74	0.1
17:00	105.97	150	130	1.51	0.09
18:00	105.97	150	130	1.53	0.09
19:00	105.97	150	130	1.44	0.08
20:00	105.97	150	130	1.56	0.09
21:00	105.97	150	130	1.58	0.09
22:00	105.97	150	130	1.59	0.09
23:00	105.97	150	130	1.61	0.09
24:00	105.97	150	130	1.61	0.09

10). Pipe P-10 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	1.41	0.08
1:00	21	150	130	1.39	0.08
2:00	21	150	130	1.36	0.08
3:00	21	150	130	1.38	0.08
4:00	21	150	130	1.39	0.08
5:00	21	150	130	1.55	0.09
6:00	21	150	130	1.52	0.09
7:00	21	150	130	1.49	0.08
8:00	21	150	130	1.52	0.09
9:00	21	150	130	1.51	0.09
10:00	21	150	130	1.49	0.08
11:00	21	150	130	1.51	0.09
12:00	21	150	130	1.49	0.08
13:00	21	150	130	1.49	0.08
14:00	21	150	130	1.48	0.08
15:00	21	150	130	1.49	0.08
16:00	21	150	130	1.52	0.09
17:00	21	150	130	1.32	0.07
18:00	21	150	130	1.34	0.08
19:00	21	150	130	1.26	0.07
20:00	21	150	130	1.36	0.08
21:00	21	150	130	1.38	0.08
22:00	21	150	130	1.39	0.08
23:00	21	150	130	1.41	0.08
24:00	21	150	130	1.41	0.08

11). Pipe P-11 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	0.93	0.05
1:00	105.97	150	130	0.92	0.05
2:00	105.97	150	130	0.90	0.05
3:00	105.97	150	130	0.91	0.05
4:00	105.97	150	130	0.92	0.05
5:00	105.97	150	130	1.03	0.06
6:00	105.97	150	130	1.01	0.06
7:00	105.97	150	130	0.99	0.06
8:00	105.97	150	130	1.01	0.06
9:00	105.97	150	130	1.00	0.06
10:00	105.97	150	130	0.99	0.06
11:00	105.97	150	130	1.00	0.06
12:00	105.97	150	130	0.99	0.06
13:00	105.97	150	130	0.99	0.06
14:00	105.97	150	130	0.98	0.06
15:00	105.97	150	130	0.99	0.06
16:00	105.97	150	130	1.01	0.06
17:00	105.97	150	130	0.88	0.05
18:00	105.97	150	130	0.89	0.05
19:00	105.97	150	130	0.84	0.05
20:00	105.97	150	130	0.90	0.05
21:00	105.97	150	130	0.91	0.05
22:00	105.97	150	130	0.92	0.05
23:00	105.97	150	130	0.93	0.05
24:00	105.97	150	130	0.93	0.05

12). Pipe P-12 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.81	150	130	0.75	0.04
1:00	763.81	150	130	0.74	0.04
2:00	763.81	150	130	0.73	0.04
3:00	763.81	150	130	0.74	0.04
4:00	763.81	150	130	0.74	0.04
5:00	763.81	150	130	0.83	0.05
6:00	763.81	150	130	0.81	0.05
7:00	763.81	150	130	0.80	0.05
8:00	763.81	150	130	0.81	0.05
9:00	763.81	150	130	0.81	0.05
10:00	763.81	150	130	0.80	0.05
11:00	763.81	150	130	0.81	0.05
12:00	763.81	150	130	0.80	0.05
13:00	763.81	150	130	0.80	0.05
14:00	763.81	150	130	0.79	0.04
15:00	763.81	150	130	0.80	0.05
16:00	763.81	150	130	0.81	0.05
17:00	763.81	150	130	0.71	0.04
18:00	763.81	150	130	0.71	0.04
19:00	763.81	150	130	0.68	0.04
20:00	763.81	150	130	0.73	0.04
21:00	763.81	150	130	0.74	0.04
22:00	763.81	150	130	0.74	0.04
23:00	763.81	150	130	0.75	0.04
24:00	763.81	150	130	0.75	0.04

13). Pipe P-13 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	764	150	130	1.21	0.07
1:00	764	150	130	1.2	0.07
2:00	764	150	130	1.18	0.07
3:00	764	150	130	1.19	0.07
4:00	764	150	130	1.20	0.07
5:00	764	150	130	1.34	0.08
6:00	764	150	130	1.31	0.07
7:00	764	150	130	1.29	0.07
8:00	764	150	130	1.31	0.07
9:00	764	150	130	1.30	0.07
10:00	764	150	130	1.29	0.07
11:00	764	150	130	1.30	0.07
12:00	764	150	130	1.29	0.07
13:00	764	150	130	1.29	0.07
14:00	764	150	130	1.27	0.07
15:00	764	150	130	1.29	0.07
16:00	764	150	130	1.31	0.07
17:00	764	150	130	1.14	0.06
18:00	764	150	130	1.15	0.07
19:00	764	150	130	1.09	0.06
20:00	764	150	130	1.18	0.07
21:00	764	150	130	1.19	0.07
22:00	764	150	130	1.20	0.07
23:00	764	150	130	1.21	0.07
24:00	764	150	130	1.21	0.07

14). Pipe P-14 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	764	150	130	1.48	0.08
1:00	764	150	130	1.47	0.08
2:00	764	150	130	1.44	0.08
3:00	764	150	130	1.45	0.08
4:00	764	150	130	1.47	0.08
5:00	764	150	130	1.63	0.09
6:00	764	150	130	1.60	0.09
7:00	764	150	130	1.57	0.09
8:00	764	150	130	1.60	0.09
9:00	764	150	130	1.59	0.09
10:00	764	150	130	1.57	0.09
11:00	764	150	130	1.59	0.09
12:00	764	150	130	1.57	0.09
13:00	764	150	130	1.57	0.09
14:00	764	150	130	1.56	0.09
15:00	764	150	130	1.57	0.09
16:00	764	150	130	1.60	0.09
17:00	764	150	130	1.39	0.08
18:00	764	150	130	1.41	0.08
19:00	764	150	130	1.33	0.08
20:00	764	150	130	1.44	0.08
21:00	764	150	130	1.45	0.08
22:00	764	150	130	1.47	0.08
23:00	764	150	130	1.48	0.08
24:00	764	150	130	1.48	0.08

15). Pipe P-15 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	25.67	150	130	0.41	0.02
1:00	25.67	150	130	0.40	0.02
2:00	25.67	150	130	0.39	0.02
3:00	25.67	150	130	0.40	0.02
4:00	25.67	150	130	0.40	0.02
5:00	25.67	150	130	0.45	0.03
6:00	25.67	150	130	0.44	0.02
7:00	25.67	150	130	0.43	0.02
8:00	25.67	150	130	0.44	0.02
9:00	25.67	150	130	0.43	0.02
10:00	25.67	150	130	0.43	0.02
11:00	25.67	150	130	0.43	0.02
12:00	25.67	150	130	0.43	0.02
13:00	25.67	150	130	0.43	0.02
14:00	25.67	150	130	0.43	0.02
15:00	25.67	150	130	0.43	0.02
16:00	25.67	150	130	0.44	0.02
17:00	25.67	150	130	0.38	0.02
18:00	25.67	150	130	0.38	0.02
19:00	25.67	150	130	0.36	0.02
20:00	25.67	150	130	0.39	0.02
21:00	25.67	150	130	0.40	0.02
22:00	25.67	150	130	0.40	0.02
23:00	25.67	150	130	0.41	0.02
24:00	25.67	150	130	0.41	0.02

16). Pipe P-16 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	2.84	0.16
1:00	105.97	150	130	2.81	0.16
2:00	105.97	150	130	2.76	0.16
3:00	105.97	150	130	2.78	0.16
4:00	105.97	150	130	2.81	0.16
5:00	105.97	150	130	3.13	0.18
6:00	105.97	150	130	3.08	0.17
7:00	105.97	150	130	3.02	0.17
8:00	105.97	150	130	3.08	0.17
9:00	105.97	150	130	3.05	0.17
10:00	105.97	150	130	3.02	0.17
11:00	105.97	150	130	3.05	0.17
12:00	105.97	150	130	3.02	0.17
13:00	105.97	150	130	3.02	0.17
14:00	105.97	150	130	2.99	0.17
15:00	105.97	150	130	3.02	0.17
16:00	105.97	150	130	3.08	0.17
17:00	105.97	150	130	2.67	0.15
18:00	105.97	150	130	2.70	0.15
19:00	105.97	150	130	2.55	0.14
20:00	105.97	150	130	2.76	0.16
21:00	105.97	150	130	2.78	0.16
22:00	105.97	150	130	2.81	0.16
23:00	105.97	150	130	2.84	0.16
24:00	105.97	150	130	2.84	0.16

17). Pipe P-17 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	5.74	0.32
1:00	21	150	130	5.68	0.32
2:00	21	150	130	5.57	0.31
3:00	21	150	130	5.62	0.32
4:00	21	150	130	5.68	0.32
5:00	21	150	130	6.33	0.36
6:00	21	150	130	6.21	0.35
7:00	21	150	130	6.09	0.34
8:00	21	150	130	6.21	0.35
9:00	21	150	130	6.15	0.35
10:00	21	150	130	6.09	0.34
11:00	21	150	130	6.15	0.35
12:00	21	150	130	6.09	0.34
13:00	21	150	130	6.09	0.34
14:00	21	150	130	6.03	0.34
15:00	21	150	130	6.09	0.34
16:00	21	150	130	6.21	0.35
17:00	21	150	130	5.39	0.3
18:00	21	150	130	5.45	0.31
19:00	21	150	130	5.15	0.29
20:00	21	150	130	5.57	0.31
21:00	21	150	130	5.62	0.32
22:00	21	150	130	5.68	0.32
23:00	21	150	130	5.74	0.32
24:00	21	150	130	5.74	0.32

18). Pipe P-18 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	8.91	0.5
1:00	105.97	150	130	8.82	0.5
2:00	105.97	150	130	8.64	0.49
3:00	105.97	150	130	8.73	0.49
4:00	105.97	150	130	8.82	0.5
5:00	105.97	150	130	9.82	0.56
6:00	105.97	150	130	9.64	0.55
7:00	105.97	150	130	9.46	0.54
8:00	105.97	150	130	9.64	0.55
9:00	105.97	150	130	9.55	0.54
10:00	105.97	150	130	9.46	0.54
11:00	105.97	150	130	9.55	0.54
12:00	105.97	150	130	9.46	0.54
13:00	105.97	150	130	9.46	0.54
14:00	105.97	150	130	9.36	0.53
15:00	105.97	150	130	9.46	0.54
16:00	105.97	150	130	9.64	0.55
17:00	105.97	150	130	8.36	0.47
18:00	105.97	150	130	8.46	0.48
19:00	105.97	150	130	8.00	0.45
20:00	105.97	150	130	8.64	0.49
21:00	105.97	150	130	8.73	0.49
22:00	105.97	150	130	8.82	0.5
23:00	105.97	150	130	8.91	0.5
24:00	105.97	150	130	8.91	0.5

19). Pipe P-19 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	350.93	150	130	0.41	0.02
1:00	350.93	150	130	0.40	0.02
2:00	350.93	150	130	0.39	0.02
3:00	350.93	150	130	0.40	0.02
4:00	350.93	150	130	0.40	0.02
5:00	350.93	150	130	0.45	0.03
6:00	350.93	150	130	0.44	0.02
7:00	350.93	150	130	0.43	0.02
8:00	350.93	150	130	0.44	0.02
9:00	350.93	150	130	0.43	0.02
10:00	350.93	150	130	0.43	0.02
11:00	350.93	150	130	0.43	0.02
12:00	350.93	150	130	0.43	0.02
13:00	350.93	150	130	0.43	0.02
14:00	350.93	150	130	0.43	0.02
15:00	350.93	150	130	0.43	0.02
16:00	350.93	150	130	0.44	0.02
17:00	350.93	150	130	0.38	0.02
18:00	350.93	150	130	0.38	0.02
19:00	350.93	150	130	0.36	0.02
20:00	350.93	150	130	0.39	0.02
21:00	350.93	150	130	0.40	0.02
22:00	350.93	150	130	0.40	0.02
23:00	350.93	150	130	0.41	0.02
24:00	350.93	150	130	0.41	0.02

20). Pipe P-20 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	25.67	150	130	0.41	0.02
1:00	25.67	150	130	0.40	0.02
2:00	25.67	150	130	0.39	0.02
3:00	25.67	150	130	0.40	0.02
4:00	25.67	150	130	0.40	0.02
5:00	25.67	150	130	0.45	0.03
6:00	25.67	150	130	0.44	0.02
7:00	25.67	150	130	0.43	0.02
8:00	25.67	150	130	0.44	0.02
9:00	25.67	150	130	0.43	0.02
10:00	25.67	150	130	0.43	0.02
11:00	25.67	150	130	0.43	0.02
12:00	25.67	150	130	0.43	0.02
13:00	25.67	150	130	0.43	0.02
14:00	25.67	150	130	0.43	0.02
15:00	25.67	150	130	0.43	0.02
16:00	25.67	150	130	0.44	0.02
17:00	25.67	150	130	0.38	0.02
18:00	25.67	150	130	0.38	0.02
19:00	25.67	150	130	0.36	0.02
20:00	25.67	150	130	0.39	0.02
21:00	25.67	150	130	0.40	0.02
22:00	25.67	150	130	0.40	0.02
23:00	25.67	150	130	0.41	0.02
24:00	25.67	150	130	0.41	0.02

21). Pipe P-21 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	2.23	0.13
1:00	105.97	150	130	2.21	0.13
2:00	105.97	150	130	2.17	0.12
3:00	105.97	150	130	2.19	0.12
4:00	105.97	150	130	2.21	0.13
5:00	105.97	150	130	2.46	0.14
6:00	105.97	150	130	2.42	0.14
7:00	105.97	150	130	2.37	0.13
8:00	105.97	150	130	2.42	0.14
9:00	105.97	150	130	2.39	0.14
10:00	105.97	150	130	2.37	0.13
11:00	105.97	150	130	2.39	0.14
12:00	105.97	150	130	2.37	0.13
13:00	105.97	150	130	2.37	0.13
14:00	105.97	150	130	2.35	0.13
15:00	105.97	150	130	2.37	0.13
16:00	105.97	150	130	2.42	0.14
17:00	105.97	150	130	2.10	0.12
18:00	105.97	150	130	2.12	0.12
19:00	105.97	150	130	2.01	0.11
20:00	105.97	150	130	2.17	0.12
21:00	105.97	150	130	2.19	0.12
22:00	105.97	150	130	2.21	0.13
23:00	105.97	150	130	2.23	0.13
24:00	105.97	150	130	2.23	0.13

22). Pipe P-22 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	5.14	0.29
1:00	21	150	130	5.09	0.29
2:00	21	150	130	4.99	0.28
3:00	21	150	130	5.04	0.29
4:00	21	150	130	5.09	0.29
5:00	21	150	130	5.67	0.32
6:00	21	150	130	5.56	0.31
7:00	21	150	130	5.46	0.31
8:00	21	150	130	5.56	0.31
9:00	21	150	130	5.51	0.31
10:00	21	150	130	5.46	0.31
11:00	21	150	130	5.51	0.31
12:00	21	150	130	5.46	0.31
13:00	21	150	130	5.46	0.31
14:00	21	150	130	5.41	0.31
15:00	21	150	130	5.46	0.31
16:00	21	150	130	5.56	0.31
17:00	21	150	130	4.83	0.27
18:00	21	150	130	4.88	0.28
19:00	21	150	130	4.62	0.26
20:00	21	150	130	4.99	0.28
21:00	21	150	130	5.04	0.29
22:00	21	150	130	5.09	0.29
23:00	21	150	130	5.14	0.29
24:00	21	150	130	5.14	0.29

23). Pipe P-23 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	8.28	0.47
1:00	105.97	150	130	8.19	0.46
2:00	105.97	150	130	8.03	0.45
3:00	105.97	150	130	8.11	0.46
4:00	105.97	150	130	8.19	0.46
5:00	105.97	150	130	9.12	0.52
6:00	105.97	150	130	8.95	0.51
7:00	105.97	150	130	8.79	0.5
8:00	105.97	150	130	8.95	0.51
9:00	105.97	150	130	8.87	0.5
10:00	105.97	150	130	8.79	0.5
11:00	105.97	150	130	8.87	0.5
12:00	105.97	150	130	8.79	0.5
13:00	105.97	150	130	8.79	0.5
14:00	105.97	150	130	8.70	0.49
15:00	105.97	150	130	8.79	0.5
16:00	105.97	150	130	8.95	0.51
17:00	105.97	150	130	7.77	0.44
18:00	105.97	150	130	7.86	0.44
19:00	105.97	150	130	7.43	0.42
20:00	105.97	150	130	8.03	0.45
21:00	105.97	150	130	8.11	0.46
22:00	105.97	150	130	8.19	0.46
23:00	105.97	150	130	8.28	0.47
24:00	105.97	150	130	8.28	0.47

24). Pipe P-24 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	344.945	150	130	3.12	0.18
1:00	344.945	150	130	3.08	0.17
2:00	344.945	150	130	3.02	0.17
3:00	344.945	150	130	3.05	0.17
4:00	344.945	150	130	3.08	0.17
5:00	344.945	150	130	3.43	0.19
6:00	344.945	150	130	3.37	0.19
7:00	344.945	150	130	3.31	0.19
8:00	344.945	150	130	3.37	0.19
9:00	344.945	150	130	3.34	0.19
10:00	344.945	150	130	3.31	0.19
11:00	344.945	150	130	3.34	0.19
12:00	344.945	150	130	3.31	0.19
13:00	344.945	150	130	3.31	0.19
14:00	344.945	150	130	3.27	0.19
15:00	344.945	150	130	3.31	0.19
16:00	344.945	150	130	3.37	0.19
17:00	344.945	150	130	2.92	0.17
18:00	344.945	150	130	2.96	0.17
19:00	344.945	150	130	2.80	0.16
20:00	344.945	150	130	3.02	0.17
21:00	344.945	150	130	3.05	0.17
22:00	344.945	150	130	3.08	0.17
23:00	344.945	150	130	3.12	0.18
24:00	344.945	150	130	3.12	0.18

25). Pipe P-25 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.2	150	130	3.12	0.18
1:00	105.2	150	130	3.08	0.17
2:00	105.2	150	130	3.02	0.17
3:00	105.2	150	130	3.05	0.17
4:00	105.2	150	130	3.08	0.17
5:00	105.2	150	130	3.43	0.19
6:00	105.2	150	130	3.37	0.19
7:00	105.2	150	130	3.31	0.19
8:00	105.2	150	130	3.37	0.19
9:00	105.2	150	130	3.34	0.19
10:00	105.2	150	130	3.31	0.19
11:00	105.2	150	130	3.34	0.19
12:00	105.2	150	130	3.31	0.19
13:00	105.2	150	130	3.31	0.19
14:00	105.2	150	130	3.27	0.19
15:00	105.2	150	130	3.31	0.19
16:00	105.2	150	130	3.37	0.19
17:00	105.2	150	130	2.92	0.17
18:00	105.2	150	130	2.96	0.17
19:00	105.2	150	130	2.80	0.16
20:00	105.2	150	130	3.02	0.17
21:00	105.2	150	130	3.05	0.17
22:00	105.2	150	130	3.08	0.17
23:00	105.2	150	130	3.12	0.18
24:00	105.2	150	130	3.12	0.18

26). Pipe P-26 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.91	150	130	3.12	0.18
1:00	354.91	150	130	3.08	0.17
2:00	354.91	150	130	3.02	0.17
3:00	354.91	150	130	3.05	0.17
4:00	354.91	150	130	3.08	0.17
5:00	354.91	150	130	3.43	0.19
6:00	354.91	150	130	3.37	0.19
7:00	354.91	150	130	3.31	0.19
8:00	354.91	150	130	3.37	0.19
9:00	354.91	150	130	3.34	0.19
10:00	354.91	150	130	3.31	0.19
11:00	354.91	150	130	3.34	0.19
12:00	354.91	150	130	3.31	0.19
13:00	354.91	150	130	3.31	0.19
14:00	354.91	150	130	3.27	0.19
15:00	354.91	150	130	3.31	0.19
16:00	354.91	150	130	3.37	0.19
17:00	354.91	150	130	2.92	0.17
18:00	354.91	150	130	2.96	0.17
19:00	354.91	150	130	2.80	0.16
20:00	354.91	150	130	3.02	0.17
21:00	354.91	150	130	3.05	0.17
22:00	354.91	150	130	3.08	0.17
23:00	354.91	150	130	3.12	0.18
24:00	354.91	150	130	3.12	0.18

27). **Pipe P-27 Time Series details**

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	1.43	0.08
1:00	105.97	150	130	1.42	0.08
2:00	105.97	150	130	1.39	0.08
3:00	105.97	150	130	1.40	0.08
4:00	105.97	150	130	1.42	0.08
5:00	105.97	150	130	1.58	0.09
6:00	105.97	150	130	1.55	0.09
7:00	105.97	150	130	1.52	0.09
8:00	105.97	150	130	1.55	0.09
9:00	105.97	150	130	1.53	0.09
10:00	105.97	150	130	1.52	0.09
11:00	105.97	150	130	1.53	0.09
12:00	105.97	150	130	1.52	0.09
13:00	105.97	150	130	1.52	0.09
14:00	105.97	150	130	1.50	0.09
15:00	105.97	150	130	1.52	0.09
16:00	105.97	150	130	1.55	0.09
17:00	105.97	150	130	1.34	0.08
18:00	105.97	150	130	1.36	0.08
19:00	105.97	150	130	1.28	0.07
20:00	105.97	150	130	1.39	0.08
21:00	105.97	150	130	1.40	0.08
22:00	105.97	150	130	1.42	0.08
23:00	105.97	150	130	1.43	0.08
24:00	105.97	150	130	1.43	0.08

28). **Pipe P-28 Time Series details**

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	1.19	0.07
1:00	21	150	130	1.18	0.07
2:00	21	150	130	1.16	0.07
3:00	21	150	130	1.17	0.07
4:00	21	150	130	1.18	0.07
5:00	21	150	130	1.31	0.07
6:00	21	150	130	1.29	0.07
7:00	21	150	130	1.27	0.07
8:00	21	150	130	1.29	0.07
9:00	21	150	130	1.28	0.07
10:00	21	150	130	1.27	0.07
11:00	21	150	130	1.28	0.07
12:00	21	150	130	1.27	0.07
13:00	21	150	130	1.27	0.07
14:00	21	150	130	1.25	0.07
15:00	21	150	130	1.27	0.07
16:00	21	150	130	1.29	0.07
17:00	21	150	130	1.12	0.06
18:00	21	150	130	1.13	0.06
19:00	21	150	130	1.07	0.06
20:00	21	150	130	1.16	0.07
21:00	21	150	130	1.17	0.07
22:00	21	150	130	1.18	0.07
23:00	21	150	130	1.19	0.07
24:00	21	150	130	1.19	0.07

29). Pipe P-29 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	0.73	0.04
1:00	105.97	150	130	0.72	0.04
2:00	105.97	150	130	0.71	0.04
3:00	105.97	150	130	0.72	0.04
4:00	105.97	150	130	0.72	0.04
5:00	105.97	150	130	0.81	0.05
6:00	105.97	150	130	0.79	0.04
7:00	105.97	150	130	0.78	0.04
8:00	105.97	150	130	0.79	0.04
9:00	105.97	150	130	0.78	0.04
10:00	105.97	150	130	0.78	0.04
11:00	105.97	150	130	0.78	0.04
12:00	105.97	150	130	0.78	0.04
13:00	105.97	150	130	0.78	0.04
14:00	105.97	150	130	0.77	0.04
15:00	105.97	150	130	0.78	0.04
16:00	105.97	150	130	0.79	0.04
17:00	105.97	150	130	0.69	0.04
18:00	105.97	150	130	0.69	0.04
19:00	105.97	150	130	0.66	0.04
20:00	105.97	150	130	0.71	0.04
21:00	105.97	150	130	0.72	0.04
22:00	105.97	150	130	0.72	0.04
23:00	105.97	150	130	0.73	0.04
24:00	105.97	150	130	0.73	0.04

30). Pipe P-30 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.848	150	130	1.45	0.08
1:00	763.848	150	130	1.43	0.08
2:00	763.848	150	130	1.40	0.08
3:00	763.848	150	130	1.42	0.08
4:00	763.848	150	130	1.43	0.08
5:00	763.848	150	130	1.60	0.09
6:00	763.848	150	130	1.57	0.09
7:00	763.848	150	130	1.54	0.09
8:00	763.848	150	130	1.57	0.09
9:00	763.848	150	130	1.55	0.09
10:00	763.848	150	130	1.54	0.09
11:00	763.848	150	130	1.55	0.09
12:00	763.848	150	130	1.54	0.09
13:00	763.848	150	130	1.54	0.09
14:00	763.848	150	130	1.52	0.09
15:00	763.848	150	130	1.54	0.09
16:00	763.848	150	130	1.57	0.09
17:00	763.848	150	130	1.36	0.08
18:00	763.848	150	130	1.37	0.08
19:00	763.848	150	130	1.30	0.07
20:00	763.848	150	130	1.40	0.08
21:00	763.848	150	130	1.42	0.08
22:00	763.848	150	130	1.43	0.08
23:00	763.848	150	130	1.45	0.08
24:00	763.848	150	130	1.45	0.08

31). Pipe P-31 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.848	150	130	1.22	0.07
1:00	763.848	150	130	1.21	0.07
2:00	763.848	150	130	1.19	0.07
3:00	763.848	150	130	1.20	0.07
4:00	763.848	150	130	1.21	0.07
5:00	763.848	150	130	1.35	0.08
6:00	763.848	150	130	1.32	0.07
7:00	763.848	150	130	1.30	0.07
8:00	763.848	150	130	1.32	0.07
9:00	763.848	150	130	1.31	0.07
10:00	763.848	150	130	1.30	0.07
11:00	763.848	150	130	1.31	0.07
12:00	763.848	150	130	1.30	0.07
13:00	763.848	150	130	1.30	0.07
14:00	763.848	150	130	1.29	0.07
15:00	763.848	150	130	1.30	0.07
16:00	763.848	150	130	1.32	0.07
17:00	763.848	150	130	1.15	0.07
18:00	763.848	150	130	1.16	0.07
19:00	763.848	150	130	1.10	0.06
20:00	763.848	150	130	1.19	0.07
21:00	763.848	150	130	1.20	0.07
22:00	763.848	150	130	1.21	0.07
23:00	763.848	150	130	1.22	0.07
24:00	763.848	150	130	1.22	0.07

32). Pipe P-32 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.81	150	130	0.95	0.05
1:00	763.81	150	130	0.94	0.05
2:00	763.81	150	130	0.93	0.05
3:00	763.81	150	130	0.93	0.05
4:00	763.81	150	130	0.94	0.05
5:00	763.81	150	130	1.05	0.06
6:00	763.81	150	130	1.03	0.06
7:00	763.81	150	130	1.01	0.06
8:00	763.81	150	130	1.03	0.06
9:00	763.81	150	130	1.02	0.06
10:00	763.81	150	130	1.01	0.06
11:00	763.81	150	130	1.02	0.06
12:00	763.81	150	130	1.01	0.06
13:00	763.81	150	130	1.01	0.06
14:00	763.81	150	130	1.00	0.06
15:00	763.81	150	130	1.01	0.06
16:00	763.81	150	130	1.03	0.06
17:00	763.81	150	130	0.90	0.05
18:00	763.81	150	130	0.91	0.05
19:00	763.81	150	130	0.86	0.05
20:00	763.81	150	130	0.93	0.05
21:00	763.81	150	130	0.93	0.05
22:00	763.81	150	130	0.94	0.05
23:00	763.81	150	130	0.95	0.05
24:00	763.81	150	130	0.95	0.05

Scenario -2

Tabulated Presentation of Nodal (Junction) Time Series

Results

1). Junction - 1 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	256.18	14.66
1:00	0	256.18	14.66
2:00	0	256.18	14.66
3:00	0	256.18	14.66
4:00	0	256.18	14.66
5:00	0	256.17	14.65
6:00	0	256.17	14.65
7:00	0	256.17	14.65
8:00	0	256.17	14.65
9:00	0	256.17	14.65
10:00	0	256.17	14.65
11:00	0	256.17	14.65
12:00	0	256.17	14.65
13:00	0	256.17	14.65
14:00	0	256.18	14.65
15:00	0	256.17	14.65
16:00	0	256.17	14.65
17:00	0	256.19	14.66
18:00	0	256.19	14.66
19:00	0	256.19	14.66
20:00	0	256.18	14.66
21:00	0	256.18	14.66
22:00	0	256.18	14.66
23:00	0	256.18	14.66
24:00	0	256.18	14.66

* T-Junction

2). Junction - 2 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	256.01	13.49
1:00	0	256.01	13.49
2:00	0	256.02	13.5
3:00	0	256.02	13.49
4:00	0	256.01	13.49
5:00	0	255.96	13.44
6:00	0	255.97	13.45
7:00	0	255.98	13.46
8:00	0	255.97	13.45
9:00	0	255.98	13.45
10:00	0	255.98	13.46
11:00	0	255.98	13.45
12:00	0	255.98	13.46
13:00	0	255.98	13.46
14:00	0	255.99	13.46
15:00	0	255.98	13.46
16:00	0	255.97	13.45
17:00	0	256.03	13.51
18:00	0	256.03	13.51
19:00	0	256.05	13.53
20:00	0	256.02	13.5
21:00	0	256.02	13.49
22:00	0	256.01	13.49
23:00	0	256.01	13.49
24:00	0	256.01	13.49

*Reducer 200mmx150mm

3). Junction - 3 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.6	256.00	13.46
1:00	1.58	256.00	13.47
2:00	1.55	256.01	13.48
3:00	1.56	256.01	13.47
4:00	1.58	256.00	13.47
5:00	1.76	255.95	13.42
6:00	1.73	255.96	13.43
7:00	1.70	255.97	13.44
8:00	1.73	255.96	13.43
9:00	1.71	255.96	13.43
10:00	1.70	255.97	13.44
11:00	1.71	255.96	13.43
12:00	1.70	255.97	13.44
13:00	1.70	255.97	13.44
14:00	1.68	255.97	13.44
15:00	1.70	255.97	13.44
16:00	1.73	255.96	13.43
17:00	1.50	256.02	13.49
18:00	1.52	256.02	13.49
19:00	1.43	256.04	13.51
20:00	1.55	256.01	13.48
21:00	1.56	256.01	13.47
22:00	1.58	256.00	13.47
23:00	1.60	256.00	13.46
24:00:00	1.60	256.00	13.46

4). Junction - 4 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.89	12.43
1:00	0	255.89	12.44
2:00	0	255.91	12.45
3:00	0	255.90	12.44
4:00	0	255.89	12.44
5:00	0	255.82	12.36
6:00	0	255.83	12.38
7:00	0	255.85	12.39
8:00	0	255.83	12.38
9:00	0	255.84	12.38
10:00	0	255.85	12.39
11:00	0	255.84	12.38
12:00	0	255.85	12.39
13:00	0	255.85	12.39
14:00	0	255.85	12.4
15:00	0	255.85	12.39
16:00	0	255.83	12.38
17:00	0	255.93	12.47
18:00	0	255.92	12.46
19:00	0	255.95	12.49
20:00	0	255.91	12.45
21:00	0	255.90	12.44
22:00	0	255.89	12.44
23:00	0	255.89	12.43
24:00:00	0	255.89	12.43

*Elbow

5). Junction - 5 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.86	12.10
1:00	0	255.86	12.11
2:00	0	255.88	12.13
3:00	0	255.87	12.12
4:00	0	255.86	12.11
5:00	0	255.78	12.03
6:00	0	255.80	12.05
7:00	0	255.81	12.06
8:00	0	255.80	12.05
9:00	0	255.80	12.05
10:00	0	255.81	12.06
11:00	0	255.80	12.05
12:00	0	255.81	12.06
13:00	0	255.81	12.06
14:00	0	255.82	12.07
15:00	0	255.81	12.06
16:00	0	255.80	12.05
17:00	0	255.90	12.15
18:00	0	255.89	12.14
19:00	0	255.92	12.17
20:00	0	255.88	12.13
21:00	0	255.87	12.12
22:00	0	255.86	12.11
23:00	0	255.86	12.10
24:00:00	0	255.86	12.10

*Elbow

6). Junction - 6 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.96	15.11
1:00	1.58	255.96	15.12
2:00	1.55	255.97	15.13
3:00	1.56	255.97	15.12
4:00	1.58	255.96	15.12
5:00	1.76	255.90	15.06
6:00	1.73	255.91	15.07
7:00	1.70	255.92	15.08
8:00	1.73	255.91	15.07
9:00	1.71	255.92	15.07
10:00	1.70	255.92	15.08
11:00	1.71	255.92	15.07
12:00	1.70	255.92	15.08
13:00	1.70	255.92	15.08
14:00	1.68	255.93	15.08
15:00	1.70	255.92	15.08
16:00	1.73	255.91	15.07
17:00	1.50	255.99	15.14
18:00	1.52	255.98	15.14
19:00	1.43	256.01	15.16
20:00	1.55	255.97	15.13
21:00	1.56	255.97	15.12
22:00	1.58	255.96	15.12
23:00	1.60	255.96	15.11
24:00:00	1.60	255.96	15.11

7). Junction - 7 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.96	15.12
1:00	0	255.96	15.12
2:00	0	255.97	15.13
3:00	0	255.97	15.13
4:00	0	255.96	15.12
5:00	0	255.9	15.06
6:00	0	255.91	15.07
7:00	0	255.92	15.08
8:00	0	255.91	15.07
9:00	0	255.92	15.08
10:00	0	255.92	15.08
11:00	0	255.92	15.08
12:00	0	255.92	15.08
13:00	0	255.92	15.08
14:00	0	255.93	15.09
15:00	0	255.92	15.08
16:00	0	255.91	15.07
17:00	0	255.99	15.15
18:00	0	255.98	15.14
19:00	0	256.01	15.17
20:00	0	255.97	15.13
21:00	0	255.97	15.13
22:00	0	255.96	15.12
23:00	0	255.96	15.12
24:00:00	0	255.96	15.12

*Reducer 200mmx150mm

8). Junction - 8 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.86	16.6
1:00	0	255.87	16.61
2:00	0	255.88	16.62
3:00	0	255.87	16.61
4:00	0	255.87	16.61
5:00	0	255.79	16.53
6:00	0	255.8	16.54
7:00	0	255.82	16.56
8:00	0	255.8	16.54
9:00	0	255.81	16.55
10:00	0	255.82	16.56
11:00	0	255.81	16.55
12:00	0	255.82	16.56
13:00	0	255.82	16.56
14:00	0	255.82	16.56
15:00	0	255.82	16.56
16:00	0	255.8	16.54
17:00	0	255.9	16.64
18:00	0	255.89	16.63
19:00	0	255.93	16.67
20:00	0	255.88	16.62
21:00	0	255.87	16.61
22:00	0	255.87	16.61
23:00	0	255.86	16.6
24:00:00	0	255.86	16.6

*Elbow

9). Junction - 9 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.83	17.11
1:00	0	255.84	17.12
2:00	0	255.85	17.14
3:00	0	255.85	17.13
4:00	0	255.84	17.12
5:00	0	255.75	17.04
6:00	0	255.77	17.05
7:00	0	255.78	17.07
8:00	0	255.77	17.05
9:00	0	255.78	17.06
10:00	0	255.78	17.07
11:00	0	255.78	17.06
12:00	0	255.78	17.07
13:00	0	255.78	17.07
14:00	0	255.79	17.08
15:00	0	255.78	17.07
16:00	0	255.77	17.05
17:00	0	255.88	17.16
18:00	0	255.87	17.15
19:00	0	255.90	17.19
20:00	0	255.85	17.14
21:00	0	255.85	17.13
22:00	0	255.84	17.12
23:00	0	255.83	17.11
24:00:00	0	255.83	17.11

*Elbow

10). Junction - 10 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.73	18.24
1:00	1.58	255.74	18.25
2:00	1.55	255.76	18.26
3:00	1.56	255.75	18.26
4:00	1.58	255.74	18.25
5:00	1.76	255.63	18.14
6:00	1.73	255.65	18.16
7:00	1.70	255.67	18.18
8:00	1.73	255.65	18.16
9:00	1.71	255.66	18.17
10:00	1.70	255.67	18.18
11:00	1.71	255.66	18.17
12:00	1.70	255.67	18.18
13:00	1.70	255.67	18.18
14:00	1.68	255.68	18.19
15:00	1.70	255.67	18.18
16:00	1.73	255.65	18.16
17:00	1.50	255.79	18.29
18:00	1.52	255.78	18.28
19:00	1.43	255.82	18.33
20:00	1.55	255.76	18.26
21:00	1.56	255.75	18.26
22:00	1.58	255.74	18.25
23:00	1.60	255.73	18.24
24:00:00	1.60	255.73	18.24

11). Junction - 11 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.73	17.92
1:00	1.58	255.74	17.93
2:00	1.55	255.75	17.94
3:00	1.56	255.74	17.93
4:00	1.58	255.74	17.93
5:00	1.76	255.63	17.82
6:00	1.73	255.65	17.84
7:00	1.70	255.67	17.86
8:00	1.73	255.65	17.84
9:00	1.71	255.66	17.85
10:00	1.70	255.67	17.86
11:00	1.71	255.66	17.85
12:00	1.70	255.67	17.86
13:00	1.70	255.67	17.86
14:00	1.68	255.68	17.87
15:00	1.70	255.67	17.86
16:00	1.73	255.65	17.84
17:00	1.50	255.78	17.97
18:00	1.52	255.77	17.96
19:00	1.43	255.82	18.01
20:00	1.55	255.75	17.94
21:00	1.56	255.74	17.93
22:00	1.58	255.74	17.93
23:00	1.60	255.73	17.92
24:00:00	1.60	255.73	17.92

12). Junction - 12 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.72	17.84
1:00	1.58	255.73	17.85
2:00	1.55	255.75	17.87
3:00	1.56	255.74	17.86
4:00	1.58	255.73	17.85
5:00	1.76	255.62	17.74
6:00	1.73	255.65	17.76
7:00	1.70	255.67	17.78
8:00	1.73	255.65	17.76
9:00	1.71	255.66	17.77
10:00	1.70	255.67	17.78
11:00	1.71	255.66	17.77
12:00	1.70	255.67	17.78
13:00	1.70	255.67	17.78
14:00	1.68	255.68	17.79
15:00	1.70	255.67	17.78
16:00	1.73	255.65	17.76
17:00	1.50	255.78	17.9
18:00	1.52	255.77	17.89
19:00	1.43	255.82	17.94
20:00	1.55	255.75	17.87
21:00	1.56	255.74	17.86
22:00	1.58	255.73	17.85
23:00	1.60	255.72	17.84
24:00:00	1.60	255.72	17.84

13). Junction - 13 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.72	17.39
1:00	1.58	255.73	17.4
2:00	1.55	255.75	17.42
3:00	1.56	255.74	17.41
4:00	1.58	255.73	17.4
5:00	1.76	255.62	17.29
6:00	1.73	255.64	17.31
7:00	1.70	255.66	17.33
8:00	1.73	255.64	17.31
9:00	1.71	255.65	17.32
10:00	1.70	255.66	17.33
11:00	1.71	255.65	17.32
12:00	1.70	255.66	17.33
13:00	1.70	255.66	17.33
14:00	1.68	255.67	17.34
15:00	1.70	255.66	17.33
16:00	1.73	255.64	17.31
17:00	1.50	255.78	17.45
18:00	1.52	255.77	17.44
19:00	1.43	255.81	17.48
20:00	1.55	255.75	17.42
21:00	1.56	255.74	17.41
22:00	1.58	255.73	17.4
23:00	1.60	255.72	17.39
24:00:00	1.60	255.72	17.39

14). Junction - 14 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.78	14.6
1:00	1.58	255.79	14.61
2:00	1.55	255.8	14.63
3:00	1.56	255.79	14.62
4:00	1.58	255.79	14.61
5:00	1.76	255.69	14.51
6:00	1.73	255.71	14.53
7:00	1.70	255.72	14.55
8:00	1.73	255.71	14.53
9:00	1.71	255.71	14.54
10:00	1.70	255.72	14.55
11:00	1.71	255.71	14.54
12:00	1.70	255.72	14.55
13:00	1.70	255.72	14.55
14:00	1.68	255.73	14.56
15:00	1.70	255.72	14.55
16:00	1.73	255.71	14.53
17:00	1.50	255.83	14.65
18:00	1.52	255.82	14.65
19:00	1.43	255.86	14.69
20:00	1.55	255.8	14.63
21:00	1.56	255.79	14.62
22:00	1.58	255.79	14.61
23:00	1.60	255.78	14.6
24:00:00	1.60	255.78	14.6

15). Junction - 15 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.76	14.59
1:00	1.58	255.77	14.6
2:00	1.55	255.79	14.61
3:00	1.56	255.78	14.61
4:00	1.58	255.77	14.6
5:00	1.76	255.67	14.5
6:00	1.73	255.69	14.51
7:00	1.70	255.71	14.53
8:00	1.73	255.69	14.51
9:00	1.71	255.70	14.52
10:00	1.70	255.71	14.53
11:00	1.71	255.70	14.52
12:00	1.70	255.71	14.53
13:00	1.70	255.71	14.53
14:00	1.68	255.72	14.54
15:00	1.70	255.71	14.53
16:00	1.73	255.69	14.51
17:00	1.50	255.81	14.64
18:00	1.52	255.81	14.63
19:00	1.43	255.85	14.67
20:00	1.55	255.79	14.61
21:00	1.56	255.78	14.61
22:00	1.58	255.77	14.60
23:00	1.60	255.76	14.59
24:00:00	1.60	255.76	14.59

16). Junction - 16 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.75	14.32
1:00	1.58	255.76	14.32
2:00	1.55	255.77	14.34
3:00	1.56	255.76	14.33
4:00	1.58	255.76	14.32
5:00	1.76	255.65	14.22
6:00	1.73	255.67	14.24
7:00	1.70	255.69	14.26
8:00	1.73	255.67	14.24
9:00	1.71	255.68	14.25
10:00	1.70	255.69	14.26
11:00	1.71	255.68	14.25
12:00	1.70	255.69	14.26
13:00	1.70	255.69	14.26
14:00	1.68	255.70	14.27
15:00	1.70	255.69	14.26
16:00	1.73	255.67	14.24
17:00	1.50	255.80	14.37
18:00	1.52	255.79	14.36
19:00	1.43	255.83	14.40
20:00	1.55	255.77	14.34
21:00	1.56	255.76	14.33
22:00	1.58	255.76	14.32
23:00	1.60	255.75	14.32
24:00:00	1.60	255.75	14.32

17). Junction - 17 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.75	14.28
1:00	0	255.76	14.28
2:00	0	255.77	14.3
3:00	0	255.76	14.29
4:00	0	255.76	14.28
5:00	0	255.65	14.18
6:00	0	255.67	14.2
7:00	0	255.69	14.22
8:00	0	255.67	14.2
9:00	0	255.68	14.21
10:00	0	255.69	14.22
11:00	0	255.68	14.21
12:00	0	255.69	14.22
13:00	0	255.69	14.22
14:00	0	255.70	14.23
15:00	0	255.69	14.22
16:00	0	255.67	14.2
17:00	0	255.80	14.33
18:00	0	255.79	14.32
19:00	0	255.83	14.36
20:00	0	255.77	14.3
21:00	0	255.76	14.29
22:00	0	255.76	14.28
23:00	0	255.75	14.28
24:00:00	0	255.75	14.28

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18). Junction - 18 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.75	12.98
1:00	0	255.76	12.99
2:00	0	255.78	13.01
3:00	0	255.77	13.00
4:00	0	255.76	12.99
5:00	0	255.65	12.89
6:00	0	255.67	12.91
7:00	0	255.69	12.93
8:00	0	255.67	12.91
9:00	0	255.68	12.92
10:00	0	255.69	12.93
11:00	0	255.68	12.92
12:00	0	255.69	12.93
13:00	0	255.69	12.93
14:00	0	255.70	12.94
15:00	0	255.69	12.93
16:00	0	255.67	12.91
17:00	0	255.80	13.04
18:00	0	255.79	13.03
19:00	0	255.84	13.07
20:00	0	255.78	13.01
21:00	0	255.77	13.00
22:00	0	255.76	12.99
23:00	0	255.75	12.98
24:00:00	0	255.75	12.98

*Elbow

19). Junction - 19 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.75	12.58
1:00	1.58	255.76	12.59
2:00	1.55	255.78	12.61
3:00	1.56	255.77	12.6
4:00	1.58	255.76	12.59
5:00	1.76	255.65	12.49
6:00	1.73	255.67	12.51
7:00	1.70	255.69	12.53
8:00	1.73	255.67	12.51
9:00	1.71	255.68	12.52
10:00	1.70	255.69	12.53
11:00	1.71	255.68	12.52
12:00	1.70	255.69	12.53
13:00	1.70	255.69	12.53
14:00	1.68	255.70	12.54
15:00	1.70	255.69	12.53
16:00	1.73	255.67	12.51
17:00	1.50	255.80	12.64
18:00	1.52	255.79	12.63
19:00	1.43	255.84	12.67
20:00	1.55	255.78	12.61
21:00	1.56	255.77	12.6
22:00	1.58	255.76	12.59
23:00	1.60	255.75	12.58
24:00:00	1.60	255.75	12.58

20). Junction - 20 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.77	13.07
1:00	1.58	255.78	13.08
2:00	1.55	255.80	13.10
3:00	1.56	255.79	13.09
4:00	1.58	255.78	13.08
5:00	1.76	255.68	12.98
6:00	1.73	255.70	13.00
7:00	1.70	255.72	13.02
8:00	1.73	255.70	13.00
9:00	1.71	255.71	13.01
10:00	1.70	255.72	13.02
11:00	1.71	255.71	13.01
12:00	1.70	255.72	13.02
13:00	1.70	255.72	13.02
14:00	1.68	255.73	13.03
15:00	1.70	255.72	13.02
16:00	1.73	255.70	13.00
17:00	1.50	255.82	13.12
18:00	1.52	255.82	13.12
19:00	1.43	255.86	13.16
20:00	1.55	255.80	13.10
21:00	1.56	255.79	13.09
22:00	1.58	255.78	13.08
23:00	1.60	255.77	13.07
24:00:00	1.60	255.77	13.07

21). Junction - 21 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.79	13.09
1:00	1.58	255.80	13.10
2:00	1.55	255.82	13.12
3:00	1.56	255.81	13.11
4:00	1.58	255.80	13.10
5:00	1.76	255.70	13.00
6:00	1.73	255.72	13.02
7:00	1.70	255.74	13.04
8:00	1.73	255.72	13.02
9:00	1.71	255.73	13.03
10:00	1.70	255.74	13.04
11:00	1.71	255.73	13.03
12:00	1.70	255.74	13.04
13:00	1.70	255.74	13.04
14:00	1.68	255.75	13.05
15:00	1.70	255.74	13.04
16:00	1.73	255.72	13.02
17:00	1.50	255.84	13.14
18:00	1.52	255.83	13.13
19:00	1.43	255.87	13.17
20:00	1.55	255.82	13.12
21:00	1.56	255.81	13.11
22:00	1.58	255.80	13.10
23:00	1.60	255.79	13.09
24:00:00	1.60	255.79	13.09

22). Junction - 22 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.75	10.24
1:00	1.58	255.76	10.25
2:00	1.55	255.77	10.27
3:00	1.56	255.77	10.26
4:00	1.58	255.76	10.25
5:00	1.76	255.65	10.14
6:00	1.73	255.67	10.16
7:00	1.70	255.69	10.18
8:00	1.73	255.67	10.16
9:00	1.71	255.68	10.17
10:00	1.70	255.69	10.18
11:00	1.71	255.68	10.17
12:00	1.70	255.69	10.18
13:00	1.70	255.69	10.18
14:00	1.68	255.70	10.19
15:00	1.70	255.69	10.18
16:00	1.73	255.67	10.16
17:00	1.50	255.80	10.29
18:00	1.52	255.79	10.28
19:00	1.43	255.83	10.33
20:00	1.55	255.77	10.27
21:00	1.56	255.77	10.26
22:00	1.58	255.76	10.25
23:00	1.60	255.75	10.24
24:00:00	1.60	255.75	10.24

23). Junction - 23 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.74	10.12
1:00	1.58	255.75	10.13
2:00	1.55	255.77	10.15
3:00	1.56	255.76	10.14
4:00	1.58	255.75	10.13
5:00	1.76	255.64	10.02
6:00	1.73	255.66	10.04
7:00	1.70	255.68	10.06
8:00	1.73	255.66	10.04
9:00	1.71	255.67	10.05
10:00	1.70	255.68	10.06
11:00	1.71	255.67	10.05
12:00	1.70	255.68	10.06
13:00	1.70	255.68	10.06
14:00	1.68	255.69	10.07
15:00	1.70	255.68	10.06
16:00	1.73	255.66	10.04
17:00	1.50	255.79	10.17
18:00	1.52	255.78	10.17
19:00	1.43	255.83	10.21
20:00	1.55	255.77	10.15
21:00	1.56	255.76	10.14
22:00	1.58	255.75	10.13
23:00	1.60	255.74	10.12
24:00:00	1.60	255.74	10.12

24). Junction - 24 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.74	10.12
1:00	1.58	255.75	10.13
2:00	1.55	255.76	10.15
3:00	1.56	255.76	10.14
4:00	1.58	255.75	10.13
5:00	1.76	255.64	10.02
6:00	1.73	255.66	10.04
7:00	1.70	255.68	10.06
8:00	1.73	255.66	10.04
9:00	1.71	255.67	10.05
10:00	1.70	255.68	10.06
11:00	1.71	255.67	10.05
12:00	1.70	255.68	10.06
13:00	1.70	255.68	10.06
14:00	1.68	255.69	10.07
15:00	1.70	255.68	10.06
16:00	1.73	255.66	10.04
17:00	1.50	255.79	10.17
18:00	1.52	255.78	10.16
19:00	1.43	255.83	10.21
20:00	1.55	255.76	10.15
21:00	1.56	255.76	10.14
22:00	1.58	255.75	10.13
23:00	1.60	255.74	10.12
24:00:00	1.60	255.74	10.12

25). Junction - 25 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.60	255.73	13.53
1:00	1.58	255.74	13.54
2:00	1.55	255.76	13.56
3:00	1.56	255.75	13.55
4:00	1.58	255.74	13.54
5:00	1.76	255.64	13.44
6:00	1.73	255.66	13.46
7:00	1.70	255.68	13.48
8:00	1.73	255.66	13.46
9:00	1.71	255.67	13.47
10:00	1.70	255.68	13.48
11:00	1.71	255.67	13.47
12:00	1.70	255.68	13.48
13:00	1.70	255.68	13.48
14:00	1.68	255.69	13.49
15:00	1.70	255.68	13.48
16:00	1.73	255.66	13.46
17:00	1.50	255.79	13.59
18:00	1.52	255.78	13.58
19:00	1.43	255.82	13.62
20:00	1.55	255.76	13.56
21:00	1.56	255.75	13.55
22:00	1.58	255.74	13.54
23:00	1.60	255.73	13.53
24:00:00	1.60	255.73	13.53

26). DMA - Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	25.56	256.23	0
1:00	25.30	256.23	0
2:00	24.78	256.23	0
3:00	25.04	256.23	0
4:00	25.30	256.23	0
5:00	28.17	256.23	0
6:00	27.64	256.23	0
7:00	27.12	256.23	0
8:00	27.64	256.23	0
9:00	27.38	256.23	0
10:00	27.12	256.23	0
11:00	27.38	256.23	0
12:00	27.12	256.23	0
13:00	27.12	256.23	0
14:00	26.86	256.23	0
15:00	27.12	256.23	0
16:00	27.64	256.23	0
17:00	23.99	256.23	0
18:00	24.25	256.23	0
19:00	22.95	256.23	0
20:00	24.78	256.23	0
21:00	25.04	256.23	0
22:00	25.30	256.23	0
23:00	25.56	256.23	0
24:00:00	25.56	256.23	0

Scenario -2

Tabulated Presentation of Pipes Time Series

Results

1). Pipe P-1 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	100	300	130	25.56	0.36
1:00	100	300	130	25.3	0.36
2:00	100	300	130	24.78	0.35
3:00	100	300	130	25.04	0.35
4:00	100	300	130	25.30	0.36
5:00	100	300	130	28.17	0.4
6:00	100	300	130	27.64	0.39
7:00	100	300	130	27.12	0.38
8:00	100	300	130	27.64	0.39
9:00	100	300	130	27.38	0.39
10:00	100	300	130	27.12	0.38
11:00	100	300	130	27.38	0.39
12:00	100	300	130	27.12	0.38
13:00	100	300	130	27.12	0.38
14:00	100	300	130	26.86	0.38
15:00	100	300	130	27.12	0.38
16:00	100	300	130	27.64	0.39
17:00	100	300	130	23.99	0.34
18:00	100	300	130	24.25	0.34
19:00	100	300	130	22.95	0.32
20:00	100	300	130	24.78	0.35
21:00	100	300	130	25.04	0.35
22:00	100	300	130	25.30	0.36
23:00	100	300	130	25.56	0.36
24:00	100	300	130	25.56	0.36

2). Pipe P-2 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	232.038	200	130	12.40	0.39
1:00	232.038	200	130	12.27	0.39
2:00	232.038	200	130	12.02	0.38
3:00	232.038	200	130	12.14	0.39
4:00	232.038	200	130	12.27	0.39
5:00	232.038	200	130	13.66	0.43
6:00	232.038	200	130	13.41	0.43
7:00	232.038	200	130	13.15	0.42
8:00	232.038	200	130	13.41	0.43
9:00	232.038	200	130	13.28	0.42
10:00	232.038	200	130	13.15	0.42
11:00	232.038	200	130	13.28	0.42
12:00	232.038	200	130	13.15	0.42
13:00	232.038	200	130	13.15	0.42
14:00	232.038	200	130	13.03	0.41
15:00	232.038	200	130	13.15	0.42
16:00	232.038	200	130	13.41	0.43
17:00	232.038	200	130	11.64	0.37
18:00	232.038	200	130	11.76	0.37
19:00	232.038	200	130	11.13	0.35
20:00	232.038	200	130	12.02	0.38
21:00	232.038	200	130	12.14	0.39
22:00	232.038	200	130	12.27	0.39
23:00	232.038	200	130	12.40	0.39
24:00	232.038	200	130	12.40	0.39

3). Pipe P-3 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	9.975	200	130	2.95	0.09
1:00	9.975	200	130	2.92	0.09
2:00	9.975	200	130	2.86	0.09
3:00	9.975	200	130	2.89	0.09
4:00	9.975	200	130	2.92	0.09
5:00	9.975	200	130	3.25	0.10
6:00	9.975	200	130	3.19	0.10
7:00	9.975	200	130	3.13	0.10
8:00	9.975	200	130	3.19	0.10
9:00	9.975	200	130	3.16	0.10
10:00	9.975	200	130	3.13	0.10
11:00	9.975	200	130	3.16	0.10
12:00	9.975	200	130	3.13	0.10
13:00	9.975	200	130	3.13	0.10
14:00	9.975	200	130	3.10	0.10
15:00	9.975	200	130	3.13	0.10
16:00	9.975	200	130	3.19	0.10
17:00	9.975	200	130	2.77	0.09
18:00	9.975	200	130	2.80	0.09
19:00	9.975	200	130	2.65	0.08
20:00	9.975	200	130	2.86	0.09
21:00	9.975	200	130	2.89	0.09
22:00	9.975	200	130	2.92	0.09
23:00	9.975	200	130	2.95	0.09
24:00	9.975	200	130	2.95	0.09

4). Pipe P-4 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	160.264	200	130	13.16	0.42
1:00	160.264	200	130	13.03	0.41
2:00	160.264	200	130	12.76	0.41
3:00	160.264	200	130	12.89	0.41
4:00	160.264	200	130	13.03	0.41
5:00	160.264	200	130	14.51	0.46
6:00	160.264	200	130	14.24	0.45
7:00	160.264	200	130	13.97	0.44
8:00	160.264	200	130	14.24	0.45
9:00	160.264	200	130	14.10	0.45
10:00	160.264	200	130	13.97	0.44
11:00	160.264	200	130	14.10	0.45
12:00	160.264	200	130	13.97	0.44
13:00	160.264	200	130	13.97	0.44
14:00	160.264	200	130	13.83	0.44
15:00	160.264	200	130	13.97	0.44
16:00	160.264	200	130	14.24	0.45
17:00	160.264	200	130	12.36	0.39
18:00	160.264	200	130	12.49	0.40
19:00	160.264	200	130	11.82	0.38
20:00	160.264	200	130	12.76	0.41
21:00	160.264	200	130	12.89	0.41
22:00	160.264	200	130	13.03	0.41
23:00	160.264	200	130	13.16	0.42
24:00	160.264	200	130	13.16	0.42

5). Pipe P-5 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	2.38	150	130	13.16	0.74
1:00	2.38	150	130	13.03	0.74
2:00	2.38	150	130	12.76	0.72
3:00	2.38	150	130	12.89	0.73
4:00	2.38	150	130	13.03	0.74
5:00	2.38	150	130	14.51	0.82
6:00	2.38	150	130	14.24	0.81
7:00	2.38	150	130	13.97	0.79
8:00	2.38	150	130	14.24	0.81
9:00	2.38	150	130	14.10	0.80
10:00	2.38	150	130	13.97	0.79
11:00	2.38	150	130	14.10	0.80
12:00	2.38	150	130	13.97	0.79
13:00	2.38	150	130	13.97	0.79
14:00	2.38	150	130	13.83	0.78
15:00	2.38	150	130	13.97	0.79
16:00	2.38	150	130	14.24	0.81
17:00	2.38	150	130	12.36	0.70
18:00	2.38	150	130	12.49	0.71
19:00	2.38	150	130	11.82	0.67
20:00	2.38	150	130	12.76	0.72
21:00	2.38	150	130	12.89	0.73
22:00	2.38	150	130	13.03	0.74
23:00	2.38	150	130	13.16	0.74
24:00	2.38	150	130	13.16	0.74

6). Pipe P-6 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.92	150	130	3.12	0.18
1:00	354.92	150	130	3.09	0.17
2:00	354.92	150	130	3.03	0.17
3:00	354.92	150	130	3.06	0.17
4:00	354.92	150	130	3.09	0.17
5:00	354.92	150	130	3.44	0.19
6:00	354.92	150	130	3.38	0.19
7:00	354.92	150	130	3.31	0.19
8:00	354.92	150	130	3.38	0.19
9:00	354.92	150	130	3.35	0.19
10:00	354.92	150	130	3.31	0.19
11:00	354.92	150	130	3.35	0.19
12:00	354.92	150	130	3.31	0.19
13:00	354.92	150	130	3.31	0.19
14:00	354.92	150	130	3.28	0.19
15:00	354.92	150	130	3.31	0.19
16:00	354.92	150	130	3.38	0.19
17:00	354.92	150	130	2.93	0.17
18:00	354.92	150	130	2.96	0.17
19:00	354.92	150	130	2.8	0.16
20:00	354.92	150	130	3.03	0.17
21:00	354.92	150	130	3.06	0.17
22:00	354.92	150	130	3.09	0.17
23:00	354.92	150	130	3.12	0.18
24:00	354.92	150	130	3.12	0.18

7). Pipe P-7 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.3	150	130	3.12	0.18
1:00	105.3	150	130	3.09	0.17
2:00	105.3	150	130	3.03	0.17
3:00	105.3	150	130	3.06	0.17
4:00	105.3	150	130	3.09	0.17
5:00	105.3	150	130	3.44	0.19
6:00	105.3	150	130	3.38	0.19
7:00	105.3	150	130	3.31	0.19
8:00	105.3	150	130	3.38	0.19
9:00	105.3	150	130	3.35	0.19
10:00	105.3	150	130	3.31	0.19
11:00	105.3	150	130	3.35	0.19
12:00	105.3	150	130	3.31	0.19
13:00	105.3	150	130	3.31	0.19
14:00	105.3	150	130	3.28	0.19
15:00	105.3	150	130	3.31	0.19
16:00	105.3	150	130	3.38	0.19
17:00	105.3	150	130	2.93	0.17
18:00	105.3	150	130	2.96	0.17
19:00	105.3	150	130	2.80	0.16
20:00	105.3	150	130	3.03	0.17
21:00	105.3	150	130	3.06	0.17
22:00	105.3	150	130	3.09	0.17
23:00	105.3	150	130	3.12	0.18
24:00	105.3	150	130	3.12	0.18

8). Pipe P-8 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.91	150	130	3.12	0.18
1:00	354.91	150	130	3.09	0.17
2:00	354.91	150	130	3.03	0.17
3:00	354.91	150	130	3.06	0.17
4:00	354.91	150	130	3.09	0.17
5:00	354.91	150	130	3.44	0.19
6:00	354.91	150	130	3.38	0.19
7:00	354.91	150	130	3.31	0.19
8:00	354.91	150	130	3.38	0.19
9:00	354.91	150	130	3.35	0.19
10:00	354.91	150	130	3.31	0.19
11:00	354.91	150	130	3.35	0.19
12:00	354.91	150	130	3.31	0.19
13:00	354.91	150	130	3.31	0.19
14:00	354.91	150	130	3.28	0.19
15:00	354.91	150	130	3.31	0.19
16:00	354.91	150	130	3.38	0.19
17:00	354.91	150	130	2.93	0.17
18:00	354.91	150	130	2.96	0.17
19:00	354.91	150	130	2.80	0.16
20:00	354.91	150	130	3.03	0.17
21:00	354.91	150	130	3.06	0.17
22:00	354.91	150	130	3.09	0.17
23:00	354.91	150	130	3.12	0.18
24:00	354.91	150	130	3.12	0.18

9). Pipe P-9 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	1.52	0.09
1:00	105.97	150	130	1.51	0.09
2:00	105.97	150	130	1.48	0.08
3:00	105.97	150	130	1.49	0.08
4:00	105.97	150	130	1.51	0.09
5:00	105.97	150	130	1.68	0.10
6:00	105.97	150	130	1.65	0.09
7:00	105.97	150	130	1.62	0.09
8:00	105.97	150	130	1.65	0.09
9:00	105.97	150	130	1.63	0.09
10:00	105.97	150	130	1.62	0.09
11:00	105.97	150	130	1.63	0.09
12:00	105.97	150	130	1.62	0.09
13:00	105.97	150	130	1.62	0.09
14:00	105.97	150	130	1.60	0.09
15:00	105.97	150	130	1.62	0.09
16:00	105.97	150	130	1.65	0.09
17:00	105.97	150	130	1.43	0.08
18:00	105.97	150	130	1.45	0.08
19:00	105.97	150	130	1.37	0.08
20:00	105.97	150	130	1.48	0.08
21:00	105.97	150	130	1.49	0.08
22:00	105.97	150	130	1.51	0.09
23:00	105.97	150	130	1.52	0.09
24:00	105.97	150	130	1.52	0.09

10). Pipe P-10 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	1.33	0.08
1:00	21	150	130	1.32	0.07
2:00	21	150	130	1.29	0.07
3:00	21	150	130	1.31	0.07
4:00	21	150	130	1.32	0.07
5:00	21	150	130	1.47	0.08
6:00	21	150	130	1.44	0.08
7:00	21	150	130	1.41	0.08
8:00	21	150	130	1.44	0.08
9:00	21	150	130	1.43	0.08
10:00	21	150	130	1.41	0.08
11:00	21	150	130	1.43	0.08
12:00	21	150	130	1.41	0.08
13:00	21	150	130	1.41	0.08
14:00	21	150	130	1.40	0.08
15:00	21	150	130	1.41	0.08
16:00	21	150	130	1.44	0.08
17:00	21	150	130	1.25	0.07
18:00	21	150	130	1.27	0.07
19:00	21	150	130	1.20	0.07
20:00	21	150	130	1.29	0.07
21:00	21	150	130	1.31	0.07
22:00	21	150	130	1.32	0.07
23:00	21	150	130	1.33	0.08
24:00	21	150	130	1.33	0.08

11). Pipe P-11 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	0.88	0.05
1:00	105.97	150	130	0.88	0.05
2:00	105.97	150	130	0.86	0.05
3:00	105.97	150	130	0.87	0.05
4:00	105.97	150	130	0.88	0.05
5:00	105.97	150	130	0.97	0.06
6:00	105.97	150	130	0.96	0.05
7:00	105.97	150	130	0.94	0.05
8:00	105.97	150	130	0.96	0.05
9:00	105.97	150	130	0.95	0.05
10:00	105.97	150	130	0.94	0.05
11:00	105.97	150	130	0.95	0.05
12:00	105.97	150	130	0.94	0.05
13:00	105.97	150	130	0.94	0.05
14:00	105.97	150	130	0.93	0.05
15:00	105.97	150	130	0.94	0.05
16:00	105.97	150	130	0.96	0.05
17:00	105.97	150	130	0.83	0.05
18:00	105.97	150	130	0.84	0.05
19:00	105.97	150	130	0.79	0.04
20:00	105.97	150	130	0.86	0.05
21:00	105.97	150	130	0.87	0.05
22:00	105.97	150	130	0.88	0.05
23:00	105.97	150	130	0.88	0.05
24:00	105.97	150	130	0.88	0.05

12). Pipe P-12 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.81	150	130	0.71	0.04
1:00	763.81	150	130	0.71	0.04
2:00	763.81	150	130	0.69	0.04
3:00	763.81	150	130	0.70	0.04
4:00	763.81	150	130	0.71	0.04
5:00	763.81	150	130	0.79	0.04
6:00	763.81	150	130	0.77	0.04
7:00	763.81	150	130	0.76	0.04
8:00	763.81	150	130	0.77	0.04
9:00	763.81	150	130	0.76	0.04
10:00	763.81	150	130	0.76	0.04
11:00	763.81	150	130	0.76	0.04
12:00	763.81	150	130	0.76	0.04
13:00	763.81	150	130	0.76	0.04
14:00	763.81	150	130	0.75	0.04
15:00	763.81	150	130	0.76	0.04
16:00	763.81	150	130	0.77	0.04
17:00	763.81	150	130	0.67	0.04
18:00	763.81	150	130	0.68	0.04
19:00	763.81	150	130	0.64	0.04
20:00	763.81	150	130	0.69	0.04
21:00	763.81	150	130	0.70	0.04
22:00	763.81	150	130	0.71	0.04
23:00	763.81	150	130	0.71	0.04
24:00	763.81	150	130	0.71	0.04

13). Pipe P-13 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	764	150	130	1.15	0.07
1:00	764	150	130	1.14	0.06
2:00	764	150	130	1.11	0.06
3:00	764	150	130	1.13	0.06
4:00	764	150	130	1.14	0.06
5:00	764	150	130	1.27	0.07
6:00	764	150	130	1.24	0.07
7:00	764	150	130	1.22	0.07
8:00	764	150	130	1.24	0.07
9:00	764	150	130	1.23	0.07
10:00	764	150	130	1.22	0.07
11:00	764	150	130	1.23	0.07
12:00	764	150	130	1.22	0.07
13:00	764	150	130	1.22	0.07
14:00	764	150	130	1.21	0.07
15:00	764	150	130	1.22	0.07
16:00	764	150	130	1.24	0.07
17:00	764	150	130	1.08	0.06
18:00	764	150	130	1.09	0.06
19:00	764	150	130	1.03	0.06
20:00	764	150	130	1.11	0.06
21:00	764	150	130	1.13	0.06
22:00	764	150	130	1.14	0.06
23:00	764	150	130	1.15	0.07
24:00	764	150	130	1.15	0.07

14). Pipe P-14 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	764	150	130	1.41	0.08
1:00	764	150	130	1.39	0.08
2:00	764	150	130	1.36	0.08
3:00	764	150	130	1.38	0.08
4:00	764	150	130	1.39	0.08
5:00	764	150	130	1.55	0.09
6:00	764	150	130	1.52	0.09
7:00	764	150	130	1.49	0.08
8:00	764	150	130	1.52	0.09
9:00	764	150	130	1.51	0.09
10:00	764	150	130	1.49	0.08
11:00	764	150	130	1.51	0.09
12:00	764	150	130	1.49	0.08
13:00	764	150	130	1.49	0.08
14:00	764	150	130	1.48	0.08
15:00	764	150	130	1.49	0.08
16:00	764	150	130	1.52	0.09
17:00	764	150	130	1.32	0.07
18:00	764	150	130	1.33	0.08
19:00	764	150	130	1.26	0.07
20:00	764	150	130	1.36	0.08
21:00	764	150	130	1.38	0.08
22:00	764	150	130	1.39	0.08
23:00	764	150	130	1.41	0.08
24:00	764	150	130	1.41	0.08

15). Pipe P-15 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	25.67	150	130	0.38	0.02
1:00	25.67	150	130	0.38	0.02
2:00	25.67	150	130	0.37	0.02
3:00	25.67	150	130	0.38	0.02
4:00	25.67	150	130	0.38	0.02
5:00	25.67	150	130	0.42	0.02
6:00	25.67	150	130	0.42	0.02
7:00	25.67	150	130	0.41	0.02
8:00	25.67	150	130	0.42	0.02
9:00	25.67	150	130	0.41	0.02
10:00	25.67	150	130	0.41	0.02
11:00	25.67	150	130	0.41	0.02
12:00	25.67	150	130	0.41	0.02
13:00	25.67	150	130	0.41	0.02
14:00	25.67	150	130	0.4	0.02
15:00	25.67	150	130	0.41	0.02
16:00	25.67	150	130	0.42	0.02
17:00	25.67	150	130	0.36	0.02
18:00	25.67	150	130	0.36	0.02
19:00	25.67	150	130	0.34	0.02
20:00	25.67	150	130	0.37	0.02
21:00	25.67	150	130	0.38	0.02
22:00	25.67	150	130	0.38	0.02
23:00	25.67	150	130	0.38	0.02
24:00	25.67	150	130	0.38	0.02

16). Pipe P-16 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	2.69	0.15
1:00	105.97	150	130	2.67	0.15
2:00	105.97	150	130	2.61	0.15
3:00	105.97	150	130	2.64	0.15
4:00	105.97	150	130	2.67	0.15
5:00	105.97	150	130	2.97	0.17
6:00	105.97	150	130	2.91	0.16
7:00	105.97	150	130	2.86	0.16
8:00	105.97	150	130	2.91	0.16
9:00	105.97	150	130	2.89	0.16
10:00	105.97	150	130	2.86	0.16
11:00	105.97	150	130	2.89	0.16
12:00	105.97	150	130	2.86	0.16
13:00	105.97	150	130	2.86	0.16
14:00	105.97	150	130	2.83	0.16
15:00	105.97	150	130	2.86	0.16
16:00	105.97	150	130	2.91	0.16
17:00	105.97	150	130	2.53	0.14
18:00	105.97	150	130	2.56	0.14
19:00	105.97	150	130	2.42	0.14
20:00	105.97	150	130	2.61	0.15
21:00	105.97	150	130	2.64	0.15
22:00	105.97	150	130	2.67	0.15
23:00	105.97	150	130	2.69	0.15
24:00	105.97	150	130	2.69	0.15

17). Pipe P-17 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	5.44	0.31
1:00	21	150	130	5.38	0.3
2:00	21	150	130	5.27	0.3
3:00	21	150	130	5.33	0.3
4:00	21	150	130	5.38	0.3
5:00	21	150	130	6.00	0.34
6:00	21	150	130	5.88	0.33
7:00	21	150	130	5.77	0.33
8:00	21	150	130	5.88	0.33
9:00	21	150	130	5.83	0.33
10:00	21	150	130	5.77	0.33
11:00	21	150	130	5.83	0.33
12:00	21	150	130	5.77	0.33
13:00	21	150	130	5.77	0.33
14:00	21	150	130	5.72	0.32
15:00	21	150	130	5.77	0.33
16:00	21	150	130	5.88	0.33
17:00	21	150	130	5.11	0.29
18:00	21	150	130	5.16	0.29
19:00	21	150	130	4.89	0.28
20:00	21	150	130	5.27	0.3
21:00	21	150	130	5.33	0.3
22:00	21	150	130	5.38	0.3
23:00	21	150	130	5.44	0.31
24:00	21	150	130	5.44	0.31

18). Pipe P-18 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	8.44	0.48
1:00	105.97	150	130	8.36	0.47
2:00	105.97	150	130	8.19	0.46
3:00	105.97	150	130	8.27	0.47
4:00	105.97	150	130	8.36	0.47
5:00	105.97	150	130	9.31	0.53
6:00	105.97	150	130	9.13	0.52
7:00	105.97	150	130	8.96	0.51
8:00	105.97	150	130	9.13	0.52
9:00	105.97	150	130	9.05	0.51
10:00	105.97	150	130	8.96	0.51
11:00	105.97	150	130	9.05	0.51
12:00	105.97	150	130	8.96	0.51
13:00	105.97	150	130	8.96	0.51
14:00	105.97	150	130	8.87	0.50
15:00	105.97	150	130	8.96	0.51
16:00	105.97	150	130	9.13	0.52
17:00	105.97	150	130	7.93	0.45
18:00	105.97	150	130	8.01	0.45
19:00	105.97	150	130	7.58	0.43
20:00	105.97	150	130	8.19	0.46
21:00	105.97	150	130	8.27	0.47
22:00	105.97	150	130	8.36	0.47
23:00	105.97	150	130	8.44	0.48
24:00	105.97	150	130	8.44	0.48

19). Pipe P-19 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	350.93	150	130	0.38	0.02
1:00	350.93	150	130	0.38	0.02
2:00	350.93	150	130	0.37	0.02
3:00	350.93	150	130	0.38	0.02
4:00	350.93	150	130	0.38	0.02
5:00	350.93	150	130	0.42	0.02
6:00	350.93	150	130	0.42	0.02
7:00	350.93	150	130	0.41	0.02
8:00	350.93	150	130	0.42	0.02
9:00	350.93	150	130	0.41	0.02
10:00	350.93	150	130	0.41	0.02
11:00	350.93	150	130	0.41	0.02
12:00	350.93	150	130	0.41	0.02
13:00	350.93	150	130	0.41	0.02
14:00	350.93	150	130	0.40	0.02
15:00	350.93	150	130	0.41	0.02
16:00	350.93	150	130	0.42	0.02
17:00	350.93	150	130	0.36	0.02
18:00	350.93	150	130	0.36	0.02
19:00	350.93	150	130	0.34	0.02
20:00	350.93	150	130	0.37	0.02
21:00	350.93	150	130	0.38	0.02
22:00	350.93	150	130	0.38	0.02
23:00	350.93	150	130	0.38	0.02
24:00	350.93	150	130	0.38	0.02

20). Pipe P-20 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	25.67	150	130	0.38	0.02
1:00	25.67	150	130	0.38	0.02
2:00	25.67	150	130	0.37	0.02
3:00	25.67	150	130	0.38	0.02
4:00	25.67	150	130	0.38	0.02
5:00	25.67	150	130	0.42	0.02
6:00	25.67	150	130	0.42	0.02
7:00	25.67	150	130	0.41	0.02
8:00	25.67	150	130	0.42	0.02
9:00	25.67	150	130	0.41	0.02
10:00	25.67	150	130	0.41	0.02
11:00	25.67	150	130	0.41	0.02
12:00	25.67	150	130	0.41	0.02
13:00	25.67	150	130	0.41	0.02
14:00	25.67	150	130	0.40	0.02
15:00	25.67	150	130	0.41	0.02
16:00	25.67	150	130	0.42	0.02
17:00	25.67	150	130	0.36	0.02
18:00	25.67	150	130	0.36	0.02
19:00	25.67	150	130	0.34	0.02
20:00	25.67	150	130	0.37	0.02
21:00	25.67	150	130	0.38	0.02
22:00	25.67	150	130	0.38	0.02
23:00	25.67	150	130	0.38	0.02
24:00	25.67	150	130	0.38	0.02

21). Pipe P-21 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	2.12	0.12
1:00	105.97	150	130	2.1	0.12
2:00	105.97	150	130	2.05	0.12
3:00	105.97	150	130	2.07	0.12
4:00	105.97	150	130	2.10	0.12
5:00	105.97	150	130	2.33	0.13
6:00	105.97	150	130	2.29	0.13
7:00	105.97	150	130	2.25	0.13
8:00	105.97	150	130	2.29	0.13
9:00	105.97	150	130	2.27	0.13
10:00	105.97	150	130	2.25	0.13
11:00	105.97	150	130	2.27	0.13
12:00	105.97	150	130	2.25	0.13
13:00	105.97	150	130	2.25	0.13
14:00	105.97	150	130	2.23	0.13
15:00	105.97	150	130	2.25	0.13
16:00	105.97	150	130	2.29	0.13
17:00	105.97	150	130	1.99	0.11
18:00	105.97	150	130	2.01	0.11
19:00	105.97	150	130	1.90	0.11
20:00	105.97	150	130	2.05	0.12
21:00	105.97	150	130	2.07	0.12
22:00	105.97	150	130	2.10	0.12
23:00	105.97	150	130	2.12	0.12
24:00	105.97	150	130	2.12	0.12

22). Pipe P-22 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	4.88	0.28
1:00	21	150	130	4.83	0.27
2:00	21	150	130	4.73	0.27
3:00	21	150	130	4.78	0.27
4:00	21	150	130	4.83	0.27
5:00	21	150	130	5.37	0.30
6:00	21	150	130	5.27	0.30
7:00	21	150	130	5.17	0.29
8:00	21	150	130	5.27	0.30
9:00	21	150	130	5.22	0.30
10:00	21	150	130	5.17	0.29
11:00	21	150	130	5.22	0.30
12:00	21	150	130	5.17	0.29
13:00	21	150	130	5.17	0.29
14:00	21	150	130	5.12	0.29
15:00	21	150	130	5.17	0.29
16:00	21	150	130	5.27	0.30
17:00	21	150	130	4.58	0.26
18:00	21	150	130	4.63	0.26
19:00	21	150	130	4.38	0.25
20:00	21	150	130	4.73	0.27
21:00	21	150	130	4.78	0.27
22:00	21	150	130	4.83	0.27
23:00	21	150	130	4.88	0.28
24:00	21	150	130	4.88	0.28

23). Pipe P-23 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	7.85	0.44
1:00	105.97	150	130	7.77	0.44
2:00	105.97	150	130	7.61	0.43
3:00	105.97	150	130	7.69	0.43
4:00	105.97	150	130	7.77	0.44
5:00	105.97	150	130	8.65	0.49
6:00	105.97	150	130	8.49	0.48
7:00	105.97	150	130	8.33	0.47
8:00	105.97	150	130	8.49	0.48
9:00	105.97	150	130	8.41	0.48
10:00	105.97	150	130	8.33	0.47
11:00	105.97	150	130	8.41	0.48
12:00	105.97	150	130	8.33	0.47
13:00	105.97	150	130	8.33	0.47
14:00	105.97	150	130	8.25	0.47
15:00	105.97	150	130	8.33	0.47
16:00	105.97	150	130	8.49	0.48
17:00	105.97	150	130	7.37	0.42
18:00	105.97	150	130	7.45	0.42
19:00	105.97	150	130	7.04	0.40
20:00	105.97	150	130	7.61	0.43
21:00	105.97	150	130	7.69	0.43
22:00	105.97	150	130	7.77	0.44
23:00	105.97	150	130	7.85	0.44
24:00	105.97	150	130	7.85	0.44

24). Pipe P-24 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	344.945	150	130	2.95	0.17
1:00	344.945	150	130	2.92	0.17
2:00	344.945	150	130	2.86	0.16
3:00	344.945	150	130	2.89	0.16
4:00	344.945	150	130	2.92	0.17
5:00	344.945	150	130	3.25	0.18
6:00	344.945	150	130	3.19	0.18
7:00	344.945	150	130	3.13	0.18
8:00	344.945	150	130	3.19	0.18
9:00	344.945	150	130	3.16	0.18
10:00	344.945	150	130	3.13	0.18
11:00	344.945	150	130	3.16	0.18
12:00	344.945	150	130	3.13	0.18
13:00	344.945	150	130	3.13	0.18
14:00	344.945	150	130	3.10	0.18
15:00	344.945	150	130	3.13	0.18
16:00	344.945	150	130	3.19	0.18
17:00	344.945	150	130	2.77	0.16
18:00	344.945	150	130	2.80	0.16
19:00	344.945	150	130	2.65	0.15
20:00	344.945	150	130	2.86	0.16
21:00	344.945	150	130	2.89	0.16
22:00	344.945	150	130	2.92	0.17
23:00	344.945	150	130	2.95	0.17
24:00	344.945	150	130	2.95	0.17

25). Pipe P-25 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.2	150	130	2.95	0.17
1:00	105.2	150	130	2.92	0.17
2:00	105.2	150	130	2.86	0.16
3:00	105.2	150	130	2.89	0.16
4:00	105.2	150	130	2.92	0.17
5:00	105.2	150	130	3.25	0.18
6:00	105.2	150	130	3.19	0.18
7:00	105.2	150	130	3.13	0.18
8:00	105.2	150	130	3.19	0.18
9:00	105.2	150	130	3.16	0.18
10:00	105.2	150	130	3.13	0.18
11:00	105.2	150	130	3.16	0.18
12:00	105.2	150	130	3.13	0.18
13:00	105.2	150	130	3.13	0.18
14:00	105.2	150	130	3.10	0.18
15:00	105.2	150	130	3.13	0.18
16:00	105.2	150	130	3.19	0.18
17:00	105.2	150	130	2.77	0.16
18:00	105.2	150	130	2.80	0.16
19:00	105.2	150	130	2.65	0.15
20:00	105.2	150	130	2.86	0.16
21:00	105.2	150	130	2.89	0.16
22:00	105.2	150	130	2.92	0.17
23:00	105.2	150	130	2.95	0.17
24:00	105.2	150	130	2.95	0.17

26). Pipe P-26 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.91	150	130	2.95	0.17
1:00	354.91	150	130	2.92	0.17
2:00	354.91	150	130	2.86	0.16
3:00	354.91	150	130	2.89	0.16
4:00	354.91	150	130	2.92	0.17
5:00	354.91	150	130	3.25	0.18
6:00	354.91	150	130	3.19	0.18
7:00	354.91	150	130	3.13	0.18
8:00	354.91	150	130	3.19	0.18
9:00	354.91	150	130	3.16	0.18
10:00	354.91	150	130	3.13	0.18
11:00	354.91	150	130	3.16	0.18
12:00	354.91	150	130	3.13	0.18
13:00	354.91	150	130	3.13	0.18
14:00	354.91	150	130	3.10	0.18
15:00	354.91	150	130	3.13	0.18
16:00	354.91	150	130	3.19	0.18
17:00	354.91	150	130	2.77	0.16
18:00	354.91	150	130	2.80	0.16
19:00	354.91	150	130	2.65	0.15
20:00	354.91	150	130	2.86	0.16
21:00	354.91	150	130	2.89	0.16
22:00	354.91	150	130	2.92	0.17
23:00	354.91	150	130	2.95	0.17
24:00	354.91	150	130	2.95	0.17

27). Pipe P-27 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	1.35	0.08
1:00	105.97	150	130	1.34	0.08
2:00	105.97	150	130	1.31	0.07
3:00	105.97	150	130	1.33	0.08
4:00	105.97	150	130	1.34	0.08
5:00	105.97	150	130	1.49	0.08
6:00	105.97	150	130	1.47	0.08
7:00	105.97	150	130	1.44	0.08
8:00	105.97	150	130	1.47	0.08
9:00	105.97	150	130	1.45	0.08
10:00	105.97	150	130	1.44	0.08
11:00	105.97	150	130	1.45	0.08
12:00	105.97	150	130	1.44	0.08
13:00	105.97	150	130	1.44	0.08
14:00	105.97	150	130	1.42	0.08
15:00	105.97	150	130	1.44	0.08
16:00	105.97	150	130	1.47	0.08
17:00	105.97	150	130	1.27	0.07
18:00	105.97	150	130	1.29	0.07
19:00	105.97	150	130	1.22	0.07
20:00	105.97	150	130	1.31	0.07
21:00	105.97	150	130	1.33	0.08
22:00	105.97	150	130	1.34	0.08
23:00	105.97	150	130	1.35	0.08
24:00	105.97	150	130	1.35	0.08

28). Pipe P-28 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	1.13	0.06
1:00	21	150	130	1.12	0.06
2:00	21	150	130	1.10	0.06
3:00	21	150	130	1.11	0.06
4:00	21	150	130	1.12	0.06
5:00	21	150	130	1.25	0.07
6:00	21	150	130	1.22	0.07
7:00	21	150	130	1.20	0.07
8:00	21	150	130	1.22	0.07
9:00	21	150	130	1.21	0.07
10:00	21	150	130	1.20	0.07
11:00	21	150	130	1.21	0.07
12:00	21	150	130	1.20	0.07
13:00	21	150	130	1.20	0.07
14:00	21	150	130	1.19	0.07
15:00	21	150	130	1.20	0.07
16:00	21	150	130	1.22	0.07
17:00	21	150	130	1.06	0.06
18:00	21	150	130	1.07	0.06
19:00	21	150	130	1.02	0.06
20:00	21	150	130	1.10	0.06
21:00	21	150	130	1.11	0.06
22:00	21	150	130	1.12	0.06
23:00	21	150	130	1.13	0.06
24:00	21	150	130	1.13	0.06

29). Pipe P-29 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	0.69	0.04
1:00	105.97	150	130	0.69	0.04
2:00	105.97	150	130	0.67	0.04
3:00	105.97	150	130	0.68	0.04
4:00	105.97	150	130	0.69	0.04
5:00	105.97	150	130	0.76	0.04
6:00	105.97	150	130	0.75	0.04
7:00	105.97	150	130	0.74	0.04
8:00	105.97	150	130	0.75	0.04
9:00	105.97	150	130	0.74	0.04
10:00	105.97	150	130	0.74	0.04
11:00	105.97	150	130	0.74	0.04
12:00	105.97	150	130	0.74	0.04
13:00	105.97	150	130	0.74	0.04
14:00	105.97	150	130	0.73	0.04
15:00	105.97	150	130	0.74	0.04
16:00	105.97	150	130	0.75	0.04
17:00	105.97	150	130	0.65	0.04
18:00	105.97	150	130	0.66	0.04
19:00	105.97	150	130	0.62	0.04
20:00	105.97	150	130	0.67	0.04
21:00	105.97	150	130	0.68	0.04
22:00	105.97	150	130	0.69	0.04
23:00	105.97	150	130	0.69	0.04
24:00	105.97	150	130	0.69	0.04

30). Pipe P-30 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.848	150	130	1.37	0.08
1:00	763.848	150	130	1.36	0.08
2:00	763.848	150	130	1.33	0.08
3:00	763.848	150	130	1.34	0.08
4:00	763.848	150	130	1.36	0.08
5:00	763.848	150	130	1.51	0.09
6:00	763.848	150	130	1.49	0.08
7:00	763.848	150	130	1.46	0.08
8:00	763.848	150	130	1.49	0.08
9:00	763.848	150	130	1.47	0.08
10:00	763.848	150	130	1.46	0.08
11:00	763.848	150	130	1.47	0.08
12:00	763.848	150	130	1.46	0.08
13:00	763.848	150	130	1.46	0.08
14:00	763.848	150	130	1.44	0.08
15:00	763.848	150	130	1.46	0.08
16:00	763.848	150	130	1.49	0.08
17:00	763.848	150	130	1.29	0.07
18:00	763.848	150	130	1.30	0.07
19:00	763.848	150	130	1.23	0.07
20:00	763.848	150	130	1.33	0.08
21:00	763.848	150	130	1.34	0.08
22:00	763.848	150	130	1.36	0.08
23:00	763.848	150	130	1.37	0.08
24:00	763.848	150	130	1.37	0.08

31). Pipe P-31 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.848	150	130	1.16	0.07
1:00	763.848	150	130	1.15	0.06
2:00	763.848	150	130	1.12	0.06
3:00	763.848	150	130	1.14	0.06
4:00	763.848	150	130	1.15	0.06
5:00	763.848	150	130	1.28	0.07
6:00	763.848	150	130	1.25	0.07
7:00	763.848	150	130	1.23	0.07
8:00	763.848	150	130	1.25	0.07
9:00	763.848	150	130	1.24	0.07
10:00	763.848	150	130	1.23	0.07
11:00	763.848	150	130	1.24	0.07
12:00	763.848	150	130	1.23	0.07
13:00	763.848	150	130	1.23	0.07
14:00	763.848	150	130	1.22	0.07
15:00	763.848	150	130	1.23	0.07
16:00	763.848	150	130	1.25	0.07
17:00	763.848	150	130	1.09	0.06
18:00	763.848	150	130	1.10	0.06
19:00	763.848	150	130	1.04	0.06
20:00	763.848	150	130	1.12	0.06
21:00	763.848	150	130	1.14	0.06
22:00	763.848	150	130	1.15	0.06
23:00	763.848	150	130	1.16	0.07
24:00	763.848	150	130	1.16	0.07

32). Pipe P-32 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.81	150	130	0.90	0.05
1:00	763.81	150	130	0.90	0.05
2:00	763.81	150	130	0.88	0.05
3:00	763.81	150	130	0.89	0.05
4:00	763.81	150	130	0.90	0.05
5:00	763.81	150	130	1.00	0.06
6:00	763.81	150	130	0.98	0.06
7:00	763.81	150	130	0.96	0.05
8:00	763.81	150	130	0.98	0.06
9:00	763.81	150	130	0.97	0.05
10:00	763.81	150	130	0.96	0.05
11:00	763.81	150	130	0.97	0.05
12:00	763.81	150	130	0.96	0.05
13:00	763.81	150	130	0.96	0.05
14:00	763.81	150	130	0.95	0.05
15:00	763.81	150	130	0.96	0.05
16:00	763.81	150	130	0.98	0.06
17:00	763.81	150	130	0.85	0.05
18:00	763.81	150	130	0.86	0.05
19:00	763.81	150	130	0.81	0.05
20:00	763.81	150	130	0.88	0.05
21:00	763.81	150	130	0.89	0.05
22:00	763.81	150	130	0.90	0.05
23:00	763.81	150	130	0.90	0.05
24:00	763.81	150	130	0.90	0.05

Scenario - 3

Tabulated Presentation of Nodal (Junction) Time Series

Results

1). Junction - 1 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	256.19	14.66
1:00	0	256.19	14.66
2:00	0	256.19	14.66
3:00	0	256.19	14.66
4:00	0	256.19	14.66
5:00	0	256.18	14.65
6:00	0	256.18	14.65
7:00	0	256.18	14.65
8:00	0	256.18	14.65
9:00	0	256.18	14.65
10:00	0	256.18	14.65
11:00	0	256.18	14.65
12:00	0	256.18	14.65
13:00	0	256.18	14.65
14:00	0	256.18	14.66
15:00	0	256.18	14.65
16:00	0	256.18	14.65
17:00	0	256.19	14.67
18:00	0	256.19	14.66
19:00	0	256.19	14.67
20:00	0	256.19	14.66
21:00	0	256.19	14.66
22:00	0	256.19	14.66
23:00	0	256.19	14.66
24:00:00	0	256.19	14.66

*T-Junction

2). Junction - 2 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	256.03	13.51
1:00	0	256.03	13.51
2:00	0	256.04	13.52
3:00	0	256.03	13.51
4:00	0	256.03	13.51
5:00	0	255.99	13.46
6:00	0	255.99	13.47
7:00	0	256.00	13.48
8:00	0	255.99	13.47
9:00	0	256.00	13.48
10:00	0	256.00	13.48
11:00	0	256.00	13.48
12:00	0	256.00	13.48
13:00	0	256.00	13.48
14:00	0	256.01	13.49
15:00	0	256.00	13.48
16:00	0	255.99	13.47
17:00	0	256.05	13.53
18:00	0	256.05	13.52
19:00	0	256.06	13.54
20:00	0	256.04	13.52
21:00	0	256.03	13.51
22:00	0	256.03	13.51
23:00	0	256.03	13.51
24:00:00	0	256.03	13.51

*Reducer 200mmx150mm

3). Junction - 3 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	256.02	13.48
1:00	1.50	256.02	13.49
2:00	1.47	256.03	13.5
3:00	1.49	256.03	13.49
4:00	1.50	256.02	13.49
5:00	1.67	255.98	13.44
6:00	1.64	255.98	13.45
7:00	1.61	255.99	13.46
8:00	1.64	255.98	13.45
9:00	1.63	255.99	13.46
10:00	1.61	255.99	13.46
11:00	1.63	255.99	13.46
12:00	1.61	255.99	13.46
13:00	1.61	255.99	13.46
14:00	1.60	256.00	13.46
15:00	1.61	255.99	13.46
16:00	1.64	255.98	13.45
17:00	1.43	256.04	13.51
18:00	1.44	256.04	13.5
19:00	1.36	256.06	13.52
20:00	1.47	256.03	13.5
21:00	1.49	256.03	13.49
22:00	1.50	256.02	13.49
23:00	1.52	256.02	13.48
24:00:00	1.52	256.02	13.48

4). Junction - 4 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.92	12.46
1:00	0	255.92	12.47
2:00	0	255.94	12.48
3:00	0	255.93	12.47
4:00	0	255.92	12.47
5:00	0	255.86	12.40
6:00	0	255.87	12.41
7:00	0	255.88	12.42
8:00	0	255.87	12.41
9:00	0	255.88	12.42
10:00	0	255.88	12.42
11:00	0	255.88	12.42
12:00	0	255.88	12.42
13:00	0	255.88	12.42
14:00	0	255.89	12.43
15:00	0	255.88	12.42
16:00	0	255.87	12.41
17:00	0	255.95	12.49
18:00	0	255.95	12.49
19:00	0	255.98	12.52
20:00	0	255.94	12.48
21:00	0	255.93	12.47
22:00	0	255.92	12.47
23:00	0	255.92	12.46
24:00:00	0	255.92	12.46

*Elbow

5). Junction - 5 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.89	12.14
1:00	0	255.9	12.14
2:00	0	255.91	12.16
3:00	0	255.90	12.15
4:00	0	255.90	12.14
5:00	0	255.82	12.07
6:00	0	255.84	12.08
7:00	0	255.85	12.10
8:00	0	255.84	12.08
9:00	0	255.84	12.09
10:00	0	255.85	12.10
11:00	0	255.84	12.09
12:00	0	255.85	12.10
13:00	0	255.85	12.10
14:00	0	255.86	12.11
15:00	0	255.85	12.10
16:00	0	255.84	12.08
17:00	0	255.93	12.18
18:00	0	255.92	12.17
19:00	0	255.95	12.20
20:00	0	255.91	12.16
21:00	0	255.90	12.15
22:00	0	255.90	12.14
23:00	0	255.89	12.14
24:00:00	0	255.89	12.14

*Elbow

6). Junction - 6 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.98	15.14
1:00	1.50	255.99	15.14
2:00	1.47	255.99	15.15
3:00	1.49	255.99	15.14
4:00	1.50	255.99	15.14
5:00	1.67	255.93	15.09
6:00	1.64	255.94	15.10
7:00	1.61	255.95	15.11
8:00	1.64	255.94	15.10
9:00	1.63	255.95	15.10
10:00	1.61	255.95	15.11
11:00	1.63	255.95	15.10
12:00	1.61	255.95	15.11
13:00	1.61	255.95	15.11
14:00	1.60	255.96	15.11
15:00	1.61	255.95	15.11
16:00	1.64	255.94	15.10
17:00	1.43	256.01	15.16
18:00	1.44	256.00	15.16
19:00	1.36	256.03	15.18
20:00	1.47	255.99	15.15
21:00	1.49	255.99	15.14
22:00	1.50	255.99	15.14
23:00	1.52	255.98	15.14
24:00:00	1.52	255.98	15.14

7). unction - 7 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.98	15.14
1:00	0	255.98	15.15
2:00	0	255.99	15.15
3:00	0	255.99	15.15
4:00	0	255.98	15.15
5:00	0	255.93	15.09
6:00	0	255.94	15.10
7:00	0	255.95	15.11
8:00	0	255.94	15.10
9:00	0	255.95	15.11
10:00	0	255.95	15.11
11:00	0	255.95	15.11
12:00	0	255.95	15.11
13:00	0	255.95	15.11
14:00	0	255.96	15.12
15:00	0	255.95	15.11
16:00	0	255.94	15.10
17:00	0	256.01	15.17
18:00	0	256.00	15.16
19:00	0	256.03	15.19
20:00	0	255.99	15.15
21:00	0	255.99	15.15
22:00	0	255.98	15.15
23:00	0	255.98	15.14
24:00:00	0	255.98	15.14

*Reducer 200mmx150mm

8). Junction - 8 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.89	16.63
1:00	0	255.90	16.64
2:00	0	255.91	16.65
3:00	0	255.91	16.64
4:00	0	255.90	16.64
5:00	0	255.83	16.57
6:00	0	255.84	16.58
7:00	0	255.85	16.59
8:00	0	255.84	16.58
9:00	0	255.85	16.59
10:00	0	255.85	16.59
11:00	0	255.85	16.59
12:00	0	255.85	16.59
13:00	0	255.85	16.59
14:00	0	255.86	16.60
15:00	0	255.85	16.59
16:00	0	255.84	16.58
17:00	0	255.93	16.67
18:00	0	255.92	16.66
19:00	0	255.95	16.69
20:00	0	255.91	16.65
21:00	0	255.91	16.64
22:00	0	255.90	16.64
23:00	0	255.89	16.63
24:00:00	0	255.89	16.63

*Elbow

9). Junction - 9 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.87	17.15
1:00	0	255.87	17.16
2:00	0	255.89	17.17
3:00	0	255.88	17.16
4:00	0	255.87	17.16
5:00	0	255.79	17.08
6:00	0	255.81	17.09
7:00	0	255.82	17.11
8:00	0	255.81	17.09
9:00	0	255.82	17.10
10:00	0	255.82	17.11
11:00	0	255.82	17.10
12:00	0	255.82	17.11
13:00	0	255.82	17.11
14:00	0	255.83	17.12
15:00	0	255.82	17.11
16:00	0	255.81	17.09
17:00	0	255.91	17.19
18:00	0	255.90	17.18
19:00	0	255.93	17.22
20:00	0	255.89	17.17
21:00	0	255.88	17.16
22:00	0	255.87	17.16
23:00	0	255.87	17.15
24:00:00	0	255.87	17.15

*Elbow

10). Junction - 10 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.78	18.28
1:00	1.50	255.79	18.29
2:00	1.47	255.80	18.31
3:00	1.49	255.79	18.30
4:00	1.50	255.79	18.29
5:00	1.67	255.69	18.19
6:00	1.64	255.71	18.21
7:00	1.61	255.72	18.23
8:00	1.64	255.71	18.21
9:00	1.63	255.72	18.22
10:00	1.61	255.72	18.23
11:00	1.63	255.72	18.22
12:00	1.61	255.72	18.23
13:00	1.61	255.72	18.23
14:00	1.60	255.73	18.24
15:00	1.61	255.72	18.23
16:00	1.64	255.71	18.21
17:00	1.43	255.83	18.33
18:00	1.44	255.82	18.32
19:00	1.36	255.86	18.36
20:00	1.47	255.80	18.31
21:00	1.49	255.79	18.30
22:00	1.50	255.79	18.29
23:00	1.52	255.78	18.28
24:00:00	1.52	255.78	18.28

11). Junction - 11 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.77	17.96
1:00	1.50	255.78	17.97
2:00	1.47	255.80	17.99
3:00	1.49	255.79	17.98
4:00	1.50	255.78	17.97
5:00	1.67	255.68	17.87
6:00	1.64	255.70	17.89
7:00	1.61	255.72	17.91
8:00	1.64	255.70	17.89
9:00	1.63	255.71	17.90
10:00	1.61	255.72	17.91
11:00	1.63	255.71	17.90
12:00	1.61	255.72	17.91
13:00	1.61	255.72	17.91
14:00	1.60	255.73	17.92
15:00	1.61	255.72	17.91
16:00	1.64	255.70	17.89
17:00	1.43	255.82	18.01
18:00	1.44	255.81	18.00
19:00	1.36	255.85	18.04
20:00	1.47	255.80	17.99
21:00	1.49	255.79	17.98
22:00	1.50	255.78	17.97
23:00	1.52	255.77	17.96
24:00:00	1.52	255.77	17.96

12). Junction - 12 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.77	17.89
1:00	1.50	255.78	17.90
2:00	1.47	255.80	17.91
3:00	1.49	255.79	17.91
4:00	1.50	255.78	17.90
5:00	1.67	255.68	17.80
6:00	1.64	255.70	17.82
7:00	1.61	255.72	17.84
8:00	1.64	255.70	17.82
9:00	1.63	255.71	17.83
10:00	1.61	255.72	17.84
11:00	1.63	255.71	17.83
12:00	1.61	255.72	17.84
13:00	1.61	255.72	17.84
14:00	1.6	255.73	17.84
15:00	1.61	255.72	17.84
16:00	1.64	255.70	17.82
17:00	1.43	255.82	17.94
18:00	1.44	255.81	17.93
19:00	1.36	255.85	17.97
20:00	1.47	255.80	17.91
21:00	1.49	255.79	17.91
22:00	1.5	255.78	17.90
23:00	1.52	255.77	17.89
24:00:00	1.52	255.77	17.89

13). Junction - 13 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.77	17.44
1:00	1.50	255.78	17.45
2:00	1.47	255.79	17.46
3:00	1.49	255.79	17.46
4:00	1.50	255.78	17.45
5:00	1.67	255.68	17.35
6:00	1.64	255.70	17.37
7:00	1.61	255.71	17.38
8:00	1.64	255.70	17.37
9:00	1.63	255.71	17.38
10:00	1.61	255.71	17.38
11:00	1.63	255.71	17.38
12:00	1.61	255.71	17.38
13:00	1.61	255.71	17.38
14:00	1.60	255.72	17.39
15:00	1.61	255.71	17.38
16:00	1.64	255.70	17.37
17:00	1.43	255.82	17.49
18:00	1.44	255.81	17.48
19:00	1.36	255.85	17.52
20:00	1.47	255.79	17.46
21:00	1.49	255.79	17.46
22:00	1.50	255.78	17.45
23:00	1.52	255.77	17.44
24:00:00	1.52	255.77	17.44

14). Junction - 14 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.82	14.64
1:00	1.50	255.83	14.65
2:00	1.47	255.84	14.67
3:00	1.49	255.83	14.66
4:00	1.50	255.83	14.65
5:00	1.67	255.74	14.56
6:00	1.64	255.75	14.58
7:00	1.61	255.77	14.60
8:00	1.64	255.75	14.58
9:00	1.63	255.76	14.59
10:00	1.61	255.77	14.60
11:00	1.63	255.76	14.59
12:00	1.61	255.77	14.60
13:00	1.61	255.77	14.60
14:00	1.60	255.78	14.60
15:00	1.61	255.77	14.60
16:00	1.64	255.75	14.58
17:00	1.43	255.86	14.69
18:00	1.44	255.86	14.68
19:00	1.36	255.89	14.72
20:00	1.47	255.84	14.67
21:00	1.49	255.83	14.66
22:00	1.50	255.83	14.65
23:00	1.52	255.82	14.64
24:00:00	1.52	255.82	14.64

15). Junction - 15 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.80	14.63
1:00	1.50	255.81	14.64
2:00	1.47	255.83	14.65
3:00	1.49	255.82	14.65
4:00	1.50	255.81	14.64
5:00	1.67	255.72	14.55
6:00	1.64	255.74	14.56
7:00	1.61	255.75	14.58
8:00	1.64	255.74	14.56
9:00	1.63	255.75	14.57
10:00	1.61	255.75	14.58
11:00	1.63	255.75	14.57
12:00	1.61	255.75	14.58
13:00	1.61	255.75	14.58
14:00	1.60	255.76	14.59
15:00	1.61	255.75	14.58
16:00	1.64	255.74	14.56
17:00	1.43	255.85	14.68
18:00	1.44	255.84	14.67
19:00	1.36	255.88	14.71
20:00	1.47	255.83	14.65
21:00	1.49	255.82	14.65
22:00	1.50	255.81	14.64
23:00	1.52	255.80	14.63
24:00:00	1.52	255.80	14.63

16). Junction - 16 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.79	14.36
1:00	1.50	255.80	14.37
2:00	1.47	255.81	14.38
3:00	1.49	255.81	14.38
4:00	1.50	255.80	14.37
5:00	1.67	255.70	14.27
6:00	1.64	255.72	14.29
7:00	1.61	255.74	14.31
8:00	1.64	255.72	14.29
9:00	1.63	255.73	14.30
10:00	1.61	255.74	14.31
11:00	1.63	255.73	14.30
12:00	1.61	255.74	14.31
13:00	1.61	255.74	14.31
14:00	1.60	255.75	14.32
15:00	1.61	255.74	14.31
16:00	1.64	255.72	14.29
17:00	1.43	255.84	14.41
18:00	1.44	255.83	14.40
19:00	1.36	255.87	14.44
20:00	1.47	255.81	14.38
21:00	1.49	255.81	14.38
22:00	1.50	255.80	14.37
23:00	1.52	255.79	14.36
24:00:00	1.52	255.79	14.36

17). Junction - 17 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.79	14.32
1:00	0	255.80	14.33
2:00	0	255.81	14.34
3:00	0	255.81	14.34
4:00	0	255.80	14.33
5:00	0	255.70	14.23
6:00	0	255.72	14.25
7:00	0	255.74	14.27
8:00	0	255.72	14.25
9:00	0	255.73	14.26
10:00	0	255.74	14.27
11:00	0	255.73	14.26
12:00	0	255.74	14.27
13:00	0	255.74	14.27
14:00	0	255.75	14.28
15:00	0	255.74	14.27
16:00	0	255.72	14.25
17:00	0	255.84	14.37
18:00	0	255.83	14.36
19:00	0	255.87	14.40
20:00	0	255.81	14.34
21:00	0	255.81	14.34
22:00	0	255.80	14.33
23:00	0	255.79	14.32
24:00:00	0	255.79	14.32

*Elbow

18). Junction - 18 Time Series details

Time (Hours)	Demand (L/s)*	Head (m)	Pressure (m)
0:00	0	255.79	13.03
1:00	0	255.80	13.04
2:00	0	255.82	13.05
3:00	0	255.81	13.04
4:00	0	255.80	13.04
5:00	0	255.71	12.94
6:00	0	255.72	12.96
7:00	0	255.74	12.98
8:00	0	255.72	12.96
9:00	0	255.73	12.97
10:00	0	255.74	12.98
11:00	0	255.73	12.97
12:00	0	255.74	12.98
13:00	0	255.74	12.98
14:00	0	255.75	12.98
15:00	0	255.74	12.98
16:00	0	255.72	12.96
17:00	0	255.84	13.08
18:00	0	255.83	13.07
19:00	0	255.87	13.11
20:00	0	255.82	13.05
21:00	0	255.81	13.04
22:00	0	255.80	13.04
23:00	0	255.79	13.03
24:00:00	0	255.79	13.03

*Elbow

19). Junction - 19 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.79	12.63
1:00	1.50	255.80	12.64
2:00	1.47	255.82	12.65
3:00	1.49	255.81	12.64
4:00	1.50	255.80	12.64
5:00	1.67	255.71	12.54
6:00	1.64	255.72	12.56
7:00	1.61	255.74	12.58
8:00	1.64	255.72	12.56
9:00	1.63	255.73	12.57
10:00	1.61	255.74	12.58
11:00	1.63	255.73	12.57
12:00	1.61	255.74	12.58
13:00	1.61	255.74	12.58
14:00	1.60	255.75	12.58
15:00	1.61	255.74	12.58
16:00	1.64	255.72	12.56
17:00	1.43	255.84	12.68
18:00	1.44	255.83	12.67
19:00	1.36	255.87	12.71
20:00	1.47	255.82	12.65
21:00	1.49	255.81	12.64
22:00	1.50	255.80	12.64
23:00	1.52	255.79	12.63
24:00:00	1.52	255.79	12.63

20). Junction - 20 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.81	13.11
1:00	1.50	255.82	13.12
2:00	1.47	255.84	13.14
3:00	1.49	255.83	13.13
4:00	1.50	255.82	13.12
5:00	1.67	255.73	13.03
6:00	1.64	255.75	13.05
7:00	1.61	255.77	13.07
8:00	1.64	255.75	13.05
9:00	1.63	255.76	13.06
10:00	1.61	255.77	13.07
11:00	1.63	255.76	13.06
12:00	1.61	255.77	13.07
13:00	1.61	255.77	13.07
14:00	1.60	255.77	13.07
15:00	1.61	255.77	13.07
16:00	1.64	255.75	13.05
17:00	1.43	255.86	13.16
18:00	1.44	255.85	13.15
19:00	1.36	255.89	13.19
20:00	1.47	255.84	13.14
21:00	1.49	255.83	13.13
22:00	1.50	255.82	13.12
23:00	1.52	255.81	13.11
24:00:00	1.52	255.81	13.11

21). Junction - 21 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.83	13.13
1:00	1.50	255.84	13.14
2:00	1.47	255.85	13.15
3:00	1.49	255.85	13.15
4:00	1.50	255.84	13.14
5:00	1.67	255.75	13.05
6:00	1.64	255.77	13.07
7:00	1.61	255.78	13.08
8:00	1.64	255.77	13.07
9:00	1.63	255.78	13.08
10:00	1.61	255.78	13.08
11:00	1.63	255.78	13.08
12:00	1.61	255.78	13.08
13:00	1.61	255.78	13.08
14:00	1.60	255.79	13.09
15:00	1.61	255.78	13.08
16:00	1.64	255.77	13.07
17:00	1.43	255.88	13.18
18:00	1.44	255.87	13.17
19:00	1.36	255.90	13.20
20:00	1.47	255.85	13.15
21:00	1.49	255.85	13.15
22:00	1.50	255.84	13.14
23:00	1.52	255.83	13.13
24:00:00	1.52	255.83	13.13

22). Junction - 22 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.79	10.28
1:00	1.50	255.80	10.29
2:00	1.47	255.81	10.31
3:00	1.49	255.81	10.30
4:00	1.50	255.80	10.29
5:00	1.67	255.70	10.19
6:00	1.64	255.72	10.21
7:00	1.61	255.74	10.23
8:00	1.64	255.72	10.21
9:00	1.63	255.73	10.22
10:00	1.61	255.74	10.23
11:00	1.63	255.73	10.22
12:00	1.61	255.74	10.23
13:00	1.61	255.74	10.23
14:00	1.60	255.75	10.24
15:00	1.61	255.74	10.23
16:00	1.64	255.72	10.21
17:00	1.43	255.84	10.33
18:00	1.44	255.83	10.32
19:00	1.36	255.87	10.36
20:00	1.47	255.81	10.31
21:00	1.49	255.81	10.30
22:00	1.50	255.80	10.29
23:00	1.52	255.79	10.28
24:00:00	1.52	255.79	10.28

23). Junction - 23 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.78	10.16
1:00	1.50	255.79	10.17
2:00	1.47	255.81	10.19
3:00	1.49	255.80	10.18
4:00	1.50	255.79	10.17
5:00	1.67	255.69	10.08
6:00	1.64	255.71	10.09
7:00	1.61	255.73	10.11
8:00	1.64	255.71	10.09
9:00	1.63	255.72	10.10
10:00	1.61	255.73	10.11
11:00	1.63	255.72	10.10
12:00	1.61	255.73	10.11
13:00	1.61	255.73	10.11
14:00	1.60	255.74	10.12
15:00	1.61	255.73	10.11
16:00	1.64	255.71	10.09
17:00	1.43	255.83	10.21
18:00	1.44	255.82	10.21
19:00	1.36	255.86	10.25
20:00	1.47	255.81	10.19
21:00	1.49	255.8	10.18
22:00	1.50	255.79	10.17
23:00	1.52	255.78	10.16
24:00:00	1.52	255.78	10.16

24). Junction - 24 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.78	10.16
1:00	1.50	255.79	10.17
2:00	1.47	255.81	10.19
3:00	1.49	255.80	10.18
4:00	1.50	255.79	10.17
5:00	1.67	255.69	10.07
6:00	1.64	255.71	10.09
7:00	1.61	255.73	10.11
8:00	1.64	255.71	10.09
9:00	1.63	255.72	10.10
10:00	1.61	255.73	10.11
11:00	1.63	255.72	10.10
12:00	1.61	255.73	10.11
13:00	1.61	255.73	10.11
14:00	1.60	255.74	10.12
15:00	1.61	255.73	10.11
16:00	1.64	255.71	10.09
17:00	1.43	255.83	10.21
18:00	1.44	255.82	10.20
19:00	1.36	255.86	10.24
20:00	1.47	255.81	10.19
21:00	1.49	255.80	10.18
22:00	1.50	255.79	10.17
23:00	1.52	255.78	10.16
24:00:00	1.52	255.78	10.16

25). Junction - 25 Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	1.52	255.78	13.58
1:00	1.50	255.79	13.59
2:00	1.47	255.80	13.60
3:00	1.49	255.80	13.60
4:00	1.50	255.79	13.59
5:00	1.67	255.69	13.49
6:00	1.64	255.71	13.51
7:00	1.61	255.73	13.53
8:00	1.64	255.71	13.51
9:00	1.63	255.72	13.52
10:00	1.61	255.73	13.53
11:00	1.63	255.72	13.52
12:00	1.61	255.73	13.53
13:00	1.61	255.73	13.53
14:00	1.60	255.73	13.54
15:00	1.61	255.73	13.53
16:00	1.64	255.71	13.51
17:00	1.43	255.83	13.63
18:00	1.44	255.82	13.62
19:00	1.36	255.86	13.66
20:00	1.47	255.80	13.60
21:00	1.49	255.80	13.60
22:00	1.50	255.79	13.59
23:00	1.52	255.78	13.58
24:00:00	1.52	255.78	13.58

26). DMA - Time Series details

Time (Hours)	Demand (L/s)	Head (m)	Pressure (m)
0:00	24.30	256.23	0
1:00	24.06	256.23	0
2:00	23.56	256.23	0
3:00	23.81	256.23	0
4:00	24.06	256.23	0
5:00	26.78	256.23	0
6:00	26.29	256.23	0
7:00	25.79	256.23	0
8:00	26.29	256.23	0
9:00	26.04	256.23	0
10:00	25.79	256.23	0
11:00	26.04	256.23	0
12:00	25.79	256.23	0
13:00	25.79	256.23	0
14:00	25.54	256.23	0
15:00	25.79	256.23	0
16:00	26.29	256.23	0
17:00	22.82	256.23	0
18:00	23.06	256.23	0
19:00	21.82	256.23	0
20:00	23.56	256.23	0
21:00	23.81	256.23	0
22:00	24.06	256.23	0
23:00	24.30	256.23	0
24:00:00	24.30	256.23	0

Scenario - 3

Tabulated Presentation of Pipes Time Series

Results

1). Pipe P-1 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	100	300	130	24.30	0.34
1:00	100	300	130	24.06	0.34
2:00	100	300	130	23.56	0.33
3:00	100	300	130	23.81	0.34
4:00	100	300	130	24.06	0.34
5:00	100	300	130	26.78	0.38
6:00	100	300	130	26.29	0.37
7:00	100	300	130	25.79	0.36
8:00	100	300	130	26.29	0.37
9:00	100	300	130	26.04	0.37
10:00	100	300	130	25.79	0.36
11:00	100	300	130	26.04	0.37
12:00	100	300	130	25.79	0.36
13:00	100	300	130	25.79	0.36
14:00	100	300	130	25.54	0.36
15:00	100	300	130	25.79	0.36
16:00	100	300	130	26.29	0.37
17:00	100	300	130	22.82	0.32
18:00	100	300	130	23.06	0.33
19:00	100	300	130	21.82	0.31
20:00	100	300	130	23.56	0.33
21:00	100	300	130	23.81	0.34
22:00	100	300	130	24.06	0.34
23:00	100	300	130	24.30	0.34
24:00	100	300	130	24.30	0.34

2). Pipe P-2 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	232.038	200	130	11.79	0.38
1:00	232.038	200	130	11.67	0.37
2:00	232.038	200	130	11.43	0.36
3:00	232.038	200	130	11.55	0.37
4:00	232.038	200	130	11.67	0.37
5:00	232.038	200	130	12.99	0.41
6:00	232.038	200	130	12.75	0.41
7:00	232.038	200	130	12.51	0.40
8:00	232.038	200	130	12.75	0.41
9:00	232.038	200	130	12.63	0.40
10:00	232.038	200	130	12.51	0.40
11:00	232.038	200	130	12.63	0.40
12:00	232.038	200	130	12.51	0.40
13:00	232.038	200	130	12.51	0.40
14:00	232.038	200	130	12.39	0.39
15:00	232.038	200	130	12.51	0.40
16:00	232.038	200	130	12.75	0.41
17:00	232.038	200	130	11.07	0.35
18:00	232.038	200	130	11.19	0.36
19:00	232.038	200	130	10.58	0.34
20:00	232.038	200	130	11.43	0.36
21:00	232.038	200	130	11.55	0.37
22:00	232.038	200	130	11.67	0.37
23:00	232.038	200	130	11.79	0.38
24:00	232.038	200	130	11.79	0.38

3). Pipe P-3 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	9.975	200	130	2.81	0.09
1:00	9.975	200	130	2.78	0.09
2:00	9.975	200	130	2.72	0.09
3:00	9.975	200	130	2.75	0.09
4:00	9.975	200	130	2.78	0.09
5:00	9.975	200	130	3.09	0.10
6:00	9.975	200	130	3.04	0.10
7:00	9.975	200	130	2.98	0.09
8:00	9.975	200	130	3.04	0.10
9:00	9.975	200	130	3.01	0.10
10:00	9.975	200	130	2.98	0.09
11:00	9.975	200	130	3.01	0.10
12:00	9.975	200	130	2.98	0.09
13:00	9.975	200	130	2.98	0.09
14:00	9.975	200	130	2.95	0.09
15:00	9.975	200	130	2.98	0.09
16:00	9.975	200	130	3.04	0.10
17:00	9.975	200	130	2.64	0.08
18:00	9.975	200	130	2.66	0.08
19:00	9.975	200	130	2.52	0.08
20:00	9.975	200	130	2.72	0.09
21:00	9.975	200	130	2.75	0.09
22:00	9.975	200	130	2.78	0.09
23:00	9.975	200	130	2.81	0.09
24:00	9.975	200	130	2.81	0.09

4). Pipe P-4 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	160.264	200	130	12.52	0.40
1:00	160.264	200	130	12.39	0.39
2:00	160.264	200	130	12.13	0.39
3:00	160.264	200	130	12.26	0.39
4:00	160.264	200	130	12.39	0.39
5:00	160.264	200	130	13.79	0.44
6:00	160.264	200	130	13.54	0.43
7:00	160.264	200	130	13.28	0.42
8:00	160.264	200	130	13.54	0.43
9:00	160.264	200	130	13.41	0.43
10:00	160.264	200	130	13.28	0.42
11:00	160.264	200	130	13.41	0.43
12:00	160.264	200	130	13.28	0.42
13:00	160.264	200	130	13.28	0.42
14:00	160.264	200	130	13.16	0.42
15:00	160.264	200	130	13.28	0.42
16:00	160.264	200	130	13.54	0.43
17:00	160.264	200	130	11.75	0.37
18:00	160.264	200	130	11.88	0.38
19:00	160.264	200	130	11.24	0.36
20:00	160.264	200	130	12.13	0.39
21:00	160.264	200	130	12.26	0.39
22:00	160.264	200	130	12.39	0.39
23:00	160.264	200	130	12.52	0.40
24:00	160.264	200	130	12.52	0.40

5). Pipe P-5 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	2.38	150	130	12.52	0.71
1:00	2.38	150	130	12.39	0.70
2:00	2.38	150	130	12.13	0.69
3:00	2.38	150	130	12.26	0.69
4:00	2.38	150	130	12.39	0.70
5:00	2.38	150	130	13.79	0.78
6:00	2.38	150	130	13.54	0.77
7:00	2.38	150	130	13.28	0.75
8:00	2.38	150	130	13.54	0.77
9:00	2.38	150	130	13.41	0.76
10:00	2.38	150	130	13.28	0.75
11:00	2.38	150	130	13.41	0.76
12:00	2.38	150	130	13.28	0.75
13:00	2.38	150	130	13.28	0.75
14:00	2.38	150	130	13.16	0.74
15:00	2.38	150	130	13.28	0.75
16:00	2.38	150	130	13.54	0.77
17:00	2.38	150	130	11.75	0.66
18:00	2.38	150	130	11.88	0.67
19:00	2.38	150	130	11.24	0.64
20:00	2.38	150	130	12.13	0.69
21:00	2.38	150	130	12.26	0.69
22:00	2.38	150	130	12.39	0.70
23:00	2.38	150	130	12.52	0.71
24:00	2.38	150	130	12.52	0.71

6). Pipe P-6 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.92	150	130	2.97	0.17
1:00	354.92	150	130	2.94	0.17
2:00	354.92	150	130	2.88	0.16
3:00	354.92	150	130	2.91	0.16
4:00	354.92	150	130	2.94	0.17
5:00	354.92	150	130	3.27	0.19
6:00	354.92	150	130	3.21	0.18
7:00	354.92	150	130	3.15	0.18
8:00	354.92	150	130	3.21	0.18
9:00	354.92	150	130	3.18	0.18
10:00	354.92	150	130	3.15	0.18
11:00	354.92	150	130	3.18	0.18
12:00	354.92	150	130	3.15	0.18
13:00	354.92	150	130	3.15	0.18
14:00	354.92	150	130	3.12	0.18
15:00	354.92	150	130	3.15	0.18
16:00	354.92	150	130	3.21	0.18
17:00	354.92	150	130	2.79	0.16
18:00	354.92	150	130	2.82	0.16
19:00	354.92	150	130	2.67	0.15
20:00	354.92	150	130	2.88	0.16
21:00	354.92	150	130	2.91	0.16
22:00	354.92	150	130	2.94	0.17
23:00	354.92	150	130	2.97	0.17
24:00	354.92	150	130	2.97	0.17

7). Pipe P-7 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.3	150	130	2.97	0.17
1:00	105.3	150	130	2.94	0.17
2:00	105.3	150	130	2.88	0.16
3:00	105.3	150	130	2.91	0.16
4:00	105.3	150	130	2.94	0.17
5:00	105.3	150	130	3.27	0.19
6:00	105.3	150	130	3.21	0.18
7:00	105.3	150	130	3.15	0.18
8:00	105.3	150	130	3.21	0.18
9:00	105.3	150	130	3.18	0.18
10:00	105.3	150	130	3.15	0.18
11:00	105.3	150	130	3.18	0.18
12:00	105.3	150	130	3.15	0.18
13:00	105.3	150	130	3.15	0.18
14:00	105.3	150	130	3.12	0.18
15:00	105.3	150	130	3.15	0.18
16:00	105.3	150	130	3.21	0.18
17:00	105.3	150	130	2.79	0.16
18:00	105.3	150	130	2.82	0.16
19:00	105.3	150	130	2.67	0.15
20:00	105.3	150	130	2.88	0.16
21:00	105.3	150	130	2.91	0.16
22:00	105.3	150	130	2.94	0.17
23:00	105.3	150	130	2.97	0.17
24:00	105.3	150	130	2.97	0.17

8). Pipe P-8 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.91	150	130	2.97	0.17
1:00	354.91	150	130	2.94	0.17
2:00	354.91	150	130	2.88	0.16
3:00	354.91	150	130	2.91	0.16
4:00	354.91	150	130	2.94	0.17
5:00	354.91	150	130	3.27	0.19
6:00	354.91	150	130	3.21	0.18
7:00	354.91	150	130	3.15	0.18
8:00	354.91	150	130	3.21	0.18
9:00	354.91	150	130	3.18	0.18
10:00	354.91	150	130	3.15	0.18
11:00	354.91	150	130	3.18	0.18
12:00	354.91	150	130	3.15	0.18
13:00	354.91	150	130	3.15	0.18
14:00	354.91	150	130	3.12	0.18
15:00	354.91	150	130	3.15	0.18
16:00	354.91	150	130	3.21	0.18
17:00	354.91	150	130	2.79	0.16
18:00	354.91	150	130	2.82	0.16
19:00	354.91	150	130	2.67	0.15
20:00	354.91	150	130	2.88	0.16
21:00	354.91	150	130	2.91	0.16
22:00	354.91	150	130	2.94	0.17
23:00	354.91	150	130	2.97	0.17
24:00	354.91	150	130	2.97	0.17

9). Pipe P-9 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	1.45	0.08
1:00	105.97	150	130	1.44	0.08
2:00	105.97	150	130	1.41	0.08
3:00	105.97	150	130	1.42	0.08
4:00	105.97	150	130	1.44	0.08
5:00	105.97	150	130	1.60	0.09
6:00	105.97	150	130	1.57	0.09
7:00	105.97	150	130	1.54	0.09
8:00	105.97	150	130	1.57	0.09
9:00	105.97	150	130	1.55	0.09
10:00	105.97	150	130	1.54	0.09
11:00	105.97	150	130	1.55	0.09
12:00	105.97	150	130	1.54	0.09
13:00	105.97	150	130	1.54	0.09
14:00	105.97	150	130	1.52	0.09
15:00	105.97	150	130	1.54	0.09
16:00	105.97	150	130	1.57	0.09
17:00	105.97	150	130	1.36	0.08
18:00	105.97	150	130	1.38	0.08
19:00	105.97	150	130	1.30	0.07
20:00	105.97	150	130	1.41	0.08
21:00	105.97	150	130	1.42	0.08
22:00	105.97	150	130	1.44	0.08
23:00	105.97	150	130	1.45	0.08
24:00	105.97	150	130	1.45	0.08

10). Pipe P-10 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	1.27	0.07
1:00	21	150	130	1.25	0.07
2:00	21	150	130	1.23	0.07
3:00	21	150	130	1.24	0.07
4:00	21	150	130	1.25	0.07
5:00	21	150	130	1.40	0.08
6:00	21	150	130	1.37	0.08
7:00	21	150	130	1.35	0.08
8:00	21	150	130	1.37	0.08
9:00	21	150	130	1.36	0.08
10:00	21	150	130	1.35	0.08
11:00	21	150	130	1.36	0.08
12:00	21	150	130	1.35	0.08
13:00	21	150	130	1.35	0.08
14:00	21	150	130	1.33	0.08
15:00	21	150	130	1.35	0.08
16:00	21	150	130	1.37	0.08
17:00	21	150	130	1.19	0.07
18:00	21	150	130	1.20	0.07
19:00	21	150	130	1.14	0.06
20:00	21	150	130	1.23	0.07
21:00	21	150	130	1.24	0.07
22:00	21	150	130	1.25	0.07
23:00	21	150	130	1.27	0.07
24:00	21	150	130	1.27	0.07

11). Pipe P-11 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	0.84	0.05
1:00	105.97	150	130	0.83	0.05
2:00	105.97	150	130	0.82	0.05
3:00	105.97	150	130	0.82	0.05
4:00	105.97	150	130	0.83	0.05
5:00	105.97	150	130	0.93	0.05
6:00	105.97	150	130	0.91	0.05
7:00	105.97	150	130	0.89	0.05
8:00	105.97	150	130	0.91	0.05
9:00	105.97	150	130	0.90	0.05
10:00	105.97	150	130	0.89	0.05
11:00	105.97	150	130	0.90	0.05
12:00	105.97	150	130	0.89	0.05
13:00	105.97	150	130	0.89	0.05
14:00	105.97	150	130	0.88	0.05
15:00	105.97	150	130	0.89	0.05
16:00	105.97	150	130	0.91	0.05
17:00	105.97	150	130	0.79	0.04
18:00	105.97	150	130	0.80	0.05
19:00	105.97	150	130	0.76	0.04
20:00	105.97	150	130	0.82	0.05
21:00	105.97	150	130	0.82	0.05
22:00	105.97	150	130	0.83	0.05
23:00	105.97	150	130	0.84	0.05
24:00	105.97	150	130	0.84	0.05

12). Pipe P-12 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.81	150	130	0.68	0.04
1:00	763.81	150	130	0.67	0.04
2:00	763.81	150	130	0.66	0.04
3:00	763.81	150	130	0.66	0.04
4:00	763.81	150	130	0.67	0.04
5:00	763.81	150	130	0.75	0.04
6:00	763.81	150	130	0.73	0.04
7:00	763.81	150	130	0.72	0.04
8:00	763.81	150	130	0.73	0.04
9:00	763.81	150	130	0.73	0.04
10:00	763.81	150	130	0.72	0.04
11:00	763.81	150	130	0.73	0.04
12:00	763.81	150	130	0.72	0.04
13:00	763.81	150	130	0.72	0.04
14:00	763.81	150	130	0.71	0.04
15:00	763.81	150	130	0.72	0.04
16:00	763.81	150	130	0.73	0.04
17:00	763.81	150	130	0.64	0.04
18:00	763.81	150	130	0.64	0.04
19:00	763.81	150	130	0.61	0.03
20:00	763.81	150	130	0.66	0.04
21:00	763.81	150	130	0.66	0.04
22:00	763.81	150	130	0.67	0.04
23:00	763.81	150	130	0.68	0.04
24:00	763.81	150	130	0.68	0.04

13). Pipe P-13 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	764	150	130	1.09	0.06
1:00	764	150	130	1.08	0.06
2:00	764	150	130	1.06	0.06
3:00	764	150	130	1.07	0.06
4:00	764	150	130	1.08	0.06
5:00	764	150	130	1.20	0.07
6:00	764	150	130	1.18	0.07
7:00	764	150	130	1.16	0.07
8:00	764	150	130	1.18	0.07
9:00	764	150	130	1.17	0.07
10:00	764	150	130	1.16	0.07
11:00	764	150	130	1.17	0.07
12:00	764	150	130	1.16	0.07
13:00	764	150	130	1.16	0.07
14:00	764	150	130	1.15	0.06
15:00	764	150	130	1.16	0.07
16:00	764	150	130	1.18	0.07
17:00	764	150	130	1.03	0.06
18:00	764	150	130	1.04	0.06
19:00	764	150	130	0.98	0.06
20:00	764	150	130	1.06	0.06
21:00	764	150	130	1.07	0.06
22:00	764	150	130	1.08	0.06
23:00	764	150	130	1.09	0.06
24:00	764	150	130	1.09	0.06

14). Pipe P-14 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	764	150	130	1.34	0.08
1:00	764	150	130	1.32	0.07
2:00	764	150	130	1.30	0.07
3:00	764	150	130	1.31	0.07
4:00	764	150	130	1.32	0.07
5:00	764	150	130	1.47	0.08
6:00	764	150	130	1.45	0.08
7:00	764	150	130	1.42	0.08
8:00	764	150	130	1.45	0.08
9:00	764	150	130	1.43	0.08
10:00	764	150	130	1.42	0.08
11:00	764	150	130	1.43	0.08
12:00	764	150	130	1.42	0.08
13:00	764	150	130	1.42	0.08
14:00	764	150	130	1.41	0.08
15:00	764	150	130	1.42	0.08
16:00	764	150	130	1.45	0.08
17:00	764	150	130	1.26	0.07
18:00	764	150	130	1.27	0.07
19:00	764	150	130	1.20	0.07
20:00	764	150	130	1.30	0.07
21:00	764	150	130	1.31	0.07
22:00	764	150	130	1.32	0.07
23:00	764	150	130	1.34	0.08
24:00	764	150	130	1.34	0.08

15). Pipe P-15 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	25.67	150	130	0.37	0.02
1:00	25.67	150	130	0.36	0.02
2:00	25.67	150	130	0.35	0.02
3:00	25.67	150	130	0.36	0.02
4:00	25.67	150	130	0.36	0.02
5:00	25.67	150	130	0.40	0.02
6:00	25.67	150	130	0.40	0.02
7:00	25.67	150	130	0.39	0.02
8:00	25.67	150	130	0.40	0.02
9:00	25.67	150	130	0.39	0.02
10:00	25.67	150	130	0.39	0.02
11:00	25.67	150	130	0.39	0.02
12:00	25.67	150	130	0.39	0.02
13:00	25.67	150	130	0.39	0.02
14:00	25.67	150	130	0.38	0.02
15:00	25.67	150	130	0.39	0.02
16:00	25.67	150	130	0.40	0.02
17:00	25.67	150	130	0.34	0.02
18:00	25.67	150	130	0.35	0.02
19:00	25.67	150	130	0.33	0.02
20:00	25.67	150	130	0.35	0.02
21:00	25.67	150	130	0.36	0.02
22:00	25.67	150	130	0.36	0.02
23:00	25.67	150	130	0.37	0.02
24:00	25.67	150	130	0.37	0.02

16). Pipe P-16 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	2.56	0.14
1:00	105.97	150	130	2.54	0.14
2:00	105.97	150	130	2.48	0.14
3:00	105.97	150	130	2.51	0.14
4:00	105.97	150	130	2.54	0.14
5:00	105.97	150	130	2.82	0.16
6:00	105.97	150	130	2.77	0.16
7:00	105.97	150	130	2.72	0.15
8:00	105.97	150	130	2.77	0.16
9:00	105.97	150	130	2.74	0.16
10:00	105.97	150	130	2.72	0.15
11:00	105.97	150	130	2.74	0.16
12:00	105.97	150	130	2.72	0.15
13:00	105.97	150	130	2.72	0.15
14:00	105.97	150	130	2.69	0.15
15:00	105.97	150	130	2.72	0.15
16:00	105.97	150	130	2.77	0.16
17:00	105.97	150	130	2.41	0.14
18:00	105.97	150	130	2.43	0.14
19:00	105.97	150	130	2.30	0.13
20:00	105.97	150	130	2.48	0.14
21:00	105.97	150	130	2.51	0.14
22:00	105.97	150	130	2.54	0.14
23:00	105.97	150	130	2.56	0.14
24:00:00	105.97	150	130	2.56	0.14

17). Pipe P-17 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	5.17	0.29
1:00	21	150	130	5.12	0.29
2:00	21	150	130	5.02	0.28
3:00	21	150	130	5.07	0.29
4:00	21	150	130	5.12	0.29
5:00	21	150	130	5.70	0.32
6:00	21	150	130	5.60	0.32
7:00	21	150	130	5.49	0.31
8:00	21	150	130	5.60	0.32
9:00	21	150	130	5.54	0.31
10:00	21	150	130	5.49	0.31
11:00	21	150	130	5.54	0.31
12:00	21	150	130	5.49	0.31
13:00	21	150	130	5.49	0.31
14:00	21	150	130	5.44	0.31
15:00	21	150	130	5.49	0.31
16:00	21	150	130	5.60	0.32
17:00	21	150	130	4.86	0.27
18:00	21	150	130	4.91	0.28
19:00	21	150	130	4.65	0.26
20:00	21	150	130	5.02	0.28
21:00	21	150	130	5.07	0.29
22:00	21	150	130	5.12	0.29
23:00	21	150	130	5.17	0.29
24:00	21	150	130	5.17	0.29

18). Pipe P-18 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	8.03	0.45
1:00	105.97	150	130	7.95	0.45
2:00	105.97	150	130	7.78	0.44
3:00	105.97	150	130	7.87	0.45
4:00	105.97	150	130	7.95	0.45
5:00	105.97	150	130	8.85	0.50
6:00	105.97	150	130	8.68	0.49
7:00	105.97	150	130	8.52	0.48
8:00	105.97	150	130	8.68	0.49
9:00	105.97	150	130	8.60	0.49
10:00	105.97	150	130	8.52	0.48
11:00	105.97	150	130	8.60	0.49
12:00	105.97	150	130	8.52	0.48
13:00	105.97	150	130	8.52	0.48
14:00	105.97	150	130	8.44	0.48
15:00	105.97	150	130	8.52	0.48
16:00	105.97	150	130	8.68	0.49
17:00	105.97	150	130	7.54	0.43
18:00	105.97	150	130	7.62	0.43
19:00	105.97	150	130	7.21	0.41
20:00	105.97	150	130	7.78	0.44
21:00	105.97	150	130	7.87	0.45
22:00	105.97	150	130	7.95	0.45
23:00	105.97	150	130	8.03	0.45
24:00	105.97	150	130	8.03	0.45

19). Pipe P-19 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	350.93	150	130	0.37	0.02
1:00	350.93	150	130	0.36	0.02
2:00	350.93	150	130	0.35	0.02
3:00	350.93	150	130	0.36	0.02
4:00	350.93	150	130	0.36	0.02
5:00	350.93	150	130	0.40	0.02
6:00	350.93	150	130	0.40	0.02
7:00	350.93	150	130	0.39	0.02
8:00	350.93	150	130	0.40	0.02
9:00	350.93	150	130	0.39	0.02
10:00	350.93	150	130	0.39	0.02
11:00	350.93	150	130	0.39	0.02
12:00	350.93	150	130	0.39	0.02
13:00	350.93	150	130	0.39	0.02
14:00	350.93	150	130	0.38	0.02
15:00	350.93	150	130	0.39	0.02
16:00	350.93	150	130	0.40	0.02
17:00	350.93	150	130	0.34	0.02
18:00	350.93	150	130	0.35	0.02
19:00	350.93	150	130	0.33	0.02
20:00	350.93	150	130	0.35	0.02
21:00	350.93	150	130	0.36	0.02
22:00	350.93	150	130	0.36	0.02
23:00	350.93	150	130	0.37	0.02
24:00	350.93	150	130	0.37	0.02

20). Pipe P-20 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	25.67	150	130	0.37	0.02
1:00	25.67	150	130	0.36	0.02
2:00	25.67	150	130	0.35	0.02
3:00	25.67	150	130	0.36	0.02
4:00	25.67	150	130	0.36	0.02
5:00	25.67	150	130	0.40	0.02
6:00	25.67	150	130	0.40	0.02
7:00	25.67	150	130	0.39	0.02
8:00	25.67	150	130	0.40	0.02
9:00	25.67	150	130	0.39	0.02
10:00	25.67	150	130	0.39	0.02
11:00	25.67	150	130	0.39	0.02
12:00	25.67	150	130	0.39	0.02
13:00	25.67	150	130	0.39	0.02
14:00	25.67	150	130	0.38	0.02
15:00	25.67	150	130	0.39	0.02
16:00	25.67	150	130	0.40	0.02
17:00	25.67	150	130	0.34	0.02
18:00	25.67	150	130	0.35	0.02
19:00	25.67	150	130	0.33	0.02
20:00	25.67	150	130	0.35	0.02
21:00	25.67	150	130	0.36	0.02
22:00	25.67	150	130	0.36	0.02
23:00	25.67	150	130	0.37	0.02
24:00	25.67	150	130	0.37	0.02

21). Pipe P-21 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	2.01	0.11
1:00	105.97	150	130	1.99	0.11
2:00	105.97	150	130	1.95	0.11
3:00	105.97	150	130	1.97	0.11
4:00	105.97	150	130	1.99	0.11
5:00	105.97	150	130	2.22	0.13
6:00	105.97	150	130	2.18	0.12
7:00	105.97	150	130	2.14	0.12
8:00	105.97	150	130	2.18	0.12
9:00	105.97	150	130	2.16	0.12
10:00	105.97	150	130	2.14	0.12
11:00	105.97	150	130	2.16	0.12
12:00	105.97	150	130	2.14	0.12
13:00	105.97	150	130	2.14	0.12
14:00	105.97	150	130	2.12	0.12
15:00	105.97	150	130	2.14	0.12
16:00	105.97	150	130	2.18	0.12
17:00	105.97	150	130	1.89	0.11
18:00	105.97	150	130	1.91	0.11
19:00	105.97	150	130	1.81	0.10
20:00	105.97	150	130	1.95	0.11
21:00	105.97	150	130	1.97	0.11
22:00	105.97	150	130	1.99	0.11
23:00	105.97	150	130	2.01	0.11
24:00	105.97	150	130	2.01	0.11

22). Pipe P-22 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	4.64	0.26
1:00	21	150	130	4.59	0.26
2:00	21	150	130	4.49	0.25
3:00	21	150	130	4.54	0.26
4:00	21	150	130	4.59	0.26
5:00	21	150	130	5.11	0.29
6:00	21	150	130	5.01	0.28
7:00	21	150	130	4.92	0.28
8:00	21	150	130	5.01	0.28
9:00	21	150	130	4.97	0.28
10:00	21	150	130	4.92	0.28
11:00	21	150	130	4.97	0.28
12:00	21	150	130	4.92	0.28
13:00	21	150	130	4.92	0.28
14:00	21	150	130	4.87	0.28
15:00	21	150	130	4.92	0.28
16:00	21	150	130	5.01	0.28
17:00	21	150	130	4.35	0.25
18:00	21	150	130	4.40	0.25
19:00	21	150	130	4.16	0.24
20:00	21	150	130	4.49	0.25
21:00	21	150	130	4.54	0.26
22:00	21	150	130	4.59	0.26
23:00	21	150	130	4.64	0.26
24:00	21	150	130	4.64	0.26

23). Pipe P-23 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	7.46	0.42
1:00	105.97	150	130	7.38	0.42
2:00	105.97	150	130	7.23	0.41
3:00	105.97	150	130	7.31	0.41
4:00	105.97	150	130	7.38	0.42
5:00	105.97	150	130	8.22	0.47
6:00	105.97	150	130	8.07	0.46
7:00	105.97	150	130	7.92	0.45
8:00	105.97	150	130	8.07	0.46
9:00	105.97	150	130	7.99	0.45
10:00	105.97	150	130	7.92	0.45
11:00	105.97	150	130	7.99	0.45
12:00	105.97	150	130	7.92	0.45
13:00	105.97	150	130	7.92	0.45
14:00	105.97	150	130	7.84	0.44
15:00	105.97	150	130	7.92	0.45
16:00	105.97	150	130	8.07	0.46
17:00	105.97	150	130	7.00	0.40
18:00	105.97	150	130	7.08	0.40
19:00	105.97	150	130	6.70	0.38
20:00	105.97	150	130	7.23	0.41
21:00	105.97	150	130	7.31	0.41
22:00	105.97	150	130	7.38	0.42
23:00	105.97	150	130	7.46	0.42
24:00	105.97	150	130	7.46	0.42

24). Pipe P-24 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	344.945	150	130	2.81	0.16
1:00	344.945	150	130	2.78	0.16
2:00	344.945	150	130	2.72	0.15
3:00	344.945	150	130	2.75	0.16
4:00	344.945	150	130	2.78	0.16
5:00	344.945	150	130	3.09	0.18
6:00	344.945	150	130	3.04	0.17
7:00	344.945	150	130	2.98	0.17
8:00	344.945	150	130	3.04	0.17
9:00	344.945	150	130	3.01	0.17
10:00	344.945	150	130	2.98	0.17
11:00	344.945	150	130	3.01	0.17
12:00	344.945	150	130	2.98	0.17
13:00	344.945	150	130	2.98	0.17
14:00	344.945	150	130	2.95	0.17
15:00	344.945	150	130	2.98	0.17
16:00	344.945	150	130	3.04	0.17
17:00	344.945	150	130	2.64	0.15
18:00	344.945	150	130	2.66	0.15
19:00	344.945	150	130	2.52	0.14
20:00	344.945	150	130	2.72	0.15
21:00	344.945	150	130	2.75	0.16
22:00	344.945	150	130	2.78	0.16
23:00	344.945	150	130	2.81	0.16
24:00	344.945	150	130	2.81	0.16

25). Pipe P-25 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.2	150	130	2.81	0.16
1:00	105.2	150	130	2.78	0.16
2:00	105.2	150	130	2.72	0.15
3:00	105.2	150	130	2.75	0.16
4:00	105.2	150	130	2.78	0.16
5:00	105.2	150	130	3.09	0.18
6:00	105.2	150	130	3.04	0.17
7:00	105.2	150	130	2.98	0.17
8:00	105.2	150	130	3.04	0.17
9:00	105.2	150	130	3.01	0.17
10:00	105.2	150	130	2.98	0.17
11:00	105.2	150	130	3.01	0.17
12:00	105.2	150	130	2.98	0.17
13:00	105.2	150	130	2.98	0.17
14:00	105.2	150	130	2.95	0.17
15:00	105.2	150	130	2.98	0.17
16:00	105.2	150	130	3.04	0.17
17:00	105.2	150	130	2.64	0.15
18:00	105.2	150	130	2.66	0.15
19:00	105.2	150	130	2.52	0.14
20:00	105.2	150	130	2.72	0.15
21:00	105.2	150	130	2.75	0.16
22:00	105.2	150	130	2.78	0.16
23:00	105.2	150	130	2.81	0.16
24:00	105.2	150	130	2.81	0.16

26). Pipe P-26 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	354.91	150	130	2.81	0.16
1:00	354.91	150	130	2.78	0.16
2:00	354.91	150	130	2.72	0.15
3:00	354.91	150	130	2.75	0.16
4:00	354.91	150	130	2.78	0.16
5:00	354.91	150	130	3.09	0.18
6:00	354.91	150	130	3.04	0.17
7:00	354.91	150	130	2.98	0.17
8:00	354.91	150	130	3.04	0.17
9:00	354.91	150	130	3.01	0.17
10:00	354.91	150	130	2.98	0.17
11:00	354.91	150	130	3.01	0.17
12:00	354.91	150	130	2.98	0.17
13:00	354.91	150	130	2.98	0.17
14:00	354.91	150	130	2.95	0.17
15:00	354.91	150	130	2.98	0.17
16:00	354.91	150	130	3.04	0.17
17:00	354.91	150	130	2.64	0.15
18:00	354.91	150	130	2.66	0.15
19:00	354.91	150	130	2.52	0.14
20:00	354.91	150	130	2.72	0.15
21:00	354.91	150	130	2.75	0.16
22:00	354.91	150	130	2.78	0.16
23:00	354.91	150	130	2.81	0.16
24:00	354.91	150	130	2.81	0.16

27). Pipe P-27 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	1.29	0.07
1:00	105.97	150	130	1.28	0.07
2:00	105.97	150	130	1.25	0.07
3:00	105.97	150	130	1.26	0.07
4:00	105.97	150	130	1.28	0.07
5:00	105.97	150	130	1.42	0.08
6:00	105.97	150	130	1.39	0.08
7:00	105.97	150	130	1.37	0.08
8:00	105.97	150	130	1.39	0.08
9:00	105.97	150	130	1.38	0.08
10:00	105.97	150	130	1.37	0.08
11:00	105.97	150	130	1.38	0.08
12:00	105.97	150	130	1.37	0.08
13:00	105.97	150	130	1.37	0.08
14:00	105.97	150	130	1.35	0.08
15:00	105.97	150	130	1.37	0.08
16:00	105.97	150	130	1.39	0.08
17:00	105.97	150	130	1.21	0.07
18:00	105.97	150	130	1.22	0.07
19:00	105.97	150	130	1.16	0.07
20:00	105.97	150	130	1.25	0.07
21:00	105.97	150	130	1.26	0.07
22:00	105.97	150	130	1.28	0.07
23:00	105.97	150	130	1.29	0.07
24:00	105.97	150	130	1.29	0.07

28). Pipe P-28 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	21	150	130	1.08	0.06
1:00	21	150	130	1.06	0.06
2:00	21	150	130	1.04	0.06
3:00	21	150	130	1.05	0.06
4:00	21	150	130	1.06	0.06
5:00	21	150	130	1.18	0.07
6:00	21	150	130	1.16	0.07
7:00	21	150	130	1.14	0.06
8:00	21	150	130	1.16	0.07
9:00	21	150	130	1.15	0.07
10:00	21	150	130	1.14	0.06
11:00	21	150	130	1.15	0.07
12:00	21	150	130	1.14	0.06
13:00	21	150	130	1.14	0.06
14:00	21	150	130	1.13	0.06
15:00	21	150	130	1.14	0.06
16:00	21	150	130	1.16	0.07
17:00	21	150	130	1.01	0.06
18:00	21	150	130	1.02	0.06
19:00	21	150	130	0.97	0.05
20:00	21	150	130	1.04	0.06
21:00	21	150	130	1.05	0.06
22:00	21	150	130	1.06	0.06
23:00	21	150	130	1.08	0.06
24:00	21	150	130	1.08	0.06

29). Pipe P-29 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	105.97	150	130	0.66	0.04
1:00	105.97	150	130	0.65	0.04
2:00	105.97	150	130	0.64	0.04
3:00	105.97	150	130	0.65	0.04
4:00	105.97	150	130	0.65	0.04
5:00	105.97	150	130	0.73	0.04
6:00	105.97	150	130	0.71	0.04
7:00	105.97	150	130	0.70	0.04
8:00	105.97	150	130	0.71	0.04
9:00	105.97	150	130	0.71	0.04
10:00	105.97	150	130	0.70	0.04
11:00	105.97	150	130	0.71	0.04
12:00	105.97	150	130	0.70	0.04
13:00	105.97	150	130	0.70	0.04
14:00	105.97	150	130	0.69	0.04
15:00	105.97	150	130	0.70	0.04
16:00	105.97	150	130	0.71	0.04
17:00	105.97	150	130	0.62	0.04
18:00	105.97	150	130	0.63	0.04
19:00	105.97	150	130	0.59	0.03
20:00	105.97	150	130	0.64	0.04
21:00	105.97	150	130	0.65	0.04
22:00	105.97	150	130	0.65	0.04
23:00	105.97	150	130	0.66	0.04
24:00	105.97	150	130	0.66	0.04

30). Pipe P-30 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.848	150	130	1.31	0.07
1:00	763.848	150	130	1.29	0.07
2:00	763.848	150	130	1.27	0.07
3:00	763.848	150	130	1.28	0.07
4:00	763.848	150	130	1.29	0.07
5:00	763.848	150	130	1.44	0.08
6:00	763.848	150	130	1.41	0.08
7:00	763.848	150	130	1.39	0.08
8:00	763.848	150	130	1.41	0.08
9:00	763.848	150	130	1.40	0.08
10:00	763.848	150	130	1.39	0.08
11:00	763.848	150	130	1.40	0.08
12:00	763.848	150	130	1.39	0.08
13:00	763.848	150	130	1.39	0.08
14:00	763.848	150	130	1.37	0.08
15:00	763.848	150	130	1.39	0.08
16:00	763.848	150	130	1.41	0.08
17:00	763.848	150	130	1.23	0.07
18:00	763.848	150	130	1.24	0.07
19:00	763.848	150	130	1.17	0.07
20:00	763.848	150	130	1.27	0.07
21:00	763.848	150	130	1.28	0.07
22:00	763.848	150	130	1.29	0.07
23:00	763.848	150	130	1.31	0.07
24:00	763.848	150	130	1.31	0.07

31). Pipe P-31 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.848	150	130	1.10	0.06
1:00	763.848	150	130	1.09	0.06
2:00	763.848	150	130	1.07	0.06
3:00	763.848	150	130	1.08	0.06
4:00	763.848	150	130	1.09	0.06
5:00	763.848	150	130	1.22	0.07
6:00	763.848	150	130	1.19	0.07
7:00	763.848	150	130	1.17	0.07
8:00	763.848	150	130	1.19	0.07
9:00	763.848	150	130	1.18	0.07
10:00	763.848	150	130	1.17	0.07
11:00	763.848	150	130	1.18	0.07
12:00	763.848	150	130	1.17	0.07
13:00	763.848	150	130	1.17	0.07
14:00	763.848	150	130	1.16	0.07
15:00	763.848	150	130	1.17	0.07
16:00	763.848	150	130	1.19	0.07
17:00	763.848	150	130	1.04	0.06
18:00	763.848	150	130	1.05	0.06
19:00	763.848	150	130	0.99	0.06
20:00	763.848	150	130	1.07	0.06
21:00	763.848	150	130	1.08	0.06
22:00	763.848	150	130	1.09	0.06
23:00	763.848	150	130	1.10	0.06
24:00	763.848	150	130	1.10	0.06

32). Pipe P-32 Time Series details

Time	Length (m)	Diameter (mm)	Roughness	Flow L/s	Velocity m/s
0:00	763.81	150	130	0.86	0.05
1:00	763.81	150	130	0.85	0.05
2:00	763.81	150	130	0.83	0.05
3:00	763.81	150	130	0.84	0.05
4:00	763.81	150	130	0.85	0.05
5:00	763.81	150	130	0.95	0.05
6:00	763.81	150	130	0.93	0.05
7:00	763.81	150	130	0.91	0.05
8:00	763.81	150	130	0.93	0.05
9:00	763.81	150	130	0.92	0.05
10:00	763.81	150	130	0.91	0.05
11:00	763.81	150	130	0.92	0.05
12:00	763.81	150	130	0.91	0.05
13:00	763.81	150	130	0.91	0.05
14:00	763.81	150	130	0.90	0.05
15:00	763.81	150	130	0.91	0.05
16:00	763.81	150	130	0.93	0.05
17:00	763.81	150	130	0.81	0.05
18:00	763.81	150	130	0.82	0.05
19:00	763.81	150	130	0.77	0.04
20:00	763.81	150	130	0.83	0.05
21:00	763.81	150	130	0.84	0.05
22:00	763.81	150	130	0.85	0.05
23:00	763.81	150	130	0.86	0.05
24:00	763.81	150	130	0.86	0.05