SMART GAS NETWORK FOR PREEMPTIVE LEAK DETECTION – PHASE 0 REPORT

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PART-1: ASSESSMENT OF THE STATE OF PRACTICE

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PART-2: GAS LEAK PROTOTYPE SYSTEM

ARTIFICIAL INTELLIGENCE BASED EARLY LEAK DETECTION FOR GAS DISTRIBUTION SYSTEM

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INTRODUCTION

Leak detection in urban gas pipelines is considered a major challenge as there is no proven methodology to pre-emptively detect leaks in the system. The utilities are still mostly dependent on conventional leak detection techniques such as mobile leak detection systems and customer complaints to detect the leaks. The fact that the piping infrastructure is very complex in an urban setup and setting up measurement and control points at every individual node might not be technically and economically feasible, makes it a challenging grey area not touched by many industry experts.

As a standard practice the utilities measure only the consumption value of gas at consumer end and the overall volume of the gas at inlet. Even the smart AMR meters that are in the process of installation across many metropolitan gas distribution networks measure only the consumption volumes and report them over a standard predefined frequency interval. While there are several attributable parameters which could be useful for the analysis of the steady state and leaks of the system such as Pressure, Flow Velocity, Temperature, Compressibility etc. that could be measure by installing an additional PTZ (Pressure, Temperature & Compressibility) module, due to the high cost of the measurement modules they are not installed with the consumer meters. There are several levels across which measurements would be possible:

Generation Station (Complex P, T & V Meters; Controlled Environment; Minimum Leaks)
Transmission Pipelines (Industrial Pipelines; Less Branching; High Pressure; Complex instruments; Easy to detect leaks)
Pumping Station (Controlled Environment; Incoming and Outgoing P, T & V Meters)
Distribution Pipelines (Medium & Low Pressure; Minimum infrastructure; More Branching; Can have Points of Measurement at Junctions)
Consumer Meters (AMR Meters, Possible to Monitor Volume (P, T &Z using Add on Device)

However as described above it may not be feasible to install measurement devices at all levels. This reduces the amount of data we have for analysis and the accuracy of Geo-Localization of leaks. The detection of leaks in gas pipelines is easy at steady state, but often due to additional nodes or operations in the network, the network becomes unstable going into the transient state mainly caused due to:

- Start and stop of pumps or compressors during start-up and shutdown
- Valve operation anywhere before, along or after the monitored pipeline segment
- Flow or pressure control action
- Changes of throughput
- Special effects such as cavitation) causing varying flow rates at inlet and outlet.

In transient state, leak signature might be available but pressure noise masks the same making it difficult to identify the leaks. There are several companies offering in the market offering analytics and leak detection systems as a part of their Gas Distribution system such as Atmos, Synergi, Simone, Gregg Engineering etc. who promise to pre-emptively detect the gas leaks in the network using mathematical models and statistical analysis. To understand the way they do it, a deep analysis of the algorithm used by them is required.

PURPOSE

The current leak detection methods have been primarily developed for linear transmission pipelines. Their deployment for leak detection and geo-localization in the gas distribution systems raise reliability concerns as they do not provide a continuous real-time monitoring throughout the entire gas network. Therefore, in order to upgrade the public safety and security it is proposed to assess the technical and economic feasibility of real time smart gas network monitoring for continuous leak detection throughout the entire gas distribution network. More specifically the purpose of this project is to assess the technical and economic feasibility of the adaptation of artificial intelligence based Command and Control System of Systems (C2SOS) [5] for early leak detection in the gas distribution system.

The cardinal purpose of this project is to assess the technical and economic feasibility of the adaptation of Artificial Intelligence based Command and Control System of Systems (C2SOS) for early leak detection in the gas distribution systems – Learning from the experience in Smart Grid and Smart Water Distribution Systems.

OBJECTIVES

- Early Leak Detection
- Pre-Emptive Warning System
- Geo- Localization of Leaks
- Optimization of Inspection and Asset Management
- Inter dependency among infrastructure systems

PART I - ASSESSMENT OF THE STATE OF PRACTICE

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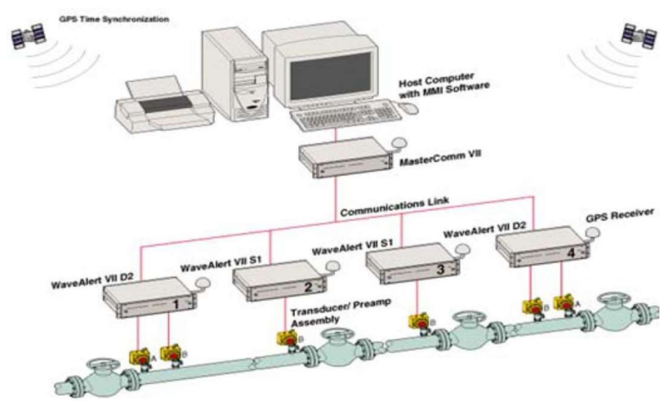
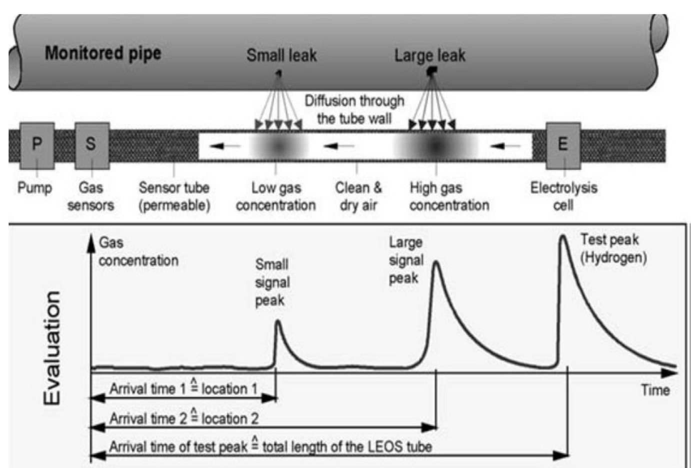
LITERATURE REVIEW

TECHNOLOGICAL ADVANCEMENTS IN SMART GAS LEAK DETECTION SYSTEMS:

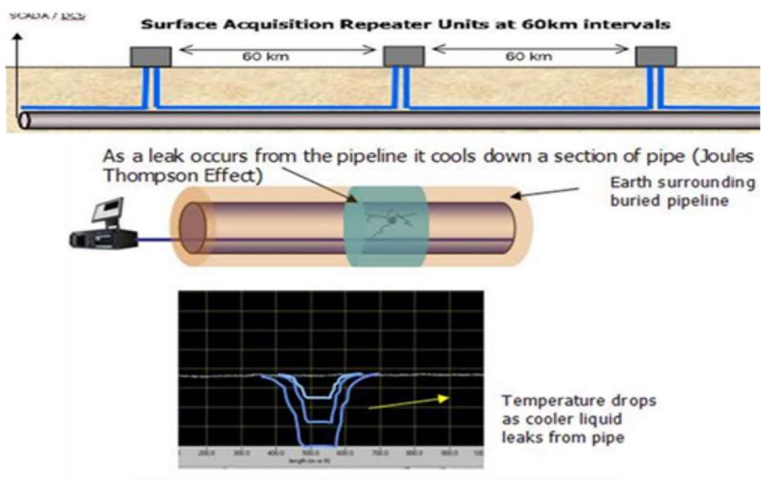
1. **Acoustic Emissions Sensing:**
Acoustic sensors placed along the pipeline detects low frequency leak signals generated by escaping fluid.



2. **Vapor Sensor Method:**
Gas Leaked is diffused to a tube laid along the pipeline which is analyzed by flushing a test gas in laboratory.

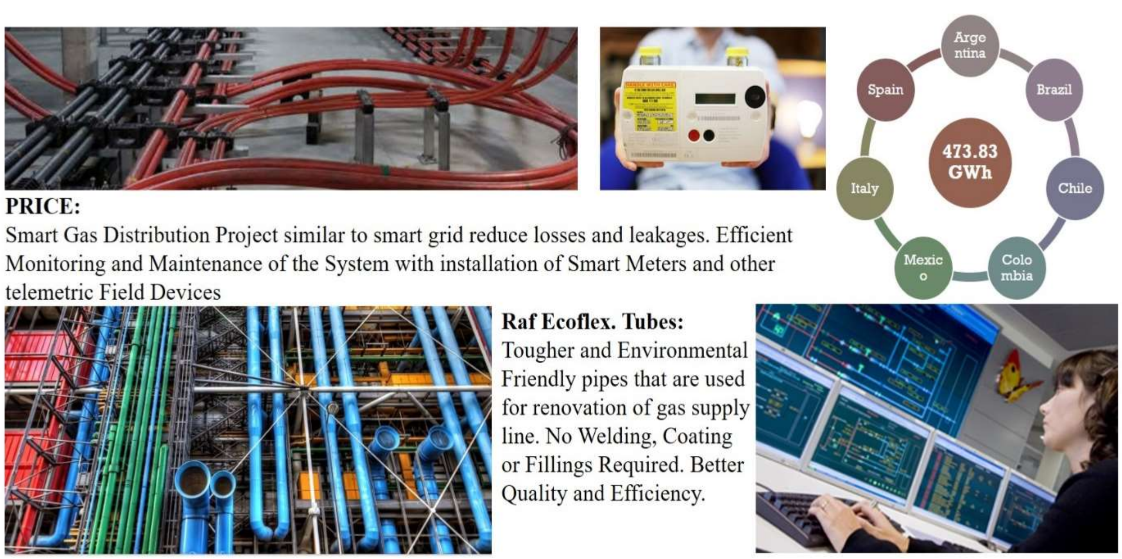


3. **Fiber Optic Sensing:**
   Fiber Optic Sensors placed in contact with pipeline in soil, escaping hydrocarbon cools surrounding area, which is sensed.

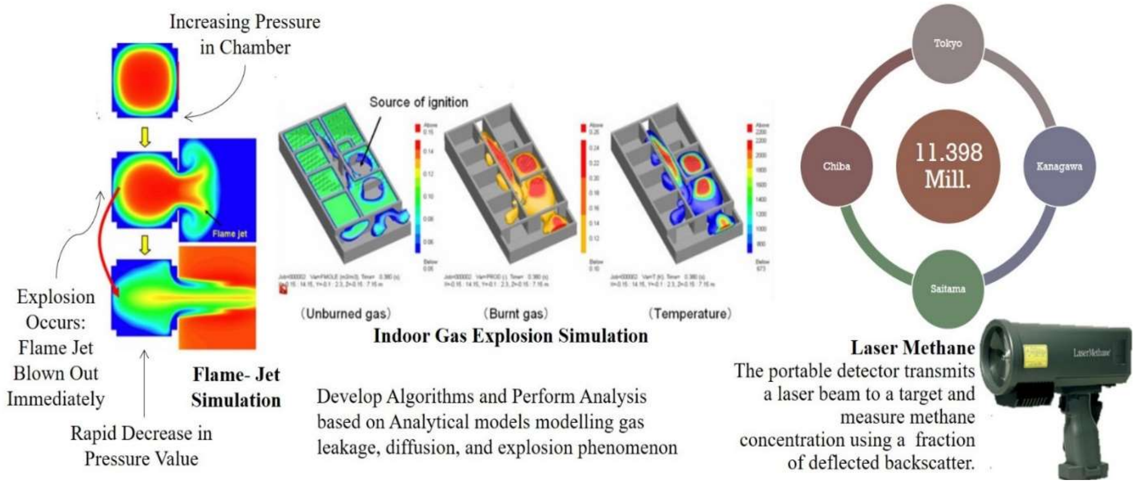


SMART GAS LEAK DETECTION TECHNIQUES ADAPTED/ON GOING RESEARCH IN COUNTRIES

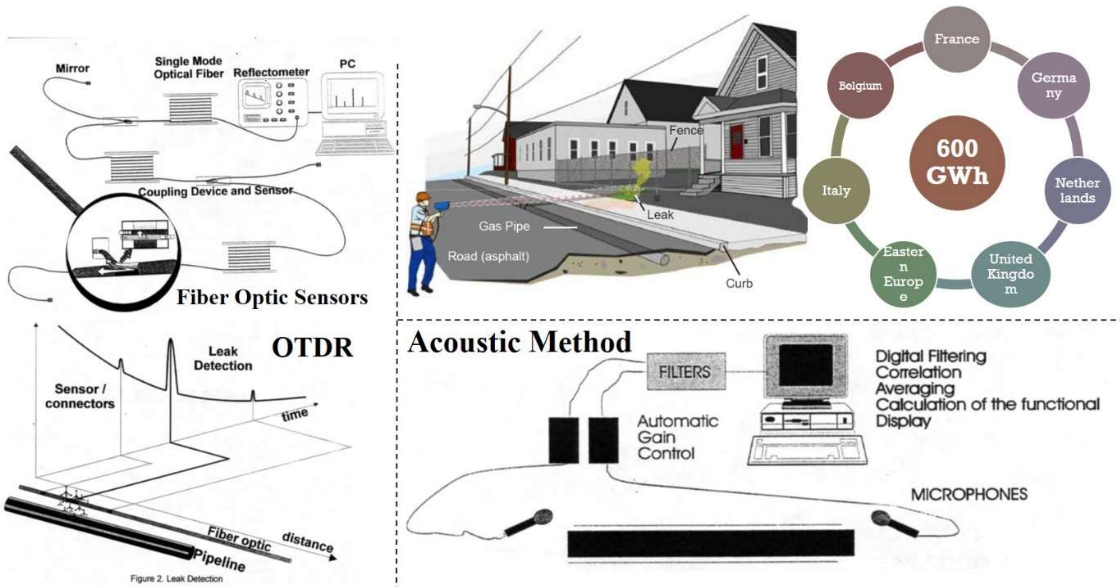
LEAK DETECTION TECHNIQUE – GAS NATURAL FENOSA



LEAK DETECTION TECHNIQUE IN TOKYO: FLAME-JET & LASER METHANE DETECTOR



LEAK DETECTION TECHNIQUE – GAS DE FRANCE



STATE OF PRACTICE OF CON-EDISON LEAK DETECTION STRATEGY:

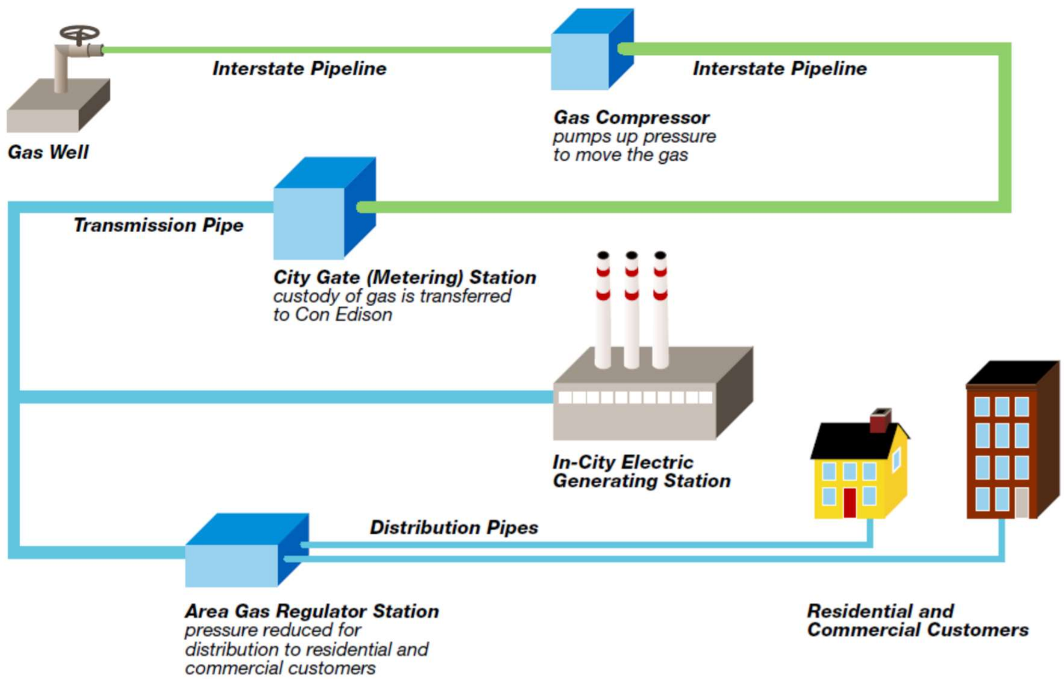
Con-Edison Supplies gas in the Manhattan, Bronx, Parts of Queens Borough of New York City and Westchester County. They serve over 1.1 Million Natural Gas customers and run over 7300 miles of gas pipes in this region. Con-Edison is also a leader in pioneering modern technologies.

Con-Edison distributes gas in pipelines across their service areas that are regulated at different pressure ranges based on the transmission distances and end consumer usage. Con Edison uses the following range of pressures for distribution of gas in the city.

Type	Pressure Scale (In PSI)
Low	0.25 – 1.00
Intermediate	1 -5
Medium	2 – 15
High	15 – 124

The Gas is received from the gas stations and then distributed to the regulator stations from where the gases are further distributed to the consumer lines. The customer is provided with a regulated low pressure service which is either regulated before the connection in the case of high or medium pressure, or directly distributed in the case of low pressure distribution.

The values mentioned above are the pumped values of pressure but in practical usage for instance in a high-pressure line the maximum pressure that the gas would reach is 60-65 PSI. In the current system that Con-Edison employs only pressure values are monitored real time and that too they are monitored at few locations that are reported to the SCADA system provided by Telvent (Schneider Electric). There are also a few temporary mobile pressure gauges that are installed in locations of high vulnerability that can store the data of pressure for up to 45 days and this value can be loaded to system for analysis. But under normal operations the monitoring frequency of pressure at transmission line varies based on the sensitivity and vulnerability of the location for instance leak monitoring frequency in transmission line is one time per day in Manhattan & 1 time per week in other areas.



Under the ideal state the system operates in a constant pressure but due to consumption, difference in pipe sizes, losses and leaks in the system it is practically not possible to maintain to constant pressure and they assure that a minimum pressure that is required for the last mile consumer is always maintained in the system. The Stoner model is used for calibration based on the record of pressure loss in the system, to control and rectify the pressure in the distribution system. demand is measured in the meters in CFH. Since the supply of Gas is not from just one regulator station but is a grid network that has multiple input regulator stations we have to consider several input and output parameters to derive at the node parameter values. The volume at each regulator station could be calculated based on inlet & outlet pressure, Size of regulator, Size of outlet pipe etc. and the volume supplied at any time by the regulator could be calculated given that the volume in the system at any given point of time is constant.

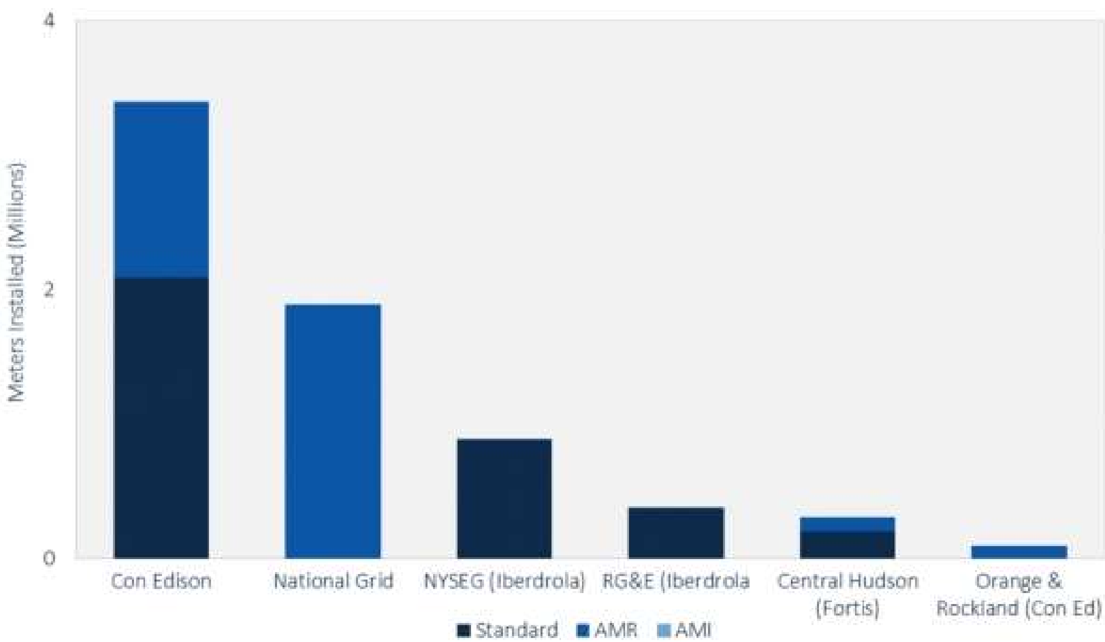
The Aging Infrastructure of Gas pipelines is one of the main concerns of leaks for Con Edison and they replace old Iron Pipes with plastic pipes except the ones in the vicinity of Steam Generation (Less than 35 feet) where they are replaced by steel pipes. Con-Edison has an annual program to replace cast iron and unprotected steel distribution mains with plastic and cathodically-protected steel pipe to reduce leaks and maintain system integrity.

The main replacement program is one other initiative taken by Con-Edison to replace aging infrastructure and this involves condition-based replacement of cast iron and unprotected steel distribution mains with plastic pipe to reduce leaks and maintain system integrity. Due to leak reduction rates increase as the rate of annual main replacement increases to 50 miles per year but the incremental, quantifiable benefits are negligible from 35 to 50 miles of main. Beyond 50 miles of annual replacement (20 miles of unprotected steel and 30 miles of cast iron main replacement), we would start to see diminishing improvement in leak reduction rates. So Con Edison Strategically manages the Asset Management program.

The gas system's reliability is highly dependent on appropriate pressure levels and controls throughout the system. And hence Con Edison is incorporating smart controls to optimize system operating pressures, which enhance reliability as well as reduce leaks and methane emissions. Automatic regulation, which involves the installation of control systems to adjust district regulator set points, is more economic than labor-intensive periodic pressure regulation and provides near real time pressure control.

Natural gas is flammable, colorless and odorless. To make its use safe, an odorant must be added so that it is easily detectable if a leak occurs. All gas transported in Con Edison's distribution system is to be adequately odorized so as to render it readily detectible by the public and company employees with a normal sense of smell.

The next biggest advent of technology that Con Edison is putting into place is the introduction of Advanced Metering infrastructure for Gas and Electricity Meter readings. Manhattan houses amongst the oldest of the buildings in the United States and has the most complex network for gas lines. Replacing the Gas lines and meters is a very challenging task undertaken by Con Edison.



Source: EIA, GTM Research

Between 2017 and 2022, Con Edison plans to invest over $1.4 Billion to install 3.6 million new electric smart meters and 1.2 million new gas smart meters that would record and report data at a given frequency of time.

This data that is obtained from the smart meters will be utilized to measure the demand of the consumer and used for demand forecasting. Also demand based pricing strategy may be implemented in the long run that may prove beneficial to Con-Edison and help in reducing the consumption of energy. Apart from measurement of demand and pricing this data would be highly useful for determining the leak in the network.

Con Edison invests a considerable amount of money on research pertaining to the gas distribution system in the urban environment. They have invested over a million dollars to procure and install methane detectors. The Coordination activities has been improvised by creating emergency gas odor response coordination with FDNY and Westchester officials. They have also launched multiple awareness campaigns on how to prevent gas leak accidents and have invested over 600 million dollars in such activities. They have also launched an interactive map displaying the location of leaks and this is 5made available to public, which increases the transparency of their infrastructure.

SOFTWARE'S USED BY CON-EDISON:

Con Edison primarily uses two software's for monitoring and analyzing the gas infrastructure in the city. They use TELVENT software from Schneider for Monitoring and Control of the system and STONER software from DNV-GL for calculating and analyzing the several different parameters of the network.

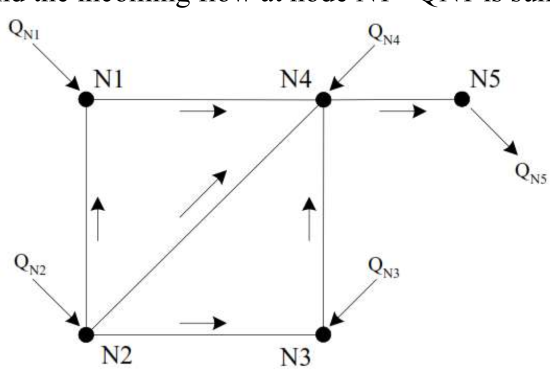
Stoner model is modelled based on Kirchoff's first law, which is a straight forward implication of mass conservation. It states that at any given node in a network the net flow must be equal to zero, i.e sum of inflow and outflow should be zero. Based on the Kirchoff's law it is possible to predict the flow, pressure, valve positions, compressor powers and speeds, pipe diameters and storage field utilization factors.

Based on this using the Newton-Raphson method a set of non-linear node continuity equations are solved. Stoner model calculates the node flow based on the input pressure

$$F_j = \sum_{i=1}^{\substack{\text{facilities} \\ \text{adjacent} \\ \text{to node } j}} Q_i + \dot{Q}N_j \qquad j = 1 \ldots NN$$

values.

In the equation, j represents each node in the network, NN is the number of nodes in the network, Q is the facility flow, QN is the node flow and the summation is for all facilities incident to node j. The net flow in a node is calculated using a very simple arithmetic solution wherein the incoming flow is taken as a positive flow and the outgoing is taken as the negative flow. For instance, let us take the node N1 of this network. The flow from Node N2 to N1 is positive $+Q_{N2,N1}$ whereas the outgoing flow from node N4 to N1 is negative $-Q_{N1,N4}$ and the incoming flow at node N1 +QN1 is summed up to get the overall flow of the node.



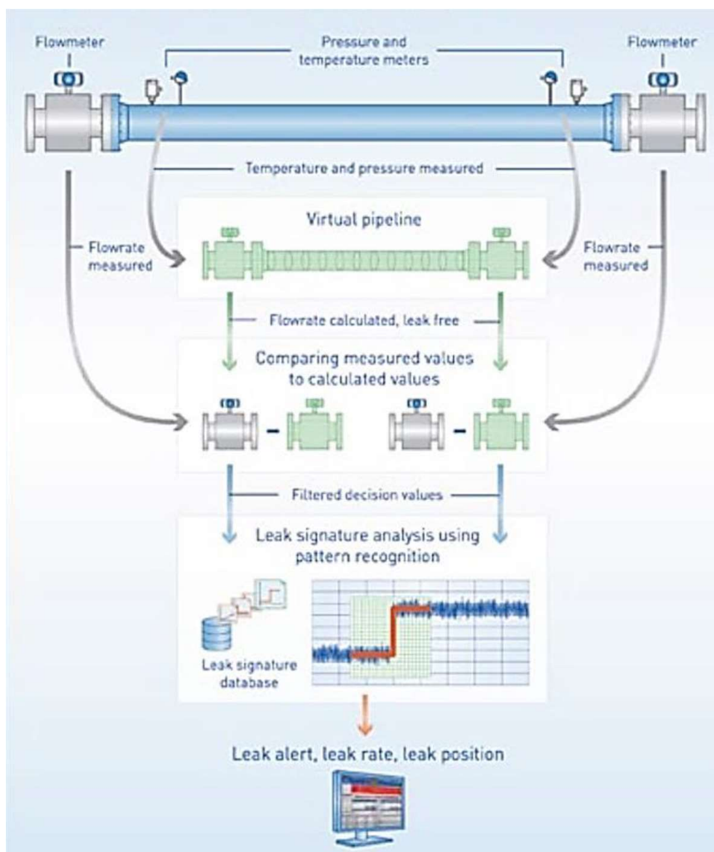
The flow of every individual node is calculated using a matrix that is indicated as below:

$$\begin{vmatrix} F_{N1} \\ F_{N2} \\ F_{N3} \\ F_{N4} \\ F_{N5} \end{vmatrix} = \begin{vmatrix} -Q_{N1,N4} & +Q_{N2,N1} & & & & & +Q_{N1} \\ & -Q_{N2,N1} & -Q_{N3,N2} & & -Q_{N4,N2} & & +Q_{N2} \\ & & +Q_{N3,N2} & -Q_{N4,N3} & & & +Q_{N3} \\ +Q_{N1,N4} & & & +Q_{N4,N3} & +Q_{N4,N2} & -Q_{N5,N4} & +Q_{N4} \\ & & & & & +Q_{N5,N4} & -Q_{N5} \end{vmatrix}$$

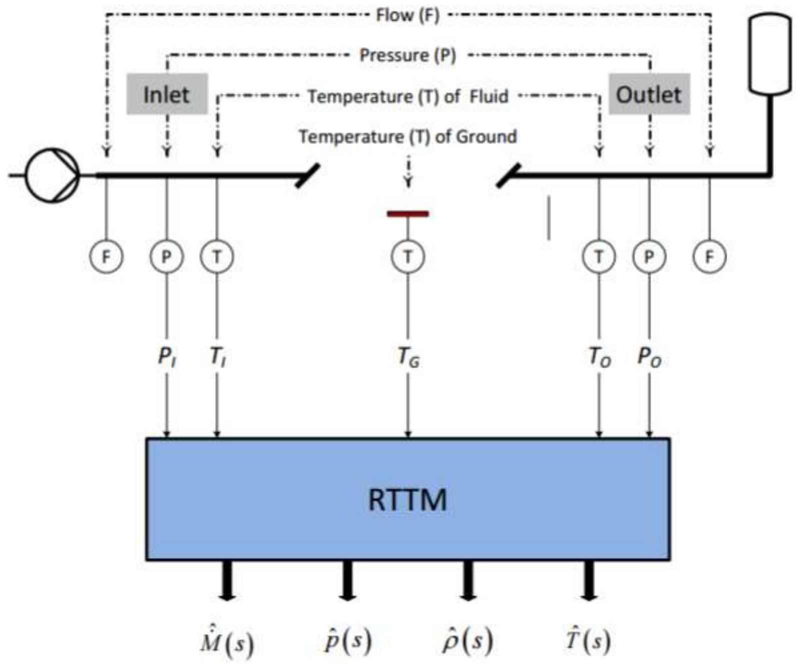
DIFFERENT MODELS THAT COULD BE IMPROVISED FOR LEAK DETECTION IN A GAS DISTRIBUTION NETWORK

Mass/Volume Balance:
The mass or volume balance leak detection technique is based on the principle of mass conservation. An imbalance between the input and output gas mass or volume can reveal the existence of a leak. The volume of gas exiting a section of the pipeline is subtracted from the volume of gas entering this section and if the difference is above a certain threshold, a leak alarm is given. The mass or volume can be computed using the readings of some commonly used process variables: flow rate, pressure and temperature.

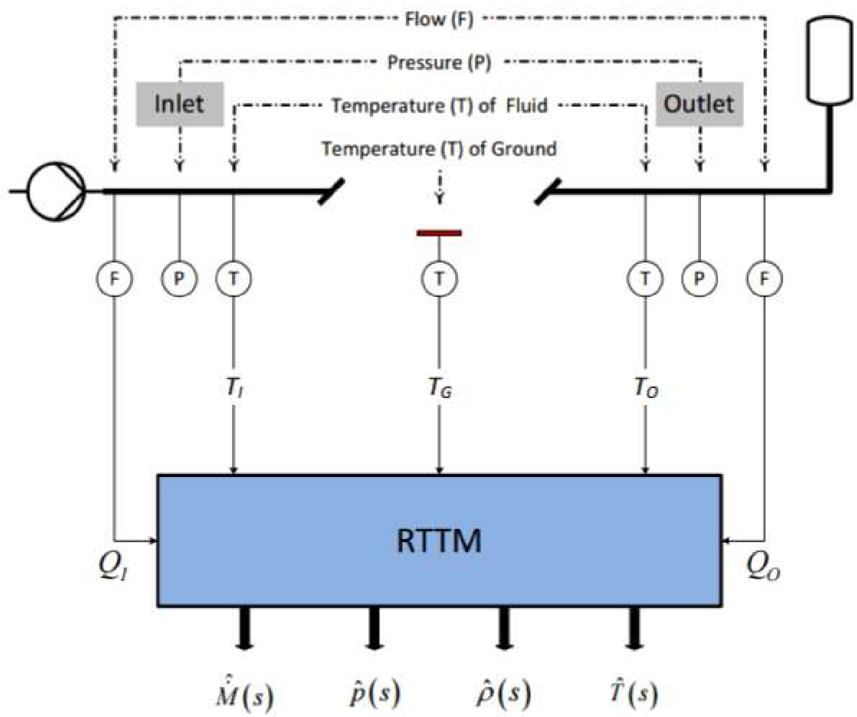
Real Time Transient Modeling:
Some leak detection techniques work on pipe flow models built using equations like: conservation of mass, conservation of momentum, conservation of energy and the equation of state for the fluid. The difference between the measured value and the predicted value of the flow is used to decide the presence of leaks. This technique requires flow, pressure and temperature measurements. Noise levels and transient events are continuously monitored in order to minimize false alarms.



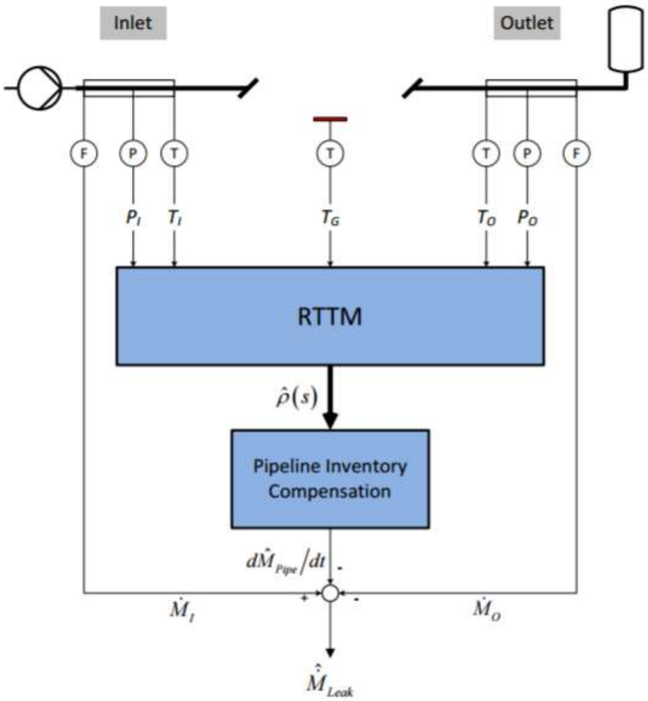
Case-1: Using Pressure and Temperature values at nodal Points
If ground temperature can be assumed constant along a pipeline in practice, we could use one sensor to measure a representative value and assume.



Case-2: Using Flow and Temperature values at nodal points



Case-3 Using Pressure and Temperature values at nodal Points to calculate the density profile along the pipeline

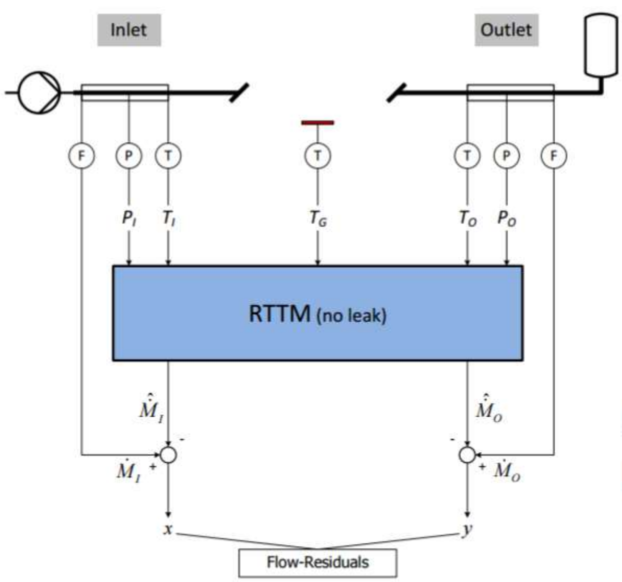


$$_{Pipe} = \bar{\rho} \cdot V_{Pipe} = \left[\frac{1}{L} \cdot \int_0^L \hat{\rho}(s)\, ds \right] \cdot V_{Pipe}$$

$$= \dot{M}_I - \dot{M}_O - \frac{d\hat{M}_{Pipe}}{dt} \begin{cases} > \gamma & \Rightarrow \quad \text{Leak} \\ \leq \gamma & \Rightarrow \quad \text{No Leak} \end{cases}$$

the threshold value assigned based on ator experiences or historical data ysis.

Case-4 Flow Residual Approach: Flow is measured at end points and also at every nodal point so the difference between the measured and calculated flow is used to determine leak



$$x \equiv \dot{M}_I - \hat{\dot{M}}_I$$

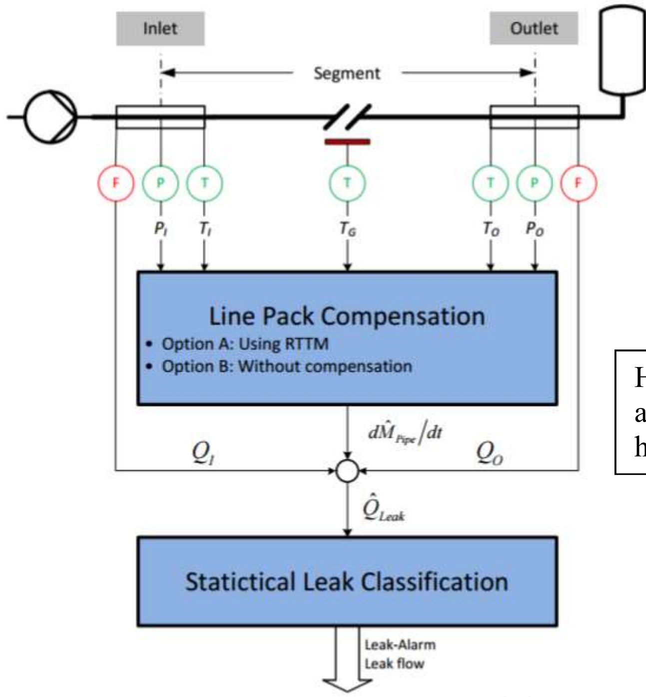
$$y \equiv \dot{M}_O - \hat{\dot{M}}_O$$

H_0 is the no-leak hypothesis and H_1 is the leak-present hypothesis

$$H_0 : \text{No leak} \quad \Rightarrow \quad x \approx 0, y \approx 0$$

$$H_1 : \text{Leak} \quad \Rightarrow \quad x > 0, y < 0$$

Case-5 Pressure Residual Approach: Pressure is measured at end points and at every nodal point so the difference between the measured and calculated pressure is used to determine leak

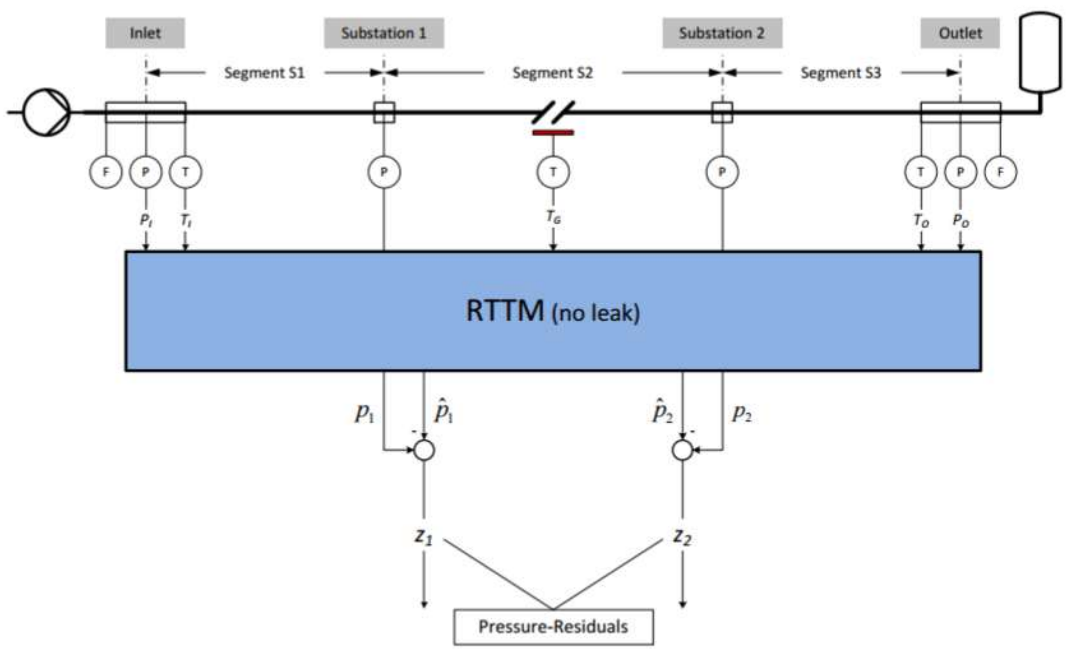


$$H_0: \text{No leak} \Rightarrow z_i \approx 0$$
$$H_1: \text{Leak} \Rightarrow z_i < 0$$

$$z_i \equiv p_i - \hat{p}_i, \quad 1 \le i \le n$$

H_0 is the no-leak hypothesis and H_1 is the leak-present hypothesis

Case-6: Combining Real Time Transient Model with Statistical Analysis where the Statistical analysis can be performed after compensation by RTTM.



Pressure Point Analysis:
It is a fast leak detection technique based on the premise that the pressure inside the pipeline drops if a leak occurs. This technique requires continuous measurements of the pressure in different points along the pipeline. Using statistical analysis of these measurements, the presence of a leak is declared when the mean value of the pressure measurements decreases under a predefined threshold.

Negative Pressure Wave:
A leak occurring in a pipeline is associated with a sudden pressure drop, at the location of the leak, which is propagated as a wave both upstream and downstream. This wave is called a rarefaction or negative pressure wave and can be recorded using pressure transducers installed at both ends of each pipe segment. The leak detection algorithm has to interpret the readings obtained from the pressure transducers and decide if a leak is present.
The location of the leak can be identified using the time difference between the moments at which the two pressure transducers from the pipe ends sense the negative pressure wave. If the leak is closer to one end of the pipe, then the transducer from this end will be the first to receive the pulse and the amount of time needed to receive the pulse at the other end can be used to detect the leak location with good precision. Negative pressure wave based leak detection systems can also estimate the size of the leak. Another way of using pressure waves to detect leaks is to purposely generate transient pressure waves by closing and opening valves periodically. If a leak is present, these pressure waves are partially reflected allowing for the detection and location of the leak. Still, using pressure waves to detect leaks was reported to be unpractical for long-range pipelines.

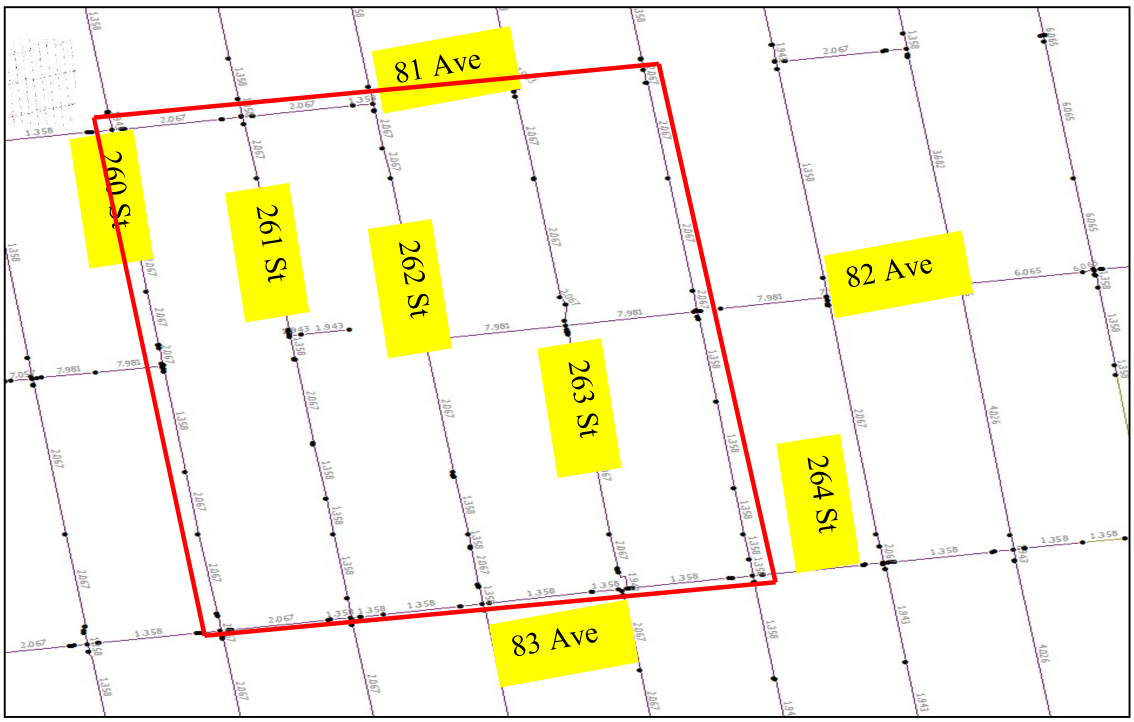
Statistical Analysis:
A simpler way of detecting gas leaks, without the need of a mathematical model, is by using statistical analysis. This analysis is done on measured parameters like pressure and flow at multiple locations along the pipeline. The system generates a leak alarm only if it encounters certain patterns consisting of relative changes in pressure and flow. The leak thresholds are set after a tuning period during which the parameter variance is analyzed under different operating states in the absence of a leak. This tuning process needs to be done over a long period of time and is required in order to reduce false alarms. If a leak is present in the system during the tuning period, it will affect the initial data collected and the system behavior will be considered as normal. This leak would not be detected unless it would grow in size enough to go beyond the threshold. Detection of 0.5% leaks has been successfully proven, however it is possible to detect even smaller leaks when using instruments with greater resolution. Statistical methods can also estimate the leak location. The technique is also easy to use, robust and easy to adapt to different pipeline configurations. Some of the main disadvantages of using this approach are the difficulty in estimating leak volume and high costs.

Digital Signal Processing:
Digital Signal Processing can be used to detect leaks by using measurements of the flow, pressure or other pipe parameters. During the set-up phase, the response given by the system to a known change in flow is measured. This measurement is used together with digital signal processing to detect changes in the system response. Digital signal processing allows for the leak response to be recognized from noisy data.
This method does not need a mathematical model of the pipeline, its main purpose being that of extracting leak information from noisy data. Like the statistical approach, if during the set-up phase a leak is already present in the system it will never be detected unless its size would

grow considerably. Furthermore, besides having a high cost, this leak detection technique is difficult to implement, retrofit and test.

PHASE-O SIMULATION USING EPANET AND ARCGIS

Test Setup:
The selected network region at Bellerose, Queens operates at value of pressures ranging from 15 to 124 PSI. The pilot site is spread across three avenues from 81st to 83rd Avenue and lies between 260th and 264th Street. The network contains a total of 207 Nodal Junctions and 209 Pipes. To isolate the network from the external environment virtual reservoirs were added and linked to the external points of the network. This simulation was performed using EPANET a software that was created by EPA used to simulate water network scenarios and ArcGIS, an ESRI software utilized for Geo Spatial Analysis.



Test Conditions:
The Head Values of reservoirs were set to specific values to obtain the normal operating pressure range (between 45 -82 PSI) in the network. The reservoirs ensured that this selected network was isolated from the remainder of the network creating a controlled scenario to work on. Below is the Single Line Diagram view of the selected network containing the nodes, virtual reservoirs (introduced into the network for simulation) and the connecting pipes (links).

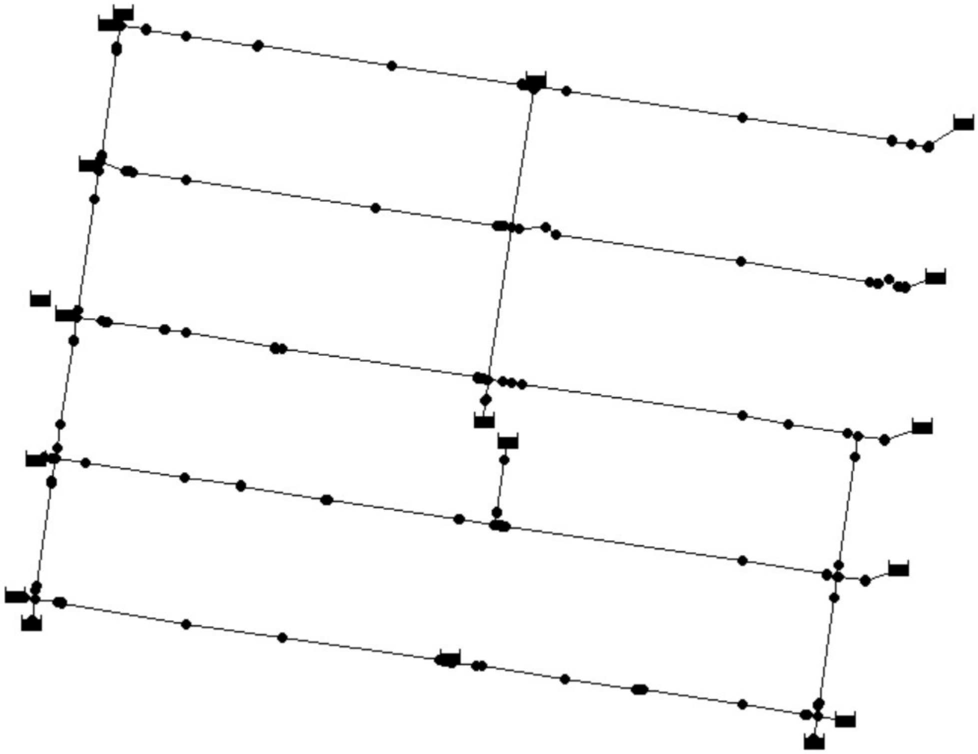


Figure 1 Selected Network Mapped on EPANET

Test Simulations:

Simulations were run for the given network using EPANET considering the following baseline conditions:

- Elevation: 10 Feet
- Average Pipe Diameter (Used for Unknown values): 1.5 inches
- Global Energy Efficiency: 75%
- Time at Simulation Run: 12:00 AM
- Head loss: H-W
- Specific Gravity: 1
- Viscosity: 1
- Trials Run: 40
- Accuracy:0.001
- Check Frequency: 2

Below is the output of the simulation run for the steady state operational conditions. The data provided by Con-Edison for the Pipes and Nodes were filtered and used as an input for running the simulation.

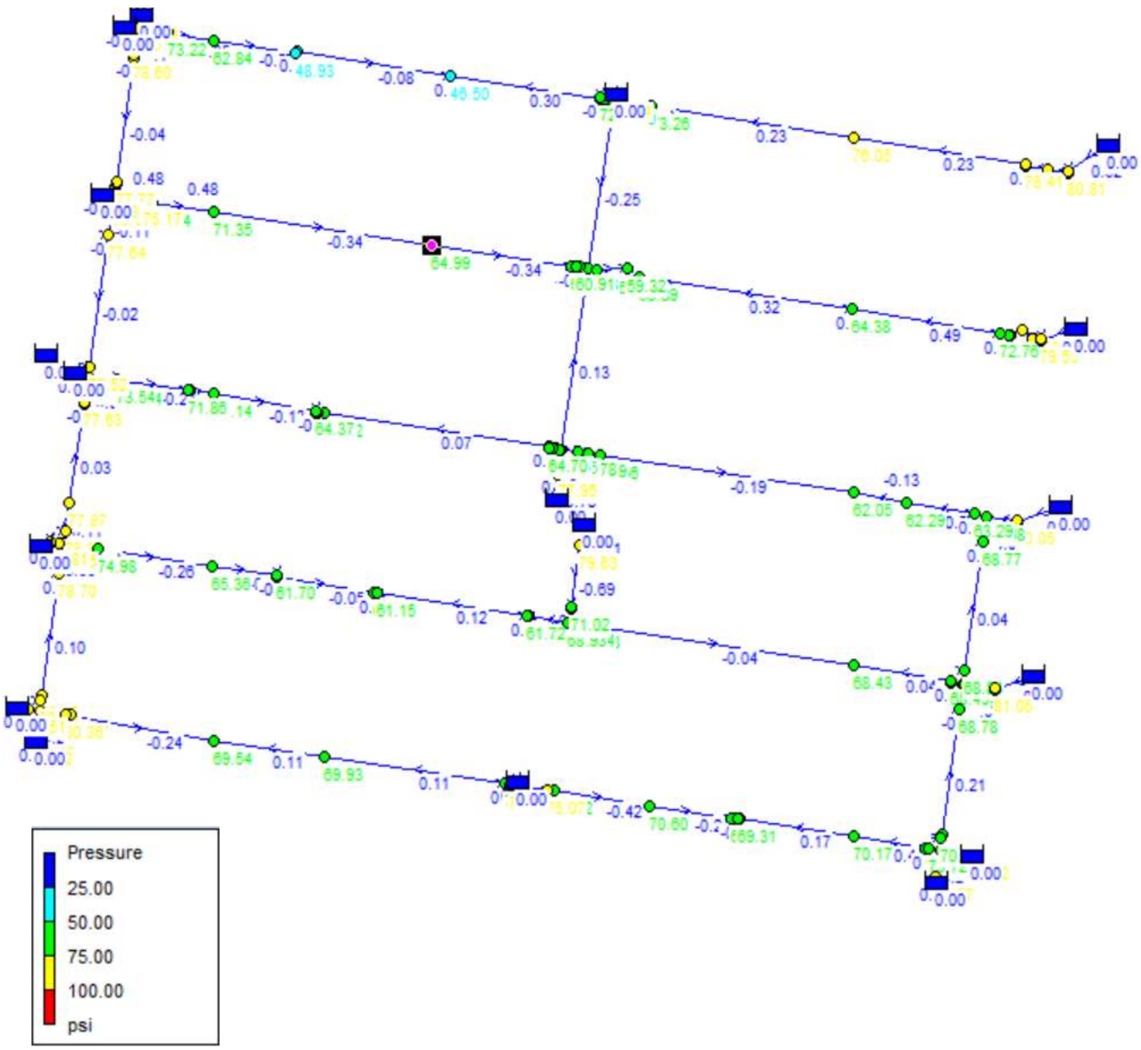


Figure 2 EPANET Simulations for Normal Operating Conditions

Simulating Leak Scenarios:

Leaks were simulated at a randomly chosen Node 2FB0094D Progressively at an interval of 0.05 for ten steps and the values of the Pressure at nodes and Flow and Flow Velocity at pipes were observed.

Leak Simulated at Node 2FB0094D					
Leak Value (Demand) in node 2FB0094D	Pressure at Node 2FB0094D	Flow in Pipe 2FB0099E	Flow Velocity in 2FB0099E	Flow in Pipe 2FB0094C	Flow Velocity in 2FB0094C
0	64.99	0.34	0.03	0.34	0.03
0.05	63.45	0.31	0.03	0.36	0.03
0.1	61.9	0.28	0.03	0.38	0.04
0.15	60.34	0.26	0.02	0.41	0.04
0.2	58.78	0.23	0.02	0.43	0.04
0.25	57.21	0.19	0.02	0.44	0.04
0.3	55.63	0.16	0.02	0.46	0.04
0.35	54.05	0.13	0.01	0.48	0.05
0.4	52.45	0.1	0.01	0.5	0.05
0.45	50.86	0.07	0.01	0.52	0.05
0.5	49.28	0.03	0.01	0.53	0.05
0.55	47.71	0	0	0.55	0.05
0.6	46.11	0.03	0	0.57	0.05

Figure 3 Leak Simulation in the Network

Therefore, a total of 12 different Scenarios for leak value ranging from 0.05 to 0.6 were implemented and the data pertaining to the simulations were stored in three excel files:

1. Pressure Data (Encl: Pressure Simulation)

   This data contains the pressure values that were simulated for various levels of leak ranging from 0.05 to 0.6. The Pressure values for individual Scenarios (Pressure_1, Pressure_2, …..Pressure_12)and the Pressure Difference between the No Leak Condition and the Leak Scenario (Pressure_1d, Pressure_2d, …..Pressure_12d) is listed in the Excel Sheet.

2. Flow Data (Encl: Flow Simulation)

   This data contains the Flow values that were simulated for various levels of leak ranging from 0.05 to 0.6. The Flow values for individual Scenarios (Flow_1, Flow_2, …..Flow_12) and the Flow Difference between the No Leak Condition and the Leak Scenario (Flow_1d, Flow_2d, …..Flow_12d) is listed in the Excel Sheet.

3. Flow Velocity Data (Encl: Velocity Simulation)

   This data contains the Flow Velocity values that were simulated for various levels of leak ranging from 0.05 to 0.6. The Flow Velocity values for individual Scenarios (Velocity_1, Velocity _2, ….. Velocity _12) and the Flow Difference between the No Leak Condition and the Leak Scenario (Velocity _1d, Velocity_2d, ….. Velocity_12d) is listed in the Excel Sheet.

Below are the screenshots of the Pressure and Velocity values simulated for different values of leaks induced onto the network. We have shown in the simulation the Difference in the values of Steady State and Leak Values of Pressure, Flow and Flow Velocity.

NETWORK LEAK SIMULATION

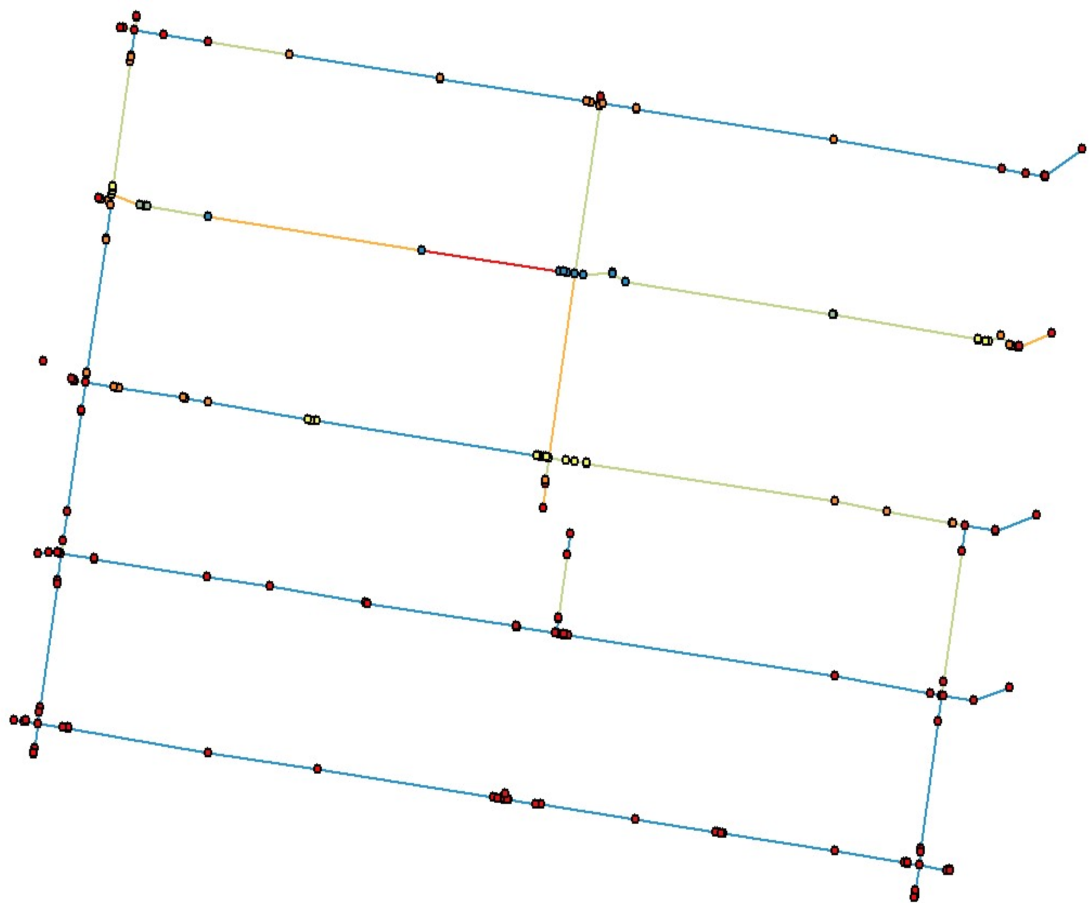


Figure 4 Simulation showing the Pressure, Flow and Flow-Velocity Variation in case of leak in a network.

PRESSURE SIMULATION

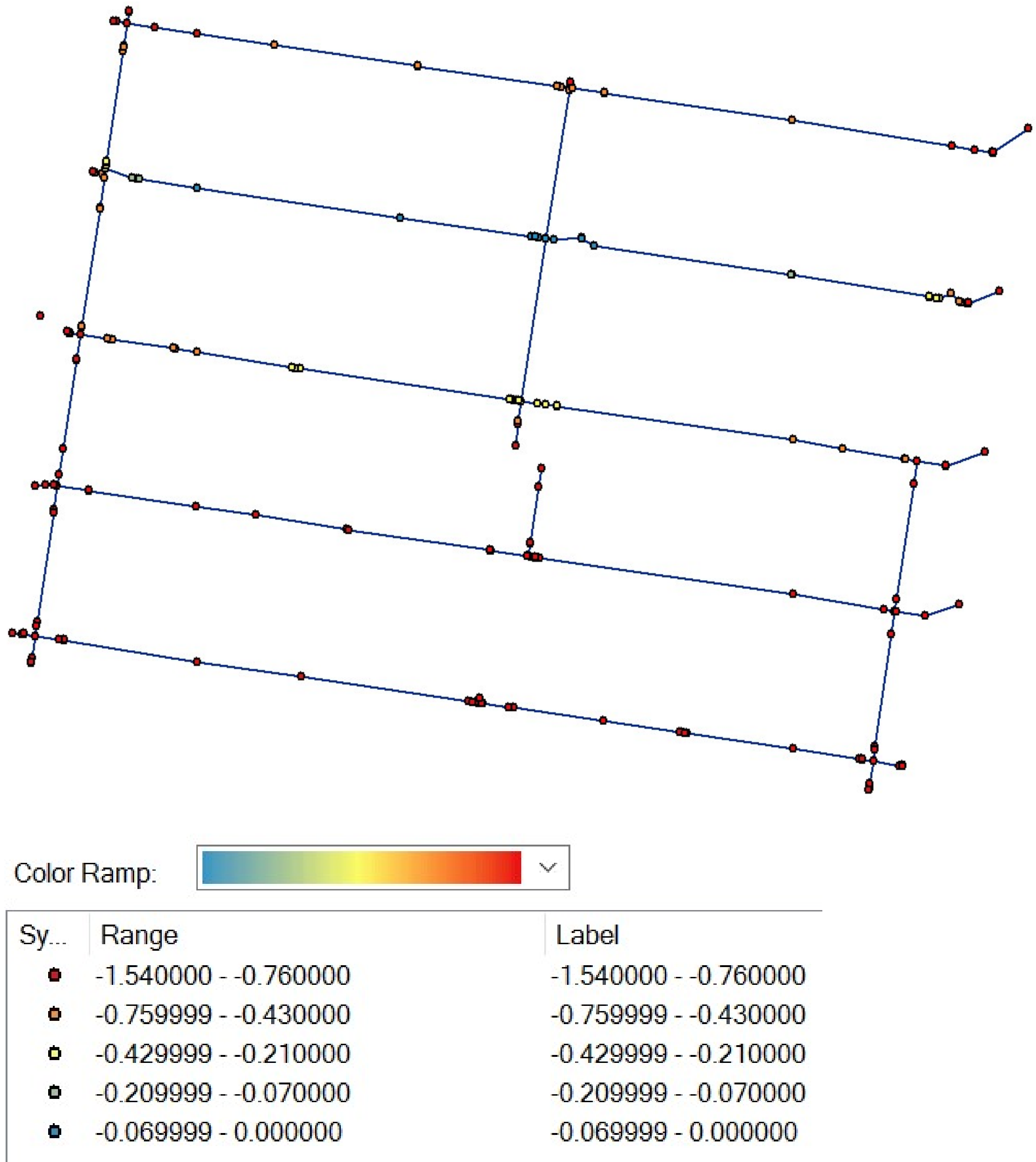


Figure 5 Simulation showing the Pressure Variation in case of leak in a network.

FLOW SIMULATION

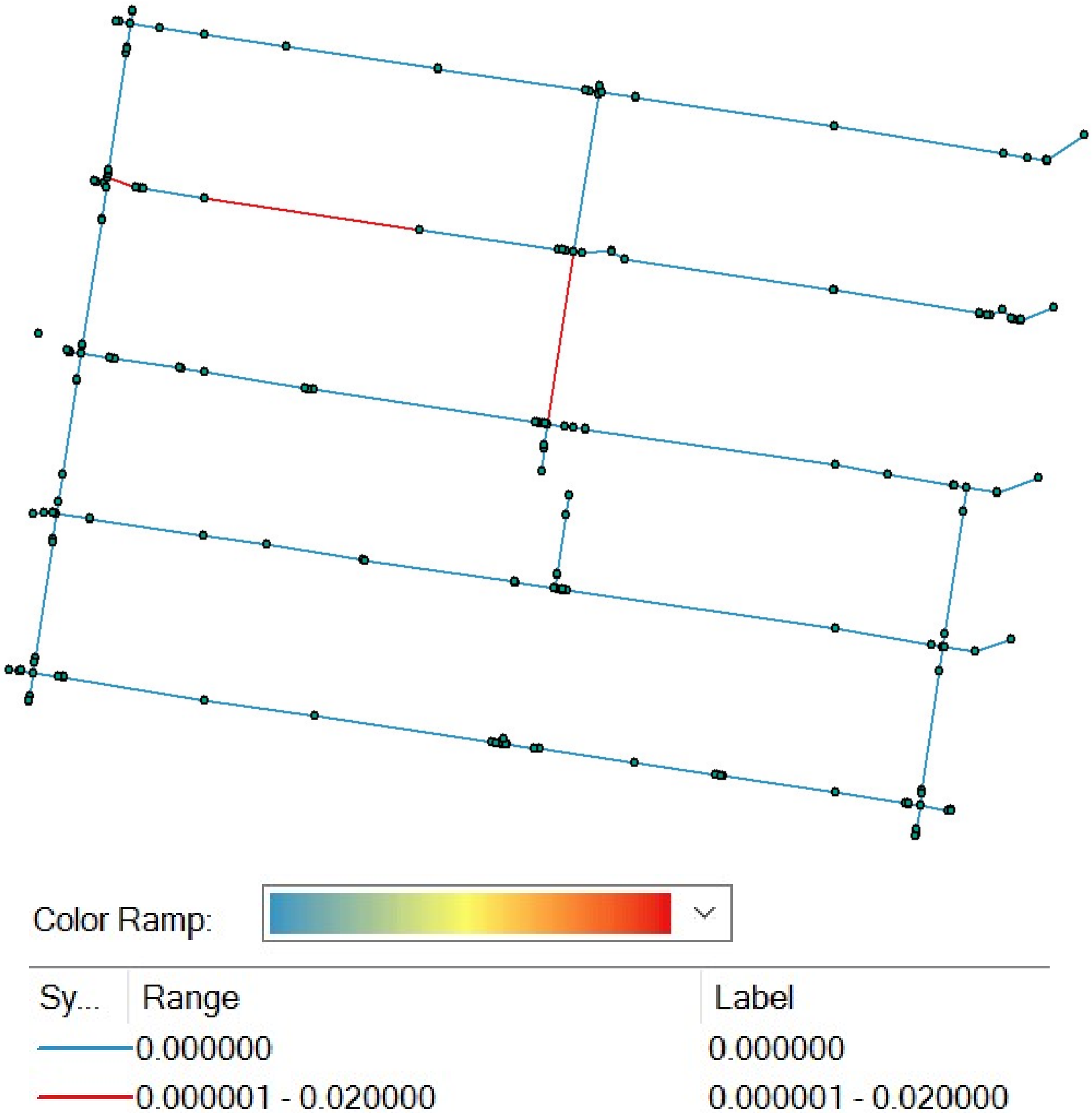


Figure 6 Simulation showing the Flow-Velocity Variation in case of leak in a network.

FLOW VELOCITY SIMULATION

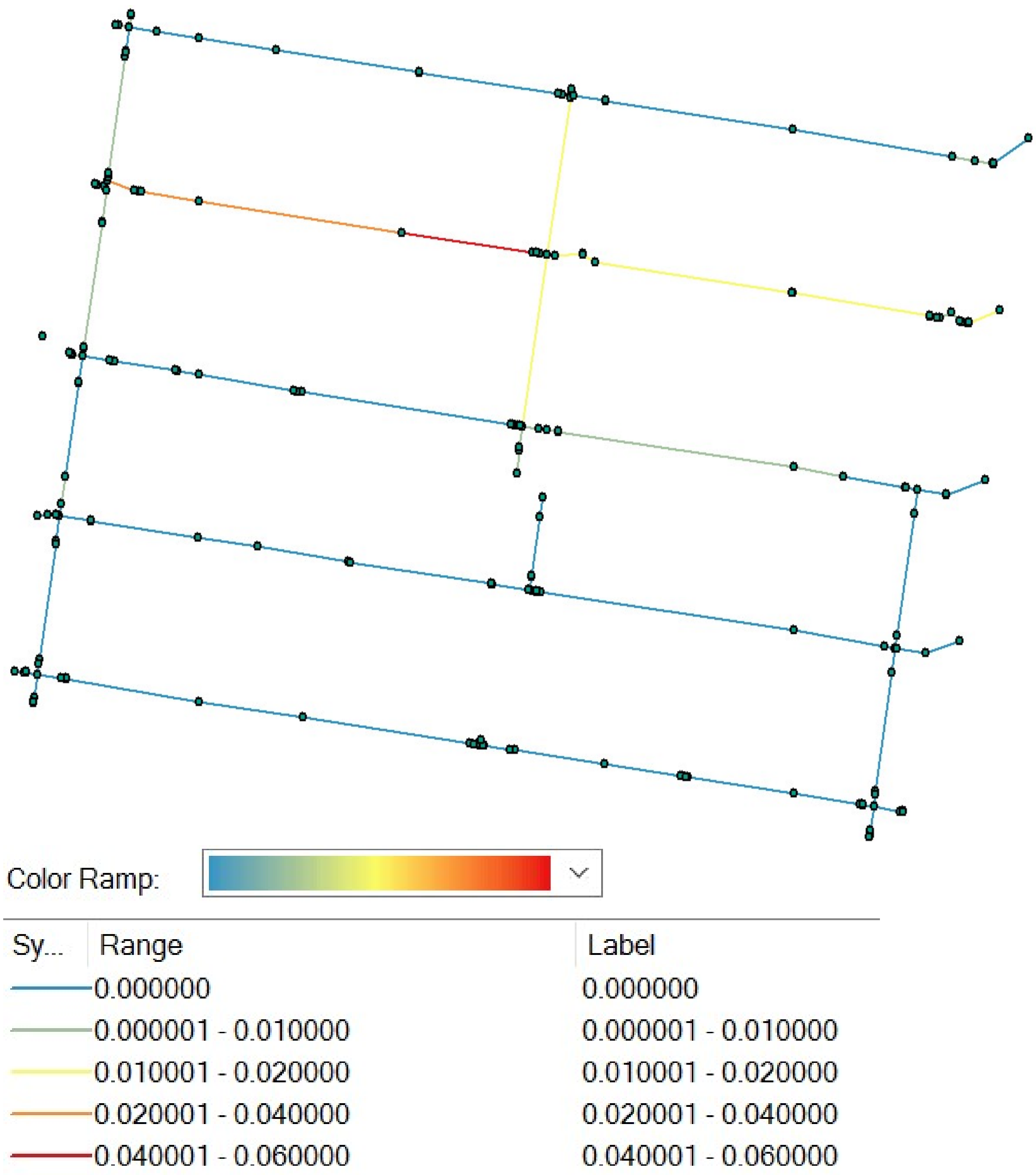


Figure 6 Simulation showing the Flow Variation in case of leak in a network.

LEAK RISK MATRIX:

In this analysis we have tried to classify the leaks by creating a leak matrix. This was made by analyzing the Severity and the Likelihood. The following formulae can give the Risk of Leak:

Risk Indicator = Likelihood * Severity

We have Made Similar network simulations based on this matrix classification. Below is the network classified based on the Risk Matrix:

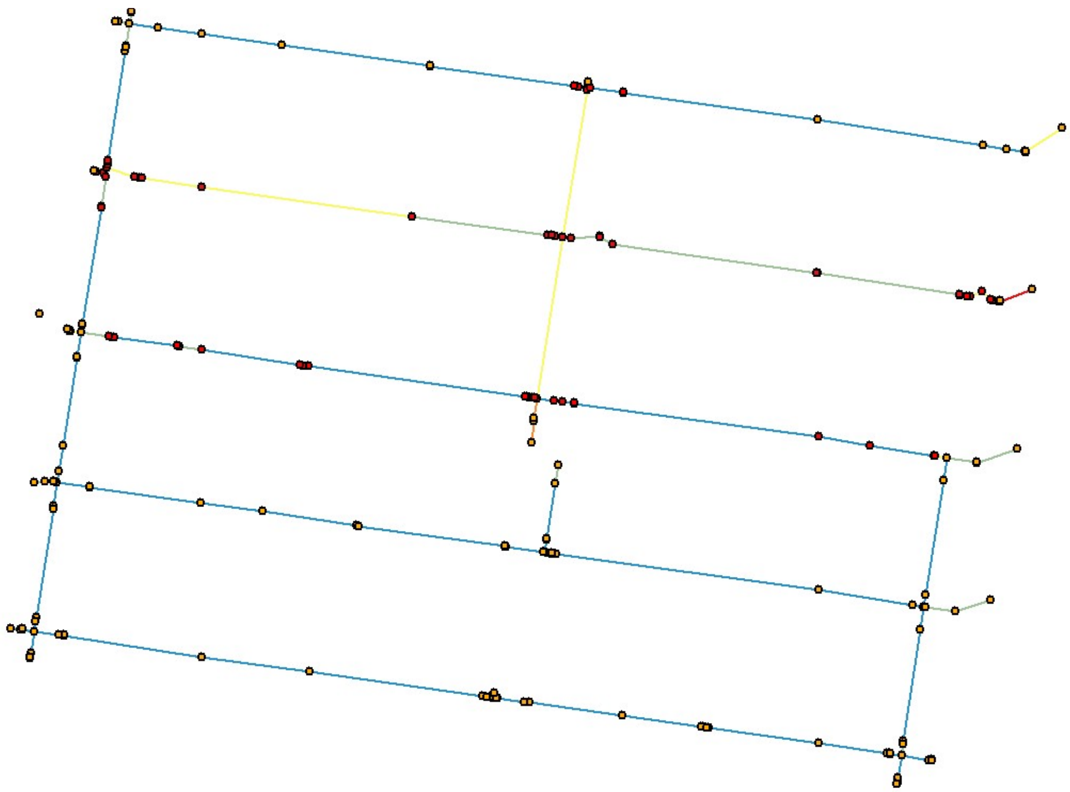
Matrix					
Pressure/Day	<1	2	3	4	>4
<0.5m	B	B	B	B	B
0.5-1m	B	G	G	Y	O
1-2m	G	Y	Y	O	O
2-3m	Y	Y	O	O	R
>3m	O	O	R	R	R
		Flow Range			
Velocity/Day	<1	2	3	4	>4
<0.005m/s	B	B	B	B	B
0.005-0.01m/s	B	G	G	Y	O
0.01-0.015m/s	G	Y	Y	O	O
0.015-0.025m/s	Y	Y	O	O	R
>0.025m/s	O	O	R	R	R
Flow/Day	<1	2	3	4	>4
<0.05m/s	B	B	B	B	B
0.05-0.1m/s	B	G	G	Y	O
0.1-0.15m/s	G	Y	Y	O	O
0.15-0.25m/s	Y	Y	O	O	R
>0.25m/s	O	O	R	R	R

Figure 7 Risk Matrix for the Network

CONCLUSION:

This initial leak scenario modeling, using Stoner data, EPANET simulations and ArcGIS, seems to indicate that provided there is a real time monitoring and calibration of pressure or flow parameters engineering flow models simulations can assist the operator in early detecting and approximately geo-locating the leak in the network based on current network situation analysis. However, the limitations of the engineering models due to uncertainties embedded in the working assumptions on the flow pattern and the need for real-time calibration clearly suggest the use of Artificial Intelligence based stochastic methods for spatial and temporal anomaly detection, which is the main objective of this R&D program.

LEAK RISK MATRIX SIMULATION



Pressure Range

Color Ramp:

Sy...	Range	Label
●	-15.710000 - -3.000000	-15.710000 - -3.000000
●	-2.999999 - -2.000000	-2.999999 - -2.000000
●	-1.999999 - -1.000000	-1.999999 - -1.000000
●	-0.999999 - -0.500000	-0.999999 - -0.500000
●	-0.499999 - 0.000000	-0.499999 - 0.000000

Flow Velocity Range

Color Ramp:

Sy...	Range	Label
—	0.000000 - 0.005000	0.000000 - 0.005000
—	0.005001 - 0.010000	0.005001 - 0.010000
—	0.010001 - 0.015000	0.010001 - 0.015000
—	0.015001 - 0.025000	0.015001 - 0.025000
—	0.025001 - 0.030000	0.025001 - 0.030000

Flow Range

Color Ramp:

Sy...	Range	Label
—	0.000000 - 0.050000	0.000000 - 0.050000
—	0.050001 - 0.100000	0.050001 - 0.100000
—	0.100001 - 0.150000	0.100001 - 0.150000
—	0.150001 - 0.250000	0.150001 - 0.250000
—	0.250001 - 0.310000	0.250001 - 0.310000

Figure 8 Simulation showing the leak in a network based on Leak Matrix (Pressure, Flow & Velocity)

“Gas Leak” Prototytpe System

ARTIFICIAL INTELLIGENCE BASED EARLY LEAK DETECTION FOR GAS DISTRIBUTION SYSTEM

Prof. Ilan Juran, Praveen Ashok & Silvia Tinelli

INTRODUCTION

Leak detection in urban gas pipelines is considered a major challenge as there is no proven methodology to preemptively detect leaks in the system. The utilities are still mostly dependent on conventional leak detection techniques such as mobile leak detection systems and customer complaints to detect the leaks. The fact that the piping infrastructure is very complex in an urban setup and the setting up measurement and control points at every individual node might not be technically and economically feasible, makes it a challenging grey area not touched by many industry experts. In fact, geo-localizing the leak, the operators can reduce false alarms and directly intervene minimizing the risk for the users.

The research conducted at the NYU Urban Infrastructure Institute aims at developing and demonstrating the technical feasibility of Artificial Intelligence based Gas Leak detection Prototype System ("Gas Leak") that will efficiently support the operators in ensuring real-time monitoring for preemptive control management. The development and adaptation of the Gas Leak Prototype System is primarily based on the adaptation of AI algorithm used for Smart Water Management Systems, recently developed and demonstrated in 10M€ European Research Project (https://sw4eu.com/), to the Gas Leak Prototype System. W-Smart experts leading leak detection system development at the European Research Project are currently working with the NYU team on the adaptation of the AI detection system.

The research consists of 4 phases, including:

1. ***Phase 1: Definition & Calibration of the Epanet model***

In this section, the research aimed at simulating the pilot network using Epanet, which is a software that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. It usually tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and even the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. Even though Epanet is designed to be a research tool for improving the understanding of the movement and fate of drinking water constituents within distribution systems, it can be used for many different kinds of applications in distribution systems analysis by changing the parameters of the used species (gas in this case). Therefore, during the Phase 1 the Epanet model was built using input data coming from Stoner, the geometry of the network and the features of the gas species.

A calibration process was needed in order to have a good correlation between Epanet and Stoner.

2. *Phase 2: Definition of matrices for classification of Leak Severity & Duration*

The recognition of each of the anomaly signature started according to matrices which differentiated three levels of Amplitude (A) and Duration (D) using a color-based procedure. For instance, green/yellow/red defined three different levels of leak Amplitude & Duration, as represented below:

Anomalies		
3	High	
2	Moderate	
1	Insignificant	
0	No Anomaly	

The anomalies are separately identified at each single node and at each single pipe of the network, since the methodology investigated the parameters in every single node/pipe. In details, pressure/demand and head were investigated to detect leaks in the nodes while flow/velocity/unit head loss were deepened to pinpoint leaks in the pipes.

3. *Phase 3: Artificial Intelligence (AI) Application*

The research developed, adapted and demonstrated the feasibility of Artificial Intelligence (AI) based smart system that will effectively detect leaks in gas system. In this context, advance pattern recognizers, such as Support Vector Machines (SVMs), and innovative sensing technology solutions, as Artificial Neural Network (ANN), have been used. In machine learning the SVMs are supervised learning models with associated learning algorithms that analyze data used for classification and regression analysis. Given a set of training examples, each marked as belonging to one or the other of two categories (anomaly and no anomaly), an SVM training algorithm builds a model that assigns new examples to one category or the other, making it a non-probabilistic binary linear classifier. The proposed model includes the evaluation of input data, associated vectors, threshold formulation and classification principle etc. The designed SVM identified two different classes, that is (+1) or (0) respectively for "anomaly" or "not anomaly" classification. The proposed multi-class SVM recursively divided the different signature of the anomalies in to two disjoint groups that will decide in which of the groups the incoming unknown data from the gas system should be assigned.

At each step of the SVM the identification of the node/pipe anomaly signatures is made based on the assigned input and the upcoming data from Epanet. Therefore, the i_{th} SVM is design to recognize one of the presented signature of the anomaly and the output of i_{th} node/pipe state will be "+1, or positive" if the contamination is actually present in the specific node/pipe, "+0, or negative" otherwise.

In order to compare the SVM results, the ANN has been applied. The ANNs are a computational model based on a large collection of connected simple units called artificial neurons, loosely analogous to axons in a biological brain. Connections between neurons carry an activation signal of varying strength. Such systems can be trained from examples, rather than explicitly programmed, and excel in areas where the solution or feature detection is difficult to express in a traditional computer program. Like the SVM, the ANNs have been used to solve a wide variety of tasks, as pattern recognition.

For this reason, different scenarios had to be created to simulate a leak. In particular, the research assumed that there was no connection to the buildings where the base demand was zero. Therefore, to simulate an increasing leak in one of those nodes, the base demand was increased from 0 GPM up to 25 GPM in steps of 5 GPM.

4. ***Phase 4: AI Testing & Validation***

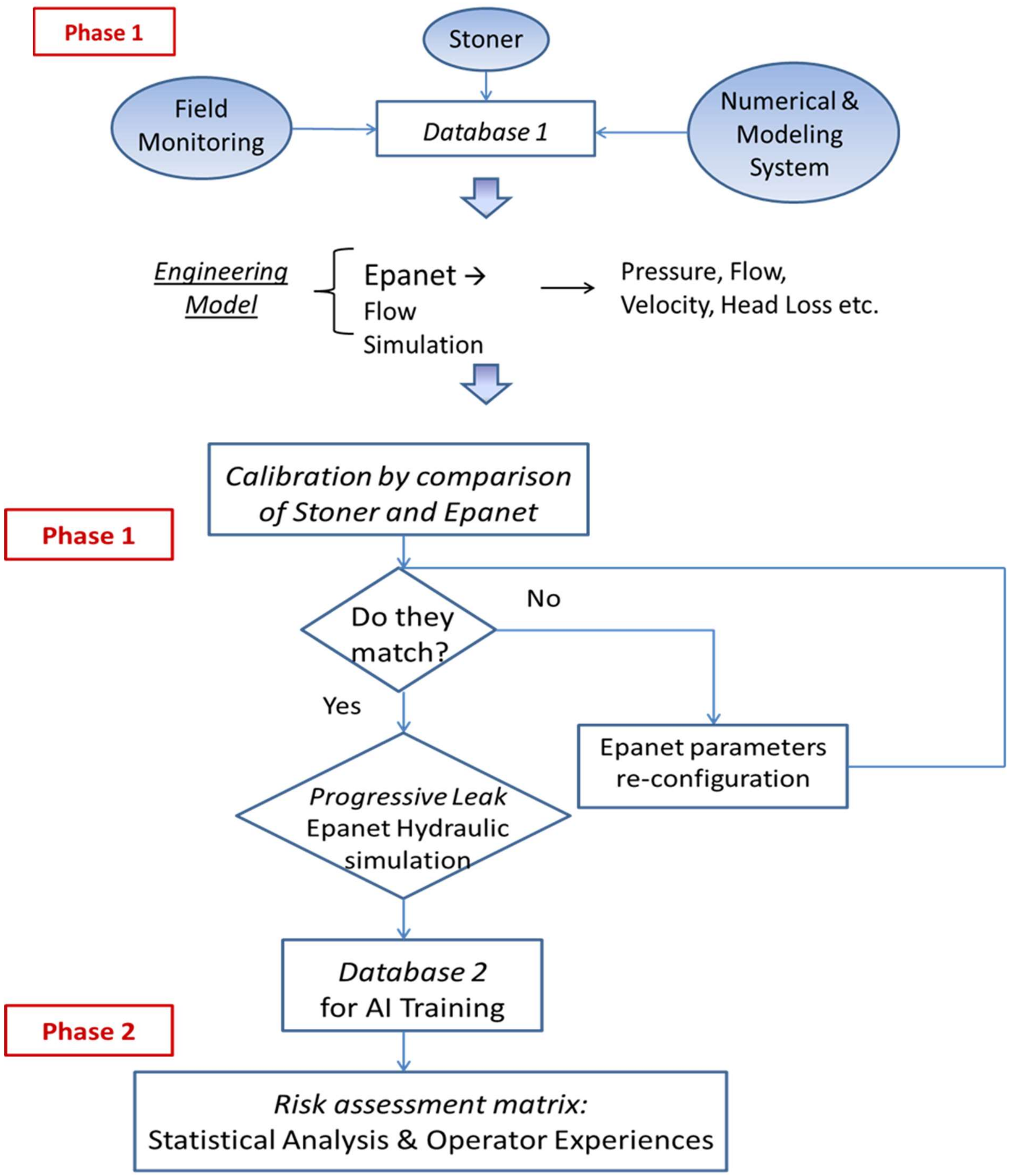
Several scenarios were created in order to test and validate the Gas Leak Prototype System. All these scenarios different from each others because they simulated several increasing leaks occurred in several points of the network.

Gas Leak System Development:

System Architecture

The four indicated phases can be summarized and outlined in the System Architecture represented below in Figure 1.

System Architecture: Gas Leak Prototype System



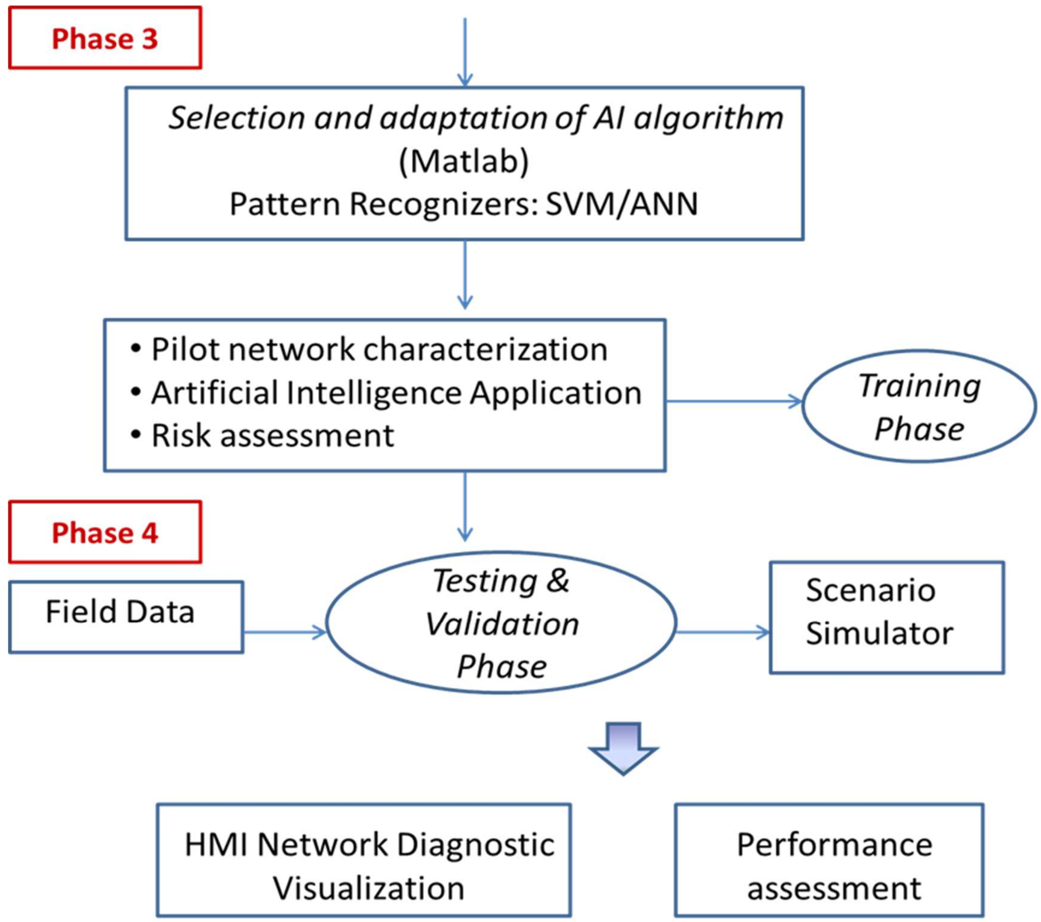


Figure-1. Gas Prototype System: System Architecture

Figure 1 shows the System Architecture of the Gas Leak Prototype System. As illustrated, the system started from a first Database (Database 1) that collected numerical and modeling system data. This database was used to create and calibrate the Epanet model which is deployed as leak simulator. In fact, progressive leaks were simulated increasing the base demand in selected nodes of the network thus, a second database was built (Database 2) for the AI application and training. At this stage, statistical analysis and operator experiences were employed for the recognition of leak in terms of the definition of leak severity and duration. Then, among the available supervised learning models, advance pattern recognizers, such as the Support Vector Machines (SVMs), as well as the Artificial Neural Network (ANN), selected in order to create a Matlab code, able to classify and pinpoint leaks in the network. For this reason, the AI, together with the pilot network and the risk assessment were combined for the AI training phase. Finally, since testing and validation are required, the field data and Epanet (here used to simulate different leaks in the network) were deployed in order to verify the good performance of the Gas Leak Prototype System.

The ultimate product will be the Human Machine Interface (HMI) Diagnostic Visualization.

System Development

The application of the four phases to the pilot network is described in details below.

1. *Phase 1: Definition & Calibration of the Epanet model*

The selected network region at Bellerose, Queens operates at a high-pressure range for value of pressures ranging from 15 to 124 PSI. The network contains a total of 206 Nodal Junctions and 226 Pipes. To isolate the network from the external environment 18 virtual reservoirs were added and linked to the external points of the network.
The Head Values of reservoirs were set to specific values to obtain the normal operating pressure range (between 45 -60 PSI) in the network. The reservoirs ensured that this selected network was isolated from the remainder of the network creating a controlled scenario to work on. Figure 2 shows the Single Line Diagram view of the selected network containing the nodes, virtual reservoirs (introduced into the network for simulation) and the connecting pipes (links).

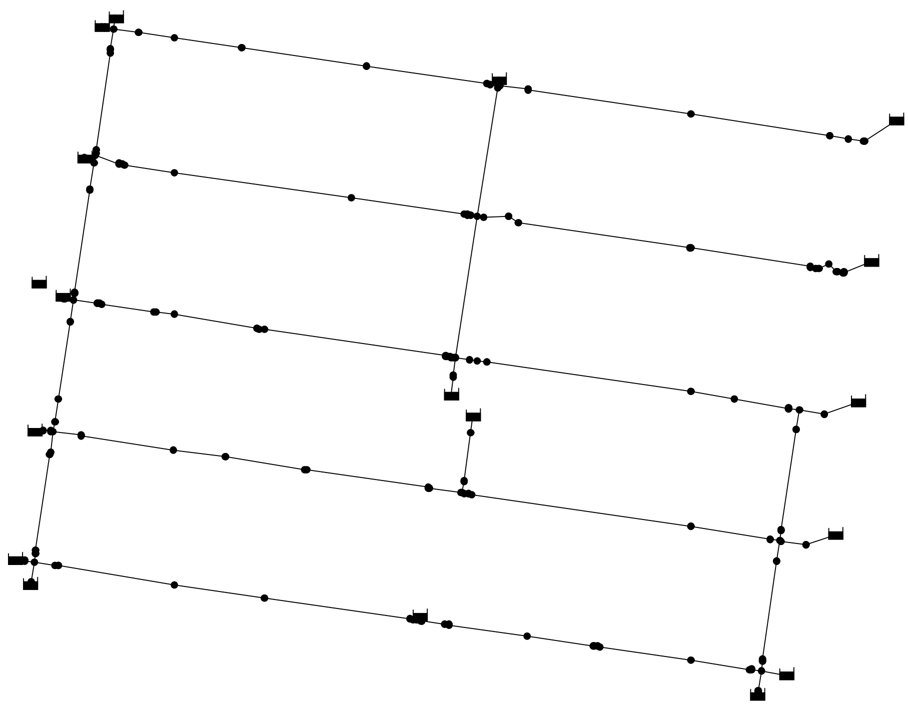


Figure-2. Bellerose layout using Epanet

Simulations were run for the given network considering the following baseline conditions:

- Elevation: 10 Feet
- Average Pipe Diameter (Used for Unknown values): 1.5 inches
- Global Energy Efficiency: 75%
- Time at Simulation Run: 12:00 AM
- Head loss: H-W
- Specific Gravity: 0.579999
- Viscosity: 2.17*10^-7

- Roughness (unitless): 100
- Trials Run: 40
- Accuracy:0.001
- Check Frequency: 2

As shown, the features of the gas were inserted and the roughness was considered around 100 since Epanet uses the formula of Hazen-Williams as default to calculate the head loss (the Hazen-Williams cannot be used for liquids other than water and was originally developed for turbulent flow only).

At this stage, data of three days of winter and three days of summer were taken from Stoner (after filtration) as input data for nodes (in terms of base demand, elevation) and pipes (in terms of roughness, diameter etc.) in order to test & calibrate the Epanet model aiming at having the same results in Epanet and Stoner.
The research work gave a good correlation between Epanet and Stoner.
The output of the simulation run for the stated operational conditions is represented below in Figures 3-4 and in Table 1.

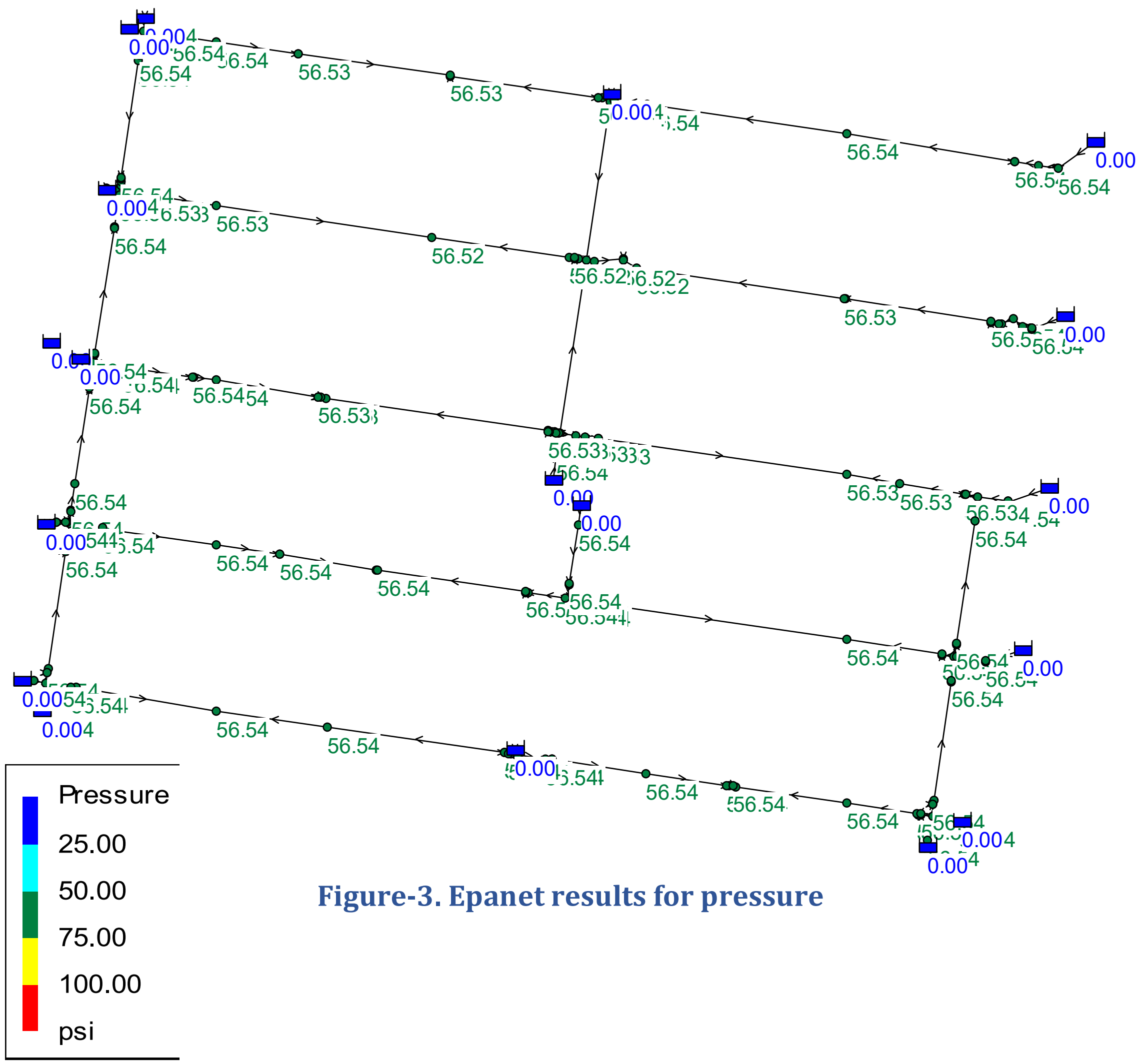


Figure-3. Epanet results for pressure

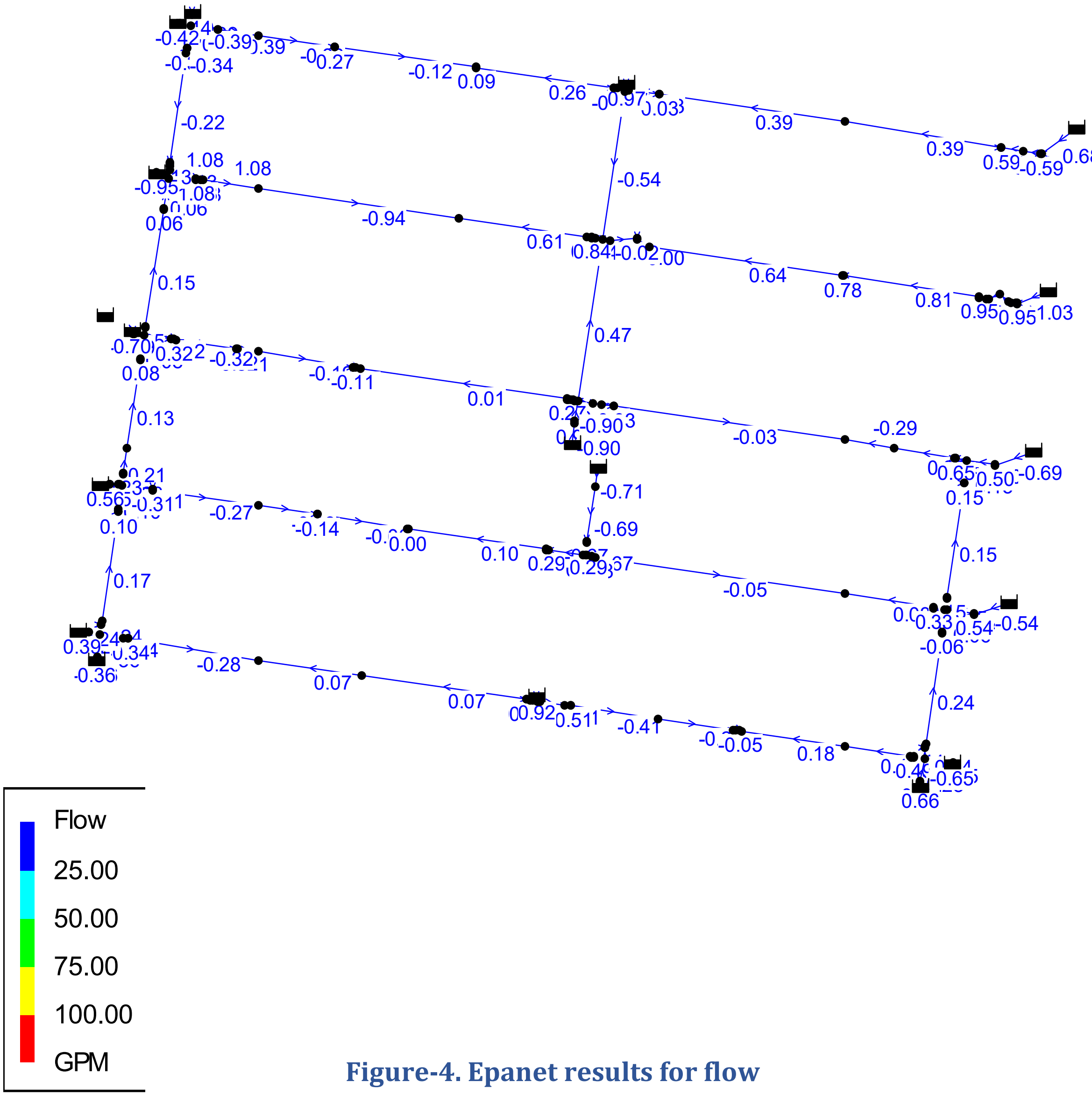


Figure-4. Epanet results for flow

Table 1 shows an example of the correlation between Epanet and Stoner results for *Pressure* and *Flow.*

`

Table 1. Epanet & Stoner results for Pressure and Flow

CONED	INITIAL PHASE		
	Pressure - psi		
Node ID	Pressure EPANET	Pressure STONER	Δ
Junc 2FB1F719	56.54	56.44757	0.09243
Junc 2FAF7AAD	56.54	56.42757	0.11243
Junc 2FB1F71A	56.54	56.124549	0.415451
Junc 2FAF7AA6	56.54	56.222625	0.317375
Junc 2FB08B9A	56.54	56.232261	0.307739
Junc 2FB20A57	56.54	56.184417	0.355583
Junc 2FAF7AA5	56.54	56.252712	0.287288
Junc 2FAF6ACE	56.54	56.253082	0.286918
Junc 2FAF7AA4	56.54	56.232261	0.307739
Junc 2FB08BA0	56.54	56.222625	0.317375
Junc 2FB08BA4	56.54	56.347099	0.192901
Junc 2FAF6ACD	56.54	56.336845	0.203155
Junc 2FAF7AA8	56.54	56.253112	0.286888
Junc 2FAF7AA9	56.54	56.253314	0.286686
Junc 2FB08BB0	56.54	56.253314	0.286686
Junc 2FAF7AAA	56.54	56.414791	0.125209
Junc 2FAF7AA7	56.54	56.347099	0.192901
Junc 2FAF7AAB	56.55	56.423614	0.126386
Junc 2FAF82EA	56.55	56.423599	0.126401
Junc 2FAF7AAC	56.54	56.417362	0.122638
Junc 2FB08BB8	56.54	56.417362	0.122638
Junc 2FB08BBC	56.54	56.42757	0.11243
Junc 2FAF7AB0	56.54	56.427005	0.112995
Junc 2FAF7AAE	56.55	56.432598	0.117402
Junc 2FAF6ACC	56.55	56.429954	0.120046
Junc 2FAF7AAF	56.55	56.429233	0.120767
Junc 2FB1F32D	56.55	56.432598	0.117402
Junc 2FAF82E9	56.55	56.423595	0.126405
Junc 2FB09B23	56.55	56.423599	0.126401
Junc 2FAF70EF	56.54	55.987628	0.552372

CONED	INITIAL PHASE			
	Flow GPM			
Pipe ID	Flow EPANET	Flow STONER - cfph	Flow EPANET - CFPH	Δ
Pipe 2FB08B92	-0.28	1.784591	-2.2456	-0.46101
Pipe 2FB08B93	-0.27	-1.769413	-2.1654	-0.39599
Pipe 2FB08B99	0.21	2.626051	1.6842	0.941851
Pipe 2FB08B9C	-0.45	-0.657682	-3.609	-2.95132
Pipe 2FB08B9D	0.23	2.645128	1.8446	0.800528
Pipe 2FB08B9F	-0.31	-1.807568	-2.4862	-0.67863
Pipe 2FB08BA3	0.1	3.795014	0.802	2.993014
Pipe 2FB08BAA	-0.45	-0.657682	-3.609	-2.95132
Pipe 2FB08BB2	0.17	3.86827	1.3634	2.50487
Pipe 2FB08BB4	-0.22	0.153144	-1.7644	-1.61126
Pipe 2FB08BB5	0.24	3.935422	1.9248	2.010622
Pipe 2FB08BB7	0.24	3.935422	1.9248	2.010622
Pipe 2FB08BBB	-0.34	1.721255	-2.7268	-1.00555
Pipe 2FB08BC3	0.36	2.367311	2.8872	-0.51989
Pipe 2FB08BC9	0.36	2.367311	2.8872	-0.51989
Pipe 2FB08BCC	-0.34	1.721255	-2.7268	-1.00555
Pipe 2FB09B22	-0.22	0.153144	-1.7644	-1.61126
Pipe 2FB0E152	0.36	2.367311	2.8872	-0.51989
Pipe 2FB0E154	0.1	3.795014	0.802	2.993014
Pipe 2FB0E155	-0.45	-0.657682	-3.609	-2.95132
Pipe 2FB00032	0.25	2.052603	2.005	0.047603
Pipe 2FB00033	-0.31	-2.750805	-2.4862	0.264605
Pipe 2FB00036	0.95	4.747316	7.619	-2.87168
Pipe 2FB0003A	1.08	3.25955	8.6616	-5.40205
Pipe 2FB0003C	-0.13	1.487765	-1.0426	0.445165
Pipe 2FB0003D	-0.39	1.670125	-3.1278	-1.45768
Pipe 2FB0003E	-0.39	-1.14139	-3.1278	-1.98641
Pipe 2FBD8B08	-0.35	-1.534933	-2.807	-1.27207
Pipe 2FB00109	-0.34	1.276581	-2.7268	-1.45022
Pipe 2FBB1012	-0.35	-1.534933	-2.807	-1.27207

Simulating Leak Scenarios:

A leak was simulated at the Node 2FAF70EF where there are no connections to the building. Figure 5 illustrates the leak location.

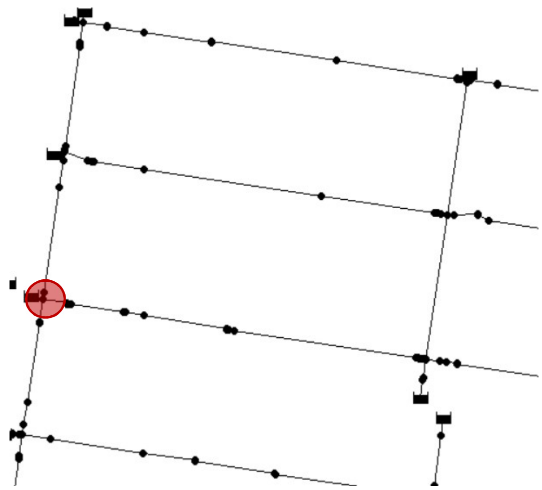


Figure-5. Leak location at Node 2FAF70EF

This node is also very sensitive to the increase of the base demand because it is close to one of
the 18 virtual reservoirs. The demand was progressively increased from 0 GPM to 25 GPM at 5 intervals of 5 GPM as clearly shown below:

Scenario 0 - Day 0	Anomaly free
Scenario 1 - Day 1	1^Increase in the Node 2FAF70EF up to 5 GPM
Scenario 2 - Day 2	2^Increase in the Node 2FAF70EF up to 10 GPM
Scenario 3 - Day 3	3^Increase in the Node 2FAF70EF up to 15 GPM
Scenario 4 - Day 4	4^Increase in the Node 2FAF70EF up to 20 GPM
Scenario 5 - Day 5	5^Increase in the Node 2FAF70EF up to 25 GPM

For the purpose of illustration of leak simulation, the values of *Demand-Head-Pressure* at nodes and *Flow-Velocity-Unit Head Loss* at pipes are reported in Appendix A for Scenarios 0 and 1.

2. *Phase 2: Definition of matrices for classification of Leak Severity & Duration*

The recognition of each of the anomaly signature started according to matrices which differentiated three levels of leak Amplitude (A) and Duration (D) using a color-based procedure.

Regarding the pressure, since it is mostly constant, three levels of amplitude were defined using slightly different thresholds, as explained below:

1- GREEN - Amplitude 1 - anomaly free +1‰ avg;

2- YELLOW - Amplitude 2 - anomaly free+1% avg;

3- RED - Amplitude 3 - anomaly free+1.5% avg.

Regarding the flow/velocity, they are sensitive to the changes in the base demand thus, the matrices that define the three levels of amplitude have to be different as explained below:

1- GREEN - Amplitude 1 - 1 to 2 GPM;
2- YELLOW - Amplitude 2 - 2 to 3 GPM;
3- RED - Amplitude 3 - > 3 GPM.
Moreover, three different levels of duration were defined considering the number of days, such as Day 1, Day 2, Day 3 for both the two matrices.
Figure 6 illustrates the two matrices described above. However, these matrices are only reported for the purpose of illustration: each amplitude & duration level can be set up by the system operators.

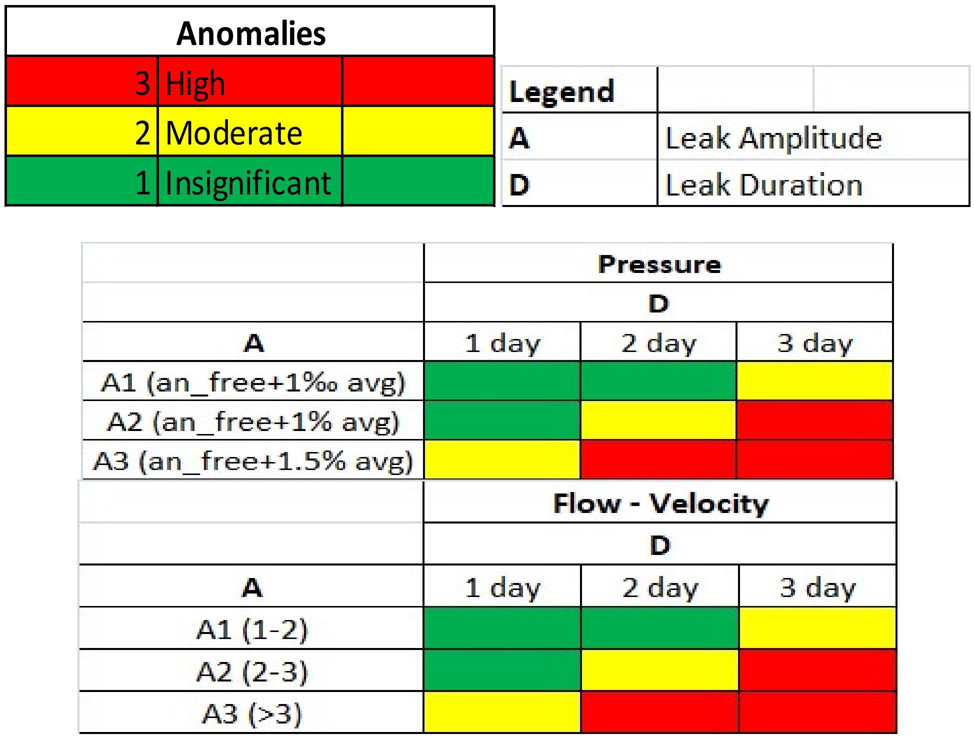


Figure-6. Matrices for parameter thresholds

3. *Artificial Intelligence (AI) Application*

The SVMs have been applied to the pilot site and the simulated leak, as explained below.
Regarding the nodes, the inputs were:

- X — Matrix of predictor data, where each row represents the daily values of gas parameters, as calculated from Epanet for the monitored nodes of the network, and each column is the analyzed parameter (Demand, Pressure in this case);
- Y — Array of class labels with each row corresponding to the value of the corresponding row in X. Y is indeed a column vector, whose values are +1 or 0, according to the belonged category of "not anomaly" or "anomaly";
- Kernel Function — The default value is 'linear' for two-classes learning, which separates the data by a hyperplane;
- ClassNames — Distinguishes between the negative and positive class, or specifies which classes to include in the data. The 0 class is here the negClass'(not anomaly) class, while the 1 is the 'posClass' (anomaly) class.

Regarding the pipes, the inputs were:

- X — Matrix of predictor data, where each row represents the daily values of gas parameters, as calculated from Epanet for the monitored pipes of the network, and each column is the analyzed parameter (Flow, Velocity and Unit HeadLoss in this case);
- Y — Array of class labels with each row corresponding to the value of the corresponding row in X. Y is indeed a column vector, whose values are +1 or 0, according to the belonged category of "not anomaly" or "anomaly";
- Kernel Function and ClassNames are the same of the previous point.

The resulting trained model (SVMModel) contains the optimized parameters from the SVM algorithm, enabling the classification of the new data.
In this case the proposed multi-class SVM recursively divided the different signature of the anomalies in to two disjoint groups that will decide in which of the groups the incoming unknown data from the gas system should be assigned. The recognition of each of the anomaly signature started according to the matrices explained in Figure 5, where different values of Amplitude (A) and Duration (D) were defined.
Since the Pressure is almost constant, the most sensitive parameters to be analyzed are Flow, Velocity and Unit Head Loss. Whereas the Unit Head Loss can be derived from the Velocity through the known hydraulic formula, Flow and Velocity are the actual analyzed parameters.
Therefore, the classes were identified based on statistical analysis: for instance, regarding the flow, the amplitude has 3 classes, according to which A3 is the worst and it is referred to an increase of more than 3 GPM, A2 is referred to an increase between 2 and 3 GPM, and A1 is referred to an increase between 1 and 2 GPM. Thus, starting from the worst scenario, the new incoming data were selected as belonging to one of the three amplitude classes. The same were made for the duration, defining 3 different durations: 1, 2, and 3 days.

The results display the properties of SVMModel to determine the Class Order which is (+1) for the negative class, and (0) for the positive class; the Kernel parameters; the Class Loss, that is the generalized classification error (it is here less than 5‰ - 0.0043).

```
>> GasLeak_pipe

SVMModel =

  ClassificationSVM
             ResponseName: 'Y'
    CategoricalPredictors: []
               ClassNames: [0 1]
           ScoreTransform: 'none'
          NumObservations: 231
                    Alpha: [2×1 double]
                     Bias: -2.3602
         KernelParameters: [1×1 struct]
           BoxConstraints: [231×1 double]
          ConvergenceInfo: [1×1 struct]
          IsSupportVector: [231×1 logical]
                   Solver: 'SMO'


  Properties, Methods


classOrder =

     0
     1
                classLoss =

                    0.0043
```

Figure-7. SVM Results

Figure 7 shows the SVM output: the multiclass-SVM model can identify different proposed signature of the networks leakage as described.
In particular, considering several parameters intead of only one (for instance, the pressure) the error decreases (considering only the pressure, the error would have been around 5%).

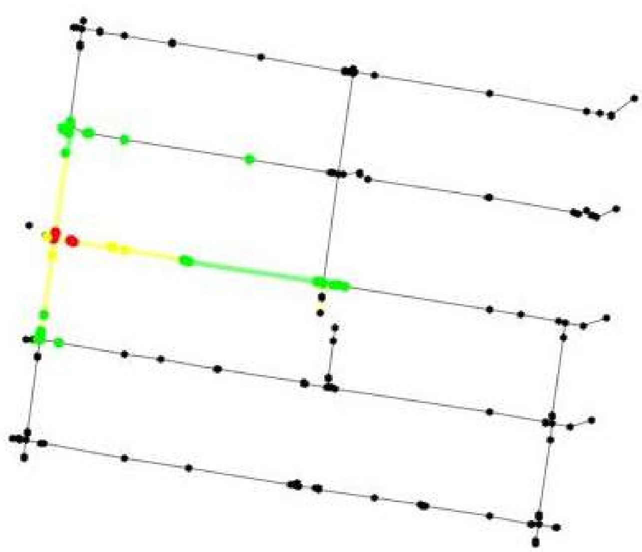


Figure-8. Leak Geo-localization using the SVMs

Figure 8 illustrates the geo-localization of the simulated leak using the SVMs according to the described matrices. The leak geo-localization seems to be more precise with the selection of

multi-parameters: there is a clear distribution of the leak along the network and a reliable color-based separation of nodes/pipes following up the 3 thresholds levels.
The same was done applying the ANN in order to compare the results, where gas parameters were input as rows in a matrix.
In fact, to define a pattern recognition problem using ANN, a set of input vectors is arranged as columns in a matrix. Then, another set of target vectors is required for the ANN so that they indicate the classes to which the input vectors are assigned. In details:

- X — Matrix of predictor data, where each row is one parameter (e.g. flow, velocity etc.) and each column is daily value of gas parameters for the monitored nodes/pipes of the network;
- Y — Array of class labels: when there are only two classes, each scalar target value is set to either 0 or 1, indicating which class the corresponding input belongs to. As in the SVM, the values are (+1) or (0), according to the category of "not anomaly" or "anomaly".

Once the input has been defined, the pattern recognition tool is able to train the network, evaluate its performance using cross-entropy and percent misclassification error and analyze the results using visualization tools, such as confusion matrices and Receiver Operating Characteristic curves (ROC curve). Confusion matrix is a table with two rows and two columns that reports the number of false positives, false negatives, true positives, and true negatives. This allows detailed analysis in terms of accuracy.

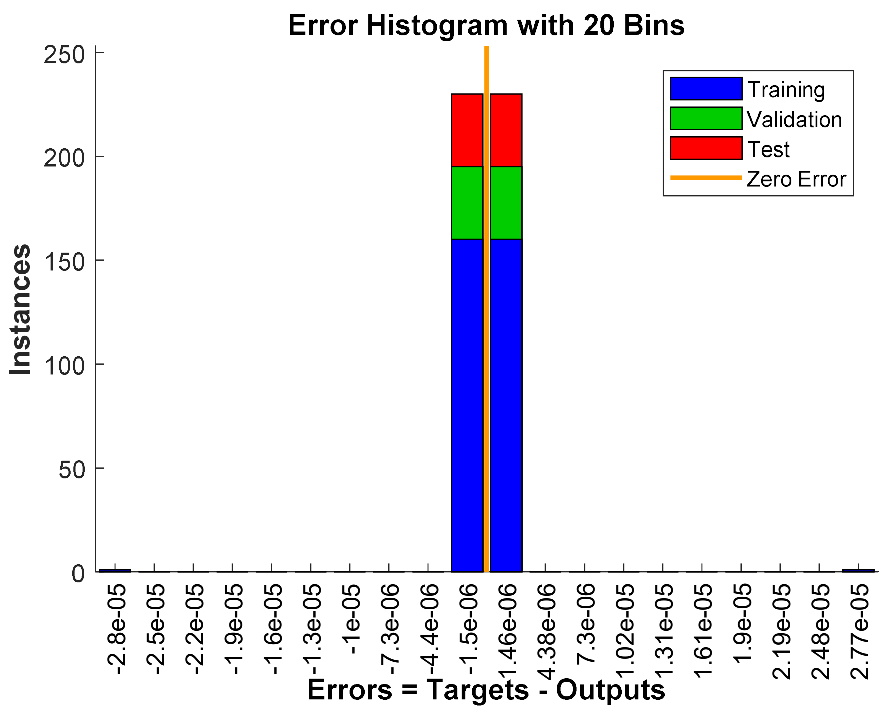


Figure-9 Error Histogram for Leak Detection using the ANN

Figure-10. Confusion Matrix

Figure 9 corroborates the fairness of the SVMs results since the errors is again under 1‰. Figure 10 shows the Confusion Matrix of the artificial network, representing the error, that is less than 1%: it confirms the obtained results, as well as, the accuracy of the methodology.

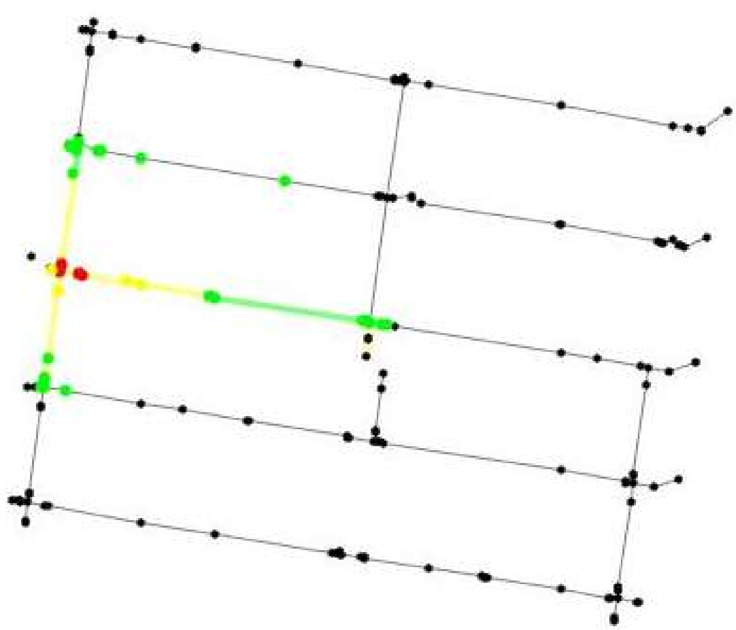


Figure-11. Leak Geo-localization using the ANN

Figure 11 illustrates the geo-localization of the same leak of Figure 8 using the ANN. Figures 8 and 11 give approximately the same results, confirming what has been explained above. The two figures also illustrate that it is important to look at both nodes and pipes because pipes are usually more sensitive than nodes.

4. *AI Testing & Validation*

Several scenarios were created in order to test and validate the AI based methodology. In particular, 12 scenarios were developed increasing the demand in different nodes as explained below in Table 2.

Table 2. Scenarios for testing/validation of the AI based methodology

Scenario 1	Anomaly free
Scenario 2	1^Increase in the Node 2FB22622 up to 5GPM
Scenario 3	2^Increase in the Node 2FB22622 up to 10 GPM
Scenario 4	3^Increase in the Node 2FB22622 up to 15 GPM
Scenario 5	4^Increase in the Node 2FB22622 up to 20 GPM
Scenario 6	5^Increase in the Node 2FB22622 up to 25 GPM
Scenario 7	1^Increase in the Node 2FB009A3 up to 10 GPM
Scenario 8	2^Increase in the Node 2FB009A3up to 20 GPM
Scenario 9	3^Increase in the Node 2FB009A3 up to 25 GPM
Scenario 10	1^Increase in the Node 2FBA5354 up to 10 GPM
Scenario 11	2^Increase in the Node 2FBA5354up to 15 GPM
Scenario 12	3^Increase in the Node 2FBA5354 up to 20 GPM

Among the all 12 scenarios, the 75% of them were used for the testing phase while the remaining 25% were employed in the validation phase.
For the purpose of illustration, Scenarios 2 and 3 (since Scenario 1 represents the anomaly free Scenario) are reported in Appendix B.

According to Scenarios 2-6, the leak was simulated at the Node 2FB22622 (again, there are no connections to the building). Figure 12 illustrates the leak location.

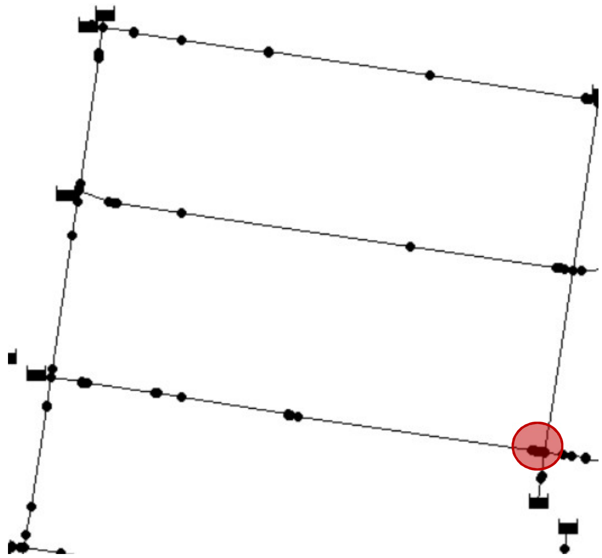


Figure-12. Leak location at Node 2FB22622

Using the color & AI-based methodology, the research work was able to pinpoint and geo-localize the leak on the network, as shown in Figures 13.

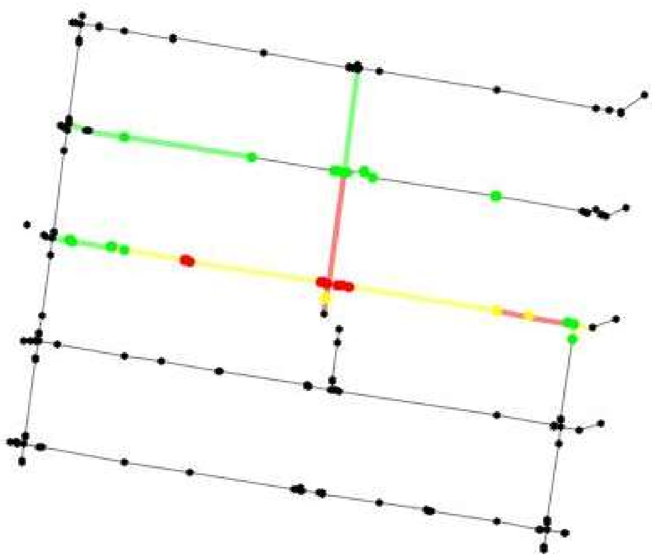


Figure- 13. Leak Geo-localization using the AI based methodology

The same was done for the other scenarios: according to Scenarios 10-12 (used for validation), the leak was simulated at the Node 2FBA5354.

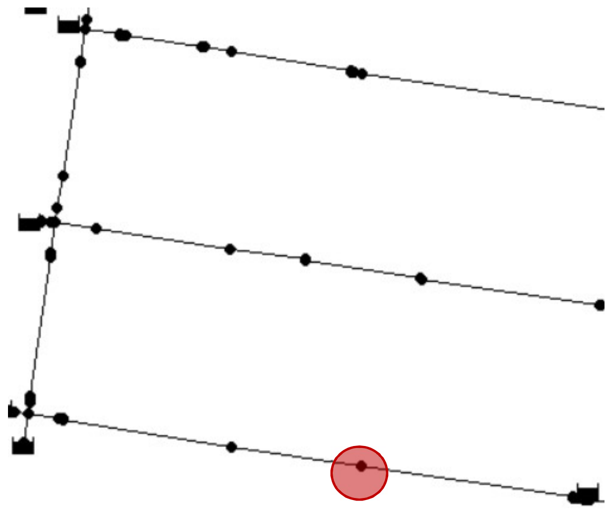


Figure-14. Leak location at Node 2FBA5354

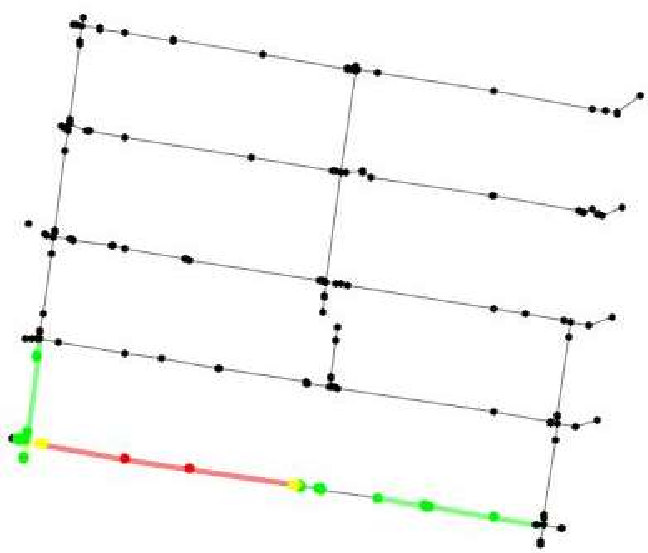


Figure- 15. Leak Geo-localization using the AI based methodology

Figure 14 illustrates the leak location while Figure 15 shows the Leak Geo-localization using the proposed methodology
Figures 13-15 corroborate the good performance of the methodology showing a gradual transition from red to green. This is due to the great accuracy of the model obtained from the evaluation of multiple parameters thus, the importance of considering either nodes and pipes is evident.

Conclusions

The present report highlights a systemic approach for automating the leak detection process that can support the operators through the analysis of Gas System in real time. The research covers the identification and adaptation of selected AI algorithms to improve data control, support the system operators in quasi real-time system monitoring and leak detection.

The most significant results include: (comparison with Stoner)

I. A good correlation between Epanet and Stoner results in terms of the analyzed gas parameters (e.g.: pressure, flow, velocity, unit head loss etc.);
II. The use of the input-output data from Epanet for nodes and pipes in order to improve the data control, the reliability and the efficiency of the current leak detection practice;
III. The visualization of leaks in the network according to color coded levels for leak severity and duration (each level can be selected by the operators);
IV. The demonstration of an efficient and reliable alternative leak detection method based on AI (SVM & ANN) simulations of leaks, complete with geo-localization on Epanet network;
V. The improvement of the results (both in terms of analysis error and visualization of the color coded leak on the network) with the selection of multi-parameters analysis related to both nodes and pipes;
VI. A sensitivity analysis shows that the flow (and consequently the velocity) is the most sensitive parameter for early leak detection.

Next phases

Prototype System assessment and Phase 1 pilot planning (January-March 2018):

1. The research demonstrated that the AI algorithm integrated into the Gas Leak Prototype System can be adapted to early leak detection in Gas Distribution System;
2. However, at this stage, the Prototype System was tested with limited amount of flow data provided from Stoner without leak scenario data. Further validation is required with Stoner data representing actual field leakage scenario;
3. Further development of the Gas Leak Prototype System should involve its deployment with actual field data for its reliability, sensitivity and accuracy assessment. As stated by Con Edison in our last project meeting, such field leakage data are expected to become available during the winter season;
4. System performance assessment and detailed Phase 1 pilot testing program.

APPENDIX A

Table A1. *Demand-Head-Pressure* at nodes/ *Flow-Velocity-Unit Head Loss* at pipes for Scenario 0.

CONED	INITIAL PHASE - Scenario 0			CONED	INITIAL PHASE - Scenario 0		
zNetwork Table - Nodes				Network Table - Links			
Node ID	Demand GPM	Head ft	Pressure psi	Link ID	Flow GPM	Velocity fps	U. H. ft/Kft
Junc 2FB1F719	0.35	234.98	56.54	Pipe 2FB08B92	-0.28	0.05	0.07
Junc 2FAF7AAD	0.06	234.99	56.54	Pipe 2FB08B93	-0.27	0.05	0.07
Junc 2FB1F71A	0.1	234.97	56.54	Pipe 2FB08B99	0.21	0.04	0.04
Junc 2FAF7AA6	0.04	234.98	56.54	Pipe 2FB08B9C	-0.45	0.08	0.17
Junc 2FB08B9A	0.02	234.99	56.54	Pipe 2FB08B9D	0.23	0.04	0.05
Junc 2FB20A57	0.08	234.98	56.54	Pipe 2FB08B9F	-0.31	0.06	0.09
Junc 2FAF7AA5	0	234.99	56.54	Pipe 2FB08BA3	0.1	0.02	0.01
Junc 2FAF6ACE	0	234.99	56.54	Pipe 2FB08BAA	-0.45	0.08	0.17
Junc 2FAF7AA4	0	234.99	56.54	Pipe 2FB08BB2	0.17	0.03	0.03
Junc 2FB08BA0	0	234.98	56.54	Pipe 2FB08BB4	-0.22	0.04	0.04
Junc 2FB08BA4	0	234.99	56.54	Pipe 2FB08BB5	0.24	0.04	0.05
Junc 2FAF6ACD	0	234.99	56.54	Pipe 2FB08BB7	0.24	0.04	0.05
Junc 2FAF7AA8	0	234.99	56.54	Pipe 2FB08BBB	-0.34	0.06	0.1
Junc 2FAF7AA9	0	234.99	56.54	Pipe 2FB08BC3	0.36	0.08	0.19
Junc 2FB08BB0	0.12	234.99	56.54	Pipe 2FB08BC9	0.36	0.03	0.02
Junc 2FAF7AAA	0.07	234.99	56.54	Pipe 2FB08BCC	-0.34	0.03	0.02
Junc 2FAF7AA7	0.07	234.99	56.54	Pipe 2FB09B22	-0.22	0.02	0.01
Junc 2FAF7AAB	0	234.99	56.54	Pipe 2FB0E152	0.36	0.03	0.02
Junc 2FAF82EA	0	234.99	56.54	Pipe 2FB0E154	0.1	0.02	0.02
Junc 2FAF7AAC	0	234.99	56.54	Pipe 2FB0E155	-0.45	0.04	0.04
Junc 2FB08BB8	0	234.99	56.54	Pipe 2FB00032	0.25	0.06	0.1
Junc 2FB08BBC	0	234.99	56.54	Pipe 2FB00033	-0.31	0.07	0.14
Junc 2FAF7AB0	0	234.99	56.54	Pipe 2FB00036	0.95	0.1	0.2
Junc 2FAF7AAE	0	235	56.54	Pipe 2FB0003A	1.08	0.12	0.25
Junc 2FAF6ACC	0	234.99	56.54	Pipe 2FB0003C	-0.13	0.01	0
Junc 2FAF7AAF	0	234.99	56.54	Pipe 2FB0003D	-0.39	0.09	0.21
Junc 2FB1F32D	0.01	235	56.54	Pipe 2FB0003E	-0.39	0.09	0.21
Junc 2FAF82E9	0.17	234.99	56.54	Pipe 2FBD8B08	-0.35	0.08	0.17
Junc 2FB09B23	0	234.99	56.54	Pipe 2FB00109	-0.34	0.08	0.17
Junc 2FAF70EF	0	234.98	56.54	Pipe 2FBB1012	-0.35	0.08	0.17
Junc 2FAF7167	0	234.98	56.54	Pipe 2FB00124	1.08	0.1	0.19
Junc 2FB20A52	0.12	234.96	56.54	Pipe 2FB00125	-0.13	0.03	0.03
Junc 2FAF7160	0.02	234.97	56.54	Pipe 2FB00126	0.89	0.1	0.17
Junc 2FAF70F1	0	234.97	56.54	Pipe 2FB00127	0.06	0.01	0
Junc 2FAF70F3	0	234.97	56.54	Pipe 2FB00128	1.08	0.1	0.18
Junc 2FAF7142	0	234.95	56.53	Pipe 2FB0012E	1.08	0.12	0.25

Junc 2FAF713E	0	234.97	56.54	Pipe 2FB00131	-0.22	0.05	0.08
Junc 2FAF70F5	0	234.99	56.54	Pipe 2FB00134	0.89	0.08	0.13
Junc 2FAF7136	0	234.99	56.54	Pipe 2FBDAFC1	0.06	0.01	0.01
Junc 2FB20A50	0.06	234.96	56.54	Pipe 2FB0018B	-0.32	0.07	0.16
Junc 2FAF7135	0	234.98	56.54	Pipe 2FB0018D	-0.32	0.03	0.02
Junc 2FAF7138	0	234.99	56.54	Pipe 2FB0018F	0.49	0.11	0.33
Junc 2FB00107	0.06	234.99	56.54	Pipe 2FB00192	-0.32	0.03	0.02
Junc 2FB0010A	0	234.98	56.54	Pipe 2FB00199	-0.32	0.03	0.02
Junc 2FB0010D	0	234.99	56.54	Pipe 2FB0019B	-0.32	0.07	0.15
Junc 2FAF7134	0.07	234.99	56.54	Pipe 2FB001A8	0.13	0.03	0.03
Junc 2FAF713D	0	234.95	56.53	Pipe 2FB001AC	0.49	0.05	0.06
Junc 2FAF7141	0	234.95	56.53	Pipe 2FB41D61	0.08	0.02	0.01
Junc 2FAF7143	0	234.97	56.54	Pipe 2FB0400C	0.92	0.17	0.68
Junc 2FAF713F	0	234.97	56.54	Pipe 2FB04010	0.18	0.02	0.01
Junc 2FAF7140	0	234.97	56.54	Pipe 2FB04011	0.4	0.07	0.14
Junc 2FB20A51	0.14	234.93	56.53	Pipe 2FB04020	-0.05	0	0
Junc 2FB0012F	0	234.95	56.53	Pipe 2FB04023	0.29	0.03	0.02
Junc 2FB00132	0.09	234.97	56.54	Pipe 2FB04024	-0.06	0.01	0.01
Junc 2FB2156D	0.12	234.98	56.54	Pipe 2FB04025	-0.51	0.01	0
Junc 2FB00135	0	234.97	56.54	Pipe 2FB04026	0.4	0.04	0.03
Junc 2FB00138	0	234.97	56.54	Pipe 2FB04027	-0.51	0.05	0.06
Junc 2FAF7144	0.06	234.97	56.54	Pipe 2FB04028	-0.41	0.04	0.03
Junc 2FAF715F	0	234.97	56.54	Pipe 2FB04029	-0.1	0.01	0.01
Junc 2FAF7165	0	234.97	56.54	Pipe 2FB0402A	-0.07	0.01	0
Junc 2FAF7163	0	234.97	56.54	Pipe 2FB04073	-0.51	0.05	0.05
Junc 2FAF7162	0	234.98	56.54	Pipe 2FB04076	-0.51	0.05	0.05
Junc 2FAF7164	0	234.97	56.54	Pipe 2FB0407C	-0.51	0.05	0.05
Junc 2FB0019C	0	234.97	56.54	Pipe 2FB04083	-0.23	0.02	0.01
Junc 2FB20072	0.05	234.98	56.54	Pipe 2FB04085	-0.05	0	0
Junc 2FB001AD	0	234.98	56.54	Pipe 2FB04096	-0.38	0.04	0.03
Junc 2FAF7169	0.21	234.98	56.54	Pipe 2FB04098	-0.38	0.04	0.03
Junc 2FB20073	0	234.98	56.54	Pipe 2FB0409A	-0.38	0.04	0.03
Junc 2FB0400D	0	234.98	56.54	Pipe 2FBD00C0	0.1	0.01	0
Junc 2FAF6FCD	0.02	234.98	56.54	Pipe 2FB040A6	0	0	0
Junc 2FB1F714	0.28	234.97	56.54	Pipe 2FB07F35	-0.18	0.04	0.05
Junc 2FAF6FF5	0.22	234.97	56.54	Pipe 2FB4E0E0	0.29	0.03	0.02
Junc 2FB258E3	0	234.98	56.54	Pipe 2FB4E0E2	-0.67	0.07	0.1
Junc 2FB1F715	0.08	234.97	56.54	Pipe 2FB4E0E7	-0.69	0.07	0.11
Junc 2FAF6FF6	0.33	234.97	56.54	Pipe 2FB00862	-0.03	0	0
Junc 2FAF6FD3	0	234.96	56.54	Pipe 2FB00863	0.47	0.09	0.19
Junc 2FAF6FF9	0	234.96	56.54	Pipe 2FB00865	0.78	0.07	0.11
Junc 2FAF6FD4	0.06	234.96	56.54	Pipe 2FB00866	0.39	0.04	0.03
Junc 2FAF6FFC	0.08	234.96	56.54	Pipe 2FB00869	-0.97	0.18	0.76
Junc 2FAF6FD5	0	234.98	56.54	Pipe 2FB0086D	-0.54	0.1	0.24
Junc 2FAF6FF0	0	234.98	56.54	Pipe 2FB0086F	0.9	0.16	0.68
Junc 2FAF6FD7	0	234.98	56.54	Pipe 2FB00877	0.27	0.03	0.02
Junc 2FAF6FF1	0	234.98	56.54	Pipe 2FB00879	0.01	0	0

Junc 2FAF6FD8	0.17	234.97	56.54	Pipe 2FB0089D	-0.11	0.02	0.01
Junc 2FAF6FF2	0.1	234.98	56.54	Pipe 2FB0089E	-0.11	0.02	0.01
Junc 2FAF6FD9	0.02	234.97	56.54	Pipe 2FB008A2	-0.19	0.04	0.06
Junc 2FAF6FF4	0.14	234.97	56.54	Pipe 2FB0094C	-0.94	0.09	0.14
Junc 2FAF6FDA	0.02	234.97	56.54	Pipe 2FB00982	-0.03	0	0
Junc 2FB04077	0	234.98	56.54	Pipe 2FB00985	-0.03	0	0
Junc 2FAF6FF3	0	234.98	56.54	Pipe 2FB00993	-0.02	0	0
Junc 2FAF6FF8	0	234.97	56.54	Pipe 2FB00996	0	0	0
Junc 2FAF6FF7	0	234.97	56.54	Pipe 2FB00999	-0.02	0	0
Junc 2FB27E17	0	234.97	56.54	Pipe 2FB0099E	0.61	0.06	0.06
Junc 2FB0409B	0	234.97	56.54	Pipe 2FB009A0	0.84	0.08	0.12
Junc 2FB040A1	0.19	234.96	56.54	Pipe 2FB009A2	0.84	0.08	0.12
Junc 2FAF6FFA	0.1	234.96	56.54	Pipe 2FB016AE	0.03	0	0
Junc 2FB07F36	0.04	234.96	56.54	Pipe 2FB016B3	0.03	0	0
Junc 2FB27E19	0	234.97	56.54	Pipe 2FB016B5	-0.54	0.1	0.25
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Junc 2FAF5901	0	234.95	56.53	Pipe 2FB02C60	0.27	0.03	0.01
Junc 2FAF5930	0.13	234.95	56.53	Pipe 2FB1CE95	0.84	0.08	0.12
Junc 2FAF58F6	0.15	234.9	56.52	Pipe 2FB1CEA3	0.47	0.04	0.04
Junc 2FB20A5B	0.03	234.92	56.53	Pipe 2FB1CEA6	0.47	0.04	0.04
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Junc 2FAF5909	0.35	234.96	56.54	Pipe 2FB4545C	0.27	0.03	0.02
Junc 2FB16165	0	234.96	56.54	Pipe 2FB4545D	0.27	0.03	0.02
Junc 2FAF590C	0	234.97	56.54	Pipe 2FB4545E	0.27	0.03	0.02
Junc 2FAF590B	0	234.96	56.54	Pipe 2FB45CD5	-0.03	0	0
Junc 2FAF58F9	0	234.98	56.54	Pipe 2FB0FB7E	0.49	0.05	0.06
Junc 2FAF58FA	0	234.97	56.54	Pipe 2FB0FB80	0.49	0.05	0.05
Junc 2FAF58FB	0	234.95	56.53	Pipe 2FB0FB86	0.15	0.01	0.01
Junc 2FB22625	0	234.95	56.53	Pipe 2FB0FB87	0.33	0.03	0.02
Junc 2FB0087A	0.25	234.95	56.53	Pipe 2FB0FB94	0.44	0.04	0.04
Junc 2FAF58FD	0.13	234.95	56.53	Pipe 2FB0FB96	0.47	0.1	0.31
Junc 2FAF58FE	0	234.95	56.53	Pipe 2FB0FBEF	0.65	0.14	0.56
Junc 2FAF58FF	0	234.95	56.53	Pipe 2FB0FBF2	0.49	0.05	0.06
Junc 2FB008A4	0.07	234.95	56.53	Pipe 2FB0FBF5	0.45	0.04	0.04
Junc 2FB0094D	1.55	234.88	56.52	Pipe 2FB0E97D	0.54	0.05	0.05
Junc 2FB00983	0	234.95	56.53	Pipe 2FB0E982	0.03	0	0
Junc 2FB1FD69	0	234.95	56.53	Pipe 2FB0E995	0.65	0.07	0.11
Junc 2FAF5902	0	234.95	56.53	Pipe 2FB0E9CA	0.47	0.1	0.31
Junc 2FB00994	0	234.9	56.52	Pipe 2FB0E9D0	0.44	0.1	0.26
Junc 2FAF5905	0	234.9	56.52	Pipe 2FB0E9D4	0.24	0.02	0.01
Junc 2FAF5904	0.64	234.9	56.52	Pipe 2FB0E9D9	-0.06	0.01	0
Junc 2FAF5903	0.02	234.9	56.52	Pipe 2FB0E9DC	0.15	0.01	0
Junc 2FAF5906	0.23	234.89	56.52	Pipe 2FB10E17	0.65	0.07	0.1

Junc 2FAF5907	0	234.9	56.52	Pipe 2FB8143E	0.39	0.04	0.03
Junc 2FAF5908	0	234.9	56.52	Pipe 2FB97F6E	0.5	0.11	0.34
Junc 2FB009A3	0	234.9	56.52	Pipe 2FB97F6C	0.65	0.14	0.56
Junc 2FB016AF	0	234.96	56.54	Pipe 2FB97F6D	-0.15	0.03	0.04
Junc 2FAF590A	0	234.96	56.54	Pipe 2FB97F7E	0.54	0.12	0.4
Junc 2FAF58F5	0	234.97	56.54	Pipe 2FB1CEE8	-0.29	0.03	0.02
Junc 2FAF590D	0.21	234.96	56.54	Pipe 2FB1CEF8	0.59	0.06	0.06
Junc 2FAF5919	0.17	234.94	56.53	Pipe 2FB1CEFE	0.95	0.1	0.2
Junc 2FB16166	0.21	234.94	56.53	Pipe 2FB1CF0F	0.95	0.09	0.15
Junc 2FB16164	0.16	234.94	56.53	Pipe 2FB1CF11	0.95	0.1	0.2
Junc 2FAF591A	0.05	234.94	56.53	Pipe 2FB1CF13	0.95	0.09	0.15
Junc 2FB22622	0	234.95	56.53	Pipe 2FB1CF16	0.95	0.09	0.15
Junc 2FB16167	0	234.96	56.54	Pipe 2FB1CF18	0.95	0.09	0.15
Junc 2FB016BC	0	234.96	56.54	Pipe 2FB1CF1A	0.81	0.08	0.11
Junc 2FB22623	0	234.95	56.53	Pipe 2FB1CF38	0.59	0.13	0.48
Junc 2FB22624	0	234.95	56.53	Pipe 2FB1CF3A	0.39	0.04	0.03
Junc 2FAF58FC	0	234.95	56.53	Pipe 2FB9C9D1	0.95	0.21	1.14
Junc 2FAF81E5	0	234.98	56.54	Pipe 2FB9CE1D	0.59	0.06	0.06
Junc 2FAF9C08	0	234.98	56.54	Pipe 2FB08BBD	-0.34	0.03	0.03
Junc 2FAF81E6	0	234.98	56.54	Pipe 2FB08BA2	-0.31	0.03	0.02
Junc 2FAF9C09	0.04	234.98	56.54	Pipe 2FB08B9B	0.23	0.02	0
Junc 2FAF81E9	0	234.97	56.54	Pipe 2FB08BA5	0.1	0.01	0
Junc 2FAF74D7	0	234.97	56.54	Pipe 2FB08BB1	-0.45	0.04	0.03
Junc 2FAF74C1	0	234.97	56.54	Pipe 2FB09B24	-0.22	0.02	0.02
Junc 2FAF81EE	0	234.97	56.54	Pipe 2FB08BB9	0.24	0.02	0
Junc 2FAF74D5	0.2	234.97	56.54	Pipe 2FB08BC5	-0.36	0.03	0.03
Junc 2FAF81EF	0	234.98	56.54	Pipe 2FB001A3	0.25	0.02	0.02
Junc 2FAF74D3	0	234.98	56.54	Pipe 2FB00130	1.08	0.1	0.2
Junc 2FB0FBF0	0	234.99	56.54	Pipe 2FB00108	-0.39	0.04	0.03
Junc 2FAF74E9	0	234.98	56.54	Pipe 2FB00105	-0.39	0.04	0.03
Junc 2FB0FBF3	0	234.98	56.54	Pipe 2FB0010E	-0.35	0.03	0.03
Junc 2FAF74C0	0	234.97	56.54	Pipe 2FB0010B	-0.34	0.03	0.02
Junc 2FB0E983	0.3	234.97	56.54	Pipe 2FB00133	-0.13	0.01	0
Junc 2FB0E996	0	234.96	56.53	Pipe 2FB00136	0.89	0.08	0.14
Junc 2FB28167	0.26	234.96	56.53	Pipe 2FB00139	0.06	0.01	0
Junc 2FAF74D2	0.2	234.99	56.54	Pipe 2FB0019D	-0.32	0.03	0.02
Junc 2FB0E9D1	0	234.97	56.54	Pipe 2FB41D62	0.08	0.01	0
Junc 2FAF74D6	0.3	234.97	56.54	Pipe 2FB96C54	-0.49	0.05	0.05
Junc 2FB0E9DA	0	234.97	56.54	Pipe 2FB040A2	0.29	0.03	0.02
Junc 2FB0E9DD	0	234.97	56.54	Pipe 2FB07F37	-0.14	0.01	0
Junc 2FAF74D8	0	234.97	56.54	Pipe 2FB04078	-0.51	0.05	0.05
Junc 2FB2585E	0.1	234.95	56.53	Pipe 2FB04070	0.4	0.04	0.03
Junc 2FB93EC7	0.19	234.98	56.54	Pipe 2FB0409C	-0.38	0.04	0.03
Junc 2FB93EC8	0	234.98	56.54	Pipe 2FB4E0E8	-0.67	0.06	0.08
Junc 2FB93EC4	0	234.97	56.54	Pipe 2FB00984	-0.03	0	0
Junc 2FB93EC5	0	234.96	56.53	Pipe 2FB016B0	0.03	0	0
Junc 2FB93EC6	0	234.97	56.54	Pipe 2FB0087B	0.27	0.03	0.02

Junc 2FB93ECB	0	234.99	56.54	Pipe 2FB008A5	-0.11	0.01	0.02
Junc 2FB93ECC	0	234.99	56.54	Pipe 2FB00995	-0.02	0	0
Junc 2FB16172	0	234.98	56.54	Pipe 2FB009A4	0.84	0.08	0.12
Junc 2FB1618C	0	234.98	56.54	Pipe 2FB016BD	-0.47	0.04	0.05
Junc 2FB16174	0	234.96	56.54	Pipe 2FB1CEA5	0.09	0.01	0
Junc 2FB1617E	0	234.95	56.53	Pipe 2FB1CE97	0.27	0.03	0.02
Junc 2FB1617B	0	234.97	56.54	Pipe 2FB0FBF1	0.65	0.06	0.08
Junc 2FB1617D	0	234.96	56.54	Pipe 2FB0E9D2	0.44	0.04	0.05
Junc 2FB1617C	0	234.96	56.54	Pipe 2FB0FBF4	0.49	0.05	0.05
Junc 2FB1617F	0	234.95	56.53	Pipe 2FB0E9DE	0.15	0.01	0
Junc 2FB16180	0	234.95	56.53	Pipe 2FB0E984	0.33	0.03	0.03
Junc 2FB16181	0.14	234.95	56.53	Pipe 2FB0E9CF	0.47	0.04	0.05
Junc 2FB1618B	0	234.99	56.54	Pipe 2FB0E997	0.65	0.06	0.08
Junc 2FB93AAC	0	234.98	56.54	Pipe 2FB0E9DB	-0.06	0.01	0.02
Junc 2FB1618D	0.21	234.98	56.54	Pipe 2FB0E9E3	0.15	0.01	0.02
Junc 2FB1618A	0.09	234.99	56.54	Pipe 2FB97F6F	0.5	0.05	0.05
Junc 2FB8DEE4	0.09	234.97	56.54	Pipe 2FB97F7F	0.54	0.05	0.05
Junc 2FB8DEE5	0	234.97	56.54	Pipe 2FB1CF3B	0.59	0.06	0.06
Junc 2FB001A2	0.1	234.98	56.54	Pipe 2FB1CF1B	0.95	0.09	0.15
Junc 2FB00104	0	234.98	56.54	Pipe 2FB9CE20	-0.59	0.06	0.06
Junc 2FAF7137	0	234.98	56.54	Pipe 2FB9C9D2	0.95	0.09	0.15
Junc 2FAF7145	0.09	234.97	56.54	Pipe EQ032985	-0.9	0.16	0.62
Junc 2FAF6FEF	0	234.98	56.54	Pipe 2FB0FB7D	-0.44	0.1	0.27
Junc 2FB0406F	0.32	234.98	56.54	Pipe 2FB0E9CD	0.28	0.06	0.12
Junc 2FAF9C07	0	234.99	56.54	Pipe 2FB04071	0.4	0.04	0.03
Junc 2FAF74D4	0	234.97	56.54	Pipe 2FBB3A84	0.4	0.09	0.22
Junc 2FB0E9CE	0.19	234.98	56.54	Pipe 2FB0406E	0.07	0.02	0.01
Junc 2FBA5353	0	234.98	56.54	Pipe 2FBB3A86	0.07	0.01	0
Junc 2FBA5354	0	234.98	56.54	Pipe 2FB040A0	0.29	0.06	0.12
				Pipe 2FBDAFC4	0.15	0.03	0.04
				Pipe 2FB4A97C	-0.34	0.08	0.17
				Pipe 2FB0010C	-0.39	0.09	0.21

Table A2. ***Demand-Head-Pressure*** **at nodes/** ***Flow-Velocity-Unit Head Loss*** **at pipes for Scenario 1.**

Network Table - Nodes				Network Table - Links			
Node ID	Demand GPM	Head ft	Pressure psi	Link ID	Flow GPM	Velocity fps	U. H. ft/Kft
Junc 2FB1F719	0.35	234.97	56.54	Pipe 2FB08B92	-0.26	0.05	0.06
Junc 2FAF7AAD	0.06	234.99	56.54	Pipe 2FB08B93	-0.16	0.03	0.02
Junc 2FB1F71A	0.1	234.94	56.53	Pipe 2FB08B99	1.09	0.2	0.89
Junc 2FAF7AA6	0.04	234.95	56.53	Pipe 2FB08B9C	-0.97	0.18	0.73
Junc 2FB08B9A	0.02	234.93	56.53	Pipe 2FB08B9D	1.1	0.2	0.92
Junc 2FB20A57	0.08	234.89	56.52	Pipe 2FB08B9F	-0.2	0.04	0.04
Junc 2FAF7AA5	0	234.95	56.53	Pipe 2FB08BA3	0.33	0.06	0.1
Junc 2FAF6ACE	0	234.95	56.53	Pipe 2FB08BAA	-0.97	0.18	0.72
Junc 2FAF7AA4	0	234.93	56.53	Pipe 2FB08BB2	0.4	0.07	0.14
Junc 2FB08BA0	0	234.95	56.53	Pipe 2FB08BB4	-0.33	0.06	0.1
Junc 2FB08BA4	0	234.96	56.54	Pipe 2FB08BB5	0.47	0.09	0.19
Junc 2FAF6ACD	0	234.96	56.53	Pipe 2FB08BB7	0.47	0.09	0.19
Junc 2FAF7AA8	0	234.95	56.53	Pipe 2FB08BBB	-0.33	0.06	0.1
Junc 2FAF7AA9	0	234.96	56.54	Pipe 2FB08BC3	0.47	0.1	0.31
Junc 2FB08BB0	0.12	234.96	56.54	Pipe 2FB08BC9	0.47	0.04	0.04
Junc 2FAF7AAA	0.07	234.99	56.54	Pipe 2FB08BCC	-0.33	0.03	0.02
Junc 2FAF7AA7	0.07	234.96	56.54	Pipe 2FB09B22	-0.33	0.03	0.02
Junc 2FAF7AAB	0	234.99	56.54	Pipe 2FB0E152	0.47	0.04	0.04
Junc 2FAF82EA	0	234.99	56.54	Pipe 2FB0E154	0.33	0.07	0.16
Junc 2FAF7AAC	0	234.99	56.54	Pipe 2FB0E155	-0.97	0.09	0.16
Junc 2FB08BB8	0	234.99	56.54	Pipe 2FB00032	-0.76	0.17	0.75
Junc 2FB08BBC	0	234.99	56.54	Pipe 2FB00033	0.64	0.14	0.54
Junc 2FAF7AB0	0	234.99	56.54	Pipe 2FB00036	0.63	0.07	0.09
Junc 2FAF7AAE	0	234.99	56.54	Pipe 2FB0003A	0.97	0.11	0.21
Junc 2FAF6ACC	0	234.99	56.54	Pipe 2FB0003C	-0.34	0.04	0.03
Junc 2FAF7AAF	0	234.99	56.54	Pipe 2FB0003D	-0.49	0.11	0.34
Junc 2FB1F32D	0.01	234.99	56.54	Pipe 2FB0003E	-0.39	0.09	0.21
Junc 2FAF82E9	0.17	234.99	56.54	Pipe 2FBD8B08	-0.44	0.1	0.28
Junc 2FB09B23	0	234.99	56.54	Pipe 2FB00109	-0.55	0.12	0.41
Junc 2FAF70EF	5	234.65	56.46	Pipe 2FBB1012	-0.44	0.1	0.28
Junc 2FAF7167	0	234.66	56.46	Pipe 2FB00124	0.97	0.09	0.16
Junc 2FB20A52	0.12	234.71	56.47	Pipe 2FB00125	-0.34	0.08	0.17
Junc 2FAF7160	0.02	234.69	56.47	Pipe 2FB00126	1.59	0.17	0.51
Junc 2FAF70F1	0	234.92	56.52	Pipe 2FB00127	-0.95	0.1	0.2
Junc 2FAF70F3	0	234.91	56.52	Pipe 2FB00128	0.97	0.09	0.15
Junc 2FAF7142	0	234.9	56.52	Pipe 2FB0012E	0.97	0.11	0.21
Junc 2FAF713E	0	234.91	56.52	Pipe 2FB00131	-0.43	0.1	0.26
Junc 2FAF70F5	0	234.98	56.54	Pipe 2FB00134	1.59	0.15	0.39
Junc 2FAF7136	0	234.99	56.54	Pipe 2FBDAFC1	-0.95	0.21	1.14
Junc 2FB20A50	0.06	234.96	56.54	Pipe 2FB0018B	0.62	0.14	0.52
Junc 2FAF7135	0	234.97	56.54	Pipe 2FB0018D	0.62	0.06	0.06

Junc 2FAF7138	0	234.99	56.54	Pipe 2FB0018F	2.66	0.59	7.62
Junc 2FB00107	0.06	234.99	56.54	Pipe 2FB00192	0.62	0.06	0.07
Junc 2FB0010A	0	234.97	56.54	Pipe 2FB00199	0.62	0.06	0.07
Junc 2FB0010D	0	234.99	56.54	Pipe 2FB0019B	0.62	0.14	0.51
Junc 2FAF7134	0.07	234.99	56.54	Pipe 2FB001A8	1	0.22	1.25
Junc 2FAF713D	0	234.9	56.52	Pipe 2FB001AC	2.66	0.29	1.37
Junc 2FAF7141	0	234.9	56.52	Pipe 2FB41D61	0.95	0.21	1.14
Junc 2FAF7143	0	234.92	56.52	Pipe 2FB0400C	0.96	0.17	0.72
Junc 2FAF713F	0	234.92	56.53	Pipe 2FB04010	0.15	0.01	0
Junc 2FAF7140	0	234.91	56.52	Pipe 2FB04011	0.41	0.07	0.14
Junc 2FB20A51	0.14	234.88	56.52	Pipe 2FB04020	-0.05	0	0
Junc 2FB0012F	0	234.9	56.52	Pipe 2FB04023	0.41	0.04	0.03
Junc 2FB00132	0.09	234.92	56.52	Pipe 2FB04024	0.06	0.01	0.01
Junc 2FB2156D	0.12	234.97	56.54	Pipe 2FB04025	-0.54	0.01	0
Junc 2FB00135	0	234.92	56.53	Pipe 2FB04026	0.41	0.04	0.03
Junc 2FB00138	0	234.85	56.51	Pipe 2FB04027	-0.54	0.05	0.06
Junc 2FAF7144	0.06	234.92	56.53	Pipe 2FB04028	-0.43	0.04	0.03
Junc 2FAF715F	0	234.68	56.46	Pipe 2FB04029	-0.12	0.01	0
Junc 2FAF7165	0	234.68	56.46	Pipe 2FB0402A	-0.1	0.01	0
Junc 2FAF7163	0	234.69	56.47	Pipe 2FB04073	-0.54	0.05	0.05
Junc 2FAF7162	0	234.78	56.49	Pipe 2FB04076	-0.54	0.05	0.05
Junc 2FAF7164	0	234.68	56.47	Pipe 2FB0407C	-0.54	0.05	0.05
Junc 2FB0019C	0	234.68	56.46	Pipe 2FB04083	-0.26	0.02	0.01
Junc 2FB20072	0.05	234.7	56.47	Pipe 2FB04085	-0.07	0.01	0
Junc 2FB001AD	0	234.78	56.49	Pipe 2FB04096	-0.38	0.04	0.03
Junc 2FAF7169	0.21	234.79	56.49	Pipe 2FB04098	-0.38	0.04	0.03
Junc 2FB20073	0	234.7	56.47	Pipe 2FB0409A	-0.38	0.04	0.03
Junc 2FB0400D	0	234.98	56.54	Pipe 2FBD00C0	0.22	0.02	0.01
Junc 2FAF6FCD	0.02	234.98	56.54	Pipe 2FB040A6	0.12	0.01	0.01
Junc 2FB1F714	0.28	234.97	56.54	Pipe 2FB07F35	-0.06	0.01	0.01
Junc 2FAF6FF5	0.22	234.97	56.54	Pipe 2FB4E0E0	0.41	0.04	0.04
Junc 2FB258E3	0	234.98	56.54	Pipe 2FB4E0E2	-0.78	0.08	0.14
Junc 2FB1F715	0.08	234.96	56.54	Pipe 2FB4E0E7	-0.8	0.09	0.14
Junc 2FAF6FF6	0.33	234.96	56.54	Pipe 2FB00862	0.33	0.03	0.02
Junc 2FAF6FD3	0	234.95	56.53	Pipe 2FB00863	0.34	0.06	0.1
Junc 2FAF6FF9	0	234.95	56.53	Pipe 2FB00865	0.91	0.09	0.14
Junc 2FAF6FD4	0.06	234.94	56.53	Pipe 2FB00866	0.42	0.04	0.03
Junc 2FAF6FFC	0.08	234.94	56.53	Pipe 2FB00869	-1.04	0.19	0.87
Junc 2FAF6FD5	0	234.98	56.54	Pipe 2FB0086D	-0.65	0.12	0.34
Junc 2FAF6FF0	0	234.98	56.54	Pipe 2FB0086F	1.35	0.25	1.45
Junc 2FAF6FD7	0	234.98	56.54	Pipe 2FB00877	1.21	0.12	0.24
Junc 2FAF6FF1	0	234.98	56.54	Pipe 2FB00879	0.96	0.09	0.15
Junc 2FAF6FD8	0.17	234.97	56.54	Pipe 2FB0089D	0.83	0.15	0.54
Junc 2FAF6FF2	0.1	234.98	56.54	Pipe 2FB0089E	0.83	0.15	0.55
Junc 2FAF6FD9	0.02	234.97	56.54	Pipe 2FB008A2	0.76	0.17	0.74
Junc 2FAF6FF4	0.14	234.97	56.54	Pipe 2FB0094C	-0.84	0.08	0.12
Junc 2FAF6FDA	0.02	234.97	56.54	Pipe 2FB00982	0.33	0.03	0.02

Junc 2FB04077	0	234.98	56.54	Pipe 2FB00985	0.33	0.03	0.02
Junc 2FAF6FF3	0	234.98	56.54	Pipe 2FB00993	0.11	0.01	0
Junc 2FAF6FF8	0	234.96	56.54	Pipe 2FB00996	0.13	0.01	0
Junc 2FAF6FF7	0	234.96	56.54	Pipe 2FB00999	0.11	0.01	0
Junc 2FB27E17	0	234.96	56.54	Pipe 2FB0099E	0.71	0.07	0.09
Junc 2FB0409B	0	234.96	56.54	Pipe 2FB009A0	0.95	0.09	0.15
Junc 2FB040A1	0.19	234.95	56.53	Pipe 2FB009A2	0.95	0.09	0.14
Junc 2FAF6FFA	0.1	234.94	56.53	Pipe 2FB016AE	0.07	0.01	0
Junc 2FB07F36	0.04	234.94	56.53	Pipe 2FB016B3	0.07	0.01	0
Junc 2FB27E19	0	234.96	56.54	Pipe 2FB016B5	-0.65	0.12	0.35
Junc 2FB27E1A	0	234.97	56.54	Pipe 2FB016B7	-1.04	0.19	0.84
Junc 2FB27E1B	0.02	234.97	56.54	Pipe 2FB016B9	0.26	0.06	0.1
Junc 2FB27E18	0.02	234.98	56.54	Pipe 2FB0202E	-0.12	0.03	0.02
Junc 2FB20A5A	0.32	234.91	56.52	Pipe 2FB02079	-0.33	0.07	0.16
Junc 2FAF5901	0	234.9	56.52	Pipe 2FB02C60	1.21	0.12	0.24
Junc 2FAF5930	0.13	234.9	56.52	Pipe 2FB1CE95	0.95	0.09	0.15
Junc 2FAF58F6	0.15	234.87	56.51	Pipe 2FB1CEA3	0.47	0.04	0.04
Junc 2FB20A5B	0.03	234.9	56.52	Pipe 2FB1CEA6	0.47	0.04	0.04
Junc 2FB1DA13	0.14	234.9	56.52	Pipe 2FB3D878	0.77	0.07	0.1
Junc 2FB20A5C	0	234.97	56.54	Pipe 2FB4545B	1.21	0.12	0.23
Junc 2FAF5909	0.35	234.96	56.54	Pipe 2FB4545C	1.21	0.12	0.23
Junc 2FB16165	0	234.96	56.54	Pipe 2FB4545D	1.21	0.12	0.24
Junc 2FAF590C	0	234.96	56.54	Pipe 2FB4545E	1.21	0.12	0.24
Junc 2FAF590B	0	234.96	56.53	Pipe 2FB45CD5	0.33	0.03	0.02
Junc 2FAF58F9	0	234.95	56.53	Pipe 2FB0FB7E	0.47	0.05	0.05
Junc 2FAF58FA	0	234.94	56.53	Pipe 2FB0FB80	0.47	0.04	0.04
Junc 2FAF58FB	0	234.9	56.52	Pipe 2FB0FB86	0.35	0.03	0.02
Junc 2FB22625	0	234.9	56.52	Pipe 2FB0FB87	0.33	0.03	0.02
Junc 2FB0087A	0.25	234.89	56.52	Pipe 2FB0FB94	0.55	0.05	0.05
Junc 2FAF58FD	0.13	234.84	56.51	Pipe 2FB0FB96	0.51	0.11	0.35
Junc 2FAF58FE	0	234.84	56.5	Pipe 2FB0FBEF	0.7	0.16	0.65
Junc 2FAF58FF	0	234.83	56.5	Pipe 2FB0FBF2	0.47	0.05	0.05
Junc 2FB008A4	0.07	234.83	56.5	Pipe 2FB0FBF5	0.43	0.04	0.03
Junc 2FB0094D	1.55	234.84	56.51	Pipe 2FB0E97D	0.62	0.06	0.07
Junc 2FB00983	0	234.9	56.52	Pipe 2FB0E982	0.03	0	0
Junc 2FB1FD69	0	234.9	56.52	Pipe 2FB0E995	1.01	0.11	0.23
Junc 2FAF5902	0	234.9	56.52	Pipe 2FB0E9CA	0.51	0.11	0.36
Junc 2FB00994	0	234.87	56.51	Pipe 2FB0E9D0	0.55	0.12	0.42
Junc 2FAF5905	0	234.87	56.51	Pipe 2FB0E9D4	0.36	0.03	0.02
Junc 2FAF5904	0.64	234.87	56.51	Pipe 2FB0E9D9	0.06	0.01	0
Junc 2FAF5903	0.02	234.87	56.51	Pipe 2FB0E9DC	0.35	0.03	0.02
Junc 2FAF5906	0.23	234.86	56.51	Pipe 2FB10E17	0.7	0.08	0.11
Junc 2FAF5907	0	234.87	56.51	Pipe 2FB8143E	0.75	0.07	0.09
Junc 2FAF5908	0	234.87	56.51	Pipe 2FB97F6E	0.66	0.15	0.57
Junc 2FB009A3	0	234.87	56.51	Pipe 2FB97F6C	1.01	0.22	1.26
Junc 2FB016AF	0	234.96	56.54	Pipe 2FB97F6D	-0.35	0.08	0.18
Junc 2FAF590A	0	234.96	56.54	Pipe 2FB97F7E	0.62	0.14	0.52

Junc 2FAF58F5	0	234.97	56.54	Pipe 2FB1CEE8	-0.65	0.06	0.07
Junc 2FAF590D	0.21	234.96	56.53	Pipe 2FB1CEF8	0.63	0.06	0.07
Junc 2FAF5919	0.17	234.93	56.53	Pipe 2FB1CEFE	1.07	0.12	0.25
Junc 2FB16166	0.21	234.93	56.53	Pipe 2FB1CF0F	1.07	0.1	0.18
Junc 2FB16164	0.16	234.94	56.53	Pipe 2FB1CF11	1.07	0.12	0.25
Junc 2FAF591A	0.05	234.94	56.53	Pipe 2FB1CF13	1.07	0.1	0.19
Junc 2FB22622	0	234.9	56.52	Pipe 2FB1CF16	1.07	0.1	0.19
Junc 2FB16167	0	234.96	56.53	Pipe 2FB1CF18	1.07	0.1	0.18
Junc 2FB016BC	0	234.96	56.53	Pipe 2FB1CF1A	0.94	0.09	0.14
Junc 2FB22623	0	234.9	56.52	Pipe 2FB1CF38	0.63	0.14	0.53
Junc 2FB22624	0	234.9	56.52	Pipe 2FB1CF3A	0.42	0.04	0.03
Junc 2FAF58FC	0	234.9	56.52	Pipe 2FB9C9D1	1.07	0.24	1.45
Junc 2FAF81E5	0	234.98	56.54	Pipe 2FB9CE1D	0.63	0.06	0.07
Junc 2FAF9C08	0	234.97	56.54	Pipe 2FB08BBD	-0.33	0.03	0.03
Junc 2FAF81E6	0	234.97	56.54	Pipe 2FB08BA2	-0.2	0.02	0.02
Junc 2FAF9C09	0.04	234.97	56.54	Pipe 2FB08B9B	1.1	0.11	0.21
Junc 2FAF81E9	0	234.96	56.54	Pipe 2FB08BA5	0.33	0.03	0.02
Junc 2FAF74D7	0	234.96	56.54	Pipe 2FB08BB1	-0.97	0.09	0.15
Junc 2FAF74C1	0	234.96	56.54	Pipe 2FB09B24	-0.33	0.03	0.02
Junc 2FAF81EE	0	234.97	56.54	Pipe 2FB08BB9	0.47	0.04	0.05
Junc 2FAF74D5	0.2	234.97	56.54	Pipe 2FB08BC5	-0.47	0.04	0.05
Junc 2FAF81EF	0	234.98	56.54	Pipe 2FB001A3	-0.76	0.07	0.11
Junc 2FAF74D3	0	234.98	56.54	Pipe 2FB00130	0.97	0.09	0.15
Junc 2FB0FBF0	0	234.98	56.54	Pipe 2FB00108	-0.49	0.05	0.05
Junc 2FAF74E9	0	234.98	56.54	Pipe 2FB00105	-0.39	0.04	0.03
Junc 2FB0FBF3	0	234.97	56.54	Pipe 2FB0010E	-0.44	0.04	0.05
Junc 2FAF74C0	0	234.96	56.54	Pipe 2FB0010B	-0.55	0.05	0.06
Junc 2FB0E983	0.3	234.96	56.54	Pipe 2FB00133	-0.34	0.03	0.03
Junc 2FB0E996	0	234.92	56.53	Pipe 2FB00136	1.59	0.15	0.41
Junc 2FB28167	0.26	234.92	56.53	Pipe 2FB00139	-0.95	0.09	0.15
Junc 2FAF74D2	0.2	234.98	56.54	Pipe 2FB0019D	0.62	0.06	0.06
Junc 2FB0E9D1	0	234.97	56.54	Pipe 2FB41D62	0.95	0.09	0.15
Junc 2FAF74D6	0.3	234.96	56.54	Pipe 2FB96C54	-2.66	0.25	1.05
Junc 2FB0E9DA	0	234.96	56.54	Pipe 2FB040A2	0.41	0.04	0.03
Junc 2FB0E9DD	0	234.96	56.54	Pipe 2FB07F37	-0.02	0	0
Junc 2FAF74D8	0	234.96	56.53	Pipe 2FB04078	-0.54	0.05	0.06
Junc 2FB2585E	0.1	234.91	56.52	Pipe 2FB04070	0.41	0.04	0.03
Junc 2FB93EC7	0.19	234.98	56.54	Pipe 2FB0409C	-0.38	0.04	0.03
Junc 2FB93EC8	0	234.98	56.54	Pipe 2FB4E0E8	-0.78	0.07	0.11
Junc 2FB93EC4	0	234.95	56.53	Pipe 2FB00984	0.33	0.03	0.02
Junc 2FB93EC5	0	234.92	56.53	Pipe 2FB016B0	0.07	0.01	0
Junc 2FB93EC6	0	234.96	56.53	Pipe 2FB0087B	1.21	0.12	0.24
Junc 2FB93ECB	0	234.99	56.54	Pipe 2FB008A5	0.83	0.08	0.12
Junc 2FB93ECC	0	234.99	56.54	Pipe 2FB00995	0.11	0.01	0.02
Junc 2FB16172	0	234.98	56.54	Pipe 2FB009A4	0.95	0.09	0.15
Junc 2FB1618C	0	234.98	56.54	Pipe 2FB016BD	-0.47	0.04	0.03
Junc 2FB16174	0	234.95	56.53	Pipe 2FB1CEA5	0.09	0.01	0

Junc 2FB1617E	0	234.94	56.53
Junc 2FB1617B	0	234.96	56.53
Junc 2FB1617D	0	234.96	56.53
Junc 2FB1617C	0	234.95	56.53
Junc 2FB1617F	0	234.94	56.53
Junc 2FB16180	0	234.94	56.53
Junc 2FB16181	0.14	234.94	56.53
Junc 2FB1618B	0	234.98	56.54
Junc 2FB93AAC	0	234.98	56.54
Junc 2FB1618D	0.21	234.98	56.54
Junc 2FB1618A	0.09	234.98	56.54
Junc 2FB8DEE4	0.09	234.96	56.54
Junc 2FB8DEE5	0	234.96	56.54
Junc 2FB001A2	0.1	234.66	56.46
Junc 2FB00104	0	234.97	56.54
Junc 2FAF7137	0	234.97	56.54
Junc 2FAF7145	0.09	234.85	56.51
Junc 2FAF6FEF	0	234.98	56.54
Junc 2FB0406F	0.32	234.98	56.54
Junc 2FAF9C07	0	234.98	56.54
Junc 2FAF74D4	0	234.97	56.54
Junc 2FB0E9CE	0.19	234.98	56.54
Junc 2FBA5353	0	234.98	56.54
Junc 2FBA5354	0	234.97	56.54

Pipe 2FB1CE97	0.27	0.03	0.02
Pipe 2FB0FBF1	0.7	0.07	0.09
Pipe 2FB0E9D2	0.55	0.05	0.05
Pipe 2FB0FBF4	0.47	0.04	0.05
Pipe 2FB0E9DE	0.35	0.03	0.02
Pipe 2FB0E984	0.33	0.03	0.03
Pipe 2FB0E9CF	0.51	0.05	0.06
Pipe 2FB0E997	1.01	0.1	0.18
Pipe 2FB0E9DB	0.06	0.01	0
Pipe 2FB0E9E3	0.35	0.03	0.03
Pipe 2FB97F6F	0.66	0.06	0.08
Pipe 2FB97F7F	0.62	0.06	0.06
Pipe 2FB1CF3B	0.63	0.06	0.08
Pipe 2FB1CF1B	1.07	0.1	0.2
Pipe 2FB9CE20	-0.63	0.06	0.08
Pipe 2FB9C9D2	1.07	0.1	0.18
Pipe EQ032985	-1.35	0.25	1.33
Pipe 2FB0FB7D	-0.55	0.12	0.41
Pipe 2FB0E9CD	0.32	0.07	0.15
Pipe 2FB04071	0.41	0.04	0.03
Pipe 2FBB3A84	0.41	0.09	0.24
Pipe 2FB0406E	0.09	0.02	0.01
Pipe 2FBB3A86	0.09	0.01	0
Pipe 2FB040A0	0.41	0.09	0.23
Pipe 2FBDAFC4	-0.87	0.19	0.95
Pipe 2FB4A97C	-0.55	0.12	0.41
Pipe 2FB0010C	-0.39	0.09	0.21
Pipe 1	0.55	0.12	2.02
Pipe 2	-0.52	0.11	1.78
Pipe 3	1.04	0.23	6.58
Pipe 4	0.71	0.16	3.23
Pipe 5	1.16	0.26	7.99
Pipe 6	-0.85	0.19	4.49
Pipe 7	-0.62	0.14	2.54
Pipe 8	-1.35	0.3	10.6
Pipe 9	-0.82	0.18	4.2
Pipe 10	-0.7	0.16	3.15
Pipe 11	0.7	0.16	3.16
Pipe 12	0.48	0.11	1.54
Pipe 13	1.09	0.24	7.09
Pipe 14	0.5	0.11	1.69
Pipe 15	-1.65	0.37	15.35
Pipe 16	2.87	0.64	42.83
Pipe 17	0.96	0.17	3.48

APPENDIX B

Table B1. *Demand-Head-Pressure* at nodes/ *Flow-Velocity-Unit Head Loss* at pipes for Scenario 2 of the testing phase.

CONED	Scenario 2: 1^ Increase			CONED	Scenario 2: 1^ Increase		
Network Table - Nodes				Network Table - Links			
Node ID	Demand GPM	Head ft	Pressure psi	Link ID	Flow GPM	Velocity fps	U. H. ft/Kft
Junc 2FB1F719	0.35	234.97	56.54	Pipe 2FB08B92	-0.28	0.05	0.07
Junc 2FAF7AAD	0.06	234.99	56.54	Pipe 2FB08B93	-0.3	0.05	0.08
Junc 2FB1F71A	0.1	234.96	56.53	Pipe 2FB08B99	0.39	0.07	0.13
Junc 2FAF7AA6	0.04	234.97	56.54	Pipe 2FB08B9C	-0.59	0.11	0.29
Junc 2FB08B9A	0.02	234.98	56.54	Pipe 2FB08B9D	0.41	0.07	0.14
Junc 2FB20A57	0.08	234.97	56.54	Pipe 2FB08B9F	-0.34	0.06	0.1
Junc 2FAF7AA5	0	234.98	56.54	Pipe 2FB08BA3	0.16	0.03	0.03
Junc 2FAF6ACE	0	234.98	56.54	Pipe 2FB08BAA	-0.59	0.11	0.28
Junc 2FAF7AA4	0	234.98	56.54	Pipe 2FB08BB2	0.23	0.04	0.05
Junc 2FB08BA0	0	234.97	56.54	Pipe 2FB08BB4	-0.25	0.05	0.06
Junc 2FB08BA4	0	234.98	56.54	Pipe 2FB08BB5	0.3	0.05	0.08
Junc 2FAF6ACD	0	234.98	56.54	Pipe 2FB08BB7	0.3	0.05	0.09
Junc 2FAF7AA8	0	234.98	56.54	Pipe 2FB08BBB	-0.34	0.06	0.11
Junc 2FAF7AA9	0	234.98	56.54	Pipe 2FB08BC3	0.39	0.09	0.22
Junc 2FB08BB0	0.12	234.98	56.54	Pipe 2FB08BC9	0.39	0.04	0.03
Junc 2FAF7AAA	0.07	234.99	56.54	Pipe 2FB08BCC	-0.34	0.03	0.02
Junc 2FAF7AA7	0.07	234.98	56.54	Pipe 2FB09B22	-0.25	0.02	0.01
Junc 2FAF7AAB	0	234.99	56.54	Pipe 2FB0E152	0.39	0.04	0.03
Junc 2FAF82EA	0	234.99	56.54	Pipe 2FB0E154	0.16	0.04	0.04
Junc 2FAF7AAC	0	234.99	56.54	Pipe 2FB0E155	-0.59	0.06	0.06
Junc 2FB08BB8	0	234.99	56.54	Pipe 2FB00032	0.17	0.04	0.05
Junc 2FB08BBC	0	234.99	56.54	Pipe 2FB00033	-0.97	0.22	1.18
Junc 2FAF7AB0	0	234.99	56.54	Pipe 2FB00036	1.26	0.14	0.33
Junc 2FAF7AAE	0	234.99	56.54	Pipe 2FB0003A	1.51	0.16	0.47
Junc 2FAF6ACC	0	234.99	56.54	Pipe 2FB0003C	-0.26	0.03	0.02
Junc 2FAF7AAF	0	234.99	56.54	Pipe 2FB0003D	-0.47	0.1	0.3
Junc 2FB1F32D	0.01	234.99	56.54	Pipe 2FB0003E	-0.41	0.09	0.24
Junc 2FAF82E9	0.17	234.99	56.54	Pipe 2FBD8B08	-0.42	0.09	0.25
Junc 2FB09B23	0	234.99	56.54	Pipe 2FB00109	-0.47	0.1	0.3
Junc 2FAF70EF	0	234.94	56.53	Pipe 2FBB1012	-0.42	0.09	0.25
Junc 2FAF7167	0	234.94	56.53	Pipe 2FB00124	1.51	0.14	0.35
Junc 2FB20A52	0.12	234.81	56.5	Pipe 2FB00125	-0.26	0.06	0.1
Junc 2FAF7160	0.02	234.86	56.51	Pipe 2FB00126	1.28	0.14	0.34
Junc 2FAF70F1	0	234.94	56.53	Pipe 2FB00127	-0.02	0	0
Junc 2FAF70F3	0	234.94	56.53	Pipe 2FB00128	1.51	0.14	0.34
Junc 2FAF7142	0	234.91	56.52	Pipe 2FB0012E	1.51	0.16	0.47
Junc 2FAF713E	0	234.94	56.53	Pipe 2FB00131	-0.35	0.08	0.17
Junc 2FAF70F5	0	234.99	56.54	Pipe 2FB00134	1.28	0.12	0.26

Junc 2FAF7136	0	234.99	56.54	Pipe 2FBDAFC1	-0.02	0	0
Junc 2FB20A50	0.06	234.96	56.53	Pipe 2FB0018B	-0.99	0.22	1.22
Junc 2FAF7135	0	234.97	56.54	Pipe 2FB0018D	-0.99	0.09	0.16
Junc 2FAF7138	0	234.99	56.54	Pipe 2FB0018F	0.91	0.2	1.03
Junc 2FB00107	0.06	234.99	56.54	Pipe 2FB00192	-0.99	0.09	0.16
Junc 2FB0010A	0	234.97	56.54	Pipe 2FB00199	-0.99	0.09	0.16
Junc 2FB0010D	0	234.99	56.54	Pipe 2FB0019B	-0.99	0.22	1.21
Junc 2FAF7134	0.07	234.99	56.54	Pipe 2FB001A8	0.3	0.07	0.14
Junc 2FAF713D	0	234.91	56.52	Pipe 2FB001AC	0.91	0.1	0.18
Junc 2FAF7141	0	234.91	56.52	Pipe 2FB41D61	0.26	0.06	0.1
Junc 2FAF7143	0	234.94	56.53	Pipe 2FB0400C	0.99	0.18	0.76
Junc 2FAF713F	0	234.95	56.53	Pipe 2FB04010	0.11	0.01	0
Junc 2FAF7140	0	234.94	56.53	Pipe 2FB04011	0.39	0.07	0.14
Junc 2FB20A51	0.14	234.87	56.51	Pipe 2FB04020	-0.26	0.03	0.01
Junc 2FB0012F	0	234.91	56.52	Pipe 2FB04023	0.26	0.02	0.01
Junc 2FB00132	0.09	234.94	56.53	Pipe 2FB04024	-0.09	0.02	0.01
Junc 2FB2156D	0.12	234.97	56.54	Pipe 2FB04025	-0.58	0.01	0
Junc 2FB00135	0	234.95	56.53	Pipe 2FB04026	0.39	0.04	0.03
Junc 2FB00138	0	234.94	56.53	Pipe 2FB04027	-0.58	0.06	0.06
Junc 2FAF7144	0.06	234.95	56.53	Pipe 2FB04028	-0.47	0.05	0.04
Junc 2FAF715F	0	234.88	56.52	Pipe 2FB04029	-0.16	0.02	0.01
Junc 2FAF7165	0	234.89	56.52	Pipe 2FB0402A	-0.14	0.02	0.01
Junc 2FAF7163	0	234.86	56.51	Pipe 2FB04073	-0.58	0.06	0.06
Junc 2FAF7162	0	234.96	56.54	Pipe 2FB04076	-0.58	0.06	0.06
Junc 2FAF7164	0	234.88	56.52	Pipe 2FB0407C	-0.58	0.06	0.06
Junc 2FB0019C	0	234.89	56.52	Pipe 2FB04083	-0.3	0.03	0.02
Junc 2FB20072	0.05	234.95	56.53	Pipe 2FB04085	-0.12	0.01	0
Junc 2FB001AD	0	234.96	56.54	Pipe 2FB04096	-0.59	0.06	0.06
Junc 2FAF7169	0.21	234.96	56.54	Pipe 2FB04098	-0.59	0.06	0.06
Junc 2FB20073	0	234.95	56.53	Pipe 2FB0409A	-0.59	0.06	0.06
Junc 2FB0400D	0	234.98	56.54	Pipe 2FBD00C0	0.07	0.01	0
Junc 2FAF6FCD	0.02	234.98	56.54	Pipe 2FB040A6	-0.03	0	0
Junc 2FB1F714	0.28	234.97	56.54	Pipe 2FB07F35	-0.21	0.05	0.07
Junc 2FAF6FF5	0.22	234.97	56.54	Pipe 2FB4E0E0	0.26	0.03	0.02
Junc 2FB258E3	0	234.98	56.54	Pipe 2FB4E0E2	-0.85	0.09	0.16
Junc 2FB1F715	0.08	234.95	56.53	Pipe 2FB4E0E7	-0.87	0.09	0.17
Junc 2FAF6FF6	0.33	234.95	56.53	Pipe 2FB00862	1.21	0.12	0.23
Junc 2FAF6FD3	0	234.95	56.53	Pipe 2FB00863	-0.8	0.15	0.51
Junc 2FAF6FF9	0	234.95	56.53	Pipe 2FB00865	1.23	0.12	0.24
Junc 2FAF6FD4	0.06	234.95	56.53	Pipe 2FB00866	0.5	0.05	0.05
Junc 2FAF6FFC	0.08	234.95	56.53	Pipe 2FB00869	-1.21	0.22	1.15
Junc 2FAF6FD5	0	234.98	56.54	Pipe 2FB0086D	-0.93	0.17	0.66
Junc 2FAF6FF0	0	234.98	56.54	Pipe 2FB0086F	2.72	0.49	5.37
Junc 2FAF6FD7	0	234.98	56.54	Pipe 2FB00877	-0.4	0.04	0.03
Junc 2FAF6FF1	0	234.98	56.54	Pipe 2FB00879	-0.65	0.06	0.07
Junc 2FAF6FD8	0.17	234.97	56.54	Pipe 2FB0089D	-0.78	0.14	0.48
Junc 2FAF6FF2	0.1	234.98	56.54	Pipe 2FB0089E	-0.78	0.14	0.49

Junc 2FAF6FD9	0.02	234.97	56.54	Pipe 2FB008A2	-0.85	0.19	0.92
Junc 2FAF6FF4	0.14	234.97	56.54	Pipe 2FB0094C	-1.38	0.13	0.29
Junc 2FAF6FDA	0.02	234.97	56.54	Pipe 2FB00982	1.21	0.12	0.23
Junc 2FB04077	0	234.98	56.54	Pipe 2FB00985	1.21	0.12	0.23
Junc 2FAF6FF3	0	234.98	56.54	Pipe 2FB00993	0.43	0.05	0.05
Junc 2FAF6FF8	0	234.95	56.53	Pipe 2FB00996	0.45	0.04	0.04
Junc 2FAF6FF7	0	234.96	56.53	Pipe 2FB00999	0.43	0.04	0.03
Junc 2FB27E17	0	234.96	56.53	Pipe 2FB0099E	0.17	0.02	0.01
Junc 2FB0409B	0	234.95	56.53	Pipe 2FB009A0	0.41	0.04	0.03
Junc 2FB040A1	0.19	234.95	56.53	Pipe 2FB009A2	0.41	0.04	0.03
Junc 2FAF6FFA	0.1	234.95	56.53	Pipe 2FB016AE	0.15	0.01	0
Junc 2FB07F36	0.04	234.95	56.53	Pipe 2FB016B3	0.15	0.01	0.01
Junc 2FB27E19	0	234.96	56.53	Pipe 2FB016B5	-0.93	0.17	0.68
Junc 2FB27E1A	0	234.96	56.54	Pipe 2FB016B7	-1.21	0.22	1.11
Junc 2FB27E1B	0.02	234.96	56.54	Pipe 2FB016B9	0.23	0.05	0.08
Junc 2FB27E18	0.02	234.98	56.54	Pipe 2FB0202E	-0.15	0.03	0.03
Junc 2FB20A5A	0.32	234.74	56.48	Pipe 2FB02079	-0.36	0.08	0.18
Junc 2FAF5901	0	234.64	56.46	Pipe 2FB02C60	4.6	0.44	2.88
Junc 2FAF5930	0.13	234.63	56.45	Pipe 2FB1CE95	0.41	0.04	0.03
Junc 2FAF58F6	0.15	234.77	56.49	Pipe 2FB1CEA3	0.44	0.04	0.03
Junc 2FB20A5B	0.03	234.84	56.51	Pipe 2FB1CEA6	0.44	0.04	0.03
Junc 2FB1DA13	0.14	234.84	56.51	Pipe 2FB3D878	1.09	0.1	0.19
Junc 2FB20A5C	0	234.96	56.54	Pipe 2FB4545B	-0.4	0.04	0.03
Junc 2FAF5909	0.35	234.95	56.53	Pipe 2FB4545C	-0.4	0.04	0.03
Junc 2FB16165	0	234.95	56.53	Pipe 2FB4545D	-0.4	0.04	0.03
Junc 2FAF590C	0	234.95	56.53	Pipe 2FB4545E	-0.4	0.04	0.03
Junc 2FAF590B	0	234.94	56.53	Pipe 2FB45CD5	1.21	0.12	0.23
Junc 2FAF58F9	0	234.81	56.5	Pipe 2FB0FB7E	0.43	0.05	0.04
Junc 2FAF58FA	0	234.79	56.49	Pipe 2FB0FB80	0.43	0.04	0.04
Junc 2FAF58FB	0	234.62	56.45	Pipe 2FB0FB86	0.83	0.08	0.11
Junc 2FB22625	0	234.62	56.45	Pipe 2FB0FB87	0.12	0.01	0
Junc 2FB0087A	0.25	234.62	56.45	Pipe 2FB0FB94	0.7	0.07	0.09
Junc 2FAF58FD	0.13	234.65	56.46	Pipe 2FB0FB96	0.55	0.12	0.42
Junc 2FAF58FE	0	234.65	56.46	Pipe 2FB0FBEF	0.76	0.17	0.76
Junc 2FAF58FF	0	234.66	56.46	Pipe 2FB0FBF2	0.43	0.05	0.05
Junc 2FB008A4	0.07	234.66	56.46	Pipe 2FB0FBF5	0.38	0.04	0.03
Junc 2FB0094D	1.55	234.77	56.49	Pipe 2FB0E97D	0.74	0.07	0.1
Junc 2FB00983	0	234.64	56.46	Pipe 2FB0E982	-0.18	0.02	0.01
Junc 2FB1FD69	0	234.64	56.45	Pipe 2FB0E995	1.89	0.2	0.75
Junc 2FAF5902	0	234.64	56.45	Pipe 2FB0E9CA	0.55	0.12	0.42
Junc 2FB00994	0	234.78	56.49	Pipe 2FB0E9D0	0.7	0.16	0.66
Junc 2FAF5905	0	234.77	56.49	Pipe 2FB0E9D4	0.51	0.05	0.05
Junc 2FAF5904	0.64	234.78	56.49	Pipe 2FB0E9D9	0.21	0.02	0.01
Junc 2FAF5903	0.02	234.78	56.49	Pipe 2FB0E9DC	0.83	0.08	0.11
Junc 2FAF5906	0.23	234.77	56.49	Pipe 2FB10E17	0.76	0.08	0.13
Junc 2FAF5907	0	234.77	56.49	Pipe 2FB8143E	1.63	0.16	0.39
Junc 2FAF5908	0	234.77	56.49	Pipe 2FB97F6E	1.05	0.23	1.36

Junc 2FB009A3	0	234.77	56.49	Pipe 2FB97F6C	1.89	0.42	4.01
Junc 2FB016AF	0	234.95	56.53	Pipe 2FB97F6D	-0.83	0.18	0.88
Junc 2FAF590A	0	234.95	56.53	Pipe 2FB97F7E	0.74	0.16	0.71
Junc 2FAF58F5	0	234.96	56.53	Pipe 2FB1CEE8	-1.53	0.15	0.35
Junc 2FAF590D	0.21	234.94	56.53	Pipe 2FB1CEF8	0.71	0.07	0.09
Junc 2FAF5919	0.17	234.92	56.53	Pipe 2FB1CEFE	1.4	0.15	0.4
Junc 2FB16166	0.21	234.92	56.53	Pipe 2FB1CF0F	1.4	0.13	0.3
Junc 2FB16164	0.16	234.93	56.53	Pipe 2FB1CF11	1.4	0.15	0.4
Junc 2FAF591A	0.05	234.93	56.53	Pipe 2FB1CF13	1.4	0.13	0.31
Junc 2FB22622	5	234.62	56.45	Pipe 2FB1CF16	1.4	0.13	0.31
Junc 2FB16167	0	234.94	56.53	Pipe 2FB1CF18	1.4	0.13	0.3
Junc 2FB016BC	0	234.94	56.53	Pipe 2FB1CF1A	1.26	0.12	0.25
Junc 2FB22623	0	234.62	56.45	Pipe 2FB1CF38	0.71	0.16	0.67
Junc 2FB22624	0	234.62	56.45	Pipe 2FB1CF3A	0.5	0.05	0.05
Junc 2FAF58FC	0	234.62	56.45	Pipe 2FB9C9D1	1.4	0.31	2.36
Junc 2FAF81E5	0	234.97	56.54	Pipe 2FB9CE1D	0.71	0.07	0.08
Junc 2FAF9C08	0	234.97	56.54	Pipe 2FB08BBD	-0.34	0.03	0.03
Junc 2FAF81E6	0	234.97	56.54	Pipe 2FB08BA2	-0.34	0.03	0.02
Junc 2FAF9C09	0.04	234.97	56.54	Pipe 2FB08B9B	0.41	0.04	0.03
Junc 2FAF81E9	0	234.95	56.53	Pipe 2FB08BA5	0.16	0.02	0
Junc 2FAF74D7	0	234.95	56.53	Pipe 2FB08BB1	-0.59	0.06	0.08
Junc 2FAF74C1	0	234.95	56.53	Pipe 2FB09B24	-0.25	0.02	0.02
Junc 2FAF81EE	0	234.96	56.53	Pipe 2FB08BB9	0.3	0.03	0.02
Junc 2FAF74D5	0.2	234.96	56.53	Pipe 2FB08BC5	-0.39	0.04	0.03
Junc 2FAF81EF	0	234.98	56.54	Pipe 2FB001A3	0.17	0.02	0
Junc 2FAF74D3	0	234.98	56.54	Pipe 2FB00130	1.51	0.14	0.37
Junc 2FB0FBF0	0	234.98	56.54	Pipe 2FB00108	-0.47	0.04	0.05
Junc 2FAF74E9	0	234.98	56.54	Pipe 2FB00105	-0.41	0.04	0.03
Junc 2FB0FBF3	0	234.97	56.54	Pipe 2FB0010E	-0.42	0.04	0.03
Junc 2FAF74C0	0	234.95	56.53	Pipe 2FB0010B	-0.47	0.04	0.05
Junc 2FB0E983	0.3	234.95	56.53	Pipe 2FB00133	-0.26	0.02	0.02
Junc 2FB0E996	0	234.81	56.5	Pipe 2FB00136	1.28	0.12	0.27
Junc 2FB28167	0.26	234.81	56.5	Pipe 2FB00139	-0.02	0	0
Junc 2FAF74D2	0.2	234.98	56.54	Pipe 2FB0019D	-0.99	0.09	0.17
Junc 2FB0E9D1	0	234.96	56.54	Pipe 2FB41D62	0.26	0.02	0.02
Junc 2FAF74D6	0.3	234.95	56.53	Pipe 2FB96C54	-0.91	0.09	0.14
Junc 2FB0E9DA	0	234.95	56.53	Pipe 2FB040A2	0.26	0.02	0.02
Junc 2FB0E9DD	0	234.95	56.53	Pipe 2FB07F37	-0.17	0.02	0
Junc 2FAF74D8	0	234.92	56.53	Pipe 2FB04078	-0.58	0.06	0.06
Junc 2FB2585E	0.1	234.76	56.49	Pipe 2FB04070	0.39	0.04	0.03
Junc 2FB93EC7	0.19	234.95	56.53	Pipe 2FB0409C	-0.59	0.06	0.06
Junc 2FB93EC8	0	234.95	56.53	Pipe 2FB4E0E8	-0.85	0.08	0.14
Junc 2FB93EC4	0	234.89	56.52	Pipe 2FB00984	1.21	0.12	0.24
Junc 2FB93EC5	0	234.81	56.5	Pipe 2FB016B0	0.15	0.01	0
Junc 2FB93EC6	0	234.92	56.53	Pipe 2FB0087B	-0.4	0.04	0.03
Junc 2FB93ECB	0	234.98	56.54	Pipe 2FB008A5	-0.78	0.07	0.11
Junc 2FB93ECC	0	234.98	56.54	Pipe 2FB00995	0.43	0.04	0.05

Junc 2FB16172	0	234.98	56.54
Junc 2FB1618C	0	234.97	56.54
Junc 2FB16174	0	234.92	56.52
Junc 2FB1617E	0	234.91	56.52
Junc 2FB1617B	0	234.93	56.53
Junc 2FB1617D	0	234.93	56.53
Junc 2FB1617C	0	234.93	56.53
Junc 2FB1617F	0	234.9	56.52
Junc 2FB16180	0	234.9	56.52
Junc 2FB16181	0.14	234.9	56.52
Junc 2FB1618B	0	234.98	56.54
Junc 2FB93AAC	0	234.98	56.54
Junc 2FB1618D	0.21	234.97	56.54
Junc 2FB1618A	0.09	234.98	56.54
Junc 2FB8DEE4	0.09	234.94	56.53
Junc 2FB8DEE5	0	234.94	56.53
Junc 2FB001A2	0.1	234.94	56.53
Junc 2FB00104	0	234.97	56.54
Junc 2FAF7137	0	234.97	56.54
Junc 2FAF7145	0.09	234.94	56.53
Junc 2FAF6FEF	0	234.98	56.54
Junc 2FB0406F	0.32	234.98	56.54
Junc 2FAF9C07	0	234.98	56.54
Junc 2FAF74D4	0	234.96	56.54
Junc 2FB0E9CE	0.19	234.98	56.54
Junc 2FBA5353	0	234.98	56.54
Junc 2FBA5354	0	234.97	56.54
Resvr 1	-0.52	235	0
Resvr 2	-0.49	235	0
Resvr 4	-1.21	235	0
Resvr 5	-0.8	235	0
Resvr 6	-1.49	235	0
Resvr 7	-1.24	235	0
Resvr 8	-2.72	235	0
Resvr 9	-0.89	235	0
Resvr 10	-0.74	235	0
Resvr 3	-0.76	235	0
Resvr 11	-0.75	235	0
Resvr 12	-0.4	235	0
Resvr 13	-0.43	235	0
Resvr 14	-0.7	235	0
Resvr 15	0	235	0
Resvr 17	-1.34	235	0
Resvr 18	-1.11	235	0
Resvr 16	-0.99	235	0

Pipe 2FB009A4	0.41	0.04	0.03
Pipe 2FB016BD	-0.44	0.04	0.05
Pipe 2FB1CEA5	0.06	0.01	0
Pipe 2FB1CE97	0.3	0.03	0.02
Pipe 2FB0FBF1	0.76	0.07	0.11
Pipe 2FB0E9D2	0.7	0.07	0.09
Pipe 2FB0FBF4	0.43	0.04	0.03
Pipe 2FB0E9DE	0.83	0.08	0.12
Pipe 2FB0E984	0.12	0.01	0
Pipe 2FB0E9CF	0.55	0.05	0.06
Pipe 2FB0E997	1.89	0.18	0.55
Pipe 2FB0E9DB	0.21	0.02	0
Pipe 2FB0E9E3	0.83	0.08	0.12
Pipe 2FB97F6F	1.05	0.1	0.18
Pipe 2FB97F7F	0.74	0.07	0.09
Pipe 2FB1CF3B	0.71	0.07	0.09
Pipe 2FB1CF1B	1.4	0.13	0.32
Pipe 2FB9CE20	-0.71	0.07	0.09
Pipe 2FB9C9D2	1.4	0.13	0.32
Pipe EQ032985	-2.72	0.49	4.88
Pipe 2FB0FB7D	-0.7	0.16	0.65
Pipe 2FB0E9CD	0.37	0.08	0.19
Pipe 2FB04071	0.39	0.04	0.03
Pipe 2FBB3A84	0.39	0.09	0.22
Pipe 2FB0406E	0.07	0.02	0.01
Pipe 2FBB3A86	0.07	0.01	0
Pipe 2FB040A0	0.26	0.06	0.1
Pipe 2FBDAFC4	0.07	0.02	0.01
Pipe 2FB4A97C	-0.47	0.1	0.31
Pipe 2FB0010C	-0.41	0.09	0.24
Pipe 1	0.52	0.12	1.82
Pipe 2	-0.49	0.11	1.61
Pipe 3	1.21	0.27	8.66
Pipe 4	0.8	0.18	3.97
Pipe 5	1.49	0.33	12.63
Pipe 6	-1.24	0.28	9.1
Pipe 7	-0.74	0.16	3.48
Pipe 8	-2.72	0.6	38.74
Pipe 9	-0.89	0.2	4.89
Pipe 10	-0.76	0.17	3.7
Pipe 11	0.75	0.17	3.56
Pipe 12	0.4	0.09	1.11
Pipe 13	0.7	0.16	3.16
Pipe 14	0.43	0.09	1.25
Pipe 15	-1.34	0.3	10.43
Pipe 16	1.11	0.25	7.42
Pipe 17	0.99	0.18	3.64

Table B2. ***Demand-Head-Pressure*** **at nodes/** ***Flow-Velocity-Unit Head Loss*** **at pipes for Scenario 3 of the testing phase.**

CONED	**Scenario 3: 2^ Increase**			CONED	**Scenario 3: 2^ Increase**		
Network Table - Nodes				Network Table - Links			
Node ID	Demand GPM	Head ft	Pressure psi	Link ID	Flow GPM	Velocity fps	U. H. ft/Kft
Junc 2FB1F719	0.35	234.97	56.54	Pipe 2FB08B92	-0.29	0.05	0.08
Junc 2FAF7AAD	0.06	234.99	56.54	Pipe 2FB08B93	-0.33	0.06	0.1
Junc 2FB1F71A	0.1	234.95	56.53	Pipe 2FB08B99	0.54	0.1	0.24
Junc 2FAF7AA6	0.04	234.96	56.54	Pipe 2FB08B9C	-0.71	0.13	0.41
Junc 2FB08B9A	0.02	234.97	56.54	Pipe 2FB08B9D	0.56	0.1	0.26
Junc 2FB20A57	0.08	234.95	56.53	Pipe 2FB08B9F	-0.37	0.07	0.12
Junc 2FAF7AA5	0	234.97	56.54	Pipe 2FB08BA3	0.22	0.04	0.05
Junc 2FAF6ACE	0	234.97	56.54	Pipe 2FB08BAA	-0.71	0.13	0.41
Junc 2FAF7AA4	0	234.97	56.54	Pipe 2FB08BB2	0.29	0.05	0.08
Junc 2FB08BA0	0	234.96	56.54	Pipe 2FB08BB4	-0.28	0.05	0.07
Junc 2FB08BA4	0	234.97	56.54	Pipe 2FB08BB5	0.36	0.06	0.11
Junc 2FAF6ACD	0	234.97	56.54	Pipe 2FB08BB7	0.36	0.06	0.11
Junc 2FAF7AA8	0	234.97	56.54	Pipe 2FB08BBB	-0.35	0.06	0.11
Junc 2FAF7AA9	0	234.98	56.54	Pipe 2FB08BC3	0.42	0.09	0.25
Junc 2FB08BB0	0.12	234.98	56.54	Pipe 2FB08BC9	0.42	0.04	0.03
Junc 2FAF7AAA	0.07	234.99	56.54	Pipe 2FB08BCC	-0.35	0.03	0.02
Junc 2FAF7AA7	0.07	234.97	56.54	Pipe 2FB09B22	-0.28	0.03	0.02
Junc 2FAF7AAB	0	234.99	56.54	Pipe 2FB0E152	0.42	0.04	0.03
Junc 2FAF82EA	0	234.99	56.54	Pipe 2FB0E154	0.22	0.05	0.07
Junc 2FAF7AAC	0	234.99	56.54	Pipe 2FB0E155	-0.71	0.07	0.09
Junc 2FB08BB8	0	234.99	56.54	Pipe 2FB00032	0.02	0	0
Junc 2FB08BBC	0	234.99	56.54	Pipe 2FB00033	-1.68	0.37	3.23
Junc 2FAF7AB0	0	234.99	56.54	Pipe 2FB00036	1.51	0.16	0.47
Junc 2FAF7AAE	0	234.99	56.54	Pipe 2FB0003A	1.9	0.21	0.71
Junc 2FAF6ACC	0	234.99	56.54	Pipe 2FB0003C	-0.38	0.04	0.04
Junc 2FAF7AAF	0	234.99	56.54	Pipe 2FB0003D	-0.54	0.12	0.4
Junc 2FB1F32D	0.01	234.99	56.54	Pipe 2FB0003E	-0.44	0.1	0.27
Junc 2FAF82E9	0.17	234.99	56.54	Pipe 2FBD8B08	-0.49	0.11	0.33
Junc 2FB09B23	0	234.99	56.54	Pipe 2FB00109	-0.6	0.13	0.47
Junc 2FAF70EF	0	234.9	56.52	Pipe 2FBB1012	-0.49	0.11	0.33
Junc 2FAF7167	0	234.9	56.52	Pipe 2FB00124	1.9	0.18	0.54
Junc 2FB20A52	0.12	234.53	56.43	Pipe 2FB00125	-0.38	0.09	0.21
Junc 2FAF7160	0.02	234.68	56.47	Pipe 2FB00126	1.69	0.18	0.57
Junc 2FAF70F1	0	234.9	56.52	Pipe 2FB00127	-0.17	0.02	0.01
Junc 2FAF70F3	0	234.9	56.52	Pipe 2FB00128	1.9	0.18	0.53
Junc 2FAF7142	0	234.86	56.51	Pipe 2FB0012E	1.9	0.21	0.72
Junc 2FAF713E	0	234.9	56.52	Pipe 2FB00131	-0.47	0.1	0.31
Junc 2FAF70F5	0	234.98	56.54	Pipe 2FB00134	1.69	0.16	0.43
Junc 2FAF7136	0	234.99	56.54	Pipe 2FBDAFC1	-0.17	0.04	0.05
Junc 2FB20A50	0.06	234.95	56.53	Pipe 2FB0018B	-1.69	0.37	3.31

Junc 2FAF7135	0	234.97	56.54	Pipe 2FB0018D	-1.69	0.16	0.44
Junc 2FAF7138	0	234.99	56.54	Pipe 2FB0018F	1.3	0.29	2.02
Junc 2FB00107	0.06	234.99	56.54	Pipe 2FB00192	-1.69	0.16	0.42
Junc 2FB0010A	0	234.96	56.54	Pipe 2FB00199	-1.69	0.16	0.44
Junc 2FB0010D	0	234.99	56.54	Pipe 2FB0019B	-1.69	0.37	3.28
Junc 2FAF7134	0.07	234.99	56.54	Pipe 2FB001A8	0.46	0.1	0.29
Junc 2FAF713D	0	234.85	56.51	Pipe 2FB001AC	1.3	0.14	0.36
Junc 2FAF7141	0	234.85	56.51	Pipe 2FB41D61	0.41	0.09	0.24
Junc 2FAF7143	0	234.9	56.52	Pipe 2FB0400C	1.04	0.19	0.84
Junc 2FAF713F	0	234.91	56.52	Pipe 2FB04010	0.04	0	0
Junc 2FAF7140	0	234.9	56.52	Pipe 2FB04011	0.38	0.07	0.14
Junc 2FB20A51	0.14	234.8	56.49	Pipe 2FB04020	-0.44	0.04	0.04
Junc 2FB0012F	0	234.86	56.51	Pipe 2FB04023	0.23	0.02	0.01
Junc 2FB00132	0.09	234.9	56.52	Pipe 2FB04024	-0.11	0.03	0.02
Junc 2FB2156D	0.12	234.96	56.54	Pipe 2FB04025	-0.64	0.02	0.01
Junc 2FB00135	0	234.91	56.52	Pipe 2FB04026	0.38	0.04	0.03
Junc 2FB00138	0	234.9	56.52	Pipe 2FB04027	-0.64	0.06	0.08
Junc 2FAF7144	0.06	234.91	56.52	Pipe 2FB04028	-0.54	0.05	0.05
Junc 2FAF715F	0	234.73	56.48	Pipe 2FB04029	-0.23	0.02	0.01
Junc 2FAF7165	0	234.74	56.48	Pipe 2FB0402A	-0.2	0.02	0.01
Junc 2FAF7163	0	234.68	56.47	Pipe 2FB04073	-0.64	0.06	0.07
Junc 2FAF7162	0	234.93	56.53	Pipe 2FB04076	-0.64	0.06	0.07
Junc 2FAF7164	0	234.73	56.48	Pipe 2FB0407C	-0.64	0.06	0.07
Junc 2FB0019C	0	234.75	56.48	Pipe 2FB04083	-0.37	0.03	0.02
Junc 2FB20072	0.05	234.91	56.52	Pipe 2FB04085	-0.18	0.02	0.01
Junc 2FB001AD	0	234.93	56.53	Pipe 2FB04096	-0.77	0.07	0.1
Junc 2FAF7169	0.21	234.94	56.53	Pipe 2FB04098	-0.77	0.07	0.1
Junc 2FB20073	0	234.91	56.52	Pipe 2FB0409A	-0.77	0.07	0.1
Junc 2FB0400D	0	234.98	56.54	Pipe 2FBD00C0	0.05	0	0
Junc 2FAF6FCD	0.02	234.98	56.54	Pipe 2FB040A6	-0.05	0	0
Junc 2FB1F714	0.28	234.96	56.54	Pipe 2FB07F35	-0.23	0.05	0.08
Junc 2FAF6FF5	0.22	234.96	56.54	Pipe 2FB4E0E0	0.23	0.03	0.02
Junc 2FB258E3	0	234.98	56.54	Pipe 2FB4E0E2	-1.01	0.11	0.22
Junc 2FB1F715	0.08	234.92	56.53	Pipe 2FB4E0E7	-1.02	0.11	0.23
Junc 2FAF6FF6	0.33	234.94	56.53	Pipe 2FB00862	2.42	0.23	0.82
Junc 2FAF6FD3	0	234.93	56.53	Pipe 2FB00863	-1.86	0.34	2.4
Junc 2FAF6FF9	0	234.93	56.53	Pipe 2FB00865	1.59	0.15	0.4
Junc 2FAF6FD4	0.06	234.93	56.53	Pipe 2FB00866	0.6	0.06	0.06
Junc 2FAF6FFC	0.08	234.94	56.53	Pipe 2FB00869	-1.4	0.25	1.51
Junc 2FAF6FD5	0	234.98	56.54	Pipe 2FB0086D	-1.23	0.22	1.13
Junc 2FAF6FF0	0	234.98	56.54	Pipe 2FB0086F	4.75	0.86	15.19
Junc 2FAF6FD7	0	234.98	56.54	Pipe 2FB00877	-1.1	0.11	0.2
Junc 2FAF6FF1	0	234.98	56.54	Pipe 2FB00879	-1.36	0.13	0.28
Junc 2FAF6FD8	0.17	234.96	56.54	Pipe 2FB0089D	-1.48	0.27	1.6
Junc 2FAF6FF2	0.1	234.97	56.54	Pipe 2FB0089E	-1.48	0.27	1.61
Junc 2FAF6FD9	0.02	234.96	56.54	Pipe 2FB008A2	-1.56	0.34	2.81
Junc 2FAF6FF4	0.14	234.96	56.54	Pipe 2FB0094C	-1.76	0.17	0.46

Junc 2FAF6FDA	0.02	234.96	56.54	Pipe 2FB00982	2.42	0.23	0.83
Junc 2FB04077	0	234.97	56.54	Pipe 2FB00985	2.42	0.23	0.83
Junc 2FAF6FF3	0	234.97	56.54	Pipe 2FB00993	0.79	0.09	0.14
Junc 2FAF6FF8	0	234.94	56.53	Pipe 2FB00996	0.81	0.08	0.11
Junc 2FAF6FF7	0	234.94	56.53	Pipe 2FB00999	0.79	0.08	0.1
Junc 2FB27E17	0	234.94	56.53	Pipe 2FB0099E	-0.21	0.02	0.01
Junc 2FB0409B	0	234.94	56.53	Pipe 2FB009A0	0.02	0	0
Junc 2FB040A1	0.19	234.93	56.53	Pipe 2FB009A2	0.02	0	0
Junc 2FAF6FFA	0.1	234.93	56.53	Pipe 2FB016AE	0.25	0.02	0.01
Junc 2FB07F36	0.04	234.94	56.53	Pipe 2FB016B3	0.25	0.02	0.01
Junc 2FB27E19	0	234.94	56.53	Pipe 2FB016B5	-1.23	0.22	1.15
Junc 2FB27E1A	0	234.95	56.53	Pipe 2FB016B7	-1.4	0.25	1.45
Junc 2FB27E1B	0.02	234.95	56.53	Pipe 2FB016B9	0.21	0.05	0.07
Junc 2FB27E18	0.02	234.97	56.54	Pipe 2FB0202E	-0.17	0.04	0.05
Junc 2FB20A5A	0.32	234.34	56.38	Pipe 2FB02079	-0.38	0.08	0.21
Junc 2FAF5901	0	234.01	56.3	Pipe 2FB02C60	8.9	0.85	9.83
Junc 2FAF5930	0.13	233.96	56.28	Pipe 2FB1CE95	0.02	0	0
Junc 2FAF58F6	0.15	234.63	56.45	Pipe 2FB1CEA3	0.42	0.04	0.03
Junc 2FB20A5B	0.03	234.76	56.48	Pipe 2FB1CEA6	0.42	0.04	0.03
Junc 2FB1DA13	0.14	234.76	56.48	Pipe 2FB3D878	1.45	0.14	0.32
Junc 2FB20A5C	0	234.95	56.53	Pipe 2FB4545B	-1.1	0.11	0.19
Junc 2FAF5909	0.35	234.93	56.53	Pipe 2FB4545C	-1.1	0.11	0.2
Junc 2FB16165	0	234.93	56.53	Pipe 2FB4545D	-1.1	0.11	0.2
Junc 2FAF590C	0	234.94	56.53	Pipe 2FB4545E	-1.1	0.11	0.21
Junc 2FAF590B	0	234.92	56.53	Pipe 2FB45CD5	2.42	0.23	0.83
Junc 2FAF58F9	0	234.46	56.41	Pipe 2FB0FB7E	0.36	0.04	0.03
Junc 2FAF58FA	0	234.41	56.4	Pipe 2FB0FB80	0.36	0.03	0.03
Junc 2FAF58FB	0	233.94	56.28	Pipe 2FB0FB86	1.45	0.14	0.32
Junc 2FB22625	0	233.94	56.28	Pipe 2FB0FB87	-0.06	0.01	0
Junc 2FB0087A	0.25	233.94	56.28	Pipe 2FB0FB94	0.95	0.09	0.15
Junc 2FAF58FD	0.13	234.04	56.31	Pipe 2FB0FB96	0.63	0.14	0.53
Junc 2FAF58FE	0	234.06	56.31	Pipe 2FB0FBEF	0.87	0.19	0.96
Junc 2FAF58FF	0	234.07	56.31	Pipe 2FB0FBF2	0.36	0.04	0.03
Junc 2FB008A4	0.07	234.07	56.31	Pipe 2FB0FBF5	0.32	0.03	0.02
Junc 2FB0094D	1.55	234.64	56.45	Pipe 2FB0E97D	0.94	0.09	0.15
Junc 2FB00983	0	234.01	56.3	Pipe 2FB0E982	-0.36	0.03	0.02
Junc 2FB1FD69	0	233.99	56.29	Pipe 2FB0E995	3.1	0.34	1.88
Junc 2FAF5902	0	233.98	56.29	Pipe 2FB0E9CA	0.63	0.14	0.53
Junc 2FB00994	0	234.64	56.46	Pipe 2FB0E9D0	0.95	0.21	1.13
Junc 2FAF5905	0	234.64	56.45	Pipe 2FB0E9D4	0.75	0.07	0.09
Junc 2FAF5904	0.64	234.65	56.46	Pipe 2FB0E9D9	0.45	0.04	0.04
Junc 2FAF5903	0.02	234.64	56.46	Pipe 2FB0E9DC	1.45	0.14	0.32
Junc 2FAF5906	0.23	234.63	56.45	Pipe 2FB10E17	0.87	0.09	0.17
Junc 2FAF5907	0	234.63	56.45	Pipe 2FB8143E	2.84	0.27	1.11
Junc 2FAF5908	0	234.63	56.45	Pipe 2FB97F6E	1.65	0.37	3.13
Junc 2FB009A3	0	234.63	56.45	Pipe 2FB97F6C	3.1	0.69	10.08
Junc 2FB016AF	0	234.93	56.53	Pipe 2FB97F6D	-1.45	0.32	2.46

Junc 2FAF590A	0	234.93	56.53	Pipe 2FB97F7E	0.94	0.21	1.1
Junc 2FAF58F5	0	234.94	56.53	Pipe 2FB1CEE8	-2.74	0.26	1.04
Junc 2FAF590D	0.21	234.93	56.53	Pipe 2FB1CEF8	0.8	0.08	0.11
Junc 2FAF5919	0.17	234.91	56.52	Pipe 2FB1CEFE	1.76	0.19	0.62
Junc 2FB16166	0.21	234.91	56.52	Pipe 2FB1CF0F	1.76	0.17	0.46
Junc 2FB16164	0.16	234.92	56.53	Pipe 2FB1CF11	1.76	0.19	0.62
Junc 2FAF591A	0.05	234.92	56.53	Pipe 2FB1CF13	1.76	0.17	0.47
Junc 2FB22622	10	233.94	56.28	Pipe 2FB1CF16	1.76	0.17	0.47
Junc 2FB16167	0	234.93	56.53	Pipe 2FB1CF18	1.76	0.17	0.46
Junc 2FB016BC	0	234.93	56.53	Pipe 2FB1CF1A	1.62	0.16	0.39
Junc 2FB22623	0	233.94	56.28	Pipe 2FB1CF38	0.8	0.18	0.85
Junc 2FB22624	0	233.94	56.28	Pipe 2FB1CF3A	0.6	0.06	0.06
Junc 2FAF58FC	0	233.94	56.28	Pipe 2FB9C9D1	1.76	0.39	3.61
Junc 2FAF81E5	0	234.96	56.54	Pipe 2FB9CE1D	0.8	0.08	0.11
Junc 2FAF9C08	0	234.96	56.54	Pipe 2FB08BBD	-0.35	0.03	0.02
Junc 2FAF81E6	0	234.96	56.54	Pipe 2FB08BA2	-0.37	0.03	0.03
Junc 2FAF9C09	0.04	234.96	56.54	Pipe 2FB08B9B	0.56	0.05	0.06
Junc 2FAF81E9	0	234.92	56.53	Pipe 2FB08BA5	0.22	0.02	0.02
Junc 2FAF74D7	0	234.91	56.52	Pipe 2FB08BB1	-0.71	0.07	0.09
Junc 2FAF74C1	0	234.92	56.53	Pipe 2FB09B24	-0.28	0.03	0.02
Junc 2FAF81EE	0	234.94	56.53	Pipe 2FB08BB9	0.36	0.03	0.03
Junc 2FAF74D5	0.2	234.94	56.53	Pipe 2FB08BC5	-0.42	0.04	0.03
Junc 2FAF81EF	0	234.98	56.54	Pipe 2FB001A3	0.02	0	0
Junc 2FAF74D3	0	234.98	56.54	Pipe 2FB00130	1.9	0.18	0.56
Junc 2FB0FBF0	0	234.98	56.54	Pipe 2FB00108	-0.54	0.05	0.06
Junc 2FAF74E9	0	234.97	56.54	Pipe 2FB00105	-0.44	0.04	0.03
Junc 2FB0FBF3	0	234.96	56.54	Pipe 2FB0010E	-0.49	0.05	0.05
Junc 2FAF74C0	0	234.92	56.53	Pipe 2FB0010B	-0.6	0.06	0.06
Junc 2FB0E983	0.3	234.92	56.53	Pipe 2FB00133	-0.38	0.04	0.03
Junc 2FB0E996	0	234.55	56.43	Pipe 2FB00136	1.69	0.16	0.44
Junc 2FB28167	0.26	234.55	56.43	Pipe 2FB00139	-0.17	0.02	0
Junc 2FAF74D2	0.2	234.98	56.54	Pipe 2FB0019D	-1.69	0.16	0.46
Junc 2FB0E9D1	0	234.94	56.53	Pipe 2FB41D62	0.41	0.04	0.05
Junc 2FAF74D6	0.3	234.92	56.53	Pipe 2FB96C54	-1.3	0.12	0.29
Junc 2FB0E9DA	0	234.92	56.53	Pipe 2FB040A2	0.23	0.02	0.02
Junc 2FB0E9DD	0	234.91	56.52	Pipe 2FB07F37	-0.19	0.02	0
Junc 2FAF74D8	0	234.85	56.51	Pipe 2FB04078	-0.64	0.06	0.08
Junc 2FB2585E	0.1	234.43	56.4	Pipe 2FB04070	0.38	0.04	0.03
Junc 2FB93EC7	0.19	234.91	56.52	Pipe 2FB0409C	-0.77	0.07	0.11
Junc 2FB93EC8	0	234.91	56.52	Pipe 2FB4E0E8	-1.01	0.1	0.17
Junc 2FB93EC4	0	234.75	56.48	Pipe 2FB00984	2.42	0.23	0.89
Junc 2FB93EC5	0	234.55	56.43	Pipe 2FB016B0	0.25	0.02	0.02
Junc 2FB93EC6	0	234.85	56.51	Pipe 2FB0087B	-1.1	0.11	0.21
Junc 2FB93ECB	0	234.97	56.54	Pipe 2FB008A5	-1.48	0.14	0.35
Junc 2FB93ECC	0	234.97	56.54	Pipe 2FB00995	0.79	0.08	0.12
Junc 2FB16172	0	234.97	56.54	Pipe 2FB009A4	0.02	0	0
Junc 2FB1618C	0	234.97	56.54	Pipe 2FB016BD	-0.42	0.04	0.03

Junc 2FB16174	0	234.88	56.51
Junc 2FB1617E	0	234.86	56.51
Junc 2FB1617B	0	234.9	56.52
Junc 2FB1617D	0	234.89	56.52
Junc 2FB1617C	0	234.89	56.52
Junc 2FB1617F	0	234.85	56.51
Junc 2FB16180	0	234.85	56.51
Junc 2FB16181	0.14	234.85	56.51
Junc 2FB1618B	0	234.98	56.54
Junc 2FB93AAC	0	234.97	56.54
Junc 2FB1618D	0.21	234.97	56.54
Junc 2FB1618A	0.09	234.98	56.54
Junc 2FB8DEE4	0.09	234.91	56.52
Junc 2FB8DEE5	0	234.91	56.52
Junc 2FB001A2	0.1	234.9	56.52
Junc 2FB00104	0	234.97	56.54
Junc 2FAF7137	0	234.96	56.54
Junc 2FAF7145	0.09	234.9	56.52
Junc 2FAF6FEF	0	234.97	56.54
Junc 2FB0406F	0.32	234.97	56.54
Junc 2FAF9C07	0	234.98	56.54
Junc 2FAF74D4	0	234.94	56.53
Junc 2FB0E9CE	0.19	234.97	56.54
Junc 2FBA5353	0	234.98	56.54
Junc 2FBA5354	0	234.97	56.54
Resvr 1	-0.6	235	0
Resvr 2	-0.56	235	0
Resvr 4	-1.4	235	0
Resvr 5	-0.89	235	0
Resvr 6	-1.84	235	0
Resvr 7	-1.84	235	0
Resvr 8	-4.75	235	0
Resvr 9	-1.04	235	0
Resvr 10	-0.94	235	0
Resvr 3	-0.87	235	0
Resvr 11	-0.83	235	0
Resvr 12	-0.43	235	0
Resvr 13	-0.46	235	0
Resvr 14	-0.83	235	0
Resvr 15	0	235	0
Resvr 17	-1.75	235	0
Resvr 18	-1.51	235	0
Resvr 16	-1.04	235	0

Pipe 2FB1CEA5	0.04	0	0
Pipe 2FB1CE97	0.33	0.03	0.02
Pipe 2FB0FBF1	0.87	0.08	0.14
Pipe 2FB0E9D2	0.95	0.09	0.15
Pipe 2FB0FBF4	0.36	0.03	0.03
Pipe 2FB0E9DE	1.45	0.14	0.35
Pipe 2FB0E984	-0.06	0.01	0
Pipe 2FB0E9CF	0.63	0.06	0.06
Pipe 2FB0E997	3.1	0.3	1.4
Pipe 2FB0E9DB	0.45	0.04	0.03
Pipe 2FB0E9E3	1.45	0.14	0.34
Pipe 2FB97F6F	1.65	0.16	0.43
Pipe 2FB97F7F	0.94	0.09	0.14
Pipe 2FB1CF3B	0.8	0.08	0.11
Pipe 2FB1CF1B	1.76	0.17	0.49
Pipe 2FB9CE20	-0.8	0.08	0.11
Pipe 2FB9C9D2	1.76	0.17	0.49
Pipe EQ032985	-4.75	0.86	13.7
Pipe 2FB0FB7D	-0.95	0.21	1.12
Pipe 2FB0E9CD	0.44	0.1	0.27
Pipe 2FB04071	0.38	0.04	0.03
Pipe 2FBB3A84	0.38	0.08	0.21
Pipe 2FB0406E	0.06	0.01	0.01
Pipe 2FBB3A86	0.06	0.01	0
Pipe 2FB040A0	0.23	0.05	0.08
Pipe 2FBDAFC4	-0.09	0.02	0.01
Pipe 2FB4A97C	-0.6	0.13	0.48
Pipe 2FB0010C	-0.44	0.1	0.27
Pipe 1	0.6	0.13	2.37
Pipe 2	-0.56	0.12	2.08
Pipe 3	1.4	0.31	11.35
Pipe 4	0.89	0.2	4.89
Pipe 5	1.84	0.41	18.87
Pipe 6	-1.84	0.41	18.82
Pipe 7	-0.94	0.21	5.37
Pipe 8	-4.75	1.05	108.73
Pipe 9	-1.04	0.23	6.57
Pipe 10	-0.87	0.19	4.66
Pipe 11	0.83	0.18	4.25
Pipe 12	0.43	0.1	1.27
Pipe 13	0.83	0.18	4.28
Pipe 14	0.46	0.1	1.42
Pipe 15	-1.75	0.39	17.19
Pipe 16	1.51	0.33	13
Pipe 17	1.04	0.19	4.05