Senior Design I

Optimal Design of Water Distribution System to Minimize Risk of Water Main Breaks in Western Fort Wayne

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Abstract

The safety of drinking water supply has critical importance to the quality of life, people's health and public welfare. However, water main break is becoming more and more frequent and acute. These breaks are very costly to repair and cause many problems including but not limited to flooding, blocking traffic, wasting water resources and contaminating drinking water. Water utilities, due to a limited budget, must use their resources wisely and proactively by prioritizing the pipe-fixing work. Therefore, it is imperative to replace the deteriorated old system pipelines with a new design that is efficient and cost effective. The main objective of this project was to optimize the system and reduce the risk of water main breaks. The senior design project was implemented by re-designing a selected water-distributed network system starting from the Westside pump station on Illinois Road down to Washington Road in Western Fort Wayne, where more water main breaks have occurred in last three years than the rest areas of Fort Wayne. The final design of this project consists of a redesigned approximately 7,300 ft. pipe network, a water tower, and galvanic corrosion protection. KY Pipe modeling was conducted to analyze and optimize the pressure and flow distributions in the pipe network. The new system would significantly save the cost brought by water main breaks and energy consumption of the pumps.

I. Section I: Problem Statement

I.1 Problem Statement

The safety of drinking water supply has critical importance to the quality of life, people's health and public welfare. However, water main breaks are becoming more and more frequent and severer. Most of today's water infrastructure system was built during World War II and the quality piping material was not available at that time. Currently the lives of these low quality cast iron pipes are approaching the end. Unfortunately, most water utilities have a limited budget and cannot afford to replace all of the pipes at once since they are publicly owned. Water utilities must use their money wisely and proactively by prioritizing the pipe-fixing work, i.e. replacing the main pipes that are of a high risk to fail and of broader impact first. Water main breaks are very costly to repair, in addition to the problems such as flooding, blocking traffic, and wasting water resources and contamination of drinking water. "Every day, 850 water main breaks occur in North America at a total annual repair cost of over $3 billion. This doesn't include the high costs of emergency equipment, depleted water supply, traffic disruptions, and lost work time." (WaterMainBreakClock.com).

A water main break will occur once the hydraulic pressure exceeds the tensile strength of the pipe. The main objective of this project is to reduce the number of those water main breaks. History shows that the area in the western part of Fort Wayne suffers the most breaks. Data will be gathered at each section of piping that exists in the Fort Wayne area. Specifically, data will be gathered starting from the West side pump Station on Illinois Rd to Washington Road. The constraints for designing the pipe system for this area are Ardmore Avenue, Portage Boulevard, and Freeman Street. A rating system will be designed to determine what pipes are the most vulnerable in the area. This will be done by researching and examining past Fort Wayne pressure surges, flow rates, water main break data, etc. Accordingly, major factors will be explored based on the pipe properties, pipe fittings, and the specific conditions surrounding the pipe; such as hydraulic pressure, flow rate for all surrounding neighborhoods, pipe material, age, and corrosion factors. Once the rating system analyzes the area based on all the factors, modeling by KY Pipe software will be performed to simulate water flow and to redesign a pipe network system for the area. Multiple design alternatives will be created and a cost-benefit analysis will be conducted for each design. The best alternative will be the pipe network system that will reduce the number of future water main breaks and improve water flow while being the most economical choice.

I.2 Scope of Project

When designing a pipe network system, it requires many different professionals such as civil, mechanical, electrical and other engineers. For the purpose of this project, the intent or responsibilities of the group is to design a pipe network system from a civil and hydraulics point of view and ensuring that the system works and will not suffer any future main breaks.

I.3. Background

I.3.1 Significance of Water Main Breaks

It is said that Fort Wayne's water utility produces millions of gallons of safe and great tasting drinking water every day. In order for this to continue, the city must be able to pay the operating expenses and invest in replacing and improving portions of the aging infrastructure. Fort Wayne has the capability of producing all the water needed to supply the communities and surrounding areas. However, certain circumstances may arise due to main breaks which can be an inconvenience for the surrounding communities. Water main breaks are becoming more frequent and severer. They are costly to repair and can result in street pavement deterioration, especially if main breaks occur in the same area. In order to reduce water main breaks, it requires a pro-active program of water main replacement.

I.3.2 Fort Wayne Water Main History

The city of Fort Wayne has a water utility distribution that transports water from the central pump station to each of the main pump stations and elevated storage tanks around the city, which can be seen in Figure 1. The main pump stations that exist in the city of Fort Wayne are the Northwest pump station, Westside pump station, and Southside pump station. There are two storage tanks located in the East, which carry approximately 1 to 1.5 million gallons. Looking at all the pressure districts in Fort Wayne, research shows that the West pressure district suffered the majority of the main breaks and is still continuing to be a problem today. Most of the pipes installed in that district were installed as early as 1929. Therefore, it is essential to renew those pipes in order to improve the hydraulic capacity/performance, system expansion, water flow and integrity of the pipes.

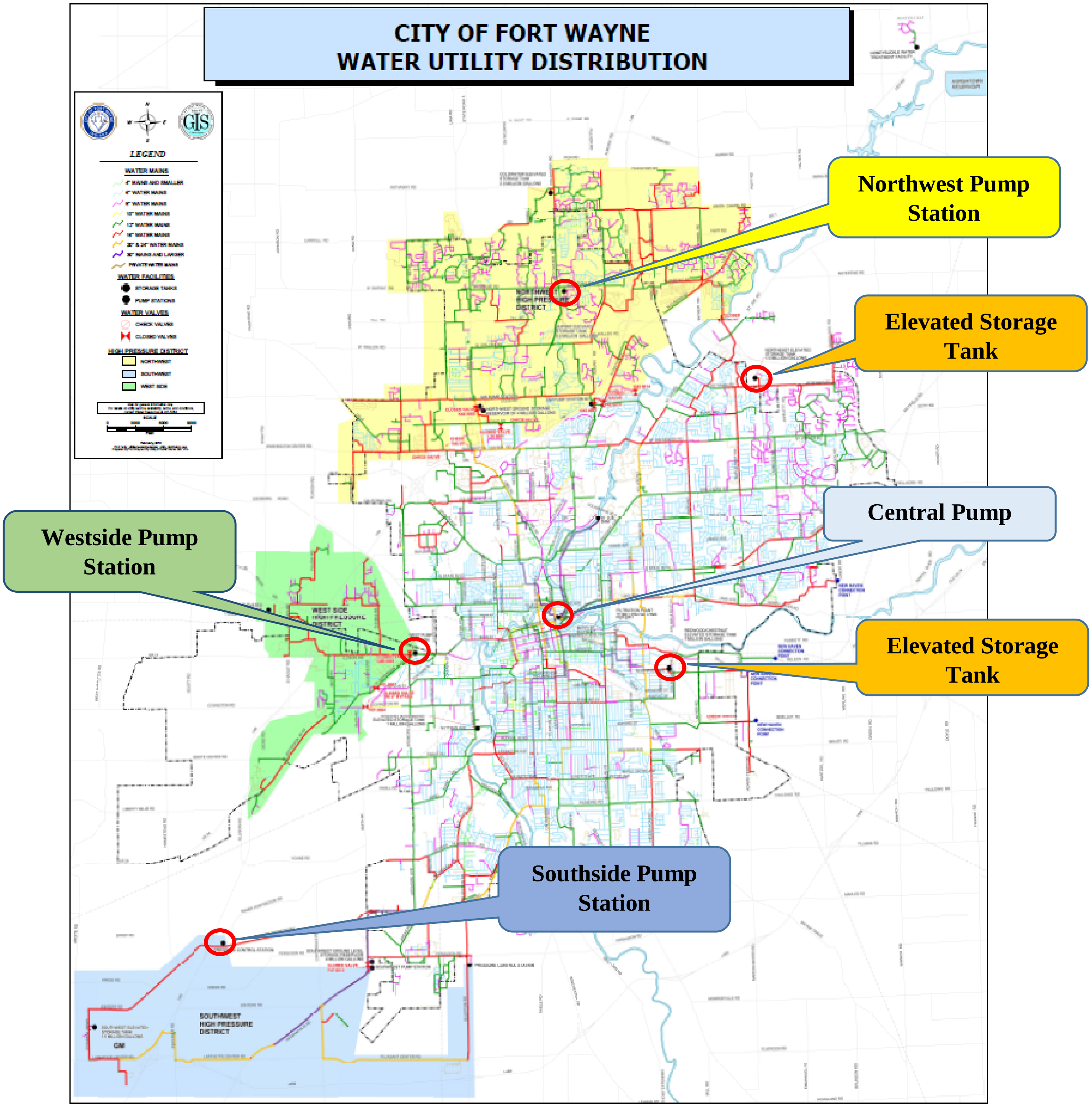


Figure 1: City of Fort Wayne Water Utility Distribution

Looking at the Westside pump station and the surrounding area, all the pipes in the area are made of cast iron and ductile iron and some of the pipes date back to 1929. A main break research analysis was performed and data was obtained from the city of Fort Wayne to determine which pipes were the most vulnerable. In the past 20 years, there were approximately 72 main breaks in the area. The number of most current main breaks from 2010-2013 totaled to 11 breaks, which can be shown in Figure 2. So, it can be seen that this area still continues to struggle with maintaining an efficient and working pipe network system.

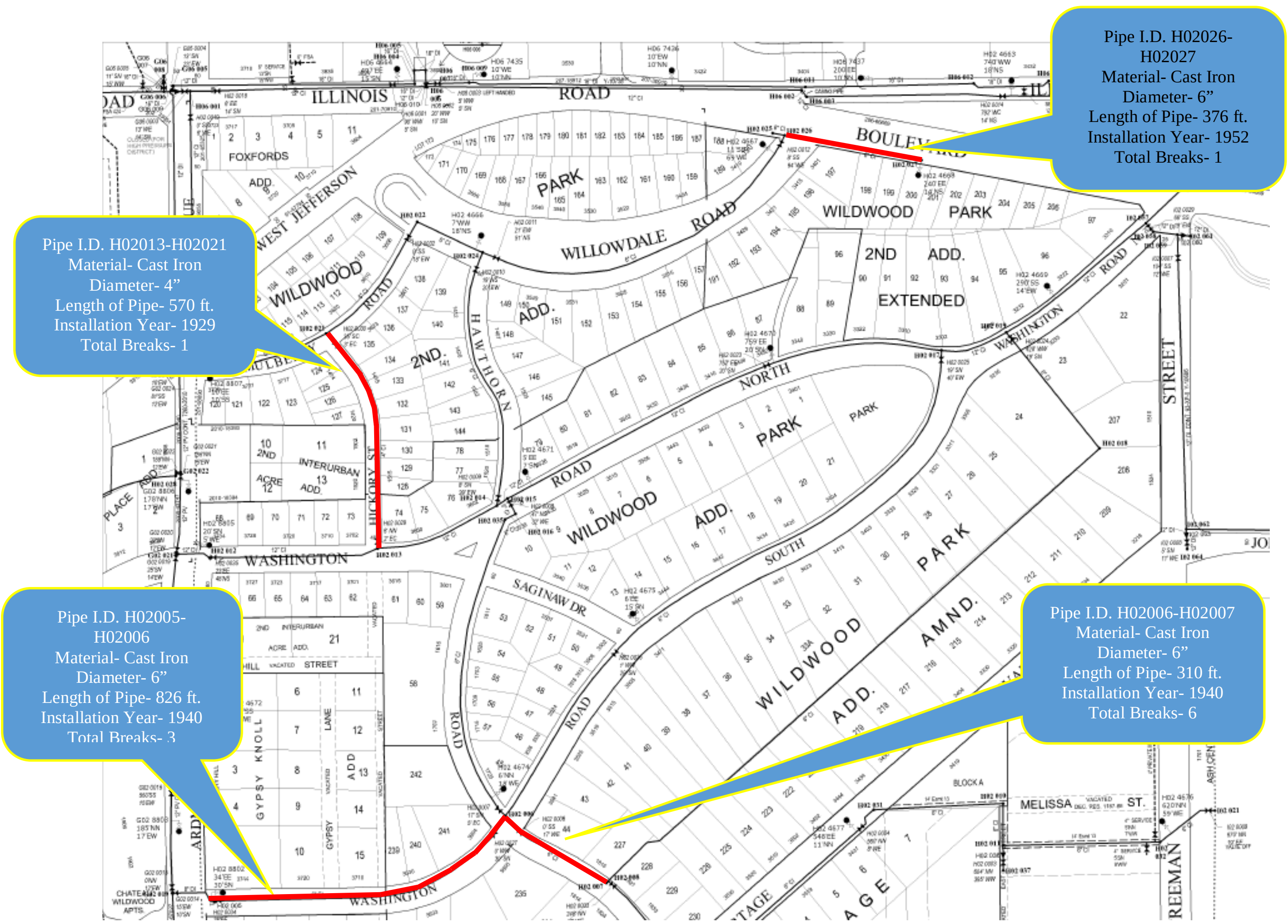
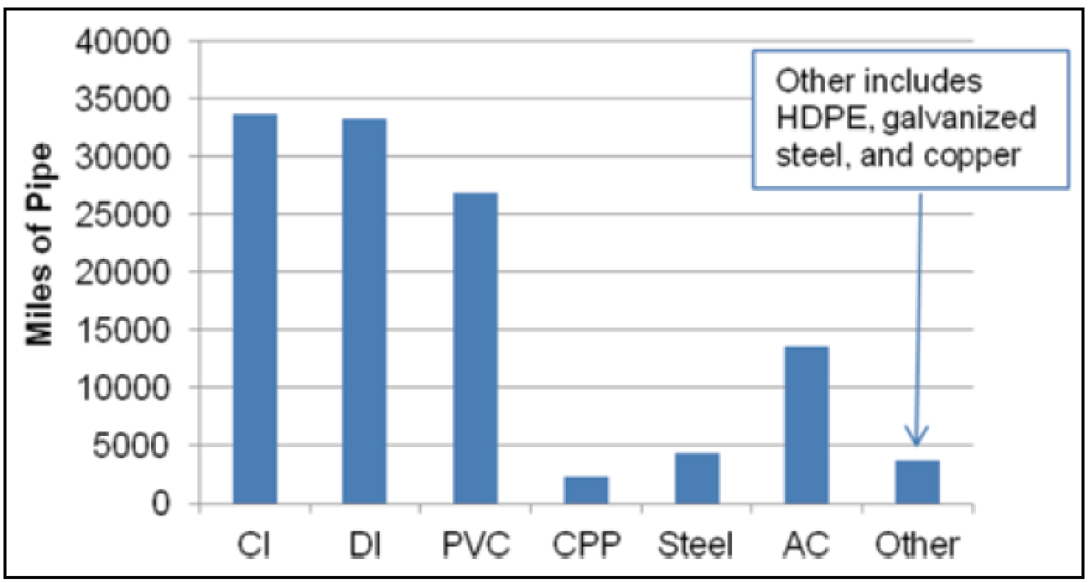


Figure 2: Main Break History 2010-2013

II. Important Design Variables to Consider

II.1 Pipe Material

The pipe material of a water main is a very important parameter for the performance of the pipe. Performance of the material varies with parameters such as ductility, corrosion resistance, strength against pressure surges and life expectancy. Some materials perform better than others depending on the required size and length of the water main. The main materials used in water distribution systems are Polyvinyl Chloride (PVC), High-Density Polyethylene (HDPE), Cast Iron (CI), Asbestos Cement (AC), Steel (ST), and Concrete Pressure Pipe (CPP). As shown in Figure 3, cast iron is the most common material in America's water distribution system as a whole. Different regions vary because some cities invest more in replacing water mains due to different budgets and priorities. The cities that invest more may have a higher percentage of PVC mains compared to cast iron mains.



(Steven Folkman)

Figure 3: Representation of Pipe Material in the US

As shown in Figure 3, it represents approximately 10% of the total length of water mains in the US. This is one of the largest surveys conducted on water mains. The reason cast iron is the most installed material is because most of the U.S Water Distribution System was built during World

War II and the good quality pipe material was not as available during the war. Due to this, a large number of cheaper and lower quality cast iron pipes were installed into the water distribution system. Cast Iron is rarely used today when installing new water mains because of its susceptibility to corrosion.

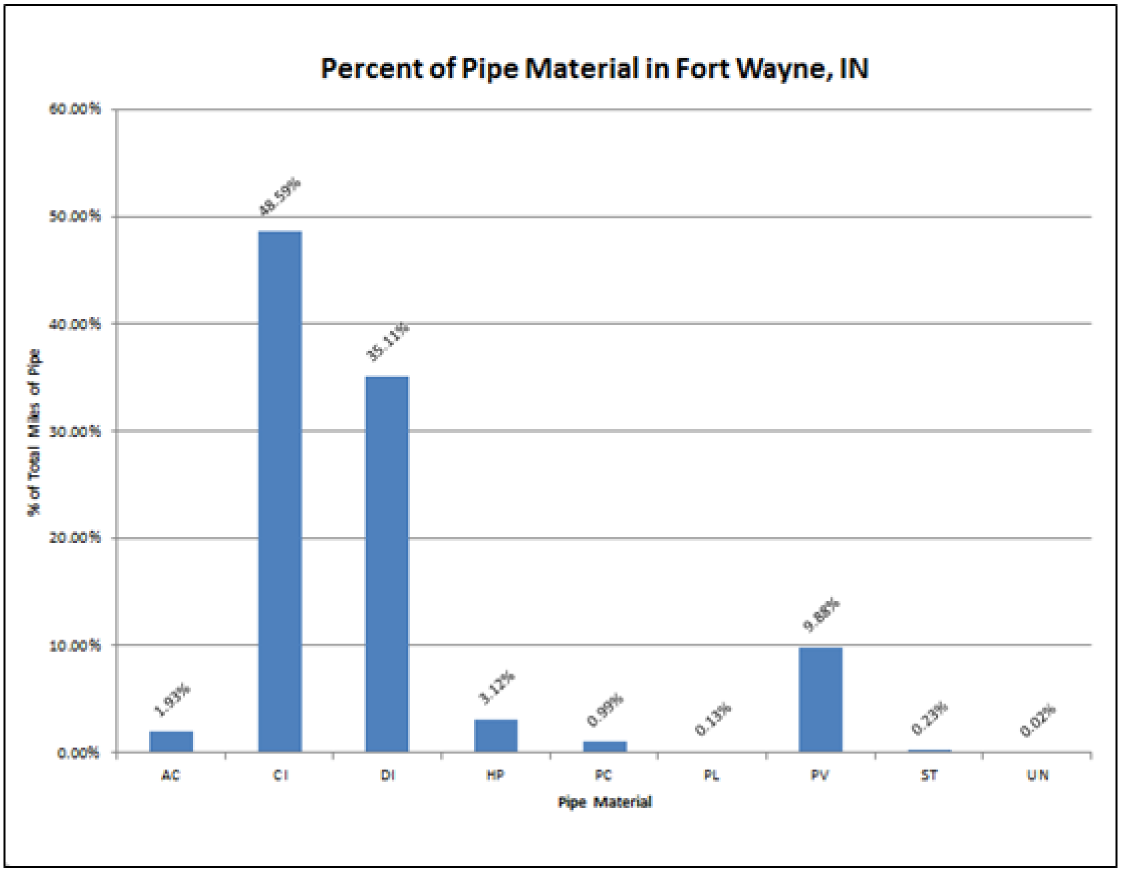


Figure 4: Total Percentage of Pipe Material Installed in Fort Wayne, IN

As shown in Figure 4 above, the percentage of pipe material distribution chart in Fort Wayne is similar to the US as a whole. "Reducing water main breaks requires a pro-active program of water main replacement. Industry standards suggest Fort Wayne Utilities should be replacing approximately 12 miles of water main each year. For several years, City Utilities maintained a flat budget while facing increased costs for electricity, chemicals, fuel and other fixed costs. In addition to rising costs, the Utility is continually shackled with unfunded federal mandates for water treatment process changes placing additional burdens on a tight budget. Such burdens have only allowed the city to replace one mile of pipe per year in lieu of the recommended 12 miles needed.

Simply stated, the system is deteriorating at a pace far faster than funds allow replacement." (City of Fort Wayne)

II.2 Pipe Size

Pipe size of a water main is determined by the water demand. The water main can be used to transmit water from a storage facility such as a reservoir or tank or it can be used to distribute water to residents. The water mains used for transmission of water are known as transmission mains. These mains are usually larger than 10 inches in diameter, because of the high flow of water being transmitted. Water mains used for distribution are known as distribution mains. These are usually smaller than 10 inches in diameter.

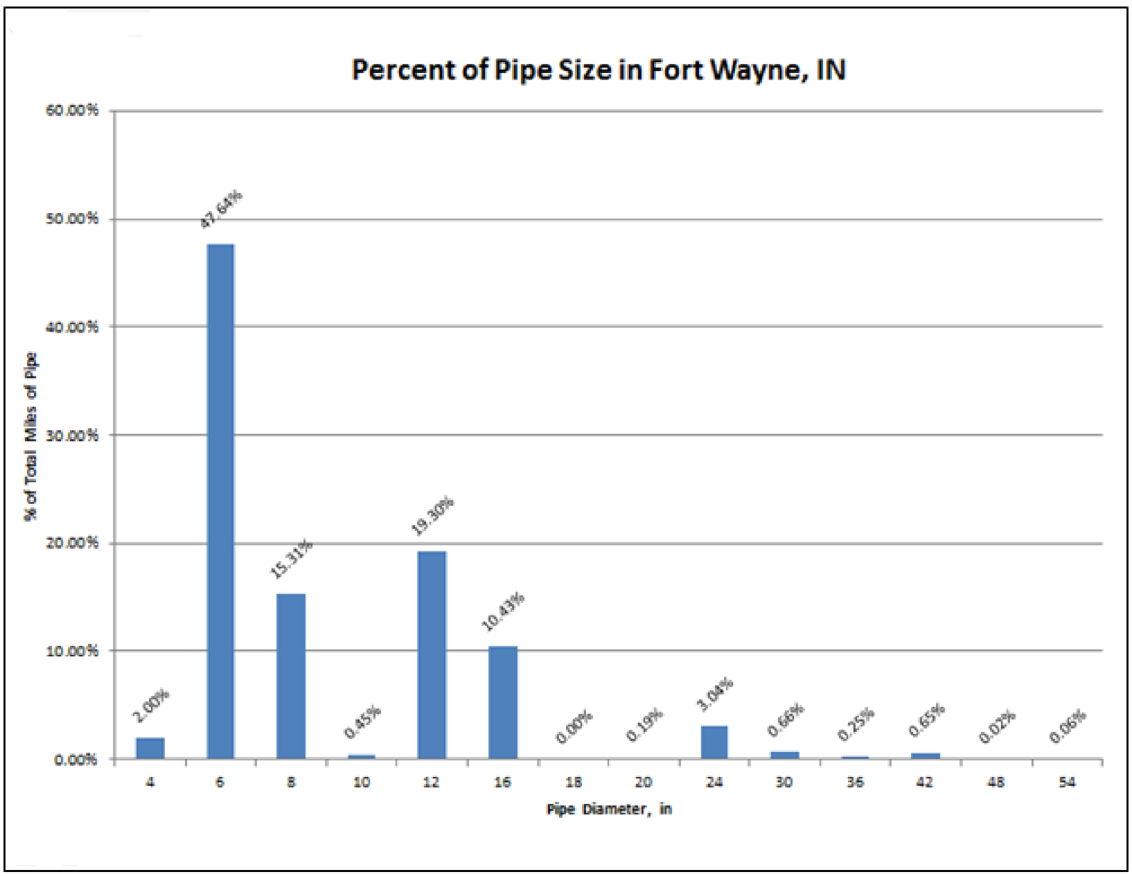


Figure 5: Percentage of Water Mains by Diameter Size in Fort Wayne, IN

As shown in Figure 5, 65 % of the water mains in Fort Wayne's water distribution system are distribution mains. Also, almost 60% of those mains are cast iron.

II.3 Pipe Age

The age of a water main is an important factor. The lifecycle of the pipe varies based on the pipe material, surrounding soil conditions and quality of installation. “Even when water mains are properly installed, the pipes will deteriorate over time. This deterioration can be slowed by matching the pipe material to the soil or by wrapping the pipe. Cast iron, ductile iron, and galvanized iron pipes can all be weakened in just a few years when laid in aggressive soil. To prevent this type of damage, the soil should be tested before laying the pipes in the ground. If necessary, the pipes can be wrapped in plastic during installation to protect the metal from the soil. The Ductile Iron Pipe Research Association can provide detailed information on the wrapping procedure.” (Pipe Materials)

The life expectancy of cast iron was designed for 100 years, but due to its lack of resistance to corrosion it gets around 70 years. The relationship between performance and age is not linear. The pipes that are around 90 years old actually outperform the pipes that have been around for 60 years. This is because the quality of cast iron was better in the 1920s than in the 1950s.

“The type of soil is also an important consideration when installing plastic pipes. Organic chemicals, especially solvents and gasoline, will weaken PVC pipes, causing the pipe to expand and rupture. The operator in charge of ditching should be alerted of any unusual odor when removing soil during the construction of the distribution system. The odor may be a sign of a chemical spill, which may remain in the soil for many years and weaken PVC pipes.

Gasoline and diesel can pass through the walls of polyethylene pipes even when the water inside is under high pressure. For this reason, plastic pipes should never be installed in the vicinity of gas stations. Instead, ductile iron and copper pipes are recommended for service lines in the vicinity of gas stations.” (Pipe Materials)

II.4 Pressure Surges

A pressure surge can come about when the flow of a fluid in a water main is quickly changed. Water distribution systems that use quick acting valves, or use pumps that start up or shut down rapidly are vulnerable to pressure surges. These circumstances can end in piping malfunction, destruction to pumps, fittings, equipment, and other system mechanisms.

The price of high pressure water main can be reduced by installing a pressure reducing valve in the pipeline. This allows using a cheaper pipe with a lower pressure rating. The total savings must always be balanced against possible operation and maintenance issues, which are often a result of installing a pressure reducing valve.

Pressure surges or water hammers can be a severe difficulty in long standard water mains. When the water is suddenly turned off, significant force is necessary to discontinue the momentum of the enormous volume of water. Real pressure build up depends on the entire volume of water in the water main, velocity at which the water is traveling, and how fast the water is shut off. Pressure surges can be considerably greater than operative pressure, and can even be greater than static pressure in the water main.

In low pressure pipelines, surges are usually not a significant consideration. The pipe and appurtenances have high enough safety factors to withstand minor surges. A pressure surge is almost always a factor that must be addressed in long, high pressure pipelines where water flow can suddenly be stopped for any reason. A frequent surge problem is encountered when the pump shuts off or the pump starts up. A rapid check valve closure sets up a pressure wave and cyclic pressure surges. If the pump system contains an automatic pressure switch, the pump can rapidly cycle on and off causing damage to the pump, pipeline, and valves. Another frequent cause of surges is rapidly turning off a hydrant. Frost free hydrants can be shut off very rapidly by slamming down the handle. This is sure to cause surges in the pipeline. (Missouri Livestock Watering Systems Handbook).

II.4.1. Pressure Surges vs. Pipe Material and Diameter

As shown in Figure 6, pressure surges are more severe for smaller diameter sizes and ductile iron pipes. This was an analysis performed on the existing condition of the water main system on Illinois Rd for the pump shut off and start up. Pressure Relief Valves will be placed accordingly in the water main system to relieve junctions with the highest pressure or near pipes with smaller diameter sizes and material of ductile iron.

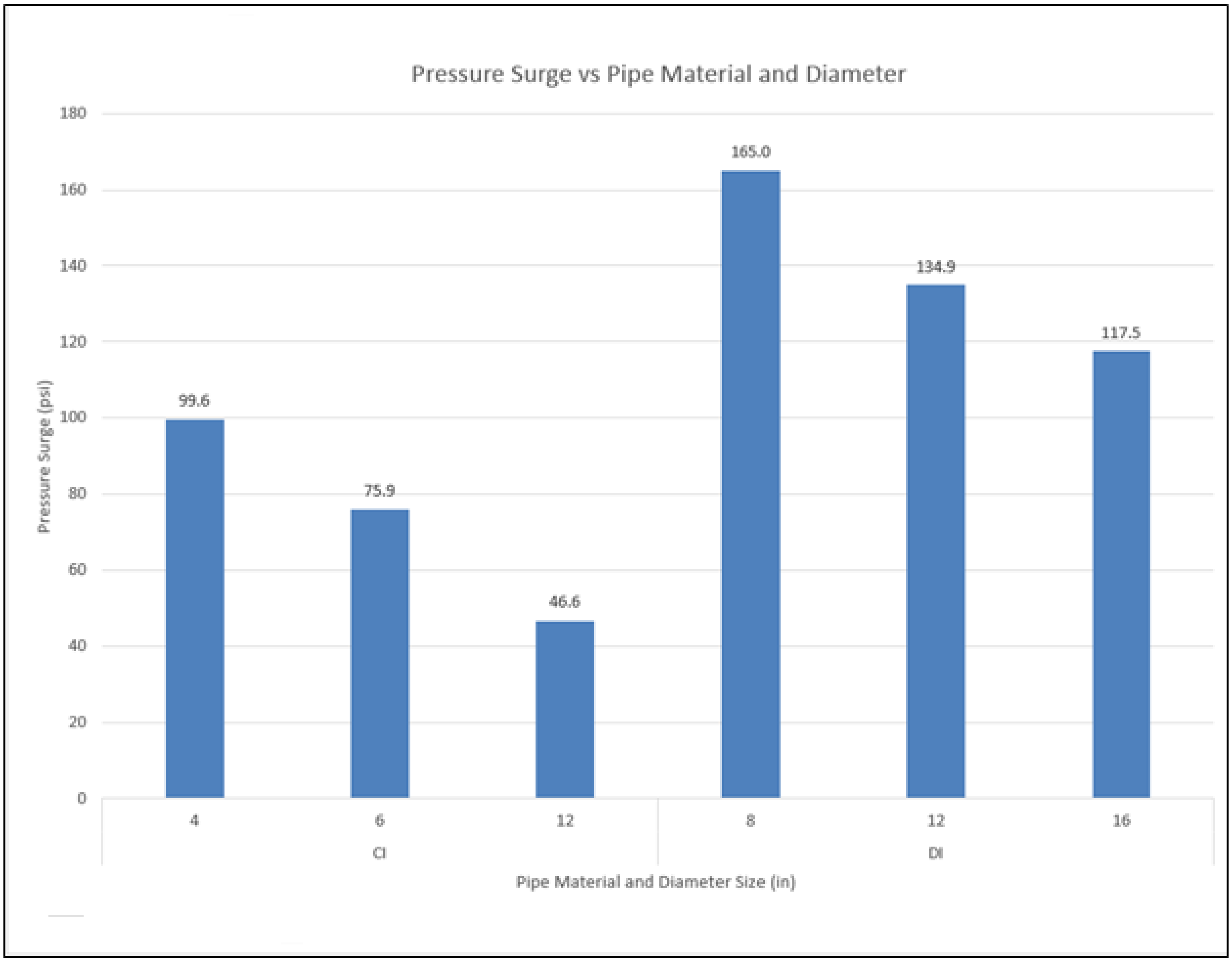


Figure 6: Pressure Surge calculations for Pump Shut off and Start Up for the Illinois Rd Section.

Pressure Surge from Shut Off and Start Up of Pump Equations

Maximum pressure surge for the water main systems is calculated based on the following equation:

$P_s = \frac{a\Delta V}{2.31g}$ ***(Equation 1)***

Where:

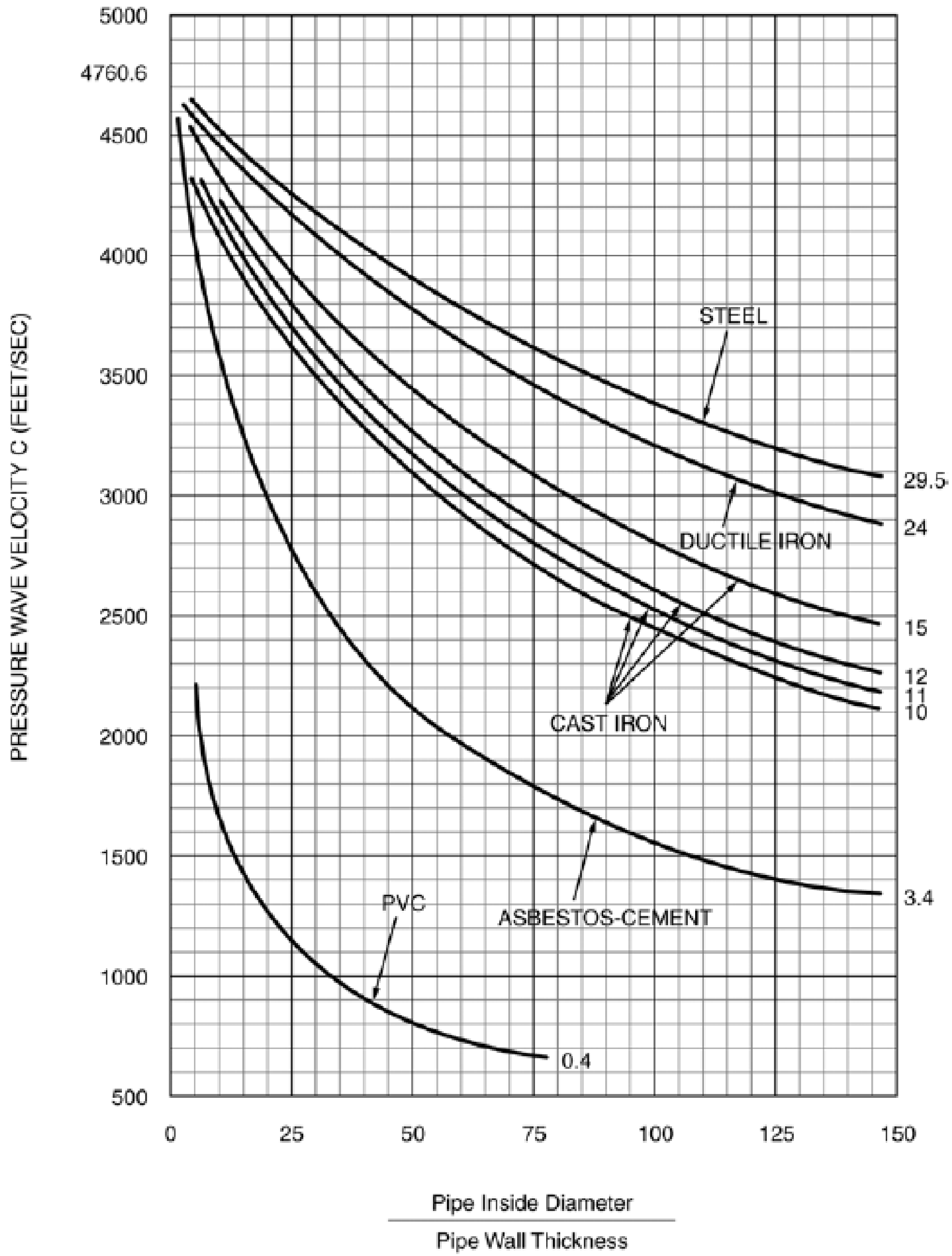
$a = Pressure\ wave\ velocity\ (\frac{ft}{s})$
$\Delta V = Velocity\ change\ (\frac{ft}{s})$
$g = Acceleration\ of\ gravity\ (\frac{ft}{s^2})$

The pressure wave velocity can be calculated either by Equation 2 or using Figure 7.

$a = \frac{V_s}{\sqrt{1+\frac{kd}{Ee}}}$ ***(Equation 2)***

Where:

$V_s = Velocity\ of\ sound\ of\ water\ (\frac{ft}{s})$
k $= Modulus\ of\ compression\ of\ water$
$d = Pipe\ internal\ diamter\ (ft.)$
$E = Modulus\ of\ elasticity\ of\ pipe$
$e = Pipe\ wall\ thickness\ (ft.)$



(Thorley Pressure Wave Velocity Figure)

Figure 7: Pressure Wave Velocity Chart (Thorley, 2004)

Valve Shut Off and On Pressure Increase Design Parameters

The pressure increase for valve shut off can be calculated using the following equation:

$P = \frac{0.070VL}{t} + P_i$ ***(Equation 3)***

Where:

P = $Pressure\ Increase$ (psi)
V = $Flow\ Velocity$ ($^{ft}/_{s}$)
$L = Length\ of\ pipe\ between\ valves\ (ft.)$
$t = Valve\ closing\ time\ (s)$
$P_i = Pressure\ inlet\ (psi)$

Table 1 shows the length, pipe material, pipe diameter, and velocities for each water main in the current section. Table 2 displays the pressure increase for each water main due to valve closure. The pressure increase for each water main is shown for closure times of 15, 30, 45 and 60 seconds. As the closure times decrease the pressure change increases. See Figure 8 to correlate the Main ID with the location of the pipe.

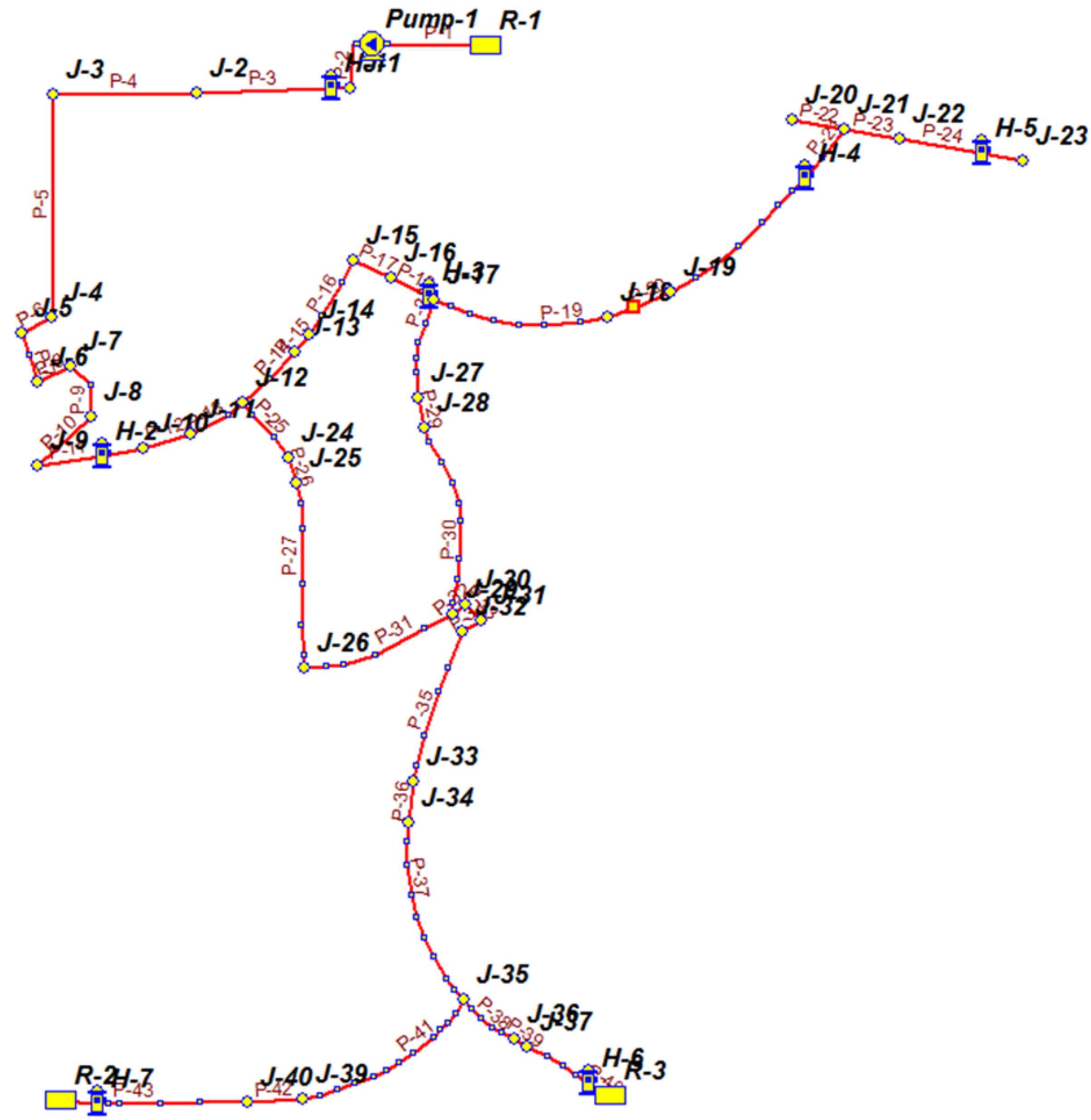


Figure 8: Shows the correlation between the main ID's and the location of the main.

Table 1: Valve Shut Off Pressure Increase Design Parameters

Main ID	Length (ft.)	Pipe Material	Pipe Diameter (in)	Ky Pipe Velocity (ft/s)	Inlet Pressure (psi)
P-1	1	DI	16	2.5	81.3
P-2	60	DI	16	2.3	110
P-3	306	DI	16	2.3	112.1
P-4	256	DI	16	2.1	111.4
P-5	460	DI	12	3.3	111
P-6	94	DI	12	3	107.8
P-7	38	DI	12	2.6	107.2
P-8	50	DI	12	2.3	107
P-9	165	CI	12	2.1	106.9
P-10	69	DI	12	1.7	106.4
P-11	100	DI	8	3	106.2
P-12	90	CI	6	5.2	105
P-13	200	CI	6	5.2	99.6
P-14	189	CI	6	2.8	87.8
P-15	83	CI	6	2.7	84.6
P-16	111	CI	6	2.7	83.3
P-17	90	CI	6	1.7	81.5
P-18	102	CI	6	1.7	80.9
P-19	445	CI	6	0.4	80.2
P-20	107	CI	6	0.5	80.4
P-21	375	CI	6	0.7	80.4
P-22	31	CI	6	0	80.8
P-23	169	CI	6	0.7	80.8
P-24	207	CI	6	0.8	81
P-25	212	CI	4	2.1	87.8
P-26	100	CI	4	1.9	83.4
P-27	258	CI	4	1.7	81.7
P-28	382	CI	6	1.2	80.2
P-29	40	CI	6	1.1	79.1
P-30	250	CI	6	1.1	79
P-31	346	CI	12	0.1	78.3
P-32	31	CI	12	1	78.3
P-33	50	CI	6	0.3	78.3
P-34	31	CI	6	0.3	78.3
P-35	359	CI	6	0.9	78.3
P-36	100	CI	6	2.7	79
P-37	400	CI	6	2.6	79.2

P-38	145	CI	6	1.3	80.4
P-39	25	CI	6	1.3	80.8
P-40	140	CI	6	1.2	80.9
P-41	363	CI	6	0.9	80.4
P-42	100	CI	6	0.7	80.7
P-43	363	CI	6	0.6	80.8

Table 2: Valve Shut Off and On Pressure Increases for Illinois Section

Valve Shut off time (Seconds)								
Main ID	**Pipe Material**	**Pipe Diameter (in)**	**Length of Pipe (ft.)**	**Inlet Pressure (psi)**	**Pressure Increase after 15 sec (psi)**	**Pressure Increase after 30 sec (psi)**	**Pressure Increase after 45 sec (psi)**	**Pressure Increase after 60 sec (psi)**
P-1	DI	16	1	81.3	81.3	81.3	81.3	81.3
P-2	DI	16	60	110	110.6	110.3	110.2	110.2
P-3	DI	16	306	112.1	115.4	113.7	113.2	112.9
P-4	DI	16	256	111.4	113.9	112.7	112.2	112.0
P-5	DI	12	460	111	118.1	114.5	113.4	112.8
P-6	DI	12	94	107.8	109.1	108.5	108.2	108.1
P-7	DI	12	38	107.2	107.7	107.4	107.4	107.3
P-8	DI	12	50	107	107.5	107.3	107.2	107.1
P-9	CI	12	165	106.9	108.5	107.7	107.4	107.3
P-10	DI	12	69	106.4	106.9	106.7	106.6	106.5
P-11	DI	8	100	106.2	107.6	106.9	106.7	106.6
P-12	CI	6	90	105	107.2	106.1	105.7	105.5
P-13	CI	6	200	99.6	104.5	102.0	101.2	100.8
P-14	CI	6	189	87.8	90.3	89.0	88.6	88.4
P-15	CI	6	83	84.6	85.6	85.1	84.9	84.9
P-16	CI	6	111	83.3	84.7	84.0	83.8	83.6
P-17	CI	6	90	81.5	82.2	81.9	81.7	81.7
P-18	CI	6	102	80.9	81.7	81.3	81.2	81.1
P-19	CI	6	445	80.2	81.0	80.6	80.5	80.4
P-20	CI	6	107	80.4	80.6	80.5	80.5	80.5
P-21	CI	6	375	80.4	81.6	81.0	80.8	80.7
P-22	CI	6	31	80.8	80.8	80.8	80.8	80.8
P-23	CI	6	169	80.8	81.4	81.1	81.0	80.9
P-24	CI	6	207	81	81.8	81.4	81.3	81.2
P-25	CI	4	212	87.8	89.9	88.8	88.5	88.3
P-26	CI	4	100	83.4	84.3	83.8	83.7	83.6
P-27	CI	4	258	81.7	83.7	82.7	82.4	82.2

P-28	CI	6	382	80.2	82.3	81.3	80.9	80.7
P-29	CI	6	40	79.1	79.3	79.2	79.2	79.2
P-30	CI	6	250	79	80.3	79.6	79.4	79.3
P-31	CI	12	346	78.3	78.5	78.4	78.4	78.3
P-32	CI	12	31	78.3	78.4	78.4	78.3	78.3
P-33	CI	6	50	78.3	78.4	78.3	78.3	78.3
P-34	CI	6	31	78.3	78.3	78.3	78.3	78.3
P-35	CI	6	359	78.3	79.8	79.1	78.8	78.7
P-36	CI	6	100	79	80.3	79.6	79.4	79.3
P-37	CI	6	400	79.2	84.1	81.6	80.8	80.4
P-38	CI	6	145	80.4	81.3	80.8	80.7	80.6
P-39	CI	6	25	80.8	81.0	80.9	80.9	80.8
P-40	CI	6	140	80.9	81.7	81.3	81.2	81.1
P-41	CI	6	363	80.4	81.9	81.2	80.9	80.8
P-42	CI	6	100	80.7	81.0	80.9	80.8	80.8
P-43	CI	6	363	80.8	81.8	81.3	81.1	81.1

As shown in Figure 9, the higher the inlet pressure of the water main the higher the pressure increase for the water main during valve closure. Pressure relief valves will be placed on the water mains with the highest pressure increases.

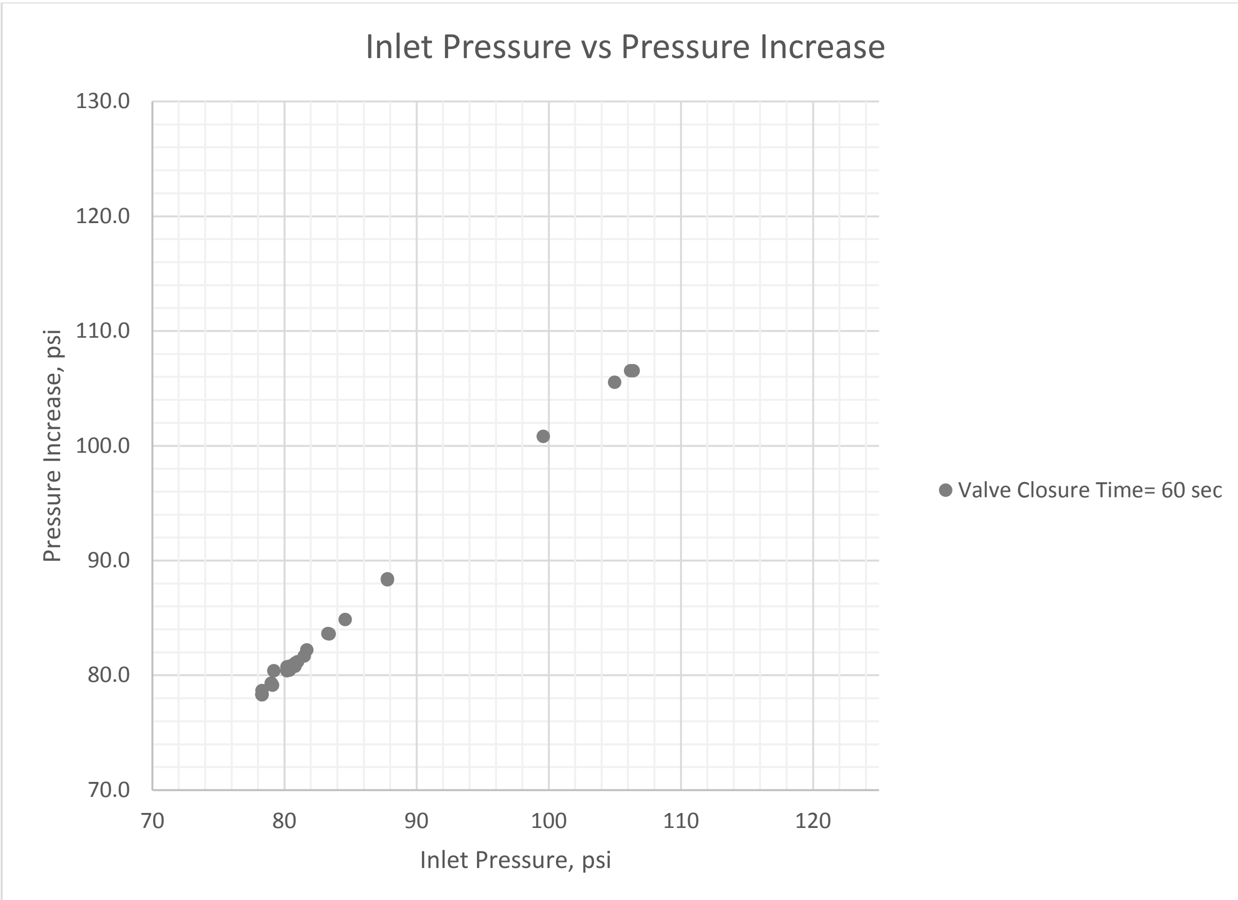


Figure 9: Inlet Pressure vs. Pressure Increase after 60 seconds valve shut off time

II.5. Corrosion

Corrosion is the degradation of metal and is caused by chemical and electrical reactions. Corrosion occurs within the water main distribution pipes, valves, fittings and joints. It can cause the degradation of the quality of our drinking water. Therefore, corrosion is a huge problem for the US water infrastructure. The EPA has estimated that $138 billion will be needed over the next 20 years to maintain and replace existing drinking water systems and that $77 billion of this will be dedicated to repairing and rehabilitating pipelines. (Baird)

Most of the water distribution system in America is made of cast iron. This material is very susceptible to corrosion. This section will explain the electrochemical reaction that occurs during corrosion. After that, the different types of corrosion will be analyzed. Next, cathodic corrosion protection will be discussed. Finally, the correlation between water main breaks and corrosion will be explained to predict which water mains will be the most susceptible to corrosion based on their properties.

Electrical Reaction

In a battery, electrons build up in the negative end, also known as the anode. The positive end, known as the cathode, is attracted to electrons due to its positive charge. If the two ends of the battery are connected with a conductive object, such as a metal wire through which electrons can flow, the electrons will flow from the anode to the cathode as an electric current. The battery and the wire make up what is known as an electrolytic cell, which is a device that causes an electric current to flow. Corrosion in a metal object, such as a pipe, acts in the same manner. A negative area of metal (the anode) is connected to a positive area (the cathode) by the pipe wall itself. As a result, electrons can flow from the anode to the cathode. (Lesson 8: Corrosion Control)

In addition to the anode, the cathode, and the connecting conductive material, the electrochemical reaction requires one more element - the electrolyte. The electrolyte is a conducting solution, which in the case of a pipe is the water within the pipe with its dissolved salts. The electrolyte accepts the electrons from the cathode, allowing the cathode to maintain a positive charge which draws more electrons to it. So, in summary, any electrochemical reaction requires four elements, all of which must be in contact – the anode, the cathode, the conductive material, and the electrolyte. In the battery, the anode and cathode are the two ends of the battery, the conductive material is a wire or other object touching both ends, and the electrolyte is found inside the battery. In the case of corrosion of a pipe, the anode, cathode, and conductive material are all found in the pipe wall while the electrolyte is the water within the pipe. If any of these four elements, which make up the corrosion cell, are absent or are not touching each other, then corrosion cannot occur. (Lesson 8: Corrosion Control)

Chemical Reaction

There must be a chemical and an electrical reaction for corrosion to take place. Iron is the main player in corrosion.

The iron found in pipe is elemental iron (Fe^0) which is unstable and tends to oxidize. In nature, this oxidation produces an iron ore such as hematite (Fe_2O_3), magnetite (Fe_3O_4), iron pyrite (FeS_2), or siderite ($FeCO_3$). In corrosion, the result of this oxidation is rust, $Fe(OH)_2$ or $Fe(OH)_3$. Oxidation of the elemental iron occurs at the anode. First, the elemental iron breaks down as shown below. In this reaction, elemental iron leaves the pipe, so pits form in the pipe's surface at the anode.

$$Fe^0 = Fe^{2+} + 2e^-$$

Equation 4: *The Elemental Oxygen Breakdown*

The reaction produces ferrous iron and two electrons. The electrons are then able to flow through the pipe wall to the cathode. Meanwhile, the ferrous iron reacts with the water (the electrolyte) in the pipe to produce rust and hydrogen ions.

$$Fe^{2+} + 2H_2O = Fe(OH)_2 + 2H^+$$

Equation 5: *Ferrous Iron Reaction with Water*

The rust builds up a coating over the anode's surface. Ferrous hydroxide may then react with more water to produce another form of rust called ferric hydroxide ($Fe(OH)_3$). These layers of rust are what create the tubercles. Tubercles can become problematic because they decrease the carrying capacity of the pipe and can be dislodged during high water flows, resulting in red water complaints. But in the corrosion process, the tubercle actually slows the rate of corrosion by cutting the anode off from the electrolyte. When the tubercle becomes dislodged and the anode comes in contact with water again, the corrosion rate increases.

The electrons from the breakdown of elemental iron flow through the pipe wall to the cathode. There, they leave the metal and enter the water by reacting with hydrogen ions and forming hydrogen gas as shown in Equation 6.

$$2H^{+} + 2e^{-} = H_2$$

Equation 6: *Hydrogen gas Formation*

Hydrogen gas will coat the cathode and separate it from the water in a process called polarization. Just as the buildup of a tubercle breaks the connection between the anode and the electrolyte and slows the corrosion process, polarization breaks the connection between the cathode and the electrolyte and slows corrosion. Dissolved oxygen in the water is able to react with the hydrogen gas surrounding the cathode; reaction shown in Equation 7.

$$2H_2 + O_2 = 2H_2O$$

Equation 7: *Reaction between DO and Hydrogen Gas*

This reaction is called depolarization. Depolarization removes the hydrogen gas surrounding the cathode and speeds up the corrosion process. So, you can see why water high in dissolved oxygen is more corrosive. (Lesson 8: Corrosion Control)

Three Different Types of Corrosion

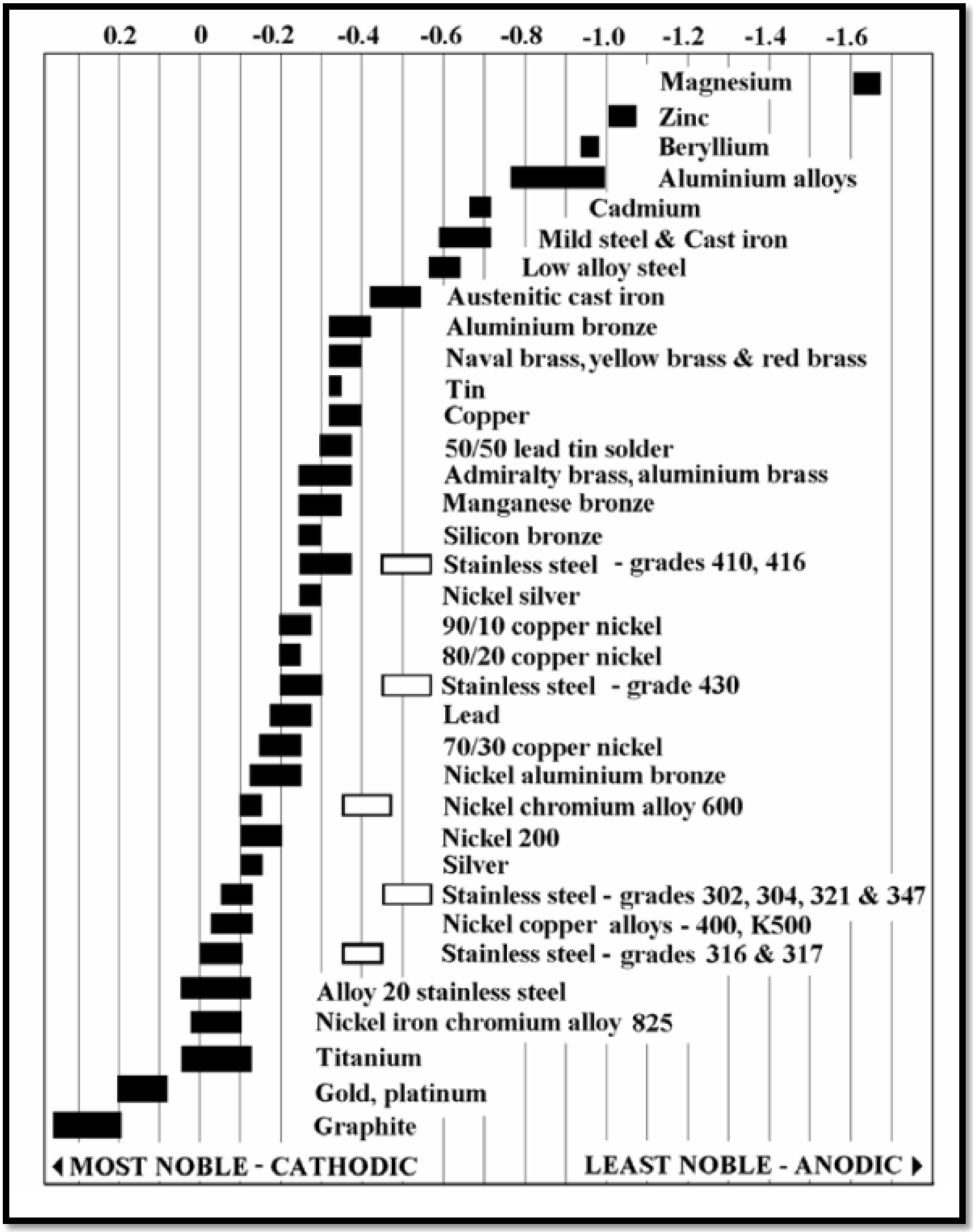
The three different types of corrosion are electrolysis (surrounding soil), oxygen concentration cell (water related), and galvanic corrosion (metal to metal contact).

Electrolysis is caused by a DC current which activates a flow of electrons through the pipe. The pipe charged with electrical current is the anode while the soil becomes the cathode. The surrounding soil causes the external part of the metal pipe to corrode.

More commonly, the water and its constituents may set up a corrosion cell within the pipe. These corrosion cells, known as oxygen concentration cells, result from varying oxygen concentration in the water. The portion of the pipe touching water with a low oxygen concentration becomes the anode, while the part of the pipe in contact with a high oxygen concentration becomes the cathode. Oxygen concentration cells are probably the primary cause of corrosion in the distribution system. They may occur at dead ends in the distribution system where the water is stagnant and loses its dissolved oxygen.

Alternatively, oxygen concentration cells may begin in annular spaces, which are ring-shaped spaces between two pipes or between a pipe and a pipe lining. In every case, oxygen becomes depleted in these regions since they are cut off from the normal flow of water, so a difference in oxygen concentration is set up between the dead end or annular space and the main flow of water. Oxygen concentration cells can also be caused by bits of dirt or bacteria. Both of these can become attached to the pipe walls, shielding the metal from dissolved oxygen in the water and setting up an anode. (Lesson 8: Corrosion Control)

When two dissimilar metals come into contact, galvanic corrosion may occur. Galvanic corrosion is often set up in the distribution system in meter installations and at service connections, couplings and fittings. As shown in Figure 10, the galvanic series is an arrangement of metals based on their corrosiveness.



(Galvanic Corrosion Bimetallic Corrosion)

Figure 10: Galvanic Series

Most of the metals used in piping are iron, steel, and copper. These are found in the middle of the galvanic series. The distance on the galvanic series between two metals will also influence the likelihood of galvanic corrosion when the two metals are placed in conjunction with each other. For example, if aluminum is brought in contact with a steel pipe, the likelihood of corrosion is low since aluminum and steel are close together on the galvanic series. However, if a stainless steel fitting is used on an iron pipe, the likelihood of corrosion is much higher. When galvanic corrosion occurs, the more active metals always become the anodes. This means that they are corroded, and in extreme cases can begin to leak. The less active metal becomes the cathode and is not damaged. (Lesson 8: Corrosion Control)

For underground pipes, the anodic index difference should be no more than 0.15 Volts between two metals in direct contact with each other. (Wikipedia)

<u>Cathodic Corrosion protection</u>

Cathodic Protection is the process of exposing the metal pipe to a more corrosive metal. By doing this, the metal pipe becomes the cathode and the sacrificial metal becomes the anode. The anode will corrode and the metal pipe (cathode) will not corrode while the sacrificial anode is still present. If the sacrificial anode is not replaced after diminishing, then the surrounding soil will be in contact with the metal pipe. This will cause the metal pipe to corrode.

There are two main practices to use cathodic protection. One approach is the galvanic method. In the galvanic method a sacrificial metal is either in direct contact, such as welded or bolted, with the cathode or having a copper wire connecting the anode and the cathode together. This allows for the differences in material voltage to be the driving force of the system. The other approach is impressed current. The impressed current method is having the anode and the cathode connected by a copper wire, no direct contact is allowed, and having an external power source that is the main driving force. For the designs, the galvanic method was chosen due to the ease of installation and the lack of an extra power source.

For the design of the galvanic method, the common anodes are made from zinc or magnesium. Both metals where designed so that a comparison could be made to see what the better choice would be between the two of them. The following equations are used to calculate the difference between zinc and magnesium and to show what the better choice is.

$I = AI'(1.0 - CE)$ ***(Equation 8)***

Where:

$\text{I} = Total\ protective\ current$ (amps)
$\text{A} = Surface\ area\ being\ protected\ (ft^2)$
$I' = Required\ current\ density\ (^{amps}/_{ft^2})$
$CE = \text{Coating efficiency}$

$R(T) = \Delta E/I$ ***(Equation 9)***

Where:

$\text{R(T)} = Total\ resistance\ of\ circuit$ (ohms)
$\Delta\text{E} = Driving\ potential\ voltage\ of\ the\ anode\ (volts)$

$R(C) = R/A$ ***(Equation 10)***

Where:

$\text{R}(C) = Structure\ to\ electrolyte\ resistance$ (ohms)
$\text{R} = Average\ coating\ resistance\ (^{ohms}/_{ft^2})$

$R(A) = R(T) - R(C)$ ***(Equation 11)***

Where:

$\text{R}(A) = Anode\ to\ electrolyte\ resistance$ (ohms)

$N = [0.0052 * \rho * (\ln\left(\frac{8L}{D}\right) - 1)]/(R(A) * L$ ***(Equation 12)***

Where:

$\text{N} = Number\ of\ anodes\ needed\ for\ system$
$\text{L} = Length\ of\ anode\ (ft)$
$D = Diameter\ of\ anode\ (ft)$

P = Soil Resistivity $\left({}^{ohms}/_{cm}\right)$

$N = (T * I * 1000)/(49.3 * W)$ ***(Equation 13)***

Where:

T = $Expected\ life\ time$ (years)
W = $Weight\ of\ one\ anode\ (lb.)$
I = $Total\ protective\ current$ (amps)

Once both the equations are calculated for the number of anodes, the greater number is chosen. The following equations in Table 3 are the above equations with the values for each material solved in terms of area.

Table 3: Cathodic Formula Comparison between Zinc and Magnesium

Zinc	Magnesium
R(T) = ΔE/I = .25/.003A = 250/3A	R(T) = ΔE/I = .9/.003A = 300/A
R(C) = R/A = 1250/A	R(C) = R/A = 4500/A
R(A) = R(T) - R(C) = 250/3A -1250/A = -3500/3A	R(A) = R(T) - R(C) = 300/A - 4500/A = -4200/A
N = .0052*ρ*(ln(8*L/D-1))/(R(A)*L)	N = .0052*ρ*(ln(8*L/D-1))/(R(A)*L)
N = .0052*2000*(ln(8*3/.33-1))/((3500/3A)*3)	N = .0052*2000*(ln(8*2.1/.28-1))/((4200/A)*2.1)
N = .0127A	N = .0048A
N = Yr*I*1000/49.3*lb	N = Yr*I*1000/49.3*lb
N = 10*.003A*1000/(49.3*150)	N = 10*.003A*1000/(49.3*46)
N = .0041A	N = .013A

The lengths and diameters were provided from Zinc Warehouse along with the price of each type of anode. The zinc anode weighing 150lbs costs $321.00 and the magnesium anode weighing 46lbs costs $190.24. With both zinc and magnesium needing roughly the same number of anodes, it is clear that magnesium is the better choice due to being about 1.5 times less expensive and only weighing a third as much as the required zinc. For a direct comparison to show how much money would be saved by using the magnesium anodes over the zinc anodes, a test calculation was run using a 12 inch pipe that was 1500 feet long.

Table 4: Comparison of pricing for Zinc and Magnesium

Zinc		**Magnesium**	
Diameter of Pipe (in)	12	Diameter of Pipe (in)	12
Length of Pipe (ft.)	1500	Length of Pipe (ft.)	1500
Number of Nodes	59.8	Number of Nodes	61.3
Price of all the Nodes	$ 19,260.00	Price of all the Nodes	$ 11,794.88
Nodes Spacing (ft.)	25	Node Spacing (ft.)	24.2

As seen in Table 4, using magnesium would save around $7,500. This may seem like an expensive alternative to replacing the pipe, but just for the new pipe alone it would cost $22,000 for 1500 feet. Therefore, using an anode would cost less to prolong the system until the rest of the pipes can be replaced within 10 years of installing the anodes.

II.6 Temperature

During the winter months, the number of water main breaks increase in areas where the temperature drops below 50 °F (Steven Folkman, 2012). According to the City of Fort Wayne, the highest number of water main breaks occur in the month of January for years 2010-2013, which is displayed in Figure 11 below.

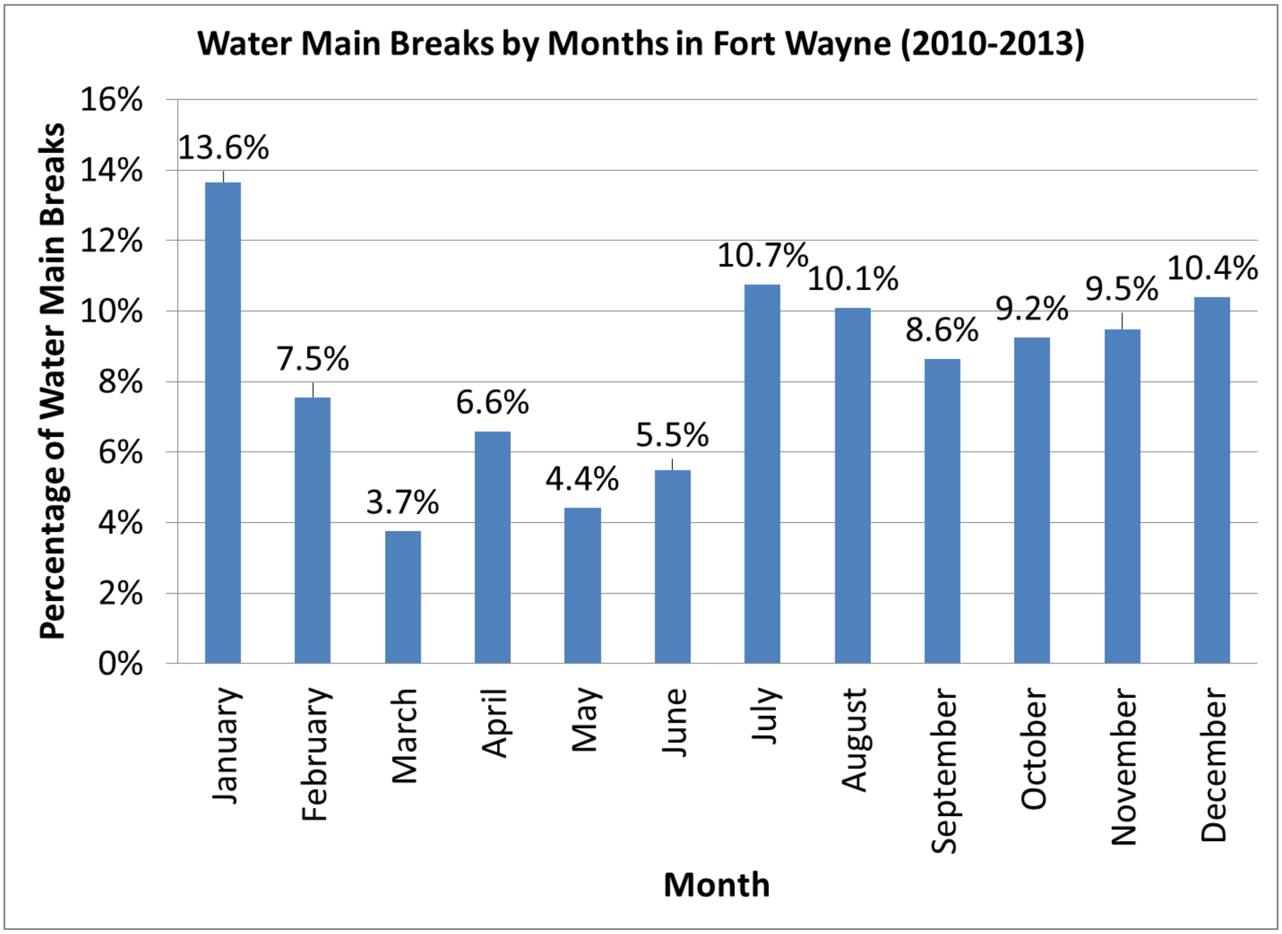


Figure 11: Displays the Percentage of Water Main Breaks by Month

The temperature change induces tensile forces in the water main. This type of break is called a circumferential break.

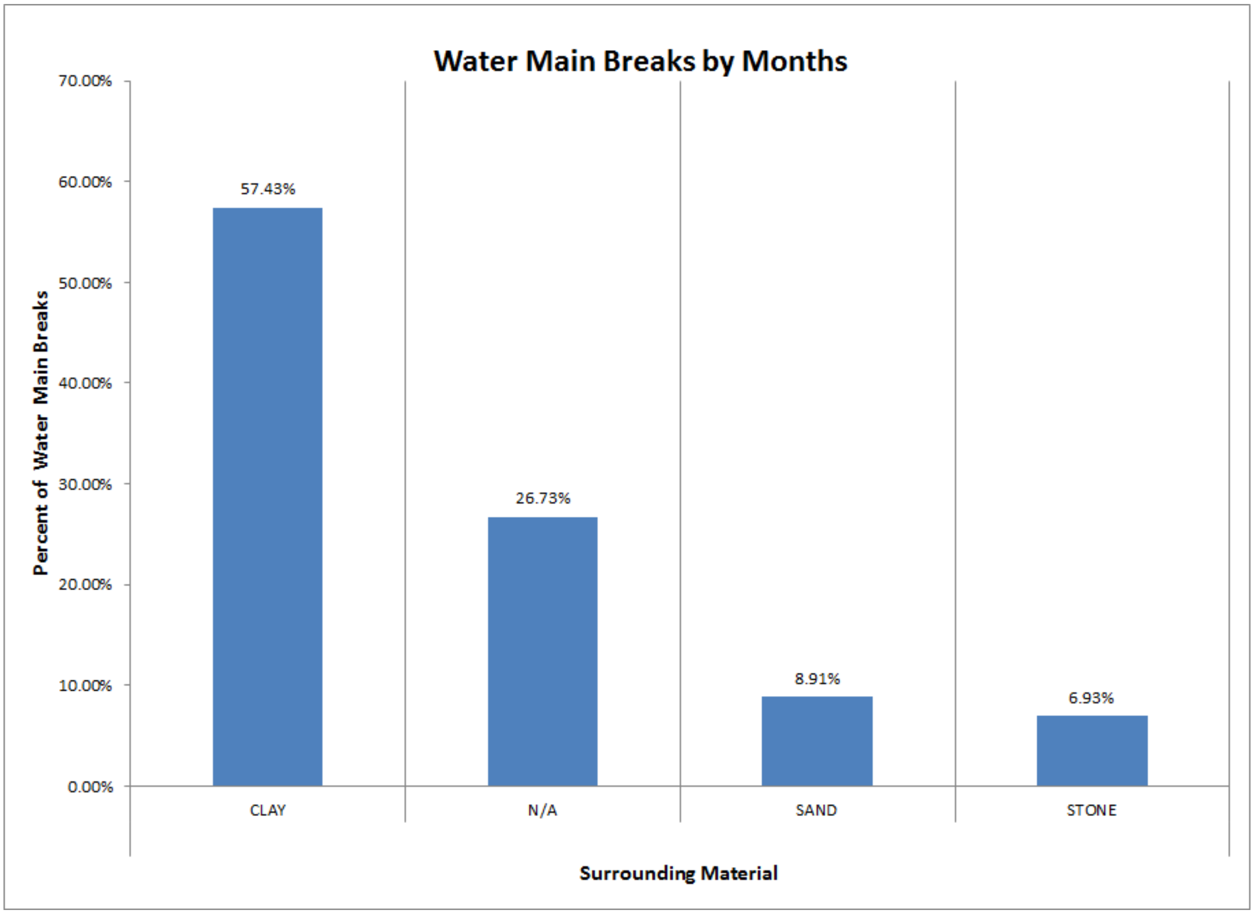


Figure 12: Surrounding Pipe Material for Water Main Breaks due to Temperature Change for 2010-2013.

Figure 12 above displays the surrounding pipe materials for water main breaks due to temperature change for 2010-2013. Circumferential breaks are caused by soil movements producing tensile forces on the pipe, producing a tensile failure. The soil movements are produced by the soil locking to the pipe wall through friction. Soil movements may then produce tension in the pipe, producing simple tensile failures. Gray cast iron pipe systems were generally designed to withstand only internal pressure and crushing forces (AWWA, 1975). The loads that produced the latter forces were assumed in the standards to be due to ground weight or truck loading above the pipe. However, frost loading and expansive clays may also produce similar loads above the pipe (Makar, 3). There is also a chance that breaks can be caused by the water temperature decrease inside the pipe. The temperature factor was not taken into the design account since all the pipe materials are the same and the temperature of the water would be approximately the same throughout the system creating a similar effect on all the pipes.

III. Analysis of Existing Condition

In order to evaluate which pipes were in the most vulnerable condition, a matrix table was set up so that the different criteria could be ranked in order of importance. Once matrix tables were set up, an evaluation was done for each pipe so that the pipe with the highest number would be the most severe pipe. The table below is the matrix used to determine the criteria's ranking.

Table 5: Decision matrix comparing different criteria of pipe

Decision Matrix for Severity Ranking									
0= Lowest Risk 6.5= Highest Risk	**Pipe Material Type**	**Surrounding Material**	**Age of Pipe**	**Length of Pipe**	**Number of Breaks**	**Break Location**	**Break Type**	**Size of Pipe**	**Total**
Pipe Material Type	-	1	1	1	0.5	1	1	1	6.5
Surrounding Material	0	-	0	1	0	0.5	0.5	1	3
Age of Pipe	0	1	-	1	0	0.5	1	1	4.5
Length of Pipe	0	0	0	-	0	0	0	1	1
Number of Breaks	0.5	1	1	1	-	1	1	1	6.5
Break Location	0	0.5	0.5	1	0	-	0.5	1	3.5
Break Type	0	0.5	0	1	0	0.5	-	1	3
Size of Pipe	0	0	0	0	0	0	0	-	0

As shown in Table 5, the pipe material and the number of breaks have the highest ratings in the matrix table followed by age of the pipe. On the lower side of the rankings are the size of pipe and the length of pipe. This means that the material and breaks are more critical than the size and length of the pipe. After this decision matrix was completed, other decision matrixes had to be made for sub category ranking. These sub matrixes would rank the different sub categories for some of the criteria, such as pipe material, surrounding material, break location and break type. Each one of the categories have several responses that needed to be ranked so that the evaluation would be actuate. The sub matrixes of each category can be displayed below and shows the ranking of each element within a category.

Table 6: Ranking of different pipe materials

Decision Matrix for Pipe Material Weights							
	Cast Iron (CI)	**Ductile Iron (DI)**	**Polyvinyl (PVC)**	**Concrete Pressure Pipe (CPP)**	**Steel (ST)**	**Asbestos Cement (AC)**	**Total**
Cast Iron (CI)	-	1	1	1	1	1	5
Ductile Iron (DI)	0	-	1	1	1	1	4
Polyvinyl (PVC)	0	0	-	0	0	0	0
Concrete Pressure Pipe (CPP)	0	0	1	-	0	0	1
Steel (ST)	0	0	1	1	-	0	2
Asbestos Cement (AC)	0	0	1	1	1	-	3

Table 7: Ranking of different types of future breaks

Decision Matrix for Break Style							
	Blowout	**Circumferential**	**Bell Split**	**Longitudinal**	**Bell Shear**	**Spiral**	**Total**
Blowout	-	0.5	0	0	0	0	0.5
Circumferential	0.5	-	0	0	0	0	0.5
Bell Split	1	1	-	0.5	0.5	1	4
Longitudinal	1	1	0.5	-	0.5	1	4
Bell Shear	1	1	0.5	0.5	-	1	4
Spiral	1	1	0	0	0	-	2

Table 8: Ranking of the surrounding material for the pipe

Decision Matrix for Surrounding Material					
	Fill	**Clay**	**Sand**	**Gravel**	**Total**
Fill	-	1	1	1	3
Clay	0	-	1	1	2
Sand	0	0	-	1	1
Gravel	0	0	0	-	0

Table 9: Ranking of worse location to have a break

Decision Matrix for Break Location			
	Joints	**Middle**	**Total**
Joints	-	1	1
Middle	0	-	0

From the sub matrixes, values can be assigned for factors like material and paired with the values from the main decision matrix. For an example, if the pipe was made out of cast iron the matrixes would show that pipe material is highly important and among pipe material cast iron is the worst.

III.1.1 Constraints

As mentioned in the problem statement, the Westside Pump Station on Illinois Road will be the starting point of the project. The pump feeds water down Illinois road and continues along Hillegas road serving a main edition. In Figure 13 below, a model of the existing condition is shown using Pipe KY software modeling. The constraints and detailed analysis of this area will be explained later on. Further analysis will be used in the software to assess the existing condition and identify the locations for improvement and design of the pipe network system.

Figure 13: Topographic view constraints of existing pipe network system

III.1.2 Pipe Characteristics

Prior to analyzing all the pipes in the area, it is important to identify and know all the important characteristics and history of the pipes in order to evaluate the integrity of those pipes. Table 10 shows the I.Ds, material, diameter, length, installation year, and total number of breaks (2010-2013). The table corresponds with the pipes in Figure 14.

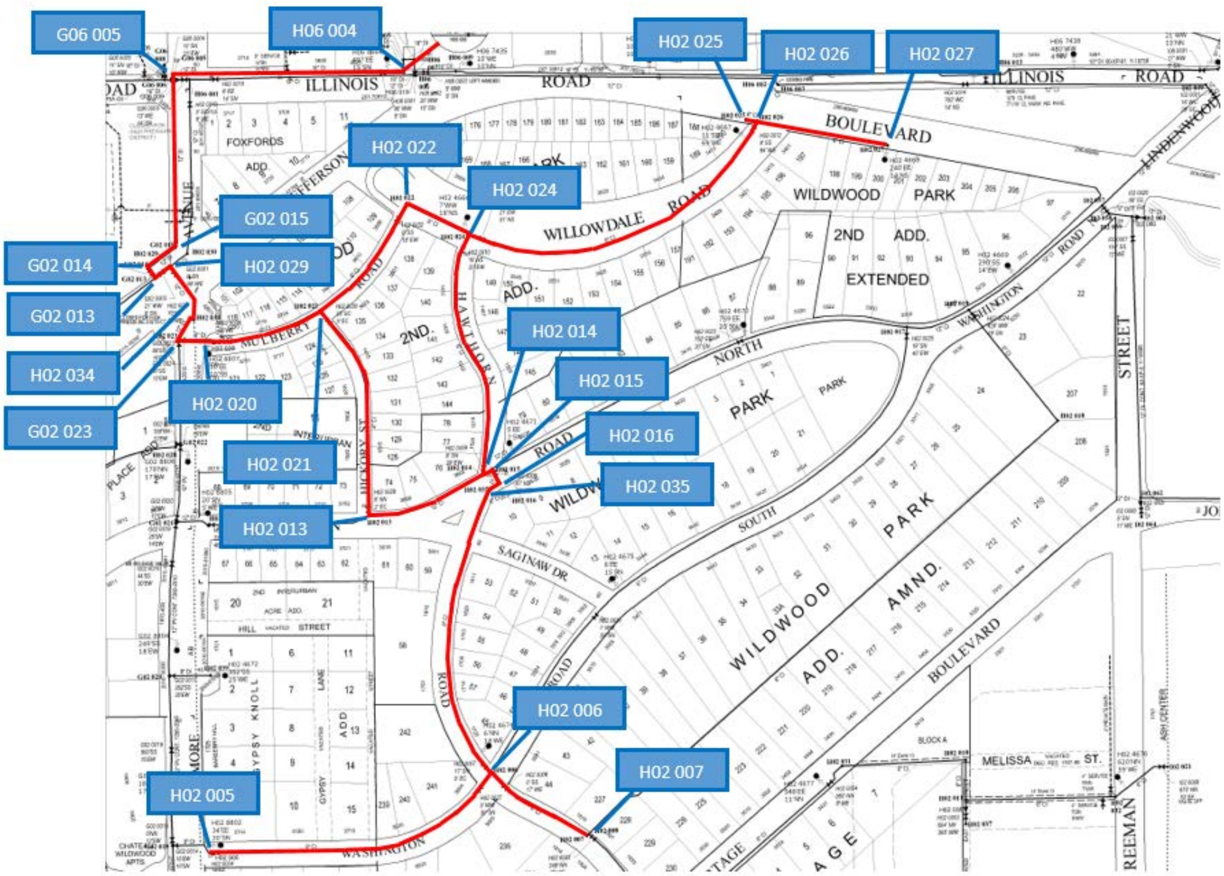


Figure 14: Pipe Node IDs

Table 10: Summary of Pipe Characteristics

Main I.D.	Material	Diameter (in.)	Length of Pipe (ft.)	Installation Year	Total Number of breaks (2010-2013)
G02 015-G06 005	DI	12	460	1992	0
G02 014-G02 015	DI	12	94	1992	0
G02 013-G02 014	DI	12	38	1992	0
G02 013-H02 029	DI	12	50	1969	0
H02 029-H02 034	CI	12	165	1969	0
G02 023-H02 034	DI	12	69	1969	0
G02 023-H02 020	DI	8	100	1969	0
H02 020-H02 021	CI	6	385	1929	0
H02 021-H02 022	CI	6	383	1929	0
H02 022-H02 024	CI	6	192	1929	0
H02 024-H02 026	CI	6	927	1952	0
H02 025-H02 026	CI	6	31	1952	0
H02 026-H02 027	CI	6	376	1952	1
H02 014-H02 024	CI	6	672	1929	0
H02 013-H02 021	CI	4	570	1929	1
H02 013-H02 014	CI	12	346	1928	0
H02 014-H02 015	CI	12	31	1928	0
H02 015-H02 016	CI	6	50	1928	0
H02 016-H02 035	CI	6	31	1928	0
H02 006-H02 035	CI	6	859	1928	0
H02 005-H02 006	CI	6	826	1940	3
H02 006-H02 007	CI	6	310	1940	6

III.1.3 Design Input Variables

The pipe system layout was drawn and modeled in the Pipe2010 KY software as can be shown in Figure 15 below. The important criteria that was considered when inputting the data into the software included data for the reservoirs, pumps, hydrants, junction and the pipes. The information was obtained from the City of Fort Wayne.

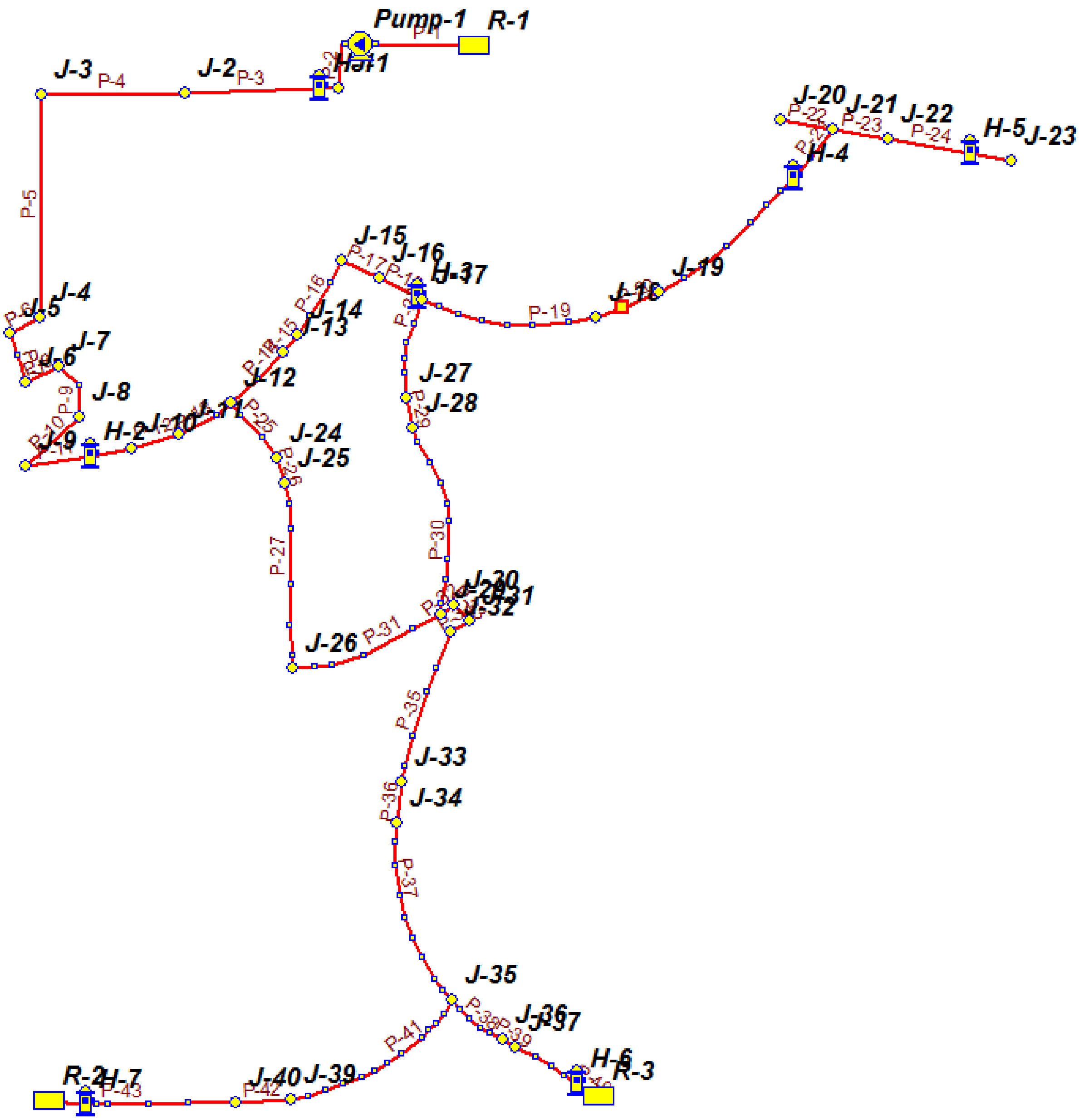
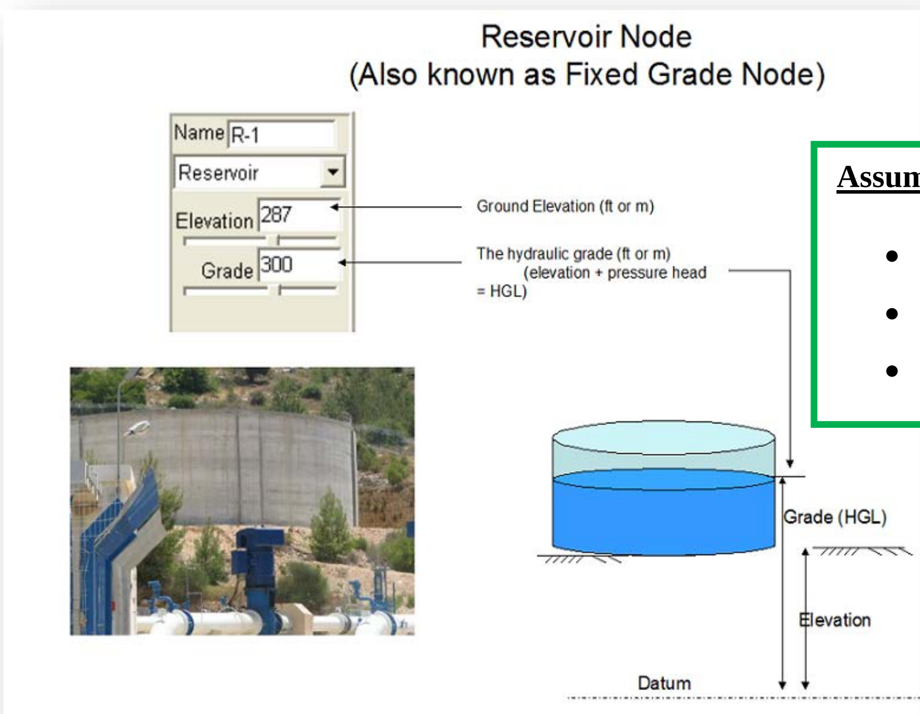


Figure 15: Existing Condition View

III.1.3.1 Reservoir Data

One of the first design criteria that was input into the software was data for the reservoir. In the real world, reservoirs did not exist in the project constraints that were set since water was being pumped from reservoirs near the Central Pump Station. The idea behind setting those reservoirs was to simulate incoming water flow. Therefore, it was assumed there would be a reservoir at the starting point, which was Pump 1 and also at the other project constraint ends. The placement of the reservoirs can be seen in Figure 15. There were a total of three reservoirs in the system. For all reservoirs, elevation, pressure and hydraulic grade data were based off data from the city. A visual for the explanation of this input data can be shown in Figure 16.



Assumptions:

- Elevation- 0 ft.
- Pressure- 81.3 psi
- Hydraulic grade- 187.6 ft.

Figure 16: Reservoir Node

The elevation was assumed at 0 ft. in order to be at the same elevation of the pipes and in order to analyze the maximum pressures and velocities for those pipe and at every junction. The pressure was assumed to be 81.3 psi since this data was obtained from the City of Fort Wayne for the peak pressure throughout the day. This pressure is converted to a hydraulic grade of 187.6 ft. The input for this data can be shown in Figure 17.

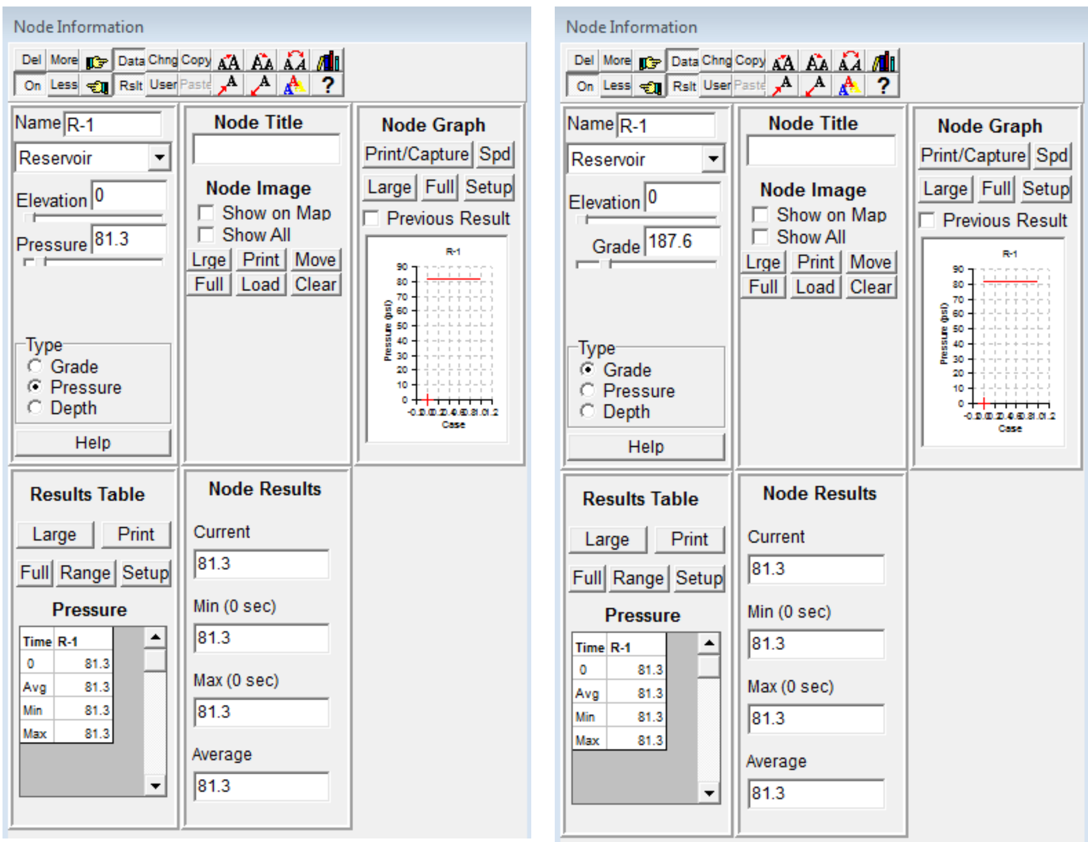


Figure 17: Reservoir Data Input for Pressure (left) and Grade (right)

III.1.3.2 Hydrant Data

The second design criteria that was important in the design was hydrant data. There were a total of seven hydrants in the system. The data needed for hydrants to analyze the existing condition of the system included the elevation, static pressure, residual pressure, and residual flow. The task proved to be difficult to obtain the exact values for those pressures since they had to be measured in the field. In order to measure the pressures for hydrants, special permission would be needed from the city and certain individuals. Therefore, the system was analyzed based on the fire hydrant design manual. The water design standard manual states that the residual pressure needs to be a minimum of 20 psi and the average residual flow is approximately 750 gallons per minute. Every hydrant in the system had the same data. The data was entered into the software and this can be shown in Figure 18.

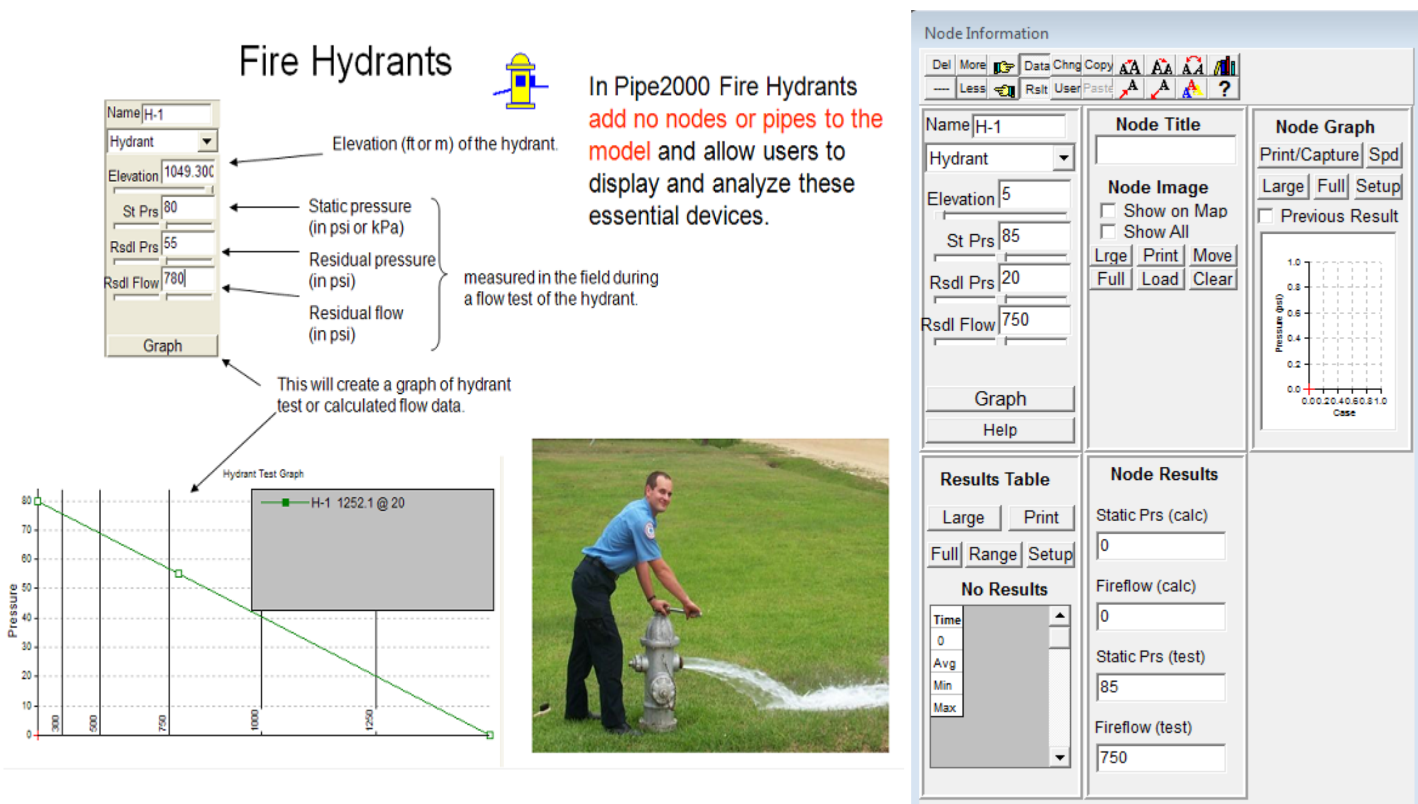


Figure 18: Hydrant Data

III.1.3.3 Pump Data

The third design criteria that was input into the software was data for the pump. Pressure data was obtained from the city in order to know the pressure readings into and out of the pump station. As mentioned before, the peak pressure into the system was from Reservoir 1 at a pressure of 81.3 psi. It was also discovered from the pressure readings that the output peak pressure from the Westside pump station had a pressure reading of 110 psi. With this input and using the Pipe KY software, the results displayed the pump having a power of 65 horsepower and an efficiency of 100%. This can be seen in Figure 19. The output pressure of the pump affects the pressures of the water junctions and velocities in the pipes, which will be discussed in the next section. Data pressure readings for the Westside Pump Station can be found in the Appendix.

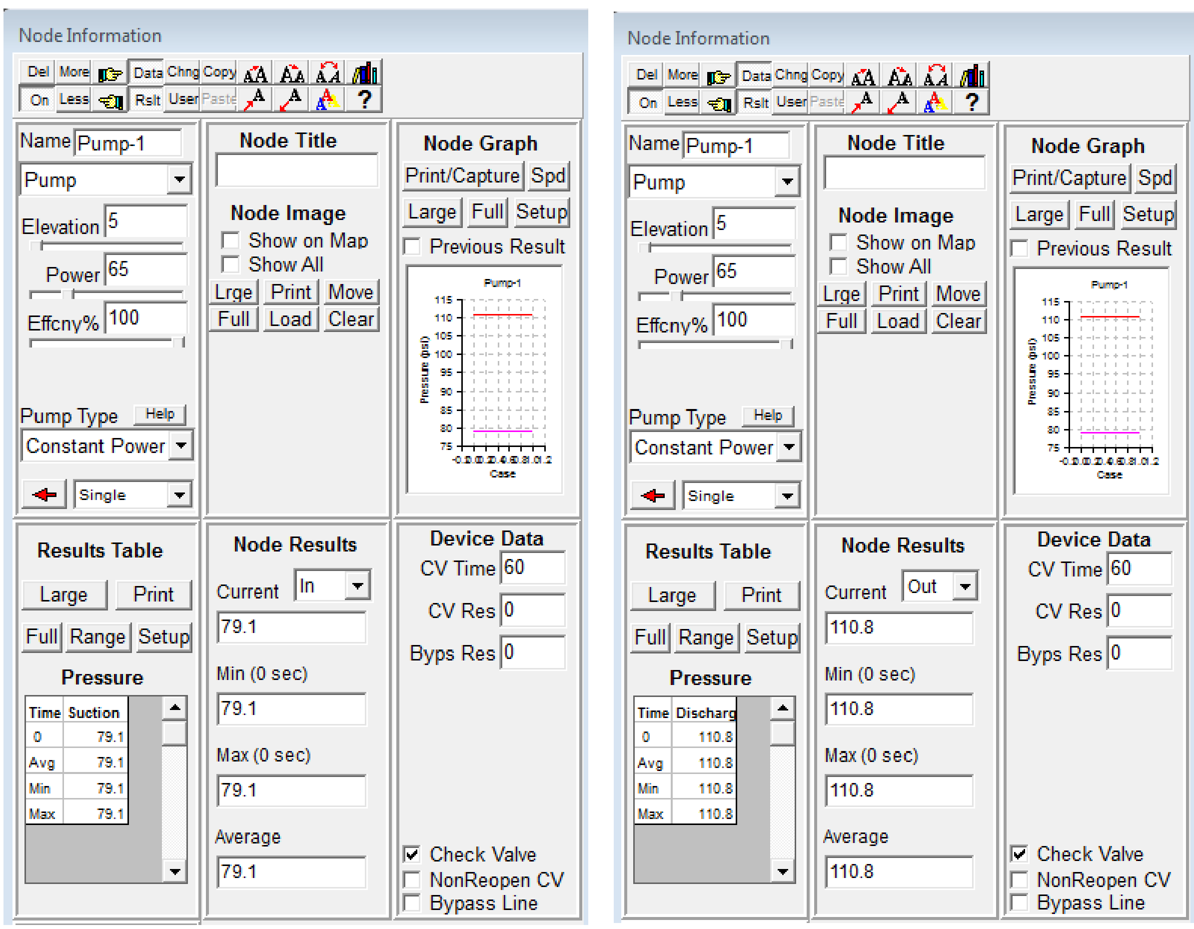


Figure 19: Pump Inlet (left) and Outlet (right) Data with Results

Furthermore, pump start up and shut-off pressure surge calculations were performed to determine the pressure wave velocities, pipe velocities and pressure surges in the pump in order to identify the most critical pressure areas in the system. This can be shown in Table 11 below.

Table 11: Parameters for Pump Shut-off and Start-up Pressure Surge Results

Main ID	Length (ft.)	Pipe Material	Pipe Diameter (in)	Pipe Wall Thickness (in)	Pipe Inside Diameter/Pipe Wall Thickness	Pressure Wave Velocity (ft./s)	Velocity (ft./s)	Change in Velocity (ft./s)	Pump Shut off and Start up Pressure Surge (psi)
P-1	1	DI	16	0.34	47.1	3800	2.5	2.5	127.7
P-2	60	DI	16	0.34	47.1	3800	2.3	2.3	117.5
P-3	306	DI	16	0.34	47.1	3800	2.3	2.3	117.5
P-4	256	DI	16	0.34	47.1	3800	2.1	2.1	107.3
P-5	460	DI	12	0.28	42.9	3890	3.3	3.3	172.6
P-6	94	DI	12	0.28	42.9	3890	3	3	156.9
P-7	38	DI	12	0.28	42.9	3890	2.6	2.6	136.0
P-8	50	DI	12	0.28	42.9	3890	2.3	2.3	120.3
P-9	165	CI	12	0.28	42.9	3250	2.1	2.1	91.8
P-10	69	DI	12	0.28	42.9	3890	1.7	1.7	88.9
P-11	100	DI	8	0.25	32.0	4090	3	3	165.0
P-12	90	CI	6	0.25	24.0	3600	5.2	5.2	251.7
P-13	200	CI	6	0.25	24.0	3600	5.2	5.2	251.7
P-14	189	CI	6	0.25	24.0	3600	2.8	2.8	135.5
P-15	83	CI	6	0.25	24.0	3600	2.7	2.7	130.7
P-16	111	CI	6	0.25	24.0	3600	2.7	2.7	130.7
P-17	90	CI	6	0.25	24.0	3600	1.7	1.7	82.3
P-18	102	CI	6	0.25	24.0	3600	1.7	1.7	82.3
P-19	445	CI	6	0.25	24.0	3600	0.4	0.4	19.4
P-20	107	CI	6	0.25	24.0	3600	0.5	0.5	24.2
P-21	375	CI	6	0.25	24.0	3600	0.7	0.7	33.9
P-22	31	CI	6	0.25	24.0	3600	0	0	0.0
P-23	169	CI	6	0.25	24.0	3600	0.7	0.7	33.9
P-24	207	CI	6	0.25	24.0	3600	0.8	0.8	38.7
P-25	212	CI	4	0.25	16.0	3900	2.1	2.1	110.1
P-26	100	CI	4	0.25	16.0	3900	1.9	1.9	99.6
P-27	258	CI	4	0.25	16.0	3900	1.7	1.7	89.1
P-28	382	CI	6	0.25	24.0	3600	1.2	1.2	58.1

P-29	40	CI	6	0.25	24.0	3600	1.1	1.1	53.2
P-30	250	CI	6	0.25	24.0	3600	1.1	1.1	53.2
P-31	346	CI	12	0.28	42.9	3250	0.1	0.1	4.4
P-32	31	CI	12	0.28	42.9	3250	1	1	43.7
P-33	50	CI	6	0.25	24.0	3600	0.3	0.3	14.5
P-34	31	CI	6	0.25	24.0	3600	0.3	0.3	14.5
P-35	359	CI	6	0.25	24.0	3600	0.9	0.9	43.6
P-36	100	CI	6	0.25	24.0	3600	2.7	1.1	53.2
P-37	400	CI	6	0.25	24.0	3600	2.6	1.2	58.1
P-38	145	CI	6	0.25	24.0	3600	1.3	1	48.4
P-39	25	CI	6	0.25	24.0	3600	1.3	1.1	53.2
P-40	140	CI	6	0.25	24.0	3600	1.2	1.2	58.1
P-41	363	CI	6	0.25	24.0	3600	0.9	0.5	24.2
P-42	100	CI	6	0.25	24.0	3600	0.7	0.7	33.9
P-43	363	CI	6	0.25	24.0	3600	0.6	0.8	38.7

III.1.3.4 Junction Data

The fourth design criteria is that the demand at each junction throughout the system. The demand at each junction was calculated by working through the system backwards starting from the two reservoirs located on Ardmore Avenue and Portage Blvd. Peak residential water demand typically occurs in the morning and evening when more than one water use is occurring. Peak demand can vary greatly based on the number of simultaneous water uses, the flow rates of individual water fixtures, and the length of time fixtures operate. According to the Department of Health, a good estimate to serve a typical household is approximately 5 gallons per minute. Therefore, every junction included the sum of the number of houses multiplied by 5 gallons per minute to calculate the demand at every junction. Sample calculations can be shown in the Appendix. Figure 20 displays the results for the maximum and minimum junction pressure, which shows J-1 having a pressure of 112.6 psi and J-23 having a pressure of 18 psi. The water design manual states that the pressure at each junction must be maintained at a minimum pressure of 35 psi. Therefore, the design alternatives will be looked at more in depth in terms of meeting this requirement.

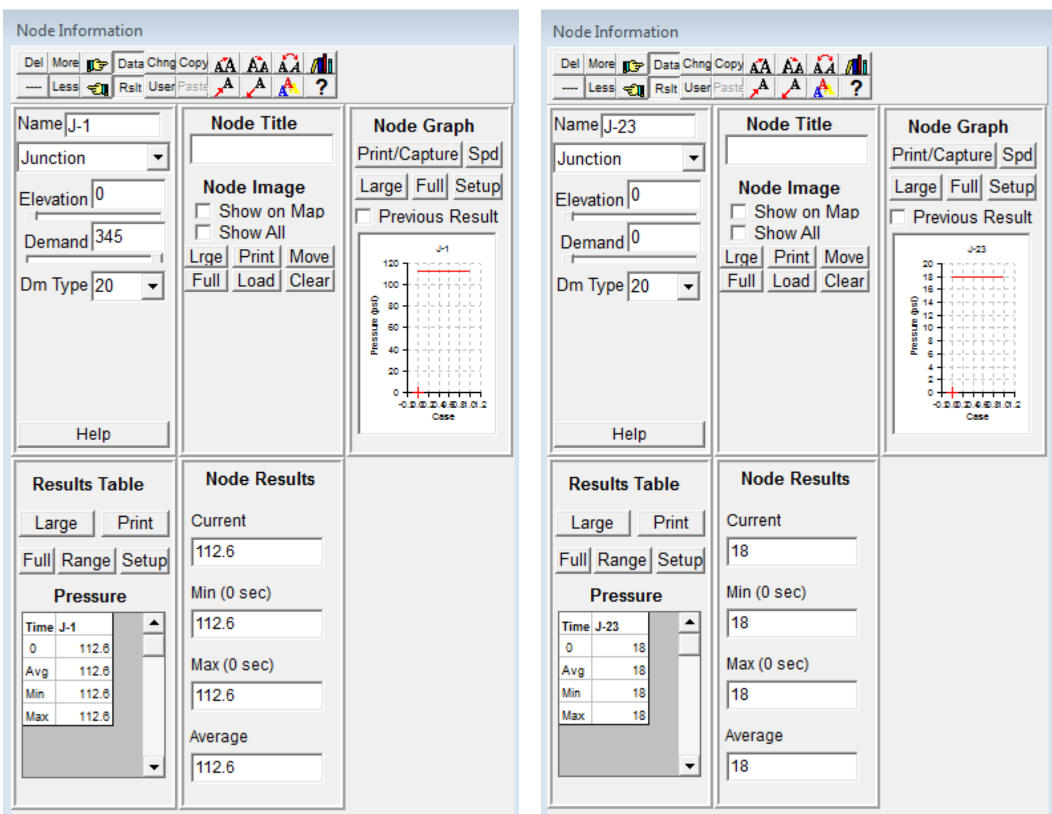


Figure 20: Junction Data & Results

III.1.3.5 Pipe Data

The fifth design criteria to input in the Pipe KY software was information about the existing pipes. The needed data for this criteria included the diameter, material, length, roughness, and age of the pipe. The input of the data can be found in Figure 21. A summary of all the pipe characteristics can be found in Table 10. As for the pipe analysis results, it showed that pipe 12, 13, 5, 6, and 1 had the maximum velocities. A summary can be shown in Table 12 for both maximum and minimum velocities and can also be found in the Appendix.

Table 12: Maximum/Minimum Velocities

Pipe Number	Maximum Velocity (ft./s)	Pipe Number	Minimum Velocity (ft./s)
P-12	8.84	P-23	0.11
P-13	8.73	P-32	0.13
P-5	7.30	P-21	0.23
P-6	6.42	P-20	0.62
P-1	5.62	P-31	0.96

Comparing the maximum velocities to the standard water design manual, it was discovered that that pipes 1, 5, and 6 failed to meet the standard requirement. Therefore, this area will be one of the areas to re-design in the design alternatives.

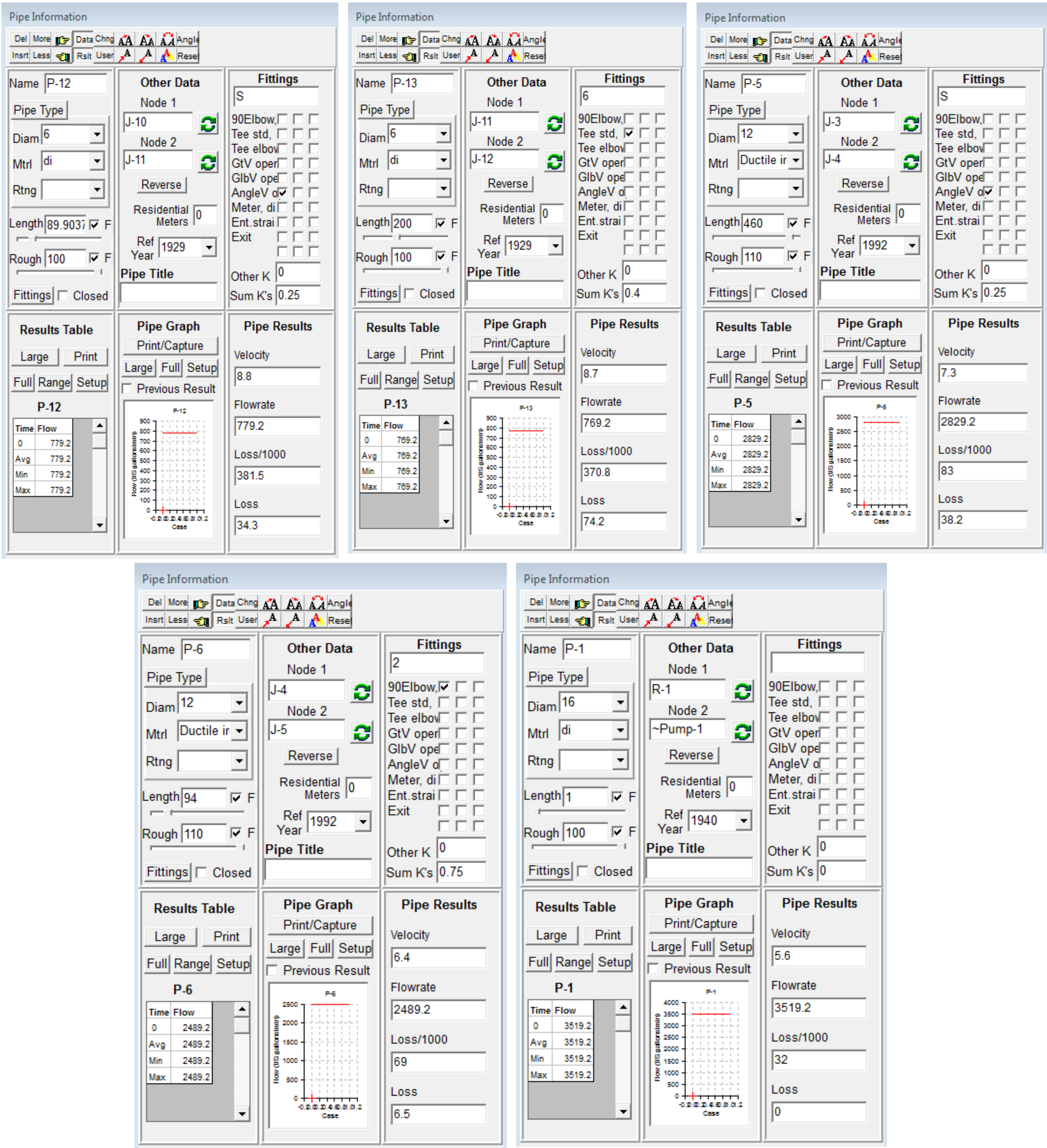


Figure 21: Pipe Data & Results

III.1.4 Existing Condition Summary Results

Table 13: Summary of Existing Items

Item	Quantity
Pipes	43
End Nodes	40
Primary Loops	1
Supply Nodes	3
Supply Zones	1

Table 14: Summary of Net System Flows

Net System	Quantity (gpm)
Inflow	4158
Outflow	0
Demand	4158

Table 15: Maximum & Minimum Pressure

Junction Number	Maximum Pressure (psi)	Junction Number2	Minimum Pressure (psi)
Pump outlet	110.78	Pump Inlet	79.12

Table 16: Maximum head losses

Pipe Number	Maximum Headloss (ft.)
P-12	381.50
P-13	370.85
P-37	132.09
P-36	120.93
P-35	104.36

From analyzing Tables 12 through 16, the results will be looked at in depth in the next design alternatives in order to improve and redesign the system in terms of those variables. The new and improved system will be much more efficient and cost effective.

IV. Design Alternative 0

Given the scope of the project, one of the first alternatives that was thought of was Design Alternative 0, which was to "do nothing." This alternative would involve replacing or patching the pipes at the location of the break by simply responding to a call-in failure. This design, of course was discarded right away since all the pipes in the selected area were at least 50 years old. This means that most of the pipes age have reached their life cycle limit. Therefore, the rest of the design alternatives are looked at in more depth.

IV.1 Advantages

One of the advantages to Design Alternative 0 is that it's the least expensive design temporarily. Also, it is the simplest design since nothing has to be done right away.

IV.2 Disadvantages

One of the disadvantages to Design Alternative 0 is that the consequence of doing nothing can result in a very expensive and catastrophic failure. For example, the cost to fix a burst water main line by call-in failure can range from $500 to $5,000 just to replace the broken section of the pipe of replace the entire main line. Also, another disadvantage for this design alternative is the fact that the reason for pipe failure may be unknown and depending on the uncertainty, water may be contaminated and this can lead to even higher costs and a risk for the safety of the public.

V. Design Alternative 1

V.1 Details of Design Alternative 1

Referring to the discussions made in the existing condition, the approaches taken to determining the first design alternative dealt with the following changes:

1) Pressure relief valve installation
2) Water tower installation
3) Pipe layout change
4) Pipe material change
5) Pump optimization
6) Cathodic Protection

A layout for the first design alternative can be seen below in Figure 22. Each section had a design criteria that was altered and this will be discussed in each individual section.

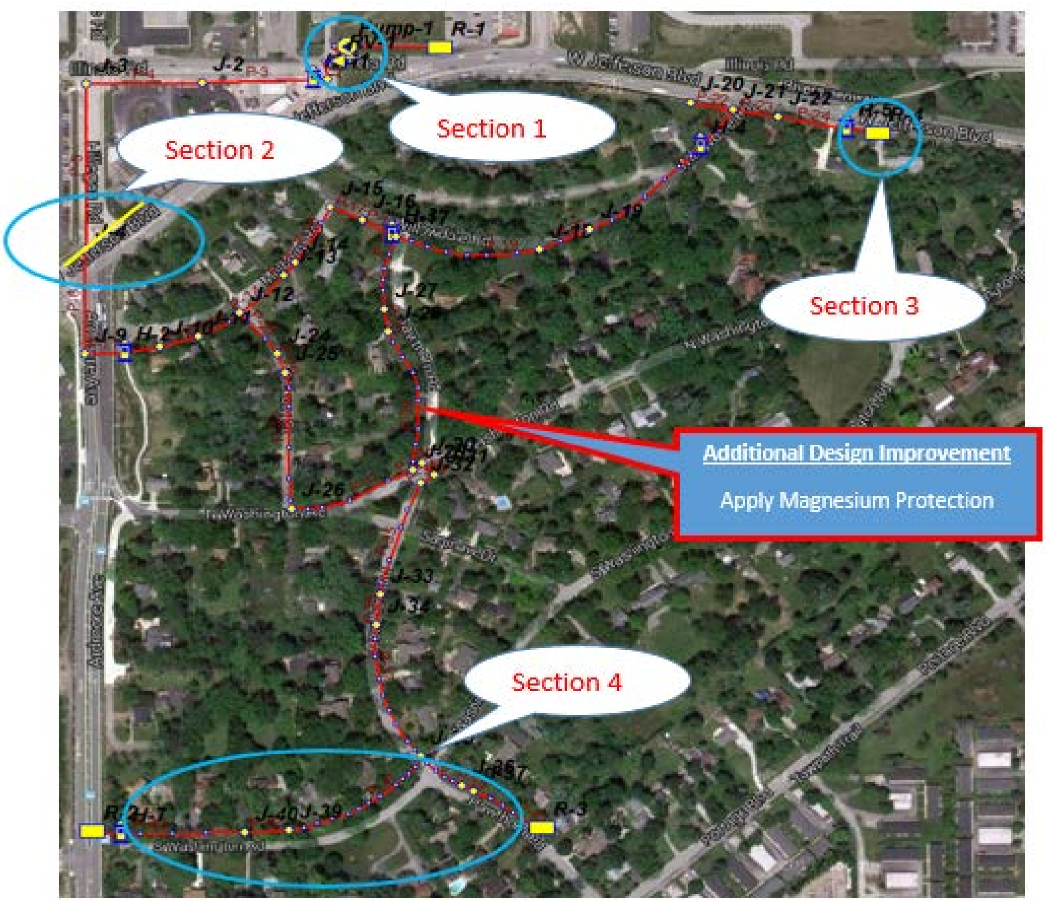


Figure 22: Design Alternative 1

V.1.1 Section 1 Design

In this section, the pump horsepower was decreased from 67 horsepower in the existing condition to 38 horsepower in order to reduce the flow rate. A pressure relief valve was added directly after the pump in order to protect the system from any pressure surges. Making these changes would affect the net system flow rate demand and protect the system from any main breaks.

V.1.2 Section 2 Design

In order to improve the flow rate and minor losses of the system, pipes 6, 7, 8, 9, and 10 were redesigned by removing them from the system and connecting pipe 5 and pipe 11 with a single straight pipe. This eliminates the minor losses in the fittings and the unnecessary turns and the only loss remaining would be the friction loss along the pipe for that section. It is important to note that in this section there is a line that crosses the pipe. The yellow line represents another pipe system that exists in the field. So, when the pipe is redesigned, it will tie into the other pipe system just like it is displayed in Figure 22.

V.1.3 Section 3 Design

For this section a water tower was added in order to supply pressure throughout the system. In the existing condition, the junctions on pipes, 22, 23 and 24 had an average pressure of 18 psi and so it did not meet the water design standard of a minimum 35 psi. Therefore, the water tower was added to increase pressure to the junctions in the system.

V.1.4 Section 4 Design

The redesign of this particular section was based on history of the main breaks and surrounding conditions of the pipes. The material of pipes 38 through 43 were changed from Cast Iron to HDPE pipes. As discussed above, history shows that these stretches of pipes suffered the most breaks due to corrosion and therefore a material change for theses pipes will increase the reliability of the system.

V.1.5 Additional Design Improvement

The additional design improvement implemented to the system as a whole was installing cathodic protection on the remaining untouched pipes using magnesium. The length of pipe remaining in the system to include cathodic protection is approximately 6035 ft.

V.2 Advantages

Design Alternative 1 had a few advantages, which included the following:

- Installing a pressure relief valve to protect the system from pressure surges from the West Side pump station.
- A large change in demand, lowering it from 4158 to 2798 gallons per minute.
- With a lower demand, the pump runs at a 38 hp. This is significantly less than the original 67 hp pump, saving energy cost from running the pump at a lower rate.
- For the design pipe layout, it requires the least amount of magnesium protection (6035 feet of pipe length), which protects the system for 10 years from corrosion.
- In section 4 the pipes where replaced as a result from the decision matrices and were replaced with HDPE. This material was chosen due to its long service life and its resistance to corrosion, which was the main reason for pipe failures in the section.

V.3 Disadvantages

The disadvantages of Design Alternative 1 included the following:

- Installation of the water tower brings up the cost of the project and would also be difficult to get approval from the surrounding residences.
- The pipe redesign layout is in an area that has higher traffic flow along it. This may hinder the road for a short period of time and also would increase the need for safety for the contractors installing the pipe line.

VI. Design Alternative 2

VI.1 Details of Design Alternative 2

The approaches taken to determining the second design alternative dealt with the following changes:

1) Pressure relief valve installation
2) Water tower
3) Pipe layout change
4) Pipe material change
5) Pump optimization
6) Cathodic protection

A layout for the first design alternative can be seen below in Figure 23.

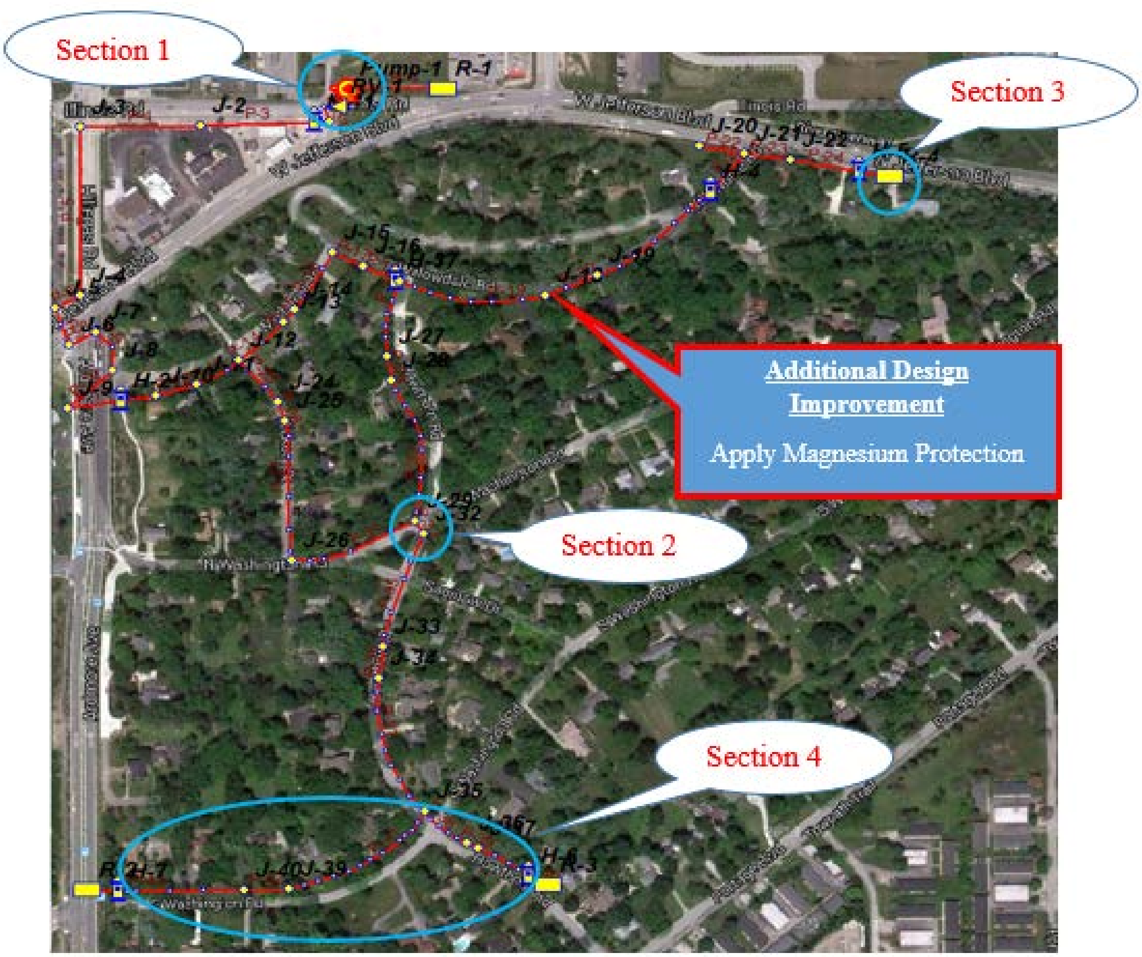


Figure 23: Design Alternative 2

VI.1.1 Section 1 Design

In this section, the pump horsepower was decreased from 67 horsepower in the existing condition to 61 horsepower in order to reduce the flow rate. A pressure relief valve was added directly after the pump in order to protect the system from any pressure surges. Making these changes would affect the net system flow rate demand and protect the system from any main breaks.

VI.1.2 Section 2 Design

The second area of design was to look into improving the flow rate and minor losses of the system. Pipes 32, 33, and 34 were redesigned by removing them from the system and connecting pipe 32 between junction 29 and junction 32. An additional elbow is installed in the design as well in order to taper the curvature of the pipe into the proposed new pipe layout. This eliminates the minor losses slightly in the fittings and the friction losses along the length of pipe.

VI.1.3 Section 3 Design

For this section, it was similar to design Alternative 1. A water tower was added in order to supply pressure throughout the system. In the existing condition, the junctions on pipes, 22, 23 and 24 had an average pressure of 18 psi and so it did not meet the water design standard of a minimum 35 psi. Therefore, the water tower was added to increase pressure to the junctions in the system.

VI.1.4 Section 4 Design

The redesign of this particular section was based on history of the main breaks and surrounding conditions of the pipes. The material of pipes 38 through 43 were changed from Cast Iron to HDPE pipes. As discussed above, history shows that these stretches of pipes suffered the most breaks due to corrosion and therefore a material change for theses pipes will increase the reliability of the system.

VI.1.5 Additional Design Improvement

The additional design improvement implemented to the system as a whole was installing cathodic protection on the remaining untouched pipes using magnesium. The length of pipe remaining in the system to include cathodic protection is approximately 6339 ft.

VI.2 Advantages

When analyzing Design Alternative 2, it had the following advantages:

- Installing a pressure relief valve to protect the system from pressure surges from the West Side pump station.
- The pipe layout redesign requires more magnesium (approximately 6339 feet) to protect the system than design 1. However, it is still a positive because it extends the life time of the system by 10 years.
- In section 4 of the redesign, the pipes were replaced as a result from the decision matrices and were replaced with HDPE. This material was chosen due to its long service life and its resistance to corrosion, which was the main reason for pipe failures in the section.
- For this pipe redesign, it is located by a road with lower traffic flow, which reduces the safety risk of the contractor installing the pipes.

VI.3 Disadvantages

Design Alternative 2 had the following disadvantages:

- The flow rate is increased with the modifications made in the system. This is the opposite of what is wanted in the project.
- Despite a higher flow rate demand, the pump was able to decrease the required power by 7 hp. These is a negative because compared to design 1 this is a very small change in horse power.
- Another negative for design 2 is the installation of a water tower. This brings up the cost of the project and also would be difficult to get approval from the surrounding residences.

VII. Design Alternative 3

VII.1.1 Details of Design Alternative 3

The approaches taken for the final design dealt with the following changes:

1) Additional pump installation
2) Pressure relief valve installation
3) Pipe layout change
4) Pipe material change
5) Pump optimization
6) Cathodic protection

A layout for the first design alternative can be seen below in Figure 24.

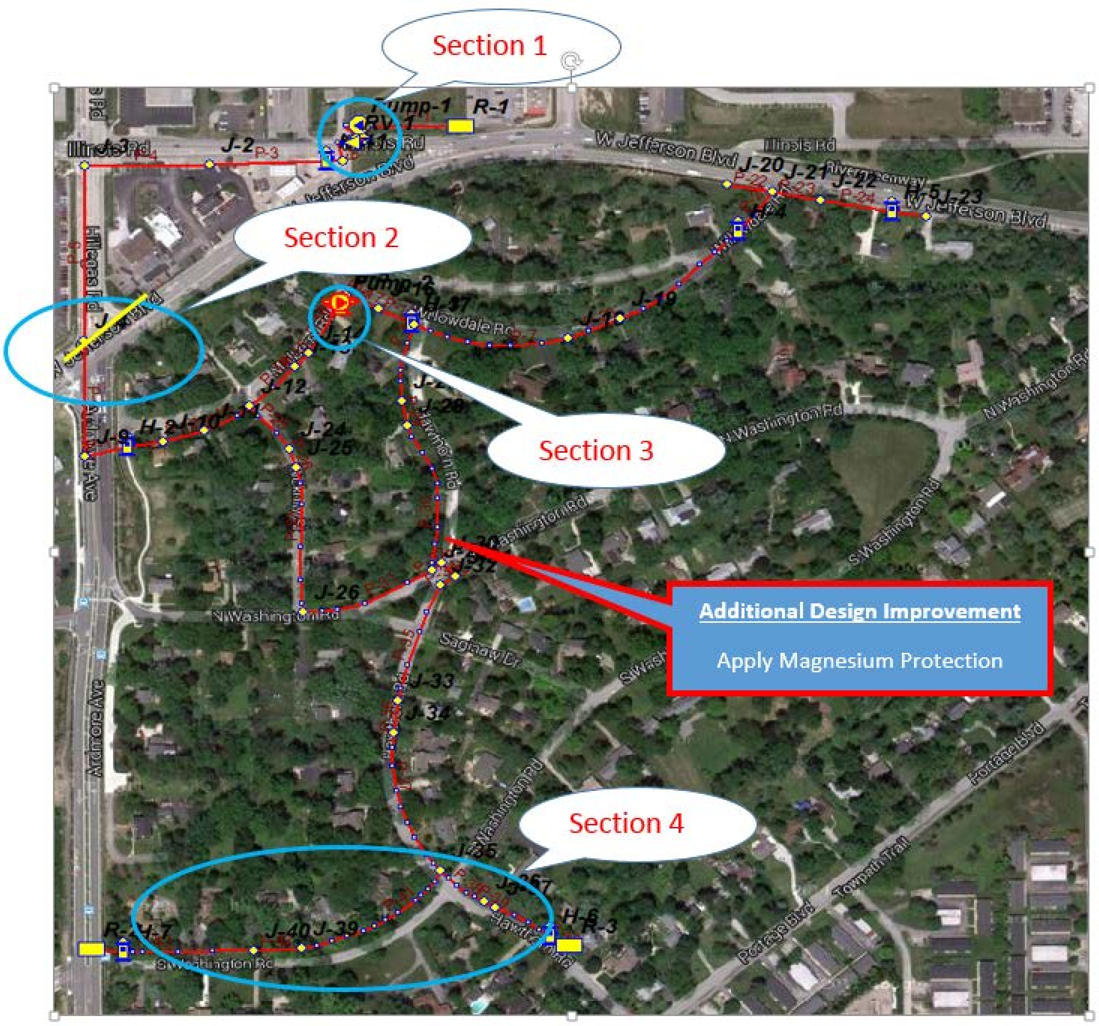


Figure 24: Design Alternative 3:

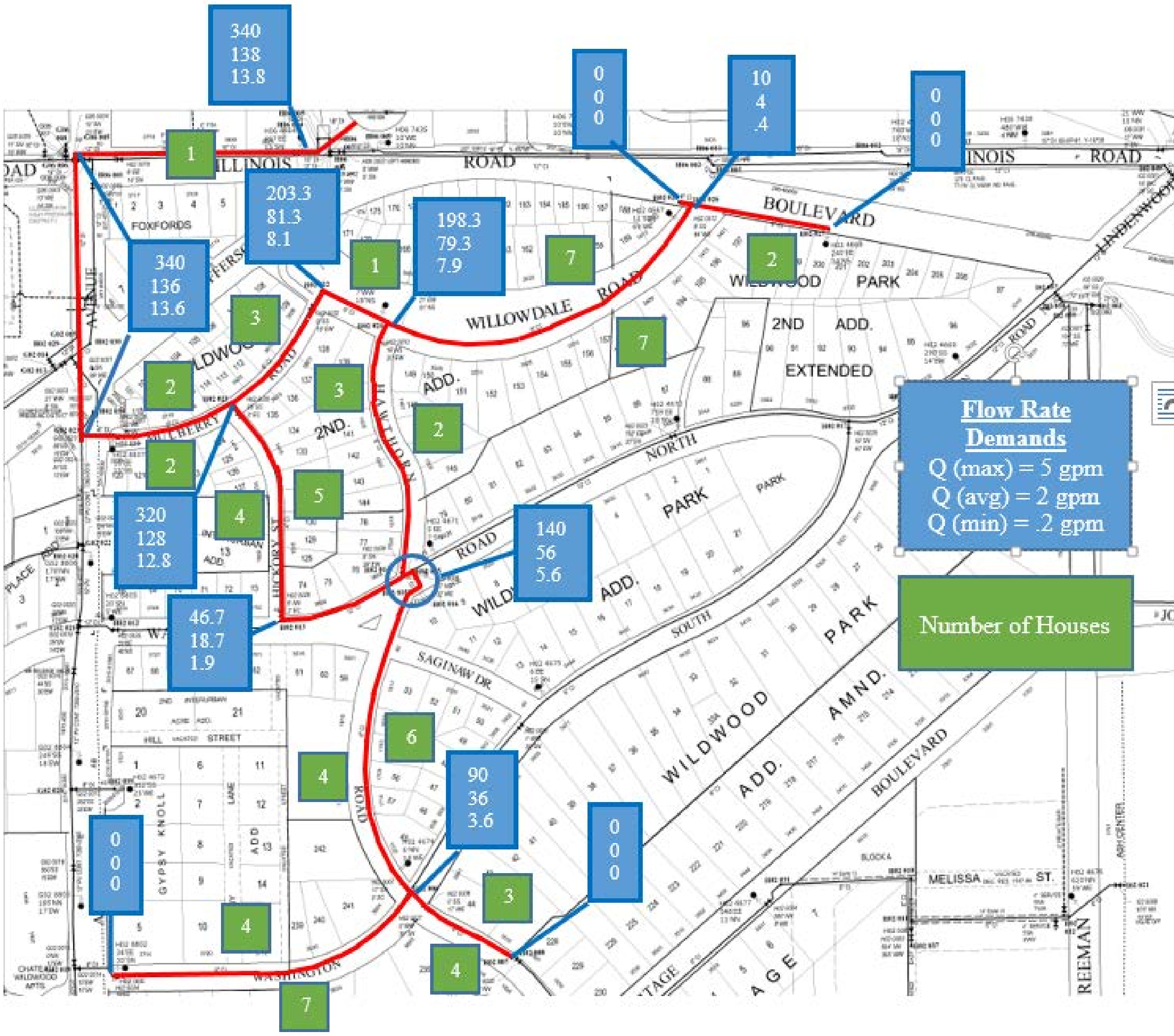


Figure 25: Flow rate demands and Number of Houses served

As displayed in Figure 25, it shows the maximum, normal, and minimum flow rate demands for every junction throughout the system. It also shows the number of houses being served and using this information determines the flow rate demand at each junction. The methodology behind this approach to calculating the flow rate demands involved working through the system backwards. For example, the starting point was at the two bottom junctions with a demand of 0 gallons per minute. Moving along the pipe network on the left, there are 4 houses north of Washington and 7 houses to the South. Therefore, there are a total number of 11 houses in this section. This total number is then multiplied by the flow rate demand of each house, which can be shown in the "Flow Rate Demands" legend box above. The same methodology is then used on the right hand side of the bottom junction, which shows there are a total of 7 houses. This number is then multiplied by the flow rate demands shown in the legend box. The combined flow rate demands for these sections are then totaled and displayed in the junction located at the intersection of Hawthorne Road and Washington Road. The same methodology is used for the remaining portion of the system all the way to the Westside pump station. These three scenarios were run to guarantee that the system would work at peak, normal, and valley hours.

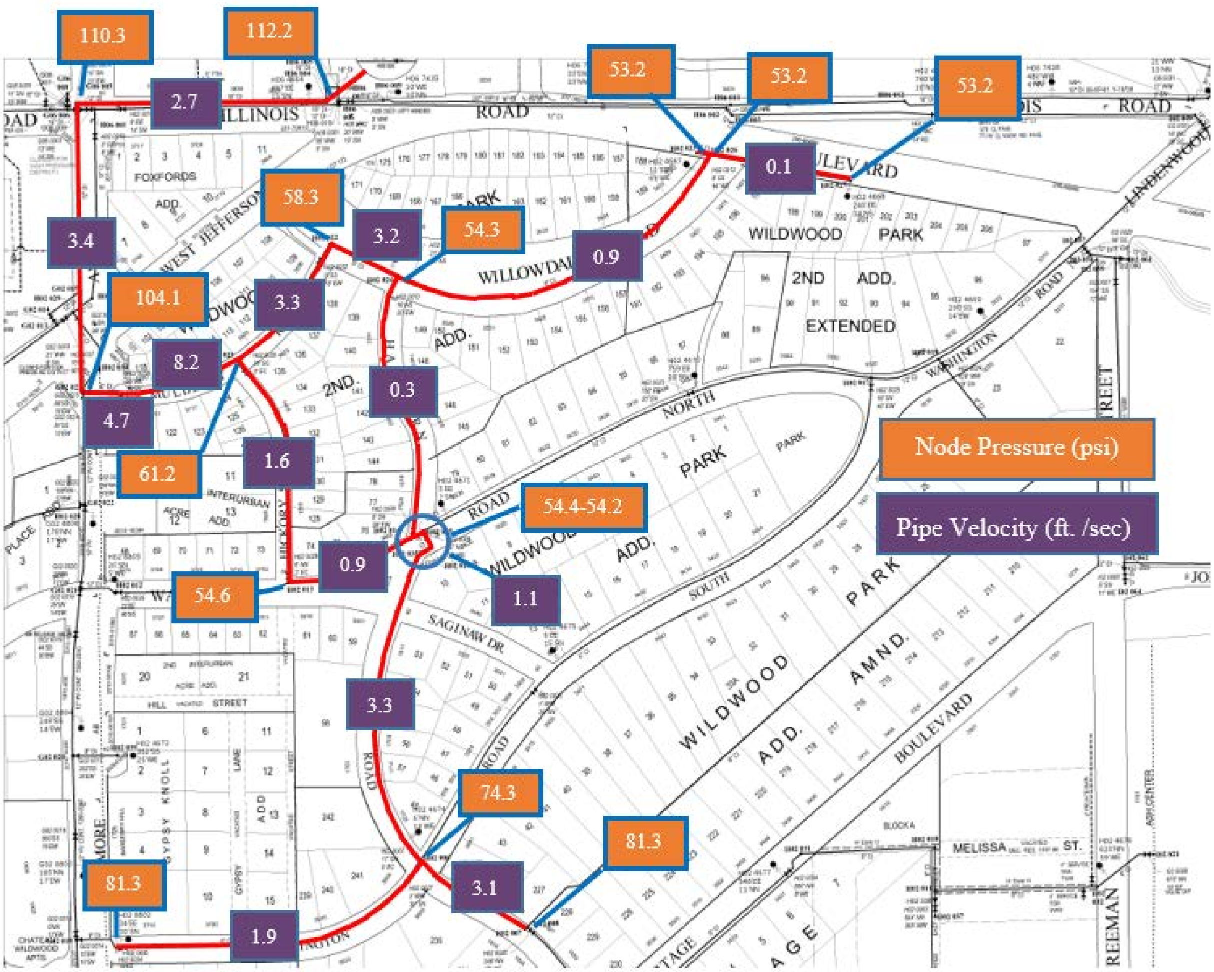


Figure 26: Node Pressure and Pipe Velocities

As displayed in Figure 26, it shows the node pressures at every junction and pipe velocities along every pipe line. When all the data was input into Pipe KY, the system showed that it successfully passed all three scenarios (peak, normal, and valley hours for flow rate) when comparing the flow rate demands, pressures, and velocities of the system to the Water Design Standard Manual.

VII.1.1 Section 1 Design

In this section and referring to Figure 24, the pump horsepower was decreased from 67 horsepower in the existing condition to 38 horsepower in order to reduce the flow rate. A pressure relief valve was added directly after the pump in order to protect the system from any pressure surges. Making these changes would affect the net system flow rate demand and protect the system from any main breaks.

VII.1.2 Section 2 Design

In order to improve the flow rate and minor losses of the system, pipes 6, 7, 8, 9, and 10 were redesigned by removing them from the system and connecting pipe 5 and pipe 11 with a single straight pipe. This eliminates the minor losses in the fittings and in the unnecessary turns and the only loss remaining would be the friction loss along the pipe for that section. It is important to note that in this section there is a line that crosses the pipe. The yellow line represents another pipe system that exists in the field. So, when the original pipe is redesigned, it will tie into the other pipe system just like it is displayed in the Figure 24. This design was chosen because it improved the flow rate more drastically when compared to replacing pipes 32, 33, and 34 in the previous design.

VII.1.3 Section 3 Design

For this area of design, an additional pump (1hp) was installed instead of a reservoir at the far right constraint of the system. The pump was installed at the intersection of Mulberry Road and Willowdale Road at the top of the loop. By adding this pump, it allowed the pressure at each junction throughout the system to be maintained above the minimum pressure of 35 psi. This also allowed a more evenly distributed pressure throughout the system. Allowing for the installation of this pump versus a reservoir was also helpful in determining that Design Alternative 3 was the better option due to less labor, maintenance, and operation of a water tower. In addition, the aesthetics of the system would not alter using a pump, whereas a water tower would deal with much more visible change and public consent.

VII.1.4 Section 4 Design

The redesign of this particular section was based on history of the main breaks and surrounding conditions of the pipes. The material of pipes 38 through 43 were changed from Cast Iron to HDPE pipes. As discussed above, history shows that these stretches of pipes suffered the most breaks due to corrosion and therefore a material change for theses pipes will increase the reliability of the system.

VII.1.5 Additional Design Improvement

The additional design improvement implemented to the system as a whole was installing cathodic protection on the remaining untouched pipes using magnesium. The length of pipe remaining in the system to include cathodic protection is approximately 6035 ft.

VII.2 Advantages

When analyzing Design Alternative 3, it had the following advantages:

- The major advantage is that instead of using a water tower to boost pressure in the system, a small 1 hp in-line booster pump was installed in the system to help equalize the pressures and to have all the junctions meet the minimum pressure required.
- Installing a pressure relief valve to protect the system from pressure surges from the West Side pump station.
- A large change in demand, lowering it from 4158 to 2595 gallons per minute.
- With a lower demand, the pump runs at a 38 hp. This is significantly less than the original 67 hp pump, saving energy cost from running the pump at a lower rate.
- Pipe layout design requires the least amount of magnesium protection (approximately 6035 feet). It was discovered that the pipe layout for design 1 produced better results than design 2, therefore the pipe layout of design 1 was used.
- In section 4 of the design, the pipes were replaced as a result from the decision matrices and were replaced with HDPE. This material was chosen due to its long service life and its resistance to corrosion, which was the main reason for pipe failures in the section.

VII.3 Disadvantages

Design Alternative 3 had only 1 disadvantage to consider:

- The disadvantage of this design is that the pipe redesign is in an area that has higher traffic flow along it. This may hinder the road for a short period of time and also would increase the need for safety for the contractors installing the pipe line.

VIII. Cost-Benefit Analysis

To establish a cost analysis for each design alternative, only the main components were considered in the pricing. The pipes, pressure relief valves, boring, excavation, anode costs, electric costs, pumps, and water towers are the factors that are taken into account. For the HDPE pipe, the prices were provided by the company Dura-line. Dura-line is the main distributer in North America of HDPE piping. The pricing of the pressure relief valves was supplied by CLA-VAL. This company supplies local businesses in Fort Wayne with pressure relief valves. The zinc and magnesium pricing came from Zinc Warehouse and they also provided the sizes of the anodes for the calculations. The boring prices were provided by the city of Fort Wayne and the excavation price is simply the local pricing for excavation per cubic yard. In one of the designs an extra booster pump is installed. The 6 inch booster pump cost $5,000 from the company Purity. As for the electric costs saved from the pump, an average price of $0.0942 per Kilowatt hour was used. The cost of a water tower is generally over $300,000 and this was the price used as part of the total cost in the design alternatives. Table 17 shows these prices used to calculate pricing for the design alternatives. Tables 18, 19 and 20 show the pricing for each design. Table 21 predicts the number of future breaks if nothing will be done versus the savings after implementing the design.

Table 17: Pricing for components used in the design alternatives

160 PSI HDPE Pipe (ft.):	**Cost ($)**
16 inch	25.20
12 inch	14.51
8 inch	6.82
6 inch	3.96
4 inch	1.92
Pressure Reducers:	**Cost ($)**
16 inch	27000
12 inch	16000
8 inch	8500
6 inch	6000
4 inch	5000
Pipe Boring Material Included (ft.):	**Cost ($)**
16 inch	145
12 inch	90

8 inch	55
6 inch	45
4 inch	40
Excavation:	**Cost ($)**
Per Cubic Yard	140
Water Tower	$300,000
Booster Pump	$5,000
Electrical Cost (KW/ hr.)	$0.0942

VII.1 Design Alternative 1

Table 18: Cost Analysis of Design Alternative 1

Design Alternative 1 Cost Analysis	
Hardware Cost	
Criteria	**Value**
Surface Area of Hole Wanted	0.00
Boring (Yes or No)	no
Length (ft.)	0
Diameter (In)	16
Number of Pressure Relief Valves	1
Change in Pump Horse Power	29
Water Tower (Yes or No)	yes
Booster Pump (Yes or No)	no
West Pipe Replacement Cost	
Criteria	**Value**
Surface Area of Hole Wanted	12.00
Boring (Yes or No)	yes
Length (ft.)	250
Diameter (In)	12
Number of Pressure Relief Valves	0

Change in Pump Horse Power	0
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	no

South Pipe Replacement Cost

Criteria	**Value**
Surface Area of Hole Wanted	18.00
Boring (Yes or No)	yes
Length (ft.)	1136
Diameter (In)	6
Number of Pressure Relief Valves	0
Change in Pump Horse Power	0
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	no

Total Cost

Cost ($)		
Pipe	$	8,128.82
Excavation	$	8,400.00
Pressure Valves	$	27,000.00
Pipe Boring	$	73,620.00
Change in Pump Horse Power	$	(178,522.04)
Water Tower	$	300,000.00
Booster Pump	$	-
Cathodic Protection	$	30,438.40
Total	$	260,936.36

VII.2 Design Alternative 2

Table 19: Cost Analysis of Design Alternative 2

Design Alternative 2 Cost Analysis	
Hardware Cost	
Criteria	**Value**
Surface Area of Hole Wanted	0.00
Boring (Yes or No)	no
Length (ft.)	0
Diameter (In)	16
Number of Pressure Relief Valves	1
Change in Pump Horse Power	6
Water Tower (Yes or No)	yes
Booster Pump (Yes or No)	no
Central Pipe Replacement Cost	
Criteria	**Value**
Surface Area of Hole Wanted	12.00
Boring (Yes or No)	yes
Length (ft.)	40
Diameter (In)	6
Number of Pressure Relief Valves	0
Change in Pump Horse Power	0
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	no
South Pipe Replacement Cost	
Criteria	**Value**
Surface Area of Hole Wanted	18.00
Boring (Yes or No)	yes
Length (ft.)	1136
Diameter (In)	6
Number of Pressure Relief Valves	0
Change in Pump Horse Power	0
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	no

Total Cost		
Cost ($)		
Pipe	$	4,661.10
Excavation	$	8,400.00
Pressure Valves	$	27,000.00
Pipe Boring	$	52,920.00
Change in Pump Horse Power (10 yr)	$	(36,935.59)
Water Tower	$	300,000.00
Booster Pump	$	-
Cathodic Protection	$	33,101.76
Total	$	384,486.17

VII.3 Design Alternative 3

Table 20: Cost Analysis of Design Alternative 3

Design Alternative 3 Cost Analysis	
Hardware Cost	
Criteria	Value
Surface Area of Hole Wanted	0.00
Boring (Yes or No)	no
Length (ft.)	0
Diameter (In)	16
Number of Pressure Relief Valves	1
Change in Pump Horse Power	29
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	yes
West Pipe Replacement Cost	
Criteria	Value
Surface Area of Hole Wanted	12.00
Boring (Yes or No)	yes
Length (ft.)	250
Diameter (In)	12
Number of Pressure Relief Valves	0

Change in Pump Horse Power	0
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	no

South Pipe Replacement Cost

Criteria	**Value**
Surface Area of Hole Wanted	18.00
Boring (Yes or No)	yes
Length (ft.)	1136
Diameter (In)	6
Number of Pressure Relief Valves	0
Change in Pump Horse Power	0
Water Tower (Yes or No)	no
Booster Pump (Yes or No)	no

Total Cost

Cost ($)		
Pipe	$	8,128.82
Excavation	$	8,400.00
Pressure Valves	$	27,000.00
Pipe Boring	$	73,620.00
Change in Pump Horse Power (10 yr)	$	(172,366.10)
Water Tower	$	-
Booster Pump	$	5,000.00
Cathodic Protection	$	30,438.40
Total	$	(27,907.70)

Table 21: Costs of Do Nothing and Alternative 3 w/o energy, Savings

	Do Nothing		**Alternative 3 (w/o energy savings)**	**Savings**
Years After Installation	Number of Future Breaks	Cost ($)	Cost ($)	Cost ($)
10	37	$161,333	$149,558	$11,875
20	73	$322,667	$179,897	$142,770
30	110	$484,000	$210,335	$273,665
40	147	$645,333	$240,774	$404,559
50	183	$806,667	$271,212	$535,455

IX. Conclusions

As seen throughout the report there are many factors that can affect the water main distribution system ranging from pipe material type to surrounding conditions. Main breaks happen every year due to a number of reasons and the cost can be more than the city's budget can handle. The purpose of doing this project was to reduce the number of main breaks in the water distribution system in the city of Fort Wayne. The only way this could be done was to select a small portion of the water network for redesigning. Not only was the purpose to select a small portion of the system, but the most vulnerable area of the water network in Fort Wayne. By designing the water main system distribution from Jefferson Blvd to Washington Street, Design Alternative 3 was the recommended design for the selected area. The selection of this design met the Water Design Manual in terms of:

- Maintaining a minimum pressure of 35 psi at every junction throughout the system
- Meeting the maximum velocity standard for each pipe size
- Meeting the standard flow rate demand for every hydrant throughout the system

The design requirements were achieved by the installation of an in-line booster pump to maintain an equally distributed pressure throughout the system, redesigning the pipe layout of the west side of the system, changing material of certain pipes, and applying magnesium protect to the remaining pipes for a longer life. In addition to Design Alternative 3 being the least expensive, the amount of saving from lowering the horse power needed at the West Pump station, was more than the design cost; leaving the City of Fort Wayne ahead in cost over the 10 year life span of the design. Overall, this proved to be a successful design since the system met all the Water Design Manual requirements and the water main distribution system runs more efficiently compared to the existing conditions.

VIII. References

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IX. Section VIII: Appendices

Zinc

$I = A I' (1.0 - CE)$

A = surface area

I' = current density; 10^{-3} from table 2

CE = coating efficiency; 70 - 90 % $\approx$ .7 assume wors

$I = A(.01)(1.0 - .7)$

$I = .003A$ amps

$R_T = \Delta E / I$

ΔE = driving potential in volts; .25

$R_T = .25 / .003A = 250 / 3A$ ohms

$R_c = R / A$

R = avg. resistanc per ft² in ohms; 1250

$R_c = 1250 / A$

$R_a = R_T - R_c$

$R_a = 250/3A - 1250/A = -3500/3A$

$$N = \frac{.0052 \rho \left[\ln 8L/d - 1 \right]}{R_a L}$$

L = length of anode in ft

d = diameter of anode in ft

ρ = 2,000 ohm - cm

Zinc

71

$$N = \frac{.0052(2{,}000)\left(\ln \frac{8 \times 3}{4/12} - 1\right)}{(3500/3A)(3)}$$

☆ $N = .0127\,A$

$N = (10)\,3A / 49.3(150)$

$N = .0041\,A$

4" x 4" x 36" 150 lb

Mg

$I = .003A$

$R_T = .9/.003A = 300/A$

$R_c = 4500/A$

$R_a = 300/A - 4500/A = -4200/A$

$$N = \frac{.0052(2{,}000)\left(\ln^{(8 \times 25.25/12)/(3.375/12)} - 1\right)}{4200/A\,(25.25/12)}$$

$N = .0048A$

$N = (10)3A/49.3(46)$

☆ $N = .0132A$

3 1/2" x 3 1/4" x 25 1/4 46 lb

$190.24 each

3.5 Design Criteria

3.5.1 Performance Criteria

3.5.1.1 General

Sound engineering judgment should be employed when designing water distribution systems. The following sections outline specific design requirements and considerations.

3.5.1.2 Pressure and Flowrate

All potable water distribution system projects shall be designed to maintain a minimum pressure of 20 psi at ground level at all points in the distribution system under maximum daily demand plus fire flow demand. In addition, all distribution systems shall be designed to maintain a minimum static (no flow) pressure of 35 psi.

3.5.1.3 Velocity

Velocity in a water main shall be determined as follows:

$$V = 0.409Q/D^2$$

where:

V = velocity, ft/sec
Q = flowrate (referred to as design demand, see Section 3.5.2), gpm
D = nominal diameter of pipe, inches

The maximum velocity of water within a proposed water main under maximum daily demand plus fire flow demand (Design Demand) shall be as follows:

Pipe Diameter (inches)	Maximum Velocity (ft/sec)	Corresponding Design Demand (gpm)
6	12.22	1075
8	7.36	1150
12	4.68	1650
16	4.23	2650
>16	Consult Water Resources	

3.5.2 Design Demand

(Unit IV, Chapter 3, Sections 3.5.2.1 through 3.5.2.7 of the Design Manual shall be referenced for detailed discussions and methodology for calculating design demand aspects. Exhibit IV-3-3 presents a worksheet to aid in design demand calculation.)

Water mains shall be designed to provide for the Design Demand in accordance with the performance criteria established in Section 3.5.1. The Design Demand is the combination of maximum daily demand plus fire flow demand as follows:

$$DD = (\text{Max day}) + FF$$

where:

DD = Design Demand (gpm)
Max day = Maximum daily demand (gpm)
FF = Fire flow demand (gpm)

3.5.4 Hydraulic Calculations

Hydraulic calculations that demonstrate the adequacy of design must be submitted with each proposed project. The calculations must be consistent with the requirements for calculations and shall address the existing conditions and translation of the flow test results as well as the determination of the changes in these conditions along existing water mains. The calculations must demonstrate that the proposed design meets required performance criteria (Section 3.5.1) at all most remote points in the proposed potable water distribution system.

Hydraulic calculations completed for distribution system design must be reproducible using the Hazen-Williams equation.

Commercial programs may be utilized to compute distribution system hydraulic calculations but if requested by Water Resources must be reproduced utilizing Hazen-Williams related equations.

3.5.4.1 General Requirements

The hydraulic calculations must adhere to the general requirements presented in this section.

3.5.4.1.1 Roughness Coefficients

Proposed projects must address design life expectancy of water mains. The roughness coefficients to be used for existing pipe and proposed pipe are as follows:

C Factor	Age of Pipe
120	new pipe (proposed)
120	less than 20 years (existing)
110	20 – 40 years (existing)
100	greater than 40 years (existing)

Theoretical methods using constants other than C factors to demonstrate pipe roughness must provide a demonstration of equivalent assumptions. Site specific C factors may be used for existing pipe in lieu of the C factors presented in this subsection.

3.5.4.1.2 Minor Losses

(Exhibit IV-3-5 of the Design Manual presents a worksheet to aid in minor loss calculation.)

Minor losses are to be determined when the length of the proposed project is less than 1,500 times the diameter of the included pipe. This determination must be included with the calculations.

3.5.4.1.3 Friction Losses

(Exhibits IV-3-6 and IV-3-7 of the Design Manual present worksheets to aid in friction loss calculation.)

Friction losses along a water main due to pipe roughness are to be determined when evaluating the adequacy of design. These friction losses can be determined using Hazen-Williams related equations. The Hardy-Cross method can be utilized to determine friction losses in loops of water mains.

IX.1. Appendix A- Existing Condition Results

IX.1.1 Pipe KY Results

```
* * * * * * * * * * *   K Y P I P E 5   * * * * * * * * * * *
*                                                            *
*              Pipe Network Modeling Software                *
*                                                            *
*                Copyrighted by KYPIPE LLC                   *
*                Version 5 - February 2010                   *
*                                                            *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

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 Date & Time:  Wed Oct 30 21:15:33 2013

 Master File : E:\Fall 2013\Senior Design I\Pipe KY Modelling\existing
pipe layout.KYP\first draft.KYP\design alternative 1.KYP\exisiting
condition.KYP\Exisiting Condition.P2K
```

```
               ************************************************
                S U M M A R Y   O F   O R I G I N A L   D A T A
               ************************************************
```

```
 U N I T S   S P E C I F I E D

    FLOWRATE ............ = gallons/minute
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig

 THE DARCY WEISBACH HEAD LOSS EQUATION IS USED, THE KINEMATIC VIS. =
0.0000100
```

```
 P I P E L I N E   D A T A

   STATUS CODE:   XX -CLOSED PIPE    CV -CHECK VALVE

   P I P E              NODE NAMES       LENGTH  DIAMETER  ROUGHNESS
MINOR
   N A M E             #1        #2        (ft)     (in)      COEFF.  LOSS
COEFF.
 --------------------------------------------------------------------------
------
       P-1            R-1  I-Pump-1        1.00     16.00  100.0000
0.00
```

P-2	O-Pump-1	J-1	32.74	16.72	110.0000	0.00
P-3	J-1	J-2	306.00	16.00	110.0000	0.00
P-4	J-2	J-3	256.00	16.72	110.0000	0.75
P-5	J-3	J-4	460.00	12.58	110.0000	0.25
P-6	J-4	J-5	94.00	12.58	110.0000	0.75
P-7	J-5	J-6	38.00	12.58	110.0000	0.75
P-8	J-6	J-7	50.00	12.58	100.0000	0.75
P-9	J-7	J-8	165.00	12.00	100.0000	0.00
P-10	J-8	J-9	69.00	12.00	100.0000	0.25
P-11	J-9	J-10	100.00	8.00	100.0000	0.00
P-12	J-10	J-11	89.90	6.00	100.0000	0.25
P-13	J-11	J-12	200.00	6.00	100.0000	0.40
P-14	J-12	J-13	189.00	6.00	100.0000	0.00
P-15	J-13	J-14	83.00	6.00	100.0000	0.25
P-16	J-14	J-15	111.00	6.00	100.0000	0.75
P-17	J-15	J-16	90.23	6.00	100.0000	0.00
P-18	J-16	J-17	101.77	6.00	100.0000	0.40
P-19	J-17	J-18	445.00	6.00	100.0000	0.25
P-20	J-18	J-19	107.00	6.00	100.0000	0.25
P-21	J-19	J-21	375.00	6.00	100.0000	0.90
P-22	J-21	J-20	31.00	6.00	100.0000	0.00
P-23	J-21	J-22	169.22	6.00	100.0000	0.00
P-24	J-22	J-23	206.78	6.00	100.0000	0.00
P-25	J-12	J-24	212.00	4.00	100.0000	0.25
P-26	J-24	J-25	100.00	4.00	100.0000	0.00
P-27	J-25	J-26	258.00	4.00	100.0000	1.00
P-28	J-17	J-27	382.00	6.00	100.0000	0.25

P-29	J-27	J-28	40.00	6.00	100.0000	0.00
P-30	J-28	J-29	250.00	6.00	100.0000	0.65
P-31	J-26	J-29	346.00	12.00	100.0000	0.00
P-32	J-29	J-30	31.00	6.00	100.0000	0.75
P-33	J-30	J-31	50.00	6.00	100.0000	0.75
P-34	J-31	J-32	31.00	6.00	100.0000	0.25
P-35	J-32	J-33	359.00	6.00	100.0000	0.25
P-36	J-33	J-34	100.00	6.00	100.0000	0.25
P-37	J-34	J-35	400.00	6.00	100.0000	0.90
P-38	J-35	J-36	145.00	6.00	100.0000	0.25
P-39	J-36	J-37	25.00	6.00	100.0000	0.00
P-40	J-37	R-3	140.00	6.00	100.0000	0.00
P-41	J-35	J-39	363.00	6.00	100.0000	0.00
P-42	J-39	J-40	100.00	6.00	100.0000	0.50
P-43	J-40	R-2	363.00	6.00	100.0000	0.00

P U M P/L O S S   E L E M E N T   D A T A

THERE IS A PUMP AT NODE   Pump-1; USEFUL POWER =   65.00 (Efficiency =   1.00%)

N O D E   D A T A

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)
J-1		345.00	0.00	
J-2		5.00	0.00	
J-3		340.00	0.00	
J-4		340.00	0.00	
J-5		340.00	0.00	
J-6		340.00	0.00	

J-7	340.00	0.00	
J-8	340.00	0.00	
J-9	340.00	0.00	
J-10	10.00	0.00	
J-11	10.00	0.00	
J-12	320.00	0.00	
J-13	15.00	0.00	
J-14	10.00	0.00	
J-15	203.00	0.00	
J-16	5.00	0.00	
J-17	198.00	0.00	
J-18	35.00	0.00	
J-19	35.00	0.00	
J-20	0.00	0.00	
J-21	10.00	0.00	
J-22	10.00	0.00	
J-23	0.00	0.00	
J-24	20.00	0.00	
J-25	25.00	0.00	
J-26	-293.00	0.00	
J-27	15.00	0.00	
J-28	10.00	0.00	
J-29	140.00	0.00	
J-30	140.00	0.00	
J-31	140.00	0.00	
J-32	140.00	0.00	
J-33	30.00	0.00	
J-34	20.00	0.00	
J-35	90.00	0.00	
J-36	15.00	0.00	
J-37	20.00	0.00	
J-39	35.00	5.00	
J-40	20.00	0.00	
I-Pump-1	0.00	0.00	
R-1	----	0.00	187.62
R-2	----	0.00	187.62
R-3	----	0.00	187.62
O-Pump-1	0.00	0.00	

O U T P U T   O P T I O N   D A T A

OUTPUT SELECTION: ALL RESULTS ARE INCLUDED IN THE TABULATED OUTPUT
MAXIMUM AND MINIMUM VELOCITIES   =   5
MAXIMUM AND MINIMUM HEAD LOSS/1000 =   5

S Y S T E M   C O N F I G U R A T I O N

NUMBER OF PIPES ....(p) =   43
NUMBER OF END NODES ....(j) =   40
NUMBER OF PRIMARY LOOPS ....(l) =   1

NUMBER OF SUPPLY NODES ....(f) = 3
NUMBER OF SUPPLY ZONES ....(z) = 1

==

Case: 0

RESULTS OBTAINED AFTER 6 TRIALS: ACCURACY = 0.00000

S I M U L A T I O N   D E S C R I P T I O N   (L A B E L)

P I P E L I N E   R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-1	R-1	I-Pump-1	3519.20	0.03	0.00	5.62	32.04	32.04
P-2	O-Pump-1	J-1	3519.20	0.86	0.00	5.14	26.40	26.40
P-3	J-1	J-2	3174.20	8.38	0.00	5.06	27.39	27.39
P-4	J-2	J-3	3169.20	5.48	0.25	4.63	22.39	21.41
P-5	J-3	J-4	2829.20	37.96	0.21	7.30	82.96	82.51
P-6	J-4	J-5	2489.20	6.00	0.48	6.42	68.99	63.88
P-7	J-5	J-6	2149.20	1.81	0.36	5.55	57.05	47.62
P-8	J-6	J-7	1809.20	1.60	0.25	4.67	37.10	32.02
P-9	J-7	J-8	1469.20	4.53	0.00	4.17	27.44	27.44
P-10	J-8	J-9	1129.20	1.12	0.04	3.20	16.79	16.21
P-11	J-9	J-10	789.20	7.63	0.00	5.04	76.29	76.29
P-12	J-10	J-11	779.20	33.99	0.30	8.84	381.50	378.12

P-13	J-11	J-12	769.20	73.70	0.47	8.73	370.85	368.48
P-14	J-12	J-13	358.29	15.12	0.00	4.07	80.00	80.00
P-15	J-13	J-14	343.29	6.10	0.06	3.90	74.15	73.44
P-16	J-14	J-15	333.29	7.68	0.17	3.78	70.73	69.23
P-17	J-15	J-16	130.29	0.96	0.00	1.48	10.60	10.60
P-18	J-16	J-17	125.29	1.00	0.01	1.42	9.92	9.80
P-19	J-17	J-18	90.00	2.25	0.00	1.02	5.07	5.06
P-20	J-18	J-19	55.00	0.20	0.00	0.62	1.91	1.90
P-21	J-19	J-21	20.00	0.09	0.00	0.23	0.25	0.25
P-22	J-21	J-20	0.00	0.00	0.00	0.00	0.00	0.00
P-23	J-21	J-22	10.00	0.01	0.00	0.11	0.06	0.06
P-24	J-22	J-23	0.00	0.00	0.00	0.00	0.00	0.00
P-25	J-12	J-24	90.91	11.19	0.02	2.32	52.90	52.80
P-26	J-24	J-25	70.91	3.21	0.00	1.81	32.14	32.14
P-27	J-25	J-26	45.91	3.48	0.02	1.17	13.57	13.49
P-28	J-17	J-27	-162.71	6.31	0.01	1.85	16.55	16.52
P-29	J-27	J-28	-177.71	0.79	0.00	2.02	19.70	19.70
P-30	J-28	J-29	-187.71	5.49	0.05	2.13	22.16	21.98
P-31	J-26	J-29	338.91	0.51	0.00	0.96	1.46	1.46
P-32	J-29	J-30	11.20	0.00	0.00	0.13	0.09	0.08
P-33	J-30	J-31	-128.80	0.52	0.02	1.46	10.86	10.36
P-34	J-31	J-32	-268.80	1.40	0.04	3.05	46.21	45.04
P-35	J-32	J-33	-408.80	37.38	0.08	4.64	104.36	104.13
P-36	J-33	J-34	-438.80	12.00	0.10	4.98	120.93	119.97
P-37	J-34	J-35	-458.80	52.46	0.38	5.21	132.09	131.15
P-38	J-35	J-36	-352.27	11.21	0.06	4.00	77.76	77.33
P-39	J-36	J-37	-367.27	2.10	0.00	4.17	84.06	84.06

P-40	J-37	R-3	-387.27	13.08	0.00	4.39	93.45	93.45
P-41	J-35	J-39	-196.53	8.75	0.00	2.23	24.09	24.09
P-42	J-39	J-40	-231.53	3.34	0.05	2.63	33.96	33.43
P-43	J-40	R-2	-251.53	14.32	0.00	2.85	39.45	39.45

P U M P/L O S S   E L E M E N T   R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
Pump-1	3519.20	187.58	260.66	73.1	75.00	0.	0.0	0.0	**	**	220.3

N O D E   R E S U L T S

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	HYDRAULIC GRADE (ft)	NODE ELEVATION (ft)	PRESSURE HEAD (ft)	NODE PRESSURE (psi)
J-1		345.00	259.79			
J-2		5.00	251.41			
J-3		340.00	245.68			
J-4		340.00	207.51			
J-5		340.00	201.03			
J-6		340.00	198.86			
J-7		340.00	197.01			
J-8		340.00	192.48			
J-9		340.00	191.32			
J-10		10.00	183.69			
J-11		10.00	149.39			
J-12		320.00	75.22			
J-13		15.00	60.10			
J-14		10.00	53.95			
J-15		203.00	46.10			
J-16		5.00	45.14			

```
      J-17                     198.00       44.13
      J-18                      35.00       41.88
      J-19                      35.00       41.67
      J-20                       0.00       41.58
      J-21                      10.00       41.58
      J-22                      10.00       41.57
      J-23                       0.00       41.57
      J-24                      20.00       64.01
      J-25                      25.00       60.79
      J-26                    -293.00       57.29
      J-27                      15.00       50.46
      J-28                      10.00       51.24
      J-29                     140.00       56.79
      J-30                     140.00       56.78
      J-31                     140.00       57.33
      J-32                     140.00       58.76
      J-33                      30.00       96.22
      J-34                      20.00      108.32
      J-35                      90.00      161.16
      J-36                      15.00      172.43
      J-37                      20.00      174.53
      J-39                      35.00      169.90      5.00   164.90
71.46
      J-40                      20.00      173.30
   I-Pump-1                      0.00      187.58
       R-1                       ----      187.62
       R-2                       ----      187.62
       R-3                       ----      187.62
   O-Pump-1                      0.00      260.66
```

M A X I M U M   A N D   M I N I M U M   V A L U E S

V E L O C I T I E S

PIPE NUMBER	MAXIMUM VELOCITY (ft/s)	PIPE NUMBER	MINIMUM VELOCITY (ft/s)
P-12	8.84	P-23	0.11
P-13	8.73	P-32	0.13
P-5	7.30	P-21	0.23
P-6	6.42	P-20	0.62
P-1	5.62	P-31	0.96

H L + M L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL+ML/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL+ML/1000 (ft/ft)
P-12	381.50	P-23	0.06

P-13	370.85	P-32	0.09
P-37	132.09	P-21	0.25
P-36	120.93	P-31	1.46
P-35	104.36	P-20	1.91

H L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL/1000 (ft/ft)
P-12	378.12	P-23	0.06
P-13	368.48	P-32	0.08
P-37	131.15	P-21	0.25
P-36	119.97	P-31	1.46
P-35	104.13	P-20	1.90

S U M M A R Y   O F   I N F L O W S   A N D   O U T F L O W S

(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (gpm)	NODE TITLE
R-1	3519.20	
R-2	251.53	
R-3	387.27	

NET SYSTEM INFLOW = 4158.00
NET SYSTEM OUTFLOW = 0.00
NET SYSTEM DEMAND = 4158.00

***** HYDRAULIC ANALYSIS COMPLETED *****

IX.2. Appendix B- Alternative 1 Detailed Design

IX.2.1. Pipe KY Results

```
* * * * * * * * * *   K Y P I P E 5   * * * * * * * * * *
*                                                       *
*            Pipe Network Modeling Software             *
*                                                       *
*              Copyrighted by KYPIPE LLC                *
*              Version 5 - February 2010                *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Date & Time: Thu Oct 31 17:17:12 2013

Master File : H:\Fall 2013\Senior Design I\Pipe KY Modelling\Design Alternatives\design alternative 1.KYP\design alternative 1.P2K

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************************************************
 S U M M A R Y   O F   O R I G I N A L   D A T A
************************************************
```

U N I T S   S P E C I F I E D

FLOWRATE .... = gallons/minute
HEAD (HGL) .... = feet
PRESSURE .... = psig

THE DARCY WEISBACH HEAD LOSS EQUATION IS USED, THE KINEMATIC VIS. = 0.0000100

R E G U L A T I N G   V A L V E   D A T A

VALVE LABEL	VALVE TYPE	VALVE SETTING (ft or gpm)
RV-1	PRV-1	265.38

P I P E L I N E   D A T A

STATUS CODE: XX -CLOSED PIPE   CV -CHECK VALVE

PIPE NAME	NODE NAMES #1	NODE NAMES #2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
P-1	R-1	I-Pump-1	1.00	16.00	100.0000	0.00
P-2	O-Pump-1	I-RV-1	28.42	16.00	100.0000	0.00
P-3	J-1	J-2	306.00	16.00	110.0000	0.00
P-4	J-2	J-3	256.00	16.72	110.0000	0.75
P-5	J-3	J-4	460.00	12.58	110.0000	0.00
P-6	J-4	J-9	250.00	12.00	120.0000	0.75
P-7	O-RV-1	J-1	35.99	16.00	100.0000	0.00
P-11	J-9	J-10	16.68	8.51	110.0000	0.00
P-12	J-10	J-11	100.00	6.00	100.0000	0.00
P-13	J-11	J-12	89.90	6.00	100.0000	0.25
P-14	J-12	J-13	200.00	6.00	100.0000	0.40
P-15	J-13	J-14	189.00	6.00	100.0000	0.00
P-16	J-14	J-15	83.00	6.00	100.0000	0.25
P-17	J-15	J-16	111.00	6.00	100.0000	0.75
P-18	J-16	J-17	90.23	6.00	100.0000	0.00
P-19	J-17	J-18	101.77	6.00	100.0000	0.40
P-20	J-18	J-19	445.00	6.00	100.0000	0.25
P-21	J-19	J-21	107.00	6.00	100.0000	0.25
P-22	J-21	J-20	375.00	6.00	100.0000	0.90
P-23	J-21	J-22	31.00	6.00	100.0000	0.00
P-24	J-22	R-4	169.22	6.00	100.0000	0.00
P-25	J-12	J-24	206.78	4.00	100.0000	0.00
P-26	J-24	J-25	212.00	4.00	100.0000	0.25
P-27	J-25	J-26	100.00	4.00	100.0000	0.00

P-28	J-17	J-27	258.00	6.00	100.0000	1.00
P-29	J-27	J-28	382.00	6.00	100.0000	0.25
P-30	J-28	J-29	40.00	6.00	100.0000	0.00
P-31	J-26	J-29	250.00	12.00	100.0000	0.65
P-32	J-29	J-30	346.00	6.00	100.0000	0.00
P-33	J-30	J-31	31.00	6.00	100.0000	0.75
P-34	J-31	J-32	50.00	6.00	100.0000	0.75
P-35	J-32	J-33	31.00	6.00	100.0000	0.25
P-36	J-33	J-34	359.00	6.00	100.0000	0.25
P-37	J-34	J-35	100.00	6.00	100.0000	0.25
P-38	J-35	J-36	400.00	6.00	100.0000	0.90
P-39	J-36	J-37	145.00	6.08	120.0000	0.25
P-40	J-37	R-3	25.00	6.08	120.0000	0.00
P-41	J-35	J-39	140.00	6.08	120.0000	0.00
P-42	J-39	J-40	363.00	6.08	120.0000	0.00
P-43	J-40	R-2	100.00	6.08	120.0000	0.50

P U M P/L O S S   E L E M E N T   D A T A

THERE IS A PUMP AT NODE   Pump-1; USEFUL POWER =   38.00 (Efficiency = 100.00%)

N O D E   D A T A

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)
J-1		345.00	0.00	
J-2		5.00	0.00	
J-3		340.00	0.00	
J-4		340.00	0.00	

J-9	340.00	0.00	
J-10	10.00	0.00	
J-11	10.00	0.00	
J-12	320.00	0.00	
J-13	15.00	0.00	
J-14	10.00	0.00	
J-15	203.00	0.00	
J-16	5.00	0.00	
J-17	198.00	0.00	
J-18	35.00	0.00	
J-19	35.00	0.00	
J-20	0.00	0.00	
J-21	10.00	0.00	
J-22	10.00	0.00	
J-24	20.00	0.00	
J-25	25.00	0.00	
J-26	-293.00	0.00	
J-27	15.00	0.00	
J-28	10.00	0.00	
J-29	140.00	0.00	
J-30	140.00	0.00	
J-31	140.00	0.00	
J-32	140.00	0.00	
J-33	30.00	0.00	
J-34	20.00	0.00	
J-35	90.00	0.00	
J-36	15.00	0.00	
J-37	20.00	0.00	
J-39	35.00	5.00	
J-40	20.00	0.00	
I-Pump-1	0.00	5.00	
R-1	----	0.00	187.62
R-2	----	0.00	187.62
R-3	----	0.00	187.62
R-4	----	0.00	187.62
I-RV-1	0.00	0.00	
O-Pump-1	0.00	5.00	
O-RV-1	----	0.00	265.38

O U T P U T   O P T I O N   D A T A

OUTPUT SELECTION: ALL RESULTS ARE INCLUDED IN THE TABULATED OUTPUT

MAXIMUM AND MINIMUM PRESSURES = 1
MAXIMUM AND MINIMUM VELOCITIES = 5
MAXIMUM AND MINIMUM HEAD LOSS/1000 = 5

S Y S T E M   C O N F I G U R A T I O N

NUMBER OF PIPES ....(p) = 40
NUMBER OF END NODES ....(j) = 36

NUMBER OF PRIMARY LOOPS ....(l) = 1
NUMBER OF SUPPLY NODES ....(f) = 4
NUMBER OF SUPPLY ZONES ....(z) = 1

==

Case: 0

RESULTS OBTAINED AFTER 5 TRIALS: ACCURACY = 0.00000

S I M U L A T I O N   D E S C R I P T I O N   (L A B E L)

P I P E L I N E   R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-1	R-1	I-Pump-1	2083.68	0.01	0.00	3.32	11.24	11.24
P-2	O-Pump-1	I-RV-1	2083.68	0.32	0.00	3.32	11.24	11.24
P-3	J-1	J-2	1738.68	2.52	0.00	2.77	8.22	8.22
P-4	J-2	J-3	1733.68	1.64	0.07	2.53	6.70	6.41
P-5	J-3	J-4	1393.68	9.22	0.00	3.60	20.03	20.03
P-6	J-4	J-9	1053.68	3.91	0.10	2.99	16.07	15.66
P-7	O-RV-1	J-1	2083.68	0.40	0.00	3.32	11.24	11.24
P-11	J-9	J-10	713.68	0.78	0.00	4.03	46.78	46.78
P-12	J-10	J-11	703.68	30.84	0.00	7.98	308.40	308.40
P-13	J-11	J-12	693.68	26.94	0.24	7.87	302.37	299.70
P-14	J-12	J-13	278.49	9.67	0.06	3.16	48.66	48.35

P-15	J-13	J-14	263.49	8.18	0.00	2.99	43.28	43.28
P-16	J-14	J-15	253.49	3.33	0.03	2.88	40.45	40.06
P-17	J-15	J-16	50.49	0.18	0.00	0.57	1.63	1.60
P-18	J-16	J-17	45.49	0.12	0.00	0.52	1.30	1.30
P-19	J-17	J-18	-172.86	1.90	0.02	1.96	18.88	18.64
P-20	J-18	J-19	-207.86	11.99	0.02	2.36	26.99	26.94
P-21	J-19	J-21	-242.86	3.93	0.03	2.76	37.05	36.77
P-22	J-21	J-20	0.00	0.00	0.00	0.00	0.00	0.00
P-23	J-21	J-22	-252.86	1.24	0.00	2.87	39.86	39.86
P-24	J-22	R-4	-262.86	7.29	0.00	2.98	43.07	43.07
P-25	J-12	J-24	95.19	11.97	0.00	2.43	57.89	57.89
P-26	J-24	J-25	75.19	7.66	0.01	1.92	36.20	36.14
P-27	J-25	J-26	50.19	1.61	0.00	1.28	16.12	16.12
P-28	J-17	J-27	20.35	0.07	0.00	0.23	0.27	0.26
P-29	J-27	J-28	5.35	0.01	0.00	0.06	0.02	0.02
P-30	J-28	J-29	-4.65	0.00	0.00	0.05	0.01	0.01
P-31	J-26	J-29	343.19	0.38	0.01	0.97	1.54	1.50
P-32	J-29	J-30	198.54	8.51	0.00	2.25	24.58	24.58
P-33	J-30	J-31	58.54	0.07	0.01	0.66	2.31	2.15
P-34	J-31	J-32	-81.46	0.21	0.01	0.92	4.35	4.15
P-35	J-32	J-33	-221.46	0.95	0.02	2.51	31.37	30.58
P-36	J-33	J-34	-251.46	14.15	0.03	2.85	39.51	39.42
P-37	J-34	J-35	-271.46	4.59	0.04	3.08	46.31	45.94
P-38	J-35	J-36	-197.86	9.77	0.07	2.24	24.59	24.42
P-39	J-36	J-37	-212.86	4.32	0.02	2.35	29.94	29.79
P-40	J-37	R-3	-232.86	0.89	0.00	2.57	35.65	35.65
P-41	J-35	J-39	-163.61	2.47	0.00	1.81	17.61	17.61

P-42	J-39	J-40	-198.61	9.42	0.00	2.19	25.94	25.94
P-43	J-40	R-2	-218.61	3.14	0.05	2.42	31.88	31.42

P U M P/L O S S   E L E M E N T   R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
Pump-1	2083.68	182.60	254.75	72.2	75.00	0.	0.0	0.0	**	**	215.6

N O D E   R E S U L T S

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	HYDRAULIC GRADE (ft)	NODE ELEVATION (ft)	PRESSURE HEAD (ft)	NODE PRESSURE (psi)
J-1		345.00	259.03			
J-2		5.00	256.51			
J-3		340.00	254.80			
J-4		340.00	245.58			
J-9		340.00	241.56			
J-10		10.00	240.78			
J-11		10.00	209.94			
J-12		320.00	182.76			
J-13		15.00	173.03			
J-14		10.00	164.85			
J-15		203.00	161.49			
J-16		5.00	161.31			
J-17		198.00	161.19			
J-18		35.00	163.11			
J-19		35.00	175.13			
J-20		0.00	179.09			
J-21		10.00	179.09			
J-22		10.00	180.33			
J-24		20.00	170.79			
J-25		25.00	163.12			

J-26	-293.00	161.50			
J-27	15.00	161.12			
J-28	10.00	161.12			
J-29	140.00	161.12			
J-30	140.00	152.61			
J-31	140.00	152.54			
J-32	140.00	152.76			
J-33	30.00	153.73			
J-34	20.00	167.92			
J-35	90.00	172.55			
J-36	15.00	182.38			
J-37	20.00	186.72			
J-39	35.00	175.01	5.00	170.01	73.67
J-40	20.00	184.43			
I-Pump-1	0.00	187.60	5.00	182.60	79.13
R-1	----	187.62			
R-2	----	187.62			
R-3	----	187.62			
R-4	----	187.62			
I-RV-1	0.00	259.43			
O-Pump-1	0.00	259.75	5.00	254.75	110.39
O-RV-1	----	259.43			

M A X I M U M A N D M I N I M U M V A L U E S

P R E S S U R E S

JUNCTION NUMBER	MAXIMUM PRESSURES (psi)	JUNCTION NUMBER	MINIMUM PRESSURES (psi)
O-Pump-1	110.39	J-39	73.67

V E L O C I T I E S

PIPE NUMBER	MAXIMUM VELOCITY (ft/s)	PIPE NUMBER	MINIMUM VELOCITY (ft/s)
P-12	7.98	P-30	0.05
P-13	7.87	P-29	0.06
P-11	4.03	P-28	0.23
P-5	3.60	P-18	0.52
P-1	3.32	P-17	0.57

H L + M L / 1 0 0 0

PIPE MAXIMUM PIPE MINIMUM

NUMBER	HL+ML/1000 (ft/ft)	NUMBER	HL+ML/1000 (ft/ft)
P-12	308.40	P-30	0.01
P-13	302.37	P-29	0.02
P-25	57.89	P-28	0.27
P-14	48.66	P-18	1.30
P-11	46.78	P-31	1.54

H L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL/1000 (ft/ft)
P-12	308.40	P-30	0.01
P-13	299.70	P-29	0.02
P-25	57.89	P-28	0.26
P-14	48.35	P-18	1.30
P-11	46.78	P-31	1.50

R E G U L A T I N G   V A L V E   R E P O R T

VALVE LABEL	VALVE TYPE	VALVE SETTING (psi or gpm)	VALVE STATUS	UPSTREAM PRESSURE (psi)	DOWNSTREAM PRESSURE (psi)	THROUGH FLOW (gpm)
RV-1	PRV-1	115.00	WIDE OPEN	112.42	112.42	2083.68

S U M M A R Y   O F   I N F L O W S   A N D   O U T F L O W S

(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (gpm)	NODE TITLE
R-1	2083.68	
R-2	218.61	
R-3	232.86	
R-4	262.86	

NET SYSTEM INFLOW =   2798.00
NET SYSTEM OUTFLOW =   0.00
NET SYSTEM DEMAND =   2798.00

***** HYDRAULIC ANALYSIS COMPLETED *****

IX.3. Appendix C- Alternative 2 Detailed Design

IX.3.1. Pipe KY Results

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* * * * * * * * * * *   K Y P I P E 5   * * * * * * * * * * *
*                                                             *
*              Pipe Network Modeling Software                 *
*                                                             *
*                Copyrighted by KYPIPE LLC                    *
*                Version 5 - February 2010                    *
*                                                             *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


 Date & Time:  Sat Nov 02 13:21:43 2013

 Master File : E:\Fall 2013\Senior Design I\Pipe KY Modelling\Design
Alternatives\Design Alternative 2\design alternative 2.P2K


               ************************************************
                S U M M A R Y   O F   O R I G I N A L   D A T A
               ************************************************


 U N I T S   S P E C I F I E D

    FLOWRATE ............ = gallons/minute
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig

 THE DARCY WEISBACH HEAD LOSS EQUATION IS USED, THE KINEMATIC VIS. =
0.0000100


 R E G U L A T I N G   V A L V E   D A T A

       VALVE        VALVE          VALVE
       LABEL        TYPE          SETTING
                                (ft or gpm)
 -----------------------------------------
        RV-1        PRV-1          265.38


 P I P E L I N E   D A T A

   STATUS CODE:   XX -CLOSED PIPE    CV -CHECK VALVE
```

PIPE NAME	NODE NAMES #1	NODE NAMES #2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
P-1	R-1	I-Pump-1	1.00	16.00	100.0000	0.00
P-2	O-Pump-1	I-RV-1	17.36	16.72	110.0000	0.00
P-3	J-1	J-2	306.00	16.00	110.0000	0.00
P-4	J-2	J-3	256.00	16.72	110.0000	0.75
P-5	J-3	J-4	460.00	12.58	110.0000	0.25
P-6	J-4	J-5	94.00	12.58	110.0000	0.75
P-7	J-5	J-6	38.00	12.58	110.0000	0.75
P-8	J-6	J-7	50.00	12.58	100.0000	0.75
P-9	J-7	J-8	165.00	12.00	100.0000	0.00
P-10	J-8	J-9	69.00	12.00	100.0000	0.25
P-11	J-9	J-10	100.00	8.00	100.0000	0.00
P-12	J-10	J-11	89.90	6.00	100.0000	0.25
P-13	J-11	J-12	200.00	6.00	100.0000	0.40
P-14	J-12	J-13	189.00	6.00	100.0000	0.00
P-15	J-13	J-14	83.00	6.00	100.0000	0.25
P-16	J-14	J-15	111.00	6.00	100.0000	0.75
P-17	J-15	J-16	90.23	6.00	100.0000	0.00
P-18	J-16	J-17	101.77	6.00	100.0000	0.40
P-19	J-17	J-18	445.00	6.00	100.0000	0.25
P-20	J-18	J-19	107.00	6.00	100.0000	0.25
P-21	J-19	J-21	375.00	6.00	100.0000	0.90
P-22	J-21	J-20	31.00	6.00	100.0000	0.00
P-23	J-21	J-22	169.22	6.00	100.0000	0.00
P-24	J-22	R-4	206.78	6.00	100.0000	0.00

P-25	J-12	J-24	212.00	4.00	100.0000	0.25
P-26	J-24	J-25	100.00	4.00	100.0000	0.00
P-27	J-25	J-26	258.00	4.00	100.0000	1.00
P-28	J-17	J-27	382.00	6.00	100.0000	0.25
P-29	J-27	J-28	40.00	6.00	100.0000	0.00
P-30	J-28	J-29	250.00	6.00	100.0000	0.65
P-31	J-26	J-29	346.00	12.00	100.0000	0.00
P-32	J-29	J-32	40.00	6.08	120.0000	0.25
P-33	O-RV-1	J-1	15.38	16.72	110.0000	0.00
P-35	J-32	J-33	359.00	6.00	100.0000	0.25
P-36	J-33	J-34	100.00	6.00	100.0000	0.25
P-37	J-34	J-35	400.00	6.00	100.0000	0.90
P-38	J-35	J-36	145.00	6.08	120.0000	0.25
P-39	J-36	J-37	25.00	6.08	120.0000	0.00
P-40	J-37	R-3	140.00	6.08	120.0000	0.00
P-41	J-35	J-39	363.00	6.08	120.0000	0.00
P-42	J-39	J-40	100.00	6.08	120.0000	0.50
P-43	J-40	R-2	363.00	6.08	120.0000	0.00

P U M P/L O S S   E L E M E N T   D A T A

THERE IS A PUMP AT NODE Pump-1; USEFUL POWER = 61.00 (Efficiency = 100.00%)

N O D E   D A T A

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)

J-1	345.00	0.00	
J-2	5.00	0.00	
J-3	340.00	0.00	
J-4	340.00	0.00	
J-5	340.00	0.00	
J-6	340.00	0.00	
J-7	340.00	0.00	
J-8	340.00	0.00	
J-9	340.00	0.00	
J-10	10.00	0.00	
J-11	10.00	0.00	
J-12	320.00	0.00	
J-13	15.00	0.00	
J-14	10.00	0.00	
J-15	203.00	0.00	
J-16	5.00	0.00	
J-17	198.00	0.00	
J-18	35.00	0.00	
J-19	35.00	0.00	
J-20	0.00	0.00	
J-21	10.00	0.00	
J-22	10.00	0.00	
J-24	20.00	0.00	
J-25	25.00	0.00	
J-26	47.00	0.00	
J-27	15.00	0.00	
J-28	10.00	0.00	
J-29	140.00	0.00	
J-32	140.00	0.00	
J-33	30.00	0.00	
J-34	20.00	0.00	
J-35	90.00	0.00	
J-36	15.00	0.00	
J-37	20.00	0.00	
J-39	35.00	0.00	
J-40	20.00	0.00	
I-Pump-1	0.00	5.00	
R-1	----	0.00	187.62
R-2	----	0.00	187.62
R-3	----	0.00	187.62
R-4	----	0.00	187.62
I-RV-1	0.00	0.00	
O-Pump-1	0.00	5.00	
O-RV-1	----	0.00	265.38

O U T P U T   O P T I O N   D A T A

```
OUTPUT SELECTION:  ALL RESULTS ARE INCLUDED IN THE TABULATED OUTPUT
        MAXIMUM AND MINIMUM PRESSURES       =    1
        MAXIMUM AND MINIMUM VELOCITIES      =    5
        MAXIMUM AND MINIMUM HEAD LOSS/1000  =    5
```

S Y S T E M   C O N F I G U R A T I O N

NUMBER OF PIPES ....(p) = 42
NUMBER OF END NODES ....(j) = 38
NUMBER OF PRIMARY LOOPS ....(l) = 1
NUMBER OF SUPPLY NODES ....(f) = 4
NUMBER OF SUPPLY ZONES ....(z) = 1

===

Case: 0

RESULTS OBTAINED AFTER 5 TRIALS: ACCURACY = 0.00004

S I M U L A T I O N   D E S C R I P T I O N   (L A B E L)

P I P E L I N E   R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-1	R-1	I-Pump-1	3359.61	0.03	0.00	5.36	29.20	29.20
P-2	O-Pump-1	I-RV-1	3359.61	0.42	0.00	4.91	24.06	24.06
P-3	J-1	J-2	3014.61	7.56	0.00	4.81	24.71	24.71
P-4	J-2	J-3	3009.61	4.94	0.23	4.40	20.19	19.31
P-5	J-3	J-4	2669.61	33.80	0.18	6.89	73.87	73.47
P-6	J-4	J-5	2329.61	5.26	0.42	6.01	60.43	55.95
P-7	J-5	J-6	1989.61	1.55	0.31	5.14	48.90	40.82
P-8	J-6	J-7	1649.61	1.33	0.21	4.26	30.84	26.62

P-9	J-7	J-8	1309.61	3.60	0.00	3.71	21.81	21.81
P-10	J-8	J-9	969.61	0.83	0.03	2.75	12.38	11.96
P-11	J-9	J-10	629.61	4.86	0.00	4.02	48.57	48.57
P-12	J-10	J-11	619.61	21.50	0.19	7.03	241.27	239.13
P-13	J-11	J-12	609.61	46.30	0.30	6.92	232.96	231.48
P-14	J-12	J-13	216.22	5.51	0.00	2.45	29.15	29.15
P-15	J-13	J-14	201.22	2.10	0.02	2.28	25.50	25.25
P-16	J-14	J-15	191.22	2.53	0.05	2.17	23.30	22.81
P-17	J-15	J-16	-11.78	0.01	0.00	0.13	0.09	0.09
P-18	J-16	J-17	-16.78	0.02	0.00	0.19	0.18	0.18
P-19	J-17	J-18	-248.40	17.12	0.03	2.82	38.54	38.47
P-20	J-18	J-19	-283.40	5.36	0.04	3.22	50.44	50.06
P-21	J-19	J-21	-318.40	23.69	0.18	3.61	63.67	63.18
P-22	J-21	J-20	0.00	0.00	0.00	0.00	0.00	0.00
P-23	J-21	J-22	-328.40	11.37	0.00	3.73	67.21	67.21
P-24	J-22	R-4	-338.40	14.76	0.00	3.84	71.36	71.36
P-25	J-12	J-24	73.39	7.30	0.01	1.87	34.50	34.43
P-26	J-24	J-25	53.39	1.82	0.00	1.36	18.24	18.24
P-27	J-25	J-26	28.39	1.33	0.01	0.72	5.20	5.17
P-28	J-17	J-27	33.61	0.27	0.00	0.38	0.71	0.71
P-29	J-27	J-28	18.61	0.01	0.00	0.21	0.22	0.22
P-30	J-28	J-29	8.61	0.01	0.00	0.10	0.05	0.05
P-31	J-26	J-29	-18.61	0.00	0.00	0.05	0.00	0.00
P-32	J-29	J-32	-150.00	0.59	0.01	1.66	15.07	14.80
P-33	O-RV-1	J-1	3359.61	0.37	0.00	4.91	24.06	24.06
P-35	J-32	J-33	-290.00	18.82	0.04	3.29	52.54	52.42
P-36	J-33	J-34	-320.00	6.38	0.05	3.63	64.33	63.82

P-37	J-34	J-35	-340.00	28.82	0.21	3.86	72.56	72.04
P-38	J-35	J-36	-278.80	7.41	0.04	3.08	51.34	51.09
P-39	J-36	J-37	-293.80	1.42	0.00	3.25	56.73	56.73
P-40	J-37	R-3	-313.80	9.06	0.00	3.47	64.71	64.71
P-41	J-35	J-39	-151.20	5.46	0.00	1.67	15.04	15.04
P-42	J-39	J-40	-186.20	2.28	0.03	2.06	23.13	22.80
P-43	J-40	R-2	-206.20	10.15	0.00	2.28	27.96	27.96

P U M P/L O S S   E L E M E N T   R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
Pump-1	3359.61	182.59	254.42	71.8	75.00	0.	0.0	0.0	**	**	215.3

N O D E   R E S U L T S

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	HYDRAULIC GRADE (ft)	NODE ELEVATION (ft)	PRESSURE HEAD (ft)	NODE PRESSURE (psi)
J-1		345.00	258.63			
J-2		5.00	251.07			
J-3		340.00	245.90			
J-4		340.00	211.92			
J-5		340.00	206.24			
J-6		340.00	204.38			
J-7		340.00	202.84			
J-8		340.00	199.24			
J-9		340.00	198.39			
J-10		10.00	193.53			

J-11	10.00	171.84			
J-12	320.00	125.25			
J-13	15.00	119.74			
J-14	10.00	117.62			
J-15	203.00	115.04			
J-16	5.00	115.04			
J-17	198.00	115.06			
J-18	35.00	132.21			
J-19	35.00	137.61			
J-20	0.00	161.49			
J-21	10.00	161.49			
J-22	10.00	172.86			
J-24	20.00	117.94			
J-25	25.00	116.11			
J-26	47.00	114.77			
J-27	15.00	114.79			
J-28	10.00	114.78			
J-29	140.00	114.77			
J-32	140.00	115.37			
J-33	30.00	134.23			
J-34	20.00	140.67			
J-35	90.00	169.69			
J-36	15.00	177.14			
J-37	20.00	178.56			
J-39	35.00	175.15			
J-40	20.00	177.47			
I-Pump-1	0.00	187.59	5.00	182.59	79.12
R-1	----	187.62			
R-2	----	187.62			
R-3	----	187.62			
R-4	----	187.62			
I-RV-1	0.00	259.00			
O-Pump-1	0.00	259.42	5.00	254.42	110.25
O-RV-1	----	259.00			

M A X I M U M   A N D   M I N I M U M   V A L U E S

P R E S S U R E S

JUNCTION NUMBER	MAXIMUM PRESSURES (psi)	JUNCTION NUMBER	MINIMUM PRESSURES (psi)
O-Pump-1	110.25	I-Pump-1	79.12

V E L O C I T I E S

PIPE NUMBER	MAXIMUM VELOCITY	PIPE NUMBER	MINIMUM VELOCITY

	(ft/s)		(ft/s)
P-12	7.03	P-31	0.05
P-13	6.92	P-30	0.10
P-5	6.89	P-17	0.13
P-6	6.01	P-18	0.19
P-1	5.36	P-29	0.21

H L + M L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL+ML/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL+ML/1000 (ft/ft)
P-12	241.27	P-31	0.00
P-13	232.96	P-30	0.05
P-5	73.87	P-17	0.09
P-37	72.56	P-18	0.18
P-24	71.36	P-29	0.22

H L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL/1000 (ft/ft)
P-12	239.13	P-31	0.00
P-13	231.48	P-30	0.05
P-5	73.47	P-17	0.09
P-37	72.04	P-18	0.18
P-24	71.36	P-29	0.22

R E G U L A T I N G V A L V E R E P O R T

VALVE LABEL	VALVE TYPE	VALVE SETTING (psi or gpm)	VALVE STATUS	UPSTREAM PRESSURE (psi)	DOWNSTREAM PRESSURE (psi)	THROUGH FLOW (gpm)
RV-1	PRV-1	115.00	WIDE OPEN	112.23	112.23	3359.61

S U M M A R Y O F I N F L O W S A N D O U T F L O W S

(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (gpm)	NODE TITLE
R-1	3359.61	

```
     R-2               206.20
     R-3               313.80
     R-4               338.40

NET SYSTEM INFLOW  =   4218.00
NET SYSTEM OUTFLOW =      0.00
NET SYSTEM DEMAND  =   4218.00

          ***** HYDRAULIC ANALYSIS COMPLETED *****
```

IX.4. Appendix D- Alternative 3 Detailed Design

IX.4.1. Pipe KY Results

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* * * * * * * * * * *   K Y P I P E 5   * * * * * * * * * * *
*                                                           *
*               Pipe Network Modeling Software              *
*                                                           *
*                 Copyrighted by KYPIPE LLC                 *
*                 Version 5 - February 2010                 *
*                                                           *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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 Date & Time:  Thu Oct 31 17:25:54 2013

 Master File : H:\Fall 2013\Senior Design I\Pipe KY Modelling\Design
Alternatives\Design Alternative 3\design alternative 3.P2K


               ************************************************
                S U M M A R Y   O F   O R I G I N A L   D A T A
               ************************************************


 U N I T S   S P E C I F I E D

    FLOWRATE ............ = gallons/minute
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig

 THE DARCY WEISBACH HEAD LOSS EQUATION IS USED, THE KINEMATIC VIS. =
0.0000100


 R E G U L A T I N G   V A L V E   D A T A

       VALVE        VALVE           VALVE
       LABEL        TYPE           SETTING
                                 (ft or gpm)
 -----------------------------------------
        RV-1        PRV-1           265.38


 P I P E L I N E   D A T A

   STATUS CODE:   XX -CLOSED PIPE    CV -CHECK VALVE

   P I P E               NODE NAMES       LENGTH  DIAMETER  ROUGHNESS
MINOR
```

N A M E	#1	#2	(ft)	(in)	COEFF.	LOSS COEFF.
P-1	R-1	I-Pump-1	1.00	16.00	100.0000	0.00
P-2	O-Pump-1	I-RV-1	16.22	16.72	110.0000	0.00
P-3	J-1	J-2	306.00	16.00	110.0000	0.00
P-4	J-2	J-3	256.00	16.72	110.0000	0.75
P-5	J-3	J-4	460.00	12.58	110.0000	0.00
P-6	J-4	J-9	250.00	11.65	120.0000	0.75
P-7	J-18	J-17	445.00	6.00	100.0000	0.25
P-8	O-Pump-2	J-5	1.62	6.00	100.0000	0.00
P-9	O-RV-1	J-1	16.52	16.72	110.0000	0.00
P-11	J-9	J-10	100.00	8.00	100.0000	0.00
P-12	J-10	J-11	89.90	6.00	100.0000	0.25
P-13	J-11	J-12	200.00	6.00	100.0000	0.40
P-14	J-12	J-13	189.00	6.00	100.0000	0.00
P-15	J-13	J-14	83.00	6.00	100.0000	0.25
P-16	J-14	I-Pump-2	109.38	6.00	100.0000	0.75
P-17	J-5	J-16	90.23	6.00	100.0000	0.00
P-18	J-16	J-17	101.77	6.00	100.0000	0.40
P-20	J-18	J-19	107.00	6.00	100.0000	0.25
P-21	J-19	J-21	375.00	6.00	100.0000	0.90
P-22	J-21	J-20	31.00	6.00	100.0000	0.00
P-23	J-21	J-22	169.22	6.00	100.0000	0.00
P-24	J-22	J-23	206.78	6.00	100.0000	0.00
P-25	J-12	J-24	212.00	4.00	100.0000	0.25
P-26	J-24	J-25	100.00	4.00	100.0000	0.00
P-27	J-25	J-26	258.00	4.00	100.0000	1.00

P-28	J-17	J-27	382.00	6.00	100.0000	0.25
P-29	J-27	J-28	40.00	6.00	100.0000	0.00
P-30	J-28	J-29	250.00	6.00	100.0000	0.65
P-31	J-26	J-29	346.00	12.00	100.0000	0.00
P-32	J-29	J-30	31.00	6.00	100.0000	0.75
P-33	J-30	J-31	50.00	6.00	100.0000	0.75
P-34	J-31	J-32	31.00	6.00	100.0000	0.25
P-35	J-32	J-33	359.00	6.00	100.0000	0.25
P-36	J-33	J-34	100.00	6.00	100.0000	0.25
P-37	J-34	J-35	400.00	6.00	100.0000	0.90
P-38	J-35	J-36	145.00	6.08	120.0000	0.25
P-39	J-36	J-37	25.00	6.08	120.0000	0.00
P-40	J-37	R-3	140.00	6.08	120.0000	0.00
P-41	J-35	J-39	363.00	6.08	120.0000	0.00
P-42	J-39	J-40	100.00	6.08	120.0000	0.50
P-43	J-40	R-2	363.00	6.08	120.0000	0.00

P U M P/L O S S   E L E M E N T   D A T A

THERE IS A PUMP AT NODE Pump-1; USEFUL POWER = 38.00 (Efficiency = 100.00%)

THERE IS A PUMP AT NODE Pump-2; USEFUL POWER = 1.00 (Efficiency = 100.00%)

N O D E   D A T A

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)
J-1		345.00	0.00	

J-2	5.00	0.00	
J-3	340.00	0.00	
J-4	340.00	0.00	
J-5	0.00	0.00	
J-9	340.00	0.00	
J-10	10.00	0.00	
J-11	10.00	0.00	
J-12	320.00	0.00	
J-13	15.00	0.00	
J-14	10.00	0.00	
J-16	5.00	0.00	
J-17	198.00	0.00	
J-18	35.00	0.00	
J-19	35.00	0.00	
J-20	0.00	0.00	
J-21	10.00	0.00	
J-22	10.00	0.00	
J-23	0.00	0.00	
J-24	20.00	0.00	
J-25	25.00	0.00	
J-26	-293.00	0.00	
J-27	15.00	0.00	
J-28	10.00	0.00	
J-29	140.00	0.00	
J-30	140.00	0.00	
J-31	140.00	0.00	
J-32	140.00	0.00	
J-33	30.00	0.00	
J-34	20.00	0.00	
J-35	90.00	0.00	
J-36	15.00	0.00	
J-37	20.00	0.00	
J-39	35.00	0.00	
J-40	20.00	0.00	
I-Pump-1	0.00	5.00	
O-Pump-2	0.00	0.00	
R-1	----	0.00	187.62
R-2	----	0.00	187.62
R-3	----	0.00	187.62
I-RV-1	0.00	0.00	
O-Pump-1	0.00	5.00	
O-RV-1	----	0.00	265.38
I-Pump-2	0.00	0.00	

O U T P U T   O P T I O N   D A T A

OUTPUT SELECTION: ALL RESULTS ARE INCLUDED IN THE TABULATED OUTPUT

MAXIMUM AND MINIMUM PRESSURES = 1
MAXIMUM AND MINIMUM VELOCITIES = 5
MAXIMUM AND MINIMUM HEAD LOSS/1000 = 5

S Y S T E M   C O N F I G U R A T I O N

NUMBER OF PIPES ....(p) = 41
NUMBER OF END NODES ....(j) = 38
NUMBER OF PRIMARY LOOPS ....(l) = 1
NUMBER OF SUPPLY NODES ....(f) = 3
NUMBER OF SUPPLY ZONES ....(z) = 1

==

Case: 0

RESULTS OBTAINED AFTER 5 TRIALS: ACCURACY = 0.00006

S I M U L A T I O N   D E S C R I P T I O N   (L A B E L)

P I P E L I N E   R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-1	R-1	I-Pump-1	2099.96	0.01	0.00	3.35	11.41	11.41
P-2	O-Pump-1	I-RV-1	2099.96	0.15	0.00	3.07	9.41	9.41
P-3	J-1	J-2	1754.96	2.56	0.00	2.80	8.38	8.38
P-4	J-2	J-3	1749.96	1.67	0.08	2.56	6.83	6.53
P-5	J-3	J-4	1409.96	9.43	0.00	3.64	20.50	20.50
P-6	J-4	J-9	1069.96	4.76	0.12	3.22	19.53	19.05
P-7	J-18	J-17	-90.00	2.25	0.00	1.02	5.07	5.06
P-8	O-Pump-2	J-5	279.86	0.08	0.00	3.18	48.82	48.82
P-9	O-RV-1	J-1	2099.96	0.16	0.00	3.07	9.41	9.41

P-11	J-9	J-10	729.96	6.53	0.00	4.66	65.28	65.28
P-12	J-10	J-11	719.96	29.02	0.26	8.17	325.72	322.84
P-13	J-11	J-12	709.96	62.79	0.40	8.06	315.95	313.93
P-14	J-12	J-13	304.86	10.95	0.00	3.46	57.93	57.93
P-15	J-13	J-14	289.86	4.35	0.04	3.29	52.88	52.37
P-16	J-14	I-Pump-2	279.86	5.34	0.12	3.18	49.90	48.82
P-17	J-5	J-16	279.86	4.41	0.00	3.18	48.82	48.82
P-18	J-16	J-17	274.86	4.79	0.06	3.12	47.69	47.10
P-20	J-18	J-19	55.00	0.20	0.00	0.62	1.91	1.90
P-21	J-19	J-21	20.00	0.09	0.00	0.23	0.25	0.25
P-22	J-21	J-20	0.00	0.00	0.00	0.00	0.00	0.00
P-23	J-21	J-22	10.00	0.01	0.00	0.11	0.06	0.06
P-24	J-22	J-23	0.00	0.00	0.00	0.00	0.00	0.00
P-25	J-12	J-24	85.10	9.81	0.02	2.17	46.37	46.28
P-26	J-24	J-25	65.10	2.71	0.00	1.66	27.10	27.10
P-27	J-25	J-26	40.10	2.66	0.02	1.02	10.36	10.30
P-28	J-17	J-27	-13.14	0.04	0.00	0.15	0.11	0.11
P-29	J-27	J-28	-28.14	0.02	0.00	0.32	0.50	0.50
P-30	J-28	J-29	-38.14	0.23	0.00	0.43	0.92	0.91
P-31	J-26	J-29	333.10	0.49	0.00	0.94	1.41	1.41
P-32	J-29	J-30	154.96	0.46	0.04	1.76	16.15	14.99
P-33	J-30	J-31	14.96	0.01	0.00	0.17	0.15	0.14
P-34	J-31	J-32	-125.04	0.30	0.01	1.42	10.01	9.76
P-35	J-32	J-33	-265.04	15.72	0.04	3.01	43.89	43.79
P-36	J-33	J-34	-295.04	5.43	0.04	3.35	54.69	54.26
P-37	J-34	J-35	-315.04	24.74	0.18	3.57	62.30	61.86
P-38	J-35	J-36	-263.37	6.61	0.03	2.91	45.82	45.60

P-39	J-36	J-37	-278.37	1.27	0.00	3.08	50.94	50.94
P-40	J-37	R-3	-298.37	8.19	0.00	3.30	58.51	58.51
P-41	J-35	J-39	-141.66	4.79	0.00	1.57	13.21	13.21
P-42	J-39	J-40	-176.66	2.05	0.03	1.95	20.82	20.53
P-43	J-40	R-2	-196.66	9.23	0.00	2.17	25.44	25.44

P U M P/L O S S   E L E M E N T   R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
Pump-1	2099.96	182.60	254.19	71.6	75.00	0.	0.0	0.0	**	**	215.6
Pump-2	279.86	120.47	134.60	14.1	75.00	0.	0.0	0.0	**	**	153.5

N O D E   R E S U L T S

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	HYDRAULIC GRADE (ft)	NODE ELEVATION (ft)	PRESSURE HEAD (ft)	NODE PRESSURE (psi)
J-1		345.00	258.89			
J-2		5.00	256.32			
J-3		340.00	254.57			
J-4		340.00	245.14			
J-5		0.00	134.52			
J-9		340.00	240.26			
J-10		10.00	233.73			
J-11		10.00	204.45			
J-12		320.00	141.26			
J-13		15.00	130.31			
J-14		10.00	125.92			
J-16		5.00	130.12			

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     J-17                          198.00       125.26
     J-18                           35.00       123.01
     J-19                           35.00       122.80
     J-20                            0.00       122.71
     J-21                           10.00       122.71
     J-22                           10.00       122.70
     J-23                            0.00       122.70
     J-24                           20.00       131.43
     J-25                           25.00       128.72
     J-26                         -293.00       126.05
     J-27                           15.00       125.31
     J-28                           10.00       125.33
     J-29                          140.00       125.56
     J-30                          140.00       125.06
     J-31                          140.00       125.05
     J-32                          140.00       125.36
     J-33                           30.00       141.12
     J-34                           20.00       146.58
     J-35                           90.00       171.51
     J-36                           15.00       178.15
     J-37                           20.00       179.42
     J-39                           35.00       176.30
     J-40                           20.00       178.38
 I-Pump-1                            0.00       187.60      5.00   182.60
79.13
 O-Pump-2                            0.00       134.60
      R-1                            ----       187.62
      R-2                            ----       187.62
      R-3                            ----       187.62
   I-RV-1                            0.00       259.04
 O-Pump-1                            0.00       259.19      5.00   254.19
110.15
   O-RV-1                            ----       259.04
 I-Pump-2                            0.00       120.47


 M A X I M U M   A N D   M I N I M U M   V A L U E S


     P R E S S U R E S

          JUNCTION    MAXIMUM             JUNCTION    MINIMUM
           NUMBER    PRESSURES             NUMBER    PRESSURES
                       (psi)                           (psi)
          ---------------------           ---------------------
       O-Pump-1        110.15          I-Pump-1        79.13

     V E L O C I T I E S

            PIPE      MAXIMUM               PIPE      MINIMUM
           NUMBER     VELOCITY             NUMBER     VELOCITY
                       (ft/s)                          (ft/s)
          ---------------------           ---------------------
```

P-12	8.17	P-23	0.11
P-13	8.06	P-28	0.15
P-11	4.66	P-33	0.17
P-5	3.64	P-21	0.23
P-37	3.57	P-29	0.32

H L + M L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL+ML/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL+ML/1000 (ft/ft)
P-12	325.72	P-23	0.06
P-13	315.95	P-28	0.11
P-11	65.28	P-33	0.15
P-37	62.30	P-21	0.25
P-40	58.51	P-29	0.50

H L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL/1000 (ft/ft)
P-12	322.84	P-23	0.06
P-13	313.93	P-28	0.11
P-11	65.28	P-33	0.14
P-37	61.86	P-21	0.25
P-40	58.51	P-29	0.50

R E G U L A T I N G   V A L V E   R E P O R T

VALVE LABEL	VALVE TYPE	VALVE SETTING (psi or gpm)	VALVE STATUS	UPSTREAM PRESSURE (psi)	DOWNSTREAM PRESSURE (psi)	THROUGH FLOW (gpm)
RV-1	PRV-1	115.00	WIDE OPEN	112.25	112.25	2099.96

S U M M A R Y   O F   I N F L O W S   A N D   O U T F L O W S

(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (gpm)	NODE TITLE
R-1	2099.96	
R-2	196.66	
R-3	298.37	

```
NET SYSTEM INFLOW  =   2595.00
NET SYSTEM OUTFLOW =      0.00
NET SYSTEM DEMAND  =   2595.00

          ***** HYDRAULIC ANALYSIS COMPLETED *****
```

IX.5. Appendix E- Alternative 3 Detailed Design (Valley Hour)

VIII.5.1 Pipe KY Results

```
* * * * * * * * * *   K Y P I P E 5   * * * * * * * * * * *
*                                                           *
*              Pipe Network Modeling Software               *
*                                                           *
*                Copyrighted by KYPIPE LLC                  *
*                Version 5 - February 2010                  *
*                                                           *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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 Date & Time:  Sat Nov 09 12:40:17 2013

 Master File : e:\fall 2013\senior design i\pipe ky modelling\design
alternatives\design alternative 3\design alternative 3 valley
hr.KYP\design alternative 3 valley hr.P2K


               ************************************************
                S U M M A R Y   O F   O R I G I N A L   D A T A
               ************************************************


 U N I T S   S P E C I F I E D

    FLOWRATE ............ = gallons/minute
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig

 THE DARCY WEISBACH HEAD LOSS EQUATION IS USED, THE KINEMATIC VIS. =
0.0000100


 R E G U L A T I N G   V A L V E   D A T A

      VALVE        VALVE           VALVE
      LABEL        TYPE           SETTING
                                (ft or gpm)
 ----------------------------------------
       RV-1        PRV-1           265.38


 P I P E L I N E   D A T A
```

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

PIPE NAME	NODE NAMES #1	NODE NAMES #2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
P-1	R-1	I-RV-1	17.22	16.00	100.0000	0.00
P-3	J-1	J-2	306.00	16.00	110.0000	0.00
P-4	J-2	J-3	256.00	16.72	110.0000	0.75
P-5	J-3	J-4	460.00	12.58	110.0000	0.00
P-6	J-4	J-9	250.00	11.65	120.0000	0.75
P-7	J-18	J-17	445.00	6.00	100.0000	0.25
P-8	O-Pump-2	J-5	1.62	6.00	100.0000	0.00
P-9	O-RV-1	J-1	16.52	16.72	110.0000	0.00
P-11	J-9	J-10	100.00	8.00	100.0000	0.00
P-12	J-10	J-11	89.90	6.00	100.0000	0.25
P-13	J-11	J-12	200.00	6.00	100.0000	0.40
P-14	J-12	J-13	189.00	6.00	100.0000	0.00
P-15	J-13	J-14	83.00	6.00	100.0000	0.25
P-16	J-14	I-Pump-2	109.38	6.00	100.0000	0.75
P-17	J-5	J-16	90.23	6.00	100.0000	0.00
P-18	J-16	J-17	101.77	6.00	100.0000	0.40
P-20	J-18	J-19	107.00	6.00	100.0000	0.25
P-21	J-19	J-21	375.00	6.00	100.0000	0.90
P-22	J-21	J-20	31.00	6.00	100.0000	0.00
P-23	J-21	J-22	169.22	6.00	100.0000	0.00
P-24	J-22	J-23	206.78	6.00	100.0000	0.00
P-25	J-12	J-24	212.00	4.00	100.0000	0.25

P-26	J-24	J-25	100.00	4.00	100.0000	0.00
P-27	J-25	J-26	258.00	4.00	100.0000	1.00
P-28	J-17	J-27	382.00	6.00	100.0000	0.25
P-29	J-27	J-28	40.00	6.00	100.0000	0.00
P-30	J-28	J-29	250.00	6.00	100.0000	0.65
P-31	J-26	J-29	346.00	12.00	100.0000	0.00
P-32	J-29	J-30	31.00	6.00	100.0000	0.75
P-33	J-30	J-31	50.00	6.00	100.0000	0.75
P-34	J-31	J-32	31.00	6.00	100.0000	0.25
P-35	J-32	J-33	359.00	6.00	100.0000	0.25
P-36	J-33	J-34	100.00	6.00	100.0000	0.25
P-37	J-34	J-35	400.00	6.00	100.0000	0.90
P-38	J-35	J-36	145.00	6.08	120.0000	0.25
P-39	J-36	J-37	25.00	6.08	120.0000	0.00
P-40	J-37	R-3	140.00	6.08	120.0000	0.00
P-41	J-35	J-39	363.00	6.08	120.0000	0.00
P-42	J-39	J-40	100.00	6.08	120.0000	0.50
P-43	J-40	R-2	363.00	6.08	120.0000	0.00

P U M P/L O S S   E L E M E N T   D A T A

THERE IS A PUMP AT NODE Pump-2; USEFUL POWER = 1.00 (Efficiency = 100.00%)

N O D E   D A T A

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)

J-1	13.80	0.00	
J-2	0.20	0.00	
J-3	13.60	0.00	
J-4	13.60	0.00	
J-5	8.10	0.00	
J-9	13.60	0.00	
J-10	0.40	0.00	
J-11	0.40	0.00	
J-12	12.80	0.00	
J-13	0.40	0.00	
J-14	0.60	0.00	
J-16	0.20	0.00	
J-17	7.90	0.00	
J-18	1.40	0.00	
J-19	1.40	0.00	
J-20	0.00	0.00	
J-21	0.40	0.00	
J-22	0.40	0.00	
J-23	0.00	0.00	
J-24	1.00	0.00	
J-25	0.80	0.00	
J-26	-11.70	0.00	
J-27	0.40	0.00	
J-28	0.60	0.00	
J-29	5.60	0.00	
J-30	5.60	0.00	
J-31	5.60	0.00	
J-32	5.60	0.00	
J-33	1.20	0.00	
J-34	0.80	0.00	
J-35	3.60	0.00	
J-36	0.60	0.00	
J-37	0.80	0.00	
J-39	1.40	0.00	
J-40	0.80	0.00	
O-Pump-2	0.00	0.00	
R-1	----	0.00	131.54
R-2	----	0.00	131.54
R-3	----	0.00	131.54
I-RV-1	0.00	0.00	
O-RV-1	----	0.00	265.38
I-Pump-2	0.00	0.00	

O U T P U T   O P T I O N   D A T A

OUTPUT SELECTION: ALL RESULTS ARE INCLUDED IN THE TABULATED OUTPUT
MAXIMUM AND MINIMUM VELOCITIES = 5
MAXIMUM AND MINIMUM HEAD LOSS/1000 = 5

S Y S T E M   C O N F I G U R A T I O N

```
NUMBER OF PIPES ...................(p) =   40
NUMBER OF END NODES ...............(j) =   37
NUMBER OF PRIMARY LOOPS ...........(l) =    1
NUMBER OF SUPPLY NODES ............(f) =    3
NUMBER OF SUPPLY ZONES ............(z) =    1
```

```
==========================================================================
======
Case:   0
```

RESULTS OBTAINED AFTER 6 TRIALS: ACCURACY = 0.00005

S I M U L A T I O N   D E S C R I P T I O N   (L A B E L)

P I P E L I N E   R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-1	R-1	I-RV-1	183.14	0.00	0.00	0.29	0.09	0.09
P-3	J-1	J-2	169.34	0.02	0.00	0.27	0.08	0.08
P-4	J-2	J-3	169.14	0.02	0.00	0.25	0.06	0.06
P-5	J-3	J-4	155.54	0.12	0.00	0.40	0.25	0.25
P-6	J-4	J-9	141.94	0.08	0.00	0.43	0.35	0.34
P-7	J-18	J-17	-3.60	0.00	0.00	0.04	0.01	0.01
P-8	O-Pump-2	J-5	159.06	0.03	0.00	1.80	15.79	15.79
P-9	O-RV-1	J-1	183.14	0.00	0.00	0.27	0.07	0.07
P-11	J-9	J-10	128.34	0.20	0.00	0.82	2.03	2.03
P-12	J-10	J-11	127.94	0.92	0.01	1.45	10.31	10.22

P-13	J-11	J-12	127.54	2.03	0.01	1.45	10.22	10.15
P-14	J-12	J-13	160.06	3.02	0.00	1.82	15.99	15.99
P-15	J-13	J-14	159.66	1.32	0.01	1.81	16.06	15.91
P-16	J-14	I-Pump-2	159.06	1.73	0.04	1.80	16.13	15.79
P-17	J-5	J-16	150.96	1.28	0.00	1.71	14.22	14.22
P-18	J-16	J-17	150.76	1.44	0.02	1.71	14.36	14.18
P-20	J-18	J-19	2.20	0.00	0.00	0.02	0.00	0.00
P-21	J-19	J-21	0.80	0.00	0.00	0.01	0.00	0.00
P-22	J-21	J-20	0.00	0.00	0.00	0.00	0.00	0.00
P-23	J-21	J-22	0.40	0.00	0.00	0.00	0.00	0.00
P-24	J-22	J-23	0.00	0.00	0.00	0.00	0.00	0.00
P-25	J-12	J-24	-45.32	2.79	0.01	1.16	13.17	13.15
P-26	J-24	J-25	-46.32	1.37	0.00	1.18	13.74	13.74
P-27	J-25	J-26	-47.12	3.67	0.02	1.20	14.30	14.21
P-28	J-17	J-27	139.26	4.62	0.01	1.58	12.13	12.10
P-29	J-27	J-28	138.86	0.48	0.00	1.58	12.04	12.04
P-30	J-28	J-29	138.26	2.98	0.02	1.57	12.03	11.93
P-31	J-26	J-29	-35.42	0.01	0.00	0.10	0.02	0.02
P-32	J-29	J-30	97.24	0.18	0.01	1.10	6.37	5.91
P-33	J-30	J-31	91.64	0.26	0.01	1.04	5.50	5.25
P-34	J-31	J-32	86.04	0.14	0.00	0.98	4.75	4.63
P-35	J-32	J-33	80.44	1.45	0.00	0.91	4.05	4.05
P-36	J-33	J-34	79.24	0.39	0.00	0.90	3.96	3.93
P-37	J-34	J-35	78.44	1.54	0.01	0.89	3.88	3.85
P-38	J-35	J-36	46.00	0.20	0.00	0.51	1.41	1.40
P-39	J-36	J-37	45.40	0.03	0.00	0.50	1.36	1.36
P-40	J-37	R-3	44.60	0.18	0.00	0.49	1.31	1.31

P-41	J-35	J-39	28.84	0.20	0.00	0.32	0.55	0.55
P-42	J-39	J-40	27.44	0.05	0.00	0.30	0.51	0.50
P-43	J-40	R-2	26.64	0.17	0.00	0.29	0.47	0.47

P U M P/L O S S   E L E M E N T   R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
Pump-2	159.06	122.00	146.87	24.9	75.00	0.	0.0	0.0	**	**	155.2

N O D E   R E S U L T S

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	HYDRAULIC GRADE (ft)	NODE ELEVATION (ft)	PRESSURE HEAD (ft)	NODE PRESSURE (psi)
J-1		13.80	131.54			
J-2		0.20	131.51			
J-3		13.60	131.50			
J-4		13.60	131.38			
J-5		8.10	146.85			
J-9		13.60	131.29			
J-10		0.40	131.09			
J-11		0.40	130.16			
J-12		12.80	128.12			
J-13		0.40	125.10			
J-14		0.60	123.77			
J-16		0.20	145.57			
J-17		7.90	144.10			
J-18		1.40	144.10			
J-19		1.40	144.10			
J-20		0.00	144.10			
J-21		0.40	144.10			
J-22		0.40	144.10			

J-23	0.00	144.10
J-24	1.00	130.91
J-25	0.80	132.29
J-26	-11.70	135.98
J-27	0.40	139.47
J-28	0.60	138.99
J-29	5.60	135.98
J-30	5.60	135.78
J-31	5.60	135.51
J-32	5.60	135.36
J-33	1.20	133.91
J-34	0.80	133.51
J-35	3.60	131.96
J-36	0.60	131.76
J-37	0.80	131.72
J-39	1.40	131.76
J-40	0.80	131.71
O-Pump-2	0.00	146.87
R-1	----	131.54
R-2	----	131.54
R-3	----	131.54
I-RV-1	0.00	131.54
O-RV-1	----	131.54
I-Pump-2	0.00	122.00

M A X I M U M   A N D   M I N I M U M   V A L U E S

V E L O C I T I E S

PIPE NUMBER	MAXIMUM VELOCITY (ft/s)	PIPE NUMBER	MINIMUM VELOCITY (ft/s)
P-14	1.82	P-23	0.00
P-15	1.81	P-21	0.01
P-8	1.80	P-20	0.02
P-16	1.80	P-7	0.04
P-17	1.71	P-31	0.10

H L + M L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL+ML/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL+ML/1000 (ft/ft)
P-16	16.13	P-23	0.00
P-15	16.06	P-21	0.00
P-14	15.99	P-20	0.00
P-8	15.79	P-7	0.01
P-18	14.36	P-31	0.02

H L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL/1000 (ft/ft)
P-14	15.99	P-23	0.00
P-15	15.91	P-21	0.00
P-16	15.79	P-20	0.00
P-8	15.79	P-7	0.01
P-17	14.22	P-31	0.02

R E G U L A T I N G V A L V E R E P O R T

VALVE LABEL	VALVE TYPE	VALVE SETTING (psi or gpm)	VALVE STATUS	UPSTREAM PRESSURE (psi)	DOWNSTREAM PRESSURE (psi)	THROUGH FLOW (gpm)
RV-1	PRV-1	115.00	WIDE OPEN	57.00	57.00	183.14

S U M M A R Y O F I N F L O W S A N D O U T F L O W S

(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (gpm)	NODE TITLE
R-1	183.14	
R-2	-26.64	
R-3	-44.60	

NET SYSTEM INFLOW = 183.14
NET SYSTEM OUTFLOW = -71.24
NET SYSTEM DEMAND = 111.90

***** HYDRAULIC ANALYSIS COMPLETED *****

IX.6. Appendix F- Alternative 3 Detailed Design (Normal Hour)

IX.6.1 Pipe KY Results

```
* * * * * * * * * *   K Y P I P E 5   * * * * * * * * * * *
*                                                           *
*              Pipe Network Modeling Software               *
*                                                           *
*                Copyrighted by KYPIPE LLC                  *
*                Version 5 - February 2010                  *
*                                                           *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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               ************************************************
                S U M M A R Y   O F   O R I G I N A L   D A T A
               ************************************************
```

```
 U N I T S   S P E C I F I E D

    FLOWRATE ............ = gallons/minute
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig

 THE DARCY WEISBACH HEAD LOSS EQUATION IS USED, THE KINEMATIC VIS. =
0.0000100
```

```
 R E G U L A T I N G   V A L V E   D A T A

       VALVE        VALVE            VALVE
       LABEL        TYPE            SETTING
                                  (ft or gpm)
 -----------------------------------------
        RV-1        PRV-1            265.38
```

```
 P I P E L I N E   D A T A
```

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

PIPE NAME	NODE NAMES #1	#2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
P-1	R-1	I-Pump-1	1.00	16.00	100.0000	0.00
P-2	O-Pump-1	I-RV-1	16.22	16.72	110.0000	0.00
P-3	J-1	J-2	306.00	16.00	110.0000	0.00
P-4	J-2	J-3	256.00	16.72	110.0000	0.75
P-5	J-3	J-4	460.00	12.58	110.0000	0.00
P-6	J-4	J-9	250.00	11.65	120.0000	0.75
P-7	J-18	J-17	445.00	6.00	100.0000	0.25
P-8	O-Pump-2	J-5	1.62	6.00	100.0000	0.00
P-9	O-RV-1	J-1	16.52	16.72	110.0000	0.00
P-11	J-9	J-10	100.00	8.00	100.0000	0.00
P-12	J-10	J-11	89.90	6.00	100.0000	0.25
P-13	J-11	J-12	200.00	6.00	100.0000	0.40
P-14	J-12	J-13	189.00	6.00	100.0000	0.00
P-15	J-13	J-14	83.00	6.00	100.0000	0.25
P-16	J-14	I-Pump-2	109.38	6.00	100.0000	0.75
P-17	J-5	J-16	90.23	6.00	100.0000	0.00
P-18	J-16	J-17	101.77	6.00	100.0000	0.40
P-20	J-18	J-19	107.00	6.00	100.0000	0.25
P-21	J-19	J-21	375.00	6.00	100.0000	0.90
P-22	J-21	J-20	31.00	6.00	100.0000	0.00
P-23	J-21	J-22	169.22	6.00	100.0000	0.00
P-24	J-22	J-23	206.78	6.00	100.0000	0.00

P-25	J-12	J-24	212.00	4.00	100.0000	0.25
P-26	J-24	J-25	100.00	4.00	100.0000	0.00
P-27	J-25	J-26	258.00	4.00	100.0000	1.00
P-28	J-17	J-27	382.00	6.00	100.0000	0.25
P-29	J-27	J-28	40.00	6.00	100.0000	0.00
P-30	J-28	J-29	250.00	6.00	100.0000	0.65
P-31	J-26	J-29	346.00	12.00	100.0000	0.00
P-32	J-29	J-30	31.00	6.00	100.0000	0.75
P-33	J-30	J-31	50.00	6.00	100.0000	0.75
P-34	J-31	J-32	31.00	6.00	100.0000	0.25
P-35	J-32	J-33	359.00	6.00	100.0000	0.25
P-36	J-33	J-34	100.00	6.00	100.0000	0.25
P-37	J-34	J-35	400.00	6.00	100.0000	0.90
P-38	J-35	J-36	145.00	6.08	120.0000	0.25
P-39	J-36	J-37	25.00	6.08	120.0000	0.00
P-40	J-37	R-3	140.00	6.08	120.0000	0.00
P-41	J-35	J-39	363.00	6.08	120.0000	0.00
P-42	J-39	J-40	100.00	6.08	120.0000	0.50
P-43	J-40	R-2	363.00	6.08	120.0000	0.00

P U M P/L O S S   E L E M E N T   D A T A

THERE IS A PUMP AT NODE   Pump-1; USEFUL POWER =   20.00 (Efficiency = 100.00%)

THERE IS A PUMP AT NODE   Pump-2; USEFUL POWER =   1.00 (Efficiency = 100.00%)

N O D E   D A T A

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	JUNCTION ELEVATION (ft)	EXTERNAL GRADE (ft)
J-1		138.00	0.00	
J-2		2.00	0.00	
J-3		136.00	0.00	
J-4		136.00	0.00	
J-5		81.30	0.00	
J-9		136.00	0.00	
J-10		4.00	0.00	
J-11		4.00	0.00	
J-12		128.00	0.00	
J-13		4.00	0.00	
J-14		6.00	0.00	
J-16		2.00	0.00	
J-17		79.30	0.00	
J-18		14.00	0.00	
J-19		14.00	0.00	
J-20		0.00	0.00	
J-21		4.00	0.00	
J-22		4.00	0.00	
J-23		0.00	0.00	
J-24		8.00	0.00	
J-25		10.00	0.00	
J-26		-117.30	0.00	
J-27		4.00	0.00	
J-28		6.00	0.00	
J-29		56.00	0.00	
J-30		56.00	0.00	
J-31		56.00	0.00	
J-32		56.00	0.00	
J-33		12.00	0.00	
J-34		8.00	0.00	
J-35		36.00	0.00	
J-36		6.00	0.00	
J-37		8.00	0.00	
J-39		14.00	0.00	
J-40		8.00	0.00	
I-Pump-1		0.00	5.00	
O-Pump-2		0.00	0.00	
R-1		----	0.00	131.54
R-2		----	0.00	131.54
R-3		----	0.00	131.54
I-RV-1		0.00	0.00	
O-Pump-1		0.00	5.00	
O-RV-1		----	0.00	265.38
I-Pump-2		0.00	0.00	

O U T P U T   O P T I O N   D A T A

OUTPUT SELECTION: ALL RESULTS ARE INCLUDED IN THE TABULATED OUTPUT

MAXIMUM AND MINIMUM PRESSURES = 1
MAXIMUM AND MINIMUM VELOCITIES = 5
MAXIMUM AND MINIMUM HEAD LOSS/1000 = 5

S Y S T E M   C O N F I G U R A T I O N

NUMBER OF PIPES ....(p) = 41
NUMBER OF END NODES ....(j) = 38
NUMBER OF PRIMARY LOOPS ....(l) = 1
NUMBER OF SUPPLY NODES ....(f) = 3
NUMBER OF SUPPLY ZONES ....(z) = 1

==
Case: 0

RESULTS OBTAINED AFTER 6 TRIALS: ACCURACY = 0.00001

S I M U L A T I O N   D E S C R I P T I O N   (L A B E L)

P I P E L I N E   R E S U L T S

STATUS CODE: XX -CLOSED PIPE CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	#2	FLOWRATE (gpm)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-1	R-1	I-Pump-1	1061.97	0.00	0.00	1.69	2.92	2.92
P-2	O-Pump-1	I-RV-1	1061.97	0.04	0.00	1.55	2.41	2.41
P-3	J-1	J-2	923.97	0.71	0.00	1.47	2.32	2.32
P-4	J-2	J-3	921.97	0.46	0.02	1.35	1.90	1.82
P-5	J-3	J-4	785.97	2.93	0.00	2.03	6.38	6.38
P-6	J-4	J-9	649.97	1.76	0.04	1.96	7.21	7.03

P-7	J-18	J-17	-36.00	0.36	0.00	0.41	0.82	0.81
P-8	O-Pump-2	J-5	291.96	0.09	0.00	3.31	53.13	53.13
P-9	O-RV-1	J-1	1061.97	0.04	0.00	1.55	2.41	2.41
P-11	J-9	J-10	513.97	3.24	0.00	3.28	32.37	32.37
P-12	J-10	J-11	509.97	14.57	0.13	5.79	163.46	162.02
P-13	J-11	J-12	505.97	31.90	0.20	5.74	160.51	159.49
P-14	J-12	J-13	301.96	10.74	0.00	3.43	56.83	56.83
P-15	J-13	J-14	297.96	4.59	0.04	3.38	55.87	55.34
P-16	J-14	I-Pump-2	291.96	5.81	0.13	3.31	54.30	53.13
P-17	J-5	J-16	210.66	2.50	0.00	2.39	27.67	27.67
P-18	J-16	J-17	208.66	2.76	0.03	2.37	27.49	27.15
P-20	J-18	J-19	22.00	0.03	0.00	0.25	0.31	0.31
P-21	J-19	J-21	8.00	0.02	0.00	0.09	0.04	0.04
P-22	J-21	J-20	0.00	0.00	0.00	0.00	0.00	0.00
P-23	J-21	J-22	4.00	0.00	0.00	0.05	0.01	0.01
P-24	J-22	J-23	0.00	0.00	0.00	0.00	0.00	0.00
P-25	J-12	J-24	76.02	7.83	0.01	1.94	37.01	36.94
P-26	J-24	J-25	68.02	2.96	0.00	1.74	29.58	29.58
P-27	J-25	J-26	58.02	5.55	0.03	1.48	21.66	21.53
P-28	J-17	J-27	93.36	2.08	0.00	1.06	5.46	5.45
P-29	J-27	J-28	89.36	0.20	0.00	1.01	4.99	4.99
P-30	J-28	J-29	83.36	1.09	0.01	0.95	4.38	4.34
P-31	J-26	J-29	175.32	0.14	0.00	0.50	0.39	0.39
P-32	J-29	J-30	202.67	0.79	0.06	2.30	27.61	25.62
P-33	J-30	J-31	146.67	0.67	0.03	1.66	14.07	13.43
P-34	J-31	J-32	90.67	0.16	0.00	1.03	5.27	5.14
P-35	J-32	J-33	34.67	0.27	0.00	0.39	0.76	0.76

P-36	J-33	J-34	22.67	0.03	0.00	0.26	0.33	0.32
P-37	J-34	J-35	14.67	0.05	0.00	0.17	0.14	0.14
P-38	J-35	J-36	-19.60	0.04	0.00	0.22	0.26	0.26
P-39	J-36	J-37	-25.60	0.01	0.00	0.28	0.44	0.44
P-40	J-37	R-3	-33.60	0.10	0.00	0.37	0.75	0.75
P-41	J-35	J-39	-1.73	0.00	0.00	0.02	0.00	0.00
P-42	J-39	J-40	-15.73	0.02	0.00	0.17	0.17	0.17
P-43	J-40	R-2	-23.73	0.14	0.00	0.26	0.37	0.37

P U M P/L O S S   E L E M E N T   R E S U L T S

NAME	FLOWRATE (gpm)	INLET HEAD (ft)	OUTLET HEAD (ft)	PUMP HEAD (ft)	EFFIC-ENCY (%)	USEFUL POWER (Hp)	INCREMTL COST ($)	TOTAL COST ($)	#PUMPS PARALLEL	#PUMPS SERIES	NPSH Avail. (ft)
Pump-1	1061.97	126.54	201.04	74.5	75.00	0.	0.0	0.0	**	**	159.7
Pump-2	291.96	128.68	142.23	13.6	75.00	0.	0.0	0.0	**	**	161.7

N O D E   R E S U L T S

NODE NAME	NODE TITLE	EXTERNAL DEMAND (gpm)	HYDRAULIC GRADE (ft)	NODE ELEVATION (ft)	PRESSURE HEAD (ft)	NODE PRESSURE (psi)
J-1		138.00	205.96			
J-2		2.00	205.25			
J-3		136.00	204.77			
J-4		136.00	201.83			
J-5		81.30	142.14			
J-9		136.00	200.03			

J-10	4.00	196.79			
J-11	4.00	182.10			
J-12	128.00	150.00			
J-13	4.00	139.26			
J-14	6.00	134.62			
J-16	2.00	139.65			
J-17	79.30	136.85			
J-18	14.00	136.48			
J-19	14.00	136.45			
J-20	0.00	136.44			
J-21	4.00	136.44			
J-22	4.00	136.43			
J-23	0.00	136.43			
J-24	8.00	142.15			
J-25	10.00	139.19			
J-26	-117.30	133.60			
J-27	4.00	134.76			
J-28	6.00	134.56			
J-29	56.00	133.47			
J-30	56.00	132.61			
J-31	56.00	131.91			
J-32	56.00	131.75			
J-33	12.00	131.47			
J-34	8.00	131.44			
J-35	36.00	131.39			
J-36	6.00	131.42			
J-37	8.00	131.43			
J-39	14.00	131.39			
J-40	8.00	131.40			
I-Pump-1	0.00	131.54	5.00	126.54	54.83
O-Pump-2	0.00	142.23			
R-1	----	131.54			
R-2	----	131.54			
R-3	----	131.54			
I-RV-1	0.00	206.00			
O-Pump-1	0.00	206.04	5.00	201.04	87.12
O-RV-1	----	206.00			
I-Pump-2	0.00	128.68			

M A X I M U M   A N D   M I N I M U M   V A L U E S

P R E S S U R E S

JUNCTION NUMBER	MAXIMUM PRESSURES (psi)	JUNCTION NUMBER	MINIMUM PRESSURES (psi)
O-Pump-1	87.12	I-Pump-1	54.83

V E L O C I T I E S

PIPE NUMBER	MAXIMUM VELOCITY (ft/s)	PIPE NUMBER	MINIMUM VELOCITY (ft/s)
P-12	5.79	P-41	0.02
P-13	5.74	P-23	0.05
P-14	3.43	P-21	0.09
P-15	3.38	P-37	0.17
P-8	3.31	P-42	0.17

H L + M L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL+ML/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL+ML/1000 (ft/ft)
P-12	163.46	P-41	0.00
P-13	160.51	P-23	0.01
P-14	56.83	P-21	0.04
P-15	55.87	P-37	0.14
P-16	54.30	P-42	0.17

H L / 1 0 0 0

PIPE NUMBER	MAXIMUM HL/1000 (ft/ft)	PIPE NUMBER	MINIMUM HL/1000 (ft/ft)
P-12	162.02	P-41	0.00
P-13	159.49	P-23	0.01
P-14	56.83	P-21	0.04
P-15	55.34	P-37	0.14
P-8	53.13	P-42	0.17

R E G U L A T I N G V A L V E R E P O R T

VALVE LABEL	VALVE TYPE	VALVE SETTING (psi or gpm)	VALVE STATUS	UPSTREAM PRESSURE (psi)	DOWNSTREAM PRESSURE (psi)	THROUGH FLOW (gpm)
RV-1	PRV-1	115.00	WIDE OPEN	89.27	89.27	1061.97

S U M M A R Y O F I N F L O W S A N D O U T F L O W S

(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (gpm)	NODE TITLE
R-1	1061.97	
R-2	23.73	
R-3	33.60	

NET SYSTEM INFLOW = 1119.30
NET SYSTEM OUTFLOW = 0.00
NET SYSTEM DEMAND = 1119.30

***** HYDRAULIC ANALYSIS COMPLETED *****