Principles of Hydraulic Analysis for Fire Protection Sprinkler Systems

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Code MP5517

The advent of Building Information Modeling (BIM) has highlighted the value of integrating the analysis of each of the systems that make up the entire building system with the tools used in the design process. The fire sprinkler system is one of those systems which require a rigorous analysis to ensure its proper application as a critical life-safety component of the building. This class will provide an outline of the underlying mathematical equations and basic engineering assumptions that are prescribed in the applicable standards for the design and analysis of those systems. This class is not intended to present the application of any product to this process but rather to detail the basic analysis approach prescribed by the standards. The class will present the formulae used to account for the pressures required to overcome discharge from a particular sprinkler orifice, friction loss through the pipe and fittings, and vertical elevation.

Learning Objectives

At the end of this class, you will be able to:

- Know the basic equations used in hydraulic analysis.
- Differentiate the design basis of fire protection from plumbing systems.
- Identify the appropriate sprinkler design standards.
- Evaluate various software products to determine their level of integration of the analysis process.

About the Speaker

Alan Johnston has been the president of Hydratec, Inc. since 1972. Hydratec specializes in the design, development, marketing and support of AutoCAD based software for the design, analysis and fabrication of fire protection sprinkler systems. Alan is the holder of several US patents including one for the retrofit of sprinklers systems into single family houses. Alan holds a BS in mechanical engineering and has served as part of the Hydratec training and support team for over 35 years. Most recently, Alan has provided advanced training of the latest features of the HydraCAD software to groups of existing users in over fifty cities around the United States. His interest in the hydraulic design of sprinkler systems has been an important part of his more than 40 years of experience in this industry.

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Introduction

The material for this class has been prepared to provide a reference for the basics of hydraulic analysis of fire protection sprinkler systems. As the target audience for this class includes members of the engineering community for whom analysis of hot and cold water supply piping may be more familiar, a contrast is drawn between the engineering approach used for those systems compared to fire protection systems. The material is divided into three major areas of comparison.

The first area of discussion focuses on the physics of the calculations. In the interest of satisfying a certain sense of curiosity about the source of the formulas (formulae would be more grammatically correct but just sounds funny to me) I will present a very down to earth representation of the empirical nature of each formula used.

The second area of discussion will present an abbreviated list of standards typically applied to the design of fire protection sprinkler systems and hot and cold water supply piping systems. Because the more widely used standards for fire protection are in fact standards it is worth noting that the various local codes often affect the application of those standards. Other requirements affecting the fire protection design also come from insurance organizations.

The third area of discussion compares the engineering assumptions used to apply the formulas for each of the two design types. We will show that the design assumptions for hot and cold water supply piping allow for the direct determination of the flow in every pipe in a given system. By contrast the flow in any given pipe in a fire protection system varies by the expected area of operation and on the pipe sizing used in the design. This will lead to a better understanding of the relative automation possibilities for the two design approaches.

Overview

	Fire Protection	Plumbing Distribution
Formulas Used		
• Flow and Pressure at Discharge	Flow Dependent	Fixed
• Friction Loss	Hazen & Williams	Hazen & Williams
• Elevation Changes	Height	Height
Standards		
• National	NFPA	UPC, IPC
• Insurance Standards	Factory Mutual	
• Local Authorities	State & Local Fire	State Plb'g Codes
Application		
• Operating Outlets	Within Fixed Area	Every Fixture
• Total Flow	From Fixed Area	Diminishing Portion
• Piping Layout	Straight, Looped	Straight
• Velocity Limits	none	8-10fps
• Required reporting	NFPA Specification	Suggested by codes

Physics of each Formula used

Pressure Required at an Open Outlet $Q = K\sqrt{P}$

Let us begin our discussion of the formulas used in fire protection design with the formula for the flow from an operating sprinkler. Without a mathematical proof I will state that the Bernoulli equation can be used to predict that for an open orifice of a given size, the pressure at the orifice will be directly proportional to the square of the flow rate through that office. However, rather than perform that mathematical exercise to develop a theoretical relationship between those parameters I would like to illustrate an empirical process by which that relationship can be demonstrated. Figure 1 illustrates a test apparatus which can be used to measure the flow rate through an open sprinkler orifice at varying measured pressures. As shown, this apparatus consists of **[A]** a very strong supply of pressure and flow from an external source. An extraordinary example might be fire pump rated at 100 psi at a flow of 500gpm. Since our subsequent test will measure operating pressures of 0 to 35 psi and operating flows of 0 to 35 gpm it is easy to see that our fire pump will have no difficulty in keeping up with our test conditions. The next key feature of our test apparatus is **[D]** a throttling valve.

This is shown in figure 1 as a single ball valve (a simple on/off device) but would be better served by two valves together. The two valves would more likely include a globe valve to 'dial in' or 'adjust' the outlet pressure in series with a ball valve to quickly start and stop the desired flow. The apparatus further features two pressure gages. The first gage **[B]** is mounted upstream of the valve assembly and will essentially read 100 psi throughout the entire test process illustrating the excess capacity of the water supply that we selected. The downstream pressure gage **[C]** will allow us to record the pressure acting on our open sprinkler orifice at varying adjustments of our valve assembly. Also featured in this test apparatus is **[E]** an open sprinkler orifice since that is the whole point of our test. And finally, our test apparatus includes a large collection**[F]** tank to allow us to measure the volume of water collected in a one minute opening of our valve assembly. If we use one minute flowing intervals then the volume collected will also be the flow rate (measured in gallons per minute) during any given test.

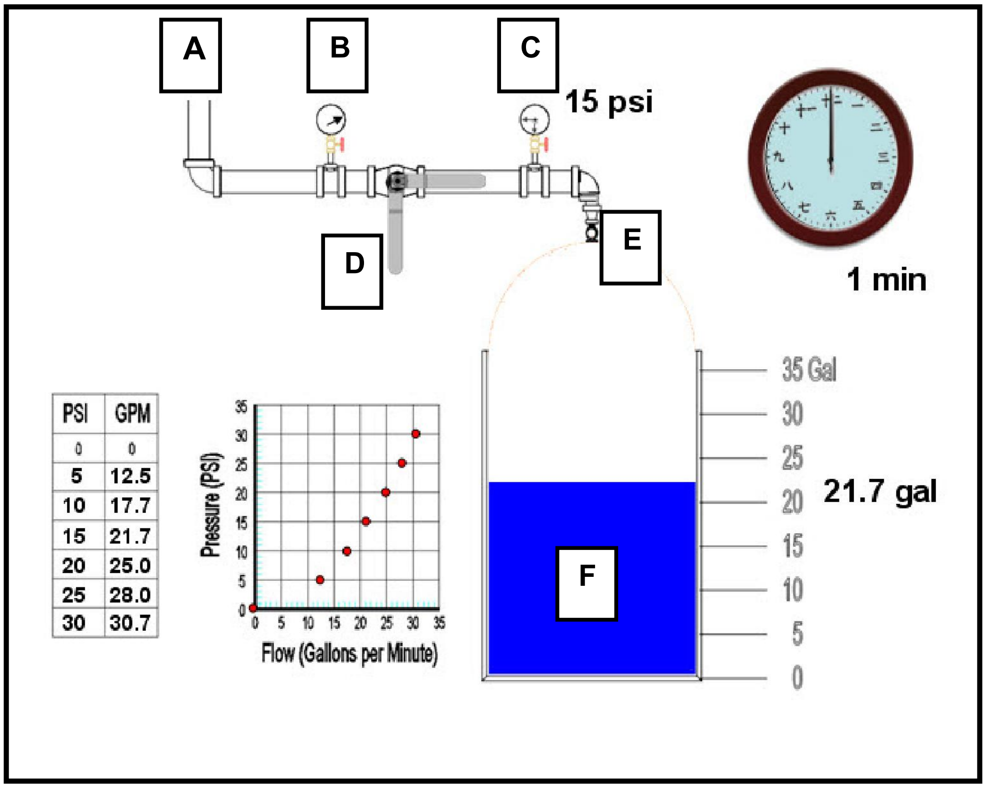


Figure 1 Sprinkler Orifice Test Apparatus

The use of this apparatus would then consist of repeated operations of the following sequence:

1. Adjust the valve assembly to an incrementally larger opening size.
2. Open the valve assembly for a one minute flowing period.
3. Record the pressure at the downstream pressure gage (the pressure acting on the operating sprinkler orifice).
4. Close the valve assembly one minute after opening it.
5. Record the volume of water in the collection vessel.

6. Empty the collection device and reset the time.
7. Repeat steps 1 to 6 until and upper limit of the expected operating pressure is reached.

The process above will result in a table of operating pressures and associated flow rates. Since the original theory predicted that there is a direct relationship between the operating pressure and the square of the flow rate or alternately stated, there is a direct relationship between the square root of the operating pressure and the flow rate, hence we can add to the table a column of values representing the square root of each of the pressures measured. If we graph those results with the flow along a vertical axis and the square root of the pressure along the horizontal axis we will find that the resulting curve is essentially a straight line passing through 0,0. This is shown in Figure 2. We will also see that the slope of that line (delta flow / delta square root of the pressure) is essentially constant (5.6 for the specific sprinkler we tested in his example). The formula for such a line would then be:

$$Q = 5.6\sqrt{P}$$

$$K = \frac{Q}{\sqrt{P}}$$

PSI	GPM	$\sqrt{P(psi)}$	
0	0	0	
5	12.5	2.2	12.5 / 2.2 = 5.6
10	17.7	3.2	17.7 / 3.2 = 5.6
15	21.7	3.9	21.7 / 3.9 = 5.6
20	25.0	4.5	25.0 / 4.5 = 5.6
25	28.0	5	28.0 / 5.0 = 5.6
30	30.7	5.5	30.7 / 5.5 = 5.6

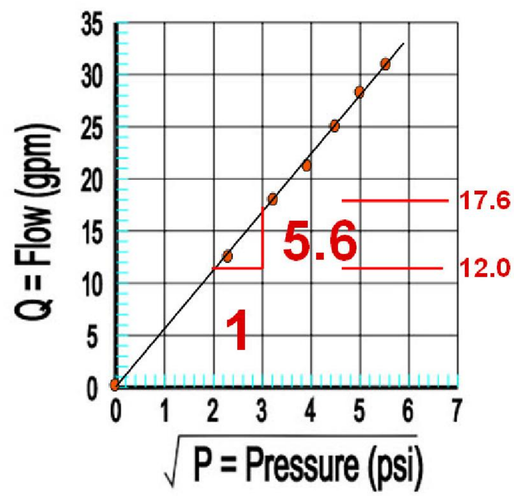


Figure 2. – Table and Graph of Q the Square Root of P

$$Q = K\sqrt{P}$$

Where: Q = flow from the operating sprinkler orifice in GPM

K = the constant sprinkler coefficient

P = Operating pressure at the sprinkler orifice in PSI

Hence we have our first calculation formula of the three used in fire protection hydraulic calculations.

Just such a test is typically conducted by the sprinkler manufacturer as part of the documentation process for any new sprinkler device and the results are verified and published by the manufacturer. This information can then be found on the manufacturers technical data sheet for any given sprinkler device. A sample data sheet is shown in figure 3 and a representative list of K factor values is shown in table 1. You will note a strong correlation between the nominal sprinkler orifice size and the published K factors. You will notice that he smaller the sprinkler orifice size, the smaller the k-factor.

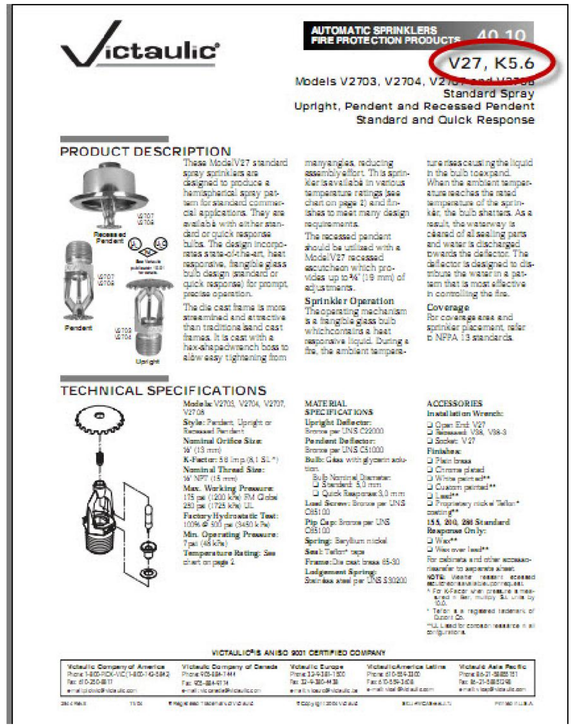


Figure 3 – Manufacturer’s Tech Data Sheet

Manu-facturer	Model	Typical Use	Orifice Size	K-Factor
Reliable	F1 Res 40	Single Family Resisence	7/16"	4
Reliable	F1	Office Space	1/2"	5.6
Reliable	F1	Light Storage	17/32"	8
Reliable	G XLO	Storage	5/8"	11.2
Reliable	K-22 Magnum	High Piled Storage	7/8"	22
Tyco	LFII	Single Family Resisence	7/16"	4.2
Tyco	TY-B	Office Space	1/2"	5.6
Tyco	TY-B	Light Storage	17/32"	8
Tyco	ELO-231	Storage	5/8"	11.2
Tyco	ESFR-1	High Piled Storage	3/4"	14
Victaulic	V27	Single Family Resisence	7/16"	4.2
Victaulic	V27	Office Space	1/2"	5.6
Victaulic	V34	Light Storage	17/32"	8
Victaulic	ECOH-ELO	Office Space	5/8"	11.2
Victaulic	ESFR	High Piled Storage	1"	25.2
Viking	Freedom	Single Family Resisence	7/16"	4.3
Viking	Microfast	Office Space	1/2"	5.6
Viking	Micromatic	Light Storage	17/32"	8
Viking	ELO	Storage	5/8"	11.2
Viking	1280	High Piled Storage	1"	25.2

Table 1 - Sample K-factors

It is also important to note that this formula ($Q=K\sqrt{P}$) only prescribes the relationship between the pressure and the flow rate at an open sprinkler orifice. The actual flow rate from that orifice is subsequently determined by the least of the following three methods:

1. Q = density x area
   where:
   Q = flow rate flow the sprinkler in gpm
   density = a prescribed flow rate per unit area in gpm per square foot derived from tests and consensus data related to the expected fire challenge presented by the building use. The NFPA standards provide one compilation of such density requirements.
   area = coverage area of the sprinkler in square feet. The NFPA standards prescribe a detailed method of calculating this coverage area but in its simplest form it is the distance between sprinklers in one direction multiplied by the distance between sprinklers in a perpendicular direction.

2. $Q = K\sqrt{P}$
   where:
   Q = flow rate flow the sprinkler in gpm
   K = sprinkler coefficient described above examples of which are shown in .table 1.
   P = Sprinkler operating pressure in psi prescribed by the manufacturer for a particular application of a specific sprinkler tested specifically for that purpose

3. $Q = K\sqrt{P}$
   where:
   Q = flow rate flow the sprinkler in gpm
   K = sprinkler coefficient described above examples of which are shown in .table 1.
   P = The actual pressure operating on the sprinkler accounting for friction loss and elevation differences between this sprinkler and all of its coincidentally operating sprinklers. The minimum sprinkler operating pressure at any sprinkler is 7.0 psi as prescribed by the NFPA standards.

This first formula is the one of the three that distinguishes the fire protection calculations from the hot and cold water supply piping calculations. The rough equivalent of an operating sprinkler in the plumbing calculation is a fixture such as a lavatory. toilet, shower, etc. These fixtures are different from sprinklers however in two respects:

1. These plumbing devices are turned on and off at will by the people in the building

2. The flow rate is often controlled by the person using the device.

In order to account for these differences, the plumbing codes generally prescribe a somewhat arbitrary flow rate and pressure requirement for these devices. The pressure required is specified as a minimum to operate the fixture. The flow rate required is specified in terms of fixture units which again are assigned by device type. An abbreviated list of some sample water supply fixture units for various fixtures is shown in Table 2. Table 2 represents an excerpt of the data found in the Uniform Plumbing Code. The codes further prescribe a correlation between fixture units and actual flow rates. The intention here is that accumulated fixture units (from multiple fixtures) can subsequently be correlated to diminishing values of flow rate. This is a logical engineering approach toward accounting for the more or less random use of all of the fixtures in a given system.

Residential Fixtures	Water Supply Fixture Units			Pressure
	Cold Water	Hot Water	Total	(PSI)
Bathrooms				
Bathtub or Tub/Shower 1/2"	1.5	1.5	2	8
Shower 1/2" Mixing Valve	1.5	1.5	2	8
Basin 1/2"	1	1	1.5	8
WC Flush Tank 1/2"	3	0	3	8
WC Flush Valve 3/4"	6	0	6	25
Kitchens				
Sink 1/2"	1.5	1.5	2	8
Dishwasher 1/2"	0	1	1	8
Laundry				
Washing Machine (8lb) 1/2"	1.5	1.5	2	8
Laundry Tray 1/2"	2.25	2.25	3	8

Table 2 – Water Supply Fixture Units for Various Fixtures

The graph shown in Figure 3 is also a partial excerpt from data found in the Uniform Plumbing Code. It relates the equivalent flow rate in gpm to various values of accumulated water supply fixture units.

In order to illustrate this, one of the items in Table 2 has been highlighted to draw your attention to the requirement for 3 water supply fixture units for a flush tank water closet with a ½" supply. Referring to Figure 4, we see that 3 fixture units equates to a flow rate of 3 gpm. If we had 10 of those same fixtures and in fact they were all operating simultaneously it would make sense that we would need a flow rate of 30 gpm to satisfy that demand. However, application of the plumbing code calculation method accounts for the unlikely event that all ten fixtures would indeed operate

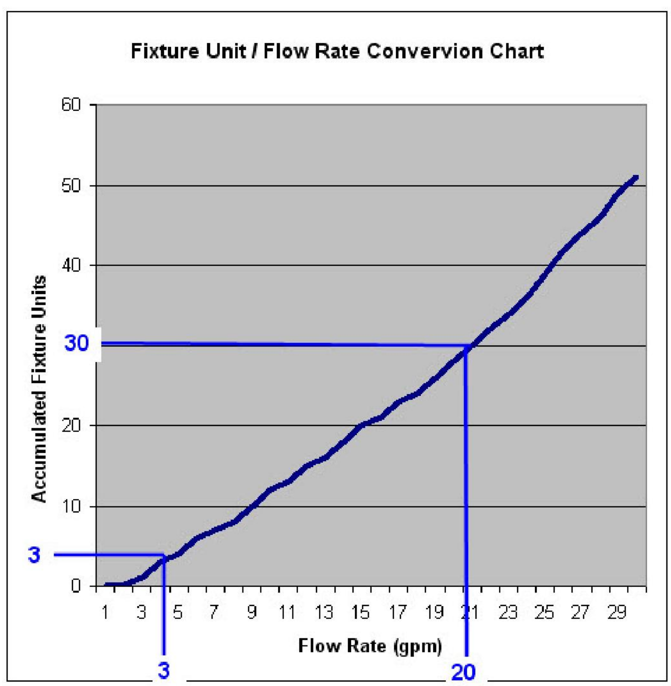


Figure 4 – Fixture Unit Flow Rate Conversion Chart

simultaneously. Hence, rather than
sum the flow rates, we would instead sum the required water supply fixture units to get a total of 30 fixture units. Subsequently, we can read the chart in Figure 3 to see that 30 fixture units equates to a flow rate of 20 gpm.

The discussion above leads to the following distinction between the two approaches:

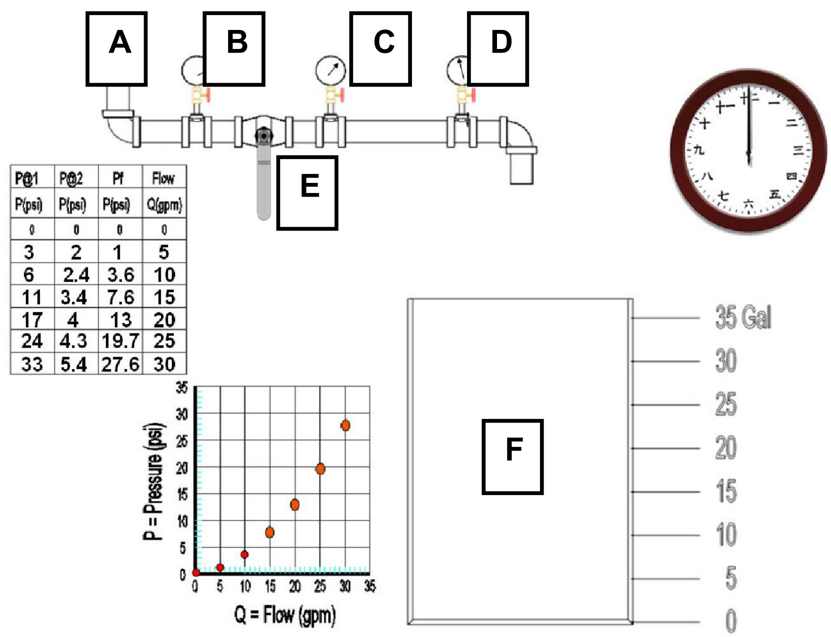
- The total flow rate required in a fire protection sprinkler system is at a minimum the sum of the minimum required flow rates of all of the operating sprinklers in the system, NEVER LESS! The flow rate from each operating sprinkler is dependent on its spacing relative to its adjacent sprinklers and the density appropriate for the expected fire challenge. The pressure acting on an operating sprinkler is dependent on the flow rate and the sprinkler coefficient (K factor) of the sprinkler. Once we've discussed friction loss and elevation pressures we will also see that the flow rate from any given operating sprinkler is also dependent on its relative position in the piping network.

- The total flow rate required of a hot and or cold water plumbing supply system make up of two or more fixtures is based on the total fixture units for that system and is ALWAYS LESS than the sum of the flow rates of the individual fixtures. The flow rate from any individual fixture in the system is dependent only on the type of fixture. The required pressure at any given fixture is likewise dependent only on the type of fixture.

Pressure Required for Friction Loss

$$P_f = 4.52 \cdot L \cdot \frac{Q^{1.85}}{C^{1.85} \cdot d^{4.87}}$$

The second equation used in fire protection hydraulic calculations is the Hazen and Williams friction loss formula. This is also an empirically derived formula, meaning that it uses experimental results to confirm the validity of the equation proposed. There are several available methods of calculating friction loss through a pipe but we will only discuss the Hazen and Williams formula as it is most widely used for fire protection and plumbing calculations and because it is the one specified by the most widely used standards and codes applied to those systems. The Hazen and Williams formula was developed specifically for water at room temperature flowing through a pipe. In the interest of time, I will describe an apparatus suitable for conducting a series of tests which could be used to develop that formula. I will not, however, subject you to the same level of detail used above to describe the outlet relationship. Figure 5 illustrates a test apparatus that can be used to develop the key relationships in the Hazen and Williams friction loss formula. That apparatus contains many of the same features of the apparatus used in Fig 1 for testing the open sprinkler outlet. As shown, this apparatus consists of **[A]** a very strong supply of pressure and flow from an external source. The next key feature of our test apparatus is **[E]** a throttling valve. This is shown in figure 5 as a single ball valve (a simple on/off device) but would be better served by two valves together. The two valves would more likely include a globe valve to 'dial in' or 'adjust' the outlet pressure in series with a ball valve to quickly start and stop the desired flow. The apparatus further features three pressure gages. The first gage **[B]** is mounted upstream of the valve assembly and will essentially read 100 psi throughout the entire test process illustrating the excess capacity of the water supply that we selected. The downstream pressure gages **[C]** & **[D]** will allow us to record the pressure difference between two points along the pipe segment of particular interest to our test at varying adjustments of our valve assembly. And finally, our test apparatus includes a large collection tank **[F]** to allow us to measure the volume of water collected in a one minute opening of our valve assembly.



P@1	P@2	Pf	Flow
P(psi)	P(psi)	P(psi)	Q(gpm)
0	0	0	0
3	2	1	5
6	2.4	3.6	10
11	3.4	7.6	15
17	4	13	20
24	4.3	19.7	25
33	5.4	27.6	30

Figure 5. – Apparatus to Record Friction Loss

The use of this apparatus would then consist of repeated operations of the following sequence:

1. Adjust the valve assembly to an incrementally larger opening size.
2. Open the valve assembly for a one minute flowing period.
3. Record the pressure at each of the two downstream pressure gages **[C]** & **[D]** (the difference: pressure at **[C]** minus the pressure at **[D]** is the friction loss acting along the segment of pipe between the gages).
4. Close the valve assembly one minute after opening it.
5. Record the volume of water in the collection vessel.
6. Empty the collection device and reset the time.
7. Repeat steps 1 to 6 until and upper limit of the expected operating pressure is reached.

The process above will result in a table of operating pressures and associated flow rates. Since the original theory predicted that there is a direct relationship between the pressure difference due to friction loss and the 1.85 power of the flow we can add to the table a column of values representing the 1.85 power of each of the flow rates measured. If we graph those results with the flow rate raised to the 1.85 power along a horizontal axis and the pressure along the vertical axis we find that the resulting curve is essentially a straight line passing through 0,0. This would verify that the formula relating friction loss to flow rate would be of the form

$$P_f = c_1 \times Q^{1.85}$$

Where:

P_f = Pressure due to friction loss (psi)

c_1 = constant for the diameter, length and roughness of the pipe used in the test

Q = the flow rate (gpm)

Since the proposed equation has multiple parameters, several additional sets of test need to be conducted. In a subsequent set of tests, all of the steps 1 to 7 above would be repeated. In this next series of tests however step 1 would involve adjusting the length of pipe between the two down stream gages. Recording the subsequent results of multiple cycles of this test would be recorded in a table relating Friction loss to length and graphing those two values would result in a straight line. This would verify that the formula relating friction loss to the length of the pipe would be of the form

$$P_f = c_2 \times L$$

Where:

P_f = Pressure due to friction loss (psi)

c_2 = constant for the diameter, flow and roughness of the pipe used in the test
L = the Length of the pipe (ft)

In yet another set of tests, all of the steps 1 to 7 above would be repeated. In this next series of tests however step 1 would involve replacing the length of pipe between the two down stream gages, each time with an increasing diameter of pipe Recording the subsequent results of multiple cycles of this test would be recorded in a table relating Friction loss to pipe diameter and graphing those two values. Since that graph is in the shape of a hyperbola it can be derived that the relationship represents an equation involving 1 / the pipe diameter to some power. Since the proposed formula included $1/d^{4.87}$, a new graph of Pressure vs. $1/d^{4.87}$ reveals a straight line and verifies that the formula relating friction loss to the internal diameter of the pipe would be of the form

$$P_f = c_3 / d^{4.87}$$

Where:

P_f = Pressure due to friction loss (psi)
c_3 = constant for the length, flow and roughness of the pipe used in the test
d = the Internal Diameter of the pipe (in)

In a final set of tests, all of the steps 1 to 7 above would be repeated. In this next series of tests however step 1 would involve replacing the length of pipe between the two down stream gages, each time with a pipe of increasing internal roughness The roughness is a measure of the size of the internal wall imperfections where a corroded steel pipe would represent a rougher surface and a glass pipe would represent a much smoother surface. The values for this characteristic seem to have been assigned somewhat arbitrarily starting with a value of around 100. Some sample values for C (the roughness factor) are shown in table 3 below. Recording the subsequent results of multiple cycles of this test would be recorded in a table relating Friction loss to pipe roughness factor and graphing those two values. Since that graph is in the shape of a hyperbola it can be derived that the relationship represents an equation involving 1 / the pipe roughness to some power. Since the proposed formula included $1/C^{1.85}$, a new graph of Pressure vs. $1/C^{1.85}$ reveals a straight line and verifies that the formula relating friction loss to the pipe roughness factor would be of the form

$$P_f = c_4 / C^{1.85}$$

Where:

P_f = Pressure due to friction loss (psi)

c_4 = constant for the length, flow and pipe diameter used in the test
C = the Pipe Roughness Factor (see table 3 below)

Combining all of the results of the sets of tests above allows a solution for the common constant in the single formula which relates all of the parameters affecting friction loss and resulting in a confirmation of the Hazen and Williams formula which can be stated as:

$$P_f = 4.52 \cdot L \cdot \frac{Q^{1.85}}{C^{1.85} \cdot d^{4.87}}$$

Where:

P_f = Pressure due to friction loss (psi)
L = the Internal Diameter of the pipe (in)
Q = the flow rate (gpm)
C = the Pipe Roughness Factor (see table 3 below)
d = the Internal Diameter of the pipe (in)

Pipe Description	C – Factor
Unlined cast iron pipe	100
Black steel pipe (dry system)	100
Black steel pipe (wet system)	120
Cement lined cast iron pipe	140
CPVC pipe	150

Table 3 – Pipe Roughness Factors (C – Factor)

This formula is used as stated above in both fire protection and plumbing supply pipe hydraulic calculations.

Pressure Required for Water Elevation $P_e = 0.4331 \times h$

The third formula used in fire protection hydraulic calculations is the water elevation pressure equation. This is also represented as one of the terms in the Bernouili Equation. However, in keeping with the presentation of the other two formulas and to use the more down to earth empirical approach, I would like to illustrate the derivation of this equation from that approach. Figure 6 shows a cube whose dimensions are 1 ft in height, length and width. If that cube were filled with water and weighed it would be found that 1 cubic foot of water weighs 64.3 lbs. Also shown in Figure 6 is the fact that the base of that cube contains 12 x 12 = 144 square inches. Therefore the highlighted column of water that is 1 sq in at its base and 1 ft high would weigh 63.3/144 lbs or .4331 lbs. From this we can see that the pressure acting on the bottom of the one square foot column of water would be 62.3 lbs / 144 square inches or .4331 psi. Similarly the pressure acting on the 1 sq in column of water would be .4331 lbs / 1 sq in or .4331 psi. We might also consider two adjacent 1 sq in columns of water. They would weigh 2 x .4331 lbs and would be supported by 2 square inches. So the pressure would still be .4331 psi. Now if we were to consider two 1 sq in columns of water stacked vertically one on top of the other they would still weigh .8662 lbs and would be supported by only 1 sqare inch at the base so the pressure to support the 2 ft high column of water would be 2 x .4331 or .8662 psi. Similarly 3 ft high would be 3 x .4331 or 1.2993 psi and therefore an arbitrary height of ‘h’ feet would be h x .4331 psi. Hence the equation for raising water to a give elevation cal be stated as:

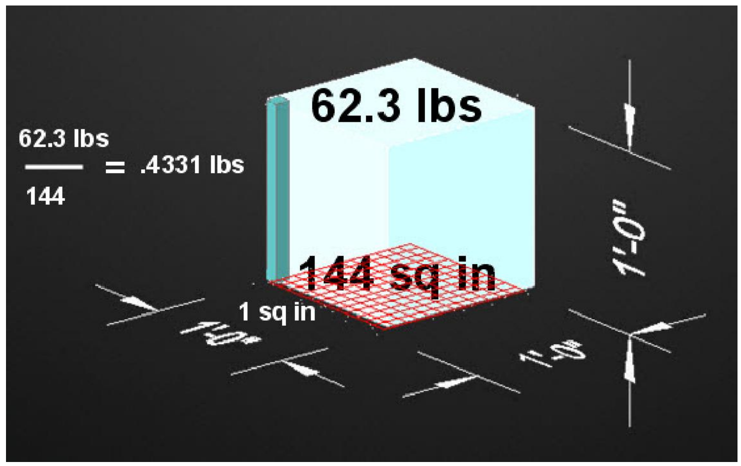


Figure 6. – One Cubic Foot of Water

$$P_e = 0.4331 \times h$$

Where:

P_e = Pressure due to elevation (psi)
h = Height of the column of water (ft)

This formula is used as stated above in both fire protection and plumbing supply pipe hydraulic calculations.

Summary of the physics of each formula used

To summarize, there are three formulas used in fire protection hydraulic calculations. They are:

The flow **O**ut of an open sprinkler $$Q = K\sqrt{P}$$

The pressure to raise the water **U**p $$P_e = .4331\ h$$

The friction loss **T**hrough a pipe $$P_f = 4.52 \bullet L \bullet \frac{Q^{1.85}}{C^{1.85} \bullet d^{4.87}}$$

And it is easier to remember what they are if you think of them as the equations necessary to determine the pressure needed to get the flow **OUT** of the sprinkler system. As one last thought it is valuable to keep in mind that two of these three formulas are applied to both fire protection and plumbing supply calculations. The flow and pressure at an outlet (open sprinkler for fire protection or plumbing fixture for plumbing calculation) are calculated very differently between the two disciplines An example of the effect of this difference will be shown as part of our discussion of the Engineering assumptions in applying each formula.

Standards and Codes applied to design

	Fire Protection	Plumbing
National	NFPA Standards	UPC, IPC Codes
Insurance	FM Global	
Local	Local Authorities	Local Plumbing Codes

Table 4 – Codes applies at various levels

Shown in table 4 above is an abbreviated list of standards and codes used in the US for both fire protection and plumbing designs. The National Fire Protection Association (NFPA) standards are not codes but are in fact the most widely referenced standards in most all of the building codes that reference fire protection sprinkler systems. And of the most widely referenced NFPA standards is NFPA 13 - Standard for the Installation of Sprinkler Systems. Below is a list of some of the sections of that standard that are of particular interest in the hydraulic analysis of those systems.

- Sprinkler Spacing Rules – Chapter 8 – section 8.5.2
- Density and Area Requirements – Chapter 11 – Section 11.2.3.2
- Special requirements for various forms of storage – Chapters 12-21
- Hydraulic Calculation Forms (printouts) – Chapter 22 – section 22.3
- Hydraulic Calculation Procedures – Chapter 22 – section 22.4

It is also worth noting that there are additional NFPA standards that relate to other common fire protection requirements. Below is a partial list of some of those standards.

- NFPA 13 – STANDARD FOR THE INSTALLATION OF SPRINKLER SYSTEMS
- NFPA 13D - … SINGLE FAMILY DWELLINGS
- NFPA 13R - … RESIDENTIAL UP TO 4 STORIES
- NFPA 14 - … STANDPIPES
- NFPA 15 - … FIXED WATER SPRAY (DELUGE)
- NFPA 20 - … STATIONARY (FIRE) PUMPS

In order to promote the widest possible use of these standards, the NFPA has provided free access to the information in all of those its standards through a free viewing utility which can be found at the following url:

http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp

… or just Google nfpa 13 online

In addition to the national codes the design of fire protection systems is often affected by insurance company requirements. FM Global is one such organization that provides improved rates as a preferred risk insurer. The improved rates reflect the value provided by designing to a higher standard. Those higher standards are prescribed through a combination of risk experience and additional testing and subsequent specification. In the case of FM Global, those additional specifications are published as data sheets and are also available for free though the following url:

http://www.fmglobaldatasheets.com

Two examples of national codes used in the design of hot and cold water plumbing supply piping are the Uniform Building Code and the International Plumbing Code. I was unable to identify a source of free access to these documents but they are both readily available through online stores such as Amazon.com or just Google… uniform building code or international building code. Both of these codes include tables of fixture units by fixture type and conversion charts to convert accumulated fixture units to flow rates. The specific values in those tables and conversion charts vary between codes but the process for performing the calculations is the same in both. Each code also suggests a format for reports for the analysis results in an appendix.

Engineering assumptions in applying each formula

Now that we have discussed the three formulas used in the hydraulic analysis and the standards and codes which prescribe the use of those formulas, it is time to further discuss some of the engineering assumptions employed in those designs. Because we will spend more time on the details of the fire protection analysis, let us start with a brief discussion of the plumbing analysis assumptions and analysis procedures first. The plumbing assumptions include the following:

Plumbing Supply Pipe Analysis Basic Assumptions

- Not all fixtures will operate simultaneously
- Fixtures in simultaneous use will be evenly distributed around the entire system
- The more fixtures there are in the system, the less likely they will all operate simultaneously
- Arbitrary flow rates are assigned to fixtures
- The predicted flow and pressure at the supply must be continuously available
- It is only useful to exactly predict the approximate flow and pressure required at the supply
- Limiting fluid velocities improves quiet operation of system

Those assumptions are not specifically stated in those terms in the codes but can be inferred by an application of the analysis procedure indicated by those codes. That analysis procedure could be summarized as follows:

Plumbing Supply Pipe Analysis Procedure

- Record the fixture units for each fixture in the system
- Accumulate the fixture units along each branch of the system
- Convert accumulated fixture units to flow rates
- Apply velocity limits to pipe sizing
- Sum the outlet pressure, friction losses and elevation pressures along a critical path.

By comparison the fire protection analysis is based on the following assumptions.

Fire Protection Analysis Basic Assumptions

- A single fire event will begin at a specific location
- The fire will grow from the point of origin until the sprinkler system controls it
- The fire is controlled by the application of the required density of flow by each sprinkler within the area of operation
- The sprinkler system must control the fire until the fire service can finish the job.
- The sprinkler system must be designed to control that single fire event regardless of its point of origin
- For any given event we can accurately predict the exact flow and pressure required of the system to control that fire
- There is NO requirement for quiet operation

And again, these assumptions are not specifically stated in the standards by are implied by the various methods and procedures that are prescribed by the standards. The following is a summary of a procedure that can be followed to apply the necessary requirements of the standards in an order that is relatively easy to follow performing the analysis of a dead ended sprinkler system. The same procedure would apply to the review of virtually any configuration of a sprinkler system. The difference between performing the analysis and performing the review of looped or gridded system configurations is that considerable trial and error assumptions for the division of flow through those systems makes it impractical to perform those iterations without the use of a computer. Once the proper flow splits have been discovered, the procedure described below will easily allow verification of the results without the same requirement for the power of a computer.

Fire Protection Analysis Procedure

1. Determine Density / Area requirements
2. Evaluate Possible Hydraulically Remote Areas
3. Measure out the area of operation
4. Measure out each sprinkler area
5. Calculate flow at remote sprinkler Q = density x area
   then use Outlet formula to determine Pressure at that point
6. Follow a path from the remote head to the supply point
   for each pipe along that path:

   a) Use pressure at pipe start point to calculate flow from any sprinkler

   b) Add sprinkler flow to previous pipe flow

   c) Use dia, length, accumulated flow and roughness to calculate friction loss

   d) Use elevation differences between pipe ends to calculate elevation pressure

   e) Calculate pressure at other end of pipe: $P_2 = P_1 + P_e + P_f$

Additional considerations for use during that procedure

- For each point along the calculated path verify:
  - Flow from any sprinkler at that point meets minimums
    and if not… raise the pressure at this point to meet the minimum and adjust the flow required to this point
  - Flow from any branch of piping can be added at the same pressure and if not . . . Recalculate the flow required from that branch of piping until the pressure balances within .5 psi
  - Flow from any alternate route of piping (looped or gridded systems) can be added at the same pressure and if not . . . Recalculate the flow required from that route of piping until the pressure balances within .5 psi

In order to illustrate this procedure we will refer to the sample sprinkler system design represented in Figure 7. That system is for the third floor of a three story classroom building. The system is fed by a city water supply in the upper right of the building and supplies the sprinkler system through a standpipe in the stairwell in that area of the building. The system also features a proposed 3" diameter feed main run in a 'C' shape through the hallway feeding cross mains at various locations into the class rooms. Those cross mains in turn feed the branch lines which connect the sprinklers in the classrooms.

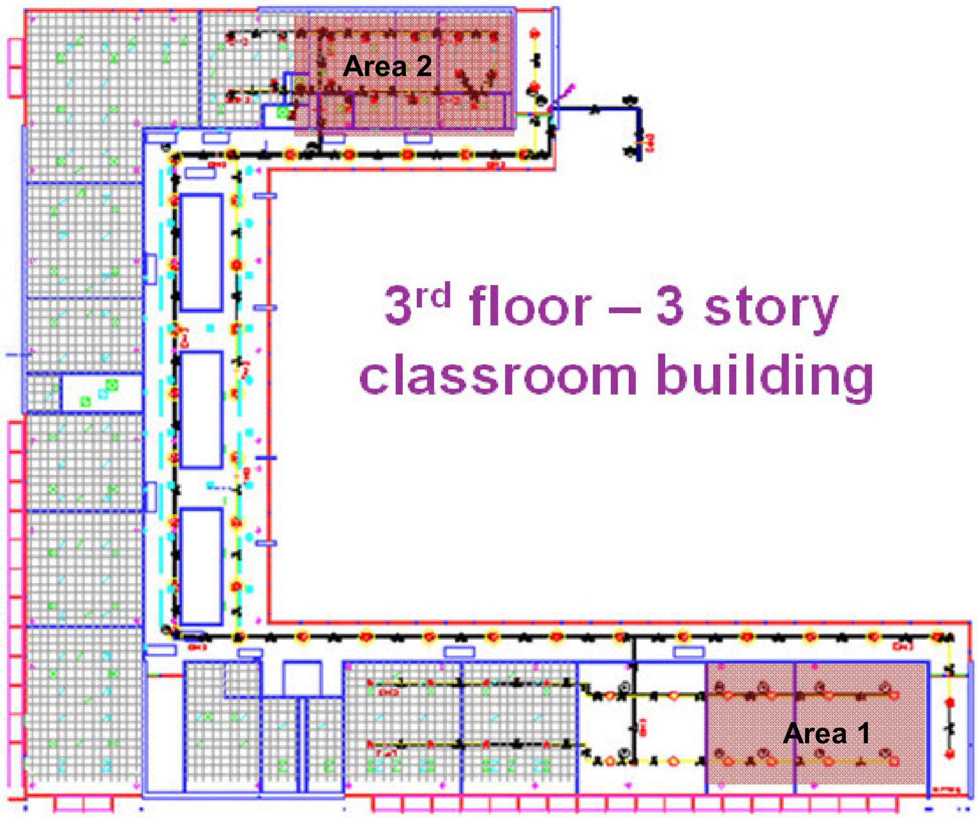


Figure 7 – Sample sprinkler system

Following the form of the procedure above starts with:

Step 1 - Determine Density / Area requirements

From NFPA 13 Chapter 11 – Section 11.2.3.2

Density = 0.10 gpm / sq ft (the density will be used later to determine outlet flow)
Area = 1500 sq ft (area of operation necessary to control the fire)

Length of area parallel to branch lines >= $1.2 \times \sqrt{Area} = 1.2 \times \sqrt{1500} =$ **46.5 ft**

Step 2 - Evaluate Possible Hydraulically Remote Areas

In this example in the application of the procedure we want to consider two potentially hydraulically remote areas of operation. In Figure 1 above you will note two shaded areas identified as Area 1 and Area 2. In considering these two candidates it would appear obvious, purely by their relative positions to the supply at the standpipe, that

Area 1 is the hydraulically most remote area. However, it is necessary that we account for all possible considerations in evaluating the 'remoteness' of any potential area. Below is a comparison of each of the factors (based on our three formulas) affecting the total pressure and flow requirements of the two areas:

	Area 1	**Area 2**
Outlet Pressure	**++** based on 225 sq ft spacing	**--** based on min 7 psi
Up to head elevation	_ to 3rd floor	_ to 3rd floor
Thru friction loss	**+** through longest path **--** for 8 head flow	**-** through shortest path **++** for 16 head flow

From the accounting above you will notice that I have included factors relating to all three formulas used to calculate the total flow and pressure needed to get the required water **OUT** of the system. You will also notice that I used a **+** sign to indicate which area exhibits the higher requirement and a **–** sign to indicate the lower requirement. Since the outlet pressure is related to the square of the flow, I used double plus and double minus signs in that comparison. I also used double plus and minus signs for the effect of head flow Thru fiction loss because the friction loss is related to the 1.85 power of the flow. Because the friction loss is directly related to the length, I only used single plus and minus signs for that effect. The same would be true for the Up pressure but in this example those factors were the same for both areas.. The net result is that Area 1 had 3 plusses and 2 minuses while Area 2 had 2 plusses and 3 minuses. Since the plusses and minuses are only qualitative and not quantitative our evaluation would indicate the need to fully analyze both areas to determine the most remote. If one had all plusses and the other all minuses then it would be possible to eliminate the area with all minuses. It is also worth noting that the most basic logic would lead the casual observer to assume area 1 was more remote than area 2. That pretty much obligates us to always fully analyze area 1 to satisfy that natural expectation. The detail below will concentrate on that area 1 analysis

Step 3 - Measure out area of operation

The density area method of calculation prescribed by NFPA Chapter 11 – Section 11.2.3.2 provides the specification of the size of the area in which the sprinklers will operate in order to control the fire. That section of the standard also prescribes the basic shape of that area as a rectangle whose length is longer than its width. Figure 8 shows an enlarged view of our sample building in the vicinity of Area 1. In this view the size and shape of the area of operation has been chosen to reflect exactly the values prescribed by NFPA 13. It can be seen that the arbitrary size and shape of that area do not conform to the actual layout of the sprinklers, ie some sprinklers are not entirely inside the bounds of that theoretical area boundary. It is typically necessary to adjust the shape of the area of operation such that it is still at least 1500 sq ft in size and still at least 46.5 ft (1.2 x sq rt of the area) long in the direction of the branch lines while truly depicting the operation of an integer number of actual sprinklers flowing. Figure 9 illustrates this redefined area of operation. You will note that it is still at least 46.5 ft long and that it is still in excess of 1500 sq ft (= 1515 sq ft). But now the area to be calculated completely encloses an exact whole number of sprinklers. In our example this is 8 sprinklers which happen to reside entirely within two adjacent rooms.

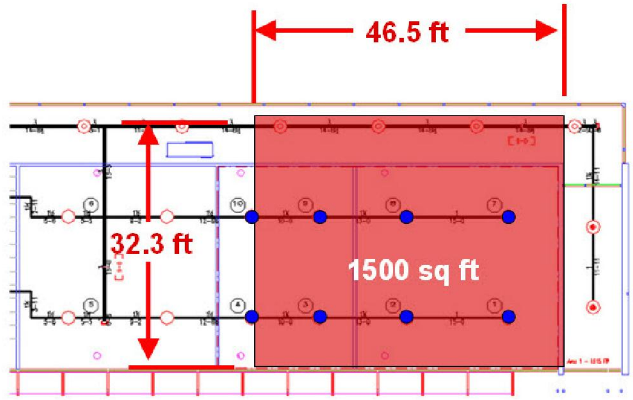


Figure 8 – Theoretical 1500 Sq Ft

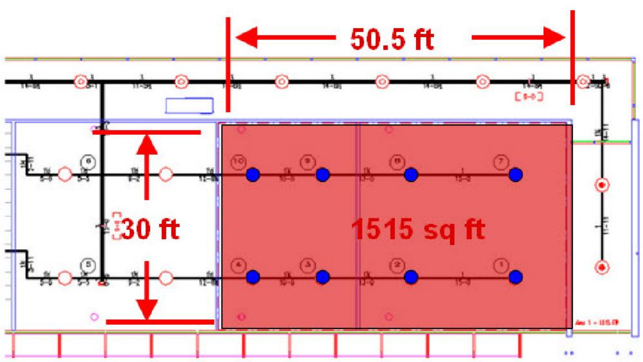


Figure 9 – Calculated Area of Operation

Step 4 - Measure out each sprinkler area

Chapter 8 – section 8.5.2 of NFPA 13 details the spacing rules for sprinklers. The most basic application of those rules indicates that the coverage area of a sprinkler is the distance between branch lines multiplied by the distance between sprinklers along the branch lines. There are additional requirements in that section of the standard that must be considered in the general case but for our example the basic calculation will suffice. Figure 10 illustrates the distance between lines (15 ft) and the distance between sprinklers along the branch lines (also 15 ft) used in calculating the sprinkler coverage of 225 sq ft for the sprinkler in the lower right corner of the remote area In a similar fashion all other sprinklers in the remote area were measured and Figure 11 shows the results of those measurements and calculations. You can see that the 4 heads in the larger room measured out to a coverage area of 225 sq ft each. And each of the 4 heads in the smaller room to the left measured out to be 15 ft between lines times 10 ft between heads on the lines for a total of 150 sq ft. each.

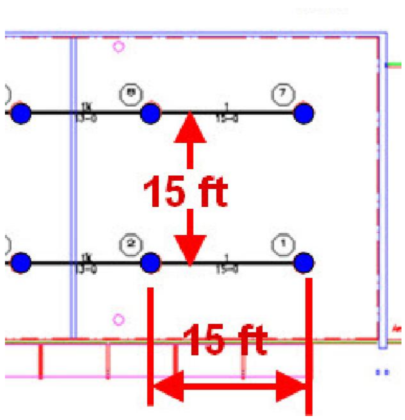


Figure 10 - Sprinkler Spacing

Figure 11 – Remote Area

Step 5 - Calculate flow at remote sprinkler Q = density x area then use Outlet formula to determine Pressure at that point

So now we finally get to start using our 3 formulas. And we will start to commit the results to the prescribed printout format specified by NFPA 13. Although NFPA 13 specifically states that the hydraulic calculations shall start at the hydraulically most remote head, this is usually interpreted as that farthest sprinkler on the farthest branch line in the remote area. Therefore, by using the required density of 0.1 gpm per sq ft determined in step 1 above and the sprinkler area of 225 sq ft determined in step 5 above we calculate the flow required from that sprinkler as 22.5 gpm. Then using our first equation ($Q = K\sqrt{P}$ rearranged to solve for P) for the Outlet pressure we calculate the pressure to be 16.14 psi.

$$Q = \text{density} \times \text{area} = 0.1 \times 225 = 22.5 \text{ gpm}$$

$$P = \left(\frac{Q}{K}\right)^2 = \left(\frac{22.5}{5.6}\right)^2 = 16.14 \text{ psi}$$

Figure 12 below shows the beginning of the NFPA printout form for this calculation with the values determined so far filled in. Also shown in Figure 12 is a small section of the sample layout with a Reference of **1** next to the most remote head. This is included in the printout under Node 1 to help identify the intended source of the rest of the information on the printout.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1		5.60	22.50						16.143
			22.5						

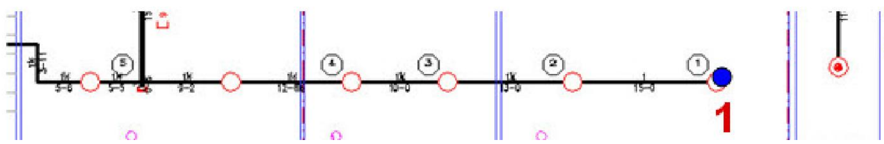


Figure 12 – NFPA printout form and related segment of the design

Since this is the beginning point of our calculation it should make sense that **Qt** (the **t**otal flow in this pipe segment) is the same as **Qa** (the flow **a**dded at this point).

Step 6c - Use diameter, length, accumulated flow and roughness to calculate friction loss

Since step 5 essentially completed parts a.) and b.) of step 6 for the very 1st point in this path of the calculation, the procedure continues with step 6c. In Figure 13 we have added highlights to the design portion to draw your attention to the reference at the other end of the 1st pipe (**2**) . We have also enlarged the notation of the nominal diameter (**1"**) and the pipe length (**15'**). From step 5 we knew that the accumulated flow (Qt) was 22.5 gpm and for black steel pipe the roughness coefficient is 120 (see table 3). Therefore we are prepared to use our 2nd formula, the Hazen & Williams friction loss formula, to calculate the pressure required to push the water Through this segment of pipe.

$$P_f = 4.52 \cdot L \cdot \frac{Q^{1.85}}{C^{1.85} \cdot d^{4.87}}$$

$$= 4.52 \bullet 15 \bullet \frac{22.5^{1.85}}{120^{1.85} \bullet 1.049^{4.87}} = 15 \bullet 0.1618 = 2.427$$

Figure 13 also highlights those newly added values in the NFPA printout form. You will note that the form includes friction loss per ft (0.1618) as well as the total friction loss (2.427).

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1		5.60	22.50	1			15.000	120	16.143
to							0.0		
2			22.5	1.049			15.000	0.1618	2.427

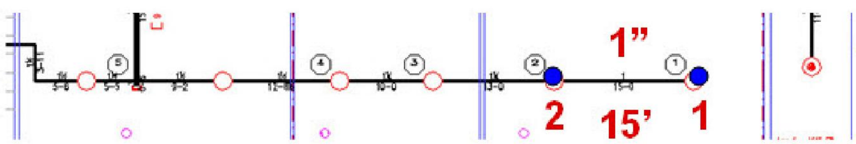


Figure 13 – NFPA printout form with friction loss

You will also notice that the diameter is recorded as both nominal size (1”) and actual internal diameter (1.049).

Step 6d - Use elevation differences between pipe ends to calculate elevation pressure

The next step in the process of completing the NFPA printout form is to use our 3rd formula to calculate the pressure due to elevation change between the two ends of the current pipe segment. Since the pipe in question is 9 ft above the 3rd floor of the building and since the 3rd floor of the building is 24 ft above our reference plane (the ground), the elevation at reference point 1 (the beginning of our pipe segment) is 33 ft. For all of the same reasons, the elevation at reference point 2 (the end of our pipe) is also 33 ft. Therefore the elevation formula can be written as:

$$P_e = 0.4331 \bullet h = 0.4331 \bullet (33 - 33) = 0$$

Figure 14 has those values filled in and highlighted.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1	33	5.60	22.50	1			15.000	120	16.143
to							0.0		0.0
2	33		22.5	1.049			15.000	0.1618	2.427

Figure 14 – NFPA printout with elevation loss

Step 6e - Calculate pressure at other end of pipe: $P_2 = P_1 + P_e + P_f$

At this point, all of the information for the first pipe has been transferred to the NFPA printout form. The last step dealing with this pipe is to transfer the resulting starting pressure to the next pipe. Using the formula prescribed by this step yields the following:

$$P_2 = P_1 + P_e + P_f = 16.143 + 0.0 + 2.427 = 18.570$$

This is illustrated in figure 15 showing all the information completed for the 1st pipe from 1 to 2 and the beginning of the information needed for the 2nd pipe starting at point 2.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1	33	5.60	22.50	1			15.000	120	16.143
to							0.0		0.0
2	33		22.5	1.049			15.000	0.1618	2.427
2									**18.570**

Figure 15 – NFPA printout at start of second pipe

Step 6a - Use pressure at pipe start point to calculate flow from any sprinkler

We will carry this example just a little further to illustrate the full cycle in this procedure. Once the first pipe information is complete the second pipe begins with the calculation of the flow Out of the sprinkler outlet at the beginning of the second pipe. To calculate this we use our 1st formula, $Q = K\sqrt{P}$. This yields the flow out of that sprinkler as:

$$Q = K\sqrt{P} = 5.6\sqrt{18.57} = 24.13 \text{ gpm}$$

This is shown in Figure 16 below where the 5.6 has been placed in the appropriate position in the printout form for the K Factor and the 24.13 gpm has been placed in the appropriate position for the flow
added.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1 to 2	33 33	5.60	22.50 22.5	1 1.049			15.000 0.0 15.000	120 0.1618	16.143 0.0 2.427
2		**5.60**	**24.13**						**18.570**

Figure 16 – Calculated flow added at beginning of second pipe

Step 6b - Add sprinkler flow to previous pipe flow

The next step is to determine the total flow in the second pipe. This is simply the total flow in the 1st pipe plus the flow added at the beginning of this pipe. This can be represented as the simple addition shown here:

$$Q_{t2} = Q_{t1} + Q_{a2} = 22.5 + 24.13 = 46.63 \text{ gpm}$$

This result is illustrated in figure 17 below.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	 Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1	33	5.60	22.50	1			15.000	120	16.143
to							0.0		0.0
2	33		22.5	1.049			15.000	0.1618	2.427
2			24.13						18.570
			46.63						

Figure 17 – Total flow through second pipe

Repeat Steps 6c, d & e – Complete calculations for 2nd pipe

The procedure would then cycle through the remaining segments of step 6 to complete the calculation of pipe 2 (pipe from reference point 2 to 3). This includes calculation of the friction loss (step 6c) the elevation pressure (step 6d) and the calculation of the starting pressure for the next pipe (step 6e). This is show in figure 18 below.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	 Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
1	33	5.60	22.50	1			15.000	120	16.143
to							0.0		0.0
2	33		22.5	1.049			15.000	0.1618	2.427
2	33	5.60	24.13	1.25			13.000	120	18.570
to							0.0		0.0
3	33		46.63	1.38			13.000	0.1639	2.131
3									20.701

Figure 18 – Calculation of the rest of 2nd pipe

Repeat Step 6 along the remainder of the critical path until the supply is reached

This procedure is simply repeated over and over until the supply point is reached. The entire printout for this sample calculation is included in appendix B. Appendix A is the

drawing showing pipe diameters and lengths as well as hydraulic reference points corresponding to the calculation printout shown in Appendix B. Figure 19 highlights a significant segment of that complete calculation. It shows the detailed information for the last pipe (HOSE to TEST) along that critical path and the total pressure and flow at reference point TEST.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
BOR	-3		0.0	8		0.0	20.420	150	64.078
to						0.0	0.0		0.0
HOSE	-3		199.75	7.98		0.0	20.420	0.0003	0.006
HOSE	-3	H100	100.00	8	1E	27.183	11.710	150	64.084
to						0.0	27.182		-1.299
TEST	0		299.75	7.98		0.0	38.892	0.0006	0.025
			0.0						
TEST			299.75						62.810

Figure 19 – Calculation at the End of the Critical Path

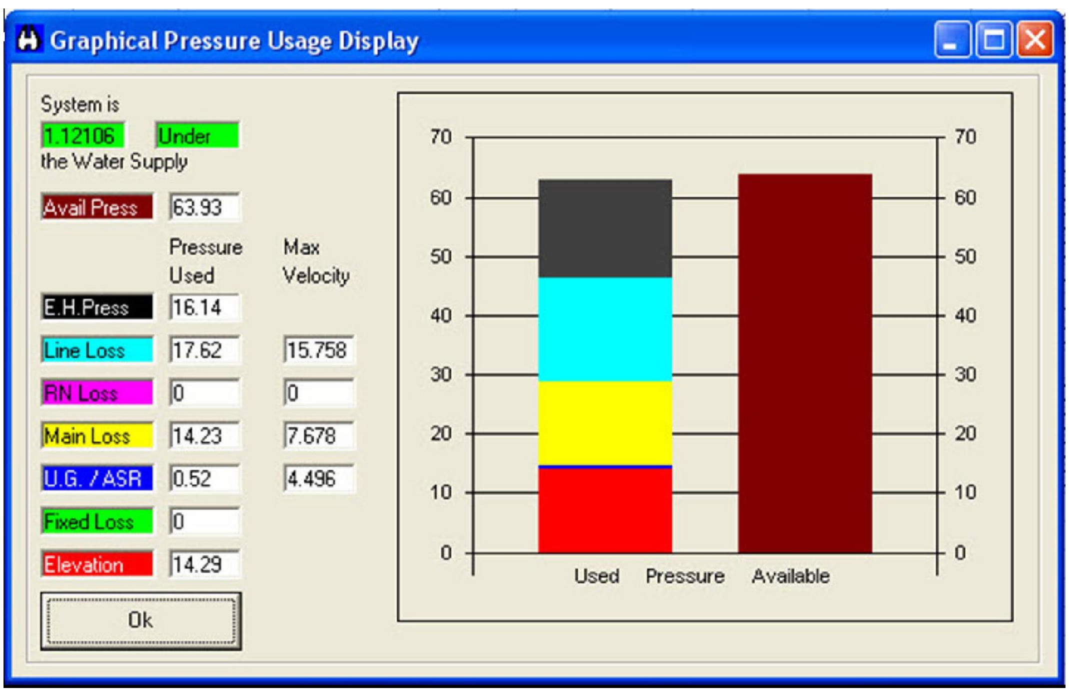


Figure 20 – Graphical Summary of Hydraulic Calculation

The Graphical summary displayed in Figure 20 is not prescribed by any standard but serves as a good method of viewing the overall results of a hydraulic calculation. The brown bar on the right represents the total available pressure at the required system flow. It is beyond the scope of the present discussion to explain the details of how that value is determined but suffice it to say that the purpose of the hydraulic analysis is to demonstrate that the available pressure is in excess of the total required pressure. Hence the brown bar on the right ought to be taller than the multicolored bar on the left. Each of the colors is in bar on the left represents the pressure required for the various parts of the system. The black section at the top corresponds to our first formula for the pressure to push water **O**ut of the outlet at the start of the calculation. The next five segments (cyan, magenta, yellow, blue and green) are all various parts of the friction loss pressure (our second formula, the Hazen and Williams friction loss formula) necessary to push the water **T**hrough the pipes in the system. And finally the bottom red segment of the bar represents the pressure required to raise the water **U**p to the necessary elevation as stated in our third formula.

Redesign and Analyze 10 heads in remote area

As a method of illustrating the strong interaction and interdependence of these three formulas and as a way to better reinforce a very strong difference between plumbing and fire protection hydraulic analysis we will examine the effects of a small change in the layout of the sprinkler system. Figure 21 shows the addition of two additional sprinklers within the hydraulically most remote area previously analyzed as area 1. In the revised layout all ten sprinklers in the remote area now have sprinkler coverage areas of 150 square feet.

Figure 21 – Remote Area with 10 Sprinklers instead of 8

Appendix C and Appendix D detail the revised layout and the complete NFPA detail printout for the revised, 10 head layout. It should be obvious even from our brief discussion of the analysis procedure for a hot or cold water plumbing supply pipe system that if we were to add two additional fixtures to any given system that the total number of fixture units would increase by an amount related to those fixtures. Consequently the total flow demand and pressure demand for that system would increase accordingly. The exact amount of that increase would be dependent on where we added the fixtures but there is no doubt that both the flow and pressure would increase.

By contrast, the addition of the two extra sprinklers would have a less predictable effect on the analysis of the revised sprinkler system. If we think back to step 2 of our analysis procedure, we need to evaluate potential remote areas in view of all three of our formulas. Below is a comparison of each of the factors (based on our three formulas) affecting the total pressure and flow requirements of the two areas:

	Area 1 (8 heads)	**Area 1 (10 heads)**
Outlet Pressure	**++** based on 225 sq ft spacing	**--** based on 150 sq ft spacing
Up to head elevation	_ to 3rd floor	_ to 3rd floor
Thru friction loss	**_** through longest path **--** for 8 head flow	**_** through longest path **++???** for 10 head flow

From the accounting above you will notice that I have included factors relating to all three formulas used to calculate the total flow and pressure needed to get the required water **OUT** of the system. You will also notice that I used a **+** sign to indicate which area exhibits the higher requirement and a **–** sign to indicate the lower requirement. Since the outlet pressure is related to the square of the flow, I used double plus and double minus signs in that comparison. I also used double plus and minus signs for the effect of head flow Thru fiction loss because the friction loss is related to the 1.85 power of the flow. Because the friction loss is directly related to the length, I only used single plus and minus signs for that effect. The same would be true for the Up pressure but in this example those factors were the same for both areas.. The net result is that Area 1(8 heads) had 2 plusses and 2 minuses while Area 1 (10 heads) had 2 plusses and 2 minuses. The two plusses for the flow for ten heads has three ?'s behind it because it is actually unclear whether 10 heads all at 150 square feet would require more or less flow than 8 heads flowing where 4 are spaced at 225 sq ft and 4 are at 150 sq ft. If we actually think about this in light of our brief experience with the behavior of the system as originally designed we will notice that each sprinkler along the branch line as we work our way up stream in the calculation requires more pressure (due to friction loss) and subsequently more flow than its downstream neighbor. Therefore since our calculation started at a sprinkler spaced at 225 sq ft every other sprinkler will discharge at a rate corresponding to at least 225 sq ft. Therefore the total flow will have to be in excess of 8 x 225 sq ft multiplied by the required density (8 x 225 x 0.1 = 180 gpm) By the same logic the 10 headed area will require a minimum of 10 x 150 x 0.1 = 150

gpm. So actually we can see ahead of time that the 10 head calculation will have less pressure for the **O**ut formula, the same pressure as the **U**p formula and less pressure for the **T**hrough formula as compared to the 8 head calculation. Again this is qualitative and we will need to do the complete analysis to determine the quantitative difference. This is shown in figures 22 and 23 below.

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf
BOR	-3		0.0	8		0.0	20.420	150	45.342
to						0.0	0.0		0.0
HOSE	-3		169.74	7.98		0.0	20.420	0.0002	0.005
HOSE	-3	H100	100.00	8	1E	27.183	11.710	150	45.347
to						0.0	27.182		-1.299
TEST	0		269.74	7.98		0.0	38.892	0.0005	0.021
			0.0						
TEST			269.74	<- Was 299.75			Was 62.81 ->		44.069

Figure 22 – Result for Hydraulic Analysis with 10 sprinklers flowing

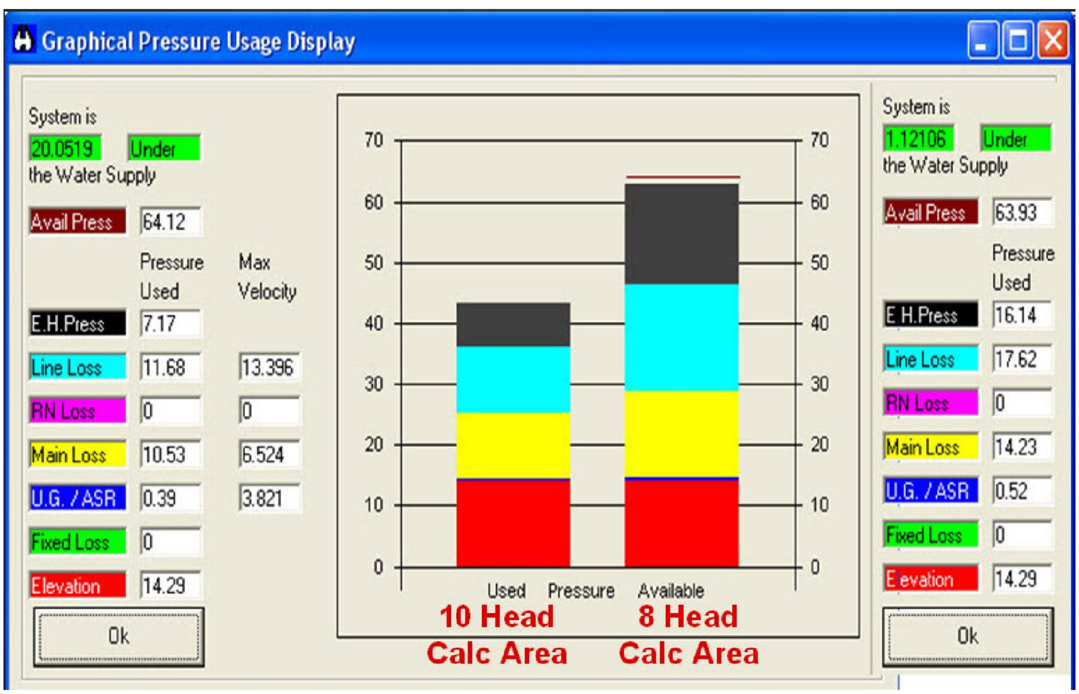


Figure 23 – Graphical comparison of 8 hd area and 10 hd area results

Summary and Conclusion

The purpose of this class was to describe the basic equations, standards and procedures used in the hydraulic analysis of fire protection sprinkler systems with attention to how those equations, standards and procedures compare to their respective equivalents in the analysis of hot and cold water plumbing systems. Although there are many similarities, we have attempted to illustrate that the necessary basic design assumptions lead to substantially different behaviors between the two types of systems. Those different behaviors can be traced to the differences between the formula used to calculate the pressure and flow relationship at the outlet point(s) of each system. Table 5 below summarizes some of the key differences between the two approaches.

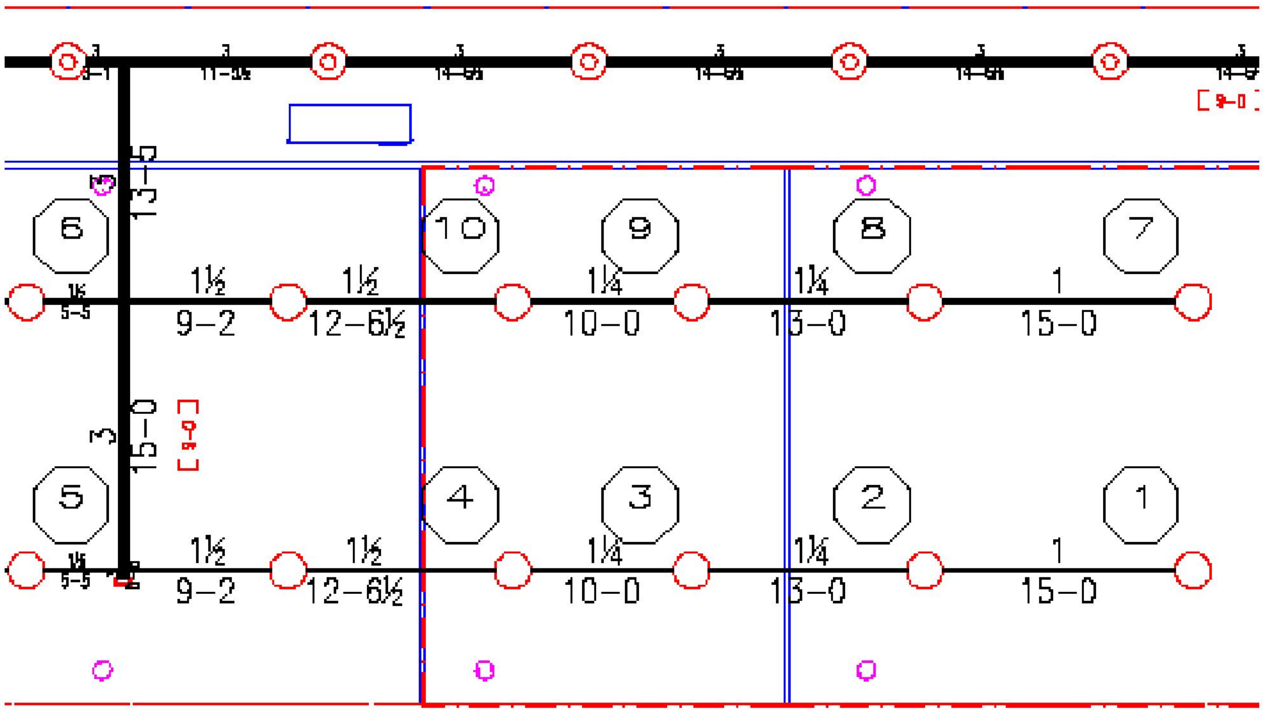
	Fire Protection	Plumbing Supply
Outlet Pressure	▪ Only outlets in expected fire area are considered ▪ Varies by coverage area of each sprinkler ▪ Varies by differences in pressure between outlets	▪ All outlets in entire system are considered flowing ▪ Constant by fixture type
Friction Loss	▪ Requires iterative guess of pipe diameter ▪ Dependent on all downstream calcs of flow	▪ Pipe diameter chosen by velocity ▪ Flow fixed by all downstream fixtures
Total System Flow	Varies by remote area, head spacing and pipe sizing	Constant for given set of fixtures

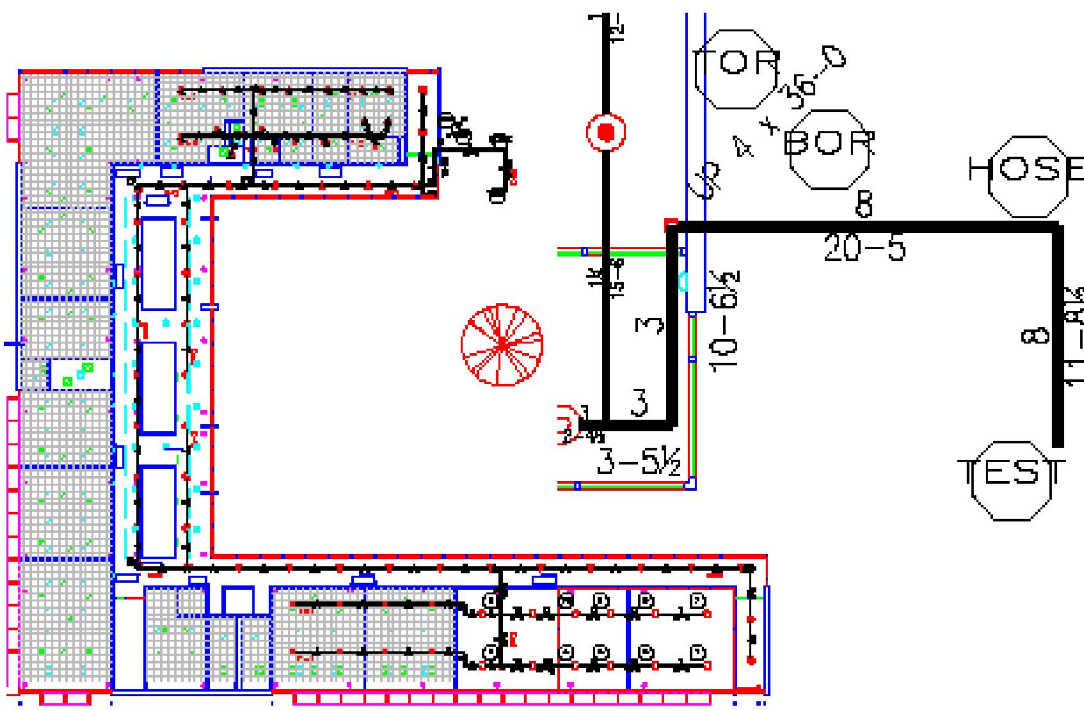
Table 5 – Summary of Hydraulic Analysis Differences

Since the results of the fire protection analysis depend so heavily of the choice of areas chosen to analyze and the details of each component in the analysis it is critical that care and good judgment be applied throughout that process.

Appendix A

Calculation Area 1 – 8 Sprinkler Head Operating Area





Appendix B

Calculation Area 1 (8 Heads) – NFPA Printout Form

Final Calculations - Hazen-Williams - 2007

Hydratec, Inc.
4-Sample-Plan-8-heads-in-mra

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Date

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf	******* Notes ******
*EQUIVALENT K'S										
*REMOTE HEAD TO SUPPLY										
1	33	5.60	22.50	1		0.0	15.000	120	16.143	
to						0.0	0.0		0.0	
2	33		22.5	1.049		0.0	15.000	0.1618	2.427	Vel = 8.35
2	33	5.60	24.13	1.25		0.0	13.000	120	18.570	
to						0.0	0.0		0.0	
3	33		46.63	1.38		0.0	13.000	0.1639	2.131	Vel = 10.00
3	33	5.60	25.48	1.25		0.0	10.000	120	20.701	
to						0.0	0.0		0.0	
4	33		72.11	1.38		0.0	10.000	0.3670	3.670	Vel = 15.47
4	33	5.60	27.65	1.5	1T	8.0	21.730	120	24.371	
to						0.0	8.000		0.0	
5	33		99.76	1.61		0.0	29.730	0.3158	9.390	Vel = 15.72
5	33		0.0	3		0.0	15.000	120	33.761	
to						0.0	0.0		0.0	
6	33		99.76	3.26		0.0	15.000	0.0102	0.153	Vel = 3.83
6	33		99.99	3	1T	20.159	118.440	120	33.914	
to					1E	9.408	29.567		0.0	
M4	33		199.75	3.26		0.0	148.007	0.0367	5.438	Vel = 7.68
M4	33		0.0	3	1E	9.408	110.580	120	39.352	
to						0.0	9.408		0.0	
M5	33		199.75	3.26		0.0	119.988	0.0367	4.408	Vel = 7.68
M5	33		0.0	3		0.0	33.350	120	43.760	
to						0.0	0.0		0.0	
M6	33		199.75	3.26		0.0	33.350	0.0368	1.226	Vel = 7.68
M6	33		0.0	3	2E	18.815	63.090	120	44.986	
to						0.0	18.815		0.0	
TOR	33		199.75	3.26		0.0	81.905	0.0367	3.009	Vel = 7.68
TOR	33		0.0	4	1E	13.167	36.000	120	47.995	
to						0.0	13.167		15.592	
BOR	-3		199.75	4.26		0.0	49.167	0.0100	0.491	Vel = 4.50
BOR	-3		0.0	8		0.0	20.420	150	64.078	
to						0.0	0.0		0.0	
HOSE	-3		199.75	7.98		0.0	20.420	0.0003	0.006	Vel = 1.28
HOSE	-3	H100	100.00	8	1E	27.183	11.710	150	64.084	
to						0.0	27.182		-1.299	
TEST	0		299.75	7.98		0.0	38.892	0.0006	0.025	Vel = 1.92
			0.0							
TEST			299.75						62.810	K Factor = 37.82

Computer Programs by Hydratec Inc. Route 111 Windham N.H. USA 03087

Appendix B

Final Calculations - Hazen-Williams - 2007

Hydratec, Inc.
4-Sample-Plan-8-heads-in-mra

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Date

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf	******* Notes ******
*NEW PATH										
7 to 8	33 33	5.60	22.55 22.55	1 1.049		0.0 0.0 0.0	15.000 0.0 15.000	120 0.1625	16.220 0.0 2.437	Vel = 8.37
8 to 9	33 33	5.60	24.19 46.74	1.25 1.38		0.0 0.0 0.0	13.000 0.0 13.000	120 0.1646	18.657 0.0 2.140	Vel = 10.03
9 to 10	33 33	5.60	25.54 72.28	1.25 1.38		0.0 0.0 0.0	10.000 0.0 10.000	120 0.3687	20.797 0.0 3.687	Vel = 15.50
10 to 6	33 33	5.60	27.71 99.99	1.5 1.61	1T	8.0 0.0 0.0	21.730 8.000 29.730	120 0.3172	24.484 0.0 9.430	Vel = 15.76
 6			0.0 99.99						 33.914	 K Factor = 17.17

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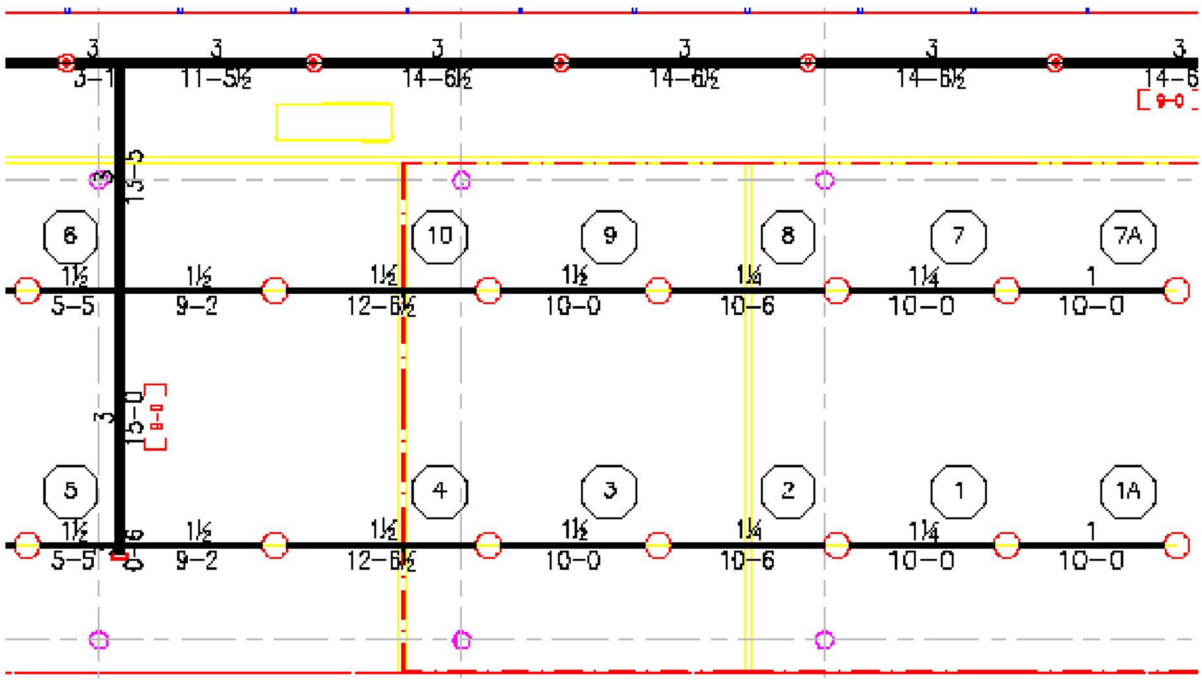
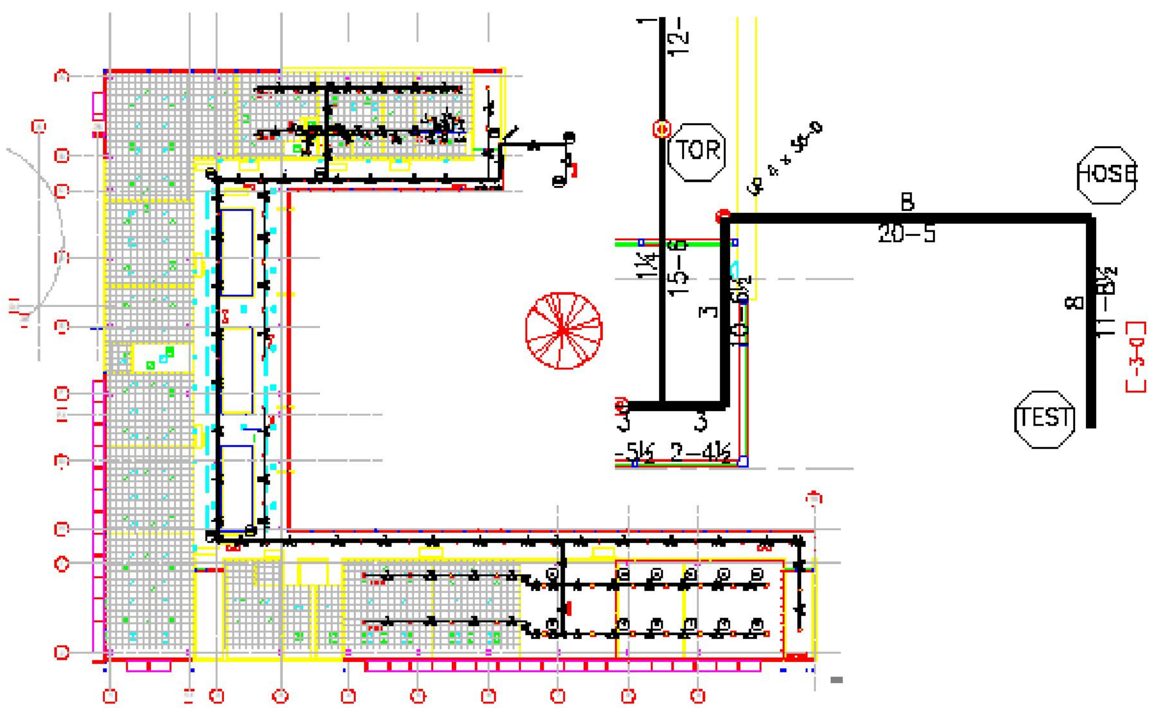
Appendix C

Calculation Area 1 – 10 Sprinkler Head Operating Area





Appendix D

Calculation Area 1 (10 Heads) - NFPA Printout Form

Final Calculations - Hazen-Williams - 2007

Hydratec, Inc.
10-heads-in-mra-2

Page 4
Date

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf	******* Notes ******
1A	33	5.60	15.00	1		0.0	10.000	120	7.175	
to						0.0	0.0		0.0	
1	33		15.0	1.049		0.0	10.000	0.0764	0.764	Vel = 5.57
1	33	5.60	15.78	1.25		0.0	10.000	120	7.939	
to						0.0	0.0		0.0	
2	33		30.78	1.38		0.0	10.000	0.0760	0.760	Vel = 6.60
2	33	5.60	16.52	1.25		0.0	10.500	120	8.699	
to						0.0	0.0		0.0	
3	33		47.3	1.38		0.0	10.500	0.1682	1.766	Vel = 10.15
3	33	5.60	18.11	1.5		0.0	10.000	120	10.465	
to						0.0	0.0		0.0	
4	33		65.41	1.61		0.0	10.000	0.1447	1.447	Vel = 10.31
4	33	5.60	19.33	1.5	1T	8.0	21.730	120	11.912	
to						0.0	8.000		0.0	
5	33		84.74	1.61		0.0	29.730	0.2335	6.943	Vel = 13.35
5	33		0.0	3		0.0	15.000	120	18.855	
to						0.0	0.0		0.0	
6	33		84.74	3.26		0.0	15.000	0.0075	0.113	Vel = 3.26
6	33		85.00	3	1T	20.159	118.440	120	18.968	
to					1E	9.408	29.567		0.0	
M4	33		169.74	3.26		0.0	148.007	0.0272	4.024	Vel = 6.52
			0.0							
M4			169.74						22.992	K Factor = 35.40
M4	33		169.74	3	1E	9.408	110.580	120	22.992	
to						0.0	9.408		0.0	
M5	33		169.74	3.26		0.0	119.988	0.0272	3.262	Vel = 6.52
M5	33		0.0	3		0.0	33.350	120	26.254	
to						0.0	0.0		0.0	
M6	33		169.74	3.26		0.0	33.350	0.0272	0.907	Vel = 6.52
M6	33		0.0	3	2E	18.815	63.090	120	27.161	
to						0.0	18.815		0.0	
TOR	33		169.74	3.26		0.0	81.905	0.0272	2.227	Vel = 6.52
			0.0							
TOR			169.74						29.388	K Factor = 31.31
TOR	33		169.74	4	1E	13.167	36.000	120	29.388	
to						0.0	13.167		15.592	
BOR	-3		169.74	4.26		0.0	49.167	0.0074	0.362	Vel = 3.82
BOR	-3		0.0	8		0.0	20.420	150	45.342	
to						0.0	0.0		0.0	
HOSE	-3		169.74	7.98		0.0	20.420	0.0002	0.005	Vel = 1.09

Appendix D

Final Calculations - Hazen-Williams - 2007

Hydratec, Inc. — Page 5
10-heads-in-mra-2 — Date

Node1 to Node2	Elev1 Elev2	K Fact	Qa Qt	Nom Act	Fitting or Eqv.	Ln.	Pipe Ftng's Total	CFact Pf/Ft	Pt Pe Pf	******* Notes ******
HOSE	-3	H100	100.00	8	1E	27.183	11.710	150	45.347	
to						0.0	27.182		-1.299	
TEST	0		269.74	7.98		0.0	38.892	0.0005	0.021	Vel = 1.73
			0.0							
TEST			269.74						44.069	K Factor = 40.63
7A	33	5.60	15.05	1		0.0	10.000	120	7.220	
to						0.0	0.0		0.0	
7	33		15.05	1.049		0.0	10.000	0.0769	0.769	Vel = 5.59
7	33	5.60	15.83	1.25		0.0	10.000	120	7.989	
to						0.0	0.0		0.0	
8	33		30.88	1.38		0.0	10.000	0.0764	0.764	Vel = 6.62
8	33	5.60	16.56	1.25		0.0	10.500	120	8.753	
to						0.0	0.0		0.0	
9	33		47.44	1.38		0.0	10.500	0.1692	1.777	Vel = 10.18
9	33	5.60	18.17	1.5		0.0	10.000	120	10.530	
to						0.0	0.0		0.0	
10	33		65.61	1.61		0.0	10.000	0.1455	1.455	Vel = 10.34
10	33	5.60	19.39	1.5	1T	8.0	21.730	120	11.985	
to						0.0	8.000		0.0	
6	33		85.0	1.61		0.0	29.730	0.2349	6.983	Vel = 13.40
			0.0							
6			85.00						18.968	K Factor = 19.52

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