HYDRAULICS OF FIRE PROTECTION SYSTEMS

Table of Contents

List of Figures

List of Tables

1.0 SCOPE

Automatic sprinklers with adequate water supplies are the best form of protection for most fire hazards. To determine the most economical means of installing a sprinkler system for a given location, both the automatic sprinkler system and the water supply available for that sprinkler system must be hydraulically analyzed. Therefore, in order to properly design and analyze an automatic sprinkler system, knowledge of water flow and energy losses within the piping network is required.

This data sheet provides guidance for determining:

- the hydraulic demands of an automatic sprinkler system, whether proposed or existing, at a given reference point.
- the available water supply, whether proposed or existing, at a given reference point.

Together, these two factors are used to determine whether the hydraulics of an automatic sprinkler system can provide an acceptable level of protection for a given hazard.

This data sheet does not provide guidance on how to determine the physical layout of sprinkler systems or water supplies.

1.1 Changes

March 2010. This data sheet has been rewritten and reformatted. Text from the previous version of this data sheet has been combined with text from obsolete Data Sheet 2-8N, *NFPA 13 Standard for the Installation of Sprinkler Systems 1996 Edition*.

1.2 Superseded Information

This data sheet supersedes Data Sheet 2-8N, *NFPA 13 Standard for the Installation of Sprinkler Systems 1996 Edition*.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Protection

2.1.1 Hydraulics of Water Supplies for Automatic Sprinkler Systems

2.1.1.1 Introduction

In order to properly analyze an automatic sprinkler system, the available water supply for that system must be thoroughly understood. This data sheet will provide guidance on determining the water supply available at a given reference point, called the base of the sprinkler riser (BOR), for the purpose of analyzing the adequacy of a sprinkler system.

To determine the water supply available at the BOR, the following basic steps are taken:

1. Gain a thorough understanding of the type of water supply available. If it is a public supply, visit the water department and obtain details regarding the piping network and the means by which water is delivered, as well as permission to test the supply. Previous test results are usually on file and can be useful for planning the water supply test.
2. Gain a thorough understanding of the underground piping, including length, diameter, material, internal lining (if applicable), roughness coefficient, and approximate age of the pipe.
3. Test the water supply to determine the flow and pressure available at the test’s Effective Point.
4. Make adjustments, as needed, for any elevation difference between the residual pressure gauge and the Effective Point.
5. Perform a friction loss analysis between the Effective Point and the BOR.
6. Make adjustments, as needed, for any elevation difference between the Effective Point and the BOR.

Once the water supply available at the BOR has been determined, it can be compared to the flow and pressure required of an existing sprinkler system, or used to determine the piping layout of a proposed sprinkler system.

For the purpose of analyzing the flow and pressure available from a water supply, round flow values to the nearest 10 gpm, and pressure values to the nearest whole number for psi (for SI units, round flow values to the nearest 50 L/min and pressure values to the nearest tenth of a bar).

2.1.1.2 The Purpose of Water Supply Testing

There are several reasons for flow-testing water supplies:

1. Flow available to a given area can be compared with demands specified in existing standards.
2. Fire pumps and drivers are subject to numerous malfunctions that can be discovered and promptly corrected.
3. Closed valves and other obstructions become apparent.
4. Water supply deterioration can be detected.
5. The potential training needs of facility personnel regarding the use of the fire protection system can be assessed.
6. Although not the intention of a water supply test, occasionally weak spots in the underground piping network will fail during a water supply test involving high-pressure systems, such as those fed by fire pumps. Although it is undesirable to have a failure involving the water supply piping, it is

far better to discover and repair these types of conditions than to have it occur during a fire event.

2.1.1.3 Precautions to Consider When Conducting Water Supply Testing

Ensure qualified personnel direct flow tests because property damage can result from improperly conducted tests. The following are some of the more common problems that can arise:

1. Improperly secured nozzles or hydrant caps can work loose.
2. Excessive flows may draw vacuums in high buildings and in hilly country, possibly contaminating water supplies, damaging boilers, and interrupting industrial processes. Avoid reducing pressure in public mains below 20 psi (1.38 bar).
3. Local flooding at low spots, such as truck docks, basements, pits, tunnels, etc., is possible.
4. Water damage can occur to storage if it is located outdoors or in low-lying buildings where water can flow through doorways.
5. High-voltage electrical equipment can be shorted by solid hose streams. Note that spray from fire protection equipment avoids this problem.
6. Rapid valve operation results in water hammer, which can rupture piping and damage sprinkler equipment.

When using fire hoses, secure the nozzles to substantial supports such as posts, trees, or deeply driven stakes; never hold fire hoses by hand during a water supply test.

When fire hoses are not available and waterflow from hydrants or pump headers must be redirected to avoid damage, use elbows and piping with adapters from hose thread to pipe thread. Ensure pipe downstream from elbows is at least ten diameters long to obtain smooth flow. If Pitot pressures are erratic or higher at orifice edges than at centers, provide piping downstream of the nearest elbow that is long enough to allow for steady Pitot pressure readings.

Avoid the hazards outlined above by creating, prior to the test, a documented plan that outlines the steps needed for testing the water supply.

2.1.1.4 Planning for a Water Supply Test

Before conducting a water supply test, plan a course of action that includes:

- Where to flow water
- Which hydrants or similar devices will be used
- Where to take pressure readings
- Which valve-operating sequence to use, if necessary

- The expected results of the test
- Notifying the appropriate people of the test
- Returning all water supplies to their normal operating condition

The intent of a water supply test is to determine the relationship between the flow and pressure available from a water supply (or supplies) that is being used to protect a facility equipped with automatic sprinklers. It is important to understand this relationship up to and including the largest required system flow (i.e., ceiling-level sprinklers, in-rack sprinklers, and hose demand) at the facility. Therefore, choose a sufficient number of hydrants, or other flowing devices, to achieve this flow demand and ensure water discharge from them will not result in damage (see Section 2.1.1.3). When possible, equip all flowing devices with discharge nozzles. When hydrants are used, ensure all hydrant caps are tightly secured before allowing water into the hydrant.

Based on the location of the flowing devices, determine the best place to take the static and residual pressure readings. In general, this is at the pressure gauge located closest to the Effective Point of the test. Always attempt to arrange the Effective Point of the test to be as close as possible to the sprinkler system with the highest flow and pressure requirement.

To avoid false pressure readings, ensure there are no check valves or shut valves in the underground piping between the flowing devices and the point where pressure readings are being taken.

If a water supply source uses a storage tank, such as a fire pump and tank, ensure the tank is full prior to testing.

If there is more than one water supply source for a facility’s automatic sprinkler system, first test each source individually, then, as a final step, conduct a water supply test with all water supply sources in service. Always maintain at least one water source in service at all times.

Testing multiple sources will require the isolation of water supply sources by closing control valves. To help identify the best method for testing each source individually and the valve closure sequencing for it, create a simple (free-hand) sketch of the facility’s underground pipe network, the water supply sources feeding it, and the valves that will be used for isolation.

Create a written procedure that identifies the sequence of water sources to be tested and the valves that need to be closed for each test. Once a test of an individual water supply source has been completed, verify that all valves that were closed for the test have been reopened prior to the start of the next water supply test. Use the FM *Red Tag Permit System* for monitoring all valve closures.

Before conducting a water supply test, determine the theoretical results of the test. Once the test has been conducted, compare the theoretical results to the actual results. If the actual results do not compare well with the theoretical results, determine the reason for this. See Section 2.1.1.7, as needed, regarding the use of hydraulic gradient testing to pinpoint areas within the underground piping network that may be causing larger than expected pressure reduction.

Check for local regulations that may affect planning. For example, if may be necessary to notify the public water service and/or fire service before conducting a water supply test, even if the water source is from a private water supply system. In addition, if there are alarms that could activate as a result of the water supply test, notify the appropriate personnel prior to the start of the test, as well as after the test has been completed.

If the water supply test will be conducted at an FM client location, determine the FM index number for the facility as well as the telephone number of the local FM servicing office. Notify the local servicing office if any valves have to be shut during the water supply test and follow the guidelines outlined in the FM *Red Tag Permit System*.

If the water supply test involves a public water system, do the following:

1. If the public water system is direct or intermittent pumping, determine the facilities that are in operation during the test.
2. If the public water system includes elevated storage, conduct the test with the pumps shut down if possible.
3. If the public water system is equipped with sources that will, or could, become active when higher flow rates are experienced, arrange the test to activate these sources (if possible), and determine (a) notification required, (b) time required to obtain service, and (c) facilities in operation.
4. Check for pressure-regulating valves.
5. Check for variations in operating procedures from day to night or from summer to winter.

2.1.1.5 Testing Water Supplies

2.1.1.5.1 Equipment Needed for Water Supply Tests

Conducting a water supply test requires, at a minimum, the following equipment:
- A device, or devices, from which to flow water
- A Pitot tube or similar device for measuring the Pitot pressure of the flowing water
- A device with which to read the static and residual pressures
- A calibrated pressure gauge equipped with an appropriate scale for the anticipated pressures

2.1.1.5.1.1 Common Devices for Flowing Water

The most common devices used for flowing water during a water supply test are fire hydrants and fire pump test headers. Water can be flowed from hydrant butts with or without attached nozzles. To flow water from a test header, a fire hose is commonly required to run the water to a safe discharge location. A nozzle is attached to the fire hose through which flow is discharged.

The exact diameter size and discharge coefficient of the orifice nozzle through which water is flowing must be known in order to determine the waterflow rate during a water supply test.

2.1.1.5.1.2 Determining Waterflow Through an Open Orifice

Waterflow from an open orifice with a known discharge coefficient is determined by measuring the velocity pressure of the water stream, also referred to as the Pitot pressure, using a Pitot tube. To obtain an accurate reading of the Pitot pressure, hold the end of the Pitot tube with the open orifice firmly in the center of the water jet. Hold the knife edge directly against the nozzle end with the blade at right angles to the nozzle axis.

The pitot pressure that is read from the Pitot tube is then converted to a corresponding waterflow rate either by using Equation 1 or by using Tables 6 through 11 in combination with the appropriate nozzle discharge coefficient (see Table 4 for typical nozzle discharge coefficient values).

Avoid Pitot readings under 10 psi (0.69 bar) whenever possible by reducing the size or number of orifices discharging water during the test.

The flow from an open orifice can be determined using the following equation:

$$Q = (a) \times (c) \times (d)^2 \times (P_V)^{0.5} \quad \textbf{(Equation 1)}$$

where:

Q is the waterflow rate through the open orifice, gpm (L/min).

a is the conversion constant; use 29.8 when P_V is in psi or 0.666 when P_V is in bar.

c is the orifice discharge coefficient (usually stamped on nozzle or orifice; otherwise see Table 4 for typical values).

d is the diameter of open orifice, in. (mm).

P_V is the velocity pressure or Pitot pressure, psi (bar).

If a nozzle or orifice opening is not stamped with its discharge coefficient, see Table 4 for values of typical nozzles and orifices used for water supply testing. See Figure 4 if the open orifice is a hydrant butt without an attached discharge nozzle.

Tables 6 through 11 provide values for Q from Equation 1 with the discharge coefficient set to a value of 1.00. The tables can be used to obtain the actual flow from the orifice opening by simply multiplying the value obtained from the table by the orifice discharge coefficient. For Pitot pressure values higher than 100 psi (6.9 bar), use Equation 1.

2.1.1.5.1.3 Static and Residual Pressure Readings

During the test, the static and residual pressures are read from a pressure gauge. Common devices on which pressure gauges are mounted include fire pumps, sprinkler risers, and non-flowing hydrants.

2.1.1.5.2 Water Supply Test Procedure

The following is the general procedure for testing a water supply.

1. Create a documented plan for the water supply test (as outlined in Section 2.1.1.4) prior to conducting the test.
2. Notify all required parties, such as any central station, proprietary supervisory service, public fire service, or water department, of the proposed water supply test.
3. Using the FM *Red Tag Permit System*, isolate as needed the desired water supply source and/or section of the underground piping network to be tested.
4. Read and record the static pressure.
5. Ensure the devices chosen for flowing water will not result in damage. See Section 2.1.1.3 for additional guidance.
6. Document the orifice diameter and discharge coefficient of each flowing device.
7. Fully open the valve on the flowing device; ensure water discharge is not creating damage.
8. Read and record the residual pressure once the pressure has stabilized (depending on the water supply, this may take a minute or two).
9. Read and record the Pitot pressure at each flow opening.
10. Slowly close the valves of all flowing devices.
11. Record the static pressure.
12. Convert the Pitot pressure readings into flows using either Tables 6 through 11 or Equation 1.
13. Plot the results of the test on $N^{1.85}$ graph paper (as outlined in Section 2.1.1.6) and compare to the anticipated results.

If the actual test results do not compare well with the anticipated test results, determine what might be causing the difference. In a case where the actual test results are much lower than the anticipated results, a hydraulic gradient, as outlined in Section 2.1.1.7, can be used to determine where excessive pressure loss is occurring within the underground piping network that has been tested.

If the actual test results do compare well with the anticipated test results, reopen any closed valves and then proceed with the next water supply source and/or section of the underground piping network to be tested, as outlined above in Step 3.

Continue this process until all water supply sources and all sections of the underground piping network have been tested. Once water supply testing has been completed, proceed as follows:

1. Dismantle the test setup and ensure all hydrant caps have been secured tightly in place.
2. Using the FM *Red Tag Permit System*, ensure all water supply control valves are returned to their normal, fully opened and locked/sealed condition.
3. Refill any gravity and/or suction tanks that were used during the test.
4. Ensure all fire pumps are placed in their normal automatic operating condition.
5. Notify all required parties that the testing has been completed and determine if any waterflow and/or valve tamper alarms were received as a result of the test procedure.

2.1.1.6 Graphical Representation of a Water Supply Test

2.1.1.6.1 Graphical Representation of the Water Supply Available at the Effective Point

The results of a water supply test can be used to graphically demonstrate the water supply available at any flow and pressure at the Effective Point of the water supply test.

For a simple public water supply, the water supply available at the Effective Point of a water supply test is represented by plotting the following two points obtained from the water supply test:

Static pressure, psi (bar)

Residual pressure at measured flow rate, psi @ gpm (bar @ L/min)

For more complex public supply systems, such as those with intermittent pumping or sources that could become active when higher flow rates are experienced, more than one residual pressure is needed to produce an accurate graphical representation of the water supply available.

For a typical fire pump supply, the water supply available at the Effective Point of a water supply test is represented by plotting, at a minimum, the following three points obtained from the water supply test:

Churn pressure, psi (bar)

Residual pressure at 100% of fire pump’s rated flow, psi @ gpm (bar @ L/min)

Residual pressure at 150% of fire pump’s rated flow, psi @ gpm (bar @ L/min)

The static pressure in combination with the residual pressures and their corresponding flows, as outlined above, represents the water supply available at the Effective Point when there is no elevation difference between the Effective Point and the pressure gauge where the static and residual pressures are read.

If there is an elevation difference between the water supply's Effective Point and the pressure gauge, adjust both the static and residual readings to account for this elevation difference using Equation 2 as follows:

P_E = (h) x 0.433 psi/ft (0.098 bar/m), when h is in feet (meters) **(Equation 2)**

where:

P_E is the pressure due to elevation, psi (bar).

If the Effective Point of the water supply test is located at a lower elevation than the pressure gauge used to measure the static and residual pressure readings, add the value of P_E to both the static and residual pressure readings obtained during the water supply test. Subtract the value of P_E from both the static and residual pressures if the Effective Point of the water supply test is located at a higher elevation than the pressure gauge used to measure the static and residual pressure readings.

The results of water supply tests are graphically shown on $N^{1.85}$ graph paper using the static pressure (at static flow conditions) and all of the residual pressures at their corresponding flow values. The y-axis of the $N^{1.85}$ graph paper is used to represent the various values of pressure whereas the x-axis of the $N^{1.85}$ graph paper is used to represent the various values of flow. This graph can then be used to determine the pressure available at any given flow and vise versa.

2.1.1.6.2 Theoretical Results of Water Supply Test at Locations Other Than the Effective Point

The results of a water supply test are applicable at the test's Effective Point and can be graphically represented on $N^{1.85}$ graph paper as outlined in Section 2.1.1.6.1. However, for sprinkler system analysis purposes, the results of the water supply test at the Effective Point need to be recalculated (or relocated) so they represent the theoretical supply that is available at the sprinkler system's base of riser (BOR).

The method for relocating the results of a water supply test from the Effective Point to another point within the water supply's piping network, such as the BOR, is accomplished graphically on $N^{1.85}$ graph paper as follows:

1. Graphically plot the results of the Effective Point on $N^{1.85}$ graph paper as outlined in Section 2.1.1.6.1.
2. Create a friction loss curve that represents the pressure loss (or gain) due to friction incurred between the Effective Point of the water supply test and the point in the piping network that the water supply test is being relocated to (such as the BOR). Plot this friction loss curve on the same

$N^{1.85}$ graph paper that contains the water supply available at the Effective Point.

3. Subtract (or add) the friction loss curve from the curve representing the water supply available at the Effective Point.
4. Adjust the water supply curve obtained from Step 3 for any elevation difference that exists between the Effective Point and the point in the piping network that the water supply test is being relocated to.

Note that if the test results are being moved to a point in the piping network that is closer to the water source than the Effective Point, the friction loss curve will represent a gain in the residual pressures available. If the test results are being moved to a point further away from the water source, the friction loss curve will represent a loss in the residual pressures available.

The water supply curve obtained from Step 4 above is the theoretical water supply available at the point in the piping network that the water supply test is being relocated to.

Once the water supply theoretically available at a sprinkler system's BOR has been determined, it can be compared to the required flow and pressure of the sprinkler system as outlined in Section 2.1.2.4.5.

2.1.1.7 Troubleshooting Water Supplies Via a Hydraulic Gradient Test

If the residual pressure values from a water supply test are unexpectedly low, there may be several reasons to account for this, including:

- partly closed valves,
- pipes with excessive tuberculation,
- obstructions within the pipe, and
- potentially pipe size errors on plans depicting the underground piping network.

When the results from a water supply are unexpectedly low and no longer provide an acceptable level of flow and pressure for an automatic sprinkler system, conduct a hydraulic gradient test to identify the segment of the underground piping network where unexpectedly high pressure loss is occurring.

The following are needed in order to conduct a hydraulic gradient test:

- Single path flow through the section of underground piping where excessive pressure drop is taking place
- Several places where static and residual pressure readings can be taken
- A flowing device that allows for relatively high flow rates

- An understanding of the underground piping network, including pipe diameter, length of pipe between pressure reading stations and where any tees, crosses, bends, valves or meters within the piping network may be located

After the testing has been completed, tabulate the data as demonstrated in Table 1 and plot the gradient profile as demonstrated in Figure 24 to determine where the significant unexpected pressure drops occur. Recommend appropriate action to rectify the situation.

An example **(Example No. 1)** of a hydraulic gradient is provided in Figure 1.

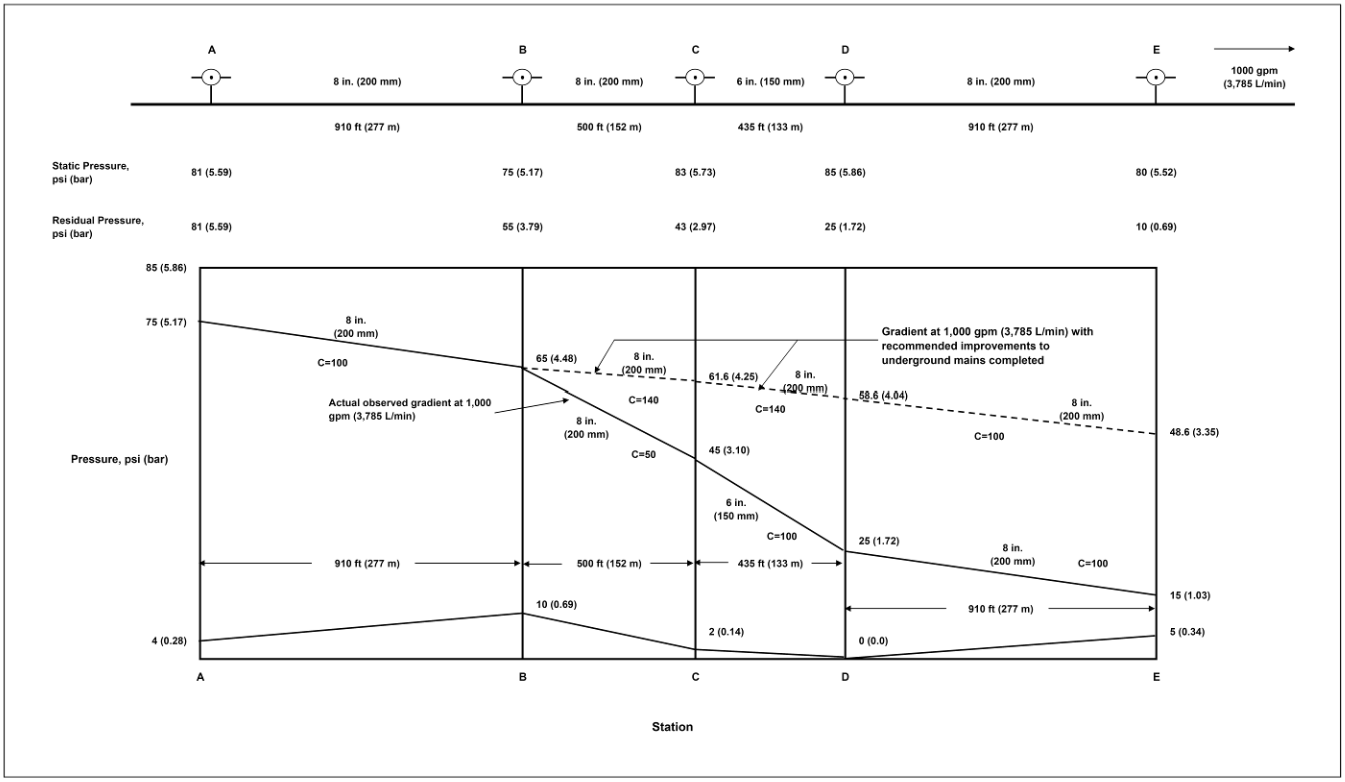
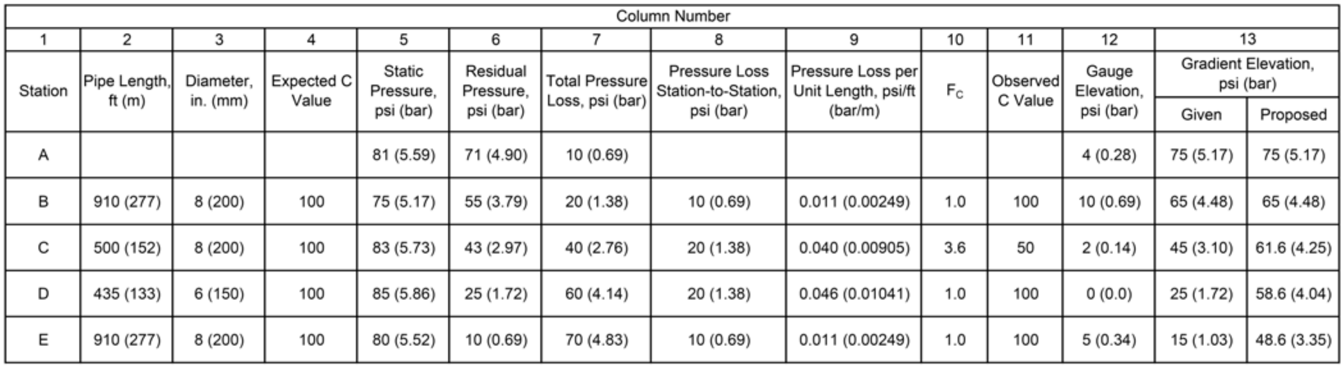


Fig. 1. Profile of a hydraulic gradient test per Example No. 1

For this example, water is in a single-path flow from a source to the left of Hydrant A and flowing at a location to the right of Hydrant E. Static and residual pressure readings are taken at Hydrants A, B, C, D and E and are labeled as stations. The distance between each pressure station is determined as is the internal pipe diameter between each station.

The data from the hydraulic gradient test is collected and presented in Table 1.

Table 1. Data for Hydraulic Gradient Example No. 1



Column Number													
1	2	3	4	5	6	7	8	9	10	11	12	13	
Station	Pipe Length, ft (m)	Diameter, in. (mm)	Expected C Value	Static Pressure, psi (bar)	Residual Pressure, psi (bar)	Total Pressure Loss, psi (bar)	Pressure Loss Station-to-Station, psi (bar)	Pressure Loss per Unit Length, psi/ft (bar/m)	F_C	Observed C Value	Gauge Elevation, psi (bar)	Gradient Elevation, psi (bar)	
												Given	Proposed
A				81 (5.59)	71 (4.90)	10 (0.69)					4 (0.28)	75 (5.17)	75 (5.17)
B	910 (277)	8 (200)	100	75 (5.17)	55 (3.79)	20 (1.38)	10 (0.69)	0.011 (0.00249)	1.0	100	10 (0.69)	65 (4.48)	65 (4.48)
C	500 (152)	8 (200)	100	83 (5.73)	43 (2.97)	40 (2.76)	20 (1.38)	0.040 (0.00905)	3.6	50	2 (0.14)	45 (3.10)	61.6 (4.25)
D	435 (133)	6 (150)	100	85 (5.86)	25 (1.72)	60 (4.14)	20 (1.38)	0.046 (0.01041)	1.0	100	0 (0.0)	25 (1.72)	58.6 (4.04)
E	910 (277)	8 (200)	100	80 (5.52)	10 (0.69)	70 (4.83)	10 (0.69)	0.011 (0.00249)	1.0	100	5 (0.34)	15 (1.03)	48.6 (3.35)

The results of the hydraulic gradient indicate the pressure drop between Stations A to B, C to D and D to E are close to the anticipated value; however, the pressure drop between Stations B to C is unexpectedly high. Therefore, the recommendation would be to determine the reason for this high pressure drop and take appropriate steps to mitigate this cause.

For this specific example, the cause of the high pressure drop is due to tuberculation of the pipe segment between Stations B and C. The easiest means to mitigate the cause is to replace the affected section of pipe with new pipe having the same pipe diameter. However, because the adjacent segment of pipe is relatively short and is only 6 in. (150 mm) in diameter, the recommendation included replacing this segment of pipe as well with new 8 in. (200 mm) pipe. Based on theoretical calculations, implementation of this recommendation would result in an increase of roughly 34 psi (2.35 bar) at a flow of 1,000 gpm (3,785 L/min).

Explanation of columns in Table 1:

Columns 1 through 6:	Data collected prior to as well as during the hydraulic gradient test
Column 7:	Obtained by subtracting Column 5 from Column 4
Column 8:	Obtained by subtracting the Column No. 7 value in Row N from the Column No. 7 value in Row N + 1 (i.e. subtract Column No. 7 value for Row Station A from the Column No. 7 value for Row Station B)
Column 9:	Obtained by dividing Column No. 8 by Column No. 2
Column 10:	Obtained by dividing Column No. 9 by the value obtained from Data Sheet 2-89 for the given flow, pipe diameter and Hazen-Williams coefficient. Note, if there are tees, crosses, bends, valves, or meters in the pipe segment being tested, obtain the pressure loss in these devices from Data Sheet 2-89 and deduct it from the observed drop in pressure before calculating the coefficient for the given pipe segment.

Column 11:	Obtained by using the value from Column No. 10 and matching it to the C value in Table 1 based on the expected C value listed in Column No. 4
Column 12:	Obtained by subtracting Column No. 5 from the largest value listed in Column No. 5
Column 13, Given:	Obtained by adding Column Nos. 6 and 12
Column 13, Proposed:	Obtained by determining the expected pressure drop from station to station once proposed changes/recommendations have been implemented

For this example, a total flow of 1,000 gpm (3,785 L/min) is being discharged from a location to the right of the hydrant shown at Station E. The static and residual pressures are read at each of the hydrants shown at Stations A, B, C, D and E with the results indicated in Table 1.

Columns 1 through 6 in Table 1 include data that is either obtained from conditions that exist prior to or are obtained during the hydraulic gradient test.

Column 7 contains the results of subtracting Column Nos. 6 from 5. In this example, at Station A the value is based on subtracting a residual pressure of 71 psi (4.90 bar) from a static pressure of 81 psi (5.59 bar) to obtain the indicated value of 10 psi (0.69 bar).

Column 8 contains the results of subtracting the values indicated in Column No. 6 from one row to the next. In this example, at Station B the value is based on subtracting a pressure differential value of 10 psi (0.69 bar) obtained at Station A from the value of 20 psi (1.38 bar) obtained at Station B to obtain the indicated value of 10 psi (0.69 bar).

Column 9 contains the results of dividing the values indicated in Column No. 8 by the values indicated in Column No. 2. For this example, at Station B the value is based on dividing 10 psi (0.69 bar) by 910 ft (277 m) to obtain the indicated value of 0.011 psi/ft (0.00249 bar/m).

Column 10 contains the results of dividing the values indicated in Column No. 9 by the corresponding values in Data Sheet 2-89. In this example the pipe between Station A and Station B is addressed in Table 9 of Data Sheet 2-89. For a flow of 1,000 gpm (3,785 L/min) and an internal pipe diameter of 8 in. (200 mm), the expected pressure drop per unit length is 0.011 psi/ft (0.00249 bar/m). Therefore, the value obtained for Column No. 10 in this example is based on dividing 0.011 psi/ft (0.00249 bar/m) by 0.011 psi/ft (0.00249 bar/m), which is 1.0.

Column 11 indicates the observed Hazen-Williams C value for the pipe segment based on the results of the hydraulic gradient test. It is obtained by using the value obtained for F_C from Column No. 10 and converting it to an equivalent Hazen Williams C value indicated in Table 1. In this example at Station C, the F_C value of 3.6 results in a Hazen Williams C value of approximately 50.

Column 12 contains the difference in static pressure values between the highest static pressure observed and those at each station. For this example the highest static pressure observed was 85 psi (5.86 bar) at Station D, therefore the values in Column No. 12 are simply the indicated static pressures subtracted from a value of 85 psi (5.86 bar).

Column 13 (Given) contains the results of adding Column Nos. 6 and 12. For this example, at Station A the value is based on adding 71 psi (4.90 bar) and 4 psi (0.28 bar) to obtain the indicated value of 75 psi (5.17 bar).

Column 13 (Proposed) contains the results of using the appropriate value of pressure loss per unit length, based on the recommendation offered, multiplied by the value listed in Column No. 2 and subtracted from the row above it. For this example, the recommendation is to replace the existing 8 in. (200 mm) segment of pipe between Stations B and C as well as the existing 6 in. (150 mm) segment of pipe between Stations C and D with new 8 in. (200 mm) pipe, which would have a Hazen Williams C value of 140. From Table 13 of Data Sheet 2-89, the pressure drop per unit length of pipe is 0.0068 psi/ft (0.00154 bar/m) resulting in a pressure drop of 3.4 psi (0.23 bar) between Stations B and C and a pressure drop of 3.0 psi (0.21 bar) between Stations C and D. Therefore, the values in this column become 61.4 psi (4.25 bar) at Station C based on subtracting 3.4 psi (0.23 bar) from the pressure indicated at Station B, which is 65 psi (4.48 bar).

Items to consider during a hydraulic gradient test include:

1. Tests of private mains usually are made on much shorter runs of pipe than tests of public mains. In order to reduce the number of tests, choose mains that are typical of the age and probable condition of the system.

2. Where obstructions are suspected, investigate that portion of the yard system. Ensure heavy flow is induced through the test section to drop pressure from station to station as much as possible, reducing effects of fluctuating pressure or small inaccuracies in gauge readings.

3. Static pressure readings from sources such as gravity tanks or private reservoirs indicate true static pressures, provided there is no facility-use draft or significant leakage. However, static pressure readings from public water supply sources are actually residual pressures and trace combinations of elevation and normal gradient instead of elevation alone. Because of this, if it is important that very accurate readings are needed, determine when the normal draft from the supply is at a minimum and arrange for the hydraulic gradient test at that time. Otherwise, determine relative gauge elevations from topographic maps, municipal survey data, or (with caution) simply by observation.

2.1.2 Hydraulics of Automatic Sprinkler Systems

2.1.2.1 Determining the Occupancy Hazard

The first step in the installation and/or hydraulic evaluation of any automatic sprinkler system is the thorough understanding of the highest hazard that is to be protected by the sprinkler system. Once this level of hazard has been established, the required protection design for the sprinkler system can be determined using the applicable occupancy-specific data sheet. For example, the occupancy-specific data sheet may be Data Sheet 3-26, *Fire Protection Water Demand for Nonstorage Sprinklered Properties*, for a typical office or manufacturing occupancy; or it could be Data Sheet 8-9, *Protection of Class 1, 2, 3, 4 and Plastic Commodities*, for a typical warehouse occupancy. Consult the Index of Data Sheets to determine the most appropriate occupancy-specific data sheet for the hazard being protected.

The hydraulic analysis of an automatic sprinkler system can be determined in more than one manner. This data sheet will demonstrate the methodology of hydraulically calculating an automatic sprinkler system from the most hydraulically remote automatic sprinkler to a reference point called the base of the riser (BOR). Once the required flow and pressure for a given protection design has been calculated to the base of the sprinkler riser, it can be plotted on $N^{1.85}$ graph paper (see Figure 70) and then compared to the water supply available to determine whether the water supply can provide an acceptable level of protection.

The following sections of this data sheet will provide guidance on determining the required flow and pressure for a given sprinkler system's protection design at the sprinkler's BOR.

2.1.2.2 Determining the Location and Shape of the Hydraulic Design on the Sprinkler System

2.1.2.2.1 Determining the Required Flow and Pressure at the Most Hydraulically Remote Sprinkler

Once a required design has been obtained, hydraulic analysis of an automatic sprinkler system originates at the most hydraulically remote sprinkler (most remote sprinkler) with the minimum required flow and pressure at that sprinkler. This is determined as indicated in Section 2.1.2.2.1.1 for Density/Demand Area design formats or Section 2.1.2.2.1.2 for Number of Sprinklers/Pressure design formats.

2.1.2.2.1.1 Density/Demand Area Format

In this format neither the required flow rate nor the required pressure at the most remote sprinkler is provided. The minimum required flow rate must first be calculated using the following equation:

$q = D \times S \times L$ (Equation 3)

where:

q is the rate of water flow from a sprinkler, gpm (L/min).

D is the required density, gpm/ft^2 (mm/min).

S is the spacing of sprinklers along the branchline, ft (m).

L is the spacing of sprinklers between branchlines, ft (m).

When analyzing the flow available from an operating sprinkler, round the values obtained to the nearest whole number for gpm or nearest multiple of 5 for L/min.

Once the flow rate (q) is determined at the sprinkler, the pressure (p) at the sprinkler can be determined using the following equation:

$p = (q/K)^2$ **(Equation 4)**

where:

p is the water pressure at the sprinkler, psi (bar).

q is the rate of water flow from a sprinkler, gpm (L/min).

K is the K-factor of sprinkler, gpm/psi$^{0.5}$ ([L/min]/bar$^{0.5}$).

When analyzing the pressure available from an operating sprinkler, round the values obtained to the nearest 0.1 decimal for psi or nearest 0.01 decimal for bar.

2.1.2.2.1.1.1 Converting from Number of Sprinklers/Pressure Format to Density/Demand Area Format

If a sprinkler system design is given in the format of Number of Sprinklers/Pressure, it can be converted to the format of Density/Demand Area as indicated below.

For Density:

$D = [K \times (p)^{0.5}]/A_{MAX}$, gpm/ft^2 (mm/min) **(Equation 5)**

where:

D is the required density, gpm/ft^2 (mm/min).

K is the K-factor of sprinkler, gpm/psi$^{0.5}$ ([L/min]/bar$^{0.5}$).

p is the minimum required water pressure at the sprinkler, psi (bar).

A_{MAX} is the maximum allowable sprinkler spacing, ft^2 (m^2). If the conversion is for an existing system then A_{MAX} becomes the actual spacing of the sprinklers.

For Demand Area:

$DA = TNOS \times A_{MAX}$, ft^2 (m^2) **(Equation 6)**

where:

DA is the demand Area, ft^2 (m^2).

TNOS is the total number of sprinklers required in the hydraulic design.

A_{MAX} is the maximum allowable sprinkler spacing. If the conversion is for an existing system then A_{MAX} becomes the actual spacing of the sprinklers.

2.1.2.2.1.2 Number of Sprinklers/Pressure Format

In this format the minimum required pressure for the most remote sprinkler is given, therefore only the flow rate from the sprinkler needs to be determined. The flow rate from the sprinkler is then calculated using the following equation:

$q = K \times (p)^{0.5}$ **(Equation 7)**

where:

q is the rate of water flow from a sprinkler, gpm (L/min).

K is the K-factor of sprinkler, $gpm/psi^{0.5}$ ($[L/min]/bar^{0.5}$) or ($[mm/min]/bar^{0.5}$).

p is the water pressure at the sprinkler, psi (bar).

2.1.2.2.1.2.1 Converting from Density/Demand Area Format to Number of Sprinklers/Pressure Format

If a sprinkler system design is given in the format of Density/Demand Area, it can be converted to the format of Number of Sprinklers/Pressure as indicated below.

For Number of Sprinklers:

$TNOS = DA/A_{MAX}$ **(Equation 8)**

where:

TNOS is the total number of sprinklers required in the hydraulic design.

DA is the demand Area, ft^2 (m^2).

A_{MAX} is the maximum allowable sprinkler spacing, ft^2 (m^2). If the conversion is for an existing system then A_{MAX} becomes the actual spacing of the sprinklers.

For Pressure:

$p = [(D \times A_{MAX})/K\,]^2$, psi (bar) **(Equation 9)**

where:

p is the minimum required water pressure at the sprinkler, psi (bar).

D is the required density, gpm/ft^2 (mm/min).

A_{MAX} is the maximum allowable sprinkler spacing. If the conversion is for an existing system then A_{MAX} becomes the actual spacing of the sprinklers.

K is the K-factor of sprinkler, gpm/psi$^{0.5}$ ([L/min]/bar$^{0.5}$) or ([mm/min]/bar$^{0.5}$).

2.1.2.2.2 Determining Total Required Number of Automatic Sprinklers to be Hydraulically Calculated

Once the minimum required flow rate and pressure at the most remote sprinkler has been determined, the total number of sprinklers required in the hydraulic design must be calculated. This is determined as indicated in Section 2.1.2.2.2.1 for Density/Demand Area design formats or Section 2.1.2.2.2.2 for Number of Sprinklers/Pressure design formats.

2.1.2.2.2.1 Density/Demand Area Format

In this format the total number of sprinklers required in the hydraulic design is not provided and therefore must be calculated. This value is determined using the following equation:

$TNOS = DA/(S \times L)$ **(Equation 10)**

where:

TNOS is the total number of sprinklers required in hydraulic design.

DA is the demand Area, ft^2 (m^2).

S is the spacing of sprinklers along the branchline, ft (m).

L is the spacing of sprinklers between branchlines, ft (m).

2.1.2.2.2.2 Number of Sprinklers/Pressure Format

In this format the total number of sprinklers required in the hydraulic design is a given value.

2.1.2.2.3 Determining Required Number of Automatic Sprinklers per Branchline to be Hydraulically Calculated

Once the total number of sprinkler required in the hydraulic design has been determined, the number of sprinklers required per branchline in the hydraulic design must be calculated. This is determined as indicated in Section 2.1.2.2.3.1 for Density/Demand Area design formats or Section 2.1.2.2.3.2 for Number of Sprinklers/Pressure design formats.

2.1.2.2.3.1 Density/Demand Area Format

In this format the number of sprinklers required per branchline in the hydraulic design is not provided and therefore must be calculated. This value is determined using the following equation:

$$\mathrm{NORSBL} = [\mathrm{SF} \times (\mathrm{DA})^{0.5}]/\mathrm{S}$$ **(Equation 11)**

where:

NORSBL is the number of required sprinklers per branchline.

SF is the shape factor.

DA is the demand Area, ft^2 (m^2).

S is the spacing of sprinklers along the branchline, ft (m).

Unless indicated otherwise by the occupancy-specific data sheet, use a shape factor of 1.2 for sprinklers installed under ceilings with slopes less than or equal to 5°, or a shape factor of 1.4 for sprinklers installed under ceilings with slopes greater than 5°.

Round the value of NORSBL to the nearest whole number using standard rounding methods (i.e. round down for fractional values of .49 and less; round up for fractional values of .50 and greater).

2.1.2.2.3.2 Number of Sprinklers/Pressure Format

In this format the number of sprinklers required per branchline in the hydraulic design is not provided and therefore must be calculated. This value is determined using the following equation:

$$\mathrm{NORSBL} = [\mathrm{SF} \times (\mathrm{TNOS} \times \mathrm{S} \times \mathrm{L})^{0.5}]/\mathrm{S}$$ **(Equation 12)**

where:

NORSBL is the number of required sprinklers per branchline.

SF is the shape factor.

TNOS is the total number of sprinklers required in hydraulic design.

S is the spacing of sprinklers along the branchline, ft (m).

L is the spacing of sprinklers between branchlines, ft (m).

Unless indicated otherwise by the occupancy-specific data sheet, use a shape factor of 1.2 for sprinklers installed under ceilings with slopes less than or equal to 5°, or a shape factor of 1.4 for sprinklers installed under ceilings with slopes greater than 5°.

Round the value of NORSBL to the nearest whole number using standard rounding methods (i.e. round down for fractional values of .49 and less; round up for fractional values of .50 and greater).

2.1.2.2.4 Determining the Location of the Most Hydraulically Remote Sprinkler

Once the number of required sprinklers per branchline has been calculated, the location of the most remote sprinkler must be determined. This is analyzed in the same manner for both the Density/Demand Area format as well as the Number of Sprinklers/Pressure format. It is however, determined differently between tree-type sprinkler systems and grid-type sprinkler systems. Determine the location of the most remote sprinkler as indicated in Section 2.1.2.2.4.1 for tree-type sprinkler systems or Section 2.1.2.2.4.2 for grid-type sprinkler systems.

2.1.2.2.4.1 Tree-Type Sprinkler Systems

For most tree-type sprinkler systems the location of the most remote sprinkler will be obvious. There will, however be times when different pipe sizes within a tree-type system will require a more thorough analysis, via equivalent pipe length, to determine the actual location of the most remote sprinkler.

The equivalent pipe length method uses Equation 13 to convert all sprinkler system piping to a given pipe diameter and a given Hazen-Williams coefficient from which the hydraulically most remote sprinkler can be determined.

$$L_{EQIV} = L_{ORIG} \text{ x } (D_{NEW}/D_{ORIG})^{4.87} \text{ x } (C_{NEW}/C_{ORIG})^{1.85} \quad \textbf{(Equation 13)}$$

where:

L_{ORIG} is the original length of pipe with diameter D_{ORIG} and Hazen-Williams coefficient C_{ORIG}.

L_{EQIV} is the equivalent length of pipe for new diameter (D_{NEW}) and/or new Hazen-Williams coefficient (C_{NEW}).

D_{ORIG} is the original diameter of pipe with pipe length L_{ORIG} and Hazen-Williams coefficient C_{ORIG}.

D_{NEW} is the diameter of pipe to which D_{ORIG} is being converted.

C_{ORIG} is the original Hazen-Williams coefficient of pipe with length of pipe L_{ORIG} and diameter D_{ORIG}.

C_{NEW} is the Hazen-Williams coefficient of pipe for new equivalent length of pipe L_{EQIV} and/or new diameter D_{NEW}.

2.1.2.2.4.2 Grid-Type Sprinkler Systems

Locating the most remote sprinkler on a grid-type sprinkler system is not obvious and typically requires a computer software analysis. However, for a “regular” grid-type sprinkler system, the location of the most remote sprinkler can be approximated using the “skew” formula. Grid-type sprinkler systems that do not meet the definition of a regular grid require a trial-and-error method of analysis, which is best handled by a computer software program designed specifically for sprinkler system hydraulic analysis.

A regular grid-type sprinkler system is defined as follows:

- All of the sprinklers on the sprinkler system have the same K-factor.
- The spacing of sprinklers along the branchline as well as between branchlines is consistent throughout the sprinkler system.
- All of the branchlines are the same length and the same pipe diameter.
- The pipe diameters of the nearmain and the farmain are no more than two pipe sizes apart.
- Sprinkler outriggers are not present as part of the sprinkler system; however, if there are outriggers present, the number of outriggers on either side of the nearmain or farmain are less than 25% of the total number of sprinklers per branchline in the hydraulic design (NORSBL as defined below).

If a grid-type sprinkler system meets the definition of a regular grid-type system, the skew formula will indicate approximately how many sprinklers toward the farmain the most remote sprinkler is from the center of the grid. The skew formula is defined as follows:

$$\text{SKEW} = [(\text{TNOS}/\text{NORSBL})/\text{TBWOS}]^{1.85} \times (\text{TLOB}/2\text{S}) \quad \textbf{(Equation 14)}$$

where:

SKEW is the approximate number of sprinklers the most remote sprinkler is located toward the farmain from the center of the sprinkler grid.

TNOS is the total number of sprinklers required in the hydraulic design as defined in Section 2.1.2.2.2.2 or in Equation 10 of Section 2.1.2.2.2.1.

NORSBL is number of required sprinklers per branchline as defined by Equation 11 in Section 2.1.2.2.3.1 or Equation 12 in Section 2.1.2.2.3.2.

TBWOS is the total number of branchlines in the sprinkler system that are not included in the hydraulic design.

TLOB is the total length of each branchline; this value includes fittings that connect the branchline to both the nearmain and the farmain.

S is the spacing of sprinklers along the branchline, ft (m).

2.1.2.2.5 Positioning the Hydraulic Design Area on the Sprinkler System

Once the total number of sprinklers included in the hydraulic design area, the number of sprinklers per branchline, and the location of the most remote sprinkler have been determined, the hydraulic design area can be positioned on the sprinkler system for the purpose of hydraulically analyzing the sprinkler system. Section 2.1.2.2.5.1 outlines how to perform this feat for a tree-type or loop-type sprinkler system whereas Section 2.1.2.2.5.2 outlines how to perform this feat for a grid-type sprinkler system.

2.1.2.2.5.1 Positioning the Hydraulic Design Area on a Tree-Type or Loop-Type Sprinkler System

The most remote sprinkler is the starting point for positioning the hydraulic design area on a sprinkler system. The number of sprinklers per branchline, in combination with the total number of sprinklers included in the hydraulic design area, help define how many branchlines will have sprinklers included in the design area.

If the total number of sprinklers in the hydraulic design area divided by the number of sprinklers per branchline results in a whole number, such as when the total number of sprinklers in the hydraulic design area is 20 and the number of sprinklers per branchline is 5, then the shape of the hydraulic design area will either be a square or a rectangle when positioned on the sprinkler system.

If the total number of sprinklers in the hydraulic design area divided by the number of sprinklers per branchline does not result in a whole number, such as when the total number of sprinklers in the hydraulic design area is 25 and the number of sprinklers per branchline is 7, then the shape of the hydraulic design area will not result in either a square or a rectangle, but will have a few “additional” sprinklers attached to the square or rectangular shape. Position the additional sprinklers as part of the hydraulic design area using the following guidelines:

- Group all of the additional sprinklers together so they are continuous on the branchline, and
- Position the additional sprinklers so they are as close to the crossmain as allowable per the shape of the hydraulic design area.

2.1.2.2.5.2 Positioning the Hydraulic Design Area on a Grid-Type Sprinkler System

The most remote sprinkler is the starting point for positioning the hydraulic design area on a sprinkler system. The number of sprinklers per branchline, in combination with the total number of sprinklers included in the hydraulic design area, help define how many branchlines will have sprinklers included in the design area.

If the total number of sprinklers in the hydraulic design area divided by the number of sprinklers per branchline results in a whole number, such as when the total number of sprinklers in the hydraulic design area is 20 and the number of sprinklers per branchline is 5, then the shape of the hydraulic design area will either be a square or a rectangle when positioned on the sprinkler system.

If the total number of sprinklers in the hydraulic design area divided by the number of sprinklers per branchline does not result in a whole number, such as when the total number of sprinklers in the hydraulic design area is 25 and the number of sprinklers per branchline is 7, then the shape of the hydraulic design area will not result in either a square or a rectangle, but will have a few "additional" sprinklers attached to the square or rectangular shape. Position the additional sprinklers as part of the hydraulic design area using the following guidelines:

- Group all of the additional sprinklers together so they are continuous on the branchline, and
- Position the additional sprinklers so they are as close to the nearmain as allowable per the shape of the hydraulic design area.

2.1.2.3 Hydraulic Calculations From the Most Remote Sprinkler to the Reference Point

2.1.2.3.1 Introduction

Once the most remote sprinkler has been determined for a given sprinkler system and the hydraulic design area has been positioned on the sprinkler system, a hydraulic analysis of the sprinkler system back to the sprinkler's base of riser (BOR) can be conducted.

For water-based sprinkler systems (this includes dry-pipe and similar systems), use the Hazen-Williams formula (Equation 15) to determine the flow and pressure required at the sprinkler system's BOR.

Although some hydraulic calculation methods use normal pressure as a means of determining a sprinkler system's required flow and pressure, FM uses a hydraulic calculation method that does not include velocity pressure.

Total pressure consists of three forms of pressure, including (1) pressure due to the required minimum flow from the most remote sprinkler, (2) pressure due to friction loss within the sprinkler piping network, and (3) pressure due to elevation.

The pressure due to the required minimum flow is defined in Equation 4 of Section 2.1.2.2.1.1 or is a given as indicated in Section 2.1.2.2.1.2.

The pressure due to friction loss within the sprinkler piping network is calculated using the Hazen-Williams formula as follows:

$$p_f = [(4.52)x(Q/C)^{1.85}]/d^{4.87}$$ **(Equation 15)**

where:

p_f is the frictional resistance in lb per in^2 (psi) per foot of pipe.

Q is the gallons per minute (gpm) flowing.

d is the actual internal diameter of pipe in inches (in.).

C is the friction loss coefficient (4.52 when the units indicated above are used).

For metric units:

p_f is the frictional resistance in bar per meter of pipe.

Q is the liters per minute (L/min) flowing.

d is the actual internal diameter of pipe in millimeters (mm).

C is the friction loss coefficient (6.05×10^{-5} when the units indicated above are used).

FM Data Sheet 2-89, *Pipe Friction Loss Tables*, provides values of friction loss per length of sprinkler pipe for nominal pipe diameters. Table 1 of Data Sheet 2-89 provides friction loss values for steel pipe having a Hazen-Williams coefficient of 100, which can be used for dry-type sprinkler systems, whereas Table 2 in Data Sheet 2-89 provides friction loss values for steel pipe having a Hazen-Williams coefficient of 120, which can be used for wet-type sprinkler systems. Data Sheet 2-89 provides adjustment values for sprinkler piping having Hazen-Williams coefficients other than 100 or 120. Table 2 from this data sheet can also be used to adjust friction loss values per unit length from either Table 1 or Table 2 of Data Sheet 2-89 to Hazen-Williams coefficient values other than 100 or 120. If the actual internal diameter of the sprinkler pipe is known, then the Hazen-Williams formula can be used to provide a more accurate friction loss value.

To obtain the total friction loss from one point within a piping system to another point where the flow, pipe diameter, and Hazen-Williams coefficient values are all constant, the following equation is used:

$$P_F = p_f \times L$$ **(Equation 16)**

where:

P_F is the total friction loss through a pipe over a distance L, psi.

p_f is the friction loss value per unit length of pipe for a pipe having a given diameter and Hazen-Williams coefficient, psi/ft (bar/m)(see Equation 15).

L is the length of the pipe through which the friction loss is calculated, ft (m). This unit length, L, may include fittings, however all equivalent fitting lengths must be of the same Hazen-Williams coefficient value as the pipe that the fitting(s) is connected to.

See Table 12 (12a) for a listing of equivalent lengths for various fittings. Note that the equivalent lengths of these fittings are based on a Hazen-Williams coefficient value of 120. See Table 13 for an adjustment multiplier in the event the Hazen-Williams coefficient value for the pipe the fitting is connected to is something other than 120.

Account for fittings when they either:

1. Cause a change in the direction of flow, or
2. Cause a change in the velocity of the flow.

Size a fitting based on the pipe size connected downstream of the fitting and calculate the friction loss across the fitting when hydraulically analyzing the sprinkler piping connected downstream of the fitting.

For sprinkler pipe having a Hazen-Williams coefficient value other than those listed in Table 13, convert the equivalent fitting length indicated in Table 12 (12a) to the appropriate Hazen-Williams coefficient using the following equation:

L_{EQADJ} = (L_{EQ} from Table 12 [12a]) x $(C_{ACTUAL}/120)^{1.85}$ **(Equation 17)**

where:

L_{EQADJ} is the equivalent length of the fitting adjusted to the Hazen-Williams value, ft (m).

L_{EQ} is the equivalent length obtained from Table 12 (12a), ft (m).

C_{ACTUAL} is the actual Hazen-Williams coefficient value (C) of the sprinkler pipe.

The pressure due to elevation is calculated using the following equation:

P_E = 0.433 psi/ft (0.098 bar/m) x h, psi (bar) (Equation 2)

where:

P_E is the pressure due to elevation forces, psi (bar).

h is the overall height between the most remote sprinkler and the BOR, ft (m).

The Darcy-Weisbach formula is another calculation method for analyzing the friction loss within a sprinkler system. It is generally used for sprinkler systems filled with antifreeze solutions where the viscosity of the solution is greater than water. See Section 2.1.2.3.6 for further discussion on hydraulic calculations involving the Darcy-Weisbach method.

The following sections give basic guidelines on conducting a sprinkler system hydraulic analysis from the most remote sprinkler to the sprinkler’s BOR.

2.1.2.3.2 Tree-Type Sprinkler Systems

For tree-type sprinkler systems, the hydraulic analysis of the sprinkler system originates at the most remote sprinkler and is calculated in a single path back to the sprinkler system’s BOR. Once the hydraulic design area has been positioned on the sprinkler system as outlined in Section 2.1.2.2.5, the hydraulic analysis initiates from the most remote sprinkler with the minimum required flow and pressure as outlined in Section 2.1.2.2.1.

Starting at the most remote sprinkler with the minimum required flow and pressure, the Hazen-Williams formula is used to determine the friction loss from the most remote sprinkler to the next closest sprinkler on the same branchline. Once the friction loss has been calculated, it is added to the pressure that is required at the most remote sprinkler to determine the minimum required pressure at the next closest sprinkler. The flow from this sprinkler can then be determined using Equation 7 from Section 2.1.2.2.1.2.

This process is continued until either (a) the next closest sprinkler is not included in the hydraulic design area, or (b) the top of the riser nipple or the crossmain are encountered. In either case, the Hazen-Williams formula is used to hydraulically calculate the minimum flow and pressure needed at the intersection of the branchline to the top of the riser nipple or to the crossmain if there is no elevation difference between the branchline and the crossmain.

If the hydraulic design area includes sprinklers only on one side of a crossmain, then the Hazen-Williams formula is used to calculate the flow and pressure requirements for each branchline with sprinklers within the hydraulic design area back to the connection of the branchline to the crossmain. If there are riser nipples, then the calculation is continued from the branchline down through the riser nipple to the connection at the crossmain. At this connection point a K-factor of the branchline can be calculated using the following equation:

$K_{LINE} = Q/P^{0.5}$ **(Equation 18)**

where:

K_{LINE} is the K-factor that represents the flow and pressure for the branchline.

Q is the total flow at the intersection point based on the minimum required flow at the sprinkler furthest from the intersection point and within the hydraulic design area.

P is the total pressure at the intersection point based on the minimum required pressure at the sprinkler furthest from the intersection point and within the hydraulic design area.

If there are sprinklers on both sides of a crossmain included in the hydraulic design area, then the minimum required flow and pressure as determined from Equation 7 from Section 2.1.2.2.1.2 is applied to both sprinklers that are furthest from the intersection point of the branchline and the crossmain and are still within the boundaries of the hydraulic design area.

The Hazen-Williams formula is then used to calculate the flow and pressure for both branchlines back to their common point of connection; typically, this is either the top of a riser nipple or at the crossmain when riser nipples are not present.

If the pressure requirements at this common point are not equal, then the calculated flow from the branchline with the lower minimum required pressure has to be hydraulically balanced up to the pressure required for the other branchline. This is accomplished using the following equation:

$$Q_{ADJ} = Q_L \times [(P_H - P_E)/(P_L - P_E)]^{0.5} \quad \textbf{(Equation 19)}$$

where:

Q_{ADJ} is the flow that has been adjusted up from P_L to P_H , gpm (L/min).

Q_L is the flow that is required at the common intersection point based on P_L, gpm (L/min).

P_L is the lower of the two pressure requirements at the common intersection point, psi (bar).

P_H is the higher of the two pressure requirements at the common intersection point, psi (bar).

P_E is any pressure due to elevation that is included in P_L, psi (bar).

Note that the exponential value for this equation is “0.50” when balancing together relatively small flow amounts, such as when balancing sprinklers on a single branchline together, but the value increases to “0.54” when relatively large flow amounts, such as balancing two sprinkler systems together, are involved.

The value of Q_{ADJ} is then added to the value of Q_H (the flow that is required at the common intersection point based on P_H) to obtain the total minimum required flow at the common intersection point.

Equation 19 is commonly referred to as the equation for hydraulic balancing. It is used whenever two calculated sprinkler flows meet at a common reference point and are at different required pressures. The flow based on the lower required pressure is always balanced up to the higher required pressure. The important aspect to realize when hydraulic balancing is required is to account for any pressure due to elevation (P_E) when using Equation 19.

If this common point is at a riser nipple, then calculate the friction loss from the nipple riser to the crossmain and add it to P_H in order to determine the minimum required flow and pressure at the connection to the crossmain. Once the minimum required flow and pressure has been calculated to the crossmain connection, the K-factor of the branchline can be determined using Equation 18.

Once all sprinklers in the hydraulic design area have been calculated back to the crossmain and the K-factor of each branchline has been determined, then the flow and pressure required at the BOR can be calculated by starting at the flow and pressure at the most remote branchline and working backward through the crossmain using the Hazen-Williams formula to calculate the friction loss through the crossmain and then adding in the sprinkler flow from each flowing branchline using the following equation:

$Q_{BL} = K_{LINE} \times (P)^{0.5}$ **(Equation 20)**

where:

Q_{BL} is the flow being sent into the branchline from the crossmain at pressure P, gpm (L/min).

K_{LINE} is the K-factor of the branchline that flow is being directed into, $gpm/psi^{0.5}$ $(L/min/bar^{0.5})$.

P is the pressure required at the intersection of the branchline and crossmain, psi (bar).

Once the flow from the last flowing branchline has been added in, this becomes the flow required at the BOR. The Hazen-Williams formula is then used to determine the friction loss from this connection point to the BOR. Once the pressure due to friction loss has been calculated, the final step is to add in any pressure due to elevation.

2.1.2.3.3 Loop-Type Sprinkler Systems

Loop-type sprinkler systems provide a means of reducing the friction loss within a sprinkler system by replacing the single-flow path crossmain with a multi-flow path loop main. Calculation of a “simple” loop-type sprinkler system (i.e. a system having dead-end branchlines and a single loop main) can be calculated by hand. If, however, the sprinkler branchlines are not of the dead-end type or the sprinkler system is equipped with more than one loop main, then calculation by hand would be very involved and would best be handled by a computer program.

The calculation method of simple loop-type sprinkler systems takes into account two basic hydraulic principles:

(1) Pressure difference between any two points of a sprinkler system is the same by any route through the system, and

(2) Water flow into a point within the sprinkler system equals the flow away from the point.

These two basic principles allow a simple loop-type sprinkler system to be calculated in the same manner as a tree-type sprinkler system with the following two differences:

(1) The shape of the hydraulic design area is established in same manner as a tree-type system but it is positioned on the sprinkler system as close as possible to the hydraulically most remote point on the loop main, and

(2) The flow from the branchline closest to the center of the hydraulic design area is split with a given amount flowing in a counter-clockwise direction within the loop main while the rest of the flow from this branchline is flowing in a clockwise direction. The percentage of flow in any one direction is determined using the following equation:

$Q_1/Q_T = 1/([L_1/L_2]^{0.54} + 1)$ **(Equation 21)**

where:

Q_T is the total amount of flow from the center branchline. It is equal to the sum of Q_1 and Q_2.

L_1 is the equivalent length of pipe from the crossmain/feedmain (CM/FM) connection to the center branchline within the hydraulic design area. It must be based on the same equivalent diameter and Hazen-Williams coefficient upon which L_2 is based.

L_2 is the equivalent length of pipe from the crossmain/feedmain (CM/FM) connection to the center branchline within the hydraulic design area. It must be based on the same equivalent diameter and Hazen-Williams coefficient upon which L_1 is based.

Q_1 is the amount of flow from the center branchline that flows through the loop main having an equivalent length L_1.

Q_2 is the amount of flow from the center branchline that flows through the loop main having an equivalent length L_2.

Once Q_1 and Q_2 have been determined, then the hydraulic analysis is the same as a tree-type system back to the CM/FM connection. At this point in the sprinkler system the flow based on the lower pressure can be hydraulically balanced up to the higher pressure and then added together. The calculation back to the BOR is the same as indicated for a tree-type system.

2.1.2.3.4 Grid-Type Sprinkler Systems

The hydraulic evaluation of a grid-type automatic sprinkler system consists of multiple trial and error calculations based on the principles that the flow into a point on a sprinkler system equals the flow out and the pressure at any point in a sprinkler system must be a single value. Due to the nature of a grid-type sprinkler, there are multiple points within the sprinkler system where water flows through multiple paths, thus resulting in the need to conduct hydraulic balancing calculations, usually to within 0.5 psi (0.003 bar).

Such calculations are very involved and are best handled by a computer software program specifically designed for the evaluation of automatic sprinkler systems using either the Hazen-Williams formula or by the Darcy-Weisbach calculation method.

2.1.2.3.5 Multiple-Level Sprinkler Systems

There are two types of multiple-level sprinkler systems from a hydraulic analysis standpoint. The first is a single sprinkler system in which there is one or more branchlines having sprinklers at different elevation levels that connect together at a reference point other than the BOR. An example of this would be sprinklers that are protecting the area below a mezzanine and are fed from the same sprinkler system that is protecting the area above the mezzanine. Another example of this would be an isolated storage rack that is protected by both ceiling and in-rack sprinklers in which the in-rack sprinklers are fed from the same sprinkler system located above the rack storage.

The other type of multiple-level sprinkler system is one in which two or more sprinkler systems are protecting the same area at different elevation levels, but connect together at the BOR. The most common example of this type of multiple-level sprinkler system combination is a ceiling-level sprinkler system and a separate in-rack sprinkler system that connect together at their BORs.

2.1.2.3.5.1 A Sprinkler System With Multiple-level Sprinklers Connecting Prior to the Base of the Sprinkler Riser

Often, an automatic sprinkler system will have sprinklers located at more than one elevation when referenced to the BOR. When this is the case, hydraulic calculations will require hydraulic balancing at some point within the sprinkler system prior to the BOR if the minimum pressure required is different at the same point of connection.

The hydraulic calculation method for such cases is no different than what has been previously discussed before in Section 2.1.2.3. To demonstrate this concept, the following example is provided.

Example No. 2: An isolated 25 ft (7.5 m) high storage rack is located within a manufacturing area and must be provided with in-rack sprinklers to provide an acceptable level of protection. Because it is an isolated storage rack, the in-rack sprinklers protecting it are fed from the ceiling system located above the storage rack. The in-rack sprinklers are located at the 15 ft (4.5 m) high tier level whereas the ceiling sprinklers are located 29 ft (8.7 m) above the floor. At the point of connection where the in-rack sprinkler piping connects to the ceiling sprinkler system, the minimum required flow and pressure for the in-rack sprinklers is 135 gpm (510 L/min) at 35 psi (2.41 bar), which includes a pressure gain of 6.1 psi (0.42 bar) due to elevation. The minimum required flow and pressure for the ceiling sprinklers at this same connection point is 660 gpm (2,500 L/min) at 45 psi (3.10 bar) and includes a pressure loss of 1.3 psi (0.09 bar) due to elevation.

Because the minimum required flows from both systems are at different pressures at their point of connection, the flow from the sprinklers at the lower pressure must be hydraulically balanced up to the higher minimum required pressure using Equation 19 as follows:

$$Q_{ADJ} = (135\text{ gpm}) \times [(45\text{ psi} - (-6.1\text{ psi}))/(35\text{ psi} - (-6.1\text{ psi}))]^{0.5} = 151\text{ gpm}$$

$$Q_{ADJ} = (510\text{ L/min}) \times [(3.10\text{ bar} - (-0.42\text{ bar}))/(2.41\text{ bar} - (-0.42\text{ bar}))]^{0.5}$$

$$= 570\text{ L/min}$$

Therefore, at the point of connection, the in-rack sprinkler adjusted flow of 151 gpm (570 L/min) is added to the minimum required ceiling sprinkler flow of 660 gpm (2,500 L/min) to obtain a minimum required flow and pressure of 811 gpm (3,070 L/min) and 45 psi (3.10 bar) at the common point of connection.

2.1.2.3.5.2 A Multiple-level Sprinkler System Consisting of Two or More Sprinkler Systems at Different Elevations Within the Same Protected Area Connecting at the Base of the Sprinkler Riser

Often, two separate automatic sprinkler systems will be used to protect the same area, such as separate ceiling and in-rack sprinkler systems. When this is the case, hydraulic analysis of the two systems will require hydraulic balancing at some point within the fire protection network, usually just below each of the sprinkler system’s BOR.

The hydraulic calculation method for such cases is no different than what has been previously discussed before in Section 2.1.2.3. To demonstrate this concept, the following example is provided.

Example No. 3: An 80 ft (24.4 m) high warehouse contains open-frame rack storage to 75 ft (23 m) high. The storage racks are protected by 5 levels of in-rack sprinklers. The demand for the in-rack sprinkler system is based on a minimum flow of 30 gpm (115 L/min) from the most remote 14 sprinklers (7 on 2 levels), which requires a flow and pressure of 475 gpm (1,800 L/min) and 75 psi (5.17 bar) at the in-rack sprinkler system’s BOR. The required pressure for this sprinkler system includes 30.3 psi (2.09 bar) due to elevation pressure. The demand for the ceiling sprinkler system is based on a minimum pressure of 10 psi (0.69 bar) from the most remote 15 sprinklers, which requires a flow and pressure of 550 gpm (2,082 L/min) and 80 psi (5.52 bar) at the ceiling sprinkler system’s BOR. The required pressure for this sprinkler system includes 34.2 psi (2.36 bar) due to elevation pressure. The two sprinkler systems are fed from a common point located just below their BOR’s.

Because the minimum required flows from both systems are at different pressures at their point of connection, the flow from the sprinklers at the lower pressure must be hydraulically balanced up to the higher minimum required pressure using Equation 19 as follows:

Q_{ADJ} = (475 gpm) x $[(80 \text{ psi} - 30.3 \text{ psi})/(75 \text{ psi} - 30.3 \text{ psi}))]^{0.54}$ = 503 gpm

Q_{ADJ} = (1,800 L/min) x $[(5.52 \text{ bar} - 2.09 \text{ bar})/(5.17 \text{ bar} - 2.09 \text{ bar})]^{0.54}$

= 1,904 L/min

Therefore, at the point of connection, the in-rack sprinkler adjusted flow of 503 gpm (1,904 L/min) is added together with the minimum required ceiling sprinkler flow of 550 gpm (2,082 L/min) to obtain a minimum required flow and pressure of 1,053 gpm (3,986 L/min) and 80 psi (5.52 bar) at the common point of connection.

2.1.2.3.6 Darcy-Weisbach Analysis Method

Use the Darcy-Weisbach analysis method for sprinkler systems containing liquid media other than water, such as an antifreeze solution, as this analysis method more accurately accounts for changes in the liquid’s temperature, density, and viscosity compared to the results obtained using the Hazen-Williams analysis method.

The Darcy-Weisbach formula is as follows:

$F_{DW} = (0.000216) \times (f) \times (L) \times (\rho) \times (Q)^2/(d)^5$ (psi) (Equation 22)

$F_{DW} = (2.252) \times (f) \times (L) \times (\rho) \times (Q)^2/(d)^5$ (bar) (Equation 22a)

where:

F_{DW} is the friction loss per the Darcy-Weisbach formula, psi (bar).

f is the friction loss factor per the Moody diagram.

L is the length of the pipe through which the friction loss is calculated, ft (m).

ρ is the density of the liquid media, lb/ft^3 (kg/m^3).

Q is the flow rate within the sprinkler piping, gpm (L/min).

d is the internal diameter of the sprinkler pipe, in. (mm).

The value of *f* is determined using the Moody diagram shown in Figure 2. The *f* values are shown on the left side of the Moody diagram along the y-axis; to obtain a particular *f* value, you need to know both the Reynolds number (Re), which is shown along the x-axis of the diagram, and the relative roughness factor, which is on the right side of the diagram along the y-axis. Where the lines for the Reynolds number and the relative roughness factor intersect, follow the line to the left to find the value of the friction loss factor.

The Reynolds number is obtained from the following equation:

$Re = 50.6 \times (Q) \times (\rho)/[(d) \times (\mu)]$ (English-based units) **(Equation 23)**

$Re = 21.22 \times (Q) \times (\rho)/[(d) \times (\mu)]$ (SI units) **(Equation 23a)**

where:

μ is the absolute (dynamic) viscosity, centipoise.

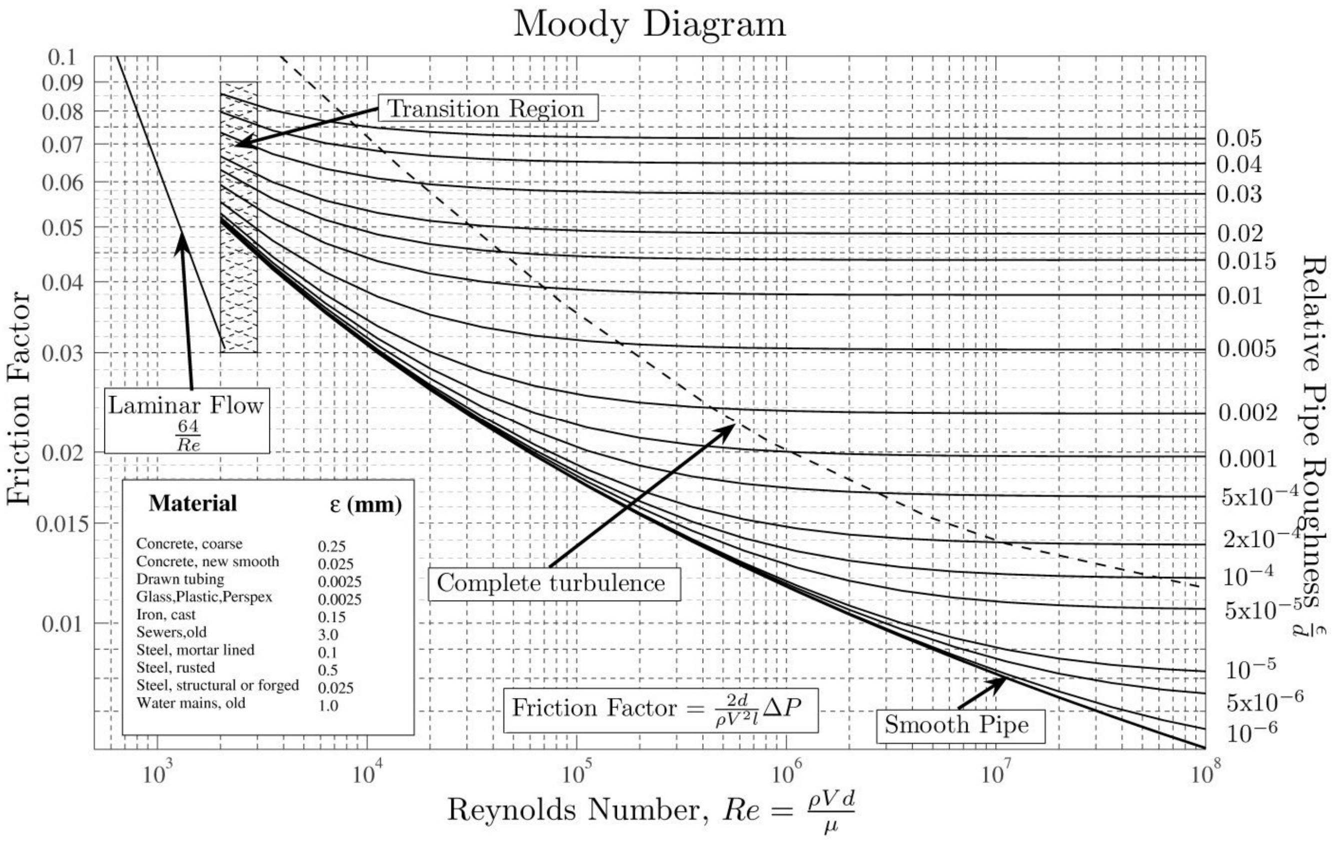
The relative roughness factor number is obtained from the following equation:

Relative roughness factor = ϵ/D **(Equation 24)**

where:

ϵ is the pipe wall roughness, ft (mm).

D is the internal pipe diameter, ft (mm).



Material	**ε (mm)**
Concrete, coarse	0.25
Concrete, new smooth	0.025
Drawn tubing	0.0025
Glass,Plastic,Perspex	0.0025
Iron, cast	0.15
Sewers,old	3.0
Steel, mortar lined	0.1
Steel, rusted	0.5
Steel, structural or forged	0.025
Water mains, old	1.0

Fig. 2. Moody Diagram (Courtesy ASME)

2.1.2.4 Graphical Representation of the Hydraulic Analysis

2.1.2.4.1 Introduction

Once the minimum required flow and pressure of any sprinkler system has been calculated at the sprinkler system's BOR, graphical representation of the hydraulic relationship between the flow and pressure of the calculated sprinkler system is required in order to determine the level of protection that is provided by the available water supply. This graphical representation, which is called a sprinkler demand curve, is illustrated using $N^{1.85}$ graph paper, as shown in Figure 5 of Appendix D.

There are two types of sprinkler systems for graphical representation purposes. The first is a single sprinkler system that is protecting a given area. The second is an area that is protected by more than one sprinkler system. Examples of multiple sprinkler systems in the same area would be an area protected by an existing ceiling sprinkler system as well as an over-lay sprinkler system, or storage racks that are provided with in-rack sprinklers fed from a system separate than the ceiling level sprinklers protecting the racks.

Discussion on how to graphically represent both types of sprinkler systems is provided in the two following sections.

2.1.2.4.2 Plotting the Results of a Single Sprinkler System Within the Protected Area

To graphically represent the minimum required flow and pressures for an automatic sprinkler system on $N^{1.85}$ graph paper, you need the following two points that help develop the sprinkler demand curve:

1. The flow and pressure at the sprinkler system's BOR to meet the minimum required design, and
2. The pressure due to elevation (at no flow) between the BOR and the sprinkler at the highest elevation located within the demand area

The sprinkler demand curve can also be represented mathematically using the following equation:

$$P_2 = (Q_2/Q_1)^{1.85} \times (P_1 - P_E) + P_E \quad \textbf{(Equation 25)}$$

where:

Q_1 is a given flow value on the sprinkler demand curve at pressure P_1, gpm (L/min).

Q_2 is any flow on the sprinkler demand curve at a pressure P_2, gpm (L/min).

P_1 is a given pressure value on the sprinkler demand curve at flow Q_1, psi (bar).

P_2 is any pressure on the sprinkler demand curve at a flow Q_2, psi (bar).

P_E is the pressure due to elevation between the highest sprinkler and the BOR, psi (bar).

2.1.2.4.3 Plotting the Results of Multiple Sprinkler Systems Within the Protected Area

To graphically represent multiple sprinkler systems within the same protected area operating simultaneously, follow these steps:

1) Plot the sprinkler demand curves for each sprinkler system individually as outlined in Section 2.1.2.4.2.
2) Draw a combined sprinkler system curve that represents all of the individual sprinkler systems operating simultaneously as follows:
    (a) Start at 0 psi (0 bar) and rise up the y-axis (pressure scale) until the first sprinkler system pressure point due to elevation is encountered.
    (b) At this pressure point the combined sprinkler system demand curve will be the same as the sprinkler demand curve until the pressure value reaches the elevation pressure of another sprinkler system.
    (c) Once the elevation pressure point of another sprinkler system is encountered, the combined sprinkler system demand curve becomes the combined flow of the sprinkler systems at the given pressure value.

3) This process is continued until all sprinkler systems have been combined into a single demand curve.

2.1.2.4.4 Plotting the Available Water Supply After Deductions

Section 2.1.2.4 outlines the procedure for graphically plotting the water supply available at an automatic sprinkler system's BOR.

In most cases the design requirements for the automatic sprinkler system will include a hose demand as part of the design. In such cases, the hose demand needs to be deducted from the water supply available at the sprinkler system's BOR if the water supply for the hose streams also feeds the automatic sprinkler system.

To adjust a water supply due to an indicated deduction, first plot the water supply available at the sprinkler system's BOR prior to any deductions and label this curve accordingly. For the water supply available after deductions, simply draw the same water supply curve, but adjust it by subtracting the required deduction flow from each pressure point on the curve.

2.1.2.4.5 Rating the Sprinkler System for Adequacy

Once the water supply available at a sprinkler system's BOR (minus any required deductions) and the sprinkler system demand curve (or combined curve if more than one sprinkler system is provided) have been plotted on $N^{1.85}$ graph paper, the adequacy rating of the sprinkler system can be determined.

Sprinkler systems are rated as either "Adequate" or "Inadequate."

An automatic sprinkler system is rated Adequate when the available water supply, after accounting for any required deductions, is able to provide the full flow and pressure required for all sprinkler systems operating concurrently within the protected area for the required duration.

An available water supply that cannot meet the requirements for a rating of Adequate is rated as Inadequate.

The process for determining the rating of an automatic sprinkler system is as follows:

1. Plot and label the water supply available at the BOR.
2. Plot and label the water supply available at the BOR after any required deductions.
3. Plot and label all concurrently operating sprinkler systems for the area being protected.
4. Plot and label the combined sprinkler system curve if more than one sprinkler system curve is drawn.

5. In a case where a single sprinkler system is provided, graphically determine the flow and pressure available to the sprinkler system from the water supply (after deductions). The flow and pressure available is based on where the sprinkler demand curve and the curve for the water supply (after deductions) intersect.
6. In a case where more than one sprinkler system is provided, graphically determine the flow and pressure available to each sprinkler system from the water supply (after deductions). The flow and pressure available to each sprinkler system is first determined by seeing where the combined sprinkler system curve and the curve for the available water supply (after deductions) intersect. Using the pressure value at this intersection, see what the corresponding flow values are for each sprinkler system on its respective sprinkler demand curve.
7. Using the flow and pressure values available at the BOR for each sprinkler system, indicate what is available for the sprinkler system using the design format required of the sprinkler system. See Section 2.1.2.4.5.1 for further details regarding this process.
8. Determine the duration available from the water supply.

If the available water supply can provide the required flow and pressure for the sprinkler system(s) for the entire required duration, the sprinkler system rates Adequate; otherwise it rates Inadequate.

See Section 2.1.2.4.5.1 for a discussion on how to convert the flow and pressure available from the water supply into a format that the sprinkler system design was based on.

See Section 2.1.2.4.5.2 for a discussion on how to determine the duration available from a water supply.

2.1.2.4.5.1 Converting Flow and Pressure Available to a Sprinkler System into a Design Format

There are three formats that the designs for most sprinkler systems are based on. They include:

- Density/Demand Area
- Minimum Required Flow @ Most Remote Sprinkler/Number of Sprinklers
- Minimum Required Pressure @ Most Remote Sprinkler/Number of Sprinklers

The entirety of the sprinkler demand curve for each individual sprinkler system represents either a fixed demand area or a fixed number of sprinklers; however, each individual point along the sprinkler demand curve represents different values of density, minimum required flow, or minimum required pressure.

2.1.2.4.5.1.1 Conversion of the Flow and Pressure Available at the BOR from a Water Supply to a Design Based on Density

Conversion of the flow and pressure available at the BOR from a water supply to a design based on density is accomplished as follows:

$D_{AVAIL} = D_{DESIGN} \times (Q_{AVAIL}/Q_{DESIGN})$ **(Equation 26)**

where:

D_{AVAIL} is the density available from the water supply based on Q_{AVAIL}.

D_{DESIGN} is the density based on the required design.

Q_{AVAIL} is the flow available from the water supply at the BOR.

Q_{DESIGN} is the flow based on the required design at the BOR.

2.1.2.4.5.1.2 Conversion of the Flow and Pressure Available at the BOR from a Water Supply to a Design Based on Minimum Required Flow at the Most Remote Sprinkler

Conversion of the flow and pressure available at the BOR from a water supply to a design based on minimum required flow at the most remote sprinkler is accomplished as follows:

$q_{AVAIL} = q_{DESIGN} \times (Q_{AVAIL}/Q_{DESIGN})$, **(Equation 27)** or

$q_{AVAIL} = q_{DESIGN} \times (D_{AVAIL}/D_{DESIGN})$ **(Equation 28)**

where:

q_{AVAIL} is the flow available from the water supply at the most remote sprinkler.

q_{DESIGN} is the flow based on the required design at the most remote sprinkler.

Q_{AVAIL} is the flow available from the water supply at the BOR.

Q_{DESIGN} is the flow based on the required design at the BOR.

D_{AVAIL} is the density available from the water supply based on Q_{AVAIL}.

D_{DESIGN} is the density based on the required design.

2.1.2.4.5.1.3 Conversion of the Flow and Pressure Available at the BOR from a Water Supply to a Design Based on Minimum Required Pressure at the Most Remote Sprinkler

Conversion of the flow and pressure available at the BOR from a water supply to a design based on minimum required pressure at the most remote sprinkler is accomplished as follows:

$p_{AVAIL} = p_{DESIGN} \times ([P_{AVAIL} - P_E]/[P_{DESIGN} - P_E])^{1.08}$ **(Equation 29)**

where:

p_{AVAIL} is the pressure available from the water supply at the most remote sprinkler.

p_{DESIGN} is the pressure based on the required design at the most remote sprinkler.

P_{AVAIL} is the pressure available from the water supply at the BOR.

P_{DESIGN} is the pressure based on the required design at the BOR.

P_E is the pressure due to elevation between the BOR and the highest sprinkler located within the sprinkler system.

2.1.2.4.5.2 Determining Duration Available from a Water Supply

In addition to meeting the flow and pressure requirements for a sprinkler system or combination of sprinkler systems, a water supply must also be available for a given time period to help ensure a fire can be extinguished before the water supply becomes exhausted.

The duration of a water supply is determined as follows:

$$\text{Duration} = (\text{Volume of Water Supply})/(Q_{AS} + Q_{DEDUCT}) \quad \text{(Equation 30)}$$

where:

Duration is the time period that the water supply will be available to provide the minimum required flow and pressure, minutes.

Volume of Water Supply is the capacity of the water supply available, gal (L).

Q_{AS} is the required minimum flow rate of all of the sprinkler systems protecting the affected area, gpm (L/min).

Q_{DEDUCT} is the required minimum flow rate for all deductions, gpm (L/min).

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Bernoulli’s Theorem and Applications

Problems of water flow in pipes are usually solved by procedures based on Bernoulli’s theorem, which states that “in steady flow, without friction, the sum of velocity head, pressure head, and elevation head is constant for a particle throughout its course.” This theorem can be expressed by the following equation:

$$(v^2/2g) + (p/w) + Z = H \quad \textbf{(Equation 31)}$$

where:

v is the velocity, ft/s (m/s).

g is the acceleration of gravity = 32.2 ft/sec^2 (9.81 m/sec^2).

p is the pressure, lb/ft^2 (bar).

w is the weight of water per unit volume = 62.4 lb/ft^3 (9,810 N/m^3).

z is the elevation head (or potential head), distance above an assumed datum, ft (m).

H is the total head of water, ft (m).

In Equation 31 the terms $(v^2/2g)$ and (p/w) express velocity head and pressure head, respectively and are defined as indicated in the following equations:

Velocity head = $h_v = v^2/2g$, **(Equation 32)**

and

Pressure head = $h_p = p/w$, **(Equation 33)**

We can rearrange Equation 32 to solve for velocity as follows:

$v = (2gh)^{0.5}$ **(Equation 34)**

Likewise, we can rearrange Equation 33 to solve for pressure as follows:

$p = (w) x (h_p)$ **(Equation 35)**

Because total head (H) is constant, a change in velocity results in the conversion of velocity head to pressure head, or vice versa.

For a pipeline flowing full between points A and B, Bernoulli’s theorem can be modified to include friction, as follows:

$(v_A^2/2g) + (p_A/w) + z_A = (v_B^2/2g) + (p_B/w) + z_B + h_{AB}$ **(Equation 36)**

where h_{AB} is the total dynamic head lost between points A and B.

Figure 3 illustrates the relationships between various factors in typical piping. Heads are indicated by heights to which water rises in the vertical tubing. Velocity magnitudes and directions are indicated by arrows. At each location, B, C, D, E, and F, pressure head, h_{pF}, h_{pB}, etc., is a measure of the potential energy of water in the pipe; velocity head, h_{vF}, etc., is a measure of the kinetic energy of the water; and the sum, $h_{pF} + h_{vF}$, etc., total head, is a measure of the total energy of the water.

Flow rate in a pipeline or discharge through an orifice can be expressed in terms of velocity and cross-sectional area of the stream as follows:

$Q = (A) x (v)$ **(Equation 37)**

where:

Q is the flow rate, ft^3/sec (m^3/sec).

A is the cross-sectional stream area, ft^2 (m^2).

v is the average water velocity, ft/sec (m/sec).

Equation 37 can be rearranged to solve for velocity as follows:

$v = Q/A$ **(Equation 38)**

In Figure 3, $Q_F = Q_B$ because no water flows out of the pipe (once stabilized in the vertical tubing).

Therefore, from Equation 37, $(A_F) \times (v_F) = (A_B) \times (v_B)$, and since the pipe does not change size, $A_F = A_B$, so that $v_F = v_B$. This means kinetic energy is the same at point F and at point B, and $h_{vF} = h_{vB}$. Pressure head decreases linearly between points F and B. The difference, $h_{pF} - h_{pB}$, is friction loss or the total dynamic head lost between points F and B (see Equation 36).

The loss rate per unit length is $(h_{pF} - h_{pB})/L$, where L is length between points F and B.

In Figure 3, water is flowing out of the pipe at point B, and the fitting between points D and E reduces the cross-sectional area. Flow at point F is the sum of flows at points B and C, $Q_F = Q_B + Q_C$. Since $Q_B > 0$, Q_C must be less than Q_F, $(A_C \times v_C < A_F \times v_F)$. The cross-sectional areas at points F and C are the same, so $v_C < v_F$. This means kinetic energy at point C is less than at point F or $h_{vC} < h_{vF}$. Pressure head, h_{pC}, is shown slightly less than h_{pF} because of friction loss straight through the fitting. Flow out of the pipe at point B has substantially increased velocity, because all potential energy is given up to friction or converted to kinetic energy. Thus, total head at point F, $h_{pF} + h_{vF}$, equals $h_{FB} + h_{vB}$, friction loss between points F and B plus velocity head at point B. From experimental observation, friction loss between points F and B for discharging water is approximately equal to velocity head at point F, $h_{FB} \approx h_{vF}$.

Between points C and D, $Q_C = Q_D$, $v_C = v_D$, $h_{vC} = h_{vD}$, and h_{pC} drops slightly because of friction to h_{pD}.

From points D to E, $Q_D = Q_E$ or $(A_E) \times (v_E) = (A_D) \times (v_D)$ (from Equation 37), but $A_E < A_D$, so v_E must be greater than v_D. Since velocity increases, kinetic energy does also, and $h_{vE} > h_{vD}$ shows this.

Since friction loss in reducers is greater than in pipes, the rate of drop from h_{pD} to h_{pE} is greater than from h_{pC} to h_{pD}.

Formulas, such as Q = (A)x(v), depending on velocity or velocity head, are not suited to the solution of problems involving flow in closed pipes because simple equipment for direct measurement of velocity or velocity head in closed pipes is not available. Ordinary pressure gauges tapped into pipelines register pressure head only, and therefore give no indication of velocity head or rate of flow. Although suitable devices and procedures for direct pipeline gauging have been developed for studies of waterworks distribution systems, penstocks, etc., these methods are seldom employed in private fire protection practice.

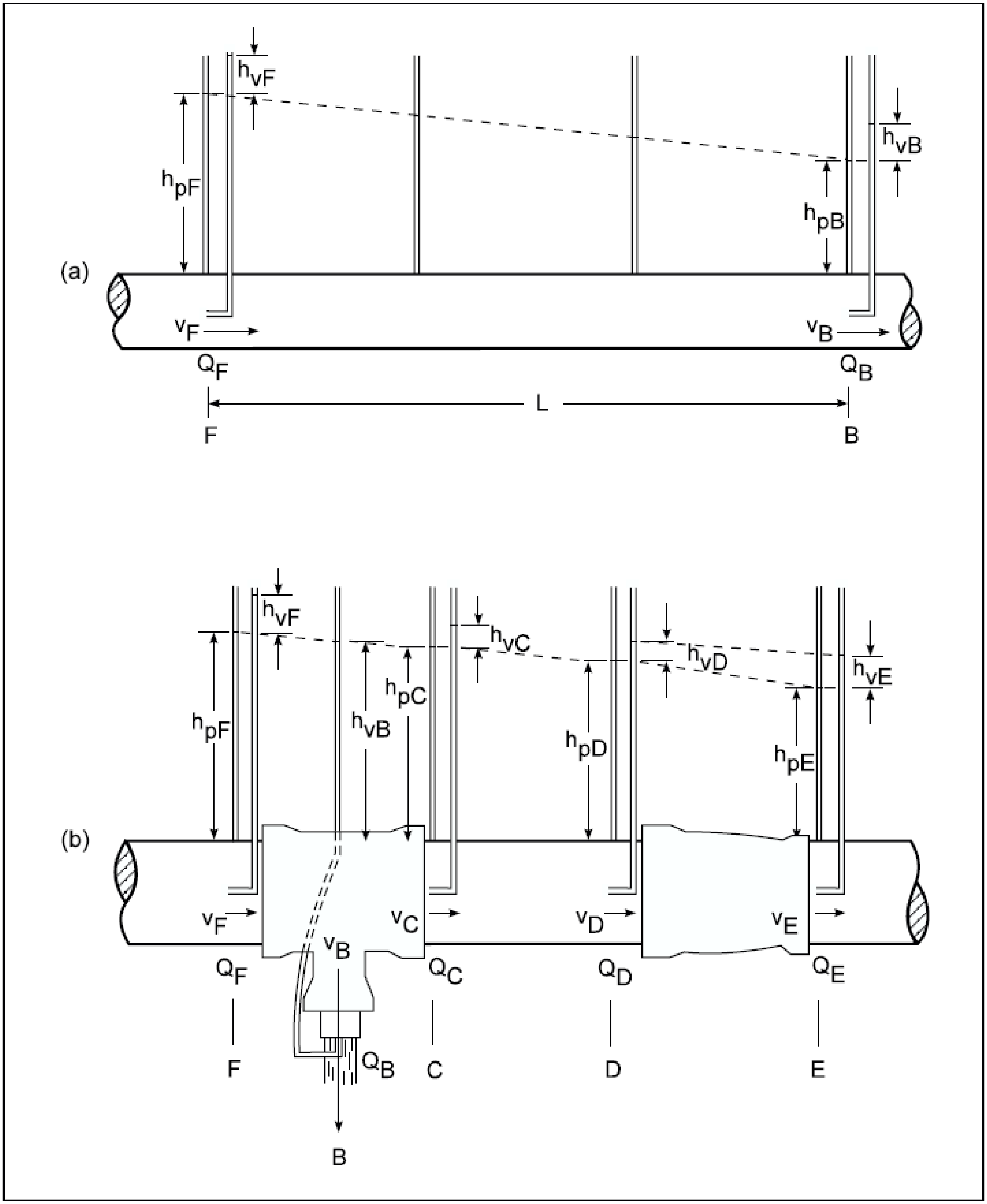


Fig. 3. Relationships between various hydraulic factors in typical piping

3.2 Hazen-Williams Formula

For fire protection and waterworks, the most widely accepted pipe flow formula was developed by G. S. Williams and Allen Hazen. In conventional fire protection units, the Hazen-Williams formula is:

$$p = (c)\ (Q/C)^{1.85}/d^{4.87}$$ **(Equation 15)**

where:

p is the loss per unit length, psi/ft (bar/m).

c is the constant = 4.52 (6.06×10^5 for p in bars).

Q is the flow rate, gpm (L/min).

C is the Hazen-Williams pipe coefficient.

d is the internal pipe diameter, in. (mm).

Other formulas, developed by Chezy, Darcy, Weisbach, Fanning, Reynolds, and others, are sometimes used.

Head is converted to pressure by the relation:

1 ft = 0.433 psi (1 m = 0.098 bar)

Under this relation, terminology changes as follows:

Total head	corresponds to	Total Pressure
Velocity head	corresponds to	Velocity Pressure
Elevation head	corresponds to	Elevation Pressure
Pressure head	corresponds to	Normal Pressure

Friction loss tables in Data Sheet 2-89 give values of p for varying flow rates, pipe coefficients, and pipe diameters. Factors for changing from one pipe coefficient to another are also given.

Suggested values of C for various kinds of pipe used underground are given in Table 3. The rate of change in the value of C with age in unlined cast-iron pipe depends on corrosive activity of the water. Saturation Index is a commonly used measure of a specific water’s corrosive quality and should be available from the water utility in the area. It establishes three categories: positive, zero, and negative, corresponding to mildly, moderately, and severely corrosive waters.

Fire protection pipe, normally without flow, is expected to deteriorate less rapidly than pipe subject to continuous or intermittent draft. Cement-lined, bitumastic-enamel-lined, or cement asbestos pipe is relatively smooth with little or no reduction in carrying capacity over a reasonable period of time.

Unlined steel pipe exposed to water for various time periods has a wide range of C values. To allow for quick early deterioration under field conditions use a Hazen-Williams C value of 120 for wet pipe sprinkler systems as well as dry pipe sprinkler systems provided with galvanized piping and a Hazen-Williams C value of 100 for dry pipe sprinkler systems equipped with black steel type sprinkler piping.

3.3 Pressure Loss at Fittings

In typical public water or fire protection pipe, losses arising from changes in flow direction and changes in velocity are called “loss due to fittings”. Such losses are proportional to velocity head ($v^2/2g$) and can be equated to losses in a length of straight pipe. Table 12 (12a) gives equivalent pipe lengths for various fittings.

In underground pipe computations, fitting loss is generally a small portion of total loss and is not normally considered unless specific devices, such as backflow preventers which can cause at least a loss of 5 psi (0.34 bar) across them, have been installed. In sprinkler system computations, fitting loss is normally considered.

Experiments have shown that pressure loss due to fittings occurs primarily downstream from the fittings and involves cavitation and turbulence. Thus, tees have larger losses than short radius elbows, which have larger losses than long radius elbows, etc.

3.4 Discharge from Nozzles

From Equations 32 and 37, it follows that:

$$Q = (A) \times [(2)\times(g)\times(h_v)]^{0.5}$$ **(Equation 39)**

In a jet discharging from a nozzle, all the available head (velocity head plus pressure head) is converted to velocity head, which can be measured with a Pitot gauge. When velocity head and nozzle diameter are known, theoretical discharge can be computed from Equation 39.

3.5 Discharge Coefficient

Actual discharge is less than computed discharge because velocity is not uniform over the cross section of the stream. Therefore, a correction factor, or discharge coefficient, is needed in order to use Equation 39.

Thus, Equation 39 is modified to include a correction factor, or discharge coefficient, as follows:

$$Q = (c)\times(A) \times [(2)\times(g)\times(h_v)]^{0.5}$$ **(Equation 40)**

where c is the discharge coefficient. Table 4 gives typical discharge coefficients.

Discharge coefficients used in calculations of flow from hydrants depend upon the character of the hydrant outlet. Figure 4 shows three typical types of hydrant outlets.

Hydrants with orifice plates or valved butts are not in any of the above categories. Use hoses with nozzles to determine flow.

In convenient fire protection units, Equation 40 may be rewritten as follows:

$Q = (a)x(c)x(d^2)x(P_V)^{0.5}$ **(Equation 1)**

where:

Q is the rate of flow, gpm (L/min).

a is the constant = 29.8 (0.666 for P_V in bars).

c is the discharge coefficient.

d is the orifice diameter, in. (mm).

P_V is the velocity pressure or Pitot pressure, psi (bar).

3.6 Theoretical Discharge

Tables 6 through 11 give theoretical discharges in gpm (L/min), based on Equation 1, for various orifice diameters and velocity (Pitot) pressures when c = 1.00. To obtain actual discharge, find theoretical discharge corresponding to known P_V and d, and multiply by appropriate coefficient from Table 4.

3.7 Nozzle K Factor

Equation 1 can also be written in the form:

$Q = (K)x(P_V)^{0.5}$ **(Equation 41)**

where:

$K = (a)x(c)x(d^2)$ **(Equation 42)**

K is a theoretical constant for a given orifice. If nozzle K is known and P_V is measured, discharge in gpm (L/min) is found from Equation 41. Nominal values of K for various nozzles are given in Table 5.

The K of a sprinkler is calculated from a variation of Equation 41 as follows:

$Q = (K) x (P_N)^{0.5}$ **(Equation 43)**

where P_N is measured upstream from the sprinkler in a pipe or reservoir.

When P_N is measured in a reservoir, P_V is essentially zero, so we use $P_N = P_t$ and write:

$Q = (K) x (P_t)^{0.5}$ **(Equation 44)**

3.1.8 Combined Sprinkler Discharge and Pipe Flow

Discharge from single sprinklers is calculated from Equation 7 (or 44). Flow in a pipe is available from Equation 15 ($p = (c/d^{4.87}) x (Q/C)^{1.85}$) where we solve for Q. For a specific piece of pipe, c, C and d are constant, so we can solve for Q to get:

$Q = (K) x (p^{0.54})$ **(Equation 44)**

where:

$K = (C) x (d^{2.63})/(c^{0.54})$ is also constant **(Equation 45)**

If several sprinklers in a constant elevation system are operating, calculations use both $p^{0.5}$ and $p^{0.54}$. A group of sprinklers with piping can thus be represented by $Q = (K) x (p^r)$, where K is constant and $0.5 < r < 0.54$. Pinpointing r within this range is impractical. When friction loss is relatively small, as with large pipe, short branch lines, or small groups of sprinklers, r is close to 0.5. Conversely, when friction loss is relatively large, r is close to 0.54.

For a fixed number of operating sprinklers, total pressure throughout a sprinkler system at constant elevation is directly proportional to total pressure at any given point. If total pressure at one point is changed from P_{t1} to P_{t2}, total pressure at every other point with the same elevation is multiplied by P_{t2}/P_{t1}.

From $Q = (K) x (p^r)$, we get $Q_1 = (K) x (p_1^r)$ and $Q_2 = (K) x (p_2^r)$ which yield $Q_2/Q_1 = (p_2/p_1)^r$. Thus to change from p_1 to p_2, find Q_2 from:

$Q_2/Q_1 = (p_2/p_1)^{0.5}$, for $r = 0.50$ **(Equation 46)**

or

$Q_2/Q_1 = (p_2/p_1)^{0.54}$, for $r = 0.54$ **(Equation 47)**

Although technically this method applies only when the sprinklers are at exactly the same elevation, it is satisfactory in single-story sections of sprinkler systems unless the ceiling is steeply pitched.

4.0 REFERENCES

4.1 FM

Data Sheet 2-89, *Pipe Friction Loss Tables*

Data Sheet 3-26, *Fire Protection Water Demand for Nonstorage Sprinklered Properties*

Data Sheet 8-9, *Protection of Class 1, 2, 3, 4 and Plastic Commodities*

Hydraulics Tables (P6920)

Pocket Guide to Automatic Sprinklers (P8807)

4.2 Others

American Society of Mechanical Engineers (ASME). "Friction Factors for Pipe Flow," by Moody, Transactions of the ASME, 1944.

National Fire Protection Association (NFPA). *Standard for Water Spray Fixed Systems for Fire Protection.* NFPA 15.

APPENDIX A GLOSSARY OF TERMS

Effective Point: The location where the results of a water flow test are applicable. Its location is based on where the column of static water starting in the residual pressure gauge meets the column of flowing water, adjusted for elevation difference.

Hydraulic Gradient: A test method that isolates any location of abnormally high pressure loss which causes low yields. It is a profile of residual pressure. It assumes a uniform rate of flow and simultaneous residual pressure readings at various points along the pipe. In practice, moving one gauge progressively from test point to test point while test flow is maintained yields maximum consistency in pressure readings.

Residual Pressure: Pressure observed at sprinkler risers, non-flowing hydrants, or other direct connections to the supply pipe during test flow conditions.

Static Pressure: Pressure observed at sprinkler risers, non-flowing hydrants, or other direct connections to the supply pipe when there is no test flow.

APPENDIX B DOCUMENT REVISION HISTORY

March 2010. This data sheet has been rewritten and reformatted. Text from the previous version of this data sheet has been combined with text from obsolete Data Sheet 2-8N, *NFPA 13 Standard for the Installation of Sprinkler Systems 1996 Edition*.

September 2006. Minor editorial changes were made for this revision.

May 2006. Data Sheet 3-0 was updated to remove any reference to Data Sheet 2-76, which was made obsolete.

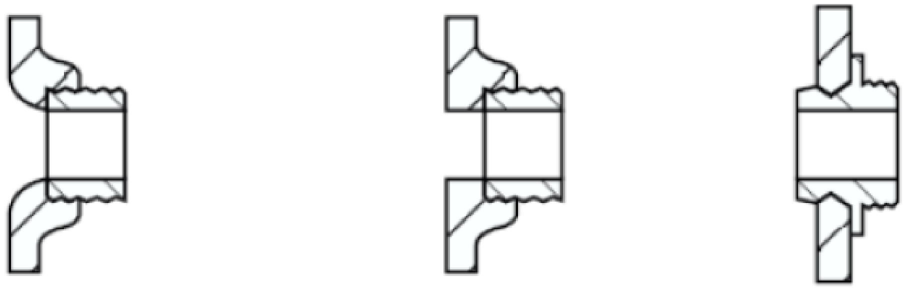
APPENDIX C HYDRAULIC TABLES

Table 2. Values of F_C for Corresponding Values of C

Corresponding Values of F_C for Given Values of C							
C Value = 100		C Value = 120		C Value = 130		C Value = 140	
C Value	F_C	C Value	F_C	C Value	F_C	C Value	F_C
180	0.337	180	0.472	180	0.548	180	0.628
170	0.375	170	0.525	170	0.609	170	0.698
165	0.396	165	0.555	165	0.643	165	0.738
150	0.472	150	0.662	150	0.767	150	0.880
145	0.503	145	0.705	145	0.817	145	0.937
140	0.537	140	0.752	140	0.872	140	1.00
130	0.615	130	0.862	130	1.00	130	1.15
125	0.662	125	0.927	125	1.08	125	1.23
120	0.714	120	1.00	120	1.16	120	1.33
110	0.838	110	1.17	110	1.36	110	1.56
105	0.914	105	1.28	105	1.48	105	1.70
100	1.00	100	1.40	100	1.62	100	1.86
95	1.10	95	1.54	95	1.79	95	2.05
90	1.22	90	1.70	90	1.97	90	2.26
85	1.35	85	1.89	85	2.19	85	2.52
80	1.51	80	2.12	80	2.46	80	2.82
75	1.70	75	2.39	75	2.77	75	3.17
70	1.93	70	2.71	70	3.14	70	3.61
65	2.22	65	3.11	65	3.61	65	4.13
60	2.57	60	3.61	60	4.18	60	4.79
55	3.02	55	4.23	55	4.91	55	5.63
50	3.61	50	5.05	50	5.86	50	6.72

Table 3. Hazen-Williams Pipe Coefficients for Underground Pipe Use

Kind of Pipe	Water Corrosiveness		
Cast-iron, unlined	Mild	Moderate	Severe
10 years old	105	90	75
15 years old	100	75	60
20 years old	95	65	55
30 years old	85	55	45
50 years old	75	50	40
Cast-iron, unlined, new		120	
Cast-iron, cement-lined		140	
Cast-iron, bitumastic-enamel-lined		140	
Cement-asbestos		140	
Approved plastic-lined steel		145*	
Approved glass-fiber-reinforced plastic		160*	
Approved PVC		150*	
*If using the Hazen-Williams formula, use these coefficients. If using nominal pipe size and Table 1 from Data Sheet 2-89, use the following artificial C coefficients in internal diameter between these pipes and Schedule 40 steel pipe: FM Approved plastic-lined steel - 165; FM Approved glass-fiber-reinforced plastic - 180; FM Approved PVC - 165			



Coefficient 0.80
Outlet smooth and
well-rounded

Coefficient 0.70
Outlet square and sharp

Coefficient 0.60
Outlet square and
projects into barrel

Fig. 4. Discharge Coefficients for three common hydrant outlets

Table 4. Discharge Coefficients of Typical Orifices and Nozzles

Type of Orifice	c
Hydrant butt, smooth, well-rounded outlet	0.80*
Hydrant butt, square outlet	0.70*
Hydrant butt, inset outlet	0.60*
Smooth Underwriter nozzles	0.97
Deluge nozzles	0.99
Open pipe, smooth and well-rounded, at least 10 diameters long	0.90
Open pipe, burred opening or less than 10 diameters long	0.80

*See Figure 4

Table 5. Values of K for Various Discharge Orifices

Type of Orifice	Nominal Diameter Size		Nominal K Value	
	in.	mm	English	Metric*
Sprinkler	3/8	10	2.8	40
	7/16		4.0	60
	1/2	13	5.6	80
	17/32	14	8.0	115
	0.64	16	11.2	160
Nozzle	1/2	13	7.2	104
	7/8	22	22.2	320
	1	25	29.1	420
	1-1/16	27	32.8	470
	1-1/8	29	36.8	530
	1-3/16	30	41.0	590
	1-1/4	32	45.4	650
	1-5/16	33	50.1	720
	1-3/8	35	54.9	790
	1-7/16	37	60.0	860
	1-1/2	38	65.4	940
	1-9/16	40	70.9	1020
	1-5/8	41	76.8	1110
	1-11/16	43	82.8	1190
	1-3/4	44	89.0	1280
	1-13/16	46	95.5	1380
	1-7/8	48	102	1470
	1-15/16	49	109	1570
	2	50	116	1670
Open pipe, smooth and well-rounded (c = 0.85)	2	50	100	1460
FM Nozzle (c = 0.86)	2-1/4	57	130	1860
(c = 0.87)	2-1/4	57	131	1890
(c = 0.88)	2-1/4	57	133	1910
(c = 0.89)	2-1/4	57	134	1940
Hydrant butt (c = 0.80)	2-3/8	60	134	1940
	2-1/2	64	149	2150
	2-5/8	67	164	2370
	4	100	381	5500
	4-1/2	113	484	6960

*For use with pressure in terms of bars

Table 6. Theoretical Discharge through Circular Orifices up to 2 in. (50 mm), gpm (L/min), with Discharge Coefficient Equal to 1.00 (See Table 4); Velocity Head Pressures up to 40 psi (2.8 bar)

Velocity Head	Velocity Pressure	Orifice Diameter, in. (mm)										
psi (bar)	ft/sec (m/sec)	3/8 (10)	1/2 (13)	5/8 (16)	3/4 (19)	7/8 (22)	1 (25)	1 1/8 (29)	1 1/4 (32)	1 1/2 (38)	1 3/4 (44)	2 (50)
10 (0.7)	39 (12)	13.3 (50.2)	23.6 (89.2)	36.8 (139)	53.0 (201)	72.1 (273)	94.2 (357)	119 (451)	147 (557)	212 (803)	289 (1092)	377 (1427)
12 (0.8)	42 (13)	14.5 (54.9)	25.8 (97.7)	40.3 (153)	58.1 (220)	79.0 (299)	103 (391)	131 (495)	161 (611)	232 (879)	316 (1197)	413 (1563)
14 (1.0)	46 (14)	15.7 (59.3)	27.9 (106)	43.6 (165)	62.7 (237)	85.4 (323)	112 (422)	141 (534)	174 (659)	251 (950)	342 (1293)	446 (1688)
16 (1.1)	49 (15)	16.8 (63.4)	29.8 (113)	46.6 (176)	67.1 (254)	91.3 (345)	119 (451)	151 (571)	186 (705)	268 (1015)	365 (1382)	477 (1804)
18 (1.2)	52 (16)	17.8 (67.3)	31.6 (120)	49.4 (187)	71.1 (269)	96.8 (366)	126 (479)	160 (606)	198 (748)	285 (1077)	387 (1466)	506 (1914)
20 (1.4)	55 (17)	18.7 (70.9)	33.3 (126)	52.1 (197)	75.0 (284)	102 (386)	133 (504)	169 (638)	208 (788)	300 (1135)	408 (1545)	533 (2018)
22 (1.5)	57 (17)	19.7 (74.4)	34.9 (132)	54.6 (207)	78.6 (298)	107 (405)	140 (529)	177 (670)	218 (827)	315 (1190)	428 (1620)	559 (2116)
24 (1.7)	60 (18)	20.5 (77.7)	36.5 (138)	57.0 (216)	82.1 (311)	112 (423)	146 (553)	185 (699)	228 (863)	329 (1243)	447 (1692)	584 (2210)
26 (1.8)	62 (19)	21.4 (80.9)	38.0 (144)	59.4 (225)	85.5 (324)	116 (440)	152 (575)	192 (728)	237 (899)	342 (1294)	465 (1761)	608 (2301)
28 (1.9)	65 (20)	22.2 (83.9)	39.4 (149)	61.6 (233)	88.7 (336)	121 (457)	158 (597)	200 (755)	246 (933)	355 (1343)	483 (1828)	631 (2387)
30 (2.1)	67 (20)	23.0 (86.9)	40.8 (154)	63.8 (241)	91.8 (348)	125 (473)	163 (618)	207 (782)	255 (965)	367 (1390)	500 (1892)	653 (2471)
32 (2.2)	69 (21)	23.7 (89.7)	42.1 (160)	65.8 (249)	94.8 (359)	129 (489)	169 (638)	213 (808)	263 (997)	379 (1436)	516 (1954)	674 (2552)
34 (2.3)	71 (22)	24.4 (92.5)	43.4 (164)	67.9 (257)	97.7 (370)	133 (504)	174 (658)	220 (832)	272 (1028)	391 (1480)	532 (2014)	695 (2631)
36 (2.5)	73 (22)	25.1 (95.2)	44.7 (169)	69.8 (264)	101 (381)	137 (518)	179 (677)	226 (857)	279 (1057)	402 (1523)	548 (2073)	715 (2707)
38 (2.6)	75 (23)	25.8 (97.8)	45.9 (174)	71.8 (272)	103 (391)	141 (532)	184 (695)	233 (880)	287 (1086)	413 (1564)	563 (2129)	735 (2781)
40 (2.8)	77 (24)	26.5 (100)	47.1 (178)	73.6 (279)	106 (401)	144 (546)	189 (713)	239 (903)	295 (1115)	424 (1605)	577 (2185)	754 (2854)

Table 7. Theoretical Discharge through Circular Orifices up to 2 in. (50 mm), gpm (L/min), with Discharge Coefficient Equal to 1.00 (See Table 4); Velocity Head Pressures Over 40 psi (2.8 bar) and up to 70 psi (4.8 bar)

Velocity Head	Velocity Pressure	Orifice Diameter, in. (mm)										
psi (bar)	ft/sec (m/sec)	3/8 (10)	1/2 (13)	5/8 (16)	3/4 (19)	7/8 (22)	1 (25)	1 1/8 (29)	1 1/4 (32)	1 1/2 (38)	1 3/4 (44)	2 (50)
42 (2.9)	79 (24)	27.2 (103)	48.3 (183)	75.4 (286)	109 (411)	148 (560)	193 (731)	244 (925)	302 (1142)	435 (1645)	591 (2239)	773 (2924)
44 (3.0)	81 (25)	27.8 (105)	49.4 (187)	77.2 (292)	111 (421)	151 (573)	198 (748)	250 (947)	309 (1169)	445 (1683)	605 (2291)	791 (2993)
46 (3.2)	83 (25)	28.4 (108)	50.5 (191)	79.0 (299)	114 (430)	155 (586)	202 (765)	256 (968)	316 (1195)	455 (1721)	619 (2343)	809 (3060)
48 (3.3)	84 (26)	29.0 (110)	51.6 (195)	80.6 (305)	116 (440)	158 (598)	207 (782)	261 (989)	323 (1221)	465 (1758)	632 (2393)	826 (3126)
50 (3.5)	86 (26)	29.6 (112)	52.7 (199)	82.3 (312)	119 (449)	161 (611)	211 (798)	267 (1009)	329 (1246)	474 (1795)	645 (2443)	843 (3190)
52 (3.6)	88 (27)	30.2 (114)	53.7 (203)	83.9 (318)	121 (458)	165 (623)	215 (813)	272 (1029)	336 (1271)	484 (1830)	658 (2491)	860 (3253)
54 (3.7)	90 (27)	30.8 (117)	54.7 (207)	85.5 (324)	123 (466)	168 (635)	219 (829)	277 (1049)	342 (1295)	493 (1865)	671 (2538)	876 (3315)
56 (3.9)	91 (28)	31.4 (119)	55.8 (211)	87.1 (330)	125 (475)	171 (646)	223 (844)	282 (1068)	348 (1319)	502 (1899)	683 (2585)	892 (3376)
58 (4.0)	93 (28)	31.9 (121)	56.7 (215)	88.7 (336)	128 (483)	174 (658)	227 (859)	287 (1088)	355 (1342)	511 (1933)	695 (2631)	908 (3436)
60 (4.1)	94 (29)	32.5 (123)	57.7 (218)	90.2 (341)	130 (492)	177 (669)	231 (874)	292 (1106)	361 (1365)	519 (1966)	707 (2676)	923 (3495)
62 (4.3)	96 (29)	33.0 (125)	58.7 (222)	91.7 (347)	132 (500)	180 (680)	235 (888)	297 (1124)	367 (1388)	528 (1998)	719 (2720)	939 (3553)
64 (4.4)	98 (30)	33.5 (127)	59.6 (226)	93.1 (353)	134 (508)	183 (691)	238 (902)	302 (1142)	373 (1410)	536 (2030)	730 (2763)	954 (3609)
66 (4.6)	99 (30)	34.0 (129)	60.5 (229)	94.6 (358)	136 (515)	185 (702)	242 (916)	306 (1160)	378 (1432)	545 (2062)	741 (2806)	968 (3665)
68 (4.7)	101 (31)	34.6 (131)	61.4 (233)	96.0 (363)	138 (523)	188 (712)	246 (930)	311 (1177)	384 (1453)	553 (2093)	753 (2849)	983 (3721)
70 (4.8)	102 (31)	35.1 (133)	62.3 (236)	97.4 (369)	140 (531)	191 (723)	249 (944)	316 (1194)	390 (1475)	561 (2123)	764 (2890)	997 (3775)

Table 8. Theoretical Discharge through Circular Orifices up to 2 in. (50 mm), gpm (L/min), with Discharge Coefficient Equal to 1.00 (See Table 4); Velocity Head Pressures Over 70 psi (4.8 bar) and up to 100 psi (6.9 bar)

Velocity Head	Velocity Pressure	Orifice Diameter, in. (mm)										
psi (bar)	ft/sec (m/sec)	3/8 (10)	1/2 (13)	5/8 (16)	3/4 (19)	7/8 (22)	1 (25)	1 1/8 (29)	1 1/4 (32)	1 1/2 (38)	1 3/4 (44)	2 (50)
72 (5.0)	103 (32)	35.6 (135)	63.2 (239)	98.8 (374)	142 (538)	194 (733)	253 (957)	320 (1211)	395 (1495)	569 (2153)	774 (2931)	1011 (3828)
74 (5.1)	105 (32)	36.0 (136)	64.1 (243)	100 (379)	144 (546)	196 (743)	256 (970)	324 (1228)	401 (1516)	577 (2183)	785 (2972)	1025 (3881)
76 (5.2)	106 (33)	36.5 (138)	64.9 (246)	102 (384)	146 (553)	199 (753)	260 (983)	329 (1245)	406 (1536)	585 (2212)	796 (3011)	1039 (3933)
78 (5.4)	108 (33)	37.0 (140)	65.8 (249)	103 (389)	148 (560)	202 (763)	263 (996)	333 (1261)	411 (1557)	592 (2241)	806 (3051)	1053 (3985)
80 (5.5)	109 (33)	37.5 (142)	66.6 (252)	104 (394)	150 (568)	204 (772)	267 (1009)	337 (1277)	417 (1576)	600 (2270)	816 (3090)	1066 (4035)
82 (5.7)	110 (34)	37.9 (144)	67.5 (255)	105 (399)	152 (575)	207 (782)	270 (1021)	342 (1293)	422 (1596)	607 (2298)	826 (3128)	1079 (4086)
84 (5.8)	112 (34)	38.4 (145)	68.3 (258)	107 (404)	154 (582)	209 (792)	273 (1034)	346 (1309)	427 (1615)	615 (2326)	836 (3166)	1093 (4135)
86 (5.9)	113 (34)	38.9 (147)	69.1 (262)	108 (409)	155 (588)	212 (801)	276 (1046)	350 (1324)	432 (1634)	622 (2354)	846 (3203)	1105 (4184)
88 (6.1)	114 (35)	39.3 (149)	69.9 (265)	109 (413)	157 (595)	214 (810)	280 (1058)	354 (1339)	437 (1653)	629 (2381)	856 (3240)	1118 (4232)
90 (6.2)	116 (35)	39.8 (151)	70.7 (268)	110 (418)	159 (602)	216 (819)	283 (1070)	358 (1354)	442 (1672)	636 (2408)	866 (3277)	1131 (4280)
92 (6.3)	117 (36)	40.2 (152)	71.5 (271)	112 (423)	161 (609)	219 (828)	286 (1082)	362 (1369)	447 (1690)	643 (2434)	875 (3313)	1143 (4328)
94 (6.5)	118 (36)	40.6 (154)	72.2 (273)	113 (427)	163 (615)	221 (837)	289 (1094)	366 (1384)	451 (1709)	650 (2461)	885 (3349)	1156 (4374)
96 (6.6)	119 (36)	41.1 (155)	73.0 (276)	114 (432)	164 (622)	224 (846)	292 (1105)	370 (1399)	456 (1727)	657 (2487)	894 (3385)	1168 (4421)
98 (6.8)	121 (37)	41.5 (157)	73.8 (279)	115 (436)	166 (628)	226 (855)	295 (1117)	373 (1413)	461 (1745)	664 (2512)	904 (3420)	1180 (4466)
100 (6.9)	122 (37)	41.9 (159)	74.5 (282)	116 (441)	168 (635)	228 (864)	298 (1128)	377 (1428)	466 (1762)	671 (2538)	913 (3454)	1192 (4512)

Table 9. Theoretical Discharge thru Circular Orifices Over 2 in. (50 mm) up to 4-1/2 in. (114 mm), gpm (Lpm), with Discharge Coeff. Equal to 1.00 (See Table 4); Velocity Head Pressures up to 40 psi (2.8 bar)

Velocity Head	Velocity Pressure	Orifice Diameter, in. (mm)										
psi (bar)	ft/sec (m/sec)	2 1/4 (57)	2 3/8 (60)	2 1/2 (64)	2 5/8 (67)	2 3/4 (70)	3 (75)	3 1/4 (83)	3 1/2 (89)	3 3/4 (95)	4 (100)	4 1/2 (114)
10 (0.7)	39 (12)	477 (1806)	532 (2012)	589 (2229)	649 (2458)	713 (2697)	848 (3210)	995 (3768)	1154 (4369)	1325 (5016)	1508 (5707)	1908 (7223)
12 (0.8)	42 (13)	523 (1978)	582 (2204)	645 (2442)	711 (2692)	781 (2955)	929 (3517)	1090 (4127)	1265 (4786)	1452 (5495)	1652 (6252)	2090 (7912)
14 (1.0)	46 (14)	565 (2137)	629 (2381)	697 (2638)	768 (2908)	843 (3192)	1004 (3798)	1178 (4458)	1366 (5170)	1568 (5935)	1784 (6753)	2258 (8546)
16 (1.1)	49 (15)	604 (2284)	672 (2545)	745 (2820)	821 (3109)	902 (3412)	1073 (4061)	1259 (4766)	1460 (5527)	1676 (6345)	1907 (7219)	2414 (9136)
18 (1.2)	52 (16)	640 (2423)	713 (2699)	790 (2991)	871 (3297)	956 (3619)	1138 (4307)	1335 (5055)	1549 (5862)	1778 (6730)	2023 (7657)	2560 (9690)
20 (1.4)	55 (17)	675 (2554)	752 (2845)	833 (3153)	918 (3476)	1008 (3815)	1199 (4540)	1408 (5328)	1633 (6179)	1874 (7094)	2132 (8071)	2699 (10210)
22 (1.5)	57 (17)	708 (2678)	788 (2984)	874 (3307)	963 (3646)	1057 (4001)	1258 (4761)	1476 (5588)	1712 (6481)	1966 (7540)	2236 (8465)	2830 (10710)
24 (1.7)	60 (18)	739 (2797)	824 (3117)	912 (3454)	1006 (3808)	1104 (4179)	1314 (4973)	1542 (5837)	1788 (6769)	2053 (7771)	2336 (8841)	2956 (11190)
26 (1.8)	62 (19)	769 (2912)	857 (3244)	950 (3595)	1047 (3963)	1149 (4349)	1368 (5176)	1605 (6075)	1861 (7045)	2137 (8088)	2431 (9202)	3077 (11650)
28 (1.9)	65 (20)	798 (3022)	890 (3367)	986 (3730)	1087 (4113)	1193 (4514)	1419 (5372)	1666 (6304)	1932 (7311)	2218 (8393)	2523 (9550)	3193 (12090)
30 (2.1)	67 (20)	826 (3128)	921 (3485)	1020 (3861)	1125 (4257)	1234 (4672)	1469 (5560)	1724 (6525)	2000 (7568)	2295 (8688)	2612 (9885)	3305 (12510)
32 (2.2)	69 (21)	853 (3230)	951 (3599)	1054 (3988)	1162 (4397)	1275 (4825)	1517 (5743)	1781 (6739)	2065 (7816)	2371 (8973)	2697 (10210)	3414 (12920)
34 (2.3)	71 (22)	880 (3330)	980 (3710)	1086 (4111)	1197 (4532)	1314 (4974)	1564 (5919)	1835 (6947)	2129 (8057)	2444 (9249)	2780 (10520)	3519 (13320)
36 (2.5)	73 (22)	905 (3426)	1008 (3817)	1118 (4230)	1232 (4663)	1352 (5118)	1609 (6091)	1889 (7148)	2190 (8290)	2514 (9517)	2861 (10830)	3621 (13700)
38 (2.6)	75 (23)	930 (3520)	1036 (3922)	1148 (4346)	1266 (4791)	1389 (5258)	1653 (6258)	1940 (7344)	2250 (8518)	2583 (9778)	2939 (11120)	3720 (14080)
40 (2.8)	77 (24)	954 (3611)	1063 (4024)	1178 (4459)	1299 (4916)	1425 (5395)	1696 (6420)	1991 (7535)	2309 (8739)	2650 (10030)	3016 (11410)	3817 (14450)

Table 10. Theoretical Discharge through Circular Orifices Over 2 in. (50 mm) and up to 4-1/2 in. (114 mm), gpm (L/min), with Discharge Coefficient Equal to 1.00 (See Table 4); Velocity Head Pressures Over 40 psi (2.8 bar) and up to 70 psi (4.8 bar)

Velocity Head	Velocity Pressure	Orifice Diameter, in. (mm)										
psi (bar)	ft/sec (m/sec)	2 1/4 (57)	2 3/8 (60)	2 1/2 (64)	2 5/8 (67)	2 3/4 (70)	3 (75)	3 1/4 (83)	3 1/2 (89)	3 3/4 (95)	4 (100)	4 ½ (114)
42 (2.9)	79 (24)	978 (3701)	1089 (4123)	1207 (4569)	1331 (5037)	1461 (5528)	1738 (6579)	2040 (7721)	2366 (8955)	2716 (10280)	3090 (11700)	3911 (14800)
44 (3.0)	81 (25)	1001 (3788)	1115 (4220)	1235 (4676)	1362 (5156)	1495 (5658)	1779 (6734)	2088 (7903)	2422 (9165)	2780 (10520)	3163 (11970)	4003 (15150)
46 (3.2)	83 (25)	1023 (3873)	1140 (4315)	1263 (4781)	1393 (5271)	1529 (5785)	1819 (6885)	2135 (8080)	2476 (9371)	2842 (10760)	3234 (12240)	4092 (15490)
48 (3.3)	84 (26)	1045 (3956)	1165 (4408)	1290 (4884)	1423 (5385)	1561 (5910)	1858 (7033)	2181 (8254)	2529 (9573)	2903 (10990)	3303 (12500)	4181 (15820)
50 (3.5)	86 (26)	1067 (4038)	1189 (4499)	1317 (4985)	1452 (5496)	1594 (6032)	1897 (7178)	2226 (8424)	2581 (9770)	2963 (11220)	3372 (12760)	4267 (16150)
52 (3.6)	88 (27)	1088 (4118)	1212 (4588)	1343 (5084)	1481 (5605)	1625 (6151)	1934 (7320)	2270 (8591)	2632 (9964)	3022 (11440)	3438 (13010)	4352 (16470)
54 (3.7)	90 (27)	1108 (4196)	1235 (4675)	1369 (5180)	1509 (5711)	1656 (6268)	1971 (7460)	2313 (8755)	2683 (10150)	3080 (11660)	3504 (13260)	4434 (16780)
56 (3.9)	91 (28)	1129 (4273)	1258 (4761)	1394 (5275)	1537 (5816)	1687 (6383)	2007 (7597)	2356 (8915)	2732 (10340)	3136 (11870)	3568 (13510)	4516 (17090)
58 (4.0)	93 (28)	1149 (4349)	1280 (4845)	1418 (5369)	1564 (5919)	1716 (6496)	2043 (7731)	2397 (9073)	2780 (10520)	3192 (12080)	3631 (13740)	4596 (17390)
60 (4.1)	94 (29)	1169 (4423)	1302 (4928)	1443 (5461)	1591 (6020)	1746 (6607)	2078 (7863)	2438 (9228)	2828 (10700)	3246 (12290)	3693 (13980)	4674 (17690)
62 (4.3)	96 (29)	1188 (4496)	1324 (5010)	1467 (5551)	1617 (6120)	1775 (6717)	2112 (7993)	2478 (9381)	2874 (10880)	3300 (12490)	3754 (14210)	4752 (17980)
64 (4.4)	98 (30)	1207 (4568)	1345 (5090)	1490 (5640)	1643 (6218)	1803 (6824)	2146 (8121)	2518 (9531)	2920 (11050)	3353 (12690)	3814 (14440)	4828 (18270)
66 (4.6)	99 (30)	1226 (4639)	1366 (5169)	1513 (5727)	1668 (6314)	1831 (6930)	2179 (8247)	2557 (9679)	2966 (11230)	3405 (12890)	3874 (14660)	4903 (18560)
68 (4.7)	101 (31)	1244 (4709)	1386 (5246)	1536 (5813)	1693 (6409)	1858 (7034)	2212 (8371)	2596 (9824)	3010 (11390)	3456 (13080)	3932 (14880)	4976 (18830)
70 (4.8)	102 (31)	1262 (4778)	1406 (5323)	1558 (5898)	1718 (6503)	1886 (7137)	2244 (8493)	2634 (9968)	3054 (11560)	3506 (13270)	3989 (15100)	5049 (19110)

Table 11. Theoretical Discharge through Circular Orifices Over 2 in. (50 mm) and up to 4-1/2 in. (114 mm), gpm (L/min), with Discharge Coefficient Equal to 1.00 (See Table 4); Velocity Head Pressures Over 70 psi (4.8 bar) and up to 100 psi (6.9 bar)

Velocity Head	Velocity Pressure	Orifice Diameter, in. (mm)										
psi (bar)	ft/sec (m/sec)	2 1/4 (57)	2 3/8 (60)	2 1/2 (64)	2 5/8 (67)	2 3/4 (70)	3 (75)	3 1/4 (83)	3 1/2 (89)	3 3/4 (95)	4 (100)	4 1/2 (114)
72 (5.0)	103 (32)	1280 (4845)	1426 (5399)	1580 (5982)	1742 (6595)	1912 (7238)	2276 (8614)	2671 (10110)	3098 (11720)	3556 (13460)	4046 (15310)	5120 (19380)
74 (5.1)	105 (32)	1298 (4912)	1446 (5473)	1602 (6064)	1766 (6686)	1939 (7338)	2307 (8733)	2708 (10250)	3140 (11890)	3605 (13640)	4102 (15520)	5191 (19650)
76 (5.2)	106 (33)	1315 (4978)	1465 (5547)	1624 (6146)	1790 (6776)	1965 (7436)	2338 (8850)	2744 (10390)	3182 (12050)	3653 (13830)	4157 (15730)	5261 (19910)
78 (5.4)	108 (33)	1332 (5043)	1485 (5619)	1645 (6226)	1814 (6864)	1990 (7535)	2369 (8965)	2780 (10520)	3224 (12200)	3701 (14010)	4211 (15940)	5330 (20170)
80 (5.5)	109 (33)	1349 (5107)	1503 (5691)	1666 (6305)	1837 (6952)	2016 (7629)	2399 (9080)	2815 (10660)	3265 (12360)	3748 (14190)	4265 (16140)	5397 (20430)
82 (5.7)	110 (34)	1366 (5171)	1522 (5761)	1687 (6384)	1859 (7038)	2041 (7724)	2429 (9193)	2850 (10790)	3306 (12510)	3795 (14360)	4318 (16340)	5465 (20680)
84 (5.8)	112 (34)	1383 (5233)	1541 (5831)	1707 (6461)	1882 (7123)	2066 (7818)	2458 (9304)	2885 (10920)	3346 (12660)	3841 (14540)	4370 (16540)	5531 (20930)
86 (5.9)	113 (34)	1399 (5295)	1559 (5900)	1727 (6538)	1904 (7208)	2090 (7910)	2487 (9414)	2919 (11050)	3385 (12810)	3886 (14710)	4422 (16740)	5596 (21180)
88 (6.1)	114 (35)	1415 (5357)	1577 (5968)	1747 (6613)	1926 (7291)	2114 (8002)	2516 (9523)	2953 (11180)	3425 (12960)	3931 (14880)	4473 (16930)	5661 (21430)
90 (6.2)	116 (35)	1431 (5417)	1595 (6036)	1767 (6688)	1948 (7373)	2138 (8092)	2544 (9630)	2986 (11300)	3463 (13110)	3976 (15050)	4523 (17120)	5725 (21670)
92 (6.3)	117 (36)	1447 (5477)	1612 (6102)	1786 (6762)	1970 (7455)	2162 (8182)	2573 (9737)	3019 (11430)	3501 (13250)	4020 (15210)	4573 (17310)	5788 (21910)
94 (6.5)	118 (36)	1463 (5536)	1630 (6168)	1806 (6835)	1991 (7535)	2185 (8270)	2600 (9842)	3052 (11550)	3539 (13400)	4063 (15380)	4623 (17500)	5851 (22140)
96 (6.6)	119 (36)	1478 (5595)	1647 (6234)	1825 (6907)	2012 (7615)	2208 (8358)	2628 (9946)	3084 (11670)	3577 (13540)	4106 (15540)	4672 (17680)	5913 (22380)
98 (6.8)	121 (37)	1494 (5653)	1664 (6298)	1844 (6979)	2033 (7694)	2231 (8444)	2655 (10050)	3116 (11790)	3614 (13680)	4149 (15700)	4720 (17870)	5974 (22610)
100 (6.9)	122 (37)	1509 (5710)	1681 (6362)	1863 (7050)	2053 (7772)	2254 (8530)	2682 (10150)	3148 (11910)	3651 (13820)	4191 (15860)	4768 (18050)	6035 (22840)

Table 12. Equivalent Pipe Length Table, ft (C=120)

Nominal Pipe Size, in.	Standard Screwed Elbow or Run of Tee Reduced 1/2 (Note 1)	45° Elbow	90° Straight Flanged (Note 2) or Medium Sweep Elbow (Note 3), or Tee Reduced 1/4	Standard Tee or Cross-Flow Turned 90° (Notes 2 and 4)	90° Long Radius Flanged Elbow (Note 2)	Gate Valve % Open				Swing Check Alarm Check or Dry Pipe Valve	Globe Valve Fully Open	Butterfly Valve Fully Open (Note 5)	Angle Valve
						100	75	50	25				
¾	2	1		4			1	8	35	7	20		7
1	2	1		5			2	10	45	8	25		9
1 ¼	3	1		6			3	13	60	12	34		11
1 ½	4	2	3	8			3	16	75	15	40		14
2	5	2	4	10	3	1	4	20	90	18	50		17
2 ½	6	3	5	12	4	1	5	25	100	23	65		20
3	7	3	6	15	5	1	6	30	125	28	80		25
3 ½	8	3	6	17	5	1	7	35	150	31	90		30
4	10	4	8	20	6	2	8	40	160	33	100	12	35
5	12	5	10	25	8	2	10	50	200	58	130		40
6	14	7	12	30	9	3	12	60	250	67	160	10	50
8	18	9	16	35	13	4	16	80	350	75		12	65
10	22	11	19	50	16	5	19	100	400	92		19	80
12	27	13	22	60	18	6	23	120	500	100		21	100
14		15	26	67	21	7	27	130	600	125		24	120
16		17	30	78	24	8	31	150	700	145		26	135
18		19	34	89	27	9	35	175	750	165		30	150
20		21	38	99	30	10	39	190	800	200		35	160
24		25	45	120	35	12	47	230	1000	220		44	200
30		31	58	145	45	15	60	290	1250	280			250
36		38	70	175	55	18	70	350	1500	330			300

Note 1: Includes reducer or bushing reduced one half

Note 2: Values apply to cast-iron flanged, bell and spigot, mechanical joint and push-on joint pipe. Ignore friction loss of straight run through tee

Note 3: Includes reducer or bushing reduced one quarter

Note 4: Equivalent lengths also apply to square elbows

Note 5: Butterfly valves values for 4 in through 12 in. originate from NFPA 15; and values for 14 in. through 24 in. are averaged and converted to equivalent feet of loss: C=120

Table 12(a). Equivalent Pipe Length Table, m (C=120)

Nominal Pipe Size, mm	Standard Screwed Elbow or Run of Tee Reduced 1/2 (Note 1)	45° Elbow	90° Straight Flanged (Note 2) or Medium Sweep Elbow (Note 3), or Tee Reduced 1/4	Standard Tee or Cross-Flow Turned 90° (Notes 2 and 4)	90° Long Radius Flanged Elbow (Note 2)	Gate Valve % Open				Swing Check Alarm Check or Dry Pipe Valve	Globe Valve Fully Open	Butterfly Valve Fully Open (Note 5)	Angle Valve
						100	75	50	25				
20	0.6	0.3		1.2			0.3	2.4	10.7	2.1	6.1		2.1
25	0.6	0.3		1.5			0.6	3.0	13.7	2.4	7.6		2.7
32	0.9	0.3		1.8			0.9	4.0	18.3	3.7	10.4		3.4
40	1.2	0.6	0.9	2.4			0.9	4.9	22.9	4.6	12.2		4.3
50	1.5	0.6	1.2	3.0	0.9	0.3	1.2	6.1	27.4	5.5	15.2		5.2
65	1.8	0.9	1.5	3.7	1.2	0.3	1.5	7.6	30.5	7.0	19.8		6.1
80	2.1	0.9	1.8	4.6	1.5	0.3	1.8	9.1	38.1	8.5	24.4		7.6
90	2.4	0.9	1.8	5.2	1.5	0.3	2.1	10.7	45.7	9.4	27.4		9.1
100	3.0	1.2	2.4	6.1	1.8	0.6	2.4	12.2	48.8	10.1	30.5	3.7	10.7
125	3.7	1.5	3.0	7.6	2.4	0.6	3.0	13.7	61	17.7	40.0		12.2
150	4.3	2.1	3.7	9.1	2.7	0.9	3.7	18.3	76	20.4	48.8	3.0	15.2
200	5.5	2.7	4.9	10.7	4.0	1.2	4.9	24.4	107	22.9		3.7	19.8
250	6.7	3.4	5.8	15.2	4.9	1.5	5.8	30.5	122	28.0		5.8	24.4
300	8.2	4.0	6.7	18.3	5.5	1.8	7.0	36.6	152	30.1		6.4	30.5
350		4.6	7.9	20.4	6.4	2.1	8.2	39.6	183	38.1		7.3	36.6
400		5.2	9.1	23.8	7.3	2.4	9.4	45.7	213	44.2		7.9	41.1
450		5.8	10.3	27.1	8.2	2.7	10.7	53	229	50		9.1	45.7
500		6.4	11.6	30.2	9.1	3.0	11.9	58	244	61		10.7	48.8
600		7.6	13.7	36.6	10.7	3.7	14.3	70	305	67		13.4	61
750		9.4	17.7	44.2	13.7	4.6	18.3	88	381	85			76
900		11.6	21.3	53	16.8	5.5	21.3	107	457	100			91

Note 1: Includes reducer or bushing reduced one half

Note 2: Values apply to cast-iron flanged, bell and spigot, mechanical joint and push-on joint pipe. Ignore friction loss of straight run through tee

Note 3: Includes reducer or bushing reduced one quarter

Note 4: Equivalent lengths also apply to square elbows

Note 5: Butterfly valves values for 100 mm through 300 mm originate from NFPA 15; and values for 350 mm through 600 mm are averaged and converted to equivalent feet of loss: C=120

Table 13. Adjustment Multiplier for Tables 12 and 12(a)

Hazen-Williams Coefficient Value	Adjustment Multiplier	Hazen-Williams Coefficient Value	Adjustment Multiplier
150	1.51	80	0.472
140	1.33	70	0.369
130	1.16	60	0.277
120	1.00	50	0.198
110	0.851	40	0.131
100	0.714	30	0.077
90	0.587	20	0.036

APPENDIX D FORMS

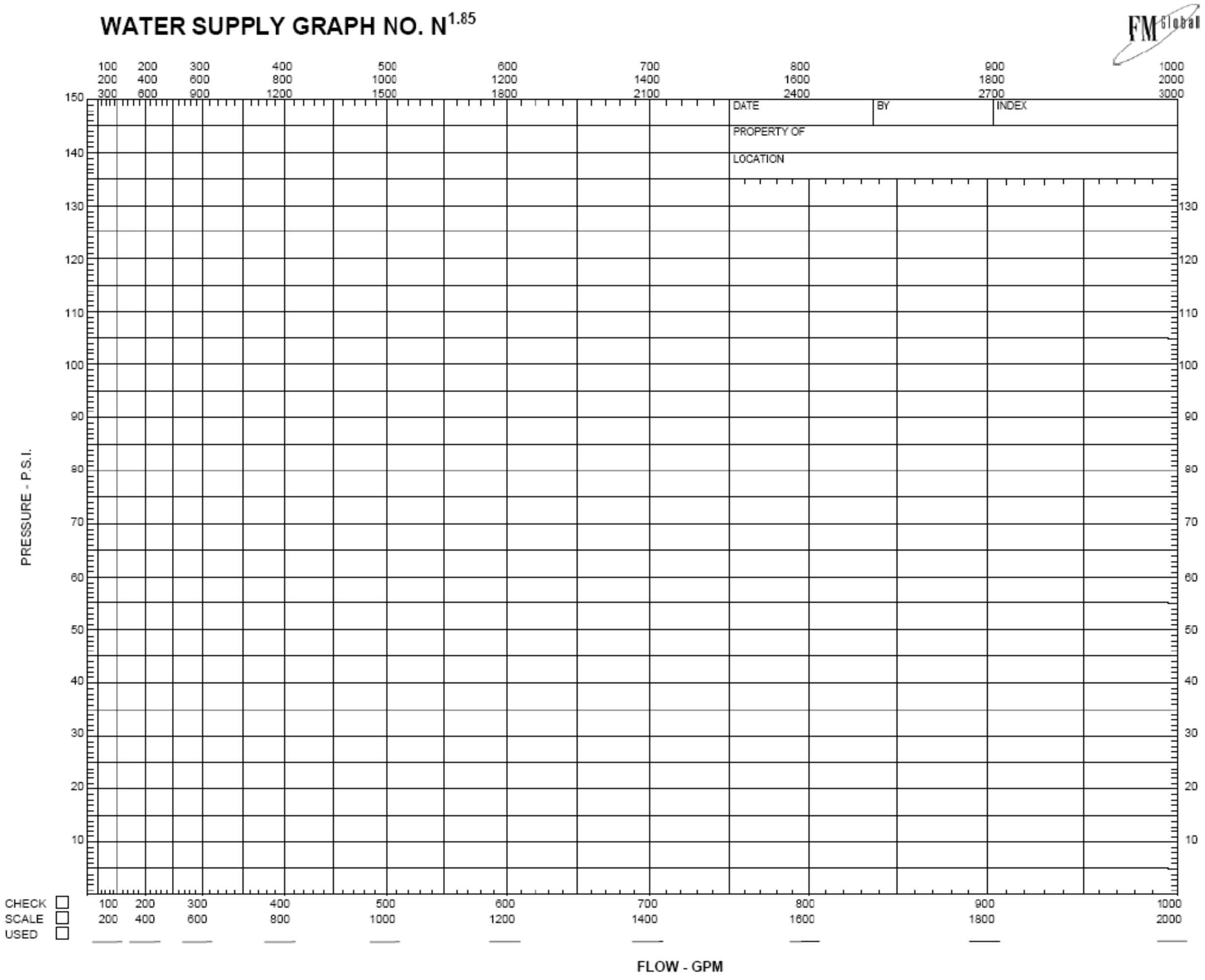
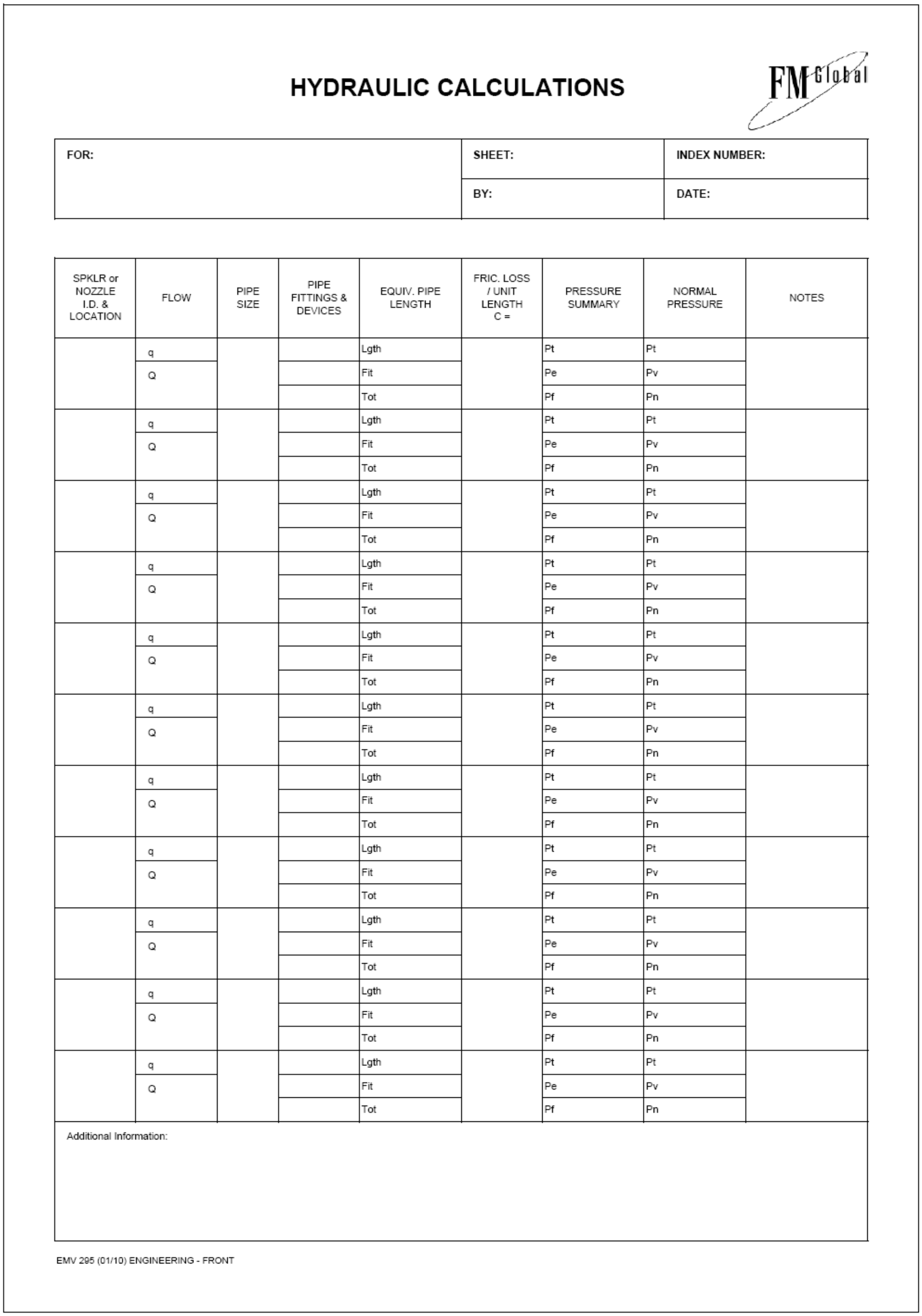


Fig. 5. Water Supply Graph $N^{1.85}$



HYDRAULIC CALCULATIONS

FM Global

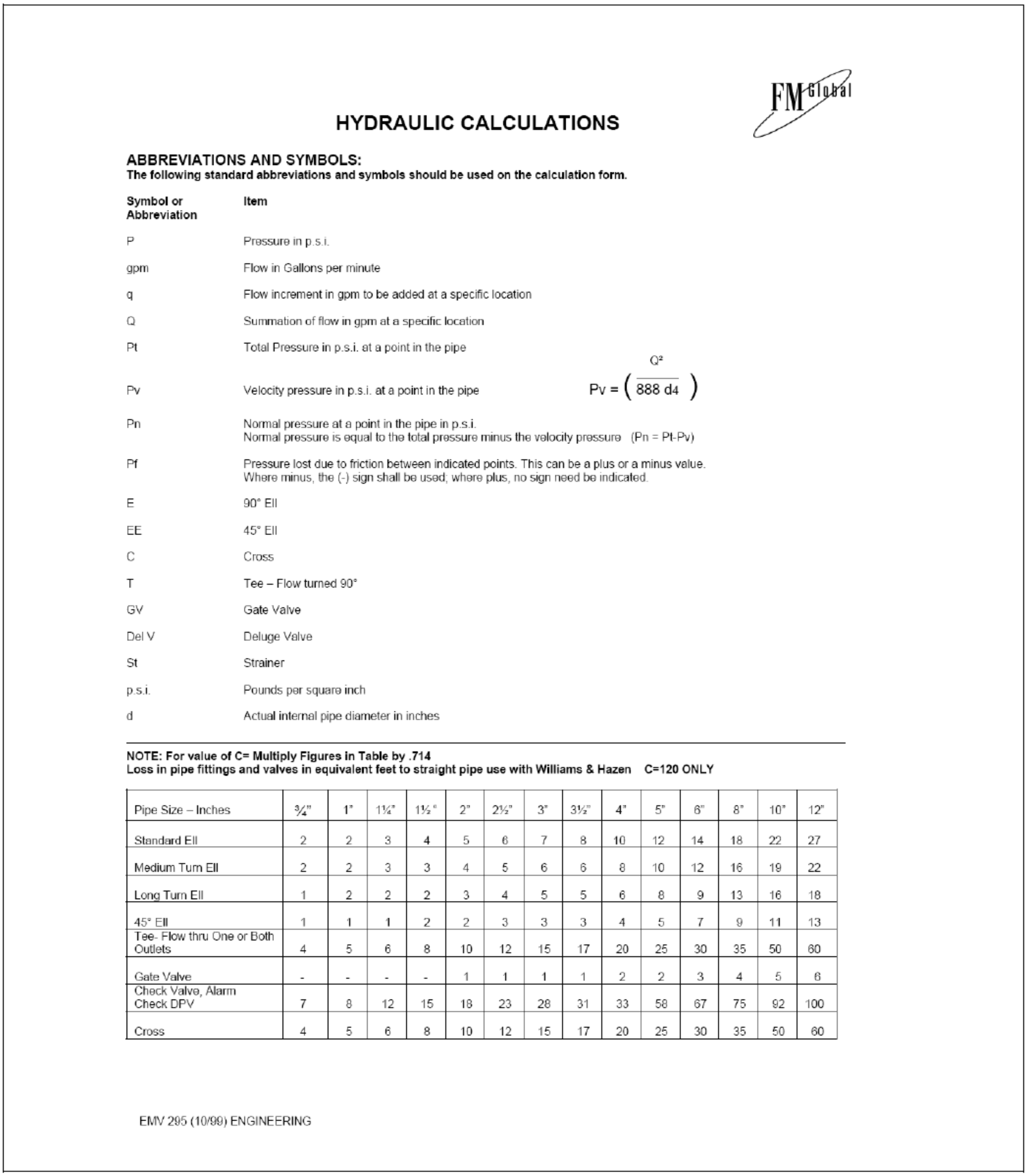
FOR:	**SHEET:**	**INDEX NUMBER:**
	BY:	**DATE:**

SPKLR or NOZZLE I.D. & LOCATION	FLOW	PIPE SIZE	PIPE FITTINGS & DEVICES	EQUIV. PIPE LENGTH	FRIC. LOSS / UNIT LENGTH C =	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	
	q			Lgth		Pt	Pt	
	Q			Fit		Pe	Pv	
				Tot		Pf	Pn	

Additional Information:

EMV 295 (01/10) ENGINEERING - FRONT

Fig. 6. Form 295 Hydraulic Calculations (front)



HYDRAULIC CALCULATIONS

ABBREVIATIONS AND SYMBOLS:

The following standard abbreviations and symbols should be used on the calculation form.

Symbol or Abbreviation	**Item**
P	Pressure in p.s.i.
gpm	Flow in Gallons per minute
q	Flow increment in gpm to be added at a specific location
Q	Summation of flow in gpm at a specific location
Pt	Total Pressure in p.s.i. at a point in the pipe
Pv	Velocity pressure in p.s.i. at a point in the pipe $Pv = \left(\frac{Q^2}{888\ d4} \right)$
Pn	Normal pressure at a point in the pipe in p.s.i. Normal pressure is equal to the total pressure minus the velocity pressure (Pn = Pt-Pv)
Pf	Pressure lost due to friction between indicated points. This can be a plus or a minus value. Where minus, the (-) sign shall be used; where plus, no sign need be indicated.
E	90° Ell
EE	45° Ell
C	Cross
T	Tee – Flow turned 90°
GV	Gate Valve
Del V	Deluge Valve
St	Strainer
p.s.i.	Pounds per square inch
d	Actual internal pipe diameter in inches

NOTE: For value of C= Multiply Figures in Table by .714
Loss in pipe fittings and valves in equivalent feet to straight pipe use with Williams & Hazen C=120 ONLY

Pipe Size – Inches	¾"	1"	1¼"	1½ "	2"	2½"	3"	3½"	4"	5"	6"	8"	10"	12"
Standard Ell	2	2	3	4	5	6	7	8	10	12	14	18	22	27
Medium Turn Ell	2	2	3	3	4	5	6	6	8	10	12	16	19	22
Long Turn Ell	1	2	2	2	3	4	5	5	6	8	9	13	16	18
45° Ell	1	1	1	2	2	3	3	3	4	5	7	9	11	13
Tee- Flow thru One or Both Outlets	4	5	6	8	10	12	15	17	20	25	30	35	50	60
Gate Valve	-	-	-	-	1	1	1	1	2	2	3	4	5	6
Check Valve, Alarm Check DPV	7	8	12	15	18	23	28	31	33	58	67	75	92	100
Cross	4	5	6	8	10	12	15	17	20	25	30	35	50	60

EMV 295 (10/99) ENGINEERING

Fig. 7. Form 295 Hydraulic Calculations (back)