Applied Sprinkler Technology 203: Hydraulic Calculations, Part 3

Course Description

This two hour online course is the third in a series covering the topic of hydraulic calculations for fire sprinkler systems. The course is designed to assist sprinkler system layout technicians and others who are seeking NICET certification and for Authorities Having Jurisdiction desiring an understanding of calculation models and applications.

Learning Objectives

Upon completion of part three the student will:

- Be able to evaluate minimum water supply needs
- Be able to determine adequacy of water supplies
- Understand the principles behind selecting design areas
- Understand hydraulic junction points and pressure balancing
- Know how to use hydraulic worksheets to complete hydraulic calculation of dead-end (tree) system

Introduction

Congratulations to those who completed parts one and two of this training series. Module three is the culmination of the knowledge that you have so far obtained in preparation for actually performing a manual hydraulic calculation of a fire sprinkler system. There are many skills that the system layout technician must incorporate in becoming a master of their profession. Indeed, the basis of all great design, and thus great technicians, is a complete understanding of hydraulics. That basis starts with developing the skill of calculating the most basic of sprinkler system configurations—the tree system.

As it is with most technical processes, the development of the skills needed for performing hydraulic calculations comes through trial and error. As the technician works with the process, he or she learns how to estimate minimum water supplies, location and shape of design areas, and pipe sizes. It must be emphasized again that mastering the skill of performing hydraulic calculations comes through repeating the calculation steps again and again until the concepts are engrained in the technician’s repertoire of skills.

Reference

To successfully complete this module, the student will need the following materials:

- NFPA 13 Standard for the Installation of Sprinkler Systems (all references in this module refer to the 2007 edition)
- Scientific Calculator with trigonometry functions

The following materials are not required but are helpful reference materials:

- Automatic Sprinkler Systems Handbook, 2007 edition. Published by NFPA.
- Fire Protection Handbook, Nineteenth edition. Published by NFPA.

Glossary

Area of Coverage: The total area covered by a single operating sprinkler. Measured in English Units as square feet.

C-Value (C-factor): Friction loss coefficient given to pipe based on the relative roughness of the inside surface.

Density: The rate of water application over a specific unit of area for a specific unit of time. Expressed in English Units as gallons per minute (gpm) over an area of one square foot.

Design Criteria: The combination of density and the area of sprinkler operation specific to a defined hazard.

Equivalent Length: The friction loss that occurs in fittings and devices expressed in the equivalent length of straight tube or pipe of the same diameter.

Grid System: A piping configuration with a primary main (connected to the water supply) and a parallel secondary main that are connected with multiple branch lines which allows water to follow multiple paths to the operating sprinkler(s).

Head: Pressure expressed in terms of elevation. A column of water one foot in height will exert a pressure of .433 psi.

Hydraulic Calculations: A series of mathematical equations that demonstrate that the water supply and fire sprinkler system layout is sufficient to deliver adequate water to meet the design criteria.

K-Factor: The discharge coefficient based on the size of an opening and the roughness of the bore. Fire sprinklers have a factory established K-Factor.

Loop System: A piping configuration in which water follows two or more mains from the supply to the branch lines feeding the operating sprinkler(s).

Normal Pressure: The pressure of water acting against, or perpendicular to, a tube or pipe wall.

Occupancy (hazard) Classification: Combination of characteristics and factors that contribute to fire severity. The characteristics include such things as combustibility, quantity, and arrangement of materials. The probability of a fire occurring is not a consideration of Occupancy Classification.

Pressure: The unit that measures force caused by compression per unit area in a fluid.

Residual Pressure: The pressure remaining in a system from the flow resulting upon a discharge from the system.

Static Pressure: The pressure in a system with no flow.

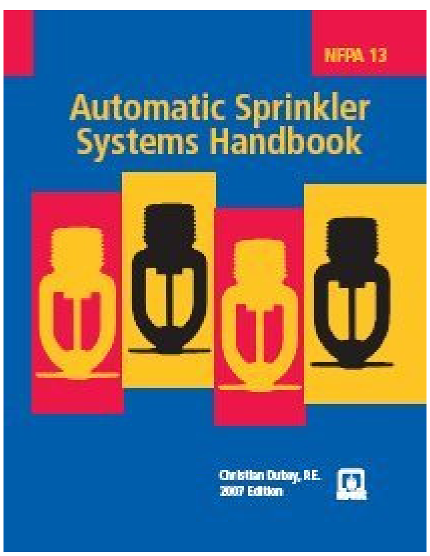
Total Pressure: The sum of normal pressure and velocity pressure added together.

Tree System: A piping configuration in which water follows a single path from the supply to the operating sprinkler(s).

Velocity Pressure: The pressure to move water through a tube or pipe.

Hydraulic Calculations

Using the concepts and principles mastered in parts one and two of this course, the student is ready to begin the procedure of hydraulic calculations. NFPA 13 stipulates the procedures that must be followed and are referenced as part of this exercise. Although not necessary, it will greatly facilitate the understanding of these procedures to have the Automatic Sprinkler Systems Handbook, 2007 Ed., published by NFPA.



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Efficient hydraulic design starts with an estimation of the volume and pressure needed to satisfy the design criteria coupled with a determination of the adequacy of the available water supply. Most sprinkler systems in the United States and Canada are supplied by a reliable water works. In some cases however, the water and pressure needed to meet the design criteria must be supplemented (in part or totally) through the use of fire pumps and/or other sources of water. Determining these needs early in the design process will save the technician much lost time and effort in performing calculations only to find that the available water supply will not deliver the system criteria.

Once the adequacy of the water supply is confirmed, the technician concentrates on developing the most cost efficient layout that will deliver the required design criteria. The simplest layout and calculation is the “tree system” which is the basis for the concepts of this module.

Minimum Water Supply

Minimum Water Supply Needs

The estimation of the minimum water supply needs combines the steps of determining 1) minimum flow, 2) minimum sprinkler pressure, 3) elevation pressure, and 4) an estimate of the pressure needed for friction loss.

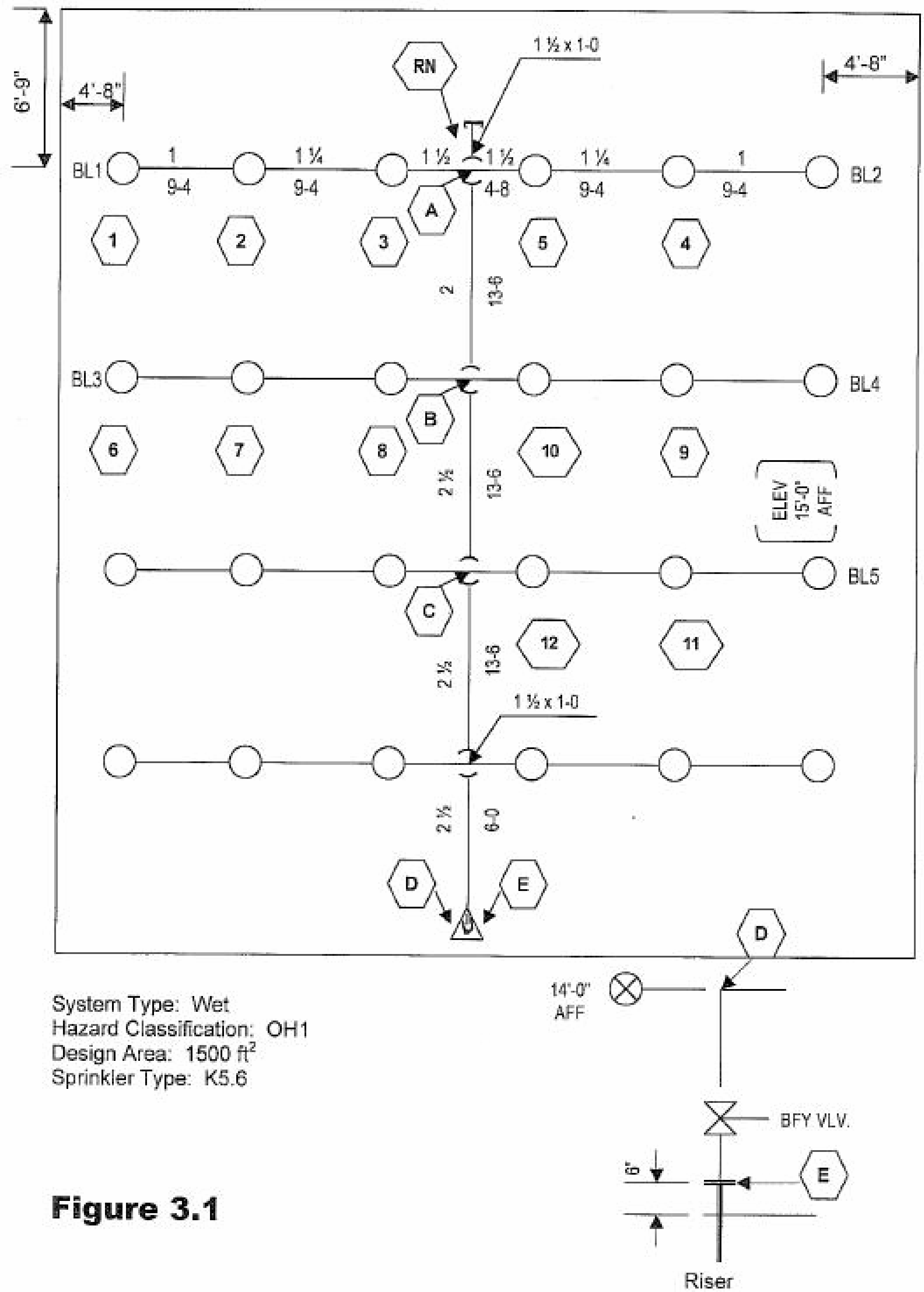

Figure 3.1

Using Figure 3.1 we will complete the following information:

- Minimum fire sprinkler flow
- Hose allowance

- Minimum sprinkler pressure
- Elevation pressure

Minimum Fire Sprinkler Flow

Using Figure 11.2.3.1.1 from *NFPA 13*, we determine the following:

Q = A x D
Q = 1500 ft² x .15 gpm/ft²
Q = 225 gpm

$$Q = A \times D$$
$$Q = 1500\ ft^2 \times .15\ gpm/ft^2$$
$$Q = 225\ gpm$$

Hose Allowance

Using Table 11.2.3.1.2 from *NFPA 13*, we find the following:

The hose allowance for ordinary hazard occupancy is 250 gpm.

Minimum Sprinkler Pressure

$$A = S \times L$$
$$A = 9.33\ ft \times 13.5\ ft$$
$$A = 126\ ft^2$$

$$Q = A \times D$$
$$Q = 126\ ft^2 \times .15\ gpm/ft^2$$
$$Q = 18.9\ gpm$$

$$P = (Q / K)^2$$

$$P = (18.9\ gpm / 5.6)^2$$

$$P = 11.4\ psi$$

Elevation Pressure

$$P = Head \times .433$$

$$P = 15\ ft \times .433$$

$$P = 6.5\ psi$$

With this information, the following is determined regarding the system needs:

Minimum Pressure before friction loss:

17.9 psi (elevation psi plus the minimum sprinkler psi)

Minimum Flow:

475 gpm (sprinkler flow plus hose allowance)

At this point, an estimation of the friction loss pressure is needed. The accuracy of this estimate will improve with experience. It includes factors such as system size (area), lengths of feed mains, types of valves on system riser, length of underground, and the size of underground pipe (if existing). Other factors are applied such as picking pipe sizes for the system riser, main piping, and branch lines. However, for the technician who is just learning the calculation process, a friction loss allowance of 15 psi is a good starting point.

With this information, it is determined that a good estimate for the water and pressure needs for the system in Figure 3.1 is:

Minimum pressure: 32.9 psi (17.9 psi plus 15 psi for friction loss)

We will examine how these minimums can be adjusted later in the module.

Adequate Water Supply

Reliable water works are the supply of choice for nearly all sprinkler systems. The amount of water and pressure available from a water works is determined by means of a flow test. The acceptable method of testing is described in the annex of NFPA 13 (Chapter 23). The determination of the available water supply is determined by either utilizing the water flow test graph (Figure 3.2) or performing a calculation. The graph method is usually sufficient.

Using the graph method, the technician completes the water supply curve as shown in Figure 3.2. The curve demonstrates a flow test with a static pressure of 45 psi and a residual pressure of 30 psi at 800 gpm flowing. The technician can then compare the available supply at any pressure and/or flow. The minimum flow and estimated pressure for the system in Figure 3.1 is plotted on the graph and compared to the water supply curve. At 475 gpm, it is noted that the water supply has approximately 39 psi available, which is about 6 psi more than the estimated pressure needed.

If a more accurate reading is needed, the available pressure can be calculated with the following formula:

$$P_d = P_s - [(P_s - P_r)(Q_d / Q_r)^{1.85}]$$

P_d = **Pressure at the desired flow**

P_s = **Static Pressure**

P_r = **Residual Pressure**

Q_d = **Desired (estimated) system flow**

Q_r = **Residual Flow**

Using the flow test from Figure 3.2, the exact available pressure at 475 gpm is calculated as follows:

$$P_d = P_s - [(P_s - P_r)(Q_d / Q_r)^{1.85}]$$

$$P_d = 45psi - [(45psi - 30psi)(475gpm / 800gpm)^{1.85}]$$

$$P_d = 45psi - [(15)(.381)]$$

$$P_d = 45psi - 5.7psi$$

$$P_d = 39.3psi$$

If the results are unacceptable, there are options available to lower pressure requirements. We can change the sprinkler type to a larger orifice or decrease the sprinkler area of coverage. The prudent technician would examine these options before looking at the water supply as increasing the orifice size can be done at little or no cost. Decreasing the area of coverage for the sprinklers is typically a much more cost effective solution than adding a fire pump or altering the water supply arrangement.

Design Areas

Selection of Design Areas

The area of sprinkler operation is determined using the curves from Figure 11.2.3.1.1 in *NFPA 13* or other criteria found in other chapters dealing with occupancies such as storage. The design area is not related to the size (area) of the building or structure. Both a 200,000 ft² or 20,000 ft² building will have the same size design area if the occupancies are the same.

NFPA 13 stipulates that the design area used for hydraulic calculations be the most hydraulically remote. It is often referred to as the “most remote area.” This means that the area selected requires the highest flow and pressure to meet the system criteria. As a result, the most hydraulically demanding design area is not necessarily the most physically remote from the system riser. By basing the design throughout the building on the most hydraulically demanding layout, ensures that a fire in all areas of the building can be controlled by the sprinkler system. The skill in selecting the most demanding design area is developed through experience. A detailed discussion regarding the selection of the most hydraulically is found in the *Automatic Sprinkler Systems Handbook* (Section 22.3) and it is recommended that the student review this material.

In selecting the design area, the technician will typically use more than one approach.

The first approach (or step) is to determine the minimum number of sprinklers the design area will include. A quick way to determine this number is to divide the total design area by the area of coverage of the individual sprinklers.

For example:

If the design selected from Figure 11.2.3.1.1 is 2500 ft² and the area of coverage for each sprinkler is 100 ft² the minimum number of sprinklers within the design area is 25. (2500 ÷ 100 = 25)

However, if this calculation results in a fraction, the minimum number must be raised to the next whole (it is impossible to have a partial sprinkler). Therefore, if the design area is 2500 ft² and the area of coverage for each sprinkler is 95 ft², the minimum number of sprinklers within the design area is 27. (2500 ÷ 95 = 26.3 which must be rounded to 27)

NFPA 13 requires that the shape of the design area be a rectangle that includes all the sprinklers on a branch line within a length that is equal to 1.2 times the square root of the minimum design area. Where the sprinklers are spaced equally, the number can be determined by using the following formula:

$S_n = (1.2 \times \sqrt{A}) / S_s$

S_n **= Number of sprinklers along branch line**

S_s **= Sprinkler Spacing**

A = Design Area

Example:

$S_n = (1.2 \times \sqrt{A}) / S_s$

$S_n = (1.2 \times \sqrt{1500}) / 12\ ft$

$S_n = 46.47\ \text{ft} / 12\ ft$

$S_n = 3.87$ **(*Equals 4 sprinklers*)**

An additional principal that must be considered is that NFPA 13 requires the design area be determined by the actual physical area of coverage. Figure 3.3 provides an example of this requirement. The flow of the illustrated sprinkler would be based on the area of coverage of 115 ft² but in calculating the design area, the actual floor area is used, which in this case is 61.25 ft².

The principal of the physical design area also includes the actual floor area. This is illustrated with the application of sloped ceilings. This is illustrated in Figure 3.4. NFPA 13 requires sprinkler spacing to be measured along the slope of the ceiling, however, the design area includes the actual floor area. Figure 3.4 shows that 49 ft of branch line length (measured along the slope) provides 47.54 ft of actual floor length. Figure 3.4a shows the effect of a 4/12 slope on a 130 ft² ceiling sprinkler spacing.

Figures 3.5 and 3.6 illustrate the difference between remote areas using the calculated area of coverage for flow and the actual physical area required for the design. Figure 3.5 shows that by using the flow based areas of coverage that the design area is almost 25 ft² too small. Figure 3.6 demonstrates that in order to meet the 1500 ft² minimum design area requirement, we must include an additional sprinkler. The floor area covered is 1555.75 ft² which exceeds the 1500 ft² minimum.

Junction Points

Junction Points and Pressure Balancing

Junction points occur where the flowing water splits into different paths or is discharged. A flowing sprinkler is a junction point but does not fall under the definition as used here. An example is the water at the top of a riser nipple splitting down each branch line to supply the flowing sprinklers. Another would be the junction where water splits and flows down two different mains in a looped system.

In module two, we learned that the flow is related to pressure. For example, sprinklers of like K-factor discharge equal amounts of water if the pressure at each sprinkler is equal. However, if more pressure is applied to one over the other sprinklers, it will flow more water.

The same principle applies to junction points. If the branch lines joining together at the top of a riser nipple have exactly the same pressure, the combined flow would simply be the sum of the flows for each branch line. However, if the pressures are different, then each branch line will flow the amount of water that is determined by the highest pressure requirement. To determine the actual flows that will occur, we apply the formulas for flow and pressure.

We have learned the calculation for actual flow requires a pressure and K-factor. In the case of sprinklers, we are given the K-factor by the manufacturer. With junction points however, we must determine the K-factor by using the following formula:

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

Using the formula, a K-factor is calculated for the branch line (or main) with the lower pressure requirement. This K-factor is then used with the formula $Q = K\sqrt{P}$ to determine the flow which will occur with the higher of the two pressures found at junction point.

Example

Using Figure 3.7, balance the pressure and flows at the top of the riser nipple (RN). The pressure and flow for BL1 is 19.62 psi @ 65.5 gpm. The pressure and flow for BL2 is 18.5 psi @ 54.3 gpm.

Determine K-factor for BL2 (lower of the two pressures)

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

$$K = 54.3\text{gpm} / \sqrt{18.5\textit{psi}}$$

$$K = 12.62$$

With this K-factor, determine the flow for BL2 at the BL1 pressure of 19.62 psi.

$$Q = 12.62\ \sqrt{19.62\textit{psi}}$$

$$Q = 55.9\text{ gpm}$$

The adjusted flow for BL2 is added to the flow from BL1. The total combined flow and pressure for BL1 and BL2 at the top of the riser is 121.4 gpm @ 19.62 psi.

Hydraulic Worksheets

Hydraulic worksheets are required to be utilized by NFPA 13. Refer to Figure 3.8a and Figure 3.8b for the approved format. The Nozzle Identification refers to the hydraulic reference point (sometimes referred to as a Node). Reference points are required at the following locations:

- Each sprinkler located within the design area
- All junction points (flow splits)
- Pipe size or type changes (in the flowing paths)
- Elevation changes (in the flowing paths)
- Water source

The Flow column is the actual volume(s) of flowing water. Q is the total flow while q is any added flow at the reference point. Pipe size can be listed as nominal or actual inside diameter. Actual inside diameter must always be used in the calculation procedure. Pipe fittings and devices include all components that add equivalent footage of pipe between reference points. See Table 22.4.3.1.1. Fittings connected directly to the sprinkler are typically not included. The equivalent pipe length is the sum of the actual center to center distance between reference points and the equivalent footage of any fittings and devices. Friction loss per foot is the pressure loss that occurs utilizing the Hazen-Williams formula. Pressure summary is the sum of any elevation loss (or gain) and friction loss between the reference points.

Example

Refer to Figure 3.1 and Figure 3.8a. Follow the illustrated steps in working through a standard tree system calculation. We have configured the design area based on 1500 ft² with the branch line length at a minimum of 1.2 times the square root of 1500. The result is 12 sprinklers with a total floor area of 1512 ft². Reference points may be identified in any fashion (numbers, letters, etc.) that the technician desires as long as all the required points are identified.

Step 1

The minimum flow and pressure for sprinkler number 1 is determined by utilizing the formulas for each. Keep in mind that the minimum flow and the actual flow are the same for the first sprinkler in our calculation.

$$A = S \times L$$
$$A = 13.5\text{ft} \times 9.33\text{ ft}$$
$$A = 126\text{ ft}^2$$

Q = A x D
Q = 126 ft² x .15 gpm/ft²
Q = 18.9 gpm **This is the minimum flow.**

$$P = \left(\frac{Q}{K}\right)^2$$

$$P = \left(\frac{18.9gpm}{5.6}\right)^2$$

P = 11.39 psi **This is the minimum sprinkler pressure.**

Step 2

A pipe size for the pipe from sprinkler number 1 to sprinkler number 2 is selected. This process is one of trial and error. Over time the technician will become familiar with general friction losses that will occur at particular flows and pipe sizes. In this particular case, 1 in. schedule 40 steel pipe is used. The C-factor is 120 as it is a wet system. The length from sprinkler number 1 to sprinkler number 2 is 9 ft. 4 in. No fittings are present. The friction loss per ft is calculated using the Hazen-Williams formula. Keep in mind that actual pipe internal diameters are used.

$$F_L = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$F_L = \frac{4.52 \times 18.9gpm^{1.85}}{120^{1.85} \times 1.049^{4.87}}$$

$$F_L = \frac{1038.9}{8865}$$

F_L **= .117**

The total friction loss between sprinkler number 1 and sprinkler number 2 is determined by multiplying the friction loss per foot by the total distance (including equivalent footage if any).

In this case, the total friction loss is **1.09psi** therefore the total pressure at sprinkler number two is **12.48psi.**

Step 3

It is time to calculate how much water will discharge from sprinkler number 2. We now know that the pressure required to be available at sprinkler #2 is 12.48 psi. This will leave enough pressure (11.39 psi) at sprinkler #1 for the 18.9 gpm (required minimum flow needed to provide the density) to discharge. This accounts for the 1.09 psi needed for the friction loss that will occur as the water travels from sprinkler #2 to sprinkler #1.

Because there is more pressure (12.48 psi) available, sprinkler #2 will automatically flow more water than sprinkler #1. To determine the proper amount, we use the formula for flow.

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

$$Q = 5.6\sqrt{12.48}$$

$$Q = 19.8\,gpm$$

Step 4

The flows for sprinkler #1 and sprinkler #2 are combined for a total of 38.7 gpm. This is the actual volume of water that will be supplied under the conditions we have described.

We now repeat Steps 2 and 3 to determine the volume of water that will flow from sprinkler #3. We determine that sprinkler #3 will discharge 20.6 gpm. The total water flowing from sprinklers #1, 2, and 3 is 59.3 gpm. The worksheet indicates that 1.5 in. pipe is selected and the friction loss per foot and total friction loss is calculated from sprinkler #2 to the top of the riser nipple (RN). Note that the total footage includes an equivalent footage of 8 ft for the tee at the top of the riser nipple.

The calculation for branch line 1 (BL1) ends at the top of the riser nipple.

Step 5

Sprinklers #4 and 5 on branch line 2 (BL2) must now be calculated. Step 1 is repeated for sprinkler #4. Steps 2, 3, and 4 are repeated to determine the needed flow and pressure at the top of the riser nipple (RN). The calculation for branch line 2 (BL2) ends at the top of the riser nipple as did branch line 1. We are now at a junction point.

Step 6

The sprinkler flows needed for BL1 and BL2 must now be combined. The pressure requirement for each branch line at the top of the riser nipple (RN) is examined. It is noted that BL1 requires a higher pressure. BL2 needs a minimum of 12.35 psi to deliver the needed water at sprinklers #4 and 5 but, because 15.09 psi is needed for BL1, the flow for BL2 will be higher because of this higher pressure. The pressures and flows must be balanced.

We first determine the K-factor for BL2:

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

$$K = \frac{38.0\,gpm}{\sqrt{12.35}}$$

$$K = 10.8$$

Using this K-factor we can now determine how much water will actually flow in BL2:

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

$$Q = 10.8\sqrt{15.09psi}$$

Q = 42.0 gpm

This adjusted flow of BL2 is added to the flow of BL1 for a total flow of 101.3 gpm. We now know that 101.3 gpm and 15.09 psi is the demand at the top of the riser nipple (RN).

Step 7

A pipe size is now selected for the riser nipple. Again, this is a process of trial and error that will become simpler as the system layout technician gains experience. In this example, 1.5 in. pipe is selected. The friction loss must be determined for the 101.3 gpm flowing through the riser nipple.

$$F_L = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$F_L = \frac{4.52 \times 101.3gpm^{1.85}}{120^{1.85} \times 1.61^{4.87}}$$

$$F_L = \frac{23201.5}{71404.78}$$

$$F_L = .324 psi / ft$$

The length of the riser nipple is 1 ft plus the equivalent footage for 1 tee, which is 8 ft. Total footage from RN to the connection to the main (A) is 9 ft. Multiplying the 9 ft by the friction loss per foot gives a total pressure loss of 2.93 psi. However, in addition to the friction loss, the elevation change must be accounted for. There is a 1 ft elevation change and the pressure required to lift the water is found by multiplying the elevation change by .433 psi. In this example, the total loss is .433 psi. Therefore, by adding the total friction loss and elevation loss to the pressure required at the top of the riser nipple, it is determined that a total pressure of 18.45 psi is needed at the connection to the main with a volume of 101.3 gpm.

P_e = 1'- 0" x .433

P_e = .43

Step 8

We are now ready to determine the pressure needed for the water to travel through the main. A pipe size is selected (2 in.) for the main pipe between points A and B and the friction loss determined.

$$F_L = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$F_L = \frac{4.52 \times 101.3gpm^{1.85}}{120^{1.85} \times 2.067^{4.87}}$$

$$F_L = \frac{23201.5}{241098.0}$$

$$F_L = .096 psi / ft$$

The length of pipe between main points A and B is 13.5 ft with no fittings. Therefore, the total friction loss is 1.30 psi resulting with a total pressure at B of 19.75 psi.

Step 9

We have arrived at a junction point. Branch lines 3 and 4 are being fed at point B. We must determine the demand needed to supply the sprinklers fed by these branch lines. Upon examination, we see that the sprinkler spacing and area of coverage for sprinklers 6 through 10 is exactly the same as sprinklers 1 through 5. The layout technician now has a choice. We can follow the same steps that were followed for sprinklers 1 through 5, performing a full compilation of calculations, or use the same pipe sizes that we used for BL1 and BL2. (It is common to keep pipe sizes typical for ease of fabrication and installation.) If the sprinkler types, spacing, areas of coverage, and pipe sizes are typical of previously calculated branch lines, it is not required to redo the steps. It is permissible to start the calculation process at the point where any of the factors may change. In this example, calculations for sprinklers 6 through 10 is typical to the main connection at point B.

Step 10

We must now balance the pressures at point B. The demand needed for BL1 and BL2 at point B is 101.3 gpm @ 19.75 psi. The demand for BL3 and BL4 is 101.3 @ 18.45 psi. (Note that the demand is the same as that for BL1 and BL2 at point A.) Since a pressure requirement of 19.75 psi is needed to supply BL1 and BL2 from point B, the flow for BL3 and BL4 must be adjusted for this higher pressure.

We first determine the K-factor for the flow from BL3 and BL4 at point B:

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

$$K = \frac{101.3gpm}{\sqrt{18.45psi}}$$

$$\mathbf{K = 23.6}$$

Using this K-factor we can now determine how much water will actually flow to BL3 and BL4 at point B:

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

$$Q = 23.6\sqrt{19.75\ psi}$$

$$Q = 104.9gpm$$

By adding this adjusted flow for BL3 and BL4 to the flow required for BL1 and BL2, it is determined that the demand at main point B is 206.2 gpm @ 19.75 psi.

Step 11

We now repeat Step 8 to determine the total friction loss between main points B and C. (Note that the layout technician chooses 2.5 in. diameter pipe.)

$$F_L = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$F_L = \frac{4.52 \times 206.2gpm^{1.85}}{120^{1.85} \times 2.469^{4.87}}$$

$$F_L = \frac{86411.7}{572879.1}$$

$$F_L = .151psi/ft$$

The total friction loss between B and C is 2.04 psi resulting in a demand at point C of 206.2 gpm @ 21.79 psi.

Main point C is a junction point. The demand for BL5 must be added at this point. As discussed in Step 9, the system layout technician determines what previous calculations can be utilized to minimize work. Upon examination we see that the calculation for BL5 is typical to BL2 and BL4. However, since the opposing branch line is not typical to the previous calculations (in this example, there are no flowing sprinklers as with BL1 and BL3), the flow through the riser nipple to main point C requires calculation.

Step 12

The total pressure loss from RN to main point C must be determined. The same process as previous calculations is followed. To save time and work, we note that we already have the friction loss for 38.0 gpm flowing through 1.5 in. pipe (.053 psi/ft). We also have the total footage of pipe from RN to point C (9.0 ft) and the elevation change (1 ft). Therefore the total pressure loss is .91 psi resulting in a demand for BL5 at main point C of 38 gpm @ 12.59 psi.

Step 13

The flow from BL5 is now added at main point C.

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

$$K = \frac{38.0gpm}{\sqrt{12.59psi}}$$

$$K = 10.7$$

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

$$Q = 10.7\sqrt{21.79psi}$$

$$Q = 49.9 \text{ gpm}$$

Using this adjusted flow, the total demand at main point C is 256.1 gpm @ 21.79 psi.

Step 14

We now have the total flow needed to supply all the sprinklers in the remote area. We can now take this flow and determine the total pressure needed to deliver the water from any point desired. *NFPA 13* requires that the calculations show that there is sufficient pressure to deliver the required flow from the water supply. This may be discharge flange of a fire pump, an elevated tank, or the connection to a water works. In the case of a water works, *NFPA 13* requires that the calculations include all pipe, fittings, and elevation from the effective point of the flow test.

In this example, the base of the system riser is the last point of the calculation. Note that hydraulic node points are shown at the top of the system riser (D) and at the base of the riser (E). The layout tech always has the option to have more nodes than those at the required points discussed earlier in this session.

Step 15

The calculation process is now centered simply on determining the total pressure needed to flow the water from the base of the riser (E) to main point C. A pipe size is selected and the friction loss is determined along with any elevation pressure.

$$F_L = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$F_L = \frac{4.52 \times 256.1gpm^{1.85}}{120^{1.85} \times 2.469^{4.87}}$$

$$F_L = \frac{129031.6}{572879.1}$$

$$F_L = .225psi/ft$$

The total length from node C to node D (top of the system riser) is 25.5 ft (19.5 plus the equivalent footage of 1 ELL). The total friction loss is 5.74 psi. The total demand at node D is 256.1 gpm @ 27.53 psi.

The total length from node D to node E (base of the system riser) is 20.5 ft (13.5 ft plus the equivalent footage of 1 Butterfly Valve). The elevation is 13.5 ft. The total pressure loss is 10.46 psi (4.61 psi in friction loss and 5.85 psi in elevation loss). The total demand at node E is 256.1 gpm @ 37.99 psi.

This is the system demand for the sprinklers. If a hose allowance is required, NFPA 13 states that it is to be added at the point where it affects the water supply. This will be covered in detail in future modules. However, for this example the hose demand (250 gpm) is added to the calculation in this example at node E. The total system demand is now 503.1 gpm @ 38 psi. This demand can be compared to our supply (flow test) to determine if there is sufficient pressure remaining to provide the required volume of water from our connection to the water works.

Using the Figure 3.2 (flow test), the layout technician compares our system demand to the available supply.

$$\mathbf{P_d = P_s - [(P_s - P_r)(Q_d / Q_r)^{1.85}]}$$

$$\mathbf{P_d = 45\textit{psi} - [(45\textit{psi} - 30\textit{psi})(503\textit{gpm} / 800\textit{gpm})^{1.85}]}$$

$$\mathbf{P_d = 45\textit{psi} - [(15)(.424)]}$$

$$\mathbf{P_d = 45\textit{psi} - 6.4\textit{psi}}$$

$$\mathbf{P_d = 38.6\textit{psi}}$$

This evaluation tells the layout tech that there is .6 psi of excess pressure available beyond the system demand. If our flow test information is effective at the base of the system riser, the system demand is .6 psi below the supply pressure. This result is acceptable but very close. If the effective point of the supply is not at the base of the system riser, then it is very probable that there is insufficient supply to meet the system demand and the layout tech must make changes to lower the demand. This can be accomplished by decreasing the sprinkler area of coverage (lowers sprinkler discharge pressure), possibly using larger K-factor sprinklers, increasing pipe sizes (lowers friction loss pressure), or a combination of these and other options.

Conclusion

With this third module, the basic calculation process was covered. We have introduced all the basic components for performing hydraulic calculations. We have followed the steps for calculation of a dead-end (tree) system configuration. The key now is to practice these principles again and again until they become ingrained in the student's skillset.

Exercises

Exercise Number 1

Refer to Figure 3.9 and the following data for this exercise.

Hazard Classification:	EH1
Design Area:	2500 ft^2
Sprinkler Type:	K 8.0
Density:	.30

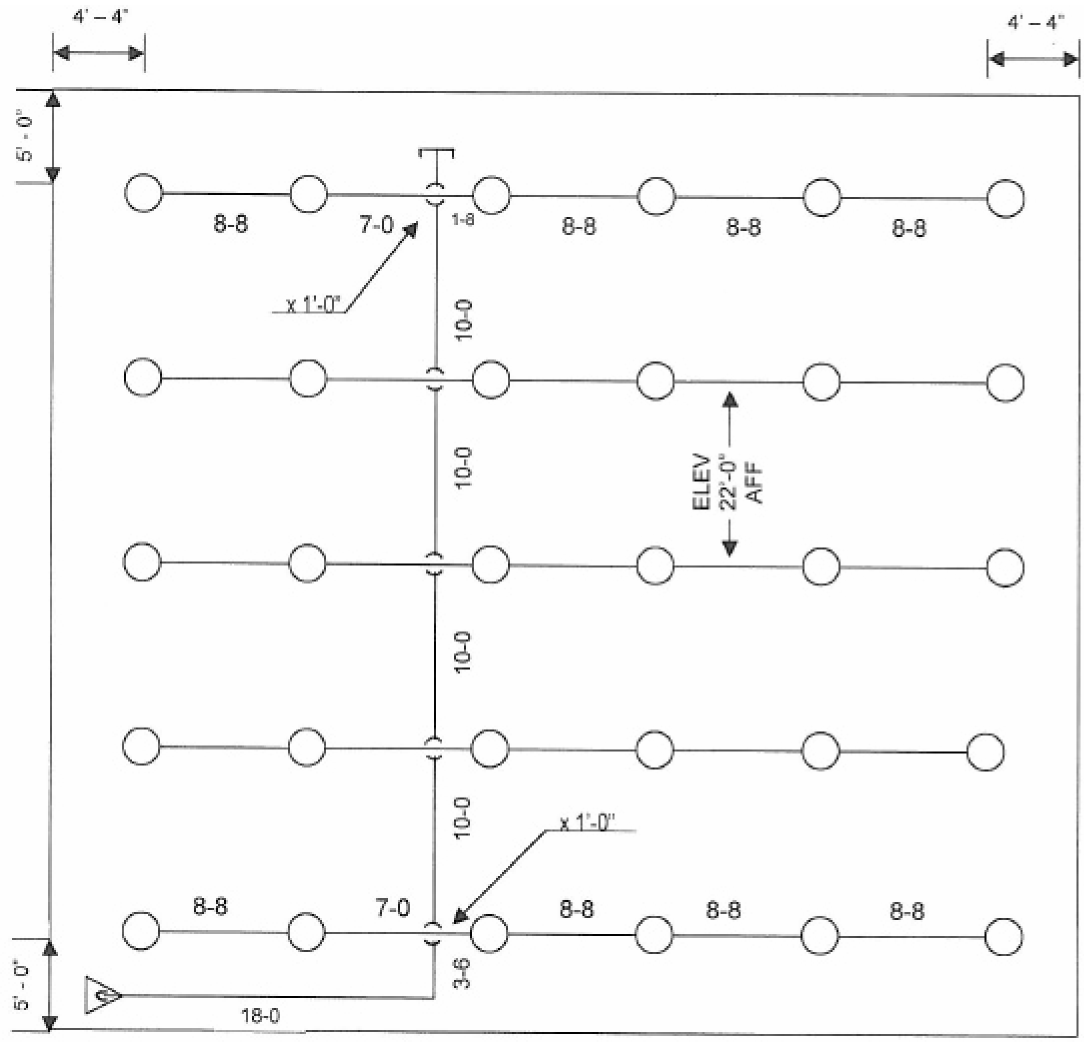

Figure 3.9

Question 1:

What is the minimum flow needed to meet the design criteria?

a. 750 gpm
b. 1000 gpm
c. 1250 gpm
d. 1500 gpm

Question 2:

What is the minimum sprinkler operating pressure?

a. 10.57 psi
b. 21.6 psi
c. 18.8 psi

d. 7.0 psi

Question 3:

Assuming a 10 psi allowance for friction loss, what is the estimated system demand?

a. 1500 gpm @ 30.0 psi
b. 1500 gpm @ 38.3 psi
c. 750 gpm @ 26.5 psi
d. 1250 gpm @ 30.0 psi

Exercise Number 2

A flow test is conducted for the system in Figure 3.9. The results yield the following information:

Static Pressure:	42 psi
Residual Pressure:	33 psi
Flow:	1150 gpm

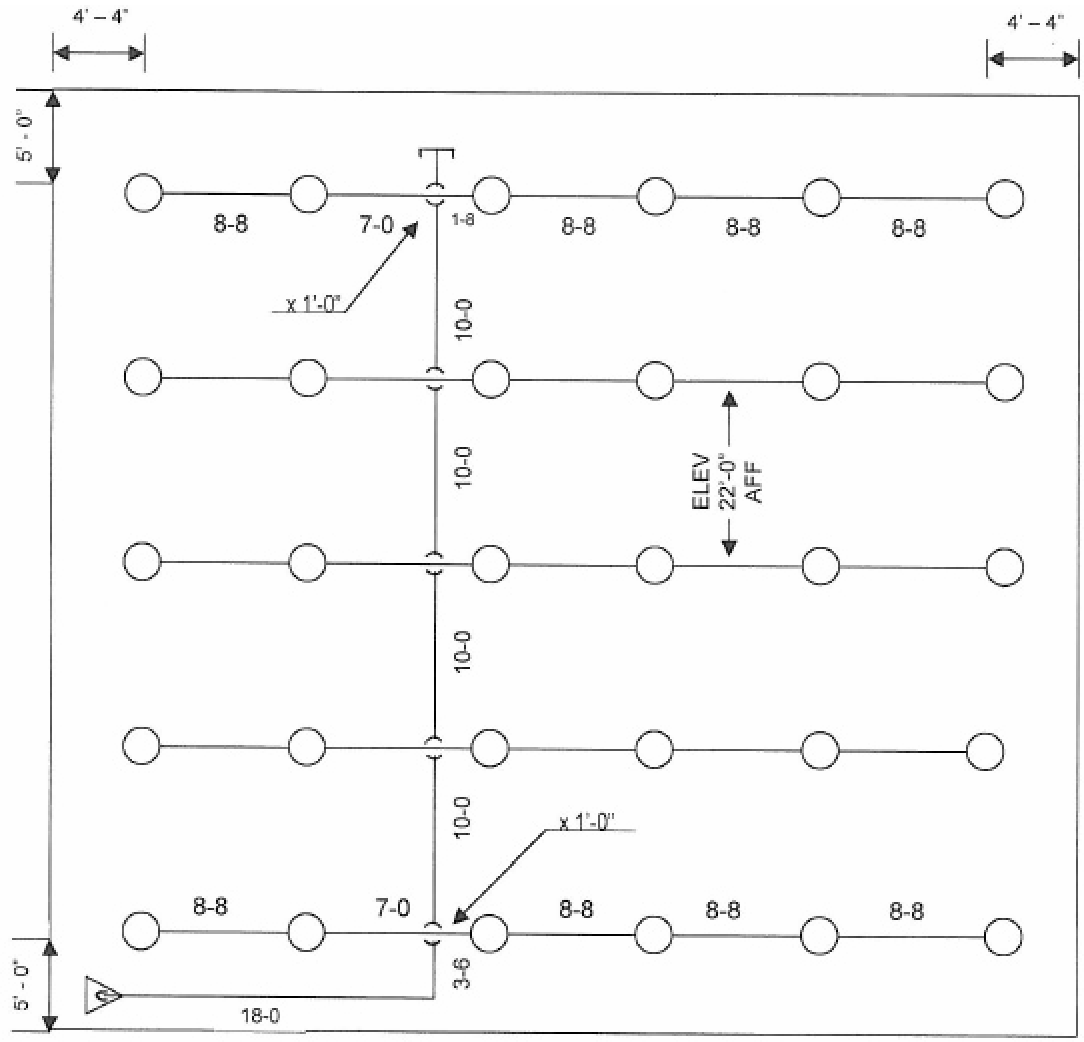

Figure 3.9

Question 1:

Using this test data, what is the available pressure for calculating the sprinkler system?

a. 36.6 psi
b. 31.5 psi
c. 32.2 psi
d. 27.3 psi

Exercise Number 3

Refer to Figure 3.9 to answer the following questions.

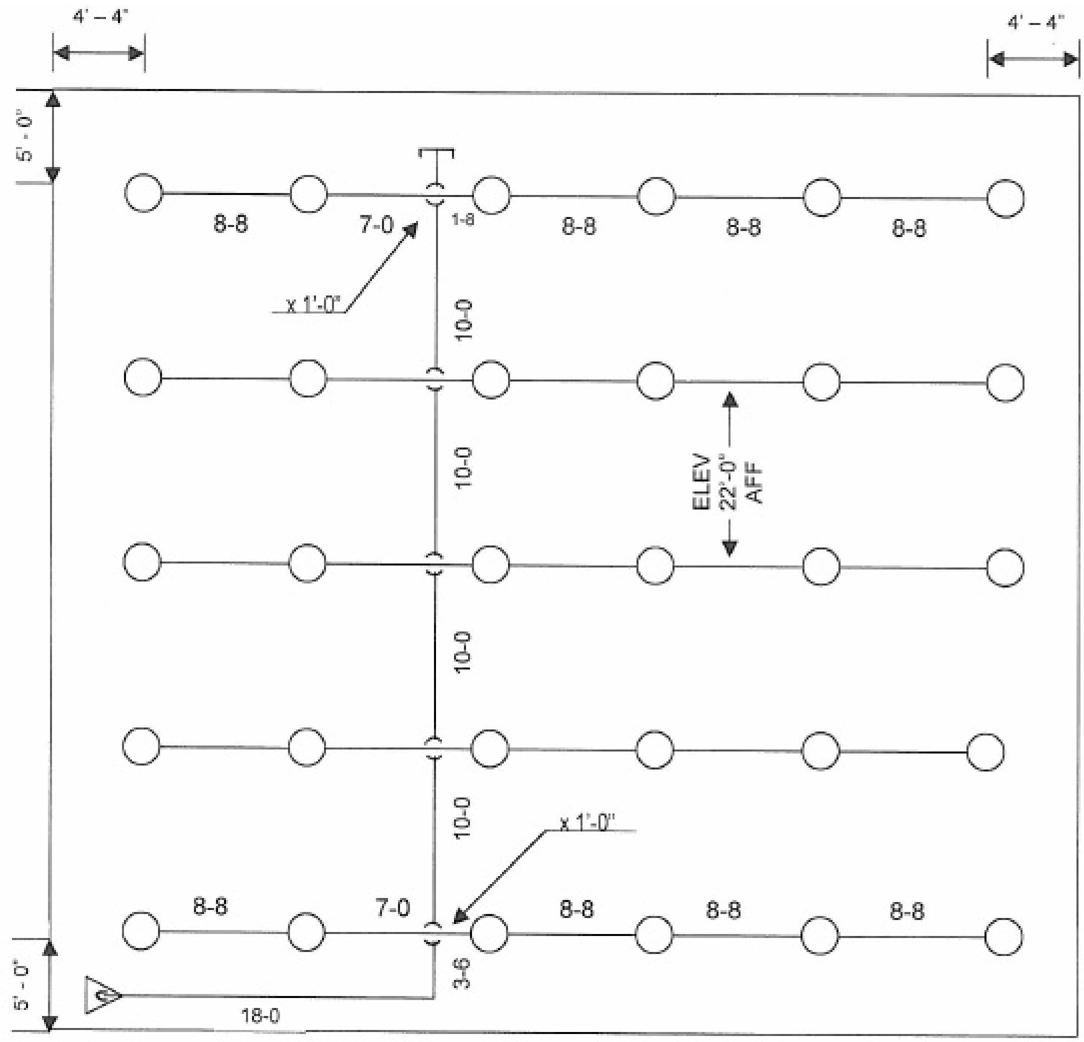

Figure 3.9

Question 1:

What is the minimum number of sprinklers for a 2500 ft^2 design area?

a. 25
b. 28
c. 29
d. 26

Question 2:

What is the minimum number of sprinklers if the design is reduced to 2000 ft^2?

a. 23
b. 24
c. 20

d. 25

Question 3:

How many sprinklers along the branch line(s) must be included in the calculation if the design area is 1500 ft^2?

a. 6
b. 5
c. 4
d. 2

Question 4:

What is the actual area covered for a design area of 1500 ft^2?

a. 1500 ft^2
b. 1514 ft^2
c. 1556.1^2
d. 1560.6 ft^2

Exercise Number 4

Refer to the following information for this exercise.

Two branch lines meet at the junction point at the top of a riser nipple. Branch line number 1 (BL1) has a demand of 64 gpm at 17.55 psi. Branch line number 2 (BL2) has a demand of 36.5 gpm at 15.30 psi.

Question 1:

What is K-factor for BL1?

a. 15.3
b. 3.7
c. 2.5
d. 10.98

Question 2:

What is the K-factor for BL2?

a. 2.4
b. 15.3
c. 9.3
d. 9.1

Question 3:

What is total combined flow needed for both branch lines?

a. 103 gpm
b. 142.8 gpm
c. 75.5 gpm
d. 100.5 gpm

Final Exam

1. Using Figure FE1, determine the area of coverage for Sprinkler 1:

A. 78 ft^2
B. 83 ft^2
C. 80 ft^2
D. 92 ft^2

2. Using Figure FE1, determine the area of coverage for Sprinkler 2:

A. 80 ft^2
B. 108 ft^2
C. 72 ft^2
D. 96 ft^2

3. Using Figure FE1, determine the area of coverage for Sprinkler 3:

A. 96 ft^2
B. 64 ft^2
C. 80 ft^2
D. 60 ft^2

4. Using Figure FE1, determine the area of coverage for Sprinkler 4:

A. 64 ft^2
B. 80 ft^2
C. 96 ft^2
D. 92 ft^2

5. Using Figure FE1, determine the area of coverage for Sprinkler 5:

A. 83 ft^2
B. 90 ft^2
C. 68 ft^2
D. 96 ft^2

6. Using Figure FE1, determine the area of coverage for Sprinkler 6:

A. 96 ft^2
B. 108 ft^2
C. 90 ft^2
D. 110 ft^2

7. Using Figure FE1, determine the area of coverage for Sprinkler 7:

A. 72 ft^2
B. 78 ft^2
C. 64 ft^2
D. 92 ft^2

8. Using Figure FE1, determine the area of coverage for Sprinkler 8:

A. 108 ft^2
B. 96 ft^2
C. 80 ft^2
D. 72 ft^2

9. Using Figure FE1, determine the area of coverage for Sprinkler 9:

A. 83 ft^2
B. 96 ft^2
C. 90 ft^2
D. 92 ft^2

10. Using Figure FE1, determine the area of coverage for Sprinkler 10:

A. 64 ft^2
B. 78 ft^2
C. 96 ft^2
D. 108 ft^2

11. Using Figure FE1, determine the area of coverage for Sprinkler 11:

A. 72 ft^2
B. 90 ft^2
C. 108 ft^2
D. 64 ft^2

12. Using Figure FE1, determine the area of coverage for Sprinkler 12:

A. 72 ft^2
B. 80 ft^2
C. 90 ft^2
D. 108 ft^2

13. Using Figure FE1, determine the area of coverage for Sprinkler 13:

A. 90 ft^2
B. 80 ft^2
C. 72 ft^2
D. 96 ft^2

14. Using Figure FE1, determine the area of coverage for Sprinkler 14:

A. 80 ft^2

B. 72 ft^2
C. 96 ft^2
D. 92 ft^2

15. Using Figure FE1, determine the area of coverage for Sprinkler 15:

A. 64 ft^2
B. 78 ft^2
C. 83 ft^2
D. 92 ft^2

16. Using Figure FE1, determine the area of coverage for Sprinkler 16:

A. 108 ft^2
B. 96 ft^2
C. 80 ft^2
D. 92 ft^2

17. Using Figure FE1, determine the minimum flow for Sprinkler 1:

A. 19.2 gpm
B. 21.6 gpm
C. 16.0 gpm
D. 12.8 gpm

18. Using Figure FE1, determine the minimum flow for Sprinkler 2:

A. 20.0 gpm
B. 18.4 gpm
C. 14.4 gpm
D. 19.2 gpm

19. Using Figure FE1, determine the minimum flow for Sprinkler 3:

A. 12.8 gpm
B. 21.6 gpm
C. 16.0 gpm
D. 11.8 gpm

20. Using Figure FE1, determine the minimum flow for Sprinkler 4:

A. 16.0 gpm
B. 14.4 gpm
C. 12.8 gpm
D. 19.2 gpm

21. Using Figure FE1, determine the minimum flow for Sprinkler 5:

A. 18.0 gpm
B. 16.0 gpm
C. 19.2 gpm

D. 21.6 gpm

22. Using Figure FE1, determine the minimum flow for Sprinkler 6:

A. 20.0 gpm
B. 21.6 gpm
C. 22.6 gpm
D. 21.0 gpm

23. Using Figure FE1, determine the minimum flow for Sprinkler 7:

A. 15.0 gpm
B. 14.4 gpm
C. 12.8 gpm
D. 16.0 gpm

24. Using Figure FE1, determine the minimum flow for Sprinkler 8:

A. 18.0 gpm
B. 18.2 gpm
C. 21.0 gpm
D. 21.6 gpm

25. Using Figure FE1, determine the minimum flow for Sprinkler 9:

A. 18.0 gpm
B. 19.2 gpm
C. 21.6 gpm
D. 12.8 gpm

26. Using Figure FE1, determine the minimum flow for Sprinkler 10:

A. 19.2 gpm
B. 20.0 gpm
C. 21.6 gpm
D. 22.4 gpm

27. Using Figure FE1, determine the minimum flow for Sprinkler 11:

A. 14.4 gpm
B. 16.0 gpm
C. 12.8 gpm
D. 13.0 gpm

28. Using Figure FE1, determine the minimum flow for Sprinkler 12:

A. 18.0 gpm
B. 23.0 gpm
C. 21.6 gpm
D. 19.2 gpm

29. Using Figure FE1, determine the minimum flow for Sprinkler 13:

A. 18.0 gpm
B. 19.2 gpm
C. 12.8 gpm
D. 16.0 gpm

30. Using Figure FE1, determine the minimum flow for Sprinkler 14:

A. 18.0 gpm
B. 19.2 gpm
C. 12.8 gpm
D. 16.0 gpm

31. Using Figure FE1, determine the minimum flow for Sprinkler 15:

A. 12.8 gpm
B. 14.4 gpm
C. 16.0 gpm
D. 10.8 gpm

32. Using Figure FE1, determine the minimum flow for Sprinkler 16:

A. 18.0 gpm
B. 19.2 gpm
C. 21.6 gpm
D. 16.0 gpm

33. Using Figure FE1, what is the actual square footage of the hydraulic design (calculation) area?

A. 1068 ft^2
B. 1168 ft^2
C. 1268 ft^2
D. 1368 ft^2

34. Using Figure FE1, what is the minimum demand (including sprinkler and hose stream allowance) needed for the system?

A. 423.6 gpm
B. 443.6 gpm
C. 463.6 gpm
D. 483.6 gpm

35. Using Figure FE2 (water flow graph), what is the available pressure at a flow of 483.6 gpm?

A. 39.3 psi
B. 41.3 psi
C. 43.3 psi
D. 45.0 psi

36. Using a blank calculation sheet, calculate the system illustrated on FE3 using the pipe sizes shown. Download and print a blank calculation sheet here.

What is the system demand including the hose stream allowance (flow and pressure) at the base of the system riser?

A. 549.6 gmp at 47.6 psi
B. 601.8 gpm at 49.8 psi
C. 584.7 gpm at 42.7 psi
D. 591.6 gpm at 48.8 psi

37. Calculate the system illustrated on FE3 using the pipe sizes shown. You may also use FE2 as a reference.

What is the available water supply pressure at the system demand?

A. 43.1 psi (at 591.6 gpm)
B. 42.3 psi (at 590.7 gpm)
C. 42.8 psi (at 590.6 gpm)
D. 43.4 psi (at 592.0 gpm)

38. Calculate the system illustrated on FE3 using the pipe sizes shown.
Is the system demand (flow and pressure) at the base of the system riser met by the available water supply?

A. Yes
B. No

39. Calculate the system illustrated on FE3 using the pipe sizes shown.
Recalculate using 3 in. diameter main from reference point D. What is the system demand with this change?

A. 589.2 gpm at 31.4 psi
B. 594.6 gpm at 41.7 psi
C. 591.6 gpm at 40.7 psi
D. 601.2 gpm at 41.3 psi

40. Calculate the system illustrated on FE3 using the pipe sizes shown. You may also use FE2 as a reference.

Recalculate using 3 in. diameter main from reference point D. Is the system demand (flow and pressure) at the base of the system riser met by the available water supply?

A. Yes
B. No