Assessment of Water Requirement and Calculation of Fire Flow Rates in Water Based Fire Fighting Installation

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Abstract- The provision of an adequate and reliable water supply is critical to the fire-fighting capabilities both from a system stand point and from a manual fire-fighting standpoint. This paper addresses the adequacy, having sufficient flow and pressure, and the reliability, the likelihood that the water supply will be there when needed, of a water supply. It discusses and outlines flow test procedures and then manipulates the results obtained during a flow test to identify ways of knowing what is available at different points on the system or at different flow rates. Recognizing that sometimes it is necessary to analyze the condition of the underground pipe, it presents a gradient analysis procedure using the Hazen-Williams formula and solving for either an inside diameter assuming a *C* factor for the pipe or solving for a *C* factor assuming a given diameter of pipe. It is only through frequent testing can the adequacy and reliability of the water supply be truly verified. These tests must be conducted on a periodic basis and adjusted for seasonal fluctuations

Keywords – water flow rate ,

I. Introduction

The amount of water needed and the economic of supply at are basic problem associated with the assessment of water requirement in water based fire fighting installation this research paper highlight the outline method used in calculation of fire flow rates in different water based fire installation the water requirement include the rate of flow ,reduced pressure required at the flow and the quantity required

II. FACTORS AFFECTING WATER REQUIREMENTS

Codes and Ordinances Fire prevention codes can effectively limit hazards and ignition sources within buildings, which, in turn, limit the number and size of fires by controlling combustibles in a fire area. A good building code further reduces the chance for a serious fire by requiring construction materials and building assemblies that will contain a developing fire to a given area. Codes alone can reduce considerably the amount of water needed for fire fighting. Zoning ordinances that establish distances between properties can be effective in controlling exposure situations

Fire Detection and Extinguishing Systems

The increased use of automatic extinguishing systems, whether they use water or some other agent, will affect the quantities of water required. Until more widespread use is made of early warning systems and automatic suppression systems, however, it will not be possible to equate the effect of these systems with required fire flow. Water supply requirements are just one factor in a system that determines what the potential for a fire is, how extensive that fire will be, and what measures will be needed to suppress it. Someday research will measure all these factors and allow us to establish fire flows on the basis of thoroughly researched and documented principle

History of Water Supply Systems

Historically, water supply systems for cities and towns were developed primarily to provide drinking water and water for sanitary purposes rather than for fire protection. However, it was found that large cities that required substantial amounts of water for domestic purposes usually had enough water to provide a useful supply for fire-fighting purposes. This led to inquiries in the late nineteenth century into the additional cost of waterworks that could provide water for fire Fighting, as well as other uses. A number of distinguished engineers associated with individual waterworks examined the problem and presented their findings in technical papers at engineering society meetings. Papers by J. Herbert Shedd,[5] J. Fanning,[6] and Emil Kuichling[7] give the details of discussions in which standards for American and Canadian waterworks were first developed.

Number of Hose Streams

In these discussions, the starting point for computing the cost of water for fire protection was to estimate the number of hose stream s that a fire department might need for fire fighting. This was usually estimated using as a basis the central portion of a city where the largest buildings were located and where there was the greatest building congestion. The number of streams was found to be related, in a very rough way, to the population .Shed's proposal, which was the first, used hose streams discharging 200 g pm (757 L/min). He suggested that a community of 5000 would need about five such streams and that the needs of other cities could be graduated up to 30 streams in a city of 180,000.Fanning proposed streams requiring about 54 psi (372 kPa) pressures. His figures were similar to Shed's, beginning at seven streams for a community of 4000 and going up to25 streams for a city of 150,000 . Kuichling suggested a formula in which the number of streams required would be the square root of the population in. thousands multiplied by 2.8. There were arithmetical differences as to how these estimates worked out for individual cities, but they were all of the same general order (see most important, they provided a basis from which waterworks designers could estimate costs. The most important paper produced during this time was John R. Freeman's "The Arrangement of Hydrants and Water Pipes for the Protection of a City Against Fire," published in 1892.[8] Freeman had done the fundamental work on water flow through hose and nozzles, so he was able to pin down the definition of a standard fire stream to one with a discharge of 250 gpm (946 L/min) at 40 to50 psi (276 to 345 kPa) pressure. He said that the relationships suggested by Shed d and fanning between population and the number of streams required were of the right order, but he did not think the needs of individual cities could be quite so definitely ascertained. He suggested two to three streams as a minimum for a population of 1000, graduated up to 30 to 50 streams at 200,000. Most significantly, he warned, "Ten streams, or as large a proportion hereof as the financial consideration will permit, may be recommended for a compact group of large, valuable buildings, irrespective of a small population."[8]

Engineering: Distribution, Network, Hydrant Spacing, Storage

Freeman noted a fundamental difference between systems designed to supply ordinary water needs and those for fire protection: Fire draft required concentration of the water, whereas domestic draft was a matter of distribution. Freeman asserted that, if a water system was to supply fire protection needs, the distribution system should be designed to concentrate the needed amounts of water. Small pipes were sufficient for distribution, but larger ones were needed to concentrate supply to fire streams. He suggested 6-in. (152-mm) diameter pipe as the minimum for residential district and note that 8-in. (203-mm) pipe was adequate only if it formed part of a network of distribution pipes whose intersections were not far apart. Another important point Freeman made was that hydrants should be placed where they could concentrate streams at specific blocks or groups of buildings rather than be placed arbitrarily a certain number of feet (m) apart on the street mains. His work on hose streams showed how long hose lines reduced the water that can be delivered promptly to a fire. Therefore, he suggest working rule for hydrant spacing of 250 ft (76 m) between hydrants in compact mercantile and manufacturing districts and 400 ft (122 m) to 500 ft (153 m) in residential districts. These working rules can still be used as guides for good design. Freeman further insisted that fire supply should be in addition to maximum domestic consumption, and he laid the foundation for the eventual recognition of this principle. He also calculated how much water should be stored in standpipes or in elevated reservoirs. He figured that flow for all of the hose streams required should be supplied from a reliable source, as an elevated storage reservoir, for at least 6 hr when the system was also furnishing maximum demands for domestic and other uses. He also calculated that to supply the combined fire and domestic needs in a system provided with reliable pump capacity a 1-hr supply in a standpipe or elevated reservoir would be acceptable.

Calculating Fire Flow Rates

The required flow rate for properties protected by automatic Sprinklers is based on the sprinkler system design as required by the flow required is that of the sprinkler system plus the anticipated hose stream or manual fire-fighting requirements. There are several methods currently used to calculate required water flow rates for non sprinkle red properties. These include:

• The Insurance Services Office (ISO) method

• The Iowa State University (ISU) method
• The Illinois Institute of Technology Research Institute method

Insurance Services Office (ISO) Method

One of the most comprehensive and widely recommended methods for estimating fire flow requirements is found in the Insurance Services Office's *Fire Suppression Rating Schedule.*3 It provides guidance for estimating fire flow requirements for specific structures and was designed for insurance rating purposes. The flows determined by this method are generally considered a good estimate, and, as a result, the ISO method has received Wide spread use. The ISO method considers building construction, occupancy, adjacent exposed buildings, and communication paths between buildings. The basic formula in the schedule is:
$NFFi= (Ci)(Oi)(X + P)i$
Where
NFF_i = needed fire flow (NFF) in gal per min (L/min)
C_i = a construction factor that depends on the construction of the structure under consideration
O_i = an occupancy factor that depends on the combustibility of the occupancy
$(X = P)_i$ = an exposure factor that depends on the extent of exposure from and to adjacent structures.

The subscripts in the formula indicate that, where portions of a building have differing characteristics, a factor can be calculated for each section and multiplied by the percentage it represents of the effective area to obtain a weighted factor. The weighted C_i factor should not be less than the individual factor required for any individual section.
Construction Factor. The construction factor, C_i , is calculated from the following formula:

$$C_i=18F\sqrt{Ai}$$

Where
F= coefficient related to the class of construction
= 1.5 for construction class 1 (frame)
= 1.0 for construction class 2 (joisted masonry)
= 0.8 for construction class 3 (noncombustible) or construction
Class 4 (masonry, noncombustible)
= 0.6 for construction class 5 (modified fire resistant) or
Construction class 6 (fire resistive)
A_i= effective building area
The effective building area is the total square foot (m2) area of the largest floor plus:
• For construction classes 1 through 4, 50 percent of all other floors
• For construction classes 5 and 6, 25 percent of the area not exceeding the two other largest floors when all of the vertical openings have at least 1½-hr-rated protection, or 50 percent of the area not exceeding eight other floors when vertical openings are unprotected or have less than 1½-hr protection.

The value of *Ci* should not be less than 500 gpm (1893 L/min) nor greater than 8000 gpm (30,280 L/min) for Construction classes 1 and 2, and 6000 gpm (22,710 L/min) forConstruction classes 3, 4, 5, and 6, or any single, one-story building, Regardless of construction.

Occupancy Factor.

The occupancy factor, *Oi*, reflects the combustibility of the occupancy on the needed fire flow and is determined from the occupancy combustibility class. Occupancy factors can be found in Table 1 Typical occupancies and their classification can be found in Table For more detailed occupancy classification information,

Occupancy Combustibility Class	Occupancy Factor (O_i)
C-1 (Noncombustible)	0.75
C-2 (Limited combustible)	0.85
C-3 (Combustible)	1.00
C-4 (Free burning)	1.15
C-5 (Rapid burning)	1.25

Exposure and Communication [($X = P$)i] Factors.
The exposure and communication factors are determined as

$$(X + p)i + \sum_{i=g}^{n} Xi + Pi$$

where
n = number of sides of subject building
($X = P$)i = a maximum value of 1.75
The exposure factor, Xi , reflects the need for additional water to reduce the exposure to adjacent buildings. It depends on
the separation distance, the construction of the exposed building wall, and a length–height value—that is, the length of the exposed wall in feet (m) multiplied by the height in stories.
The communication factor, Pi , reflects the potential fire spread through open or enclosed communicating passageways\between buildings and is taken from Table Where there is more than one connection, only the one with the largest factor is used. Where there are no openings, Pi=0

Needed Fire Flow (NFF). The needed fire flow is calculated from the formula given previously and from the foregoing factors .The *NFF* calculated from the formula should be rounded to the nearest 250 gpm (946 L/min) for flows under 2500 gpm(9463 L/min) and to the nearest 500 gpm (1893 L/min) for larger flows and then adjusted by the following:
• For buildings with a wood roof, add 500 gpm (1893 L/min).
• The needed flow should not exceed 12,000 gpm (45,420 L/min) nor be less than 500 gpm (1893 L/min). The practical reason for these figures is that manual fire-fighting methods using hose streams and heavy stream appliances are not likely to need a larger supply, considering the general arrangement of buildings and the availability of hydrants.
• For habitation buildings, use the calculated *NFF* up to3500 gpm (13,248 L/min) maximum.
• For groupings of one-family and small two-family dwellings not more than two stories high

Iowa State University (ISU) Method

The Iowa State University method4 is another common method used to determine water flow rates for fire fighting. It uses amore theoretical approach and is based on the amount of water needed to deplete the oxygen in a confined area when the water is vaporized into steam by the heat of the fire. Tests conducted by the university indicate that a fire is best controlled if the amount of water necessary to deplete the oxygen is applied
within 30 s The required flow in gpm is given as:
Required flow =
where V is the enclosed volume in cubic feet. (For SI units:
1 gpm = 3.785 L/min;1 cu ft C 0.0283 m3.)
This method is unique in that it does not consider the occupancy hazard, only the volume of the building to be filled with stream.
Due to inefficiencies in applying water, some experts feel that the rate should be 2 to 4 gal per 100 cu ft (7.6 to 15 L/2.8m3) of building volume rather than the 1 gal per 100 cu ft (3.785 L/2.8m3) in the formula. Other variations include changing the value in the denominator based on the occupancy hazard. This formula has been used for approximately 30 years and is extremely simple to apply. For most buildings, the entire volume of the structure should be used, including the volume of basements, attics, crawl spaces, and other concealed spaces. For groups of buildings, the largest flow rate should be used.

Illinois Institute of Technology Research Method

The Illinois Institute of Technology method was based on a survey of 134 fires in the Chicago area. The results of the survey were used with regression analysis to develop fire flow formulas based on building area. The fire flow rate is based on one of the following formulas:

Flow for residential occupancies
$$=9 \times 10^{-5} A^2 + 50 \times 10^{-2} A$$
Flow for other occupancies
$$=-1.3 \times 10^{-5} A^2 + 42 \times 10^{-2} A$$

where *A* is the area of the fire in square feet. (For SI units: 1 sq ft C 0.0929 m2.)

Other Flow Considerations

Regardless of the method used to determine the flow rate, the required fire flow should be available simultaneously with consumption at the maximum daily rate. When evaluating the flow required for general public protection, both the AWWA and the ISO suggest that 3500 gpm (13,248 L/min) is the upper limit to be provided and that large facilities or those with severe hazards that need flow rates up to 12,000 gpm (45,420 L/min) be individually analyzed to determine the required flow rate. There are fires in which quantities of water in excess of the required fire flow are used. Water supplies of 50,000 gpm (189,250 L/min) or greater have been used in fire suppression, but designing systems capable of delivering flows of that magnitude is not cost-effective nor practical.

Fire Flow Duration

The number of hours during which the required fire flow should be available varies from 2 to 10 hr, as indicated in Table. It should be noted that many water authorities place an upper limit of 2 to 4 hrs on fire water supply duration due to economics.

Case Study based on fire flow calculation

Case-1 A 2500-gpm test flow from a group of street hydrants dropped the pressure from 69 to 44 psi. Then (1) what flow would be available at 20 psi, and (2) what would the residual pressure be if flow were increased to 3000 gpm?

SOLUTION 1: Since the flow rate, Q, is directly proportional to the 0.54 power of the head (friction) loss, by proportion

$Q2= (S – R_2)^{0.54}/Q_1 (S-R_1)^{0.54}$ & $Q_2= Q_1 (S – R_2)^{0.54}/(S-R_1)^{0.54}$

Substituting the known values:
$S - R_2 = 6 – 20 = 49$ psi

$49^{0.54} =8.18.$
$S – R_1 = 69 – 44 = 25$ psi

$25^{0.54} = 5.69$

Q_2= 2500 8.18/5.69 = 2500 x 1.438 = 3595 gpm (answer)

SOLUTION 2: Calculate R_2 when Q_2=3000 gpm.

$3000=2500\ (69-R_2)^{0.54}/ (69-44)^{0.54}$

or
$(69-R_2)^{0.54} = 3000/2500\ (69-44)^{0.54}$
Since $(69-R_2)^{0.54} = 5.69$, than
$(69-R_2)^{0.54} = 1.20x5.69= 6.83$

Case-2 A 5000 L/min test flow from a group of street hydrants dropped the pressure from 500 to 350 kPa.
What flow would be available at 140 kPa (approximately 20 psi)?

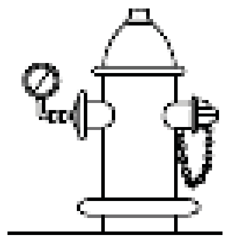
SOLUTION: Again, flow rate, Q, is directly proportional to the 0.54 power of the head (friction) loss, by proportion:
$Q2= (S – R_2)^{0.54}/Q_1 (S-R_1)^{0.54}$ & $Q_2= Q_1 (S – R_2)^{0.54}/(S-R_1)^{0.54}$

Substituting known values,
S - R2=500- 140=360 kPa and $360^{0.54}$=24.01
S - R1=500- 350=150 kPa and $150^{0.54}$=14.97

Q_2 = 5000 x 24.01/14.97 = 8019 L/min

CONDUCTING FLOW TESTS

Hydrant flow tests are fairly simple to conduct and the results usually are easily interpreted. Once the objective of the test has been determined, it is only necessary to discharge water at a known rate from one or more hydrants. The pressure drop the discharge produces is observed simultaneously at a second hydrant or at other points of connection to the system that is supplying the flowing hydrants. The tester should identify the static (non flowing) hydrant and the flowing hydrant. In a single-direction-feed water supply, the non flowing hydrant should be the one nearer the source. In a gridded-type system (in which the water comes from more than one direction), the location of the static and residual hydrants is not critical. In any case, the test should be conducted in the vicinity of the required point of connection. Upon identification of the hydrants to be used, the tester should remove a hydrant cap and flush the hydrants. This is intended to reduce the possibility of damage to the test equipment or to the tester. Once a clean, steady stream of water is observed, the hydrant valve should be slowly closed. The non flowing hydrant is then prepared by installing the hydrant cap and gauge with the petcock open. The hydrant is opened and the petcock is closed. The pressure with no hydrants flowing is recorded This is the static pressure. The tester proceeds to the flow hydrant and measures the opening (assuming no flow aid is attached, such as stream straighteners, play pipes, etc.). The tester also, at this point, should determine the hydrant coefficient of discharge. After obtaining the diameter of the opening and the hydrant coefficient, the tester should open up the flow hydrant.



When clean, steady stream of water is present, the tester should measure the flowing pressure by inserting the Pitot tube and gauge assembly into the middle of the stream, one half the diameter away from the edge of the opening. The tester should record the Pitot gauge reading while simultaneously someone records the gauge pressure on the non flowing hydrant. The pressure recorded by the Pitot tube assembly will be used to calculate flow through the use of the following formula:

where
Q= flow (gpm)
c = coefficient of discharge
d = diameter of outlet (in.)
p = flowing pressure (Pitot reading)
In SI units the formula is:
$Q= 0.0666cd^2$

where
Q = flow (L/min)
c = coefficient of discharge
d = diameter of outlet (mm)
P = flowing pressure (kPa)
Should additional flow rates be desired, other butts or hydrants may be opened and pressures measured accordingly. After the flowing hydrants have been slowly shut off, the static pressure should be observed and compared with the initial reading. Pitot readings of less than 10 psi (69 kPa) or over 30 psi (207 kPa) at any open hydrant should be avoided. To keep within these pressure limits, the rate of flow can be controlled by throttling the hydrant or opening a second outlet, or both. However, the flow hydrants should be opened sufficiently so that hydrant drains are closed. Water continuously discharged through the drains tends to erode the soil from the base of the hydrant. Avoid using the larger pumper connection on a hydrant for testing unless flow and pressure are strong enough to produce a full stream. When pumper outlets are used, a proper coefficient of discharge must be determined, based on the extent to which the orifice is completely filled with water. On occasion, it may be desirable to obtain an average velocity pressure by moving the Pitot tube through the entire vertical dimension of the orifice. No. 1 was the gauging point, and hydrant No. 2 was the point.

Hydrant flow tests show the available flow over and above water consumption that occurs during the test. To evaluate the adequacy and reliability of a system properly, consideration is given to the sources of supply, the levels of water in distribution storage, and the overall operating condition of the system. The hour of the day, the day of the week, the month of the year, the weather, or an impairment made necessary by construction or system expansion are all factors that may affect the results of flow tests. Fire flow may be adequate one time and inadequate another because of variations in consumption or in the mode of operation of the system.

Location:						
Hydrants: 2__-in. square shape assumed C = 0.80						
Pressure Hyd1	Pilot pressure				gpm	Total gpm
	Hyd2	Hyd3	Hyd4			
72	-	-	-		0	0
62	18	0	0		633	633
50	10 10		-		472 472	944

Sometimes unsuspected faults other than insufficient supplies are disclosed by hydrant flow tests. Valves may be partly or entirely shut; sometimes they are found broken or with bent valve stems. Valve boxes may be filled with muck or sand, or even paved over with concrete or asphalt cement. Silt, stones, fish, and other foreign material may be found in pipe systems or hydrants, effectively reducing the available water supply. Many or all of these faults may be due to lack of maintenance and operational control. It is customary to report the results of hydrant flow tests conducted in public systems in gallons per minute (L/min) available at 20-psi (138-kPa) residual pressure, which is the minimum recommended residual pressure at hydrants for fire engine use. The observed flow and pressures can be converted to any desired residual pressure or flow rate by a simple proportion derived from the Hazen-Williams pipe flow formula. This formula shows that the flow rate in gallons per minute is directly proportional to the 0.54 power of the head loss or the drop in pressure from static to residual observed during the test. Head loss, which is mostly pipe friction, is the difference between the observed static pressure, *S,* and the residual pressure, *R.* The gauge value of *S* seldom indicates the true static (no flow) pressure; actually, it is the residual pressure for the normal Location:

Steps involving in flow test of hydrant system.

Step No. 1. A gauge was attached to No. 1 hydrant with a cap. The hydrant was opened, and the static pressure [72 psi (496 kPa)] was recorded . No. 1 hydrant was chosen for the gauging point. The gauge could have been located on the sprinkler riser in the building, but the hydrant location probably was more convenient.

Step No. 2. The caps were removed from No. 2 hydrant. The diameter of the outlets was measured, and the outlets were found to be square and sharp (After one cap was replaced, the hydrant was opened, and a Pitot reading of 18 psi (124 kPa) was made and recorded. Before the flow was shut off, the residual pressure at No. 1 hydrant was recorded as 62 psi (427 kPa).

Step No. 3. The second butt at No. 2 hydrant was opened, and 10-psi (69-kPa) Pitot readings were noted on both streams. At No. 1 hydrant, the residual pressure was now 50 psi (345 kPa). It is always desirable to obtain data for at least two rates of flow, one of which should be as large as facilities, conditions, and time will allow.

Step No. 4. No. 2 hydrant was shut down slowly and carefully, and the caps were replaced. The static pressure at No. 1 hydrant was read and found to be 72 psi (496 kPa), as before the test. The hydrant was then shut down, the gauge cap removed, and the regular cap replaced.

IV.CONCLUSION

The time to worry about the requirements of a fire protection water supply is not when the fire has broken out but rather long before the incident occurs. Fire protection water is almost always a shared entity with the domestic users and fire protection supplies are only needed when there is an emergency. However, the total supply available to an area has to consider both normal and emergency uses.

The fire service has a number of methods available to help determine how great the water supply has to be in the event of a fire. The amount of water needed will always be a function of the occupancy and the construction of the building in question, and in many cases, the outside exposures to the structure. There are quick ways to develop fire flow needs that encompass all of these parameters, and the fire service uses these routinely.
Adequacy and reliability of the water supply system when needed are not to be taken for granted. Careful planning as to what is needed and then careful analysis of availability is key to planning before the incident occurs.

REFERENCES

[1] Bychowski, J. A., and Balingit, C., "Back-Flow Prevention forToday's Sprinkler Systems," *Consulting-Specifying Engineer,* Vol. 20, No. 4, 1996, pp. 54–56.

[2] Cain, B., "Will Your Sprinkler System Function Correctly?" *Fire Safety Engineering,* Vol. 7, No. 5, 2000, pp. 9–10.

[3] "Canada's Quake-Proof Water Supplies," *Fire International,* No. 152,July 1996, p. 40.

[4] Carson,W. G., and Klinker, R. J., *Fire Protection Systems, Inspection ,Test & Maintenance Manual,* 2nd ed., National Fire Protection

[5] Association, Quincy, MA, 1993.Comeau, E., and Duval, R. F., "School Fire, Pangnirtung, Northwest Territories, Canada, March 9, 1997," National Fire Protection Association, Quincy, MA, NFPA Fire Investigation Report,1998.

[6] Covey, B., "Static Water Supply Challenges: Australia's Solution,"*Fire Engineering,* Vol. 152, No. 8, 1999, pp. 143–144.

[7] Damon,W. A., "Testing Pressure-Regulating Devices in Water-Based Fire Protection Systems," *Fire Engineering,* Vol. 146, No. 11, 1993, pp. 51, 55–57.

[8] Davis, S., "Fire Fighting Water: A Review of Fire Fighting Requirements :A New Zealand Perspective," University of Canterbury,

[9] Christchurch, New Zealand, Fire Engineering Research Report\ 00/3, March 2000.

[10] Dubay, C. E., "Pressure's Building," *NFPA Journal,* Vol. 91, No. 4,1997, pp. 68–72.Dunn, V., "13-Point Size-Up of a High-Rise Fire," *Firehouse,* Vol. 24,No. 1, 1999, p. 16.Fredericks, A. A., "Little Drops of Water: 50 Years Later. Part 2," *FireEngineering,* Vol. 153, No. 3, 2000, pp. 113–114.

[11] Fredericks, A. A., "Standpipe System Operations: The Standpipe Kit,"*Fire Engineering,* Vol. 152, No. 2, 1999, pp. 71–72.Gamble, C., "Pre-Planning Rural Water Supplies," *Fire Chief,* Vol. 39,No. 3, 1995, pp. 68, 70, 72.

[12] Gamble, C. C., Jr., "Training the Water Supply Officer," *Fire Chief,*Vol. 37, No. 10, 1993, pp. 43–45.Garcia, R., "Never Again?" *Fire Chief,* Vol. 41, No. 6, 1997, pp. 35–36.

[13] Goyer, D., "High School Blaze," *Fire Fighting in Canada,* Vol. 40,No. 8, 1996, pp. 6–7. Granito, J. A., and Hickey, H. E., "ISO, Inc. Public Protection Classification Process: A Current Perspective," *Firehouse,* Vol. 24, No. 8, 1999, p. 104.

[14] Hanley, M., and Murchison, D., "Dry Hydrants and Static Water Supplies,"*Fire Engineering,* Vol. 153, No. 2, 2000, pp. 79–80.

[15] Keith, G., and Garner, D., "Sprinkler System Water Supply Analysis," *Fire Engineering,* Vol. 144, No. 12, 1991, pp. 67–68, 70–71.

[16] Kidd, S., "Managing Fire Safety in Heritage Premises," *Fire Protection,* Vol. 23, No. 2, 1997, pp. 12–1.

[17] Kitchen, M., "Poor Information on Residents Hampers Surrey Blaze

[18] Rescue," *Fire,* Vol. 91, No. 1116, 1998, p. 8.Klaene, B., and Sanders, R., "Figuring Flow Rates," *NFPA Journal,* Vol. 95, No. 6, 2001, p. 25.

[19] "Kobe," National Fire Protection Association, Quincy, MA, NFPA Investigation Report, 1996.

[20] Leihbacher, D., "Overcoming Common Water Supply Problems," *Fire Engineering,* Vol. 151, No. 4, 1998, pp. 119–124.

[21] Loeb, D. L., "Don't Stop Fire Training," *Fire Chief,* Vol. 41, No. 4,1997, p. 56.

[22] Loeb, D. L., "Tires and Fires," *Fire Chief,* Vol. 40, No. 3, 1996,pp. 51–52.

[23] St. Louis, E., and Wilder, S., "Train Disasters Test the Fire Service: Tragedy on the City of New Orleans," *Fire Engineering,*

[24] Vol. 152, No. 6, 1999, pp. 61–62.

[25] Torvi, D., Hadjisop hocleous, G., Guenther, M. B., and Thomas, G., "Estimating Water Requirements for Firefighting Operations

[26] Using FIERA system," *Fire Technology,* Vol. 37, No. 3, 2001, pp. 235–262.

[27] Toth, M. J., "Water Delivery Basics: From Pea Shooters to Cannons, "*American Fire Journal,* Vol. 48, No. 10, 1996, pp. 11–14.

[28] Tracy, G. A., "High-Rise Standpipe Flow Test," *Fire Engineering* ,Vol. 152, No. 4, 1999, pp. 107–109.

[29] Wallace, G., "Charlestown Factory Fire Tests Mutual Aid Respons e.On the Job: New Hampshire," *Firehouse,* Vol. 22, No. 8, 1997, pp. 78–80.

[30] Williams, A. S., and Halford, S. D., "Improved Water Supply in Non hydrant Areas: One Department's Approach," *Fire Engineering,* Vol. 151, No. 4, 1998, pp. 109–118.

[31] Zenofsky, S., "Fire on the Horizon: Preventing the Loss from Vbush,Forest, Brush, Grass and Wildland Fires," *Fire Engineers Journal,* Vol. 59, No. 201, 1999, pp. 6–9.