Residential Fire Sprinklers –
Water Usage and Water Meter Performance Study

Final Report

Prepared by:

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THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

FIRE RESEARCH

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FOREWORD

When mandates for sprinkler requirements in one and two family dwellings are discussed at a local or state level, a number of issues come up with respect to water supply requirements. Often, these issues are true barriers to residential sprinkler requirements because the water authority is not knowledgeable about residential sprinklers systems and how they are different from commercial fire sprinkler systems. There are two related issues: one is total water usage during sprinkler actuation at a fire scene (fire flow) in comparison with water usage by the fire service; the other is conventional water meter performance during sprinkler actuation.

This report describes the results of a study on water usage and water meter performance during residential sprinkler system actuation in residences, designed to provide guidance information on this topic in a format suitable for water utilities and local jurisdictions. It includes the results of a survey of fire departments on their average use of water at fire scenes at single family homes; fire flow calculations for a variety of single family home fire sprinkler systems and a study of the performance of conventional residential water meters in maximum and minimum fire sprinkler flow scenarios.

The content, opinions and conclusions contained in this report are solely those of the authors.

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Residential Fire Sprinklers – Water Usage and Water Meter Performance Study

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Acronyms and Abbreviations

AWWA	American Water Works Association
BM	Basement
ERF	Emergency Response Facilities
ERU	Emergency Response Unit
FM	Factory Mutual
ft	feet
gpm	gallons per minute
HP	horsepower
IFC	International Fire Code
in	inch
ISO	Insurance Services Office
lb	pound
LV	Listed Vertical Turbine
MJ	Multi-Jet
NFF	Needed Fire Flow
NFPA	National Fire Protection Association
NPT	National Pipe Thread
PD	Positive Displacement
PSAP	Public Safety Access Point
psi	pounds per square inch
UL	Underwriters Laboratories
U.S.	United States
VT	Vertical Turbine

Executive Summary

Automatic fire sprinkler systems are effective in saving lives in residential occupancies.[1] Consequently, model building codes have recently included provisions requiring residential fire sprinklers in all newly constructed one- and two-family homes. However, factors related to water supplies[2] are considered by state and local jurisdictions in making decisions on the adoption of such model codes and their residential fire sprinkler requirements. In addition to saving lives, there are unrecognized benefits in protecting homes with residential fire sprinklers, such as the conservation of water and the potential reduction of water infrastructure demands in communities. Water usage by fire services is expected to be significantly less for homes protected by a fire sprinkler system.[3] Another consideration by state and local jurisdictions is that conventional water meters for combined service (i.e. domestic potable and fire sprinkler system service) are perceived to be unsuitable for residential fire sprinkler systems based on pressure loss characteristics, flow capacity limitations, and reliability characteristics. To address these factors, the research team performed the following tasks: 1) a study of water consumption during fire events and the resulting impact of sprinklers on the water infrastructure demand for detached one- and two-family home communities, and 2) an evaluation of the performance of water meters when used to supply residential fire sprinkler systems.

The first task involved three parts: 1) an estimation of water used per home fire by responding fire services, 2) calculations of the expected water discharged by fire sprinklers per home fire, and 3) an estimation of the reduced water infrastructure demand when fire sprinkler systems are present in all homes within a community. To obtain a value for water consumption by fire services during fire events, the research team conducted a survey of reported water discharged by responding fire services at reported home fires[4]. Data was compiled from eight communities

[1] Hall, J.R., U.S. Experience with Sprinklers and Other Automatic Fire Extinguishing Equipment, National Fire Protection Association, Quincy, MA, 2010.

[2] The National Fire Protection Association, Integration of Residential Sprinklers with Water Supply Systems – A Survey of Twenty U.S. Communities, 2010

[3] Wieczorek, C.J., Ditch, B., and Bill, R.G., Environmental Impact of Automatic Fire Sprinklers, Technical Report, FM Global Research Division, 2010.

[4] Due to limited number of fire events occurred during the survey period, only water usage data for house fires without fire sprinkler systems were available.

selected based on the status of a local sprinkler ordinance, availability of fire service equipment, availability of municipal water supply, geography, and availability of data. Based on the collected data, the amount of water used by responding fire services at home fires without sprinkler systems ranged from 100 to 41,000 gallons, with an average of 3,524 gallons per fire. This broad range of data is primarily attributed to the fire conditions upon the arrival of fire services. An approximate 10-times increase of water used per fire was reported when the fire extended beyond the room of origin, or when the degree of fire involvement increased from visible flame and smoke to a fully-involved fire.

To determine the estimated water discharged by a fire sprinkler system during a fire, hydraulic calculations were performed on 18 fire sprinkler system designs for typical one- and two-family homes (based on total floor area) using the provided water supply information. The calculations assumed one- or two-sprinkler operation in system locations that simulate the conditions of both the highest water flow and the greatest system pressure demand. Based on the most probable scenario, where only one sprinkler operates in a home fire[5], a typical fire sprinkler system will discharge 22 to 38 gpm with an average of 28 gpm during the event. Due to the design margin, the calculated fire sprinkler discharge flow exceeds the minimum flow of 18 gpm, as required by NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-family Dwellings and Manufactured*. Assuming ten minutes of operation[6], a home fire sprinkler system could discharge up to 280 gallons of water per fire. By comparison, the average water discharged at a home fire without a fire sprinkler system is over 1200% greater than the water discharged by a home fire sprinkler system per fire event.

To estimate the water infrastructure demand for communities, the needed fire flows (NFFs) were calculated for 17 homes in accordance with various industry recognized methods, such as those provided by the Insurance Services Office (ISO), *Guide for Determination of Needed Fire Flow*, the International Code Council (ICC), *International Fire Code*, and National Fire Protection Association (NFPA) 1, *Fire Code*. These calculations suggest that the projected

[5] Operation Life Safety (OLS) Newsletter, Sprinkler Activations, Vol. 6, No. 12, Dec 1991.

[6] Based on NFPA 13D 6.1.2 for a minimum of 10 minutes of stored water supply and an average time to arrival of fire department (6.2 minutes) found in the survey in this study.

water infrastructure demand is reduced at least 47% when the homes within the community are protected by fire sprinkler systems.

A series of experiments were conducted on 16 commercially available residential water meters under a range of flow conditions to investigate pressure loss profiles, metering accuracy, and the functional integrity of the meter. The population of meters represented products from six manufacturers, and four were listed for residential fire service.[7] Ten of the 16 tested water meters produced pressure loss profiles in good agreement with their manufacturer reported values. The pressure loss profiles from these ten water meters was less than or similar to the generic NFPA 13D suggested values at the respective flow rates. The six remaining meters (five from the same manufacturer and one from another manufacturer) exhibited pressure losses greater than their manufacturer's published curves and the NFPA 13D suggested values. Two of these six water meters (one from each manufacturer) were ¾-in and listed for residential fire service. but exhibited pressure losses exceeding the listing requirements.

All water meters exhibited metering accuracy within the industry standards at flow conditions up to approximately 150% of their normal operating range, except one 1-in meter that over-reported flows. The normal operating range is based on meter size and the upper flow limit increases with the meter size. Above approximately 35 gpm, certain 5/8-in meters showed a significant decrease in metering accuracy. At low flow rates below the meter normal operating range (less than 3 gpm for 1-in meters) no significant loss of metering accuracy was found in any meter.

No water meters failed resulting in flow obstruction during any tests, and post-test visual inspections indicated no signs of physical damage to any meter. All tested residential water meters are capable of handling the minimum fire sprinkler flows required by NFPA 13D, as well as the expected flows (estimated to be 28 gpm for single sprinkler operation) without failure and with reasonable metering accuracy. Each meter was furnished with a unique metering accuracy certificate from manufacturer testing, but none contained any actual test data for hydraulic performance testing (i.e. pressure loss characterization). Based on the pressure

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[7] UL Subject 327A, Outline of Investigation for Inferential Type Residential Water Flow Meters, No 3, 2008

loss profiles for the tested water meters, an additional pressure buffer may be necessary to overcome the unexpected pressure loss specific to certain water meters. Additional measures should be implemented to regulate the pressure loss performance of water meters through standardized testing and quality control.

1 Introduction

Available data shows that the majority of deaths due to fires occur in one- and two-family homes.[8] To reduce fatalities resulting from home fires, recent model codes development has included requirements for fire sprinkler systems in one- and two-family residential occupancies. Several state and local jurisdictions plan to adopt the model codes and enforce ordinances for the installation of residential fire sprinkler systems in all newly constructed one- and two-family homes. However, several factors are considered by the local municipality when making a decision to adopt the residential fire sprinkler requirement. These factors include the benefit of fire sprinkler systems in saving lives, the differential of water consumed for fire suppression when fire sprinkler systems are present, and the suitability of water metering components connected to the fire sprinkler system. Without appropriate data to guide the decision making progress, water authorities may have reservations in supporting adoption of residential fire sprinkler system mandates.

When a fire occurs in a home protected by a fire sprinkler system, only one or two sprinklers are expected to activate and control the fire at its early stages, in most cases, prior to the arrival of fire services at the scene. The water demand for manual firefighting in comparison to fire sprinkler system operation is important to the local water authority. The water usage by the fire services responding to a fire in a home without fire sprinkler protection is expected to be significantly greater than a home with fire sprinkler protection. Additionally, industry recognized standards used to determine the capacity of the water infrastructure for communities allow for a reduction in the required fire flow when the building is provided with a fire sprinkler system. Reduction in the water infrastructure capacity for communities can benefit the water authority.

The suitability of conventional water meters in line with residential fire sprinkler systems is a concern of the water authority.[9] Residential water meters are used to measure water

[8] Badger, S. "Large-Loss Fires in the United States 2008," National Fire Protection Association, Quincy, MA, 2009.

[9] Integration of Residential Sprinklers with Water Supply System – A Survey of Twenty U.S. Communities, 09/2009, p. 9

consumption for billing purposes. Although residential water meters provide accurate readings in nominal domestic flow conditions[10], their measuring mechanism is perceived to create a severe flow restriction and potentially unsuitable hydraulic performance in high flow rate conditions, such as during fire sprinkler system operation. When larger water meters are used to accommodate high flow conditions, the larger meters are perceived to lose metering accuracy[11] for typical domestic (i.e. low) flow rates, resulting in unaccounted for water consumption.

1.1 Objectives

The objective of this research project is to provide an understanding of: 1) water consumption during fire events in homes with and without fire sprinklers and the resulting impact of fire sprinklers on the water infrastructure demand for residential communities, and 2) the performance of water meters when used in one- and two-family homes protected with a fire sprinkler system.

1.2 Scope and Methodology

To obtain a value for water consumption during fire events, a literature review was performed. A survey of water discharge reported by responding fire services at home fires with and without fire sprinkler systems in select communities across the United States was conducted based on the status of a local sprinkler ordinance, availability of fire service equipment, geography, and availability of data. An overall average of water consumption by fire services was calculated per fire and primary factors that may influence the result were identified.

A comparison of water consumption was made for fires that occurred in homes protected with a fire sprinkler system versus unprotected homes where fire department response was necessary. The expected amount of water discharged by a fire sprinkler system during a fire event was hydraulically calculated based on a number of sprinkler system designs developed for typical single family homes with provided water supply information.

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[10] "Water Meters – Selection, Installation, Testing, and Maintenance", American Water Works Association, 1999 Ed.

[11] Integration of Residential Sprinklers with Water Supply System – A Survey of Twenty U.S. Communities, 09/2009, p. 41.

To illustrate the resulting impact of fire sprinkler systems on the water infrastructure demand in communities, an estimation of the fire flow requirement or the needed fire flows (NFFs) were determined for a population of single family homes based on industry recognized methods, including National Fire Protection Association (NFPA) 1[12], *Fire Code*, the International Code Council (ICC), *International Fire Code* (IFC)[13], and the Insurance Services Office (ISO), *Guide for Determination of Needed Fire Flow*.[14]

Finally, the performance of water meters utilized in residential fire sprinkler systems was investigated through a series of experiments conducted on a number of commercially available water meters to evaluate the following key parameters: 1) pressure loss profiles, 2) metering accuracy, and 3) functional integrity of the meter. The water meters tested in this study were of a typical size and type used for one- or two-family homes, as well as types specifically listed for residential fire sprinkler system use.

[12] NFPA 1 – 2009 Fire Code, National Fire Protection Association,

[13] 2009 International Fire Code, International Code Council.

[14] Guide for Determination of Needed Fire Flow, Insurance Services Office, Edition 05-2008

2 Water Usage Study

State and local jurisdictions consider several factors when deciding whether or not to adopt fire sprinkler system legislation. In addition to the benefit of fire sprinkler systems in saving lives, other important factors that are considered by the water authorities include, the suitability of water metering components in line with fire sprinkler systems, the efficiency of water used for fire suppression in the event of a fire, and implications on the water infrastructure demands in a community with homes protected by fire sprinkler systems.

Data from previous work supports the benefits of fire sprinkler systems on the reduction in water infrastructure demands. A review[15] of data compiled over 15 years in a single community, Scottsdale, Arizona, indicates that fire sprinkler systems discharged an average of 341 gallons of water per fire, in comparison to an average 2,935 gallons of water applied by responding fire services per fire that occurred in homes without fire sprinkler systems. The Scottsdale, Arizona water authority was able to accommodate the growth of water infrastructure demands better, because the implementation of fire sprinkler systems assisted in reducing the overall water usage required to manually fight fires. An experimental study[16] conducted by Factory Mutual (FM) Global provides a comparison of water usage based on a series of large-scale fire tests where 1) fire extinguishment was achieved solely by fire service intervention and 2) the fire was controlled by water discharging from a single residential fire sprinkler until final extinguishment was achieved by fire services. The FM Global study indicates that the combination of fire sprinkler and hose stream discharged 50% less water than the hose stream alone. Further analysis based on extrapolation[17] of the data shows that for an average-size home (1,765 sq. ft), the reduction in water usage by a fire sprinkler system could be as much as 91% compared to manual suppression by responding fire services.

[15] 15 Years of Built-in Automatic Sprinklers: The Scottsdale Experience, 2001 and Automatic Sprinklers: A 10 Year study – Detailed history of the effects of the automatic sprinkler code in Scottsdale AZ, 1997.

[16] Wieczorek, C.J., Ditch, B., and Bill, R.G., Environmental Impact of Automatic Fire Sprinklers, Technical Report, FM Global Research Division, 2010.

[17] Ibid., p. 63. Assuming the quantity of water needed to extinguish the fire is directly proportional to the area of the tested room and a single sprinkler operates.

To supplement the water usage data available in the literature, data is provided for 1) water consumption during a home fire based on a survey of reported water used by responding fire services in multiple communities across the U.S., 2) expected water discharged by fire sprinkler system operation during a home fire based on hydraulic calculations performed on a number of fire sprinkler system designs, and 3) a reduction of water infrastructure demand when fire sprinkler systems are present in communities based on fire flow requirements, as calculated using multiple industry recognized methods.

2.1 Survey of Water Usage by Fire Services

To obtain the water consumption during fire events over the last year, the research team conducted a survey of reported water discharged by responding fire services at home fires with and without fire sprinkler systems in select communities across the U.S. An estimation of fire service water usage per fire and the primary factors that can influence the overall result are provided.

2.1.1 Community Selection Criteria

Water usage by fire services in a fire event can differ from one fire to another depending on several factors, including the severity of the fire at the arrival of fire services, availability of a water supply for manual fire suppression, and the availability and type of combustible materials that have direct influence on the fire propagation. To capture potential differences in water usage across communities, the criteria for community selection were based on:

- **Status of a local fire sprinkler ordinance.** Fire sprinkler systems can have a significant impact on the water used by fire services responding to a fire. The presence of fire sprinkler systems installed in homes can depend largely on the local sprinkler ordinance status. In communities that adopted residential fire sprinkler system requirements, most newly constructed and some existing homes are likely to have fire sprinklers installed. To evaluate the potential effect of fire sprinkler systems on water usage, communities with and without a local fire sprinkler system ordinance were selected.

- **Availability of fire service equipment**. Methods of fire extinguishment performed by fire services can depend on the availability and types of the fire apparatus. Water usage for fire extinguishment may differ for a community with more available fire apparatus or units as compared to a community that has fewer fire units and resources.
- **Availability of municipal water supply.** Availability of the municipal water supply may also affect the total response time[18], mostly initiate action/intervention time[19], and quantity of water that can be used in manual firefighting. If municipal water is not readily available, in addition to water from fire apparatus tanks, fire services may rely on other water sources, such as lakes or canals. Water usage by fire services in communities where a municipal water supply is available can differ from that in communities that rely on both the municipal water supply and/or other water sources.
- **Geography**. To ensure the gathered data represents broad geographic locations, communities were selected from different regions of the U.S.

2.1.2 Community Overview

A total of 25 communities participated in the water usage survey by responding fire services at house fires from June 2010 to October 2010. However, due to a limited number of residential fires that occurred within the survey period, water usage data was reported from only eight of 25 communities. Figure 1 shows the location of the communities and Table 1 presents the community information.

[18] Total response time – the time interval from the receipt of the alarm at the primary Public Safety Access Point (PSAP) to when the first emergency response unit is initiating action or intervening to control the incident. NFPA 1710-2010: Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments.

[19] Intervention time – the time interval from when a unit arrives at the scene to the initiation of emergency mitigation. NFPA 1710-2010.

Figure 1 Map of communities included in water usage survey

Table 1 Community Overview

Community	Community ID	Residential Fire Sprinkler Ordinance	Water Supply Structure	Survey Participant
Anne Arundel County, MD	COM1	Yes	Public	Anne Arundel Co. Fire Dept.
Austin, TX	COM2	No	Public	Austin Fire Dept.
Billings, MT	COM3	No	Public	Billings Fire Dept.
Columbia, SC	COM4	No	Public	Columbia Fire Dept.
El Paso, TX	COM5	No	Public	El Paso Fire Dept.
Lexington, KY	COM6	No	Public	Lexington Fire Dept.
Miami-Dade County, FL	COM7	No	Public	Miami-Dade Fire Rescue Dept.
Portland, OR	COM8	Yes	Public	Portland Fire and Rescue

2.1.3 Survey Format

To estimate water used by responding fire services at house fires, the research team formulated and distributed a survey document to the participating fire services to complete for each house fire response. The survey requested key data, including:

- Estimated flow rate during the fire service operation, duration of operation, and total capacity of water usage;
- Building characteristics (exterior construction type, property use, number of stories, and estimated size of the building);
- Presence of fire sprinkler system;
- Distance from hydrant;
- Exterior conditions upon arrival of fire services;
- Extent of fire and smoke damage;
- Action taken by the fire services;
- Method of extinguishment and water supply characteristics; and
- Fire event timeline, including fire service total response time[20] (which includes alarm handling time[21], turnout time[22], travel time[23], and action initiation/intervention time[24] or set-up time[25]), water-on-fire time, and incident termination time.

An example of the survey document as well as the detailed instructions for completion of the survey are presented in Appendix A.

[20] Total Response Time – The time interval from the receipt of the alarm at the primary PSAP to when the fire emergency response unit is initiating action or intervening to control the incident. NFPA 1710-2010.

[21] Alarm Handling Time – The time interval from the receipt of the alarm at the primary PSAP until the beginning of the transmittal of the response information via voice or electronic means to emergency response facilities (ERFs) or the emergency response units (ERUs) in the field. NFPA 1710-2010.

[22] Turnout Time – The time interval that begins when the ERFs and ERUs notification process begins by either an audible alarm or visual annunciation or both and ends at the beginning point of travel time. NFPA 1710-2011.

[23] Travel Time – The time interval begins when a unit is en route to the emergency incident and ends when the unit arrives at the scene.

[24] Initiating Action/Intervention Time – The time interval from when a unit arrives on the scene to initiation of emergency mitigation.

[25] Set-up Time – "Setup time begins once a fire engine or other apparatus arrives on the scene and ends after personnel established a water supply, set up necessary equipment". U.S. Fire Administration, Structure Fire Response Times, Topical Fire Research Series, Vol 5 – Issue 7.

2.1.4 Survey Results

A total of 35 home fires[26] were reported from the eight responding communities, as shown in Table 2. No fire sprinkler systems were present in any of the reported fires. Based on the collected data, the amount of water used by fire services at a home fire without fire sprinkler protection ranged from 100 to 41,000 gallons per fire, with an overall average of 3,524 gallons per fire and a standard deviation of 7,745 gallons per fire. A histogram for the reported amount of water used by fire services per fire is presented in Appendix A.

Table 2 Estimated Total Water Usage per Fire by Each Community

Community ID	Number of House Fires	Sprinkler System Installed	Estimated Flow Rate Used per Fire (gpm)	Estimated Water Usage per Fire (gallon)
COM1	4	No	150 – 400	300 – 4,000
COM2	3	No	140 – 450	280 – 4,500
COM3	1	No	200	2,000
COM4	6	No	250 – 1,750	500 – 41,000
COM5	1	No	125	300
COM6	6	No	110 – 1,000	200 – 4,500
COM7	8	No	100 – 250	100 – 1,000
COM8	6	No	150 – 1200	150 – 18,000

Table 3 presents the estimated water usage per fire based on factors that may have influenced water usage during the fire event. Based on the fire conditions upon the fire services' arrival, fully-involved fires required an average of 8,077 gallons per fire, compared to an average of 833 gallons used for fires with light to heavy smoke observed. Water usage increases with fire involvement and the extent of damage. On average, an increase from 518 to 6,707 gallons per fire was reported when the fires extended beyond the room of origin. This data also suggest that the amount of water needed to suppress a fully-involved fire is an order of magnitude greater

[26] Excluding home fires where only portable extinguishers or garden hoses appeared to used for extinguishment (Total water used was less than 100 gallons or the flow rate was less than 100 gpm) and home fires where the reported water used did not reflect the reported property and content damage.

than the water required to control the fire at its early stage, regardless of the water source or suppression method.

Based on Table 3, the broad range of data was primarily attributed to the fire conditions upon arrival of fire services, which is likely to be influenced by fire growth and the total response time. The interior content (e.g. fuel load and arrangement) of a home is another important factor that could influence fire growth, and thus, the water usage during response to a fire event. However, no reliable means could be implemented during the survey to document the interior content of the reported home fires.

Table 3 Estimated Water Usage per Fire by Category

Category		Number of House Fires	Estimated Water Usage per Fire	
			Range (gallon)	Average (gallon)
Condition on Fire Department Arrival	Light to heavy smoke	22	100 – 4,500	833
	Fully-involved / visible flame	13	375 – 41,000	8,077
Extent of Damage [a]	Within room of origin	17	100 – 2,000	518
	Beyond room of origin	17	220 – 41,000	6,707
Water Supply Source	Fire apparatus tank	16	100 – 3,900	903
	Public water supply	16	250 – 41,000	5,759
	Apparatus tank and public water supply	3	1,750 – 11,000	5,583
Fire Service Total Response Time[27,b]	From 5 to 10 minutes	18	100 – 4,500	1,412
	From 10 to 15 minutes	7	280 – 11,000	2,522
	More than 15 minutes	3	1,750 – 41,000	19,417
Overall		**35**	**100 – 41,000**	**3,524**

a. Excluding one fire event where the extent of damage was not indicated.
b. Excluding seven fire events where the initiating action/intervention time was not reported.

[27] Total response time includes the alarm handling time, turnout time, travel time, and initiating action/intervention time. NFPA 1710-2010.

2.2 Water Usage from the Operation of a Fire Sprinkler System

Data regarding the actual discharge of water by a fire sprinkler system in response to a fire event is not readily available. As an alternative, an estimation of water discharged by a fire sprinkler system during a fire event was performed. Hydraulic calculations for a number of fire sprinkler system designs for typical one- and two-family homes were performed to estimate fire sprinkler system flows in the event of a fire, based on the provided water supply information.

2.2.1 Characteristics of Selected Fire Sprinkler System Designs

Eighteen (18) fire sprinkler system layouts designed in accordance with NFPA 13D were selected for evaluation based on availability and size of the home. The selected designs represented a population of typical single family homes with gross sprinkler-protected floor areas (including basements) ranging from 1,855 to 6,314 square feet. Water supplies consisted of either a metered public water source or a private fire pump/water tank. Table 4 presents the characteristics of the selected fire sprinkler designs.

Table 4 Residential Fire Sprinkler System Design Characteristics

Home ID	Floor Area (ft^2)	No. of Stories	k-factor and [No. of Sprinklers in the Home]	Water Supply	Water Meter Size	Location
H1	1,855	1	4.9 [14]	Public	3/4"	Orlando, FL
H2	2,682	1	4.9 [22]	Public	1"	Umatilla, FL
H3	2,808	1	4.2 [29]	Public	5/8”	-
H4	3,112	1	4.9 [29]	Public	1"	Longwood, FL
H5	3,121	2 + BM	4.9 [28]	Public	5/8”	St. Mary’s, MD
H6	3,545	1 + BM	4.9 [28]	Pump and Tank	N/A	Fort Collins, CO
H7	3,633	3 + BM	4.9 [31]	Public	1"	Ponce Inlet, FL
H8	3,673	1	4.9 [29]	Public	5/8”	Maitland, FL
H9	3,773	2	4.9 [40]	Public	1"	Gulf Stream, FL
H10	3,928	2	4.2 [38]	Public	5/8”	-
H11	4,019	2 + BM	4.9 [36]	Public	3/4”	Odenton, MD
H12	4,243	2 + BM	4.9 [32]	Public	1.5"	Huntley, IL
H13	4,663	1	4.2 [44]	Public	1"	Oviedo, FL

H14	4,704	2 + BM	4.9 [44]	Public	3/4”	Gibsonia, PA
H15	5,378	3 + BM	4.9 [59]	Public	3/4”	Bethesda, MD
H16	6,163	2 + BM	3.1, 4.9 [56]	Public	5/8”	Stafford, VA
H17	6,216	2	4.9 [53]	Public	1"	Melbourne, FL
H18	6,314	2	4.9 [67]	Public	1"	Lake Mary, FL

* BM refers to basement

2.2.2 Hydraulic Calculations

Previous work[28] shows that in 91% of the reported 182 residential fires, only a single sprinkler operated. In the remaining 9% of the reported incidents, two or more sprinklers operated. While the selected system layouts were based on a maximum two-sprinkler design in accordance with NFPA 13D, in an actual fire, only one sprinkler is likely to operate in residential occupancy fires. To estimate the range of water flow discharged in a fire event, hydraulic calculations were performed and assumed one-sprinkler operation in system locations that simulate the conditions of highest water flow and greatest system pressure demand. The pressure losses associated with fire sprinkler system components, including water meters, piping, fittings, and valves were assumed to be in accordance with NFPA 13D. Based on the specific sprinkler design and the provided water supply information, the calculated flow conditions, assuming single sprinkler operation, are presented in Table 5.

[28] Operation Life Safety (OLS) Newsletter, Sprinkler Activations, Vol. 6, No. 12, Dec 1991.

Table 5 Hydraulic Calculation Results Assuming Single Sprinkler Operation

Home ID	Water Supply Info.		Flow Data for Highest Flow Demand		Flow Data for Highest Pressure Demand	
	Static (psi)	Flow@Res. (gpm@psi)	Flow (gpm)	Pressure (psi)	Flow (gpm)	Pressure (psi)
H1[a]	66	N/A	29.6	66.0	26.3	66.0
H2	55	920@40	30.2	54.9	27.8	54.9
H3	124	1509@90	32.5	123.9	28.2	123.9
H4	37	400@34	23.3	36.9	21.5	37.0
H5	74	949@44	29	73.9	24.8	73.9
H6[b]	-	40@50	33.9	51.9	29.4	54.7
H7[a]	76	N/A	34.4	76.0	25.7	76.0
H8	74	500@64	30.6	73.9	23.7	73.9
H9	50	888@20	24.6	49.9	22.0	49.9
H10	124	1509@90	32.6	123.9	26.7	123.9
H11	52	2069@25	28.2	51.9	22.1	51.9
H12	63	1188@58	32.7	62.9	23.4	62.9
H13	82	1000@70	32.9	81.9	28.9	81.9
H14	106	1890@20	38.3	105.9	27.0	105.9
H15	54.3	500@53.9	28.7	54.3	23.8	54.3
H16	114	3824@52	24.3	113.9	23.9	113.9
H17	58	1010@44	30.9	57.9	25.3	58.0
H18	67	920@40	31.9	66.9	25.4	66.9
		Average	30.5	73.7	25.3	73.9
		Overall Average[c]	**28 gpm**			

a. Only static pressure was provided as permitted by NFPA 13D.

b. Private fire pump.

c. Includes flow data from both highest flow and pressure demand conditions.

The calculated flow discharged by a fire sprinkler system assuming one sprinkler operation ranges from 22 to 38 gpm with an average of 28 gpm. Due to the pressure buffer included in the selected system designs, the calculated flow is expected to be greater than the minimum required flow of 18 gpm for single sprinkler operation, as mandated by NFPA 13D.[29] Absent

[29] Section 8.1.1.1.2 of NFPA 13D – 2010.

the design margin, the calculated discharge flow at the highest pressure demand condition is equal to the minimum design flow criteria of 18 gpm. The calculated discharge flow is directly correlated to the pressure buffer. Any designed flows greater than the NFPA 13D minimum requirements are at the discretion of the fire sprinkler system designer.

Newer homes have an increasing trend in size and a larger home is likely to have a greater domestic water demand (i.e. more plumbing fixtures). Based on the 2009 International Residential Code (2009 IRC), the domestic water demands for the selected 18 single-family homes were estimated to range from 18 to 23 gpm with an average of 20 gpm[30] and a minimum pressure of 40 psi[31] at the main supply connection. The water required for domestic use in typical single-family homes is comparable to or greater than the minimum sprinkler flow required by NFPA 13D for single head operation. The water supply satisfying the plumbing demands is the driving factor for the design of a potable water supply system for single family homes.

Although only one sprinkler is likely to operate in most residential fires, calculations for two sprinkler operation are performed. The hydraulic calculation results assuming two sprinkler operation on the selected designs are shown in Table 6. The expected flow from a fire sprinkler system with two sprinkler operation ranges from 26 to 55 gpm with an average of 39 gpm. This range of flows exceeds the minimum required flow of 26 gpm (at 7 psi) for a two sprinkler design per NFPA 13D[32], due to the design margins.

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[30] Section P2903.6, Table P2903, and Table P2903.6(1) of 2009 IRC.

[31] Section P2903.3 of 2009 IRC.

[32] Section 8.1.1.1.1 of NFPA 13D – 2010.

Table 6 Hydraulic Calculation Results Assuming Two Sprinkler Operation

Home ID	Water Supply Info.		Flow Data for Highest Flow Demand		Flow Data for Highest Pressure Demand	
	Static (psi)	Flow@Res. (gpm@psi)	Flow (gpm)	Pressure (psi)	Flow (gpm)	Pressure (psi)
H1[a]	66	N/A	40.8	66.0	31.9	66.0
H2	55	920@40	49.3	54.9	41.1	54.9
H3	124	1509@90	42.2	123.9	34.5	123.9
H4	37	400@34	38.3	36.9	37.2	37.0
H5	74	949@44	55.0	73.9	31.3	73.9
H6[b]	-	40@50	52.4	35.6	41.3	54.7
H7[a]	76	N/A	39.8	76.0	32.8	76.0
H8	74	500@64	37.1	73.9	30.4	73.9
H9	50	888@20	42.5	49.9	31.8	49.9
H10	124	1509@90	37.6	123.9	34.0	123.9
H11	52	2069@25	54.9	51.9	31.3	51.9
H12	63	1188@58	50.1	63.0	33.2	62.9
H13	82	1000@70	48.0	81.9	40.7	81.9
H14	106	1890@20	41.1	105.9	32.9	105.9
H15	54.3	500@53.9	32.9	54.3	33.3	54.3
H16	114	3824@52	48.0	113.9	26.2	113.9
H17	58	1010@44	47.7	57.9	33.8	58.0
H18	67	920@40	55.0	66.9	33.0	66.9
		Average	44.3	72.8	33.9	73.5
		Overall Average[c]	**39 gpm**			

a. Only static pressure was provided as permitted by NFPA 13D.

b. Private fire pump.

c. Includes flow data from both highest flow and pressure demand conditions.

Based on the hydraulic calculations, the fire sprinkler system flow is dependent on the available water supply characteristics, the number of operating sprinklers, the hydraulic remoteness of the operating sprinklers within the system, and other system components. Based on the most probable scenario, where only one sprinkler operates in a home fire, a typical fire sprinkler system will discharge an average of 28 gpm of water during a fire event. Assuming ten minutes of system operation[33], a home fire sprinkler system could discharge up to 280 gallons of water per fire.

2.3 Fire Flow Requirements

The water supply required for firefighting purposes is generally the largest demand projected for the water infrastructure in residential communities. An estimation of the water infrastructure demand for communities with homes protected by fire sprinkler systems based on calculations of the fire flow requirements for a number of one- and two-family homes in accordance with various industry recognized methods is provided.

2.3.1 Overview of Fire Flow Requirements

Industry recognized standards including NFPA 1[34], the IFC[35], and the ISO[36], outline the procedures for determining fire flow requirements for buildings in communities. In general, the fire flow requirement or NFF[37], is defined as the flow rate of the water supply measured at a residual pressure of 20 psi, that is available for firefighting. All three methods incorporate building characteristics into the calculation, such as occupancy classification, type of construction, and the total floor area of the building. Furthermore, the ISO method incorporates additional details of the structure, including the separation distance, as well as the exposure and communication between buildings. In all calculation methods, a reduction in NFF is allowed for buildings protected by fire sprinkler systems.

[33] Based on NFPA 13D 6.1.2 for a minimum of 10 minutes of stored water supply and an average time to arrival of fire department (6.2 minutes) found in the survey in this study.

[34] NFPA 1 – 2009 Fire Code, National Fire Protection Association,

[35] 2009 International Fire Code, International Code Council.

[36] Guide for Determination of Needed Fire Flow, Insurance Services Office, Edition 05-2008

[37] Needed Fire Flow (NFF) is the terminology used by ISO for amount of water available for municipal fire protection.

2.3.2 NFF Calculations

The NFF for 17 selected single family homes were calculated. The selected homes, comprising nine homes used in the hydraulic calculations described in Section 2.2 and eight other homes from the survey data provided in Section 2.1, were conservatively assumed to be of wood-frame construction.[38]. Table 7 shows the comparison between the calculated NFF for the selected homes with and without fire sprinkler systems.

Table 7 NFF Calculations

Home ID	Estimated Floor Area (ft^2)	Distance btw. Buildings[b] (ft)	NFF with Sprinkler Protection (gpm)			NFF without Sprinkler Protection (gpm)		
			NFPA 1	IFC	ISO	NFPA 1	IFC	ISO
H1	1,855	20	500	500	500	1,000	1,000	1,000
H2	2,682	248	500	500	500	750	1,000	500
H4	3,112	26	500	500	500	1,000	1,000	1,000
H6	3,545	>100	500	500	500	750	1,000	500
H8	3,673	14	500	875	500	1,000	1,750	1,000
H9	3,773	29	500	875	500	1,000	1,750	1,000
H13	4,663	77	500	875	500	750	1,750	750
H17	6,216	79	1,125	1,125	500	2,250	2,250	750
H18	6,314	18	1,125	1,125	500	2,250	2,250	1,000
H19[a]	2,000	140	500	500	500	750	1,000	500
H20[a]	1,800	11 - 30	500	500	500	1,000	1,000	1,000
H21[a]	2,000	<10	500	500	500	1,000	1,000	1,500
H22[a]	1,200	11-30	500	500	500	1,000	1,000	1,000
H23[a]	3,500	<10	500	500	500	1,000	1,000	1,500
H24[a]	<3,600	<10	500	500	500	1,000	1,000	1,500
H25[a]	1,500	11 - 30	500	500	500	1,000	1,000	1,000
H26[a]	1,000	11 - 20	500	500	500	1,000	1,000	1,000
		Average	574	640	500	1,088	1,279	971

a. H19 to H26 data are based on the single family homes in COM6 (Lexington, KY) reported in Table 1.
b. Estimated distance between buildings is based on publicly available satellite maps and the reported address of the selected home.

On average, the NFF as determined by the IFC method produced the largest water demand for homes with and without a fire sprinkler system. However, the reduction in NFF varies based on

[38] Wood frame construction is referred to as Construction Type V(000) in NFPA 1 and Type VB in IFC.

the selected method for calculation. When homes are protected with a fire sprinkler system, the NFPA 1 and IFC methods allow for a 50% reduction of NFF, but no less than 500 gpm. The NFF for homes less than three stories in height and protected by a fire sprinkler system calculated using the ISO method is reduced to a fixed flow rate of 500 gpm regardless of home size (e.g. floor and number of stories). The smallest reduction in the average NFF between homes with and without sprinkler protection is 47% using the NFPA 1 method. The greatest reduction in the average NFF between homes with and without fire sprinkler protection is 50% using the IFC method. Based on this analysis, at least a 47% reduction of the NFF and the projected water infrastructure demand for fire flow in residential communities can be expected when homes are protected with fire sprinkler systems.

2.4 Section Summary

Three aspects of water consumption related to fire sprinkler systems were studied: 1) the actual water discharged by responding fire services at home fires without fire sprinkler systems, 2) the expected water discharged by fire sprinkler systems during a fire, and 3) the potential reduction of water infrastructure demand for communities with homes protected by fire sprinkler systems.

Based on a survey of the reported water used by fire services at 35 one- and two-family home fires from eight select communities, an average of 3,524 gallons of water was discharged for firefighting at homes without fire sprinkler system protection. The data shows a range of 100 to 41,000 gallons of water used per fire, which is primarily attributed to the fire condition upon the arrival of fire services. Approximately 10 times increase of water used per fire was reported when the fire extended beyond the room of origin, or when the degree of fire involvement increased from visible flame and smoke to a fully-involved fire.

To estimate the water discharged by a fire sprinkler system during a fire, hydraulic calculations were performed on 18 fire sprinkler system designs of detached single-family homes and their provided water supply information. The calculations show that the expected water flow discharged by a single sprinkler operation during a fire ranges from 22 to 38 gpm with an average of 28 gpm. All of the fire sprinkler designs contained a pressure buffer (design margin) resulting in a calculated discharge flow that is higher than the minimum required flow per

NFPA 13D[39]. The level of the design margin included in a fire sprinkler design may vary and is at the discretion of the system designer. Assuming up to 10 minutes of operation, water consumption by a fire sprinkler system during a fire is approximately 280 gallons. In comparison, the average water used for firefighting in homes without fire sprinkler systems can be up to 1200% greater than the water discharged by a fire sprinkler system. These results are consistent with previous studies of water consumption during fires in homes with and without fire sprinkler systems. The results also correlate with the survey data for the water needed to control the fire based on stage of fire development (i.e. within the room of origin), compared to the water used during the suppression of a fully-involved fire (i.e. extending beyond the room of origin). Fire sprinkler systems are designed to operate at the early stages of the fire, and have successfully controlled most fires prior to the arrival of fire services. Therefore, water used by fire services responding to fires in homes protected by fire sprinkler systems is expected to be significantly less than homes without fire sprinkler systems.

The NFFs for 17 selected single family homes were determined based on NFPA 1, IFC, and ISO methods. In general, at least a 47% reduction of the projected water infrastructure demand for fire flow is produced when a community is protected by fire sprinkler systems.

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[39] Section 8.1.1.1.2 of NFPA 13D – 2010 requires a minimum discharge flow of 18 gpm for one sprinkler operation.

3 Water Meter Study

Suitability of the water metering components in line with a fire sprinkler system is an important factor that is considered in the adoption process of residential fire sprinkler system requirements in a community. This includes the use of conventional water meters in line on the potable domestic water source connected to the residential fire sprinkler systems. Conventional water meters (i.e. 5/8-in and 3/4-in meters[40]) used to measure the domestic water consumption for billing purposes are perceived to be inappropriate for use under high flow conditions, due to significant pressure loss across the meters and operational integrity concerns.[41] Larger meters (e.g. 1-in and above), typically produce less pressure loss, but are perceived to be less accurate[42] in measuring low flow rate conditions (e.g. nominal domestic consumption) compared to conventional meters.

To provide an understanding of these issues, the performance of various water meters under a range of flow conditions, including fire sprinkler system flow rates, was investigated. A series of tests were conducted on 16 water meters of typical sizes and types used for potable water service in one- or two-family homes, as well as types specifically listed for residential fire sprinkler system use. A water meter flow test apparatus was designed and instrumented so as to accommodate observations and measurements of the following key metrics:

- Pressure loss in water meters;
- Volume reading accuracy of water meters; and
- Functional integrity of the meter.

[40] AWWA M6 4th Edition, Water Meters – Selection, Installation, Testing, and Maintenance, 1999, p.25. Size Designations .

[41] Ibid, p.24. High pressure losses of water meters can be due to their complicated design and partly deliberate to reduce the possibility of running the meter too fast.

[42] Integration of Residential Sprinklers with Water Supply System – A Survey of Twenty U.S. Communities, 09/2009, p. 41.

3.1 Selection of Water Meters

Sixteen (16) water meters were selected from six different manufacturers, and obtained from standard commercial retail channels. Meter sizes tested are 5/8-in, 5/8-in by 3/4-in[43], 3/4-in, and 1-in. The size designation of a water meter is commonly described in terms of the nominal NPT diameter pipe to which the meter is connected.[44] Meter types include positive displacement (PD), multi-jet (MJ), and vertical turbine (VT). Four of sixteen meters are listed as "residential fire meters".[45] All meters have flow registers of straight-reading odometer type and are equipped with inlet strainers. All meters were furnished with a certificate of metering accuracy testing in accordance with American Water Works Association (AWWA) standards[46]. Table 8 shows the description of the selected water meters.

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[43] 5/8-in by 3/4-in water meter is a 5/8-in meter (with 5/8-in inside diameter inlet and outlet) with 1-in threads on the meter body and 3/4-in couplings used to connect a 3/4-in pipe. – AWWA M6 4th Edition, Water Meters – Selection, Installation, Testing, and Maintenance, 1999, p.25. Size Designations

[44] AWWA M6 4th Edition, Water Meters – Selection, Installation, Testing, and Maintenance, 1999, p.25. Size Designations

[45] Meters intended for installation in dedicated residential sprinkler protections or combined domestic plumbing and residential fire sprinkler systems - UL HDRZ. Guide Info – Residential Fire Meters, 3/15/2006.

[46] AWWA C700-09, *Cold-Water Meters – Displacement Type Bronze Main Case*, and AWWA C708-05, *Cold-Water Meters – Multi-jet Type* Sec A.2.3.

Table 8 Selected Water Meters

Meter ID	Meter Size	Meter Type	Manufacturer
5/8-PD-1	5/8”	Positive Displacement	A
5/8x3/4-PD-2	5/8”x3/4”	Positive Displacement	B
5/8x3/4-PD-3	5/8”x3/4”	Positive Displacement	C
5/8-PD-4	5/8”	Positive Displacement	B
5/8x3/4-MJ-1	5/8”x3/4”	Multi-Jet	D
5/8x3/4-MJ-2	5/8”x3/4”	Multi-Jet	E
5/8x3/4-MJ-3	5/8”x3/4”	Multi-Jet	F
5/8-MJ-4	5/8”	Multi-Jet	E
3/4-PD	3/4”	Positive Displacement	C
3/4-MJ	3/4”	Multi-Jet	F
3/4-LMJ	3/4”	Listed Multi-Jet	F
3/4-LVT	3/4”	Listed Vertical Turbine	C
1-PD	1”	Positive Displacement	C
1-MJ	1”	Multi-Jet	F
1-LMJ	1”	Listed Multi-Jet	F
1-LVT	1”	Listed Vertical Turbine	C

3.2 **Performance Criteria**

Industry recognized standards, AWWA C700-09, *Cold-Water Meters – Displacement Type Bronze Main Case*, and AWWA C708-05, *Cold-Water Meters – Multi-jet Type*, prescribe benchmarks for the design of residential water meters. These benchmarks, including operating range (i.e. normal flow range), pressure loss limit, and metering accuracy, for PD and MJ meters are summarized in Table 9. The AWWA normal flow limits vary based on the meter size. Analysis of the AWWA minimum test flow criteria[47] is outside the scope of this work.

[47] AWWA C700-09, Sec 4.2.8.2 and AWWA C708-05,Sec 4.2.8.2.

Table 9 AWWA Requirements for PD and MJ Meters

Meter Size	Safe Maximum Operating Range (gpm)	Maximum Pressure Loss at Safe Maximum Operating Range (psi)	Recommended Maximum Rate for Continuous Operation (gpm)	Accuracy at Normal Flow Limit (% at gpm)
5/8”	20	15	10	±1.5% at 1-20 gpm
5/8”x3/4”	20	15	10	±1.5% at 1-20 gpm
3/4”	30	15	15	±1.5% at 2-30 gpm
1”	50	15	25	±1.5% at 3-50 gpm

AWWA standards recommend all water meters be tested for accuracy both before[48] and periodically after[49] installation. As for pressure loss testing, AWWA standards recommend that at least one meter of each size and design be tested for pressure loss performance, but testing for others with the same design and size is not necessary[50].

Underwriters Laboratories (UL) Subject 327A, *Outline of Investigation for Inferential Type Residential Water Meters*, provide requirements for listed residential fire sprinkler system water meters (3/4-in to 2-in). The UL requirements include performance criteria, such as: 1) operating pressure at 175 psi or 130 psi for meters intended in multipurpose piping systems in accordance with NFPA 13D; 2) pressure loss not exceeding 10 psi (meters equipped with strainers) while flowing water at a velocity of 15 ft/sec[51]; 3) metering accuracy not exceeding ±3%[52]; and 4) endurance of non-metallic parts when exposed to elevated temperatures.

In addition to the AWWA and UL standards, NFPA 13D, Table 8.4.4 (g), provides pressure losses for several meter sizes at various flows to be used for hydraulic calculations in residential

[48] AWWA C700-09, Sec A.2.3, and AWWA C708-05, Sec A.2.3

[49] AWWA M6 4th Edition, Water Meters – Selection, Installation, Testing, and Maintenance, 1999, p.59.

[50] AWWA C700-09, Sec A.2.1, and AWWA C708-05, Sec A.2.1, “Once a meter of each size of a given design has been tested for pressure loss at safe maximum operating capacity, it should not be necessary to test others of the same design.”

[51] Velocity based on the nominal pipe size of schedule 40 steel pipe – UL Subject 327A

[52] Accuracy within flow limits of 2-30 gpm for 3/4” meter and 2-50 gpm for 1” meter – UL Subject 327A

fire sprinkler system design. The industry benchmarks and the suggested pressure losses are used as a basis to evaluate the performance of the selected water meters.

3.3 Test Setup

A water meter flow test assembly (see Figure 2), was constructed at Exponent's facility in Bowie, Maryland, to measure the pressure losses and accuracy of the water meters at the flow conditions specified in the AWWA standard[53] and UL Subject 327A.[54] The test assembly is comprised of a flow-loop configuration with a reservoir (1)[55] and a weight measurement apparatus with a graduated collection tank (11). An electric 5-HP centrifugal pump (2) with a variable speed controller is used to produce the flow conditions required for testing. The flow-loop configuration is designed to accommodate flow testing at various flow rates for extended time intervals. The meter is placed at a position sufficiently downstream from the pump to ensure a uniform flow. Two calibrated transducers are used to measure the pressures[56] upstream (5) and downstream (7) of the meter. The water collection tank is positioned on a calibrated platform scale (14) with a 0.1 lb precision, and the weight of the container over time is used to calculate the water flow through the meter. Based on the measured weight, the registration accuracy of the meter and the actual test flow rate (in gpm) are determined. A data acquisition system (15) is used to record the pressures and the water weight throughout the test duration.

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[53] AWWA Manual M6 4th Edition: Water Meters – Selection, Installation, Testing, and Maintenance, p. 47-72.

[54] Underwriters Laboratories (UL) Subject 327A, *Outline of Investigation for Inferential Type Residential Water Meters.*

[55] The numbers designated in parentheses in Sections 3.3and 3.4 are referred to the test apparatus indicated in Figure 2.

[56] Normal pressures are measured in lieu of total pressures as the flow velocities at the upstream and downstream transducers are assumed to be identical based on incompressibility and continuity assumption

1) Reservoir	6) Water meter	11) Collection tank
2) Pump with variable speed controller	7) Pressure transducer B	12) Collection tank drain
3) Pressure gauge	8) Flow control valve	13) Reservoir drain
4) Isolating valve	9) Flow meter (reference only)	14) Scale
5) Pressure transducer A	10) Diverter valve	15) DAQ system and control station

Figure 2 Water meter testing assembly

3.4 **Test Conditions and Procedures**

Based on the findings of expected fire sprinkler flow for typical one- or two-family homes (reported in Section 2.2) and the design criteria set forth in NFPA 13D, the test conditions and procedures were developed for water meter testing as follows. Each meter was tested to a minimum of five flow rates starting at a lower flow rate of approximately 1.5 gpm and increasing upward. The upper boundary flow rates were based on the test assembly hydraulic capacity and the pressure loss characteristics of the meter. The pressure at the pump outlet pressure gauge (3) was maintained at a minimum 60 psi[57] and each flow rate was held steady for the 20-minute test duration.[58] Throughout the test, the water temperature in the reservoir was

[57] At the maximum flow rate, the pressure at the pump outlet is dependent on the pump characteristic (exceeding 60 psi) and the friction loss characteristic of the flow test assembly.

[58] NFPA 13D-07 Section 6.1.2 and 6.1.3 require residential fire sprinkler operation of 10 minutes

monitored to ensure that it did not exceed 80°F.[59] The water flow test assembly was drained and refilled with tap water after each test.

The odometer[60] reading of the water meter was recorded before and after testing. During each 20-minute test, the upstream and downstream pressures were recorded and observations were made to detect any signs of meter failure (e.g. sudden decline in downstream pressure or irregular noise produced by damaged water meter components). After each 20-minute test, the flow was diverted to the collection tank and the weight of the collected water was measured. The test was complete when a minimum of 30 gallons[61] of water were deposited in the collection tank. Figure 3 illustrates the flow direction during the testing.

Flow direction from reservoir

Flow direction during pressure loss testing – Diverter Valve (10) is turned toward the reservoir (1)

Flow direction during accuracy testing – Diverter Valve (10) is turned toward the collection tank (11)

Figure 3 Water flow diagram

[59] AWWA C700-09 and C708-05, cold-water meters are not affected by temperatures up to approximately 80ºF.

[60] AWWA C700-09 and C708-05, the term "odometer" is used for straight-reading water meter register.

[61] AWWA Manual M6 4th Edition: Water Meters – Selection, Installation, Testing, and Maintenance, p. 58. Corresponding to a measurement error of 0.04% when a scale with 0.1 lb precision is used.

3.5 Test Results and Discussion

A total of 92 flow tests were performed on the 16 selected water meters. A summary of the maximum tested flow data is presented in Table 10. All detailed test results are presented in Appendix B. Analysis and discussion on the test results are provided in the following sections.

3.5.1 Pressure Loss

For each flow test, an average value of differential pressure from upstream and downstream of the water meter was used to determine the pressure loss profile of the water meter. The average differential pressure comprises not only the pressure loss across the water meter, but also includes the pressure loss associated with fittings and piping between the pressure transducers and the meter. As a result, a series of flow tests without a water meter installed on the apparatus were conducted to characterize the pressure loss of the fittings and piping included as part of the test assembly (refer to Appendix B for pressure loss data of fittings). The pressure loss of each tested water meter is corrected by the differential pressure associated with the test apparatus.

Table 10 Maximum Tested Flow Rate and Total Tested Flow

Meter ID	Maximum Tested Flow Rate (gpm)	Total Flow (gallon)
5/8-PD-1	49.8	9,376
5/8x3/4-PD-2	58.0	3,999
5/8x3/4-PD-3	60.2	4,491
5/8-PD-4	46.3	5,450
5/8x3/4-MJ-1	51.1	3,207
5/8x3/4-MJ-2	48.8	2,300
5/8x3/4-MJ-3	37.5	3,797
5/8-MJ-4	45.9	3,902
3/4-PD	74.5	7,164
3/4-MJ	40.4	4,030
3/4-LMJ	47.1	3,708
3/4-LVT	37.3	2,277
1-PD	85.6	4,309
1-MJ	65.6	3,807
1-LMJ	75.2	3,720
1-LVT	77.8	4,522

Examples of pressure losses for 5/8-in meters are shown in Figure 4, in comparison to the manufacturer reported data and NPFA 13D suggested values.[62] The complete pressure loss data for all tested water meters is provided in Appendix B.

[62] NFPA 13D-07, Table 8.4.4 (g) – Pressure Losses in psi in Water Meters.

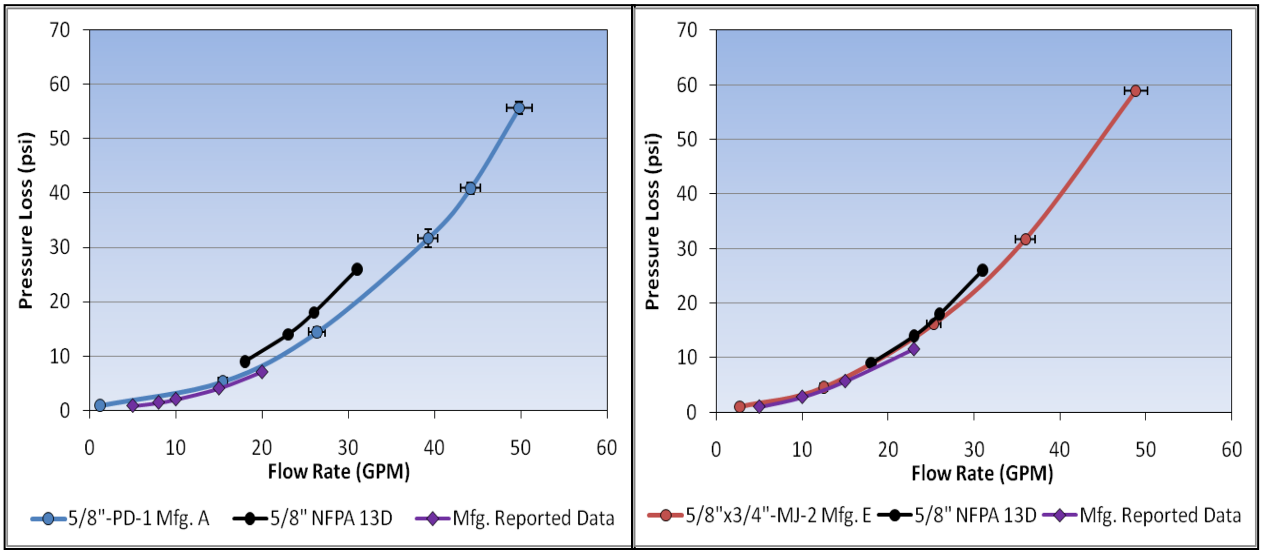


Figure 4 Pressure loss characteristics of 5/8”-PD-1 (left) and 5/8”-MJ-2 (right)

Based on the test results from the 5/8-in meters, excellent agreement is seen between the pressure losses found in this study and the data reported by the manufacturers in all but one meter (5/8”x3/4”-MJ-3) as shown in Appendix B and Figure 6.

As shown in Figure 5, the pressure losses for all 5/8-in PD type meters are found to be lower than the NFPA 13D recommended values at the respective flow rates. This suggests that the pressure losses provided in NFPA 13D are slightly conservative when 5/8-in PD type meters are used in the fire sprinkler system design. In addition, 5/8-in PD type meters perform well hydraulically within the AWWA standard operating range. In the most conservative case (5/8”-PD-4), the pressure loss for a 5/8-in PD meter can be up to approximately 20 psi when subjected to flow at 28 gpm, an estimated average flow discharged by residential fire sprinkler systems assuming one sprinkler operation (Section 2.2.2) .

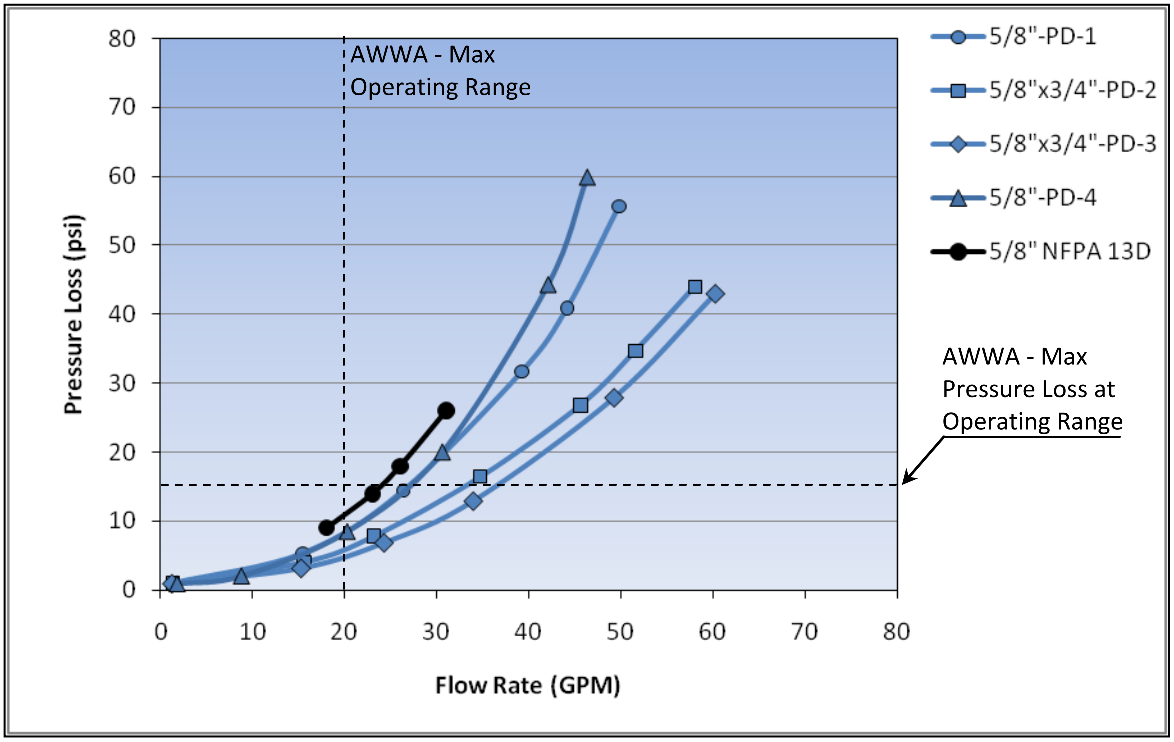


Figure 5 Pressure loss characteristics of 5/8-in PD meters

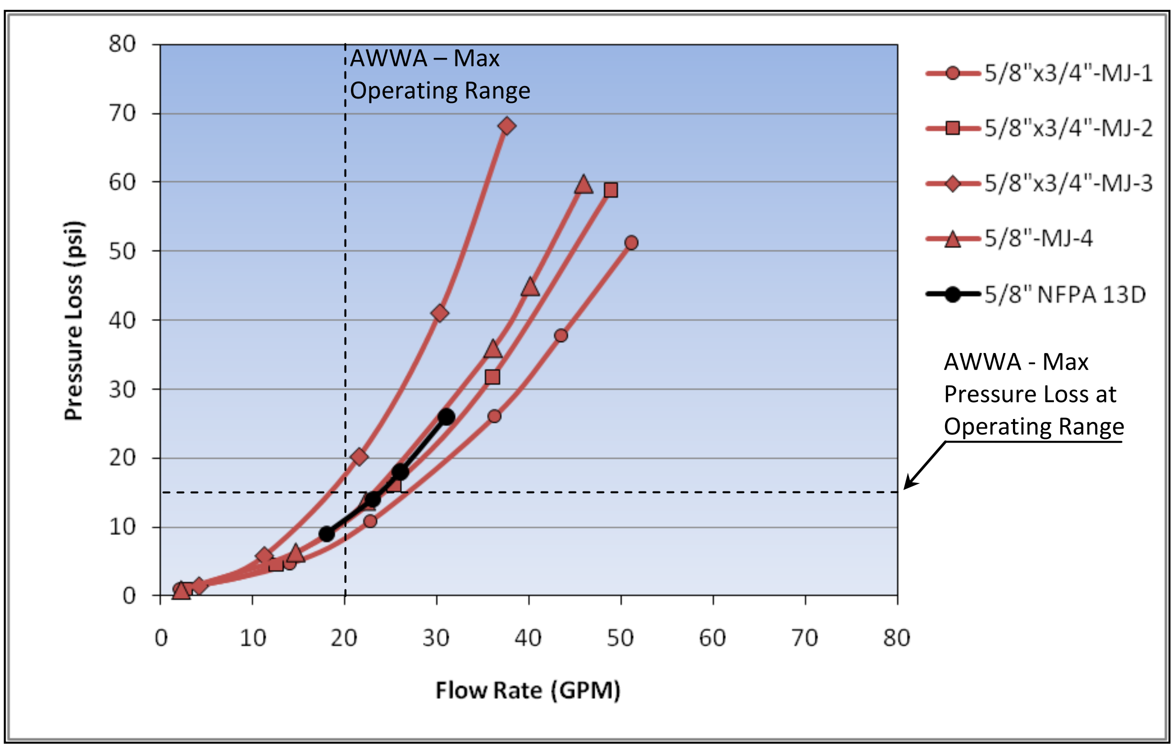


Figure 6 Pressure loss characteristics of 5/8-in MJ meters

In comparison to the 5/8-in MJ meters, the 5/8-in PD meters perform slightly better in pressure loss characteristics. As shown in Figure 6, three out of four 5/8-in MJ meters produced pressure losses consistent with the NFPA 13D suggested values and well below the AWWA maximum pressure loss threshold at 20 gpm. However, in one case, 5/8"x 3/4"-MJ-3, the pressure losses were approximately 40 psi, 60% higher than the NFPA 13D suggested values at a flow rate of 28 gpm. The pressure loss from the same meter marginally exceeded the AWWA maximum pressure loss requirement at 20 gpm.

Pressure losses from 3/4-in meters are presented in Figure 7. In addition to the AWWA standards, the performance criteria for the listed residential fire sprinkler system water meters are also included (as indicated by red dashed lines). Based on the test results for 3/4-in meters, only the PD-type produced pressure losses that satisfied the AWWA pressure loss requirement within the AWWA operating range. Both listed 3/4-in meters (3/4"-LVT and 3/4"-LMJ) and the 3/4-in MJ type meter appear to underperform with respect to the AWWA criteria, the UL listing pressure loss criteria, and the NFPA 13D suggested values. Based on the test results, the pressure losses from 3/4-in MJ or VT meters[63] can be up to 30 psi when subjected to flow at 28 gpm, whereas for the 3/4-in PD-type meter, the pressure loss can be up to 4 psi at 28 gpm. With the exception of the 3/4-in PD meter, the 3/4-in meters performed hydraulically similar to the 5/8-in meters.

[63] Both MJ and VT meters are considered to be inferential flow meter where flow volume is based on direct relationship between the rotational velocity of the impeller and the rate of water flow through the meter – UL Subject 327A

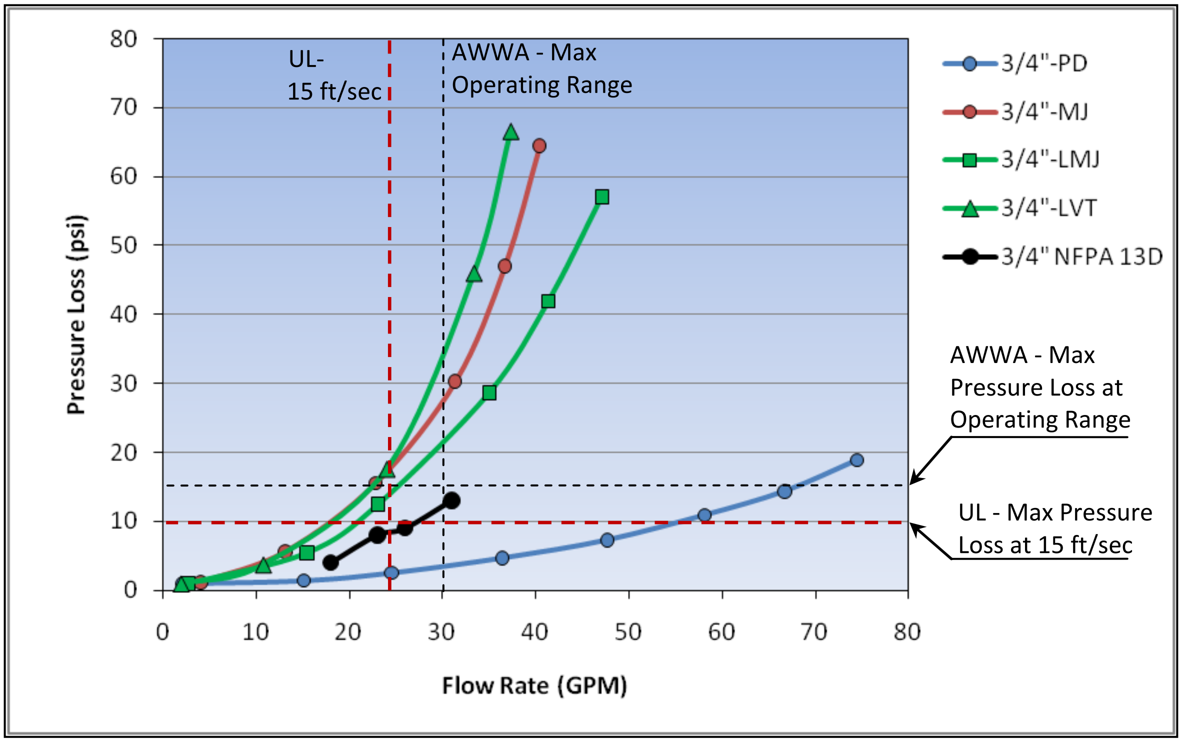


Figure 7 Pressure loss characteristics of 3/4-in meters

For 1-in meters, the PD-type meter outperformed both the MJ meter and the listed meters (1"-LMJ and 1"-LVT), as shown in Figure 8. Both listed 1-in meters meet the UL criteria for pressure loss, but only 1"-LVT produces pressure losses consistent with NFPA13D suggested values. Based on the test results, the pressure loss from 1"- MJ can be up to 10 psi when subjected to flow at 28 gpm.

The UL pressure loss criteria for 3/4-in and 1-in meters with strainers are approximately 17% (1.5 psi) and 40% (3 psi) higher than the pressure losses suggested by NFPA 13D respectively. This implies that a 3/4-in or 1-in water meter, listed for fire service in accordance with UL Subject 327A and equipped with strainers, may produce a slightly higher pressure losses than the values suggested by NFPA 13D.

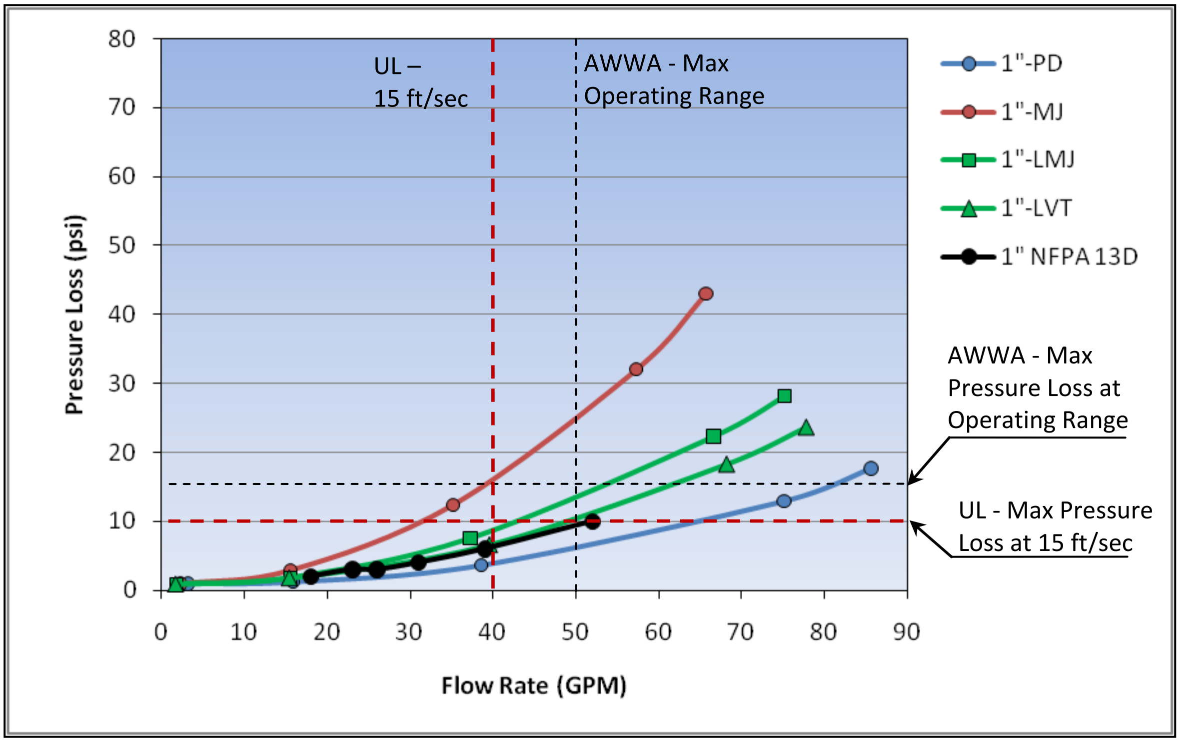


Figure 8 Pressure loss characteristics of 1-in meters

Upon reviewing the test results, five meters (MJ and LMJ types) from Manufacturer F and one meter (3/4"-LVT) from Manufacturer C produced higher pressure loss curves than both NFPA 13D values and the manufacturer's curves (approximately 100% to 270% higher than the manufacturer's published pressure loss when subjected to flow at 28 gpm). Two of these six water meters (one from each manufacturer) were 3/4-in and listed for residential fire service, but exhibited pressure losses exceeding the listing requirements. Figure 9 shows a comparison of pressure losses between meters from Manufacturer F and Manufacturer C, whose PD-type meters performed consistent with their published pressure loss curves. Refer to Appendix B of this report for further comparison of the curves.

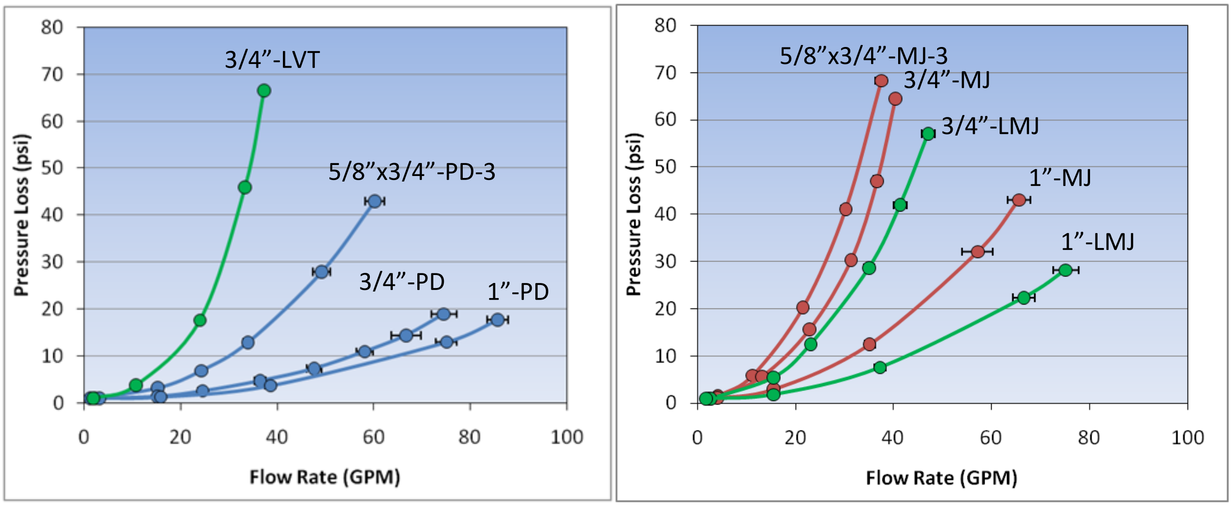


Figure 9 Pressure losses from Manufacturer C meters (left), Manufacturer F meters (right)

3.5.2 Accuracy

Accuracy of the water meter is determined based on the measured weight of the water flow through the meter, in accordance with the AWWA standard.[64] The accuracy test results for 5/8-in, 3/4-in and 1-in meters are presented in Table 11 and Figure 10 to Figure 12. In general, based on the AWWA accuracy limits of ±1.5%, all 5/8-in and 3/4-in meters perform well within their rated operating range. One out of the four 1-in meters (MJ-type) exhibited metering accuracy that was marginally outside the prescribed AWWA limits during flow tests that covered its operating range.

[64] AWWA Manual M6, Water Meters – Selection, Installation, Testing, and Maintenance: Testing of Meters – Test Procedures and Equipment, p 47-77, 1999.

Table 11 Water Meter Accuracy

Meter ID	AWWA Normal Operating Range (gpm)	Tested Low Flow[a]		Tested Medium Flow[b]		Tested High Flow[c]	
		Flow Rate (gpm)	Accuracy (%)	Flow Rate (gpm)	Accuracy (%)	Flow Rate (gpm)	Accuracy (%)
5/8-PD-1	1 – 20	1.2	100.4	15.5	99.8	26.4	99.8
5/8x3/4-PD-2	1 – 20	1.4	101.4	15.6	98.7	23.2	99.0
5/8x3/4-PD-3	1 – 20	1.3	101.5	15.3	98.5	24.3	98.8
5/8-PD-4	1 – 20	1.8	99.9	8.7	99.5	20.2	98.8
5/8x3/4-MJ-1	1 – 20	2.1	100.6	14.0	99.9	22.7	100.2
5/8x3/4-MJ-2	1 – 20	2.7	100.1	12.5	99.8	25.3	99.1
5/8x3/4-MJ-3	1 – 20	4.2	99.9	11.3	99.6	21.5	99.6
5/8-MJ-4	1 – 20	2.2	98.8	14.6	99.8	22.3	100.2
3/4-PD	2 – 30	2.1	100.2	15.1	99.0	36.5	98.5
3/4-MJ	2 – 30	4.1	101.4	13.2	99.5	31.4	100.7
3/4-LMJ	2 – 30	2.7	99.1	15.5	99.1	35.0	98.7
3/4-LVT	2 – 30	1.9	99.3	24.0	100.0	33.3	101.5
1-PD	3 – 50	3.2	100.0	15.9	991	75.1	99.1
1-MJ	3 – 50	2.3	100.1	15.6	102.1*	57.2	100.8
1-LMJ	3 – 50	1.8	100.9	15.5	100.1	66.6	100.4
1-LVT	3 – 50	1.6	98.2	15.4	99.1	68.2	99.7

a. Minimum tested flow rates near the lower value of the AWWA normal operating range.

b. Tested flow rates within the AWWA normal operating range.

c. Tested flow rates near the upper value of the AWWA normal operating range.

* Accuracy outside the AWWA metering accuracy limit of ±1.5% for tested flow within the normal operating range.

As shown in Figure 10, 5/8-in PD-type meters maintain accuracy within ±1.5% throughout the range of tested flows, with one exception, 5/8”-PD-4, where the accuracy drops to approximately 96% at 40 gpm. For 5/8-in MJ-type meters, the accuracy drops significantly at flow rates higher than 35 gpm. The drops in accuracy are consistent with observations made during testing at high flows, where the reading dial appeared to move slowly or become jammed and the odometer failed to register the proper flow. Reducing the flow appeared to restore the normal metering operation of both reading dial and odometer.

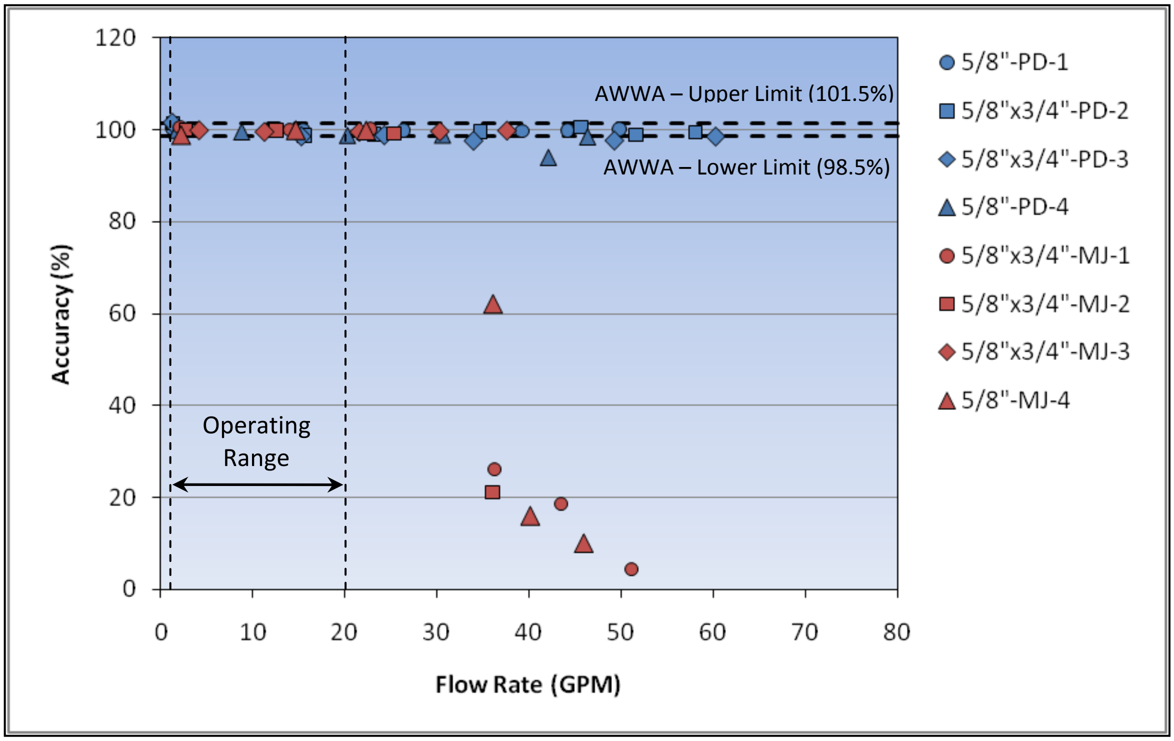


Figure 10 Registration accuracy of 5/8-in meters

All 3/4-in meters appear to perform well in metering accuracy per AWWA and UL criteria, where applicable, throughout the range of the tested flows, as shown in Figure 11. Only a slight drop of accuracy below the AWWA criteria occurred on 3/4”-PD at high flows.

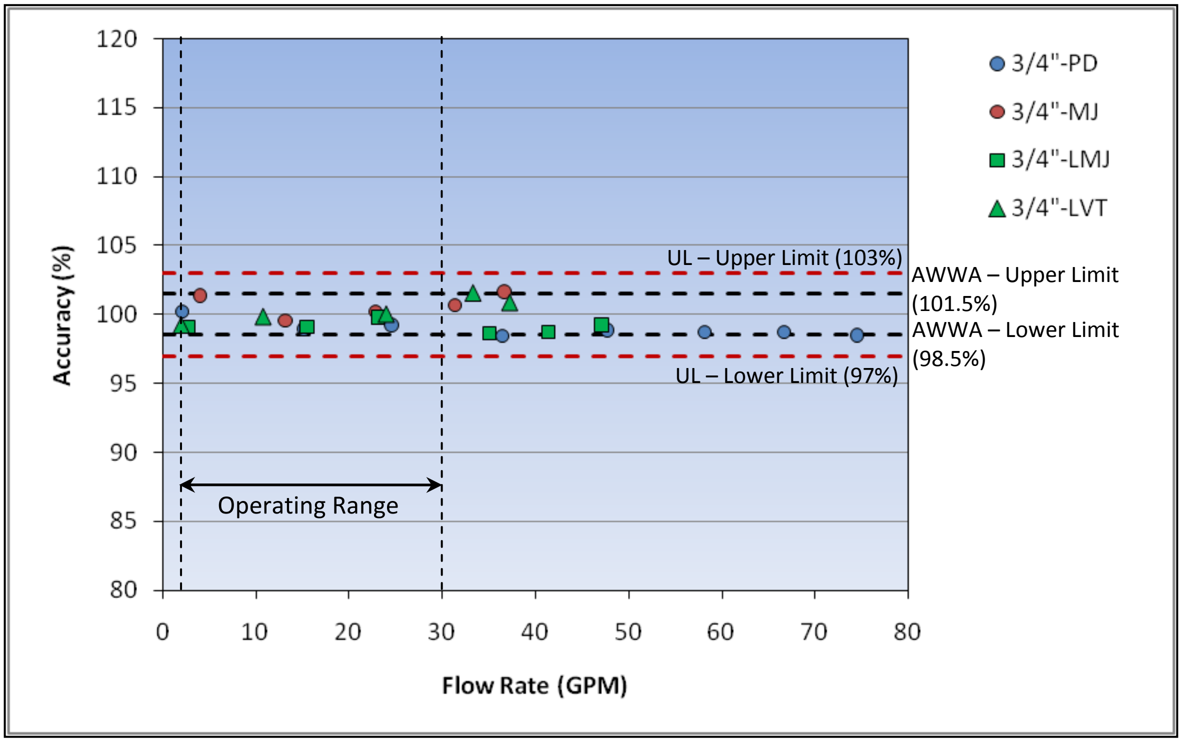


Figure 11 Registration accuracy of 3/4-in meters

For 1-in meters, the accuracy of the listed types (LVT and LMJ) and the PD-type complies with the AWWA accuracy requirements. At flows lower than the rated operating range (i.e. less than 3 gpm), only one meter (1"-LVT) showed a marginal drop of accuracy (less than 0.5%) below the AWWA standard. UL criteria allows for a wider range of accuracy in comparison to the AWWA standard, as shown by the wider bands in Figure 11 and Figure 12. All listed 1-in meters (1"-LVT and 1"-LMJ) are in compliance with UL prescribed accuracy requirements.

The tested 1-in MJ-type meter registration accuracy was observed to exceed the AWWA criteria over the operating range, as shown in Figure 12. This meter registered slightly higher flow rates than actual, and was manufactured by the same manufacturer of other four meters that produced pressure loss curves that exceeded the manufacturer-provided values.

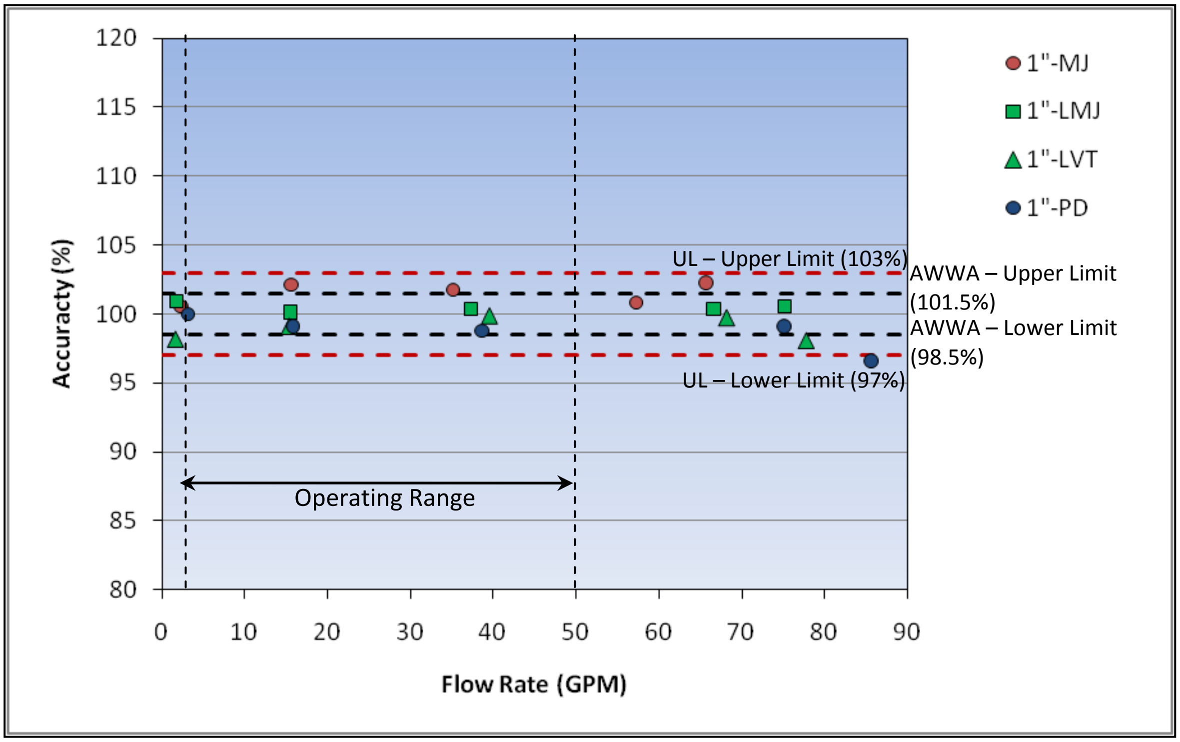


Figure 12 Registration accuracy of 1-in meters

3.6 Overall Performance and Post Test Observations

In all 94 tests performed on the 16 water meters, each meter experienced a flow of 2,200 to 9,300 gallons of water. During testing, no permanent or physical damage to the water meter components resulting in obstruction of flow was observed. In meters that appeared to have reduced meter accuracy at high flow rates, normal metering operation was restored after reducing the flow rate. All meters were capable of handling high flow rates (approximately 25% to 200% higher than their respective rating) without permanent damage, throughout the multiple 20-minute test sequences. Even in the cases where the meter accuracy significantly dropped and abnormal movements of the register dial occurred during high flow testing, such as in the 5/8-in MJ-type meters, the meters remained capable of supporting high flow rates with no unusual flow obstruction.

Post-test visual inspections on the exterior and/or interior of the meters were conducted. No damage was observed on the external and/or internal components of any of the meters. A limited amount of small particulate matter and debris was observed at or near the water meter inlet strainers, but this material did not appear to significantly obstruct any moving components or compromise the operation of the meters. This test did not intend to reproduce real-world conditions, where greater amounts of debris may be transported through upstream water supplies and introduced to the water meters. Due to the variables controlling the transport of debris in water supplies, such conditions are outside the scope of this study.

3.7 Section Summary

An experimental study was conducted to evaluate the performance and reliability of 16 residential water meters at fire sprinkler system flow conditions based on pressure loss, registration accuracy, and operational integrity of the meter. In general, ten of the 16 tested water meters produced pressure loss profiles in good agreement with their manufacturer reported values. The six remaining meters (five from the same manufacturer and one from another manufacturer) exhibited pressure losses greater than their manufacturer's published curves and the NFPA 13D suggested values. Two of these six water meters (one from each manufacturer) were 3/4-in and listed for residential fire service, but exhibited pressure losses exceeding the listing requirements.

Most 5/8-in meters produced pressure losses within the maximum limit at the recommended operating flow rate, per the AWWA standard. The test results from eight of nine 5/8-in meters are in good agreement with the manufacturer reported pressure losses. At flow rates expected for fire sprinkler systems, most 5/8-in MJ-type meters produced pressure losses consistent with NFPA 13D suggested values. For 3/4-in meters, the PD-type meter produced pressure losses below the values suggested by NFPA 13D; however, the pressure loss profiles from the listed 3/4-in water meters and MJ-type meter underperformed compared to both the AWWA and UL requirements. Both listed 1-in meters met the UL pressure loss criteria, but only the LV-type meter produced pressure losses consistent with NFPA13D suggested values. The 1-in PD-type meter outperformed both the 1-in MJ–type meter and the 1-in listed meters.

Based on the test results, PD-type meters appear to outperform MJ-type meters in terms of hydraulic pressure loss. When flow rates were higher than 35 gpm, significant pressure losses were observed in 5/8-in and 3/4-in meters.

All tested water meters exhibited metering accuracy within industry standards at flow conditions up to approximately 150% of their normal operating range, except one 1-in meter that over-reported flows. At flow rates below the meter normal operating range (flow less than 3 gpm for 1-in meters) no significant loss of metering accuracy was observed in any meter. Above approximately 35 gpm, certain 5/8-in meters showed a significant decrease in metering accuracy.

No failure of the water meters or components that resulted in unusual flow obstruction was observed in any test. Abnormal register readings occurred at high flow rates for some meters, but the metering accuracy was observed to be temporary and was restored upon flow rate reduction. Post test visual inspection indicated no signs of physical damage to any meter or metering components.

The tested water meters were observed to be capable of handling the minimum fire sprinkler system flow rates required by NFPA 13D, as well as the expected fire sprinkler system flow rates and duration (estimated to be 28 gpm for single sprinkler operation up to 20 minutes). Although metering accuracy in certain meters was temporarily affected during high flow rate conditions, the meters did not mechanically fail, causing abnormal hydraulic performance. The hydraulic performance of the water meters varies significantly by design and manufacturer. Design of a residential fire sprinkler system using the water meter hydraulic performance curves found in Section 8.4.4 of NFPA 13D may serve as preliminary guidance, but the manufacturer's curves for the specified water mater must be considered in the fire sprinkler system design. Based on the pressure loss profiles for the tested water meters, an additional pressure buffer may be necessary to avoid a potential hydraulic deficiency due to the unexpected pressure loss specific to certain water meters. Additional measures should be implemented to regulate the hydraulic performance (pressure loss characteristic) of water meters through standardized testing and quality control.

4 Conclusions

Research was conducted to provide data on water consumption during fire events in one- and two-family homes with and without fire sprinkler systems, the resulting impact of fire sprinkler systems on water infrastructure demand for residential communities, and the performance of water meters when used in line with residential fire sprinkler systems.

Based on a survey of reported water usage by responding fire services at fire events, an average of 3,524 gallons of water is discharged for firefighting at homes without fire sprinkler system protection. The data showed a range of 100 to 41,000 gallons of water used per fire, which was primarily attributed to the fire condition upon the arrival of fire services. An approximate 10 times increase of water used per fire was reported when the fire extended beyond the room of origin, or when the degree of fire involvement increased from visible flame and smoke to a fully-involved fire.

Based on the hydraulic calculations performed on fire sprinkler system designs for typical single family homes and their provided water supply information, the expected water flow discharged by residential fire sprinkler system operation during a fire event can range from 22 to 38 gpm, with an average of 28 gpm, assuming a single sprinkler operation. The average water usage for firefighting in homes without fire sprinkler systems can be up to 1200% higher than the water discharged by a fire sprinkler system with a 10 minute operation.

These results correlate with the current survey data for reported water usage during fire event, as well as previous studies of water consumption in homes with and without fire sprinkler systems. Residential fire sprinkler systems operate much earlier in a fire and consequently discharge considerably less water to control a house fire than that would be needed through manual suppression by responding fire services absent a fire sprinkler system.

Furthermore, based on the NFF determined for single family homes using industry recognized methods, at least a 47% reduction of the projected water infrastructure demand is produced when homes in a community are protected by fire sprinkler systems. Based on the findings of this study, communities can benefit from not only a fire sprinkler system's effectiveness in saving lives, but also the reduced water consumption during a fire event, as well as a possible reduction of water infrastructure demand in communities where fire sprinkler systems are installed.

Sixteen (16) commercially available residential water meters were tested under fire sprinkler system flow conditions to investigate the performance of water meters based on the pressure loss profile, metering accuracy, and functional integrity of the meter. Ten of the 16 meters produced pressure loss curves in good agreement with their manufacturer reported values and NFPA 13D suggested pressure loss curves; however, six meters produced higher pressure loss curves than both NFPA 13D and their manufacturer's curves (five meters are from the same manufacturer and one meter from another manufacturer). Metering accuracy for all tested meters was in accordance with industry standards up to approximately 150% of their normal operating flow range, except one 1-in meter that over-reported flows. Above approximately 35 gpm, certain 5/8-in meters showed a significant decrease in metering accuracy. At flow rates below the meter normal operating range (less than 3 gpm for 1-in meters) no significant loss of metering accuracy was found in any meter.

No failure of water meters or components resulting in unusual flow obstruction was observed in any test. Abnormal register readings occurred at high flow rates for some meters, but the metering accuracy was observed to be temporary and was restored upon flow rate reduction. Post-test visual inspection indicated no signs of physical damage to any meter or metering component. The tested residential water meters were observed to be capable of handling fire sprinkler system flow rates and duration without permanent damage resulting in abnormal hydraulic performance; although some reduction in accuracy and significant pressure losses were observed above the listed operating range in some meters.

Metering accuracy was observed to be within industry standards during normal flow conditions and flows typical of fire sprinkler system operation during a fire. Based on the pressure loss profiles for the tested water meters, a pressure buffer may be necessary to overcome the unexpected pressure loss specific to certain water meters. Each meter was furnished with a unique metering accuracy certificate from manufacturer testing, but none contained any actual test data for hydraulic performance testing (i.e. pressure loss characterization). Additional measures should be implemented to regulate the pressure loss performance of water meters through standardized testing and quality control.

Appendix A

Survey Data of Water Usage by Fire Service

Incident ID	Property Use			Type of Exterior Construction				Exterior Condition Upon Fire Service Arrival				
	One-Family Home	Two-Family Home	Manu-factured Home	Wood Frame	Engineered wood/ Light wood	Ordinary	Masonry/ Non-Combustible	Show Nothing	Light Smoke	Heavy Smoke	Visible Smoke and Flame	Flashover/Fully-involved
F1	Yes				Yes				Yes			
F2	Yes		No	Yes					Yes			
F3	Yes		No		Yes				Yes			
F4	Yes		No	Yes						Yes		
F5	Yes		No		Yes				Yes			
F6	Yes		No		Yes				Yes			
F7		Yes	No		Yes					Yes		
F8	Yes			Yes						Yes		
F9	Yes		No	Yes						Yes		
F10	Yes		No			Yes					Yes	
F11	Yes		Yes		Yes							Yes
F12	Yes		Yes	Yes								Yes
F13		Yes	Yes			Yes					Yes	
F14	Yes		No		Yes						Yes	
F15	Yes		No						Yes			
F16	Yes		No	Yes						Yes		
F17	Yes		No			Yes			Yes			
F18	Yes		No			Yes			Yes			
F19	Yes		No		Yes				Yes			
F20	Yes		No			Yes						Yes

Incident ID	Property Use			Type of Exterior Construction				Exterior Condition Upon Fire Service Arrival				
	One-Family Home	Two-Family Home	Manu-factured Home	Wood Frame	Engineered wood/ Light wood	Ordinary	Masonry/ Non-Combustible	Show Nothing	Light Smoke	Heavy Smoke	Visible Smoke and Flame	Flashover/Fully-involved
F21	Yes		Yes		Yes							Yes
F22	Yes						Yes		Yes			
F23	Yes		No				Yes		Yes			
F24	Yes		Yes		Yes					Yes		
F25		Yes					Yes			Yes		
F26			Yes				Yes			Yes		
F27		Yes					Yes				Yes	
F28	Yes		No				Yes				Yes	
F29	Yes		No				Yes				Yes	
F30	Yes		No	Yes						Yes		
F31	Yes		No	Yes					Yes			
F32	Yes		No	Yes					Yes			
F33		Yes		Yes							Yes	
F34	Yes		No	Yes							Yes	
F35	Yes		No	Yes							Yes	

Incident ID	Community ID	Extent of Smoke and Flame Damage					Estimated Water Usage		
		Confined to Area of Origin	Confined to Room of Origin	Extended Beyond Room of Origin	Extended Beyond Floor of Origin	Extended beyond Structure	Estimated Water Flow (gpm)	Estimated Flow Duration (minute)	Estimated Total Water Used (gallon)
F1	COM1				Yes		150	2	300
F2	COM1		Yes				100	5	500
F3	COM1		Yes				250	7	1,750
F4	COM1				Yes		400	10	4,000
F5	COM2		Yes				140	2	280
F6	COM2		Yes				250	5	1,250
F7	COM2					Yes	450	10	4,500
F8	COM3	Yes					200	10	2,000
F9	COM4						250	2	500
F10	COM4			Yes			300	10	3,000
F11	COM4			Yes			300	13	3,900
F12	COM4					Yes (to grass)	220	50	11,000
F13	COM4			Yes			1550	10	15,500
F14	COM4					Yes	Handlines 750 gpm (deckgun 1000)	48 min (5 min deckgun)	41,000
F15	COM5		Yes				125	2.5	313
F16	COM6			Yes			110	2	220
F17	COM6	Yes					120	2	240
F18	COM6	Yes					150	2	300
F19	COM6		Yes				200	2	400
F20	COM6					Yes	1000	3	3,000

Incident ID	Community ID	Extent of Smoke and Flame Damage					Estimated Water Usage		
		Confined to Area of Origin	Confined to Room of Origin	Extended Beyond Room of Origin	Extended Beyond Floor of Origin	Extended beyond Structure	Estimated Water Flow (gpm)	Estimated Flow Duration (minute)	Estimated Total Water Used (gallon)
F21	COM6					Yes	300	15	4,500
F22	COM7		Yes				100	1	100
F23	COM7		Yes				100	2	200
F24	COM7		Yes				125	2	250
F25	COM7	Yes					125	2	250
F26	COM7	Yes					125	3	375
F27	COM7					Yes	125	3	375
F28	COM7			Yes			125	5	625
F29	COM7			Yes			250	4	1,000
F30	COM8	Yes					150	1	150
F31	COM8	Yes					150	1	150
F32	COM8	Yes					300	1	300
F33	COM8				Yes		300	2	600
F34	COM8				Yes		250	10	2,500
F35	COM8					Yes	1200	15	18,000

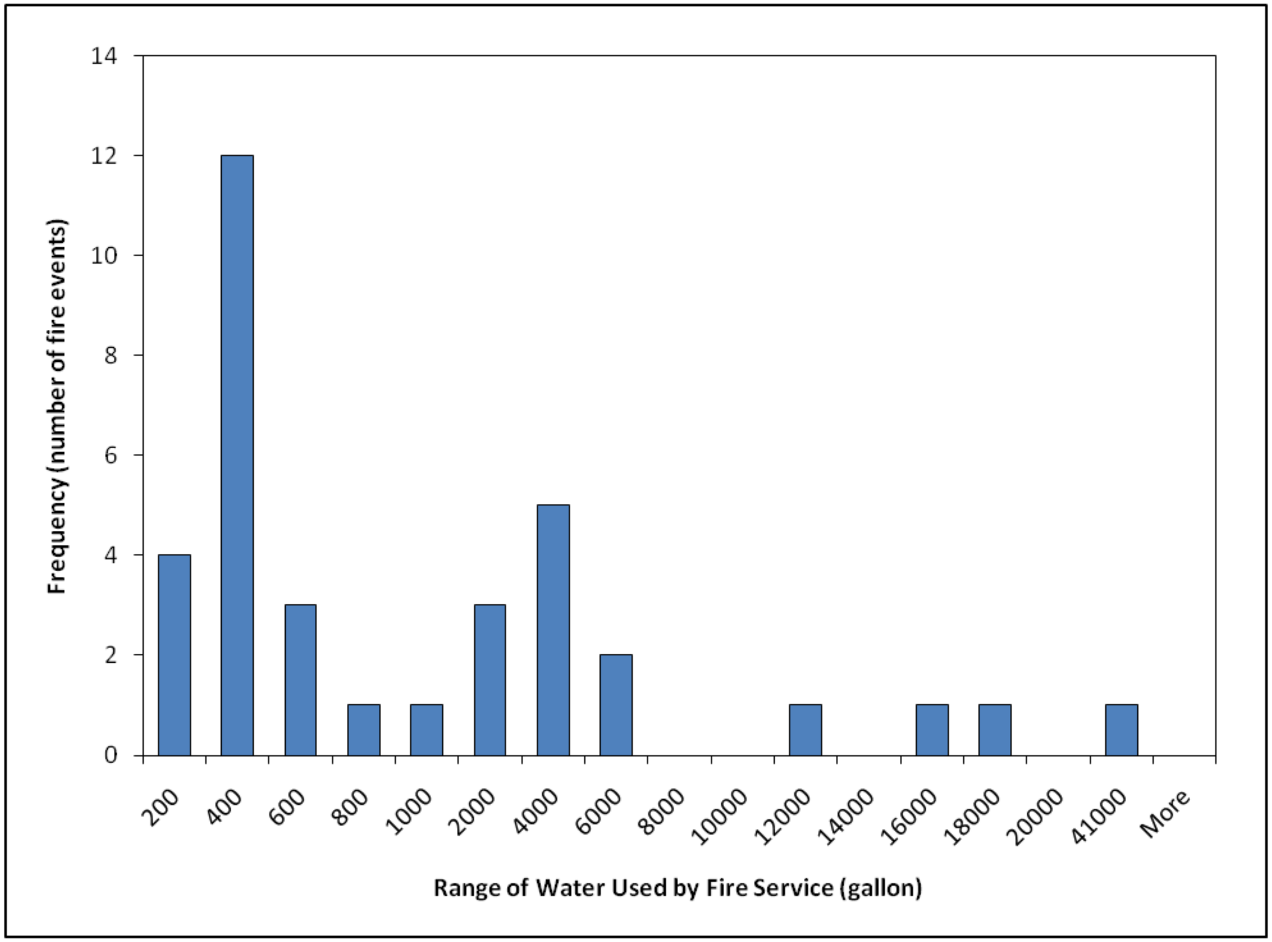
Incident ID	Method of Extinguishment						
	Portable Extinguisher	Preconnected hose-line(s) water from apparatus tank (# of lines)	Preconnected hose-line(s) + water supply (# of lines)	Hydrant Distance	Hand-laid hose lines + water supply (# of lines)	Hydrant Distance 2	Master Stream Device (types/gpm)
F1			Yes (3)	200 ft			
F2		Yes (1) standard preconnect					
F3	Yes (by FD)	Yes (1) standard preconnect	Yes (2) (Drafting Tank 5000 gals not used)				
F4	Yes (by FD)	Yes (2) standard preconnect	Yes (3)	500 ft			
F5		Yes (1) standard preconnect					
F6		Yes (2) standard preconnect		200 ft			
F7			Yes (4)	50 ft			
F8	Yes (by occupant)		Yes (2)	50 ft			
F9		Yes (2)					
F10		Yes (2) standard preconnect		300 ft			
F11		Yes (2) standard preconnect					
F12	Yes (by FD)	Yes (3)	Yes (3)	6000 ft			
F13	Yes (by FD)		Yes (4) 2-2 1/2 handlines + 2 - 1 3/4 handlines	10 ft			Yes (750 gpm)
F14	Yes (by FD)		Yes (3)	< 100 ft			Yes (Deckgun-1000gpm) (only 5 min)
F15			Yes (1)				
F16		Yes (1) standard preconnect		500 ft			
F17		Yes (2)		500 ft			
F18		Yes (2) standard preconnect					
F19		Yes (1) Other: 3 sections 1-3/4" hose, automatic nozzle					
F20		Yes (2) standard preconnect; Other: 2-1/2" hose (4) nozzle					

Incident ID	Method of Extinguishment						
	Portable Extinguisher	Preconnected hose-line(s) water from apparatus tank (# of lines)	Preconnected hose-line(s) + water supply (# of lines)	Hydrant Distance	Hand-laid hose lines + water supply (# of lines)	Hydrant Distance 2	Master Stream Device (types/gpm)
F21			Yes (2)	200 ft			
F22		Yes (1) standard preconnect					
F23		Yes (1) standard preconnect					
F24			Yes (1)	150 ft			
F25		Yes (1) standard preconnect					
F26			Yes (2) (attack line and backup line)		Yes	<50 ft	
F27					Yes (2) (attack line and backup line)	100 ft	
F28			Yes (2) (attack line and backup line)	200 ft			
F29			Yes (2)	300 ft			
F30		Yes (1) standard preconnect					
F31		Yes (2) standard preconnect					
F32			Yes (2) x 1.75"	200 ft			
F33			Yes (3) x 1.75"	120 ft			
F34			Yes (4) 1.75" lines	60 ft	Yes (1) 2.5" line	60 ft	Yes (500) gpm for knockdown
F35			Yes (6) x 1.75" and (1) x 2.5'	100 ft	Yes (1) 2.5" line		Yes (500) gpm for knockdown

Incident ID	Alarm Time						
	Received by 911	Received by FD	First Suppression Unit Arrival	Estimated Time takes to arrive (minute)	Water On Fire	Fire Out	Incident Terminated
F1	12:20	12:20	12:27	7	12:28	12:38	13:53
F2	11:33	11:34	11:40	7	11:44	11:46	12:50
F3	7:53		8:03	10	8:10	8:30	9:56
F4	11:33		11:40	7	11:44	12:12	13:44
F5	13:54:55	13:55:14	14:03:27	9	14:05:30	14:12:28	14:38:17
F6	6:07:56	6:07:56	6:14:12	7	6:16:00	6:30:00	11:12:52
F7	4:47	4:47	4:51	4	4:53	5:35	8:37
F8	7:22	7:22	7:23	2	7:28	7:23	10:23
F9	18:42	18:43	18:51	9	18:53	19:08	
F10	2:08	2:09	2:15	7	2:16		4:45
F11	20:41	20:42	20:47	6	20:48		22:35
F12	3:53	3:54	4:03	10	4:05		
F13	6:31	6:34	6:38	7	6:48		
F14	18:39	18:41	18:56	17	18:57	19:45	21:21
F15	11:28:00 PM	22:31	22:34	6			
F16	11:59	11:59	12:04	5	12:06	12:10	13:50
F17		16:35	16:40	5	16:42	16:44	21:25
F18	16:37	16:37	16:42	5	16:45	16:50	18:00
F19	4:07	4:07	4:12	5	4:15	4:19	6:37
F20	1:51	1:51	1:59	8	2:00	2:20	5:26
F21	2:22:56	2:23:41	2:29:15	7	2:31	2:37	4:17
F22	14:48	14:50	14:54	8	14:54	14:55	16:01
F23	1:45	1:46	1:50	5	1:51	1:53	4:22
F24		10:20	10:23	3	10:26	10:30	11:42

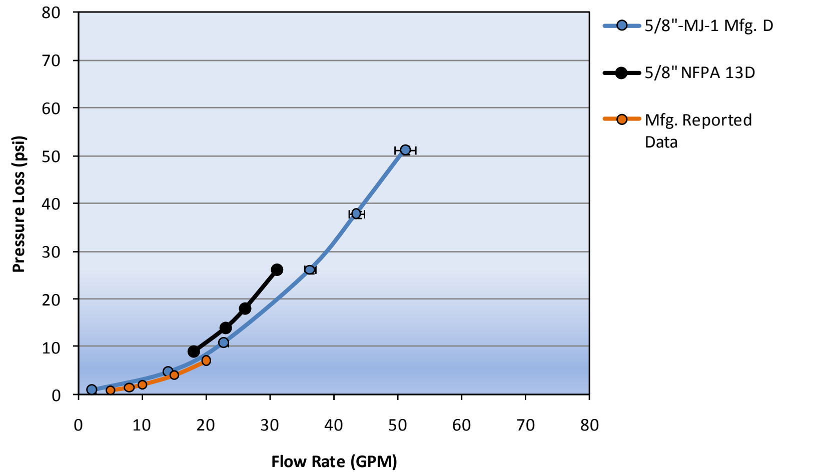
Incident ID	Alarm Time						
	Received by 911	Received by FD	First Suppression Unit Arrival	Estimated Time takes to arrive (minute)	Water On Fire	Fire Out	Incident Terminated
F25	16:50	16:52	16:57	7	16:58	16:58	17:45
F26	23:22	23:25	23:30	8	23:37	23:46	1:50
F27	8:00	8:03	8:06	6	8:10	8:18	11:24
F28		0:58	1:01	2	1:09	1:16	6:01
F29	14:19	14:19	14:24	5	14:32	14:40	16:56
F30	10:23:37	10:24:01	10:27:31	5		10:44:36	11:28:46
F31	2:10:49	2:11:21	2:15:07	5		2:24:48	3:33:36
F32	16:07:28	16:08:03	16:11:06	4		16:32:27	18:13:51
F33	3:31:03	3:31:27	3:35:32	4		3:58:37	5:18:29
F34						7:19:15	10:41:52
F35						4:44:44	10:03:34

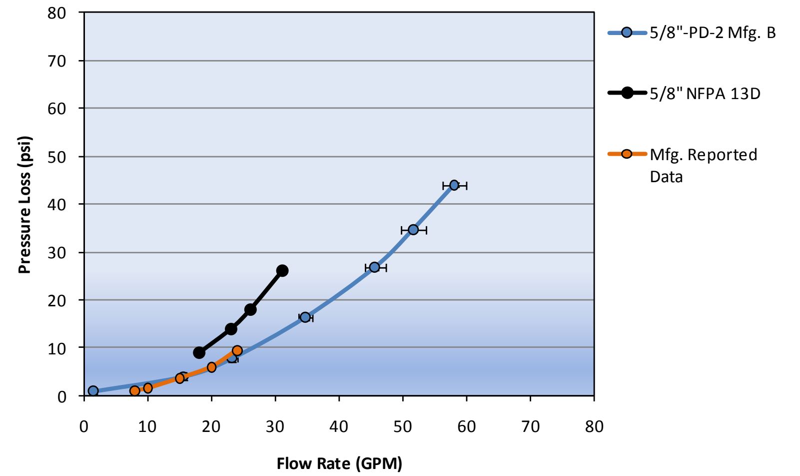
Histogram for Survey Data of Water Usage by Fire Service

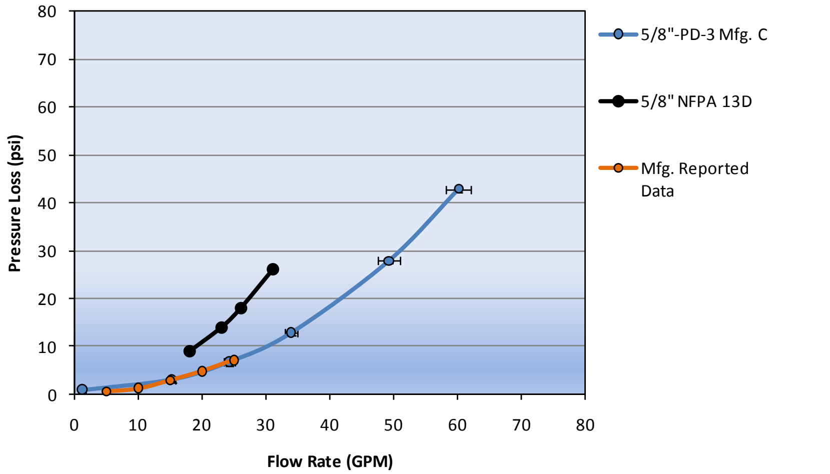


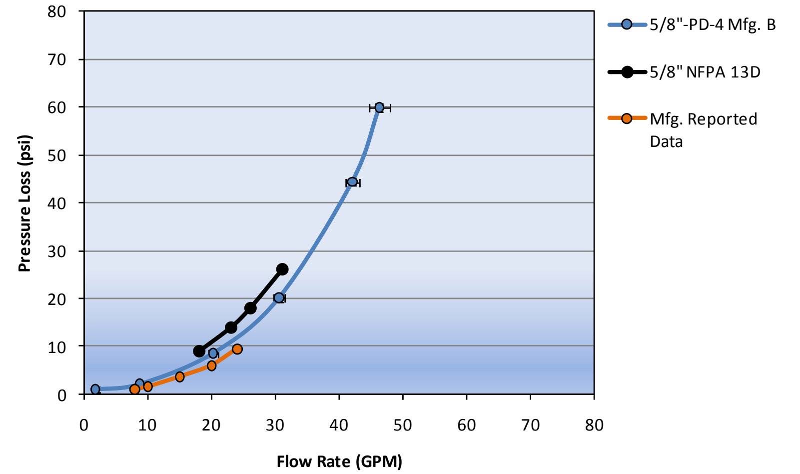
Appendix B

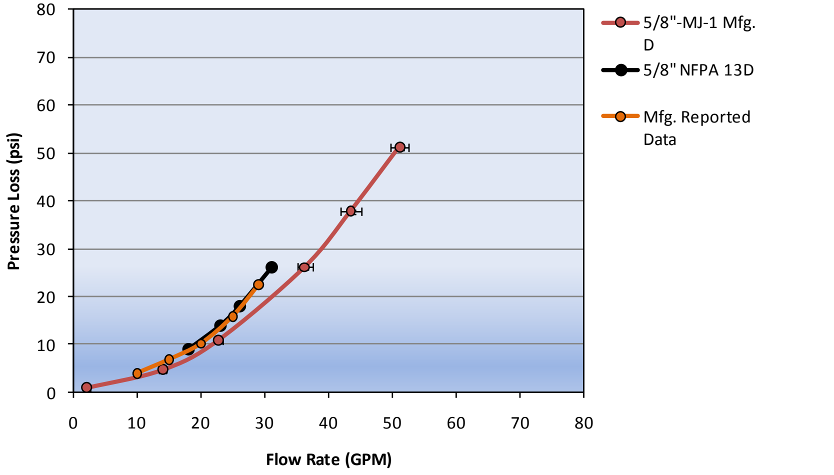
Water Meter Pressure loss data



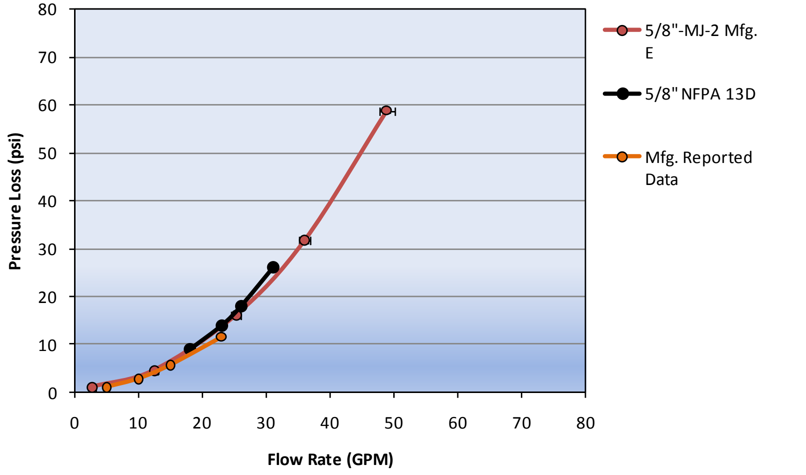




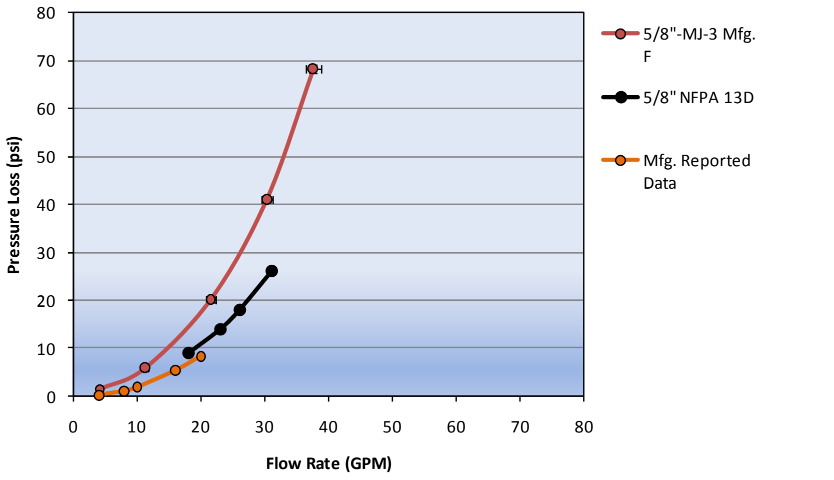




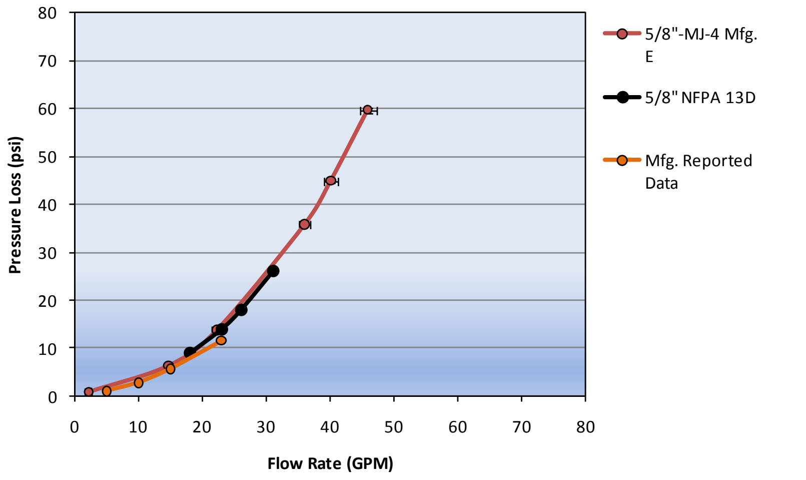
Pressure Loss (psi)
Flow Rate (GPM)
5/8"-MJ-1 Mfg. D
5/8" NFPA 13D
Mfg. Reported Data



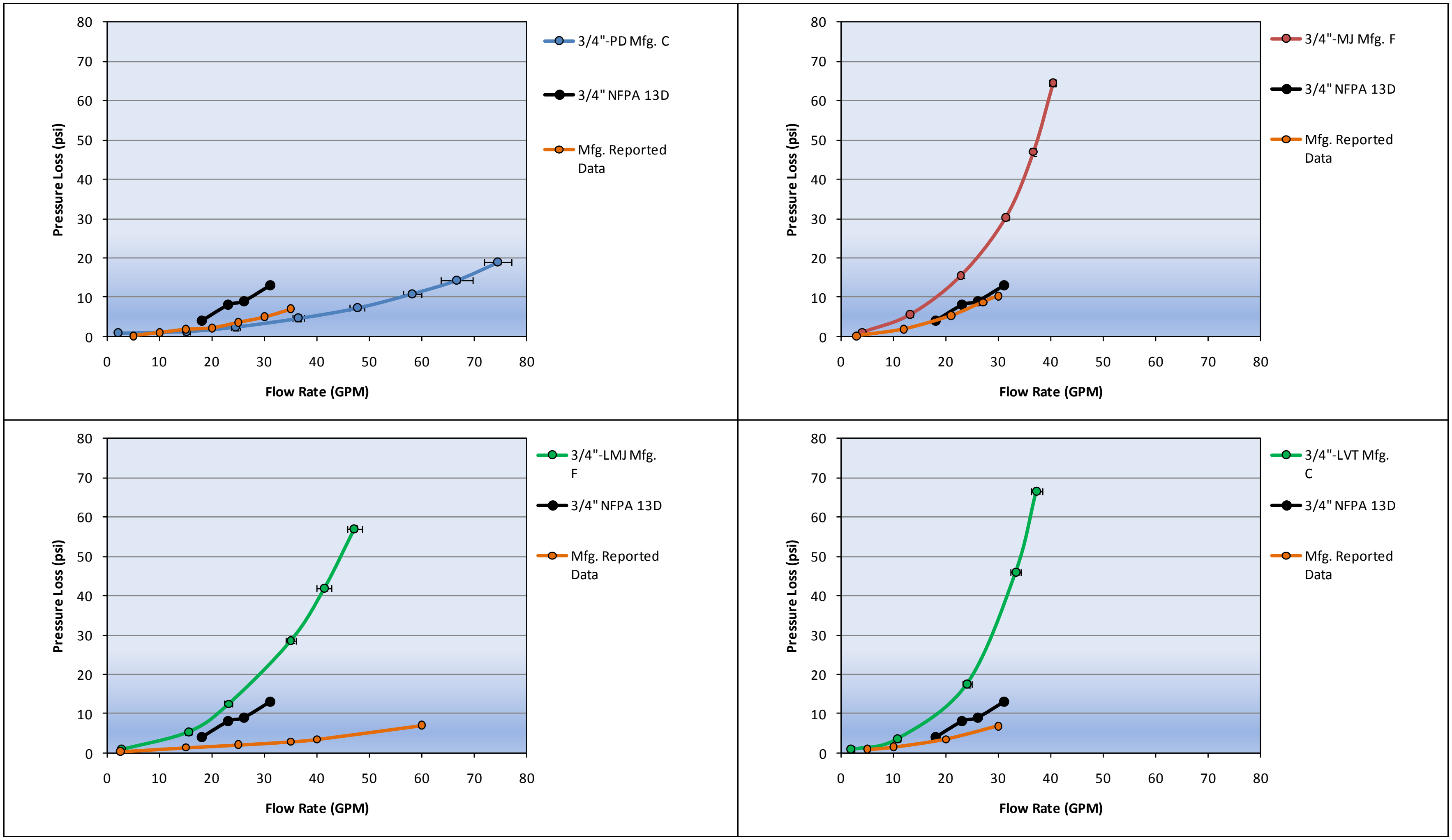
Pressure Loss (psi)
Flow Rate (GPM)
5/8"-MJ-2 Mfg. E
5/8" NFPA 13D
Mfg. Reported Data



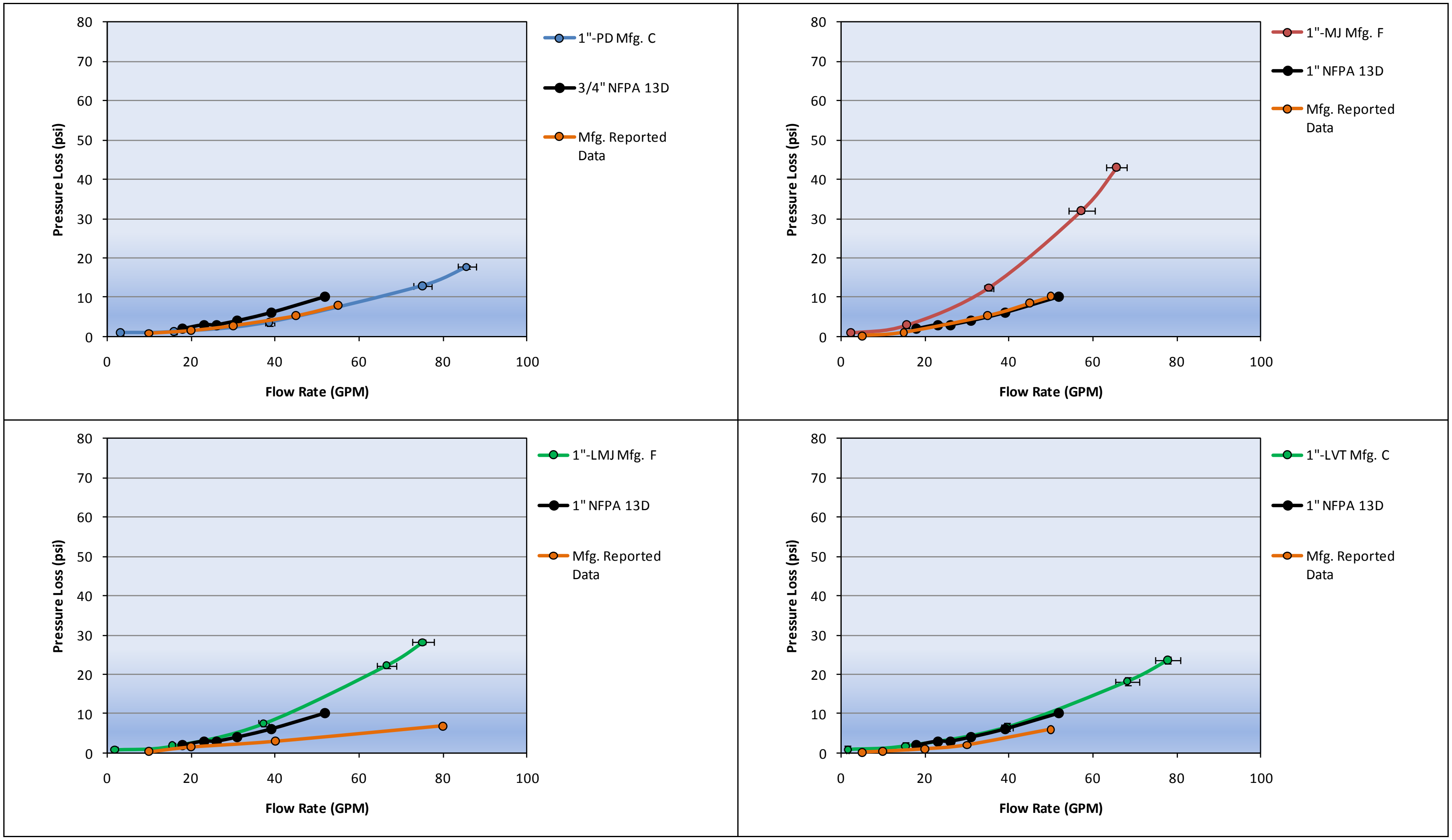
Pressure Loss (psi)
Flow Rate (GPM)
5/8"-MJ-3 Mfg. F
5/8" NFPA 13D
Mfg. Reported Data



Pressure Loss (psi)
Flow Rate (GPM)
5/8"-MJ-4 Mfg. E
5/8" NFPA 13D
Mfg. Reported Data



QMS QA ID No. 1003676.000 C0F0 0211 YU01


Pressure Loss (psi)
Flow Rate (GPM)
1"-PD Mfg. C
3/4" NFPA 13D
Mfg. Reported Data
1"-MJ Mfg. F
1" NFPA 13D
Mfg. Reported Data
1"-LMJ Mfg. F
1" NFPA 13D
Mfg. Reported Data
1"-LVT Mfg. C
1" NFPA 13D
Mfg. Reported Data

Pressure Loss for Fittings Connected to Water Meters