Quantification of Water Flow Data Adjustments for Sprinkler System Design

FINAL REPORT

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FOREWORD

When a water flow test is taken to determine the available flow and pressure of the community's water supply for sprinkler system design, that data is used to define the system for the remainder of its useful life. If that test is not taken at a conservative time in regards to water usage and water distribution operations, the system has the potential to be under designed. Water usage varies with the time of day, as well as the time of year. In addition, over time the water availability to an area can change due to a multitude of reasons, including but not limited to development.

Currently no method is specified to adjust for this time centric variable, and as a result tests are being conducted without consideration of an adjusting factor regardless of the actual water usage and demand during the completion of said tests. The purpose of this project is to clarify the varying demands on a typical water supply system and determine available methods to quantify an adjustment to water flow tests based on both the time of day and the time of year at which the test was conducted, while also identifying the numerous other variables affecting the testing of water flow.

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

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All NFPA codes and standards can be viewed online for free.

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Keywords: water flow, sprinkler system, data adjustment, NFPA 13, NFPA 24

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QUANTIFICATION OF WATER FLOW DATA ADJUSTMENTS FOR SPRINKLER SYSTEM DESIGN

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1. EXECUTIVE SUMMARY

The goal of this research was to identify the variables in water supplies that affect hydrant flow tests, which are used in the design of water based fire protection systems. The results of this research are intended to be used to establish recommendations for adjustment to water supply data to be used for the design of fire protection systems. Adjustments would be necessary to ensure that data used for design of fire protection systems represents the actual water supply system conditions during peak demand, accounting for parameters such as tank level during testing and normal system operations.

A literature review (Task 1) was performed to compile available data regarding pertinent variables that can impact fire protection water supplies. The primary focus was to identify variables that affect water demand, system conditions (such as age, type of pipe, corrosion, internal roughness, occlusion, etc.) and water distribution system operations.

A significant amount of research has been performed on topics that affect water supplies, including modeling and water demands; however, very limited research has been performed on adjustments to water supplies. The majority of the literature reviewed as part of Task 1 had been written to address other purposes. While this data does not directly relate to water flow adjustments, it is beneficial in describing variables that impact water demand and use.

Water is provided to a variety of users, including residential, industrial, commercial, and institutional users. The ratio between these users and their typical demands vary from one community to the next. Use patterns have been shown to be affected by time of day, day of week, season, climate, location, water, growth, recession, socioeconomic factors, and leakage. These patterns affect demands within a community which directly impact water availability and flow.

The water distribution systems used to provide water to end users have many components that impact the available flow of water. These systems range in age, material, and configuration. System components affecting water flow include the type of pipe, the water supply infrastructure, tanks, booster pumps, well pumps, pressure regulating valves, and interconnections. In conjunction with the physical components of the water distribution system, operational procedures influence the function of the different components. These operational procedures include maintenance, system operations, water and energy conservation, system operating pressure, pressure fluctuations, and manual operations. Both the system components and the operating procedures impact the available flow within the system.

Task 2 included an analysis of water estimation methods. Simple calculations, computer modeling of water supplies and hydraulic modeling of water supplies were evaluated as part of this task. Simple water supply calculations are typically used by water purveyors for determining capacity. Computer models have been used to predict future demands of water distribution systems as well estimate pressure and flows within the system. Forecasting models are used to estimate current water demands as well as future water demands using different parameters, variables, and algorithms. Hydraulic models are the most applicable to fire protection and use mathematical equations to determine pressure and flow at certain points within the system. Hydraulic models require input parameters for all components of the water supply system, which may not be known and can change throughout the system over time. Many water purveyors already use hydraulic models for design, operation, and water quality monitoring. These models can also be used for fire protection purposes by providing modeled flow test data.

Task 3 included development of general recommendations regarding water supply adjustments. However, due to the limited available literature regarding the topic of water supply adjustments, insufficient data was considered available to support recommendations for development of adjustment factors at this time. The data was considered insufficient for the following reasons: 1) there is a lack of data associating flow rates and available pressure, 2) there is insufficient data to provide meaningful comparisons between regions and within specific regions, 3) there is a lack of data for all identified variables, and 4) data was not limited to a single variable or discrete number of variables, which would allow for development of adjustment factors.

Research that includes pressure data with associated system demands is needed. Predictive calculations and changes in procedural operations to meet water supply demands are typically based on water supply capacity and do not consider available water supply pressure throughout a water distribution system. As a result, there is no way to utilize available data in a meaningful way to allow for development of a water supply adjustment factor or development of an equation for adjusting data. Additional research correlating pressure and flow is needed to allow for the development of such a factor for fire protection system design purposes.

Research is also needed to characterize the effects of seasonal changes and climate changes for a variety of different, yet typical locations, which will allow for comparison to water supplies in similar communities. The research should attempt to limit variables as much as possible so that the impact of each variable can be related to fluctuations in the available pressure and flow of a given water supply. It is recommended that the research include a study to determine how water distribution system operations impact fluctuations in the available pressure and flow of a given water supply.

In addition to recommendations for further study, several recommendations have been made, including: 1) coordinating with water utilities and forming a joint AWWA and NFPA task group, 2) utilizing water distribution system models, 3) determining water supply degradation parameters, 4) standardizing water flow test procedures, and 5) evaluating these changes to determine their ability to be widely distributed.

2. INTRODUCTION

Designers use water flow test data to establish available flow and pressure for a fire protection system. Currently, National Fire Protection Association (NFPA) 13, *Standard for the Installation of Sprinkler Systems*, requires that a flow test be recent (e.g., within the past year), but it does not require any margin of safety between the fire protection system demands and the available water supply defined by the flow test (NFPA 13, 2013).

Similarly, sprinkler systems designed for residential occupancies using NFPA 13R, *Standard for the Installation of Sprinkler Systems in Low-Rise Residential Occupancies,* and NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes* are not required to have specified margins of safety between the sprinkler system demands and water supplies defined by flow tests.

NFPA 291, *Recommended Practice for Fire Flow Testing and Marking of Hydrants* only suggests that a flow test be performed during a period of ordinary demand, but there are no suggestions for the time of day or season (NFPA 291, 2013). Often times, other factors need to be taken into consideration when determining when a test can be performed. Such factors include; need and availability of water utility staff or fire department personnel required for equipment operation or to witness testing, permission to close roadways, inability to contain water, and a host of other practical concerns.

NFPA 24, *Standard for the Installation of Private Fire Service Mains and Their Appurtenances*, requires the volume and pressure of a public water supply to be determined from water flow test data or other approved methods, but only lists adjustments (daily and seasonal fluctuations, large simultaneous industrial use, future demand on the water supply system, etc.) to this data in the appendix of the code which is considered to be best practice, but not enforceable for most jurisdictions (NFPA 24, 2013). If a water flow test has been performed during a period of low demand, there is a potential that the water flow test data does not accurately reflect the available water during normal or peak demands. Additionally, without adjusting the water flow test results for variations in pressure associated with tank fill levels or other system components, the data used to design the system may not be sufficient when the tanks are not full.

The American Water Works Association (AWWA) manual on *Distribution System Requirements for Fire Protection* has acknowledged this variation in water supplies. The manual states that “the design of sprinkler systems requires knowledge of the water pressure in the street. However, there is no such thing as a single, constant water pressure in the street that should be used for design. The pressure in water mains varies over time due to a large number of factors”. These factors include: normal daily variations, long term system changes, long term variations in water use patterns, and short term emergencies. Additionally, “With all of the sources for variations in pressure, it’s clear that there is no single water pressure in the street. Instead, pressure fluctuates over time, and the sprinkler system designer must select a single value as the basis for design from a reasonable worst-case condition” (AWWA, 2008).

Task groups from NFPA 13 and NFPA 24 have reviewed proposals directed to both the discharge and underground water supply committees to provide further details on adjustments to water flow test data; however, these proposals were held due to a belief of insufficient data needed to address this issue.

2.1. Terminology

The terminology used throughout this report is typically used in the field of fire protection. While this topic includes aspects of civil engineering and fluid mechanics pertaining to water supplies, the generally accepted definitions used in the field of fire protection will be used. In most cases these definitions are included in NFPA codes and standards. However, alternate definitions may also be found in AWWA or ASCE documents.

2.2. Background

The analysis of the water supply is the responsibility of the designer. Handbooks, standards, and books for the design engineer have stated this responsibility and have provided considerations for years, but have not provided any guidance for quantifying these considerations. This vagueness results in variations of practice and inability to ensure a minimum standard of care.

2.2.1. NFPA Fire Protection Handbook

The chapter titled, “*Test of Water Supplies*” of the NFPA Fire Protection Handbooks dating back to the twelfth edition recognized that a single water flow test is only accurate for a short duration and that variables such a closed valves, sediment, and obstructions can change the pressure readings (NFPA, Fire Protection Handbook, 12 Edition, 1962). This point was expanded upon in the thirteenth edition, which stated that flow tests are only accurate for the prevailing conditions, i.e. the conditions at the time of the test. It conveyed that the time of the day, the day of the week, month of the year, and weather were all factors that impacted the water flow tests and to properly evaluate the adequacy and reliability of the system, consideration was needed into the overall operations of the system. This implies that the sprinkler designer must have an understanding of all variables described in Section 2 of this report, which is impracticable in most situations.

A dialogue should be established with the water utility operators to obtain a sufficient understanding of the water supply system for the purpose of designing the fire protection system. The thirteenth edition of the handbook stated that “fire flow found satisfactory when tested, might be hopelessly inadequate at another time” (NFPA, Fire Protection Handbook, 1969). More recent editions of the NFPA Fire Protection Handbook included a chapter on “*Determining Water Supply Adequacy*.” This chapter suggested that hydrant flow test should not be attempted until all the operational characteristics of a water system are known (NFPA, 2003). The past several editions of the Fire Protection Handbook, have provided a stronger emphasis on determining the underlying causes of water fluctuations, but have not provided any means to quantify these fluctuations.

2.2.2. Factory Mutual (FM) Global Data Sheets

The March 2010 version of FM Global Property Loss Prevention Data Sheet 3-0, *Hydraulics of Fire Protection Systems*, includes the following steps to determine the water supply for fire protection systems. “1. Gain a thorough understanding of the type of water supply available. If it is a public supply, visit the water department and obtain details regarding the piping network and the means by which water is delivered… 2. Gain a thorough understanding of the underground piping, including length, diameter, material, internal lining (if applicable), roughness coefficient, and the approximate age of the pipe.” The data sheet also includes a requirement to “check for variations in operating procedures from day to night or from summer to winter” (FM Global, 2010). This reference provides instructions for obtaining water supply data, but when the water department is unavailable or unwilling to assist with providing the means by which the water is delivered, the end user still does not have an accurate means to quantify the variations in the data.

2.2.3. Fire Protection Hydraulics and Water Supply Analysis

The book *Fire Protection Hydraulics and Water Supply Analysis* by Pat D. Brock is one of the leading books on hydraulics for fire protection systems. This book contains a chapter on *Testing and Analysis of Water Supply Systems* in which considerations such as factory use, population increase, corrosion, and system changes are cited as reason for changes is water supplies at a particular location (Brock, 1990). Similar to the other publications, while these considerations are identified, there is no recommendation for adjusting the water supply.

2.3. Safety Factors and Adjustments

Several Authorities Having Jurisdiction (AHJs) require water supplies or hydraulic calculations to be adjusted when water flow test data is used to establish the available supply for fire protection systems. A few of the requirements are provided here for reference, but no justification was included in the majority of the publications which contained the safety factors or adjustments.

2.3.1. Montgomery County, Maryland

Montgomery County, Maryland amends NFPA 13, NFPA 13D and NFPA 13R to require both a safety factor and adjustments to the water flow test for low hydraulic gradient. The amendments are included in “Executive Regulation 19-13, Fire Safety Code – Fire Protection Systems”, which requires a 20% safety factor for all uses of NFPA 13 systems. For NFPA 13D and NFPA 13R systems, a 10% safety factor is required to “account for minor field changes”. Additionally, the county requires all supply information to be corrected for the low hydraulic gradient (Department of Permitting Services, 2014).

Adjusting for the low hydraulic gradient consists of an adjustment of the entire water supply curve by subtracting the elevation of the test hydrant from the hydraulic grade line provided by the water supplier, converting the difference into a pressure and comparing the calculated pressure to the observed static pressure of the test hydrant. If the calculated pressure is greater than the observed pressure, the entire test data is then shifted by the difference to the lower calculated pressure (Office of the Fire Marshal - Fire Prevention Division, 2009).

2.3.2. Clark County, Nevada

Clark County, Nevada modifies NFPA 13 and NFPA 20. NFPA 13 is modified to require a minimum of 10 psi between the required fire protection system pressure and the available supply pressure. No justification for this requirement is provided. NFPA 20 is modified to limit the design of systems to be within 110% of the rated pump capacity (flow) (Clark County Government, 2015).

2.3.3. Ocean County, California

The Ocean County Fire Administrator (OCFA) modifies the International Building Code to require a minimum of 10% safety factor for pressures less than 100 psi. For system pressures between 100 psi and 150 psi a graph shows the minimum safety factor required with a maximum safety factor of 25% for system pressures of 150 psi (City of Aliso Viejo, California, 2013).

2.3.4. City of Clovis, California

The city of Clovis Water Department provides water for all buildings within the city limits. For the design of sprinkler systems, standard water supply data is provided for all buildings within the city limits unless specifically requested by the fire department to perform a flow test. The standard water supply data is 45 psi static, 35 psi residual flowing 1,800 gpm (Clovis Fire Department).

2.3.5. Abilene, Texas

The city of Abilene requires a minimum safety factor of 10% or 5 psi, whichever is greater for all sprinkler systems. In addition, a member of the Fire Prevention Department must witness the test for it to be used during design. This limits the hours of testing to the Fire Prevention Departments working hours (City of Abilene, Texas).

3. TASK 1: LITERATURE REVIEW

The first task of this project, Task 1, included a literature review on the topic of water supply adjustments. A significant amount of research has been performed on topics that affect water supplies, including modeling and water demands: however, very limited research was performed on adjustments to water supplies. The majority of the literature reviewed for this task was performed for other purposes. While this data does not directly relate to water flow adjustments it is beneficial in describing variables that impact water demand and use.

In addition to a detailed literature review, a survey was sent out to a variety of water purveyors within the United States to understand common practices. A copy of a survey letter sent to water utilities as part of this project, as well as the responses to the survey, are included in Appendix A of this report. The survey was intended to characterize some of the common practices. However, the usefulness of the responses for this purpose was considered to provide limited benefit due to ambiguities and vagueness of the responses.

3.1. Water Users

Water is provided to a variety of users typical of most communities, including residential, commercial, institutional, and industrial. The ratio between these users vary from one community to the next. Multiple studies have been performed to quantify the use by these water consumers (Mayer, 1999) (Dziegielewski, 2000) (DeOreo, et al., 2011). Additionally, research has been performed regarding modeling future demands for use by water purveyors (Adamowski, 2008) (Goodchild, 2003) (Gutzler & Nims, 2005) (Miaou, 1990) (Donkor, Mazzuchi, Soyer, & Roberson, 2014). Results of these studies have discussed many variables impacting water demands, which have implications on the results of water flow tests.

In order to understand the variables, it first necessary to describe the various users of water and available means used to calculate these variables.

3.1.1. Residential Users

Residential (domestic) uses of water include indoor and outdoor consumption. These uses range from drinking and cooking, to sanitary and cleaning, to watering the lawn and filling swimming pools. Residential indoor daily uses are typically classified in the following categories: dishwashers, baths, faucets, showers, clothes washers, toilets, other domestic uses and unknown (Mayer, 1999). Typical outdoor uses include irrigation, washing cars, filling pools, and other tasks performed by homeowners. Outdoor uses of water are not as easily categorized and are typically dominated by irrigation and filling pools. For this reason, research on outdoor residential use focuses on irrigation and pools.

The *Residential End Uses of Water* (REUW) report calculated an average consumption of 69.3 gallons per capita per day (gpcd) for indoor residential use and 100.8 gpcd for outdoor residential use for the sites surveyed (Mayer, 1999). This study did note that while the data for each site is representative for the overall community at each site, the data does not represent North America as a whole. The water use data is depicted in Figure 1 for REUW. Another study, the *California Single Family Water Use Efficiency Study* (CSFWUES), tabulated usage based upon gallons per house daily (gphd) versus per capita. The CSFWUES calculated an average indoor use of 175 gphd for the study (DeOreo, et al., 2011). The CSFWUES study estimated that for water users in the state of California, approximately 47% of residential water was used indoors and 53% of water used outdoors (DeOreo, et al., 2011).

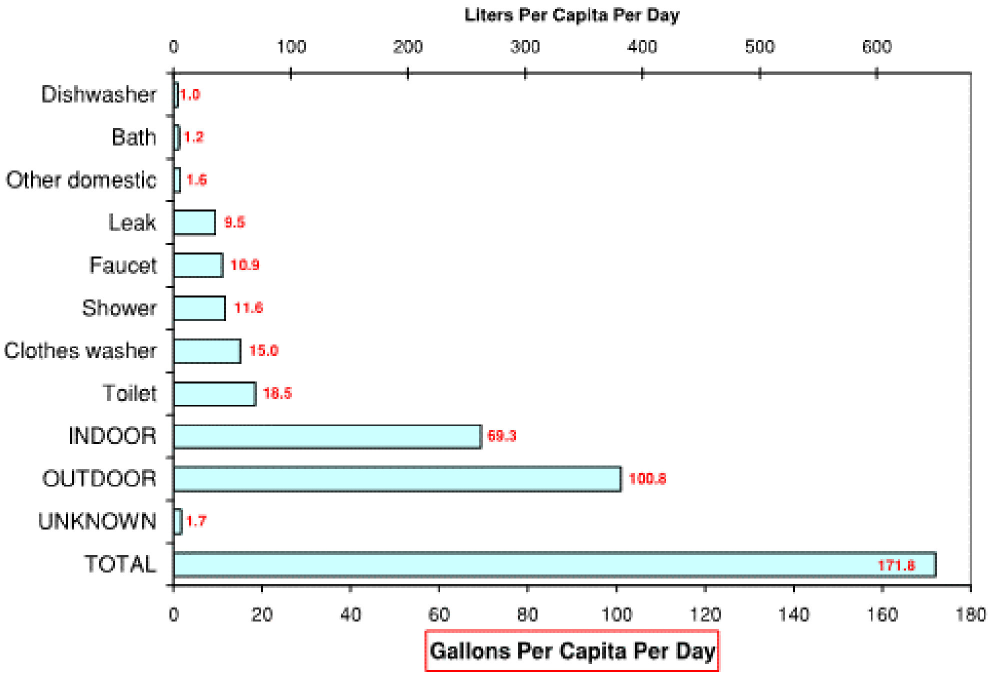


Figure 1 – Mean Daily per Capita Water Use (REUW) (Mayer, 1999)

Daily residential consumption rates are not directly accounted for in the establishment of the water supply. These rates are used for sizing pipes and water supply components.

3.1.2. Commercial and Institutional Users

Commercial and institutional uses are very diverse. In order to provide comparable and useable data, these users are typically grouped into subsectors based on function. These subsectors are comprised of office buildings, schools and colleges, hotels and motels, laundries/laundromats, hospitals/medical offices, storage facilities, restaurants, food stores, and auto shops to name a few (Funk & DeOreo, 2011). Typical water uses for these facilities include domestic/sanitary, cooling and heating, laundry, kitchen, ice-making, washing and sanitation, laboratories, process water, water purification, landscape use, and other water features including pools, spas, and fountains (CDM, 2008).

Providing generalizations for this group as a whole is difficult based on the variety of the different uses (car wash versus hospital). Furthermore, even providing generalizations based on subsector is difficult due to the varying size of users within each subsection (multi story office building versus five person office). For these users, the *Commercial and Institutional End Uses of Water* (CIEUW) report calculated water demands based on number of employees, number of beds, and per square footage (Dziegielewski, 2000).

3.1.3. Industrial Users

Industrial users of water include agricultural, manufacturing, and power generating to name a few. The demands for these users are typically continuous in the case of processes that are performed throughout the day, scheduled for uses that only occur at certain times, and sporadic for processes that need water on an irregular schedule. Uses of water for industrial users varies significantly, but can include irrigation for farms, drinking water for livestock, incorporation into products for food manufacturers, and cooling water for power generating stations. The least amount of data accompanies industrial users since the type of industry and the water needs vary drastically.

3.2. Variables that Impact Water Demand

This report will discuss impacts on water flow and demand in terms of water demand (flow) only. Both the pressure and flow are critical parts of a water supply; however, it is assumed that the water distribution system can accommodate the increased demand with the necessary flow. Variations in pressure will be assumed to be related to demands. As demands increase, pressure will decrease. This is based on the following hydraulic principles: (1) friction loss increases with increased flow through pipes, (2) increased demands will result in more water being used from storage and a reduction in the elevation of water in elevated water storage tanks resulting in a lower pressure, and (3) increased demands will reduce the pressure output of pumps.

This report focuses on fluctuations in water supplies that cause pressure deficiencies for fire protection systems designed with higher pressure results obtained from previous tests or predictive modeling; however, the opposite can also occur. A water supply test can under characterize the water supply pressure causing the need for pump or other provisions to meet the fire protection demands. Higher operating pressure conditions or pressure surging after a pump has been added can subsequently result in system working pressures during churn that are greater than the ratings of system components. This scenario often requires the addition of pressure reducing valves or other means to correct the conditions. While these over pressurization conditions should be addressed when identified, the systems will most likely perform as designed

3.2.1. Water Demands

The following variables have been identified as impacting water demands:

- Time of Day
- Day of Week
- Season, Climate, and Location
- Weather
- Growth and Recession
- Socioeconomic
- Leakage

3.2.1.1. Time of Day

Water demands by users vary based on the time of day. Normal routines of water usage define “daily” patterns. Typically, for residential areas, water demand can be split into four usage categories: 1) the lowest usage during the night (11 pm to 5 am), 2) highest usage in the morning (5 am to 11 am), 3) moderate usage during the midday (11 am to 6 pm), and 4) high evening usage (6 pm to 11 pm) (Mayer, 1999). Figure 2 depicts a daily pattern for the 12 sites included in the REUW study.

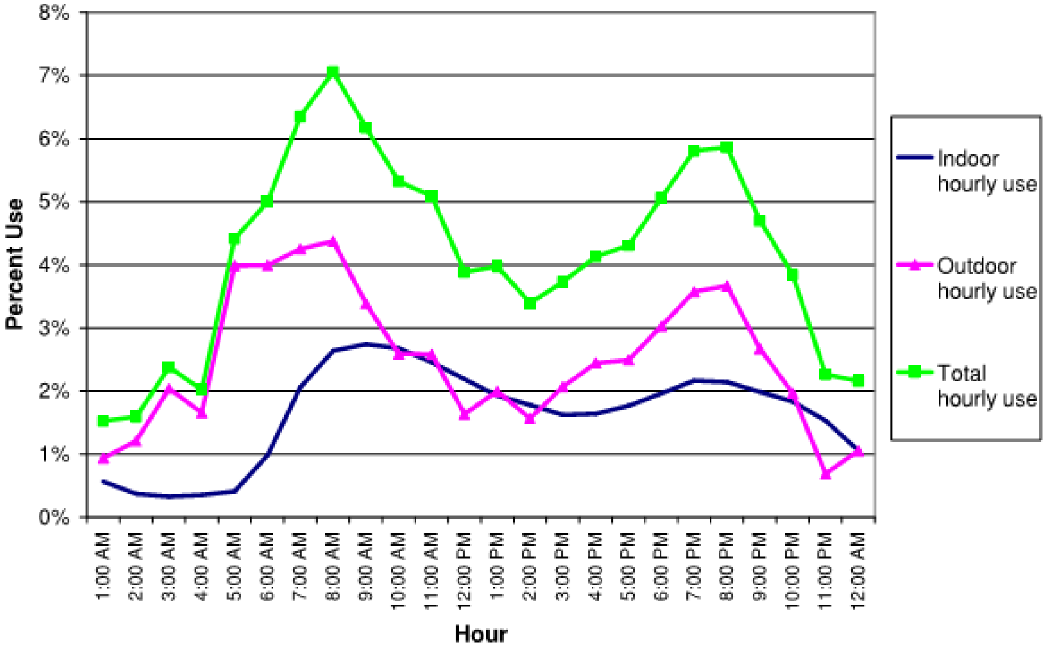


Figure 2 – Hourly Use Patterns, 12 Sites (Mayer, 1999)

While the REUW study provides indoor, outdoor, and total hourly use rates for the 12 study sites, other publications including the AWWA *Distribution System Requirements for Fire Protection* have also provided water use patterns in a typical city. This daily pattern for the "typical city" is provided in Figure 3. The daily use patterns for California homes for winter and summer are shown in Figure 10, in the Season, Climate, and Location section and daily patterns for days of the week for an urban city in Spain is provided in Figure 5 of the Day of the Week section.

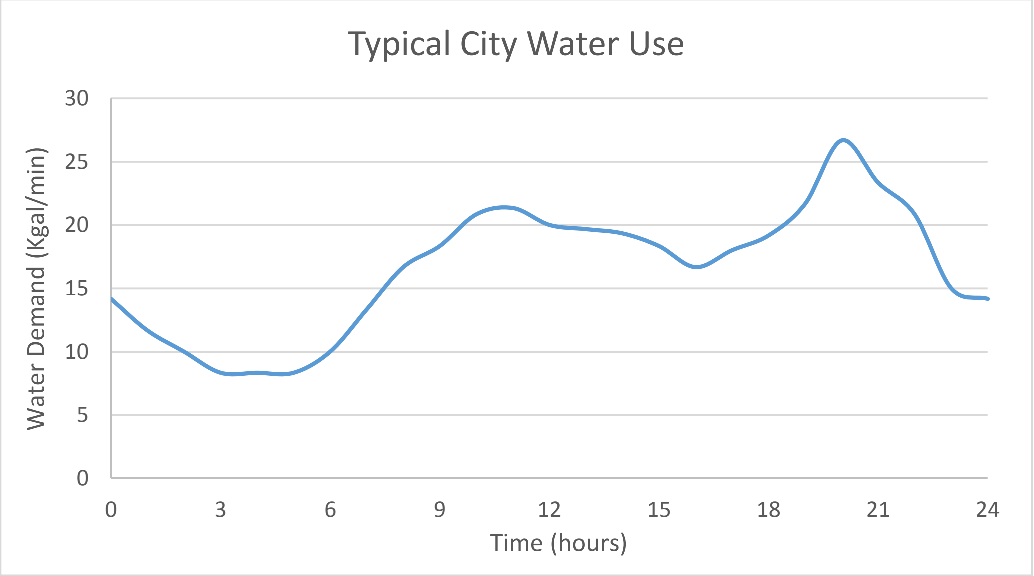


Figure 3 – Typical City Water Use (AWWA, 2008)

The demands for industrial, commercial and institutional users vary; however, similar profiles could be established based on the functions of the facilities. General retail had low indoor usage in the mornings and at night with peak usage in the late afternoon. Stores with irrigation systems, had peaks at night when these irrigation systems were being used. Hotels and motels had their peak demand during the morning between 7am and 8am with high use throughout the day and low usage at night. Office buildings had an indoor peak between 10am and 11am and a second smaller peak mid-morning. Office outdoor use was also high at night due to the presence of irrigation systems (Funk & DeOreo, 2011). Figure 4 is from Study 3: End-use Water Demand Profiles and the x-axis is the time of day in hours.

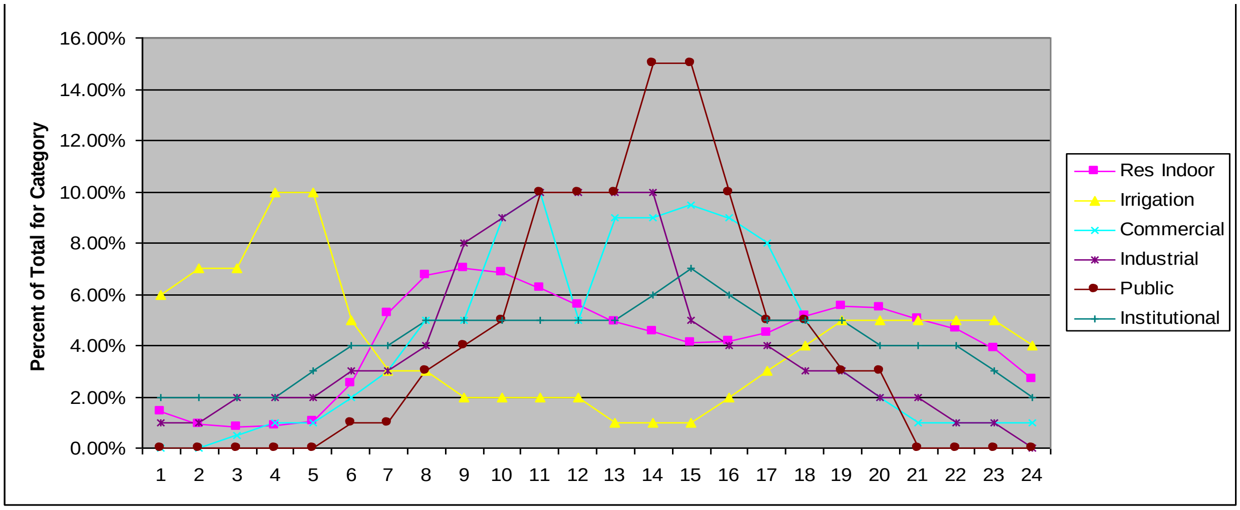


Figure 4 – Treated Water Demand Profiles (Funk & DeOreo, 2011)

From the data shown in Figure 4, generalizations can be made about water demands. Irrigation usage is the greatest during early morning hours. Commercial and industrial users may have continuous uses throughout the night and day, but their high demands not associated with irrigation occur during daylight hours. Residential users have peak demands during the morning and evening with high use during the day and the lowest usage at night. All of the daily patterns follow similar trends based on the water users, but they have slightly different peaks and the entire curve can be shifted up, down, left, or right depending on the composition of the community.

3.2.1.2. Day of the Week

Water use varies depending on the day of the week. In residential areas, midday water usage is less during the typical work week (Monday through Friday) than on weekends. In commercial areas, midday water usage on the weekend is significantly lower than the work week. These variations are typically due to normal working habits of the water users.

Figure 5 and Figure 6 show the mean and maximum water demand based on the days of the week. The data used to create these graphs was from a city in south-eastern Spain collected from January 2005 through April 2005 on an hourly basis. As you can see from these graphs, usage generally follows a similar pattern throughout the day, with the exception of the weekends. While they follow similar patterns, there are differences between weekends and the work week (Herrera, Torgo, Izquierdo, & Perez-Garcia, 2010).

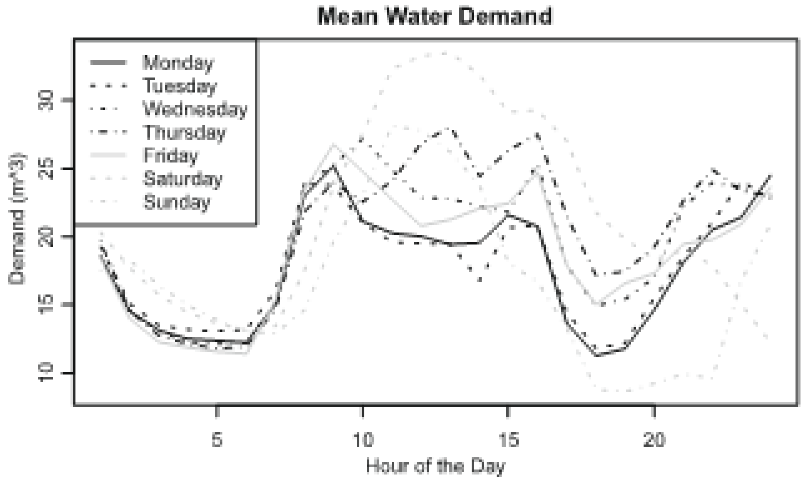


Figure 5 – Mean Water Demand Profile Based on Day of the Week (Herrera, Torgo, Izquierdo, & Perez-Garcia, 2010)

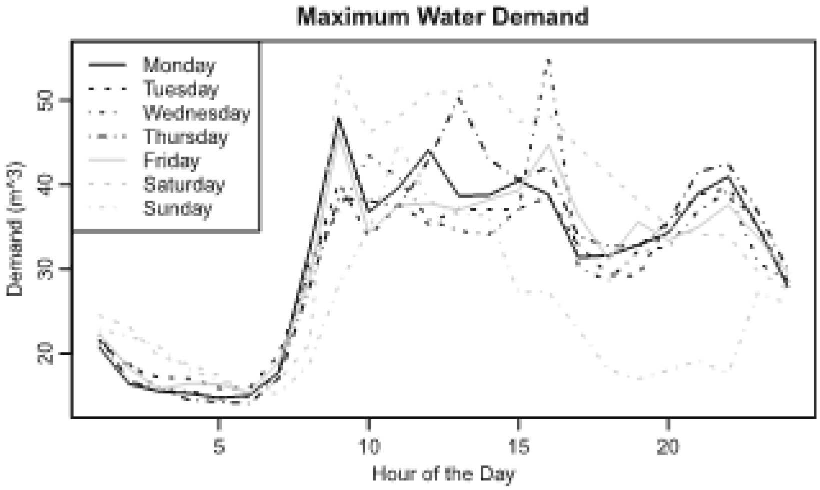


Figure 6 – Maximum Water Demand Profile Based on Day of the Week (Herrera, Torgo, Izquierdo, & Perez-Garcia, 2010)

3.2.1.3. Season, Climate, and Location

Season, climate, and location have been grouped together due to the fact that they are interrelated. Residential indoor water usage does not appear to vary significantly between seasons. Several reports estimate outdoor water usage compared to the indoor water use by subtracting the average winter demands (AWD) from the summer water demands. While these demands are typically the same for most areas, it is not the case for all areas. Figure 7 provides the monthly water demands for the City of Dacono, Colorado (Aquacraft, Inc., 2003).

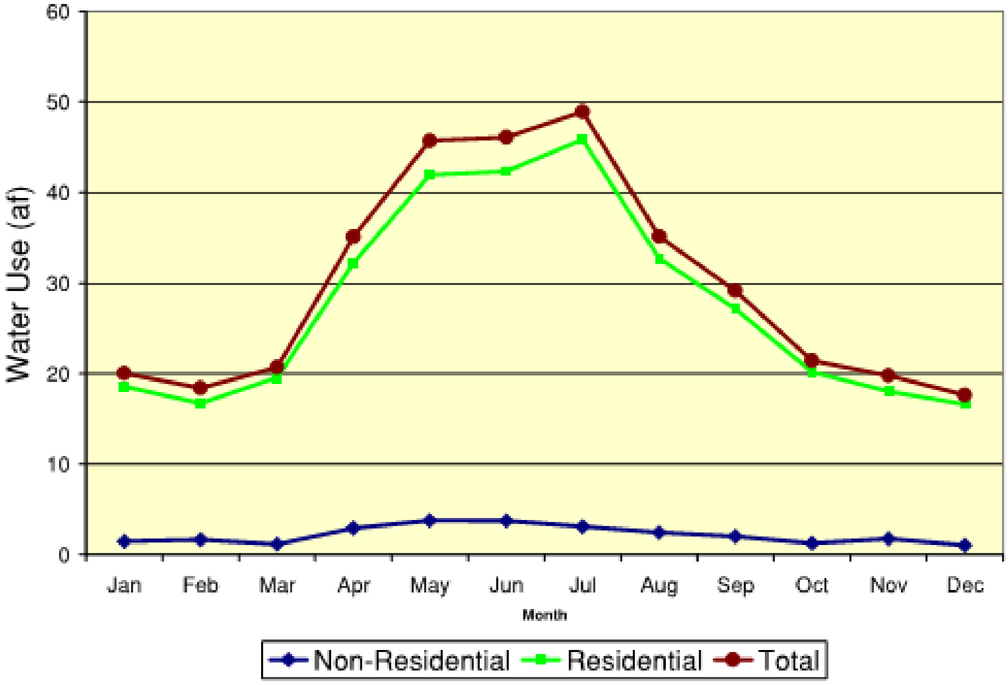


Figure 7 – Monthly Water Demands by Customer Category, City of Dacono (Aquacraft, Inc., 2003)

Figure 8 provides the seasonal demands used in a case study of a community located on the south coast of Newfoundland east of Channel-Port aux Basques labeled “Community C”. The community is primarily residential; however, the average per capita water use during the winter was approximately four times higher than would be predicted based on the demographics. A fish plant operates in the community, for 10 – 15 weeks a year, but the spikes in water usage were not related to the fish plant operation (occurring at different times). When trying to determine the reason for the spikes during the winter months, it was discovered that many of the residents open their faucets at night to prevent the pipes from freezing. The monthly water demand shown in Figure 8 is assumed to be an example of users running their faucet to prevent their pipes from freezing (CBCL Limited, 2011).

Other studies including the REUW report suggest that indoor use remained fairly constant throughout the year. The data in Table 1 (Table 5.14 of the REUW report), was extrapolated from indoor logged use and historic billing data versus using the AWD method. Additionally, indoor annual usage rates identified in Table 1 show that the mean usage in the sample sites was fairly consistent between the different areas with a low of 55.3 kgal/home and a high of 71.2 kgal/home. The data shows larger variation in outdoor annual usage ranging from 7.8 kgal/home to 213.2 kgal/home **(Mayer, 1999)**.

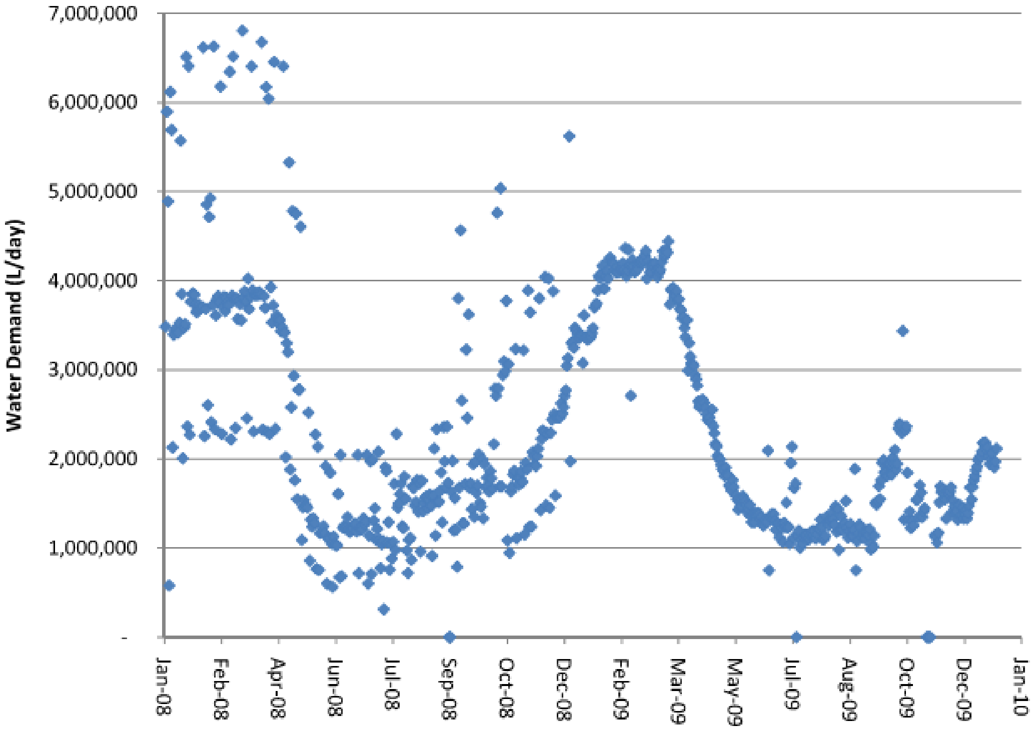


Figure 8 – Water Use Measured at the Outlet of the Treatment System in Community C (2008 and 2009) (CBCL Limited, 2011)

Seasonal migration of residents is also a factor of location and climate. Certain parts of the country that stay warm throughout the year have an influx of residents (often referred to as snowbirds) who migrate there from their primary residence in other locations of the country where it gets cold in the winter. This creates a higher demand during winter months as compared to summer months in these communities.

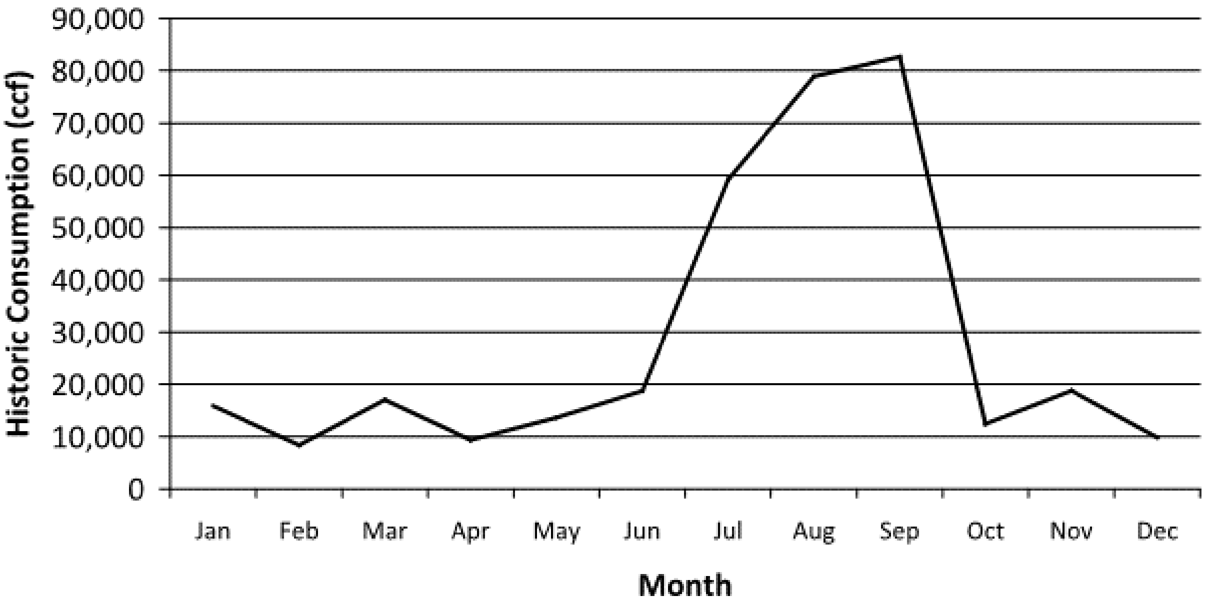
Non-residential indoor water usage during the year can fluctuate based on seasonal agriculture and manufacturing processes. Figure 9 shows monthly water demands for a fruit processing facility. The high water demands towards the end of the summer are a result of additional water being used to wash the produce (Funk & DeOreo, 2011).

Table 1 – Annual Indoor, Outdoor, and Total Use for the Logging Samples (Mayer, 1999)

Study Site	Sample Size	Outdoor Annual Use (kgal/home)	Indoor Annual Use (kgal/home)	Total Annual Use (kgal/home)
Waterloo	37	7.8	67.7	75.5
Cambridge	58	7.8	71.2	79.0
Tampa	99	90.5	56.1	86.6
Lompoc	100	43.5	62.1	105.6
Seattle	99	21.7	54.1	75.8
Eugene	98	48.8	65.1	113.9

Denver	99	104.7	61.9	166.6
Walnut Valley WD	99	114.8	76.3	191.1
Boulder	100	73.6	54.4	128.0
Tempe	40	100.3	65.2	165.5
LasVirgenes MWD	100	213.2	70.9	284.1
Scottsdale	59	156.5	60.1	216.6
Phoenix	100	161.9	70.8	232.7
San Diego	100	99.3	55.3	154.6

Note: Uses extrapolated indoor logged use and historic billing data to estimate outdoor demand: outdoor use = annual use – extrapolated indoor use measured from logging periods.



Note: CCF = centum cubic feet. (1 CCF = 748 gallons)

Figure 9 – Historic Monthly Water Demand – Agricultural Processors (Funk & DeOreo, 2011)

Outdoor water usage can be a significant portion of total demand. The REUW study indicated that in general, the demand expressed in units of gallon per capita per day (gpcd) is more for outdoor usage than indoor usage for residential demands (Mayer, 1999). The CSFWUES also indicated that 47% of water use per house is for indoor use with the remaining 53% for outdoor usage (DeOreo, et al., 2011). Therefore, outdoor usage and how season, climate and location affect this usage are important.

Irrigation is the largest usage of outdoor water for most water users. This use; however, changes with the season depending on the climate. In areas of the country where the temperature stays constant, irrigation is a year round occurrence. In areas of the country where the seasons change, the use of water for irrigation is greater in the warmer months and much lower in the winter months. Some jurisdictions, such as Lee County in Southwest Florida, have year round watering restriction. This county has approved irrigation days and times based on the address. Additionally, there are times when irrigation is prohibited (Water Restrictions, 2015). Figure 10 shows the difference between winter and summer demands in the CSFWUES.

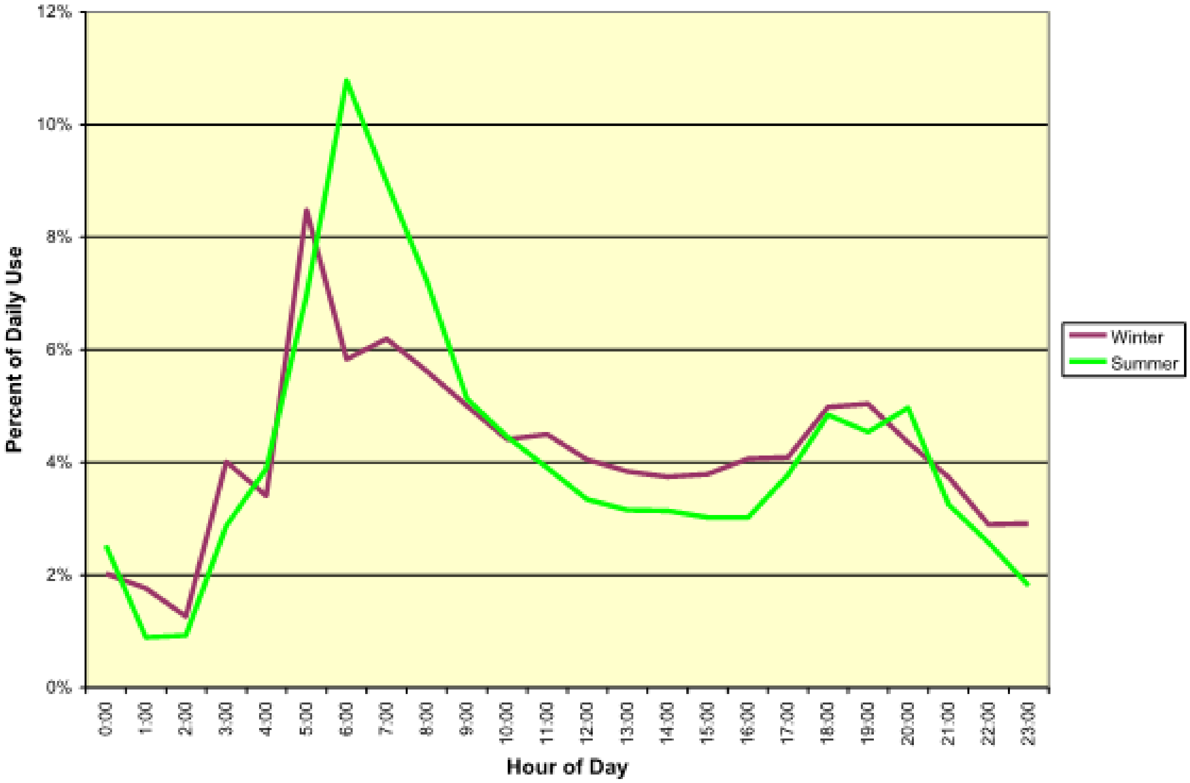


Figure 10 – Daily Use Patterns for Total Household Use, Winter and Summer (DeOreo, et al., 2011)

The location of the water users also plays an important role in water use. In cities, where there is little green space, outdoor water use for irrigation is much less compared to suburban areas.

The location and climate also impact how water is used outdoors. In Scottsdale, Arizona, more than 50% of the survey respondents in the REUW study reported having a swimming pool. In Denver, Colorado, this number was less than 10% (Mayer, 1999). While this is not the only difference between these two cities, when comparing the outdoor annual water use between these two cities, as shown in

Table 1, a 50% higher outdoor annual use is observed in Scottsdale versus Denver.

3.2.1.4. Weather

Weather has been shown to significantly impact water demand for outdoor water usage. Forecast modeling has studied water demands compared to temperature, rainfall, 2 mm of rainfall (a commonly used factor), evapotranspiration, sunshine hours, humidity, as well as other weather factors (Donkor, Mazzuchi, Soyer, & Roberson, 2014). These studies have indicated that daily rainfall has both a dynamic and state-dependent effect on water use. The dynamic effects suggest that the occurrence of a rainfall causes a temporary reduction in seasonal water usage that could last from one to two weeks. The state dependent property of rainfall effect has two important implications: (1) people respond more to its occurrence than to its amount; in other words, the effect is more psychological than physical (at least in the short run), and (2) rainfall has relatively no effect when water use approaches its base (or indoor) use level, which is either a result of low temperature in the winter or several days of sustained rainfalls (Miaou, 1990). For this reason, several models have a threshold of 2 mm of rain or the occurrence of rain as a determinant.

Temperature impacts water demand by directly factoring into evapotranspiration, the amount of water required to maximize growth of turf grass, or by increasing the amount of energy required to cool buildings, which directly impacts water requirements for cooling towers. The higher the temperature, the higher the water demand.

Water use data from Ottawa West Center (OWC), Canada in 2002 indicated that a typical winter day (September to April) had a water demand of 5.63 Mgal/day (21.3 ML/day), a typical low summer day (rain day) had a water demand of 6.55 Mgal/day (24.8 ML/day), and an average summer (May to August) day had a water demand of 8.56 Mgal/day (32.4 ML/day), with a peak daily summer water demand of 28.9 Mgal/day (109.3 ML/day) (Adamowski, 2008).

Several studies have concluded that forecasting peak summer demands is difficult due to outdoor water usage being a major component of water demands, which depend on the duration and intensity of rainfall as well as temperature. Additionally, since this is related to climate, its influence may be different in various climates (Gutzler & Nims, 2005) (Adamowski, 2008).

3.2.1.5. Growth vs Recession

The changing dynamics of the community impact the reliability of the water flow data when considering the life of the system. The Commercial and Institutional End Uses of Water (CIEUW) report indicates growth or recession of industry as a factor that determines the current and future water demands for the area. Rapid development in areas without similar improvements in the water supply infrastructure can significantly decrease the available pressure while a recession can reduce demands and increase the available pressure. The growth or recession of an area is as important for industrial as for commercial and residential. For new developments, the availability of the water prior to the building being occupied can significantly alter the available pressure compared to when the buildings are occupied and using water. For industrial areas that produce goods, during a recession, the need for water to assist with production will likely be reduced. During periods of growth, or new industry settling in the area, constant demands could increase, reducing the available water (Dziegielewski, 2000).

Gutzler et al. state that while it should be obvious, it shouldn't be surprising that population growth is the single largest factor in determining long term trends of total water demands (Gutzler & Nims, 2005). Figure 11 supports this claim until conservation started around 1995.

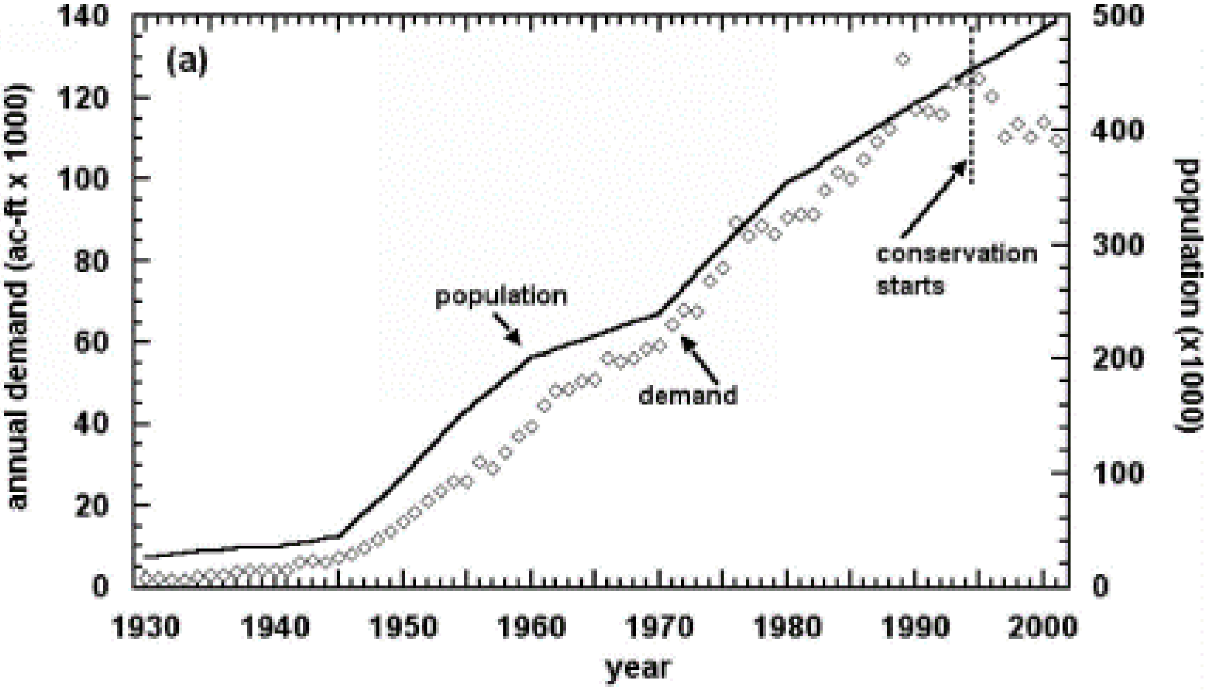


Figure 11 – Total Annual Water Demand and Population for Albuquerque, NM (Gutzler & Nims, 2005)

3.2.1.6. Socioeconomic

Research has studied the effects on household income on water use. Data gathered during Study 3 indicates that while the demand peaks are slightly different (one hour later for low income), the indoor usage rates are comparable between the two groups. The outdoor usage rates between the two groups varied significantly. The studies showed that outdoor annual usage of water in single family homes was approximately 93.9 kgal versus an average outdoor annual usage of water in low income single family homes of 85.5 kgal. The demand profiles were also different with single family homes having the peak outdoor demand between 7am and 8am with a minor peak between 7pm and 8pm versus low incoming single family homes having two equally large peaks in the morning between 6am and 7am and at night between 7pm and 8pm (Funk & DeOreo, 2011).

In Austin, Texas, the data acquired from hourly monitoring of single family homes was divided into three groups. Figure 12 depicts the daily pattern for these three areas. The first group in an areas of middle to high housing values with automatic lawn sprinkler systems showed an increase in water demand between 4am and 8am. The second group, a similar neighborhood without automatic lawn sprinkler systems had a peak daily use between 7pm and 10pm. The third group in an area of low to middle housing values, the daily curve was comparatively flatter, indicating irrigation was not a common practice (Rhoades, 1995).

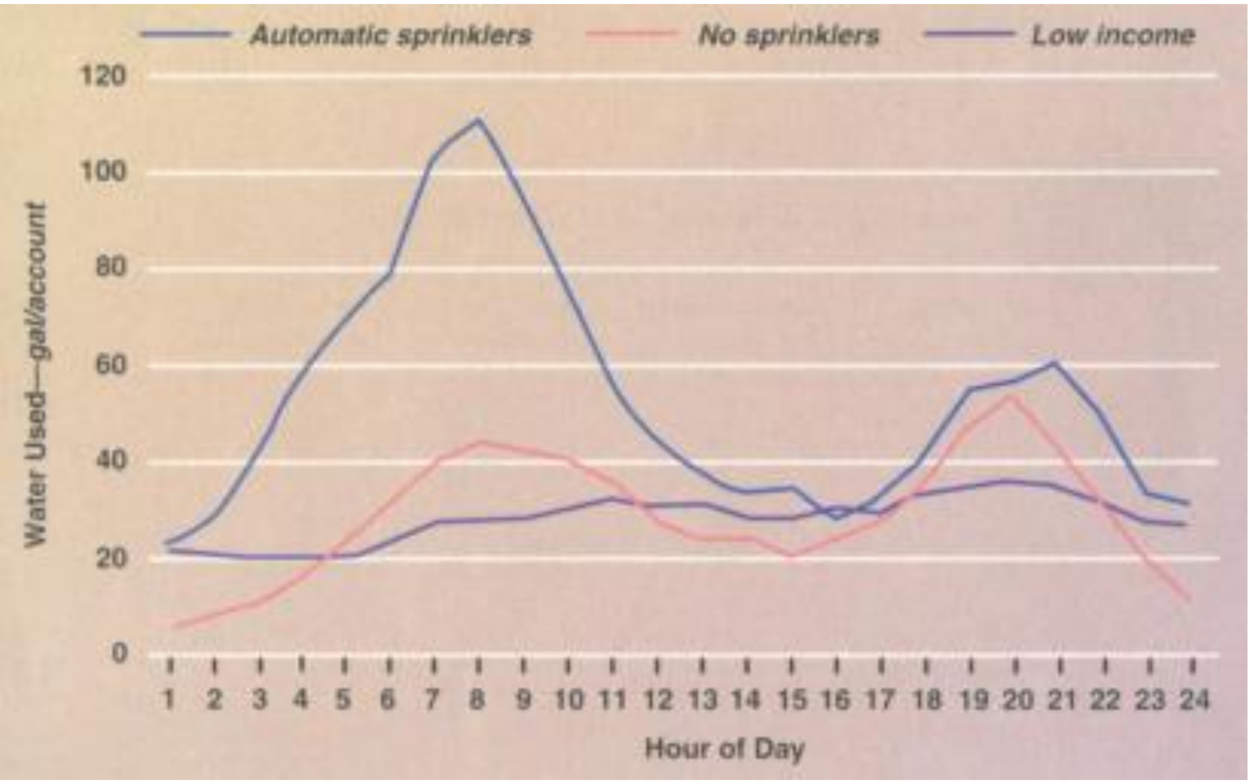


Figure 12 – Patterns of Water Consumption in Three Residential Areas, Summer 1992 (Rhoades, 1995)

Other socioeconomic variables including the price of water, income, and housing characteristics (lot size, house size, appliance ownership, and number of people living in the house) have been used as determinants in different models to forecast water demands. The research has suggested that these factors also impose long-term changes on water use patterns (Miaou, 1990).

3.2.1.7. Leakage

Studies have found that leakage rates within single family homes and for water distribution systems have an impact on total demand. Leakage affects how average daily demand or maximum daily demand is calculated. Only calculating daily use or maximum daily demand based on meter readings does not capture leakage or use through non-metered connections. Metering the output of water treatment facilities will include the losses from system leakage and non-metered use. A factor that is common both in leaks for end users and water producers is that the size of the system contributes to leaks. The larger the system the more connections available for leakage.

Municipal water use in Canada suggested that the average losses due to leaks in the systems evaluated was approximately 12.8 percent of the total amount of water used (Environment Canada, 2010). Reliability studies in Georgetown Charter Township, City of Dacono, and City of Belding calculated water losses of approximately 2 to 6 percent, 6.6 percent, and 3 percent respectively (Prein & Newhof, 2012) (Aquacraft, Inc., 2003) (Fleis and Vandenbrink Engineering, Inc., 2007). Losses through distribution pipes can also increase seasonally as water purveyors flow water through pipes at night to prevent freezing.

The CSFWUES calculated an average leakage rate of 30.8 gphd or approximately 17.5 percent of indoor uses (DeOreo, et al., 2011). REUW calculated leakage rates of 13.7 percent and Study 3 calculated 17.3 for single family and 13.6 percent for low-income single family indoor water use (Mayer, 1999) (Funk & DeOreo, 2011). These figures indicate that leakage creates a measurable demand on water supply systems and shift the demand patterns up.

3.2.2. Water Distribution System

Water distribution systems play a vital role in ensuring the availability of water. The majority of the cost of providing water to users is in the cost related to the infrastructure used to deliver the water. Installing, maintaining, and repairing the system not only represents a significant cost, but also plays an important role in the ability of the water supply system to provide adequate supply during periods of increased demands.

The following are several key aspects of water distribution systems in terms of being able to deliver adequate water during peak demands. The following system aspects have been identified as impacting water availability:

- Type of Pipe
- Water Supply Infrastructure
- Maintenance
- Water Distribution System Operations
- Tanks
- Booster Pumps
- Well Pumps
- Pressure Regulating Valves
- Cost Savings
- Interconnections
- Operating Pressure
- Fluctuations
- Manual Operations

3.2.2.1. Type of Pipe

The type of pipe, age, and corrosiveness of the water all play important factors into the hydraulic properties of pipe. Older water systems will have unlined cast iron pipe or even bored out trees supplying portions of the water distribution system. As unlined cast-iron pipe ages in a corrosive water supply, the coefficient of friction used in Hazen-Williams hydraulic calculations change. Other characteristics of pipe may change including the internal diameter due to accumulation on the interior pipe walls or tuberculation which can restrict the flow of water through the pipe. However, since these characteristics change throughout the system, they are generally accounted for in hydraulic models by adjusting the internal pipe diameter or coefficient of friction (C-Factor) or both (Engineering Computer Application Committee, 1999).

FM Global Data Sheet 3-0, Table 2 indicates that C factors vary based on the age of the pipe and the corrosiveness of the water. For example, this could range from a C=120 for new to a C=40 for 50 year old pipe with severe water corrosiveness (FM Global, 2010). Decreases in the coefficient of friction used in the Hazen-Williams calculations increase the friction loss associated with flow through that section of pipe. An increase in the friction loss through the pipe will decrease the observed pressure at the point of discharge.

3.2.2.2. Water Supply Infrastructure

As previously mentioned, the water supply infrastructure plays a large role in the availability of water. Increasing the redundancy of a system by providing multiple loops or supplies to a single area increase the reliability and reduces single points of failure. Modifications to the water supply infrastructure can both enhance the water supply in an area and reduce the available water in another area.

A prime example of this tradeoff is where a development is located either at the end of a dead end main or when it is supplied through only one connection. In order to increase the reliability of the service in that area, the water purveyor plans on connecting that development into another community that is already supplied by multiple connections. Once that new connection is made into the development, the dead end main will most likely have an increase in pressure since it will now be supplied from two sources. The area that now connects to the previously single supplied area may see a reduction in water pressure due to additional demand to supply the new connection. However, while this is typically the result, there are many factors that can affect these outcomes.

3.2.2.3. Maintenance

Maintenance plays an important part is system reliability. Many systems have aging infrastructures that are at or approaching their life expectancy. Additionally, water main breaks in many systems result in the highest daily demands for the year. Preventive maintenance can reduce the number of catastrophic events such as water main breaks that can impact system demands. While this preventive maintenance is necessary, the maintenance can also be a temporary cause of reduced water availability.

Maintenance of water supply systems includes: installing and repairing sections of pipe; installing and servicing pumps; repairing and inspecting tanks; as well as maintenance of a water treatment plant. This maintenance can involve the isolating of sections of the system in the case of repair or installation, or could include flowing large amounts of water for flushing operations. Most maintenance can go unnoticed where redundant systems are in place; however, as previously stated, these operations can temporarily reduce the availability of water for portions of the system.

To increase system reliability, some hydraulic models used by water purveyors can predict or recommend sections of pipe for replacement. The use of these models can increase system reliability by reducing the frequency of high daily demands caused by system failures.

3.2.3. Water Distribution System Operations

Water distribution system operations can vary significantly between different water purveyors. Some of the key components to the water distribution system that impact water availability are how often and when the tanks are filled and the number of pumps in the system.

3.2.3.1. Tanks

Many systems use a combination of pumps and elevated water storage tanks to maintain pressure throughout the system. Elevated water storage tanks (gravity systems) provide pressure through the difference in elevation between the water user and the water level in the tank. As water is used throughout the day, the level in the tank reduces resulting in a lower observed output pressure. Tanks do not cycle from completely full to completely empty, rather the water level routinely cycles between a defined low elevation and a defined high elevation level for each tank. The frequency of tank refilling depends on the amount of water drawn from the tank, whether the tank is automatically filled or manually filled and consumption rates. Depending on the demands, this could be several times a day, or only a couple times a week. Water flow tests performed when the tank is full will not reflect the water distribution system capabilities when the tank is nearly empty.

3.2.3.2. Booster Pumps

Pumps are commonly used to maintain pressure within a system. Many systems have the ability to add or reduce the number of pumps operating on the system at any time. This can be done automatically through supervised control and data acquisition (SCADA) systems that continuously, remotely measure system pressures at different locations in the system, or it can be done manually at the water pumping stations. Some systems use variable frequency drive pumps that can throttle the output pressures depending on the desired system pressure. These types of pumps are used to maintain consistent pressures throughout the system. The number, size, on/off settings, and distribution of pumps is unique for each system.

3.2.3.3. Well Pumps

Well pumps provide water for many distribution systems. Depending on how the system is configured, well pumps can discharge into a water storage tank or directly into the distribution system. During high demands, additional wells can be placed online to handle the increased demands and maintain supply if available. Similar to booster pumps, many systems have automatic settings for turning on and off well pumps to meet demands.

3.2.3.4. Pressure Regulating Valves (PRVs)

Pressure regulating valves are used in many water distribution systems between high pressure zones and low pressure zones. These valves help to maintain constant supply pressure to the low pressure zones over a range of system demands. The valves can be adjusted to increase or decrease the pressure to the low pressure zone as needed.

3.2.3.5. Cost Savings

Currently with the high prices of electricity, water purveyors are trying to cut costs where possible. Several areas where cost savings have been identified are reducing energy costs associated with providing water to consumers and by reducing demands overall and during peak energy use times.

Some areas provide incentives to reduce the overall use of water with low flow fixtures and toilets. These fixtures reduce the overall demand by reducing the amount of water used for daily actives including flushing toilets, showers, laundry, and faucets. This reduction in typical water demands is generally associated with new construction; however, new products are increasingly becoming low flow.

The reduction in energy use by water purveyors results in performing as many energy demanding tasks when energy costs/demands are lowest which is typically late at night. This energy savings results in many purveyors filling elevated water storage tanks at night. This results in higher water tank elevations early in the morning and lower water tank elevations towards the end of the day for systems that only fill up daily. In some instances, this is also a function of reduced demand at night.

In areas where water purveyors need to heat water in water storage tanks, in order to reduce costs, many purveyors do not keep their water storage tanks as full as they do during warmer months to reduce the heating costs for larger volumes of water.

3.2.3.6. Interconnections

Some water distribution systems are interconnected with adjacent water distribution systems. While these connections may not always be open, they serve as options to increase available water during high demands or emergencies. These interconnections typically require manual actions to open, but are still a means to support additional demands.

3.2.3.7. Operating Pressure

The system operating pressure depends on pump output pressures, elevation changes throughout the area of distribution, elevated storage tank levels, diameters on distribution lines and other factors. Many purveyors have operating pressure ranges that they try to maintain during normal and peak demands. These normal operating pressures differ from one system to another. Table 2 provides several water pressure ranges for distribution systems reported in the REUW report. Table 3 provides responses to surveys sent to water utilities as part of the Task 1 literature search. Since these pressures were reported during surveys to the water purveyors, it is assumed that these ranges are the pressures observed at the customer’s meters; however, based on the high pressures reported, this may not be the case for all the pressures reported. A compiled list of questionnaire responses is included in Appendix A.

Table 2 – Water Pressure Ranges in Distribution Systems (REUW) (Mayer, 1999)

Utility/Provider	What are the range of pressures in your water distribution system?
Boulder, Colorado	80 – 160 PSI
Cambridge, Ontario	20 – 100 PSI
Waterloo, Ontario	20 – 100 PSI
Denver, Colorado	40 – 110 PSI
Eugene, Oregon	40 – 80 PSI
Las Virgenes MWD, California	30 – 500 PSI
Lompoc, California	85 – 120 PSI
Phoenix, Arizona	60 – 120 PSI
Municipal Region of Waterloo	50 – 70 PSI
San Diego, California	40 – 85 PSI
Scottsdale, Arizona	40 – 120 PSI
Seattle, Washington	40 – 80 PSI
Tampa, Florida	20 – 65 PSI
Tempe, Arizona	50 – 90 PSI
Walnut Valley WD, California	40 – 180 PSI

Table 3 – Water Pressure Ranges in Distribution Systems (Surveys)

Utility/Provider	What are the range of pressures in your water distribution system?
Rochester, New York	35 – 135 PSI
Springfield, Ohio	50 – 105 PSI
Richmond, Virginia	35 – 110 PSI
Raleigh, North Carolina	55 – 85 PSI
Marysville, Washington	20 – 110 PSI
Modesto, California	50 – 60 PSI
Lubbock, Texas	40 – 80 PSI
Omaha, Nebraska	40 – 160 PSI
Edmond, Oklahoma	50 – 70 PSI
Fairfax, Virginia	40 – 80 PSI

Lawrence, Kansas	40 – 135 PSI

3.2.3.8. Fluctuations

Many different factors have been discussed that cause fluctuations in water pressure. These fluctuations can occur daily, weekly, monthly, or seasonally depending on the particular uses of the communities. What is considered to be the normal fluctuation for a water supply system depends on what is acceptable to the water purveyor. When contacted, several purveyors indicated that they maintain the same system pressure throughout the day and throughout the year while varying the amount of water supplied. Other water purveyors indicated that they have a typical fluctuation throughout the day. The amount of fluctuations allowed within a system depends on the thresholds setup by the water purveyor for systems that are controlled automatically, and by the operator or procedures for systems that are manually controlled or monitored.

3.2.3.9. Manual Operations

One of the biggest variables in terms of water distribution system operations is when and how manual operations are performed. Some systems have set pressures that turn additional pumps on to maintain system pressure while others rely on operators to constantly monitor output pressure. Some systems have dedicated pumps that are used to boost pressures during a fire incident and are manually activated. Modeling or predicting available pressures on systems with manual operations are difficult due to the fact that these manual operations have to be input as automatic outputs. While in most cases, they will be performed, it is not an absolute when it has to be done manually, and the point at which the operator initiates the action is not always the same. For these reasons, some manual systems may not perform consistently under similar circumstances.

3.3. Water Supply Estimates

There are several methods to estimate water supplies. Water demand estimates performed by water purveyors focus on the amount of water used. These types of estimates attempt to predict future demands for a given period of time. This can be based on peak hourly demand over the course of a day or future demands in 30 years. These water demand models contrast with hydraulic models used by water purveyors that provide both pressure and flow estimates of the current or proposed water supply distribution system. These models can be used with demand models to create scenarios for future demands.

The following section provides information on the different types of models used to estimate water supplies.

3.3.1. Simple Calculations

Many system demand calculations do not require sophisticated modeling software to complete. The average daily demand, maximum daily demand, and peak hourly demands can all be calculated with basic arithmetic. Information that is used in the models such as per capita demands or household demands in many instances needs to be calculated first before it can be input into sophisticated computer models.

Average daily demands (ADD), maximum daily demands (MDD), per capita demands, and peak hourly demands (PHD) are the commonly used terms when comparing demands between users and water supplies. Other terms are used, but they are generally specific for the comparison and include gallons per employee daily (GED) or gallons per bed. These have specifically been used when comparing subsectors for commercial, institutional, and industrial users.

The average daily demands may also be referred to as average daily consumption (ADC), which is the total amount of water used per year divided by the number of days. This represents what the anticipated demand should be on any given day. Depending on the data available, this could be the total consumption for the year divided by the number of days, or many days averaged (Hickey, 2008).

The maximum daily demand is the peak day demand on a system for a given timeframe, usually over three years. This demand is usually calculated from usage data from the water purveyor. This represents the maximum anticipated daily demands on the system, which is typically associated with hot/dry days. This data should also exclude abnormal uses such as large fires or water main breaks (Hickey, 2008).

The peak hourly demand is the demand during the peak time of the day for a given timeframe, usually over three days (Hickey, 2008).

The previously mentioned demands should be calculated using historical data or metered water usage, but correlations are available that can relate average daily demands to per capita demands and vice versa. While these correlations are available, they are not recommended unless they are necessary due to the tendency of the correlations to under or overestimate total water use (CBCL Limited, 2011). Peaking factors are the ratio of the maximum flow over the average flow for a given timeframe. They are also available when historical data is not available, but they encounter the same problems of not being reliable. Peaking factors are dependent on the number of users. Barrufet found that peaking factors increase from a constant 1.5 for more than 100,000 consumers to as much as 98 for a two person apartment (Barrufet, 1985). This is consistent with the concept that as more consumers use water, their different use patterns flatten curves and reduce peaks.

3.3.2. Complex Models

Complex models are models that due to the number of nodes, parameters used, and the number of iterations performed require the use of a computer to complete in a timely manner. These computer models used by water purveyors can be divided into two categories, water demand forecasting models and hydraulic models.

3.3.3. Water Demand Forecasting Models

A large amount of research has been performed in water demand forecasting modeling. This is a function of water purveyors trying to ensure their water distribution system can handle the demands of its customers now and in the future.

Forecast modeling used by water utilities can be divided among three goals: operational, tactical, and strategic (Donkor, Mazzuchi, Soyer, & Roberson, 2014). With these different goals, different forecast horizons are used in the models. Operational forecasting is concerned with system operation management and optimization. These goals are short term and the forecast periodicity is usually hourly, daily, weekly, or monthly. Tactical goals focus on revenue forecasting, investment planning, and staging system improvements. These goals are generally classified as medium term with a forecast horizon typically between 1 and 10 years. Models that are used for tactical goals have forecast periodicity of monthly or annual demands. Strategic goals deal with capacity expansion. These are long term goals with horizons of more than 10 years. Models associated with strategic goals usually tend to have annual forecast periodicity (Donkor, Mazzuchi, Soyer, & Roberson, 2014).

In 2014, a review of selected journal papers from 2000 to 2010 on water demand forecasting models evaluated 33 different models that were being utilized (Donkor, Mazzuchi, Soyer, & Roberson, 2014). The high number of models represents the different parameters, variables, and algorithms used to predict future demands. Some of the determinants used in the models include time, seasonal dummies, derivatives of weather, price, population density, building size, lot size, household size, income, price, temp rain, drought dummies, per capita demand, max temperature, 2 mm rainfall, evapotranspiration, temperature dummy, employment, inventory cost, industrial value, residents, bedrooms, appliance ownership, water demand of previous days, total rainfall, sunshine hours, peak demand for previous week, and day of week (Donkor, Mazzuchi, Soyer, & Roberson, 2014).

Based upon the number of horizons, forecasting periods, determinants, and model type/algorithm, a single all-encompassing water forecasting is not available. Instead, different models are more suited for different types of horizons and forecasting periods. For this reason, the forecast variable, its periodicity, and horizon must be determined first before choosing the appropriate model. However, even with all this research, water forecasting is difficult, models can be extremely complicated, and the determinants used in the models can be hard to collect and track (Goodchild, 2003).

Since one of the easier determinants to track for a water purveyor is per capita water demands, a simplistic model is often utilized for predicting water demands. Billings and Jones surveyed utilities and found that approximately 65% spent resources in forecasting per capita water demands (Billings & Jones, 2008). This is consistent with the City of Belding, Michigan Water System Reliability Study, the Georgetown Charter Township, Michigan Water System Reliability Study, the City of Dacono Water Supply Study and others that have used per capita demands along with forecasted population growth to predict future demands (Fleis and Vandenbrink Engineering, Inc., 2007) (Prein & Newhof, 2012) (Aquacraft, Inc., 2003).

3.3.4. Water Distribution System Models

Water distribution system models use computers to predict the performance of the system to solve a wide variety of design, operation, and water quality problems (AWWA, 2012). These models can predict the pressure and flows at various locations within the system. Depending on the software used and the level of detail input into the model, they can change water tank levels, turn off and on pumps, and close valves.

Mathematical equations are used to determine pressure and flow at certain points within the system for simple layouts; however, the complexity of current water distribution systems becomes too burdensome to accurately calculate manually. Current water distribution systems can be a complex network of supply pipes, tanks, pumps, wells, valves, and users. Starting with FORTRAN based programs in the 1960's, computers were used as a means to track the number of equations and calculate hydraulic demands for complex piping systems (AWWA, 2012).

New modeling software is capable of importing information from other systems including geographic information systems (GIS), computer-aided design and drafting (CADD), supervisory control and data acquisition (SCADA), customer information systems (CIS), computerized maintenance management systems (CMMS), and asset management systems (AMS). This cross over helps reduce the time required to initially set up these models. Input from CIS and SCADA also help to continually provide accurate results of the model based on actual system parameters and use profiles (AWWA, 2012).

Water distribution system models have many benefits including planning, engineering design, system operations, and water quality improvement; however, this report will focus on engineering design. As previously mentioned, water distribution system models are complex hydraulic models. When they are properly set up and calibrated, they can predict pressure and flows at certain nodes. Since many models are calibrated using hydrant flow tests, system hydrants may already be set up as hydraulic nodes. In these instances, some jurisdictions provide design engineers and technicians with modeled hydrant flow data instead of actual flow test results.

Some hydraulic modeling software allows the user to set up different scenarios with different tank levels, number of pumps running, and varying system demands. This could be beneficial when providing modeled hydrant flow data. The models can be set up with low tank levels, below normal number of pumps running, and peak summer demand when calculating the flow test results.

While setting up a water distribution system model can be extremely time consuming, importing information from different systems can help with the creation of the model. Once the model is created and tested to confirm that it runs, it needs to be calibrated to ensure that the outputs provided are consistent with actual results. The AWWA manual on *Computer Modeling of Water Distribution Systems* indicates that there are no established standards for hydraulic calibration (AWWA, 2012). The Engineering Computer Applications Committee of AWWA produced calibration guidelines for water distribution systems modeling, but the guidelines are not intended to establish standards for model calibration.

Hydraulic models created for the City of Belding compared measured flows calculated to a fire flow at 20 psi to the values obtained in the calibrated water model. The water model values predicted within +/-10% accuracy for flows at 20 psi (Fleis and Vandenbrink Engineering, Inc., 2007). Georgetown Charter

Township compared the calibrated model results at the nearest model node to 17 test hydrant sites. Static pressures were within 2 psi at all hydrant test locations, and residual pressures were within 5 psi. Furthermore, all fire flow calculations were +/- 10% (Prein & Newhof, 2012). While these models have pressure variations of 20% (+/-10%), they represent the more calibrated and validated models, with typical models having larger pressure variations. Many models have higher pressure variations due to the size and complexity of the system or the lack in funding to properly calibrate and validate the model.

4. TASK 2 – ANALYSIS OF WATER ESTIMATION METHODS

The second task in this research was to perform an analysis of the different methods available to estimate water supplies identified during the literature search. Two types of water models were found to be used to estimate water supply demands. These two types of models consist of simple calculations and complex calculations that require computers. The complex calculations can be further divided into water forecasting models and water distribution system models. Simple calculations, water forecasting models, and water distribution system models are discussed in this section of the report.

A summary table describing the range of implications for each variable determined in the previous task was intended to be included in this task. Unfortunately, due to the lack of available data on the subject of water supply adjustments, this information is not currently available and the table could not be created at the time of this report.

4.1. Simple Calculations

Simple calculations are available for determining a variety of parameters, such as average daily demands, maximum daily demands, per capita demands, and peak hourly demands. The significance of these simple calculations is limited since they utilize historical data to create averages, maximum (peak) and minimum needs. However, the results can be utilized for determination of water storage needs for both domestic and fire protection. The calculated data can also be used for comparison to historical storage data and periodic averages for projection of future needs.

The results of these simple calculations can be evaluated in conjunction with other estimates such as population increase or decrease to further evaluate future water storage needs based on current consumption data. Since simple calculations are based on trends in historical data, changes in use over time including water conservation practices, changes in the composition of the community, changes in industrial use of water, transition to low flow fixtures and regulations in water use will not be factored in to the projections of future needs. Further evaluation using more complicated means will be necessary to account for these variables. Data averages derived from simple calculations can be utilized for data entry in complex water models discussed in sections 4.2 and 4.3 of this report.

These simple calculation methods provide limited benefit when attempting to characterize water supplies in fire protection models since the calculations yield capacity or flow data without regard to associated pressure requirements as is needed for assessing fire protection systems. Having flow rates without available pressure at specific locations does not provide sufficient information necessary for evaluating water supply capabilities in meeting calculated fire protection demands. Many fire protection models require entry of both pressure and flow data in order to estimate water supply conditions for comparison to calculated fire protection system demands.

4.2. Water Forecasting Models

Water forecasting models are used to estimate water supplies; however, similar to simple calculations, their focus is on water capacity needs and output data does not relate to available flow and pressure. As a result, the benefits and limitations discussed for simple calculation methods also apply to water forecasting models.

The primary benefit of water forecasting modeling is that they utilize a variety of parameters to predict future demands besides historical data. This benefit, in some regards, also has several drawbacks. Development of a single set of parameters for use in comparing predictions through multiple models is not possible. A wide array of models are available, each using different parameters and algorithms to produce similar predictions with varying degrees of accuracy.

There are several key parameters that are needed to provide meaningful predictive data. These parameters include: horizons, forecasting periods, and determinants. Each of these parameters must be specified in a manner associated with the desired output of the model. This requirement leads to facing a complex decision regarding which model is best for the given application. It also suggests that one model will not be accurate for all jurisdictions. For example, in areas where rainfall is the strongest predictor of water usage, utilizing a model that does not include rainfall would not yield the most accurate results. Knowledge of how results will be applied and identification of key parameters to be utilized in each of the models is needed when evaluating if a model should be utilized for a particular application.

4.3. Water Distribution System Models

Water distribution system models are the most applicable to quantifying water flow adjustments for fire protection purposes. When properly created and calibrated, these models can predict pressure and flow conditions at specific points (nodes) within the modeled water distribution system, which is necessary for designing water based fire protection systems.

These models require continuous updating to provide a reliable representation of a water distribution system. There are several limitations associated with using water distribution system models including: 1) not every water purveyor utilizes a water distribution model, 2) the cost to create a model is considerable for large systems and 3) the cost for continually updating the model based on construction can be very high. These weaknesses are usually overcome by the water distribution system already allocating funding to perform these tasks for purposes other than fire protection. Additionally, since modeling is extremely beneficial, the number of water purveyors that utilize water distribution system models is anticipated to increase.

5. TASK 3 – GENERAL RECOMMENDATIONS

The available data on water supplies and especially on variables that can impact water flow did not provide the necessary data to create an all-encompassing equation that could be used to adjust water supply tests performed in the design of fire suppression systems. The data that was available corroborates the concerns that have been present for years, highlighting the fact that the available water fluctuates based on many factors including time of day, day of week, season, climate, location, weather, growth, recession, socioeconomic area, the configuration, age and operation of the water distribution system. Based on the available data, the following recommendations are suggested to improve the accuracy of water flow tests conducted for the purpose of designing fire protection systems:

1. Coordinate With Water Utility Operators
2. Utilize Water Distribution System Models
3. Determine Water Supply Degradation Parameters
4. Standardize Flow Test Procedures
5. Evaluate Case Studies

Each of these suggested improvements will be discussed in the following subsections of this report.

5.1. Coordinate With Water Utility Operators

Water distribution systems are critical components of all water based fire protection systems that are not provided with a dedicated water supply, such as a gravity tank, tank and pump or raw water source and pump. This dependency on water distribution systems is not conveyed within current NFPA code requirements. Changes to water distribution systems can affect the performance capabilities of supplied fire protection systems since these systems are often designed using hydrant flow test data without adjustment for anticipated future changes in water supply consumption, aging of infrastructure or changes to operational practices.

Lowering the output of pumps or increasing demands in areas over time can directly impact systems. In addition to understanding these systematic changes, the water suppliers are the most intimate with the operations of their water distribution system. They can provide information on when their systems experience high demands, tank levels at the time of testing, what pumps are operating and if conditions are reflective of peak demand.

From this knowledge, they should be able to assist on suggesting how much to degrade pressure and flow for average “peak” use conditions based on when and where the test was conducted. The critical component is that the water supplier needs to provide input into the pressure and flow observed during flow tests and what is typically available for the design of fire protection systems.

It is recommended that NFPA and AWWA start a task group to improve communication between the water utility and fire protection communities regarding water supply adjustments. Although, the specific requirements for adjustment may vary on a case by case basis, the most reliable source of information will come from the individuals responsible for designing, maintaining, and operating the water distribution systems. This is becoming increasingly important since codes require the installation of fire protection systems in most structures including single family homes.

5.2. Utilize Water Distribution System Models

Water distribution system models are becoming increasingly prevalent among water purveyors. While not all water purveyors use these types of models, many operators of large water distribution systems do utilize these models for design, operation, and water quality. Many of these models are calibrated through flow tests conducted at fire hydrants which are included in the model as nodes. The fire protection system designer along with the water purveyor could perform an actual flow test and compare the results to a modeled flow test for the specific time and location. The difference between the actual flow test and the modeled flow test would then be the minimum acceptable safety factor for the design. The water purveyor could repeat the modeled flow test for a set of parameters including the low hydraulic gradient, the normal number of pumps operating, and peak demand on the system. This modeled flow data, adjusted by the previously determined safety factor could then be used to design the fire protection system encompassing many of the variables that were identified as affecting the available water. While this would not adjust for all the possible fluctuations, it would include the majority of the variables and would be specific to the water distribution system that is actually supplying the water to the fire suppression system.

5.3. Determine Water Supply Degradation Parameters

The AWWA manual on Distribution System Requirements for Fire Protection indicated the “sprinkler system designer must select a single value as the basis for design from a reasonable worst case condition” (AWWA, 2008). With many systems being supplied by multiple tanks and pumps and redundant mains, a set of conditions should be established by which to degrade water models. Most current hydraulic modeling software have the capability of turning on and off pumps, changing the water level in elevated storage tanks, and closing valves. The designer can provide the design input, but the NFPA committees associated with water based fire protection systems should determine the minimum to which these models should be adjusted. This could be as minimal as having the normal number of pumps operating at the low hydraulic gradient during peak demand conditions or could include reducing the number of operating pumps to a worst case condition. By creating a set of minimum parameters, all water purveyors could adjust their modeled flow for these conditions. It would also create a starting point for AHJs to increase or decrease these minimums based on their specific circumstances.

5.4. Standardize Flow Test Procedures

The procedures for conducting hydrant flow tests identified in NFPA 291 are recommended practices. Consideration should be given to including specific requirements in NFPA 13, NFPA 13R, NFPA 13D

NFPA 24 and other NFPA standards for water based fire protection systems for adopting the procedures of NFPA 291 for conducting hydrant flow tests.

5.5. Create a Pilot Program

These recommendations should be tested with a pilot program to determine how feasible they are for a wider distribution of the requirements. The first potential obstacle is that not all water purveyors use water distribution system modeling. Based on the cost of the software, there is a significant investment required to upgrade to these types of systems. From our questionnaire, approximately 75% of the water purveyors surveyed utilize water distribution system models and based on the advantages of using these models, it is assumed that this number will increase. For jurisdictions without water distribution system models, these recommendations will not be able to be implemented, but for the small percentage, it should not restrict the wider distribution of the recommendations.

Other potential problems could be that the initially set parameters are too conservative. Between having to include the safety factor between the modeled flow and the actual flow on top of the adjusted modeled flow could create a situation where the majority of the test cases required a fire pump even in locations with generally high water pressures. This will have to be discussed and adjusted based on initial findings.

6. CONTINUED RESEARCH

One of the main goals of this research was to attempt to identify an adjustment factor that could be applied to existing water supplies to accommodate for the variances identified within this report. Discussing the history of where this project started, several individuals were interested in the data to suggest a percentage or fixed pressure (psi) safety factor that could be incorporated into the codes immediately, or an adjustment equation that could be applied to all water supplies. For example, these factors would be an adjustment for taking the flow test during the evening when the peak daily demand is in the morning, or taking the flow test on a Wednesday, when the peak flow is on a Thursday. The data; however, cannot support any recommendations to a specific percentage or fixed pressure (psi) adjustment at this time for several reasons.

The data available from research primarily focuses on flow. The main method used to collect this data is to monitor the flow meters of individual residences/buildings or to install flow meters on communities without monitoring pressure. The AWWA also indicated that they do not have data available that associates pressures with flow variations. Until pressure readings are recorded with associated flows, the impact of the varying demands cannot be evaluated for a particular community.

As indicated above, multiple adjustments may be required based on when the flow test was performed. The data shows that time of day, day of week, season, climate, location, weather, growth, recession, socioeconomic area, the configuration, age and operation of the water distribution system may all need to be accounted for separately. To do this, each of the variables would have to be identified and accounted for with data to be able to be used as an input into an adjustment equation.

The data available was not in sufficient quantity nor was it divided into regions that could be used to represent areas as a whole. Climate, season, and location were all identified as having an impact, but not enough data is available to separate different areas based on climate and seasonal data. Research would have to be conducted throughout the United States in varying climates through multiple seasons. Additionally, this data would need to be analyzed to ensure it is comparable to other regions with similar climates and seasons.

For these reasons, included in the recommendations is to start a task group with AWWA and NFPA. It is recommended that one of the objectives for this task group should be to consider additional research needs. The AWWA has several studies looking into water usage. It is most likely that these studies will focus on flows and not pressures. If the scope could be revised to also gather pressure data, this could assist with gathering the necessary information to determine required water adjustment factors.

7. SUMMARY

After a thorough literature review was performed it was identified that very little research has been performed on the topic of fluctuations in water pressure. The majority of the research performed on water supplies pertains to demands, with the focus of current research on conservation or future adequacy of existing water supplies. While the research did not specifically address the issue of fluctuations in water pressure, using a few assumptions, the variables that affect demand could still be identified for use in providing recommendations for future research. A review of research on water forecasting models was performed to document the method of estimating water supplies, as well as the research that was performed on the topic to determine model input parameters that affect demand. This research also highlighted the complex relationships that all of these variables have on user demands since it is still difficult to predict water demands for specific communities.

The Fire Protection Handbook and other resources with guidance for engineers and technicians designing water based fire protection systems identified that water supplies fluctuate over time. The available research confirmed that use patterns have been shown to be affected by time of day, day of week, season, climate, location, water, growth, recession, socioeconomic factors and leakage. These patterns affect demands within a community which directly impact water availability and flow.

In addition to use patterns, the water distribution systems used to provide water to end users have many components that impact the available flow of water. Research and literature on water distribution system infrastructure was limited and mainly consisted of handbooks used for designing, operating, and maintaining these systems. In order to understand common practices, a survey was performed which identified that the design, operation, and maintenance practices varied from one water system operator to the next.

The system components that were identified to impact available flow include the type of pipe, the water supply infrastructure, tanks, booster pumps, well pumps, pressure regulating valves, and interconnections. In conjunction with the physical components of the water distribution system, operational procedures impact the function of the different components. These operational procedures include maintenance, system operations, cost savings, system operating pressure, pressure fluctuations, and manual operations. Both the system components and the operating procedures dictate the available flow within the system.

Computer models have been used to predict future demands of water distribution systems as well as to estimate available pressure and flows within the system. Forecasting models are used to estimate current water demands as well as future water demands using different parameters, variables, and algorithms. Since the typical output of forecasting models is demand (flow), these models are not extremely useful for fire protection unless they are coupled with another models that includes pressure with the future demand such as a hydraulic model. Hydraulic models use mathematical equations to determine pressure and flow at certain points within the system under specific conditions. These hydraulic models require input parameters for all the components of the water supply system, which may be unknown, and can change within a single section of pipe and overtime. Hydraulic models currently offer the best estimation tool for fire protection use, such that some jurisdictions already provide modeled hydrant data for engineers to use in designing water based fire protection systems.

The goal of this research was to identify the variables in water supplies that affect hydrant flow tests which are used to design water based suppression systems. The results of this research were intended to be used to provide adjustments to water supply data to ensure that the data used for fire protection system designs represents the actual system conditions during peak demand and is adjusted based on system parameters such as tank level during testing and normal system operations.

Due to the limited available literature regarding the topic of water supply adjustments, insufficient data was considered available to support recommendations for development of adjustment factors at this time. The data was considered insufficient for the following reasons: 1) there is a lack of data associating flow rates and available pressure, 2) there is insufficient data to provide meaningful comparisons between regions and within specific regions, 3) there is a lack of data for all identified variables, and 4) data was not limited to a single variable or discrete number of variables, which would allow for development of adjustment factors.

Research that includes pressure data with associated system demands is needed. Predictive calculations and changes in procedural operations to meet water supply demands are typically based on water supply capacity and do not consider available water supply pressure throughout a water distribution system. As a result, there is no way to utilize available data in a meaningful way to allow for development of a water supply adjustment factor or development of an equation for adjusting data. Additional research correlating pressure and flow is needed to allow for the development of such a factor for fire protection system design purposes.

Research is also needed to characterize the effects of seasonal changes and climate changes for a variety of different, yet typical locations, which will allow for comparison to water supplies in similar communities. The research should attempt to limit variables as much as possible so that the impact of each variable can be related to fluctuations in the available pressure and flow of a given water supply. It is recommended that the research include a study to determine how water distribution system operations impact fluctuations in the available pressure and flow of a given water supply.

In addition to recommendations for further study, several recommendations have been made, including: 1) coordinate with water utilities and forming a joint AWWA and NFPA task group, 2) utilizing water distribution system models, (3) determining water supply degradation parameters, 4) standardize water flow test procedures, and 5) evaluating these changes to determine their ability to be widely distributed.

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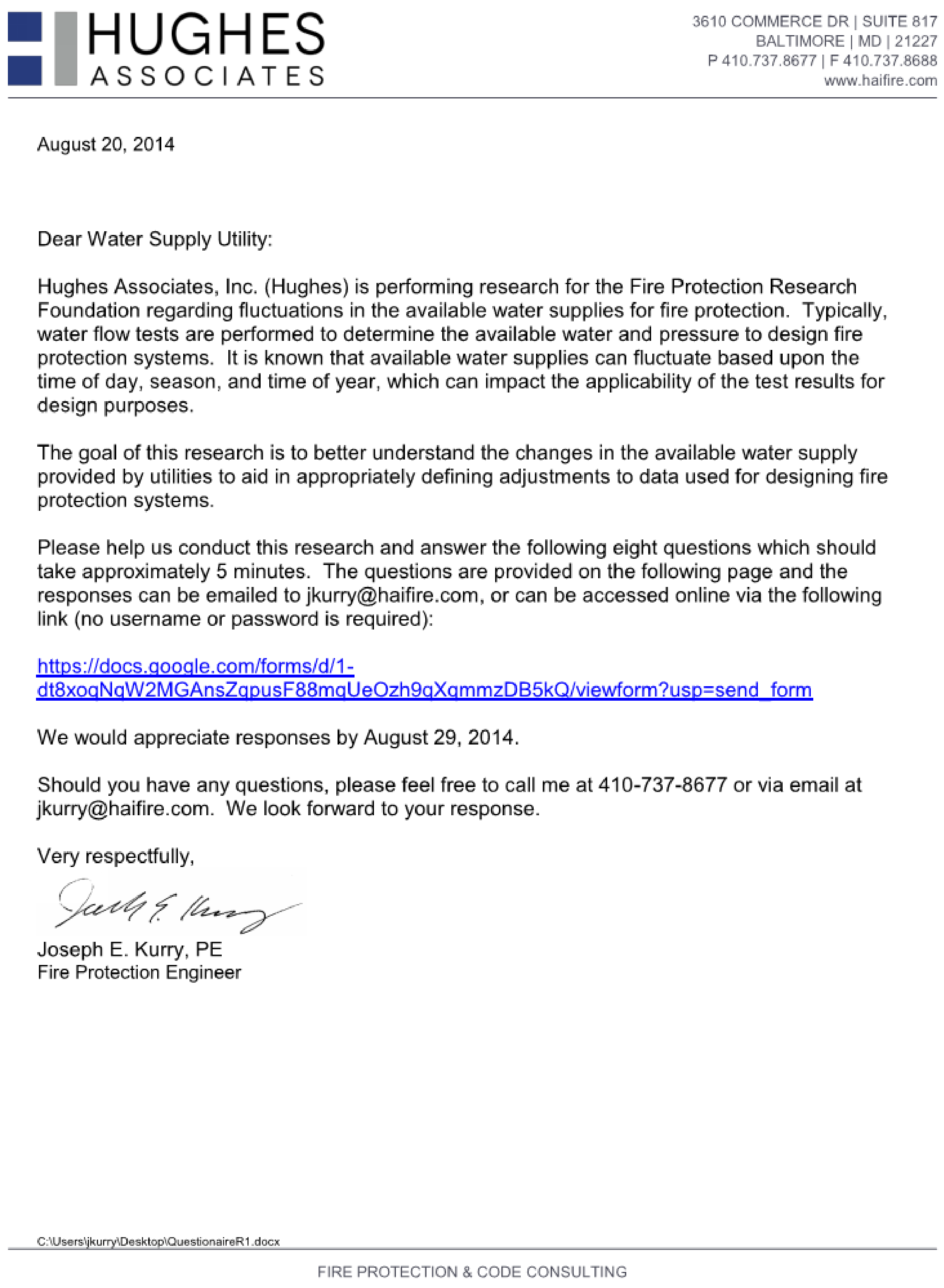
APPENDIX A. WATER SUPPLY SURVEY



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August 20, 2014

Dear Water Supply Utility:

Hughes Associates, Inc. (Hughes) is performing research for the Fire Protection Research Foundation regarding fluctuations in the available water supplies for fire protection. Typically, water flow tests are performed to determine the available water and pressure to design fire protection systems. It is known that available water supplies can fluctuate based upon the time of day, season, and time of year, which can impact the applicability of the test results for design purposes.

The goal of this research is to better understand the changes in the available water supply provided by utilities to aid in appropriately defining adjustments to data used for designing fire protection systems.

Please help us conduct this research and answer the following eight questions which should take approximately 5 minutes. The questions are provided on the following page and the responses can be emailed to jkurry@haifire.com, or can be accessed online via the following link (no username or password is required):

https://docs.google.com/forms/d/1-dt8xoqNqW2MGAnsZqpusF88mqUeOzh9qXqmmzDB5kQ/viewform?usp=send_form

We would appreciate responses by August 29, 2014.

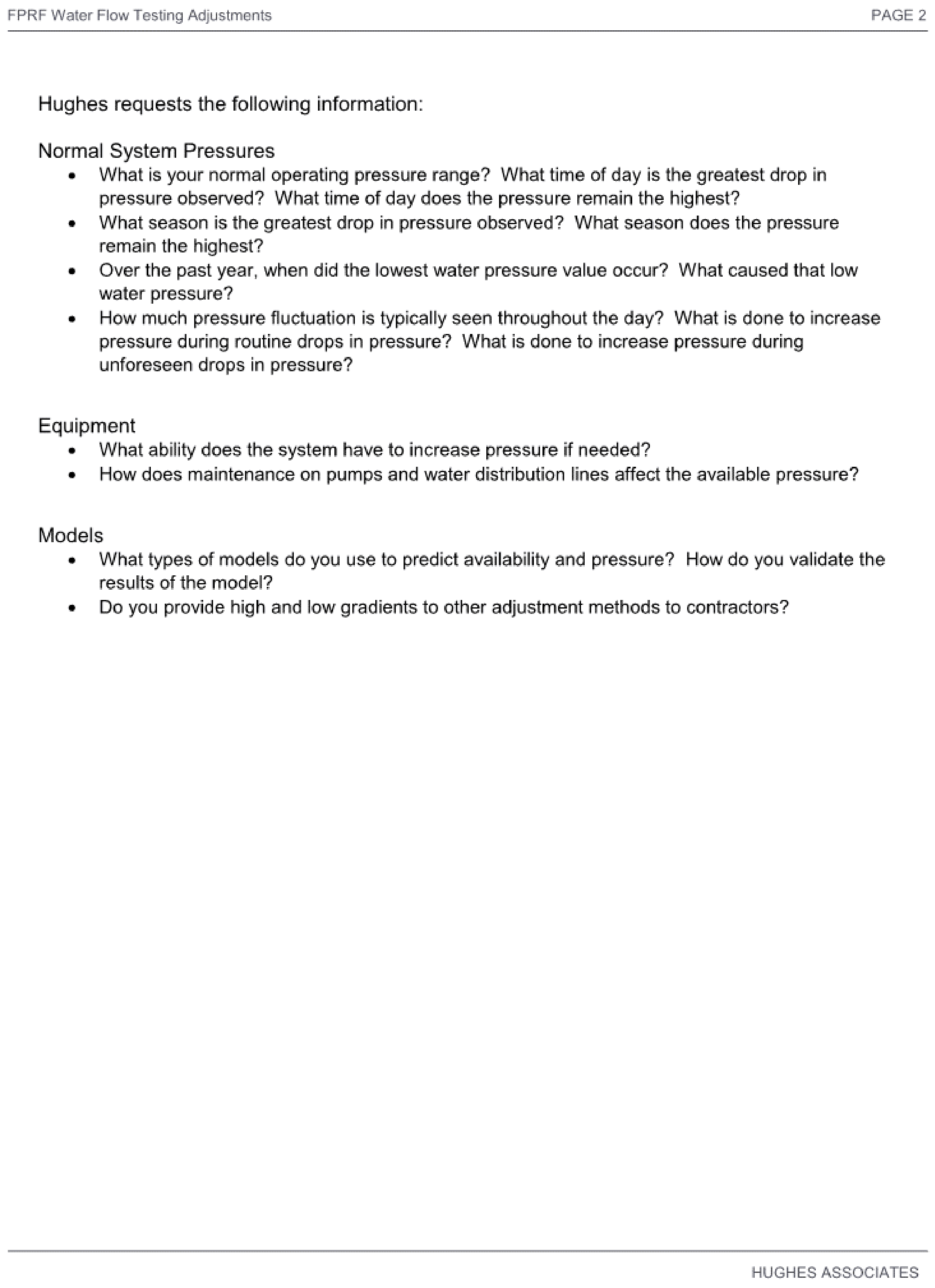
Should you have any questions, please feel free to call me at 410-737-8677 or via email at jkurry@haifire.com. We look forward to your response.

Very respectfully,

Joseph E. Kurry, PE
Fire Protection Engineer

C:\Users\jkurry\Desktop\QuestionaireR1.docx

FIRE PROTECTION & CODE CONSULTING



Hughes requests the following information:

Normal System Pressures

- What is your normal operating pressure range? What time of day is the greatest drop in pressure observed? What time of day does the pressure remain the highest?
- What season is the greatest drop in pressure observed? What season does the pressure remain the highest?
- Over the past year, when did the lowest water pressure value occur? What caused that low water pressure?
- How much pressure fluctuation is typically seen throughout the day? What is done to increase pressure during routine drops in pressure? What is done to increase pressure during unforeseen drops in pressure?

Equipment

- What ability does the system have to increase pressure if needed?
- How does maintenance on pumps and water distribution lines affect the available pressure?

Models

- What types of models do you use to predict availability and pressure? How do you validate the results of the model?
- Do you provide high and low gradients to other adjustment methods to contractors?

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
1	Normal Ops pressure: 45-70psi The lowest usually appears at around 7pm, The highest around 4am.	About 15psi range. booster pumps will start to increase pressure during routine drops. Turn on pumps to increase pressure during unforeseen drops.	Summer season is the greatest drop in pressure observed. In summer time the pressure remain the highest.	In the peak summer time, the lowest water pressure value occur, because the water demand are highest in the summer plus the tourists useage are high.
2	Normal operating pressure depends on the area of town and the elevation of the town. Pressure is steady, with very little fluctuation.	There are no observed, daily effects on pressure.	There are no observed, seasonal effects on pressure.	There are no observed, yearly effects on pressure.
3	Our average customer pressure is 103 psi. Greatest drop in pressure usually occurs 5am to 7 am. Highest pressure usually occurs 12am to 2am.	Pressure fluctuation averages around 25 psi. Operate booster pumps via SCADA. Operate booster pumps via SCADA.	Greatest pressure drop observed summer (August and September). Most constant pressure in winter (December thru February).	August 30, 2013. High demand primarily from irrigation.
4	We have an operating pressure between 65-75 PSI. Around 5pm is when we see the greatest drop in pressure. Mid morning, around 9am to 10am is when we see the highest pressure.	We don't see much of a pressure fluctuation unless there is a high demand for water during the dry summer months. But our pressure can fluctuate between 60-80 PSI. Running an extra service pump is usually how we keep our pressure up in the system during drops in pressure.	Summer is when there is a greatest drop in pressure. Winter is when the pressure remains high.	Earlier this year in January we had an equipment failure that caused extremely low pressure.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
5	A: 45 psi to 120 psi B: Mornings roughly 9am C: Overnights, routhly midnight to 2am	A: 15-18 psi B: Increased plant production C: Identify casue - Increased plant production	A: Summer B: Winter	A: zero. B: Customers on main with a failure A: (System Wide Normal) 30 B: (System Wide Normal) High Demand and lag in makeup production
6	Normal operating range is dependent upon location with the City, but generally between 55-60 psi. 1900 hrs (7:00PM) is the typical peak hour when we see highest demands (lowest pressures). Highest pressures are overnight (12:00AM - 4:00AM).	Pressure fluctuations are minimal in the City due to the number of elevated storage tanks and standpipes throughout the City, which help mitigate the pressure swings.	Summer is the peak time of year for pressure drop due to higher demands, winter usually has the higher pressures.	Do not have that information available
7	We have five pressure zones and within those zones we have pressure ranges from 20 psi in the highest portions of the City to 140 psi in the lowest. Tanks are typically filled overnight so the pressure is the greatest first thing in the morning and are the lowest at the end of the day.	The pressure typically does not fluctuate more than about 10 psi during the day. High service pumps are turned on and off to maintain pressure in each pressure zone and keep the tank levels consistent.	The Winter sees the biggest fluctuation in pressure due to the need to prevent freezing in the storage tanks. Summer sees the least in pressure fluctuation due to the high demand and the regular pumping that takes place.	I can't give you an exact date, but we have times when pressure levels reach near zero in an isolated section of the distribution system due to major water main breaks. We have never dropped below 20 psi in the system as a whole.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
8	Normal operating pressure varies from 40 psi to 100 psi depending on the location in the Water Distribution System. Greatest drop is pressure is between 6 AM till 9 AM Highest pressure is between 1 AM till 5 AM	Newark has two separate distribution systems High pressure Pequannock level has a normal pressure from 55 psi to 100 psi depending on locations. Pressure does not drop much at all unless there is a big main break (20 inch and above) or a big demand for water at one time for fire protection. Low pressure Wanaque level has a normal pressure from 40 psi to 60 psi. This pressure is regulated from its origin at connect at Belleville. Newark both systems pressure is regulated by 43 pressure regulators in the distribution system and therefore pressure variation at each location is minimal.	Pressure remains the same at all seasons.	We did not have a pressure drop incident.
9	The pressure at the our primary delivery point in the Village of Libertyille is 81 and at the secondary point it is 51 psig. Pressure is consistent all day.	Pressure can vary from 0 to 110 psig. Pressure only drops if sections of the system needs to be isolated and drained. Repairs are made and pressure is restored.	Typically pressure is the highest in summer and lowest in winter.	In May due to a repair.
10	60 - 100 psi, the pressure is more a function of elevation, there isn't much fluctuation at any given location.	We don't experience much fluctuation or at least we are not aware of it if it exists.	We don't have any form of contionuos monitoring but I would anticipate the gretaest drop would be during the summer months during the time of the highest demands.	The lowest pressure to occur would be in the event of a fire when the hydrants are being used in a high demand situation.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
11	Greatest drop in PSI is between 5pm-8pm PSI remains the highest from 12am-3am	Pressure fluctuation is between 3psi to 5psi. A series of wells or booster pumps is used to increase pressure during drops both routine and unforeseen.	Winter is the time of lowest pressure. Pressure is highest in the summer when more pumps or boosters are running.	Our lowest pressure is October-March due to the lower water levels in the reservoirs.
12	Normal pressure leaving the distribution pump stations is 63 psi. Normal pressure in high parts of town is 54 psi. Normal pressure in lower elevations of town is 66.	We normally operate an elevated tank on the system. Therefore, pressure slightly fluctuates as we either slowly fill or allow tank to slowly empty. We have vfds on our high service pumps to adjust for smaller variations in pressure and we start an additional pump to make up for large pressure demands.	Pressure is not an issue due to seasons, or anything else. We have a large water reclamation system for irrigation, therefore, smoothing out demands for potable water.	The only pressure drops we have is when the commercial electrical power company experiences outages.
13	Our normal operating pressure ranges from 40-60. Greatest drop in pressure is usually during a main break, other than that our system does not usually see significant drops.	We do not have large increased fluctuations of pressure in our system. We do not usually increase any pressure, with a drop in our system we will react quickly and it usually stabilize on its own.	The hot months (May, June, July, August, September) always see the greatest drop in pressure due to water main leaks/breaks. This is also due to an increase in water demands. Our rainier months (November, December, January, February, March, April) will remain much higher due to less water demands and a drop in leaks & breaks due to wetter soil conditions.	Our greatest recorded drop was during our 16" water main break, in which pressure dropped to 41 psi. Once crews fixed the issue, pressure regained.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
14	120-30 psi/around noon every day/4p.m & 7a.m.	There will be a total fluctuation of about 10psi at the most. Day to day pressure changes have not been a concern due to the pressure consistency. We will run pumps to increase pressure in certain areas as needed.	We do not have any seasonal pressure fluctuations.	Our pressure fluctuations are not seasonal.
15	40-110 psi throughout the system in various pressure zones 6 am - lowest pressure 2-3 pm in the summer - highest pressure	30-35 psi within a pressure zone worst case, <20 psi is typical PRVs come open or we pump more Pump more	Summer - greatest drop Winter - highest pressure	0 psi - Main breaks or planned & unplanned outages
16	We operate in several pressure zones. Pressures in these zones can have a normal value from 45 psi to 120 psi. Pressure fluctuations are kept to a minimum by our extensive elevated tank system and booster pumps.	Please see above. [normal operating pressure]	No real seasonal fluctuations.	Don't know.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
17	We have five different pressure zones, but system average is 60 psi. 3:30 to 9:00 pm on hot days (peak demand periods) 10:00 pm to 4:00 am	On a normal day, 5-6 psi at most in most zones. Re-set tank/well start/stop elevation levels if demand is high There is sufficient redundancy in the system to allow for additional wells or boosters to start up.	Summer high peak demand period, high fire hazards Winter low peak demand periods	Had two simultaneous multi-alarm fires in the same pressure zone. All sources and boosters operated to maximum capacity. Very rare occurance.
18	Normal range is 50-110 psi Greatest drop 5-7am Highest 2-4 am	Typical fluctuation is 10 psi. We have spare pumps we can turn on during both routine and unforeseen drops.	Summer has the greatest drop. Winter is when pressure remains the highest.	Mid-July at the end of a drought caused by excessive lawn sprinkling.
19	65 psi to 105 psi Approximately 6:00 PM Noon & Midnight	Approximately 15 psi Operate additional pumps Operate additional pumps	Summer Fall	Summer Pressure was not low, but decrease due to increase consumpsion.

System Operating Pressures

Response	Normal Operating Pressure	Daily Pressure Fluctuations	Seasonal Pressure Fluctuations	Yearly Pressure Fluctuations
20	Normal range- 45-85 psi Highest pressure drop- Morning 6:30a-9am Lowest pressure drop- Nights/midday 11a-2pm	Average 10-15 psi fluctuation Add additional finish water pumps/keep a finish pump on as much as possible/minimize elevated tanks low levels What is done to increase pressure during unforeseen drops in pressure? Add finish water pumps as needed (SCADA pressure point alarms alerts operators to add addition finish pumps and alert distribution crew of possible main break.	Summer- Higher demands Winter- Lower demands	Winter- Water Main breaks
21	We leave the treatment plant at between 79 and 87 psi. The greatest drop in pressure generally occurs from about 10 pm and 5 am. The pressure is highest between 5 am and 8 am, and again between 6 pm and 10 pm.	Pressure fluctuation is generally between 79 and 87 psi. We increase pressure by turning on High Service Pumps and additional booster pumps in the distribution system. We continually monitor the entire system 24 hours a day. We increase pressure at any time by turning on pumps.	We maintain the same pressure in the distribution system regardless of the season.	Continually maintain system pressure between 79 and 97 psi.
22	Normal operating pressure: 68 psi - 80 psi Greatest daily pressure drop - 1pm - 4pm Highest pressure - 10pm - 5am	Pressure fluctuation - 10psi Increase pressure - routine & unforeseen - start up additional high-service pump(s)	Winter - we run fewer pumps to keep water in elevated storage tanks moving in and out. Summer - more water use, more pumps in service.	January. See above.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
23	35-135psi depending on the zone. usually pressure will drop during high demand (in the morning and then late afternoon)	5-7psi	Winter time we keep the reservoirs at a lower level. resulting in approx. 2-3 psi drop in the upper zone closer to the reservoir. the opposite for summer time when we try to utilize max. storage	none noticed
24	75-90 psi, 5-8 a.m., 12:00 midnight and 5:00 a.m	3-5 lbs., Adjustment of pump speeds.	Summer due to high usage, Winter under normal operation.	Winter, Water breaks.
25	Average Daily Min: 37.4 psi Average Daily Max: 168.9 psi Average Daily Range: 43.3 psi These numbers reflect monitoring stations within each pressure zone. One monitoring station is impacted by pressure transients associated with zone transfer pumping and has skewed the average daily range, which is typically 20 psi. The greatest drop in pressure occurs between 2000 and 2100 hours. Pressures typically remain highest between 1000 and 1200 hours.	Annual Average Daily Range: 43.3 psi (typically 20 psi, see not in question 1) As system pressures drop routinely, we allow the distribution pumping strategy to drive operations. Pressures are balanced with energy conservation and water quality efforts. During emergency, or unforeseen pressure drops, operators increase pumping to maintain system pressures above 20 psi until field crews can isolate system failure.	The winter time has the greatest pressure variability. The summer experiences the highest pressures.	The lowest occurred in December and was caused due to transmission valves being closed inadvertently by construction crews.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
26	@ the city of Fort Worth we have 10 pressure planes. Low pressure occurs most frequently between 1pm to 5am or 7am. However, this is also dependent on the season in which the data is being taken. The time of day when pressure is the highest acr is between 1pm to 2 pm and 8pm to 10pm	Depending on the pressure plane and the season the pressures can fluctuate 20-30 psi. From a seasonal max to a seasonal low can be as much as 50 to 60 psi. Our summer demand is between 300 to 360 MGD supplied by 3 treatment plants and 15 intermediate pump stations. Elevated tanks are monitored through SCADA and pumps are brought on and off line based on anticipated daily demand. In cases of unforeseen drops in pressure additional pump are brought on line or an emergency interconnect from a higher pressure plane can be opened to provide additional water if necessary.	"Pressure Drop" is a somewhat vague term. If you mean lowest pressure overall then winter has lower pressure, as the demand is lower and therefore the less water is being pumped into the system. if you mean greatest delta between hour x and hour y at any given point, then this question is somewhat impossible to quantify.	Winter typically as demands are low which require less pumping so less head is being generated at the pump stations resulting in lower pressures in areas near pump stations. But overall pressure is maintained by elevated storage which when properly operated is stable throughout the year.
27	45-165 psi we do not observe drops in pressure unless there is a major problem such as a water main break.	We do not observe pressure fluctuations due to time of day or season.	We do not observe pressure fluctuations due to time of day or season.	We do not observe pressure fluctuations unless there is a serious issue such as a water main break.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
28	EBMUD's normal operating pressure range within approximately 122 pressure zones is between 40 to 130 psi. EBMUD typically operates its distribution reservoirs within the top 30 percent and observes time of use pumping (between April and October) at its distribution pumping plants between 12 pm to 6 pm (i.e., no pumping between these times). System pressures are typically highest when the reservoir operating level is high and the pumping plants are operating, which typically occurs sometime between midnight and noon, depending on system demand and pumping plant /reservoir sizes. System pressures are typically lowest when the reservoir operating level is low and when the pumping plants are not operating, typically between noon and 6:00 pm. This operation will vary seasonally where the demands may be lower and it may take longer (i.e. multiple days) to cycle the reservoirs.	Typically, a pressure fluctuation of 5 psi is seen due to distribution reservoirs operating within the top 30 percent. In addition, pressure fluctuations can be seen due to increased demands and pumping and flow control operations. Fluctuations are greater near pumping plants and flow control valves and lower near reservoirs. EBMUD Engineering Standard Practice is to limit the maximum pressure fluctuation to a maximum of 30 psi under normal operating extremes, not including fire flow. There are small areas within the existing distribution system that experience pressure fluctuations greater than 30 psi. Balancing water demands with pumping and flow control operations helps minimize routine pressure drops.	Summer is typically where the greatest drop in pressure is observed due to high system demands. Winter is typically the season where the pressure drop is lower.	EBMUD typically operates its distribution reservoirs within the top 30 percent; therefore, the lowest water pressure value should remain constant throughout the year as the distribution reservoirs approach their lower operating value. If there is an upset in distribution system operations due to an emergency facility outage or pipeline break, high demands, and decrease of supply which would typically occur in the summer, system pressures may decrease but this is not typical for EBMUD.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
29	The normal range at pumping facilities is 55-90 psi. It varies in the five pressure zones because of elevation changes. There is rarely a great drop in pressure. Pressure is most consistent from 10;00 pm to 4:00 am.	We have automated controls through SCADA that limit pressure changes at pumping facilities. The daily range for pressure variation is less than 10 psi. We can override the SCADA controls to make manual adjustments if necessary.	The pressure varies most in summer months due to irrigation water use. The pressure remains highest in late fall before winter weather causes leaks.	The lowest pressure occurred in early summer and was caused by irrigation use and fire department hydrant use.
30	1. 40-90 PSI Goal, 20-100 PSI is not uncommon in some elevations, <20 to 130 in a few areas 2. 5 PM to 8 PM. The water storage reservoirs fill over-night and drop during the day. This allows some turnover of the water in the tank and help maintain water quality. 3. 3 AM and 6 AM. The water storage reservoirs fill over-night and reach their maximum level around 6 AM.	1. 5 to 8 PSI 2. Increase production at the treatment facility, however it takes hours to raise the reservoir levels to actually increase teh pressure. 3. same as #2	1. There is little difference in pressure seasonally in our system. During extended dry periods, the pressure may be lower by an additional 4-5 PSI for 8-12 hours, if many customers are use a lot more water than normal. It may take the treatment plant a day to catchup. 2. same as #1	We had an extended shutdown of 8 hours at the treatment plant between 6 AM and 2 PM, so that planned process upgrades could be installed. Usually we have redundant equipment that can be run, but once every 7-10 years or so, a significant change requires a longer shut-down.
31	Normal Operating Pressure - 70 - 75 psi. Greatest drop 0600 Highest 2200 - 0400	We see very little fluctuation. We increase pressure for both routine and unforeseen pressure drops through our SCADA system which allows for an automated system in which boosters come on automatically when there is a drop in pressure below what the site is programmed for.	Greatest drop in pressure would be in the early morning hours during summer. Pressure will remain the highest during the winter months.	The last week of March. During a test of the load on the generators at the water treatment plant, the power was switched and all of our finished pumps were running. It was an operator error. This situation has never occured before and will never happen again.

System Operating Pressures				
Response	**Normal Operating Pressure**	**Daily Pressure Fluctuations**	**Seasonal Pressure Fluctuations**	**Yearly Pressure Fluctuations**
32	45 - 100 psi. Very small areas may be as low as 35 and as high as 110. Late Am to early pm hours may be lowest buy only by 5-10 psi. Very ea ly am is highest.	Lincoln has good storage and capacity so pressure remains relatively constant throughout day. Storage is topped off late pm to early am to prepare for am irrigation	Flexuations are minimal throughout system all year.	Low pressures are only caused from main breaks or facility failure
33	Our normal operating range is from 124-136 psi on the low service the pressure generally stays consistent all day .however early morning from 0045 to 0700 we will see and increase in system pressure generally to 136 or so due to lack of use on the low service and head pressure on system	We generally only see a fluctuation of about 12 psi a few times during the day ,We do not take any measures to increase pressures during that time .We do have the ability however to increase pressure by increasing finished water flow at the pump. This increase in finished water flow at the pump can and has been used to increase pressure at times of need.	Seasons do not seem to play a role in pressure drops at our plant. Our summer season is where our highest use is do to irrigation and extra residential use ,but our pressures stay consistent with the rest of the year.	The only time we get a low pressure alarm at the plant may be because of a power failure causing the finish pump to stop it all happens quickly and stays isolated mainly to the plant until the finished flow valve is shut or power is restored .
34	The pressure leaving the treatment plant is consistently 70 to 80 psi. The pressure at the storage tanks is consistently 50 to 65 psi, averaging approximately 60 psi.	10 psi at the plant 10 to 15 psi in the system. Pumps at the plant and at remote storage tanks are turned on and off to increase and decrease system pressure.	Summer is the time when the system experiences the most variation in pressure. During winter, and the colder months, pressures consistently remain high.	

Water Supply Distribution System Infrastructure		
Response	**Water Supply Expand-ability**	**System Maintenance**
1	The system has many tanks and pump stations that can increase pressure if needed.	It depends.
2	Volume of water in the tanks.	Very little, if any, depending on how hard they flow the system.
3	Bring additional booster pumps on-line.	Obviously critical. Without pumps on-line and/or available and without significant water main breaks, pressure could not be maintained.
4	We have a total of 3 service pumps, one runs at a time to maintain pressure and if another is needed we have 2 for backup.	Pump maintenance does not affect our pressure since we have 2 backup pumps. Distribution line maintenance could affect our pressure depending on the size of the line and where the line is located. If a main 12" line is down for maintenance, that could limit other lines from getting a strong feed and result in lower pressure.
5	Pressure can only be increased until the highest tank is full. Beyond that, there would be extreme risk to lower elevation water mains to failure due to high pressures. Increased plant production can increase tank levels for all but extreme water use periods.	Maintenance on pumps and critical water mains is not scheduled for high usage months. If a critical main or pumps were out of service due to a failure, the results would be catestrophic.
6	this would have to be done at the treatment plant level and water pump station level but could be done if the need was there.	anytime there are shutdowns there are inherent pressure drops.
7	Our system pressure is determined by elevated tank levels so our ability to increase pressure is limited by elevation.	It has very little affect. We have a looped system with back up pumps to maintain system pressure.
8	The Wanaque level pressure can be increased by adjusting the regulators at Belleville, the origin of the connection. Pequannock level pressure is regulated at several locations in teh system and therefore there will not be much variations..	We only run one pump at Wayne connected to our Pequannock Aqueducts to transfer additional water from another system, partially owned by Newark on a daily basis. However any shut down or repair of this pump station has no impact on pressure because we have a large (650 million gallon) capacity distribution reservoir below this pump station

Water Supply Distribution System Infrastructure		
Response	**Water Supply Expand-ability**	**System Maintenance**
9	The standpipes could remain higher.	Repair to the system may result in loss of pressure in the effected area.
10	Our system pressure is controlled by the water level in our storage tanks.	it doesnt
11	We have the ability to raise and lower reservoir levels or turn on more wells or booster pumps.	No affect on pressure.
12	More than ample high service pumps available	More than ample redundancy. No effect
13	Gravity from our towers sets pressure for our system. During a system event, our system usually only drops from 5-10 psi, and stabilizes on its own.	Occasionally we could see "pulses" in the system which could cause a main break, which would drop pressure in the system until crews fix the issue. It is usually very rare during maintenance.
14	Pumps	We have a maintenance plan for all operations.
15	We can increase pressure in certain pressure zones remotely by pumping more. In other pressure zones we would manually have to adjust PRV settings.	All of our scheduled outages are planned in order to minimize affects on pressure
16	Booster pumps only. Tank levels can only be raised to max.	N/A Redundant pumping
17	Can decrease the "operational" portion in the tanks to maintain ore water ins storage at a higher level. Can increase the number of booster pumps operating	There is sufficient redundancy to cover routine maintenance of single pump/motor assemblies. Back-up systems are available if an entire facility is down.
18	We have multiple pumps at multiple sources of supply.	Pumps not much since we have multiple pumps. Mains on temporary. We have a good valve spacing.

Water Supply Distribution System Infrastructure		
Response	**Water Supply Expand-ability**	**System Maintenance**
19	Additional pumping units	Minimal impact
20	Finish water pumps located at the treatment plant	Redundancy on finish pumps to allow PM and emergency pump repair.
21	We can increase pressure at the push of a button.	Little to none.
22	High-service pumps can be added, elevated storage tanks are filled nightly.	No loss of pressure. Pumps can be added as needed.
23	only by adjusting the PRV. Our comp plan states that we must maintain water pressure between min35psi to 135 max psi	we are gravity feed thru reservoirs.
24	Pump speeds, We have two finished water reservoirs that equal 3 days storage.	As for the whole system it is minimal. Certain areas can be affected at times but we are redundant on pumps and have good isolation capabilities.
25	There is a battery of pump stations that can increase pressures throughout much of the system in the event of an emergency. Increased pressure, as a driver, conflicts with other operational considerations such as water quality, water loss/conservation and energy management.	The system is fairly resilient. Plants and tanks can be temporarily taken off-line and the system can still operate at the desired level of service.
26	We maintain firm pumping capacity at all pump stations which allows for additional pumping as well as emergency inter connects to adjoining pressure planes.	Maintaining firm pumping capacity allows any pump stations to operate without impact to the system with the largest pump out of service. We also have redundant pumping facilities supplying each pressure plane.
27	Volume	it doesn't, not notable.

Water Supply Distribution System Infrastructure		
Response	**Water Supply Expand-ability**	**System Maintenance**
28	Distribution pumping plants and flow controls can be operated to minimally increase pressure if needed. During an emergency facility outage or pipeline break, EBMUD has the ability to crack open zone gates between pressure zones with different hydraulic gradients to help provide a source of water during the outage and increase the pressure but this is not typically done. Should a pump failure or emergency outage be encountered, EBMUD maintains portable pumping plants that may be utilized to maintain system pressures within a pressure zone.	For planned maintenance, EBMUD produces outage plans to ensure, to the extent practicable, that existing level of service and pressures meet our ESP. Mitigations could include those discussed in the previous question. Unplanned maintenance may result in impacts to pressures, but we don't track this information. Since EBMUD sizes its pumping plants with a standby unit, we typically don't have an impact due to maintenance on a given unit.
29	We can adjust the control points.	We have redundant pumps at all facilities but leaks on large transmission mains could impact pressure under certain conditions.
30	None in the gravity system. In a boosted pressure system, which is only 15% of our service area, we can start a pump and sometimes a second pump to increase pressure.	Redendant pumps allow continued production during maintenance. Redundant transmission lines,,a well-grided distribution system, and valves approximately every 500' minimized the impacted outages when shutdowns for repair or replacement have to occur. During planned projects, sometimes temporary lines can be installed, but not in cold weather or they will freeze.
31	As previously noted we have an automated system, that turns boosters on automatically when there is a decrease in pressure.	We haved a very redundant system, so these issues do not effect the pressure.
32	Pressure is provides by storage elevation. Lincolns stores its max hour demand.	System has sufficient redundancy to allow maintenance with affecting pressure

Water Supply Distribution System Infrastructure		
Response	**Water Supply Expand-ability**	**System Maintenance**
33	We can increase pressure with the finish pumps if the need arises ,how ever it must be done carefully as to not create a water hammer in the pipes causing breakage.	As pumps wear obviously there efficiency drops as does there max output we have 3 finish pumps to sustain pressure .Broken lines rarely cause our pressure to drop our use goes up but pressure is stabilized.
34	There is a considerable amount of flexibility within our system. We own and operate two treatment plants on opposite ends of the system which can regulate pressure using VFD pumps. Additionally, there are multiple elevated an ground storage tanks in the distribution system, some of which also have pumps which can augment pressure as needed. The system is also interconnected with two other surrounding water utilities which can be utilized for pressure increase as needed.	The city maintains redundancy in the pumps it maintains in its water distribution tanks (there are at least two, if not three pumps at each location). Periodic maintenance is conducted on these units.

Water Supply Models Used

Response	Water Supply Models Used	Adjustment Factors
1	We have used hydraulic models- Infowater. We compare the junction pressure and the flow test readings to validate the results.	N/A
2	n/a	n/a
3	Use InfoWater/H2OMap for modeling. Field calibration and confirmation is made.	Yes, usually give the maximum available pressure available and an average pressure available (80% of max).
4	I am not sure of this answer.	To my knowledge we do not provide this.
5	We use Bently Water Gems as our model. We use history as a predicictor of demands. With the SCADA system, system pressure is constantly monitored and plant production is adjusted based on trends.	No one has control of the system pressure & operations except the operators at MWC.
6	We use a calibrated City-wide hydraulic model which is validated thru pressure recorders at the hydrant level.	our model results are provided for design purposes and account for all appropriate adjustment factors (e.g. pipe age, material, C-factor, fittings, etc.)
7	We are just now in the process of having a comprehensive water model done by a consultant. We verify the information by doing flow tests.	No.
8	WE have a hydraulic model. WE may be hiring a consultant next year to create a new hydraulic model.	No
9	WaterCAD	No
10	We have a hydraulic model developed back in 2006. We do fire flow tests to validat results.	No
11	SCADA system trending is all that is available.	No
12	We have model that has been validated and is used for potential development planning and sometime water quality.	
13		
14	Our engineer handles the distribution model.	yes

Water Supply Models Used		
Response	**Water Supply Models Used**	**Adjustment Factors**
15	EPANet all-pipes calibrated model. Validate using SCADA data and current field flow test data.	Usually we provide the modeled results (gpm, residual, static) but we can give a range for static if requested.
16	Not sure which model. Update every 5 years.	On occasion
17	Bentley Water-Gems...Innovyze modeling software. Field hydrant flows	Not normally
18	We have a full pipe model known as H2O MAP. We verify with hydrant flow test field checks.	Yes
19	GIS Model Perform periodic field verification.	No
20	We use Innovyze Infowater, a hydraulic modeling package that stores model features and parameters in relational databases and integrates directly into our ArcGIS environment. Infowater uses a Modified Hybrid EPANet engine which is based on the Newton-Raphson numerical method for loop analysis, and one of several formulas, including Hazen-Williams for headloss. The model was initially calibrated using field measurements for fire flow and hydraulic grade line. Fire flow measurements were utilized to calibrate sections of smaller pipe and HGL measurements were used to calibrate along system trunks. The model was calibrated at steady state and extended period. Model results are generally compared to recent fire flow measurements and system pressure nodes (SCADA) for validation.	No. We currently only provide field hydrant flows to consultants along with the conditions in which that flow was derived (Time of day, pump status, etc). It is left to the consultants professional judgment to determine high and low gradients and more specifically, if the flow provided will meet the requirements related to their proposed need
21	N/A	N/A
22	We don's currently have a water model.	No.
23	we have an engineering firm that this is done thru	no
24	Currently no models.	If possible.

Water Supply Models Used		
Response	**Water Supply Models Used**	**Adjustment Factors**
30	1. H2O Net 2. Ask fire departments if the color-coded hydrants appear to accurately reflect real flows and do hydrant flow tests to compare the results to the model.	No, actual hydrant pressure and sometimes normal minimum water reservoir levels if the location is close to a high elevation in the system
31	I do not know that answer to this question.	I do not know the answer to this question.
32	H2o map with gis interface. Some occasional flow testing is done at hydrants	No
33	We do have water modeling software that helps us determine flow for certain repairs.	We certainly could do that.
34	MIKE Urban	

Water Supply Information			
Response	**Community Size**	**Location**	**Contact Information**
1	Under 500,000	South East	Yes
2	Under 500,000	South East	Yes
3	Under 500,000	South Central (Arkansas)	Yes
4	20,000-25,000	Sulphur, Louisiana	Yes
5	Under 500,000	Northern Middlesex County New Jersey with Contract sales to northern Monmouth County	Yes
6	Under 500,000	Suffolk, VA	No
7	Under 500,000	Sioux City, IA	Yes
8	Under 500,000	Newark, Essex County, NJ	Yes
9	Under 500,000	1/3	No
10	Under 500,000	Waltham, ma	Yes
11	15000	Pierre SD	Yes
12	Under 500,000	City of St. Petersburg, FL	Yes
13	Under 500,000	Pittsburg, Kansas	Yes
14	500,000-1,000,000	berks county	Yes
15	Over 1,000,000	Metro Denver	Yes
16	Under 500,000	Forsyth Cty, NC	No
17	Under 500,000	Lakewood, WA	Yes
18	Under 500,000	Madison, WI	Yes
19	Under 500,000	Garland, TX	No
20	Under 500,000	Southeast	Yes
21	36,000	Washington County and we sell to 8 wholesalers	Yes
22	55,000	Jackson, Michigan	Yes
23	6,000 connections	mukilteo , wa	
24	Under 500,000	Portsmouth, Ohio, Scioto County	Yes
25	Over 1,000,000	Mecklenburg County, NC	Yes
26	Over 1,000,000	Fort Worth, Texas	Yes
27	20,000	Lebanon ohio	Yes
28	Over 1,000,000	21 cities and unicorporated areas in portions of Alameda and Contra Costa Counties, California	Yes
29	Under 500,000	South Bend, Indiana	Yes
30	Under 500,000	Portland, ME	Yes
31	Under 500,000	Chandler, Arizona	Yes
32	Under 500,000	Lincoln, ne	Yes
33	44000	Burlington, VT.	Yes
34	Under 500,000	Chesapeake, VA	Yes