

Sizing Water Service Lines and Meters

Fourth Edition



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Fourth Edition



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Manual of Water Supply Practices—M22, Fourth Edition

Sizing Water Service Lines and Meters

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Preface



The American Water Works Association published the first edition of M22, *Sizing Water Service Lines and Meters*, in 1975. The manual was the first effort to provide guidance to the water industry on sizing water meters and service lines to meet the objectives of water utilities and their customers. The AWWA Distribution and Plant Operations Division recognized that the manual needed an update to incorporate changes in water demands that had occurred over the past 10 years and to offer a method for sizing dedicated irrigation meters that aligns with practices used by the Irrigation Association. In 1995, a manual revision subcommittee was established to review the existing manual and begin the process of developing an updated version and incorporating the impacts of existing technology into this sizing process. The efforts of that subcommittee resulted in the second edition (2004) of the meter and service-line sizing manual. In 2010, the Customer Metering Practices Committee formed a subcommittee to begin work on the third edition (2014) of M22. The subcommittee regrouped in 2020 to begin work on the fourth edition and met regularly over a three-year period to complete this most recent update.

This manual provides guidance on sizing water meters and service lines to meet the objectives of water utilities and their customers. The information in this manual can be used to estimate customer demand and maximum expected flow at a site, and this can be used to appropriately size a new service line and meter. This manual includes a useful field method called *demand profiling* that can be used to evaluate actual customer use patterns and help optimize meter size selection.

The data presented in the manual were obtained using a variety of methods including field measurements, utility surveys, technical publications, and hydraulic design calculations. This information has been condensed into a simplified format to assist readers in addressing most common service conditions. However, water and building systems are unique, and there may be complex meter and service line sizing situations that are beyond the scope of this manual.

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Chapter **1**

Introduction

OVERVIEW

The physical interface between water providers and their individual customers begins and ends at the water meter, service connection, and service line. Ownership and responsibility for the meter and service line vary by utility and jurisdiction, but this connection is often understood as the place where utility-maintained infrastructure ends and customer-maintained infrastructure begins. This is where customer usage is measured and where utility revenue is determined.

Service connections and water meters are sized first and foremost to provide peak water demand at adequate pressure under all anticipated customer demand requirements, which may include fire protection. The size of the service connection and meter is important for other reasons as well. Connection fees are paid whenever a new service is established or when a customer requires additional capacity at an existing service. Volume-based utility revenue is determined from metered consumption, and meter accuracy is affected by flow rates and usage. Properly sizing water meters ensures revenue can be collected for all water that is delivered to end users.

This is the fourth edition of AWWA Manual M22, *Sizing Water Service Lines and Meters*. AWWA aims to produce manual updates every 10 years to keep current with industry changes. The first edition was printed in 1975, the second edition in 2004, and the third edition in 2014. This fourth edition includes a new approach for sizing meters for single-family and many multifamily residential buildings and includes results from recent research on measured peak demands. This fourth edition includes improved guidance on the sizing of water service lines and new approaches and data for the sizing of water meters.

M22 TARGET AUDIENCE

This manual is intended for use by:

- water utility managers,

- engineers,
- planners,
- technicians and field operations personnel,
- consultants involved with designing and constructing projects requiring water service,
- academicians,
- meter manufacturers, and
- property developers.

UPDATES

When the first edition (1975) of M22 was written, the primary guideline for projecting water demands was the fixture value method, which conservatively projected water demands based on then-existing fixtures and appliances. This method emphasized identifying the worst-case instantaneous peak demand that could occur for a given water customer by assuming all fixtures were drawing water simultaneously.

The second edition (2004) of M22 included methods for developing locally specific demand profiles to enable meters and service lines to be sized based on current local conditions that reflect changes in water use patterns that have occurred. These revisions were necessary to reflect changes in how much water fixtures used, irrigation demands, and the resulting implications on meter and service line sizing.

The third edition (2014) expanded on the second edition's approach and called for new research. One result was the 2020 Water Research Foundation (WRF) report, "Assessing Water Demand Patterns to Improve Sizing of Water Meters and Service Lines" (project 4689), which found evidence of meter oversizing (Mayer et al. 2020).

Summary of Fourth Edition Content

This fourth edition of M22 provides a new approach for sizing residential water meters and adjusts the sizing curves for nonresidential meters. The fourth edition incorporates findings and data from the 2020 WRF project 4689 study; the 2016 "Residential End Uses of Water, Version 2" study (WRF project 4309B; DeOreo et al. 2016); and other studies including similar high-resolution demand profiling approaches. The "Residential End Uses of Water, Version 2" study provides an updated and expanded assessment of water use in single-family households across North America and presents detailed information and data about how water use has changed since WRF's oft-cited 1999 "Residential End Uses of Water" was published (Mayer et al. 1999). These results and data as well as other entities advancing the knowledge of domestic water usage were used to develop a new methodology and calculator for sizing water meters for single-family and small to mid-sized multifamily buildings. Every chapter in the manual has been updated to include the latest information and guidance, and Chapter 4 has been significantly expanded from earlier editions. A summary of each chapter follows.

Chapter 2: Consumer water demands, trends, and considerations. The manual is structured to establish predicted peak water demand as the fundamental factor to consider when sizing water service lines and meters. Currently, more is known and understood about general water demand patterns and peak demands because of the increasing focus on demand management in the water industry. Many water demand studies have been conducted in recent years that indicate distinctly different water demand patterns between and among various user classes, land uses, and geographic regions. For example, peak

demands can vary greatly depending on the regional location (e.g., semi-arid West versus the more temperate Northeast) and seasonal variation of a particular location. Some water service areas contain several microclimates, which may impact sizing decisions.

This chapter reviews demand changes that have occurred and presents current data on water demands and fixture specifications.

Chapter 3: Demand profiling for optimal meter sizing. More equitable billing is achieved by right-sizing a higher percentage of meters so that water charges more accurately reflect water used. Current technology is helping water professionals to better understand the water demand conditions that are embedded in sizing decisions. Chapter 3 reviews equipment and technology that are available to help water utilities and their constituencies better understand typical peak demand patterns and how water is used in their systems. The chapter also reviews how demand measurement equipment measures real-time peak demands and outlines general guidelines for using this equipment for meter sizing purposes. Numerous utilities actively collect and use demand profile information to improve sizing decisions. Many water utilities have used demand profile information to downsize meters, reduce nonrevenue water, and bill for service more equitably in their water system. This chapter also includes examples of how utilities are using demand profiling in their operations.

Chapter 4: Estimating peak water demands for service lines and meters. To properly size water taps, meters, and service lines, the peak demands must be estimated for any specific tap. Chapter 4 presents significantly new and revised approaches for estimating peak demands in residential and nonresidential buildings. For nonresidential buildings equipped with flush-valve style toilets, revised demand curves based on recently completed research are presented. For residential and small buildings with tank-type toilets, a new and freely available water demand calculator based on empirical data collected through recent end-use studies is presented.

Chapter 5: Service-line sizing. There is a distinction between service-line sizing decisions and meter-sizing decisions. Service lines must be able to meet the instantaneous peak demand of a particular customer and any possible successor customer, preferably without impacting the level of water service to the customer. Meter sizing must primarily consider the accurate measurement for all expected flow ranges for the current customer to ensure accurate billing of consumption. The difference is that the service line should be more conservatively sized than the meter in general (as local conditions warrant).

This chapter provides the framework for local water utilities to ensure service lines are sized to meet peak demands while considering all relevant factors, including system pressure, line size, material, head loss, elevation changes, and type of use. Considerations for fire flow and fire sprinkler configurations are presented. Sample calculations are included as a guideline to assist the users in their own calculations.

Chapter 6: Meter sizing and selection. This chapter presents guidelines on meter selection based on actual or likely demands. The chapter includes system components review, meter selection, and metering configurations for fire services.

CONSIDERATIONS WHEN SIZING WATER METERS AND SERVICE LINES

The following changes highlight the need to continually improve and update sizing methods.

Changes in Technology

Existing water meters are technological products, some with advanced reading capabilities. Meter technology for both measuring volume and transmitting measurements is changing, and this manual includes important updates such as the inclusion of electronic meters.

Technology changes are also reducing average and peak demands. This fourth edition of M22 has also taken these factors into account.

Demand Pattern Changes

Demand management has been institutionalized through national energy and water efficiency standards and codes and wider acceptance of water use efficiency. The result is that overall demands have decreased, resulting in lower peak and average flows. This fourth edition of M22 includes data and analysis from recent research on peak demands in residential and nonresidential buildings.

Policy Changes in Water Rate and Connection Fees

Water rate charges and connection fees are most often based on the meter size and service line size. As a result, sizing decisions have heightened relevance, with life-cycle cost and benefit implications for both the utility and customer.

Some utilities have separated meter sizing from the connection fee process. These utilities use demand-based approaches to connection fees and infrastructure charges for new customers. These approaches are independent of the meter and service line size and enable the utility and customer to focus on the expected annual demands at the site rather than the peak instantaneous demands needed for meter sizing.

Additionally, some combined water, wastewater, and stormwater utilities have removed the stormwater charge from the base, or fixed, charge to bill properties in a tailored fashion based on their land characteristics or stormwater management practices. Thus, the fixed charge based on meter size has decreased in these utilities. This trend may have an additional benefit in the case of oversized meters. Historically, some utilities lacked motivation to downsize oversized meters to obtain better low-flow accuracy because a higher fixed charge could be obtained from the larger meter. With a smaller fixed charge based on meter size, water utilities may be motivated to replace oversized meters with an optimally sized meter.

Growing Use of Residential Fire Sprinkler Systems

Jurisdictions have long had the opportunity to adopt requirements for residential fire sprinkler systems (RFSS) as prescribed under the National Fire Protection Association (NFPA) 13D Standard. While hundreds of local jurisdictions in the United States have done just that, the inclusion of a residential fire sprinkler requirement under the NFPA 13D Standard in the International Residential Code in 2009 spurred some state-level requirements to implement these systems. The design approaches for RFSS include many unique aspects that differ from the traditional fire connections to commercial, industrial, and multiunit residential buildings. For example, while traditional fire-protection systems for commercial and industrial buildings are usually designed under the NFPA 13 or NFPA 13R Standard and frequently require a separate and distinct line for the fire supply, RFSS designed under the NFPA 13D Standard provide several design options, including separate fire lines or a single line that provides both the domestic water supply and fire supply from the water main.

As RFSS begin to be installed in a community, the water utility often needs guidance to assist it in creating policy, procedures, and regulations for the infrastructure supplying water to these systems. In response, AWWA created a guidance report that explains the functional and design parameters for RFSS and outlines the considerations the water utility needs to set policy and procedures. The report, “Residential Fire Sprinkler Systems: Guidance for Water Utilities (2018),” is available for free download at:

<https://www.awwa.org/Portals/0/AWWA/ETS/Resources/ResidentialFireSprinkler-Systems.pdf>.

This report is a valuable tool for water utilities and will guide them in working with multiple stakeholders including fire departments, code officials, fire system designers, builders, and customers. The report discusses the factors around customer meter sizing; customer service line sizing, materials, and configuration; backflow protection; water rates and charges; and public relations. The report identifies appropriate references for readers to seek additional guidance. This edition of AWWA M22 details the most important elements of RFSS design guidance, particularly as related to customer service line and water meter sizing. Water utilities benefit from the information included in this edition of M22 and AWWA's RFSS guidance report to assist them in managing improved residential fire protection in their service area.

AWWA MANUALS RELATED TO METERING AND SERVICE LINES

AWWA publishes several manuals of water supply practices that are focused on water meters and service lines. Manual M22 is one of a suite of manuals that form AWWA's core metering and service line guidance documents. A summary of AWWA manuals related to metering follows.

M1, Principles of Water Rates, Fees, and Charges, Seventh Edition (2017)

M1 provides financial managers, water policymakers, and rate analysts with relevant information needed to evaluate and select water rate structures, fees, charges, and pricing policies.

M6, Water Meters: Selection, Installation, Testing, and Maintenance, Fifth Edition (2012)

M6 provides a complete manual of practice for water utilities on the selection, installation, operation, and maintenance of customer water meters and also provides sample record-keeping forms, a history of water-use measurement, and the development of modern water meters. M6 is heavily illustrated with photos, diagrams, and performance requirements.

M33, Flowmeters in Water Supply, Third Edition (2018)

M33 describes in detail the design and operation of commonly used flowmeters in water systems and field-testing methods.

M36, Water Audits and Loss Control Programs, Fourth Edition (2016)

M36 describes how to conduct a water loss audit and provides guidance in improving accountability and economically control water and revenue losses; it includes details on production meter testing.

REFERENCES

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Chapter **2**

Consumer Water Demands, Trends, and Considerations

INTRODUCTION

Peak customer demand is an important factor in many elements of the design of a water utility's production and distribution capacity and in customer metering. The maximum day demands often are used for sizing of water treatment plants,* and peak instantaneous demands, along with fire flows, are critical for sizing treated water storage and distribution systems. Another important use of peak instantaneous demands, and the main topic of this manual, is for sizing service lines and meters for individual customers.

Updates to recent end-use studies and additional data sets obtained from a broad range of utilities provide useful information for evaluating meter and service line sizing. This topic can be controversial because water rate commodity charges and connection fees are typically based on water meter size. Additionally, new development fees for sewer service can be based on water meter size and can increase disproportionately to water meter capacity. As a result, water meter sizing decisions are critical to new customers, and life-cycle cost and benefit implications from both the utility and customer perspective require thoughtful decision-making and defensible methodologies.

* Because of the high cost of providing treatment, some utilities have trended toward using peak flows over a longer period (such as 2–5 days) and relying on system storage to meet peak demands above treatment capacity. Such an approach has serious water quality implications, however. The Water Industry Database (AWWA and AwwaRF 1992) indicates an average distribution system retention time of 1.3 days and a maximum retention time of 3.0 days based on a survey of more than 800 US utilities.

Proper sizing of water lines requires anticipating all water demands, including fixtures and fire flow within the building, and then determining the smallest appropriate pipe size. Meter sizing presents additional challenges. Accurately sized water meters allow for full and accurate revenue recovery through rates as they were designed and provide satisfactory water service and full accountability for end users. Inaccurately sized water meters, either too big or too small, create a variety of financial, maintenance, and inaccurately measured demand problems.

Right-sizing water meters and service lines for modern, water-efficient buildings is aided by new data (collected through several Water Research Foundation [WRF] projects) on which to base estimates of peak instantaneous demands or flow ranges. This fourth edition of M22 includes updates for both residential and nonresidential buildings equipped with water-efficient fixtures and includes analysis from new data collected for the purpose of evaluating meter and service line sizing for multifamily and nonresidential customers.

There are seven major reference sources for sizing and typing water meters. These include four plumbing codes: Uniform Plumbing Code (UPC), National Standard Plumbing Code (NSPC), International Residential Code (IRC), and International Plumbing Code (IPC). They also include AWWA M22, AWWA M6, and local experience by individual water utilities, which develop their own criteria and tables for sizing and typing water meters to meet local water demand and pressure needs.

Four decades ago, when the first edition of M22 was written, the main approach for predicting peak water demand was called the fixture value method. This method conservatively estimated peak water demands based on required flow of then-existing plumbing fixtures and appliances. The method and resulting demand versus fixture value curves for different building types calculated worst-case instantaneous peak demand that could occur for a specific water customer. In the past 40 years, fixtures, appliances, irrigation demands, residential fire sprinkler demands, and their implications for water meter sizing have changed dramatically. Demand reductions have been driven by the national Energy Policy Act, customer education, conservation requirements and ethics, delivered water pricing, and water efficiency standards and codes.

WATER-USE TRENDS

Background

A common method for determining per-capita water use is to divide the sum of water used in a given period by the total number of people served. The type of customer base, climate, irrigated area, and efficiency of use thus influence per-capita water use for a water utility. In the 20th century, urban per-capita use first increased as households installed new water-using devices and fixtures and then decreased as federal plumbing codes and national standards required these products to be more water efficient, and metering and conservation pricing were enacted (Tanverakul and Lee 2015). Currently, North America is in a period of declining per-capita water use (Tanverakul and Lee 2015).

Up until 1980, urban per-capita water use in the United States increased from an annual average of about 60 gal per capita per day (gpcd) in 1920 to about 180 gpcd in the 1970s. From 1940 to 1970, per-capita water use doubled, increasing from 85 gpcd to 175 gpcd. Since the late 1980s, indoor per-capita use has leveled or declined across the United States. A Water Research Foundation (WRF) study, “North America Residential Water Usage Trends Since 1992,” found the typical American household reduced its use by 12,000 gal/yr over 20 years (Coomes et al. 2010).

The Energy Policy Act of 1992 (DOE 1992) and other codes and standards have mandated reductions in toilet flush volumes, clothes washer volumes, and shower and faucet flow rates; a recent residential end-use study from the WRF documents the impact

of these changes over the past 15 years. During this time, many water providers have discovered that increasing population does not necessarily result in a proportional increase in water use (DeOreo et al. 2016).

The “Residential End Uses of Water, Version 2” (DeOreo et al. 2016) provides an updated and expanded assessment of water use in single-family households across North America and presents detailed information and data about how water use has changed since WRF’s often-cited 1999 “Residential End Uses of Water” was published (Mayer et al. 1999).

Water use in the nonresidential sector within a given climate zone tends to be more site-specific. This tendency is especially true in the industrial sector in which use often depends on employees, process needs, and irrigated landscape demand.

Residential Per-Capita Use

In “Residential End Uses of Water, Version 2” (2016), average per-capita indoor daily water use was 58.6 gpcd. In the 1999 “Residential End Uses of Water,” the average per-capita indoor daily water use was 69.3 gpcd. This indicates an overall 15.4% reduction in indoor per-capita usage between the two studies. This change was found to be statistically significant at the 95% confidence level. Data from these two studies were used to develop the revised residential meter-sizing methods described in this fourth edition of M22.

Additional indoor efficiency is possible and should be expected. A sample of new homes built with high-efficiency fixtures and appliances (including WaterSense-labeled toilets, faucets, showers, and high-efficiency clothes washers) had an average daily per-capita water use of 36.7 gpcd measured in research using similar methods (DeOreo et al. 2001, 2012).[†] An average indoor per-household usage level below 40 gpcd appears achievable with full saturation of high-efficiency fixtures and appliances. Several states including California, Colorado, Georgia, Texas, and Washington have mandated that fixtures sold meet WaterSense (or similar) specifications.

Things have changed a lot in 45 years. In 1980, the first maximum volume flush standard for toilets was established at 3.5 gallons per flush (gpf). Table 2-1 shows the national fixture standards for US manufacturers that took effect in January 1994 as part of the 1992 Energy Policy Act. The conversion to high-efficiency fixtures has had a major impact on annual average demand and daily peak instantaneous water demands because they affect the peak flow for each device. Before the 1992 legislation, toilet flush volumes of 5 gal and showerhead flow rates of 5–10 gpm were common.

National water efficiency programs such as USEPA WaterSense; local green building codes such as the California CalGREEN code; and states including Georgia, Texas, Colorado, and California have encouraged and mandated water efficiency beyond the

Table 2-1 National fixture standards and specifications

Fixture	2019 WaterSense Specifications	1992 Energy Policy Act Standards	1980 Standards
Showerheads	2.0 gpm	2.5 gpm	3.0 gpm
Lavatory and kitchen faucets	1.5 gpm	2.2 gpm	3.0 gpm
Metering faucets	—	0.25 gpm	—
Gravity, flushometer tank, and electro-mechanical hydraulic-valve type toilets	1.28 gpf	1.6 gpf	3.5 gpf
Urinals	0.5 gpf	1.0 gpf	3.5 gpf

[†] New homes equipped with WaterSense toilets (1.28 gpf), showers (2.0 gpm), and faucets (1.0 gpm) and high-efficiency clothes washers.

1992 Energy Policy Act requirements. Similarly, the EnergySTAR program has resulted in more water-efficient and more energy-efficient clothes washers and dishwashers being manufactured that have provided additional indoor efficiencies. The biggest reduction in per-capita water use between the 1999 and 2016 end-use studies was measured in the clothes washer category, which fell by 35.9% from 15.0 gpcd in 1999 to 9.6 gpcd in 2016 (Mayer 2016). Over the same period, toilet use fell 23.2% from 18.5 gpcd to 14.2 gpcd.

Additional indoor conservation potential exists in the single-family sector. Daily average indoor use below 40 gpcd is achievable in the coming years through replacement of old toilets and clothes washers and as customer side leakage is reduced through automated metering leak alert programs (DeOreo and Mayer 2012).

Outdoor water use is driven by the size of the irrigated landscape, type of plant material, and weather. However, the flow rate for automated irrigation systems can be controlled by the design criteria and thus impact meter and service-line sizing to some degree. For existing sites, automated irrigation systems can often be designed based on the size of the existing water meter and service line. In these cases, flow rates are determined by the number and flow rates of the sprinkler heads (or emitters) for each station (also called *valves* or *zones*). Besides landscape irrigation, other outdoor consumptive uses include water for pools, spas, ponds, and vehicle and hardscape cleaning. Although the percent breakdown of these outdoor uses would vary widely around the country and from customer to customer, the largest percent of use on average is for landscape irrigation. In the Southwest, outdoor residential use can account for over 50 percent of the total residential annual use. More utilities are offering irrigation-specific water meters for residential use, meaning utilities will install two separate meters at homes with irrigation systems. These meters help identify the single largest residential water use and allow utilities enhanced control over water irrigation during droughts. These meters tend to improve conservation when homeowners can identify where water is used.

Per-capita indoor water use has declined significantly over the past 25 years, and the efficiency standards in place coupled with building codes that are increasingly focused on water and energy efficiency will result in further demand reductions. Outdoor water use has also decreased in some regions; however, outdoor use is more variable and subject to the impacts of the prevailing climate.

Nonresidential Use—Improved Efficiency

In the nonresidential sector (commonly called commercial, industrial, and institutional, or CII), water demand trends are more difficult to predict because of the wide variety of land uses, manufacturing processes, and inherent site-specific differences. There will be increased efforts to ensure that water is used as efficiently as possible as demand stresses existing water supply sources, as the cost of water increases, and as incentives are provided to reduce demand. The general trend, therefore, is toward increased efficiencies of use and lower instantaneous peak demands versus historical norms.

Trends to improve nonresidential water-use efficiency include:

- increasing cooling system efficiencies;
- switching from water-cooled to air-cooled ice machines and refrigerant compressors;
- increasing water use efficiency in restrooms;
- improving the efficiencies of water-using processes and eliminating single-pass cooling;
- increasing water use efficiency in commercial kitchens;
- water reuse or recycling in car washes, commercial dishwashers, and other industrial and commercial water-using processes; and
- utility incentive programs.

WATER USE PATTERNS

Residential Use

Typical single-family indoor use for a standard high-efficiency home is shown in Table 2-2. Data for the standard home come from the 2016 WRF report, “Residential End Uses of Water, Version 2” (DeOreo et al. 2016). The homes in this study came from cities in the United States and Canada and reflect a reasonable mix of the current housing stock. The high-efficiency data come from a sample of homes equipped to meet the WaterSense New Home Specification, which includes 1.28 gpf toilets and high-efficiency clothes washers designed to use less than 15 gal per load (DeOreo et al. 2012). More homes are likely to use water similarly to the high-efficiency homes in the future.

Nonresidential Use

While nonresidential water use tends to vary from site to site, ranges of use can be found for different business classes, such as schools, hospitals, offices, restaurants, etc. Per-account use and monthly peaking factors are shown in Table 2-3 for selected business classes in the East Bay Municipal Utility District (EBMUD) service area in the San Francisco (Calif.) Bay Area in the 1990s and Westminster, Colo. (a suburb of Denver) in 2017. This table is presented primarily for illustrative purposes. Average use in each category may vary considerably from community to community and from customer to customer, but there are similarities. The peaking factor is the ratio of the peak to the average month of use.

Evaluating nonresidential uses requires a comprehensive water assessment of all known water uses in the facility. Understanding how water will be used within a facility is the foundation for proper meter and line sizing. Each facility type has different water use patterns, depending on its function and use. While the equipment and processes vary widely, there are opportunities in all commercial and institutional buildings to achieve significant water savings indoors and outdoors by making improvements in operational areas. Submetering by the facility to routinely monitor component water use allows building owners and operators to more effectively understand and manage facility water use. Submetering enables a facility to quickly find and fix leaks or other unnecessary water use. The added benefit is that the facility can identify cost-effective water-use reduction opportunities and track project savings.

Table 2-2 Per-capita residential indoor use

Inside Water Use	Standard		High-Efficiency	
	<i>percent</i>	<i>gpcd</i>	<i>percent</i>	<i>gpcd</i>
Toilet	24	14.2	15	5.5
Shower	19	11.1	31	11.1
Bath	3	1.5	3	1.2
Laundry	16	9.6	11	4.0
Dishwashing	1	0.7	1	0.5
Faucets	19	11.1	17	6.2
Leaks	13	7.9	18	6.5
Other/Misc.	4	2.5	2	0.6
Total	100	58.6	100	35.6

Note: Table 2-2 was created using data from DeOreo, W.B.; Mayer, P.W.; Kiefer, J.; and Dziegielewski, B. 2016. “Residential End Uses of Water, Version 2”. Denver: Water Research Foundation.

Table 2-3 Average per-account consumption and monthly peaking factors* for selected customer types in Oakland, Calif., area and Westminster, Colo.[†]

Business Type	Annual Average Consumption, gpd	Monthly Peaking Factor	Data Source
Auto Repair	300	1.3	EBMUD
Auto Repair	200	1.6	Westminster
Car Wash	3,000	2.0	EBMUD
Car Wash	6,000	2.2	Westminster
Retail	500	1.3	EBMUD
Retail	1,600	2.6	Westminster
Grocery	800	1.5	EBMUD
Grocery	7,600	1.7	Westminster
Large apartments	3,000	1.3	EBMUD
Multifamily (50–100 bathrooms)	2,600	1.2	Westminster
Hospital	15,000	1.3	EBMUD
Hospital	14,100	1.8	Westminster
School	6,000	2.0	EBMUD
School	2,400	1.5	Westminster
Hotel (with food)	7,000	1.3	EBMUD
Hotel	7,700	1.9	Westminster
Office	1,100	1.7	EBMUD
Office	1,000	2.9	Westminster

* Summer (July and August) use over winter (December and January) use.

[†] East Bay Municipal Utility District and City of Westminster, Colo., consumption data (1997 and 2017, respectively).

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Chapter **3**

Demand Profiling for Optimal Meter Sizing

ACCURATELY MEASURING CUSTOMER USAGE

Customer usage data is typically generated by attaching an electronic flow recorder directly to a customer's water meter and logging the customer usage over short increments of time. For utilities that have deployed water meters with advanced internal data storage capabilities, a mobile Automated Meter Reading (AMR) system, or a fixed-network Advanced Metering Infrastructure (AMI) system to read their meters, these technologies may also be leveraged to collect detailed consumption data. In so doing, a customer-specific demand profile is created, which accurately represents that customer's water-use characteristics.

Demand profiles generated from existing water meters are uniquely valuable because a water meter represents the most precise means to measure potable water use. Flow recorders (such as the one shown in Figure 3-1) with accompanying software accomplish their mission without interrupting the registration of the water meter and, typically, without altering the existing meter configuration. In a small number of cases, adapters are required and easily installed. The existing meter must be accurate for the data obtained by the flow recorder to be valuable. Meter accuracy specifications can be found in the AWWA M6 manual (AWWA 2012) and in the C700 series standards, which cover specific meter types.



Source: Courtesy of F.S. Brainard and Co.

Figure 3-1 Meter Master EL 100 flow recorder and water meter

Applications for customer demand profiles may be grouped into three categories: (1) meter sizing, typing, and maintenance; (2) water use audits; and (3) cost-of-service studies. While only the first category is discussed in detail in this manual, the same data gathered for meter-sizing and typing purposes has other important uses and can benefit several utility functions including distribution, metering, conservation, customer service, engineering, planning, and finance. In the case of water use audits, demand profiles assist with conservation programs, leak detection, customer service, and hydraulic modeling. For cost-of-service studies, demand profiles are used to obtain data regarding the variability of use by residential, commercial, industrial, and wholesale customer-class groups. Because the same data can support all these applications, as well as spatial variation analyses, all potential applications must be considered for which the data may be of value—either in the present or in the future—when making the decision to collect the data. For example, if a cost-of-service study or hydraulic model requires only hourly demand data, one may still choose to store the data in 10-, 30-, or 60-s increments so that the same data can be used effectively for meter sizing and maintenance programs. An example of a software program that uses demand profile data to determine appropriate meter sizing is provided in Appendix A.

Flow recorders have been used to size meters since the 1930s. Although the technology has changed a great deal since then, recorders remain the most accurate meter-sizing methodology provided that the meter being recorded is accurate per the appropriate AWWA manual or standard (e.g., M6 [AWWA 2012] or C700-series standards) and/or manufacturer standards. Mobile AMR and fixed-network AMI can be leveraged to provide usable data as well and do not require the labor that is associated with logger deployments. However, while AMR/AMI data are useful, they come with lower sample rates compared to data loggers, unless the meter and/or endpoint are specifically configured to collect data on a more frequent interval schedule—which, in turn, may affect battery life. Other methods to gauge water use, such as pipe size or fixture count, do not provide the actual usage patterns that are essential for determining the ideal meter type and size.

In general, a demand profile should accurately provide peak-usage flow rate data and the percentage and volume of water used in critical flow rate ranges. Critical flow rate ranges would include, as a minimum, flow rates below the specified accuracy range of a meter; flow rates at the crossover range in a compound meter setting; flow rates greater than the midpoint of a meter's specified flow range; and maximum flow rates. The objective is to minimize the size of the meter (and its cost) for maximum accuracy and revenue recovery without adversely affecting meter reliability, pressure levels, or fire-flow requirements. Meter maintenance costs are important to consider. It may be that a 6-in. turbo meter could better serve a customer with constant flows of 600 gpm than a 4-in.

turbo; while both would accurately measure the flows, the 6-in. turbo would experience less degradation from wear and tear. The more closely a meter is matched to a customer's usage pattern, the more water will be accurately measured and billed.

In *The Large Water Meter Handbook* (1st ed.) (Edgar 1995), Tim Edgar illustrates this potential revenue gain with the case of a 100-unit apartment building with a 4-in. turbo meter. The monthly consumption was 500,000 gal, but much of that volume was at low-flow rates. Because the turbo meter was less accurate at flow rates below 12 gpm, 15 percent of the volume went unrecorded and unbilled in both water and, as is often the case, sewer charges. The result was a revenue loss of \$1,700 per year (at \$3/1,000 gal for combined water and sewer). As Edgar points out, if a utility has 100 such incorrectly sized meters, those meters would cost a utility over \$1 million in lost revenue over six years.

As another example, an Energy Services Company (ESCO) developed a water-loss optimization project for a large water utility in Illinois in 2018. This water utility had 404 large water meters, all of which were of the horizontal turbo type—regardless of the application. The utility initially had chosen to install horizontal turbo-type water meters because of the lower initial cost, lower maintenance costs, and ease of maintenance. In 2009, the utility did not give much consideration to the volume of nonrevenue water and to the unbilled water revenue at that time.

Shortly before commencing the water-loss optimization project, the utility had replaced the measuring chamber assemblies of 43 large horizontal turbo water meters with new chambers that were designed to accurately measure usage at low, intermediate, and high flow rates. Engineers at the ESCO identified an additional 124 large horizontal turbo-type meters that appeared to be improperly typed for the application. The engineers installed flow recorders to each of those services and analyzed the data.

Only eight of those 124 large horizontal turbo water meters were properly typed for the application. Eighteen of those 124 large horizontal turbo water meters were grossly oversized for the application. If the water meters were correctly sized, the decrease in base charge water revenue would never offset the increase in volume water revenue; there was insufficient usage at those services to recover the higher cost of the new measuring chamber assemblies that were designed to accurately measure usage at low, intermediate, and high flow rates.

Ninety-eight of the 124 large horizontal turbo water meters were improperly typed for the application. At a water rate of \$2.97/100 ft³ (sewer treatment was provided by a different organization and therefore not available to the utility), the utility could realize a revenue increase of at least \$105,925 annually from replacing the existing horizontal turbo measuring chamber assemblies with new measuring chamber assemblies that were designed to accurately measure usage at low, intermediate, and high flow rates at those 98 services. Had the utility provided sewer treatment, the total annual benefit from large water meter typing would have been even higher.

While the most direct benefit of proper meter sizing is increased revenue, cost-of-service billing equity, and accountability, meters offer much more value than just revenue enhancement to a distribution system. Any decision made by a utility related to water usage can only be as good as the consumption data collected from meters. In general, demand profiles provide valuable data to improve distribution system design sizing, performance, and management. In addition to identifying increasing supply/customer demand water-balance accuracy and revenue, demand profiles help to:

- identify service size requirements,
- clarify meter maintenance requirements,
- define and improve water use characteristics,
- enhance customer satisfaction and awareness, and
- establish equitable and justifiable rate structures.

With increased water scarcity, conservation has also become an important industry issue. For many utilities, conservation has become the most cost-effective means to increase water resource availability. All these distribution system design, performance, and management objectives depend on the ability of a system's meters to account for usage as accurately as possible, which can only occur because of sizing and typing meters correctly.

RECORDER DESIGN

Theory of Operation

Demand profiles are generated with electronic flow recorders or with internal data logging using meters with electronic registers and/or AMR/AMI system endpoints, where available. The portable flow recorders discussed herein are also referred to as *demand profilers*, *demand recorders*, and *loggers*. These devices collect data from a meter's internal drive magnets, a meter's pointer movement, or the meter's integral encoder, digital, or analog output and then store the data that is later downloaded and analyzed. Recorders can be moved from one setting to the next with minimum effort; these devices work with standard mechanical water meters, thereby eliminating the need for special registers. A recent new recorder design by F.S. Brainard works with many electronic meters. If a magnetic or optical sensor is used, it is typically either strapped to the outside of a meter using Velcro®, cable ties, wire, or heavy-duty tape, or it is integral to an adapter located between the meter body and the existing register.

Because of adverse operating conditions (e.g., meter pits, temperature extremes, rough handling, public access), recorders should be submersible, durable, and secure. To provide extended data storage capability in remote locations, recorders should also offer substantial battery life of more than two weeks.

Recording Methods

Data formats can be divided into three categories: pulse (or count), encoder, and analog (e.g., 4–20 mA or variable voltage). Flow recorders typically use pulse data and sometimes encoder data. Analog formats are rarely used in demand profiling. Although the analog formats are not explicitly discussed in this chapter, the following information should assist if an analog output is the only option available.

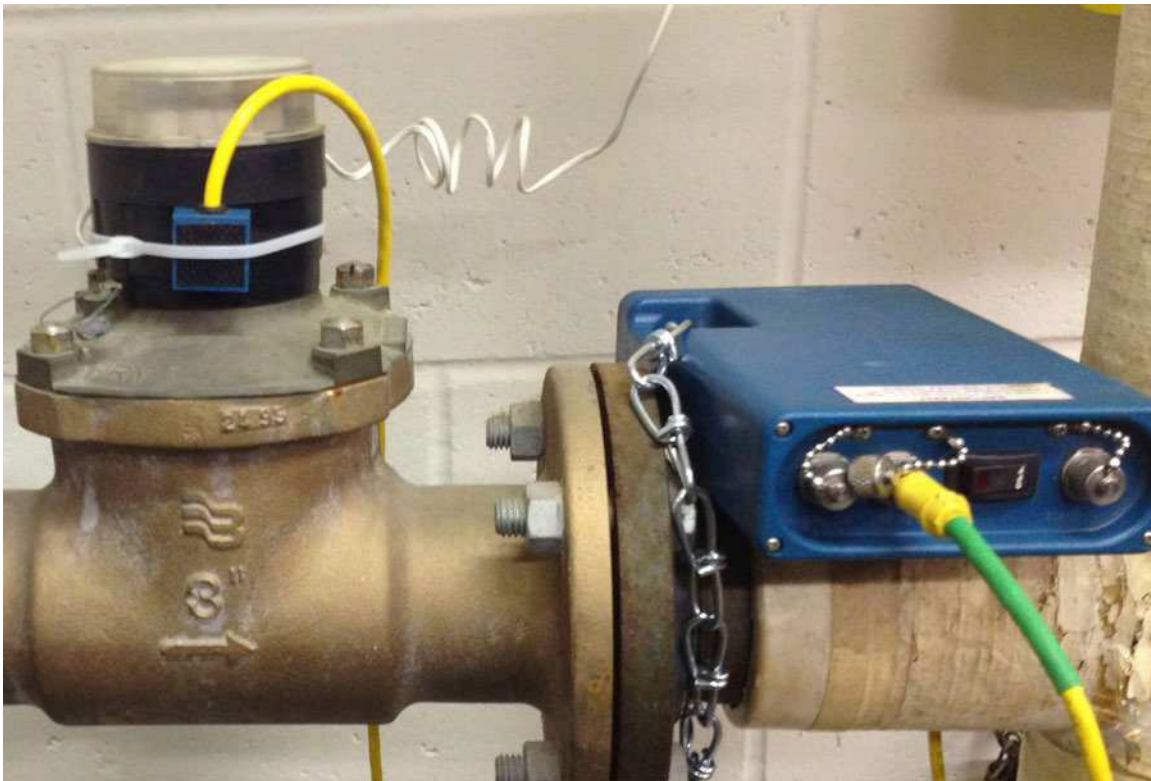
A frequently used solution for getting pulse data from existing meter installations that do not have a built-in pulse output is a magnetic flux sensor. Flow recorders using magnetic pick-ups sense the magnetic field generated by the magnetic coupling of a water meter's internal drive magnets and convert the magnetic flux change into a digital pulse that is logged into memory and later downloaded for analysis. Optical pick-up recorders sense the meter pointer passing beneath the sensor and store the signal as digital pulses to be downloaded later. Some solutions, including AMI/AMR, use an encoder interface, in which case a prior meter reading is subtracted from the current reading to calculate the volume of water for each interval. Some newer meters incorporate pulse output options that can be used for gathering usage data. In the case of pulse data, each pulse is associated with a known volume of water.

The principal advantage of a magnetic pick-up is the higher resolution of data made possible by the rotation speed of a meter's internal drive magnets. In most cases, the drive magnets inside a meter rotate much faster than the sweep hand (pointer) on the register's dial face. In small meters, the number of magnet rotations per unit of time can be as high as approximately 30 per s at 20 gpm. At this rate, the magnets are rotating 900 times as

fast as the sweep hand. In the case of turbo meters, the rotation speed of the magnets can vary greatly, from approximately 800 times the speed of the sweep hand to the same speed as the sweep hand. Conversely, the advantage of using a meter's pulse or encoder output is the avoidance of possible electromagnetic interference from other equipment near a meter that a magnetic flux sensor can potentially detect. Static water meters, such as electromagnetic, ultrasonic, and fluidic oscillators, do not have rotating magnets in their respective measuring chamber assemblies, which eliminates magnetic sensors as a signal-sensing option. For these meters, a strap-on ultrasonic meter, data log stored on internal nonvolatile meter memory, or an AMR/AMI endpoint may be used for data logging. Optical and mechanical adapters enable compatibility with older gear-driven meters that preceded magnetic-drive meters.

Magnetic Sensors

Because most mechanical water meters have the magnetic coupling directly under the register, a reliable signal can be detected by placing the sensor on the side of the register as shown in Figure 3-2. If one is present, the magnetic coupling is directly under the register in the case of all 2-in. and smaller positive displacement, singlejet, and multijet meters. With larger meters, if the magnetic coupling is not directly under the register, it is typically in the center of the turbo rotor in the middle of the flow. In this case, the magnetic sensor must be placed on the side of the meter body to be as close to the drive magnets as possible.



Source: Courtesy of F.S. Brainard and Co.

Figure 3-2 Flow recorder (right) collecting and storing a demand profile from a 3-in. water meter (left)

If the magnetic coupling is under the register, but the register has shielding on the sides, the sensor may have to be located directly on top of the register to circumvent the shield. Because the recorder's magnetic sensor is picking up the electromagnetic noise generated by a water meter, the sensor can be susceptible to picking up noise generated by other sources of electromagnetic noise, such as motors, generators, and alarm systems. The recorder's sensing circuitry should be designed to consistently pick up the magnetic signal generated by a water meter's drive magnets while minimizing the potential for picking up electromagnetic noise from other sources.

Encoder Outputs

Water meters with an encoder output use a 2- or 3-conductor connection to enable meter reading by the utility via a touch or radio read interface device. The meter's encoder output provides the current meter reading in a text string in accordance with one of the water industry's standard protocol formats. To log the encoder output with a flow recorder, this 2- or 3-conductor cable must be temporarily connected to a recorder capable of reading the encoder output protocol. The meter readings are logged into memory, and the difference between each reading becomes the interval usage value. Because static water meter designs have neither drive magnets nor a revolving sweep hand, using a 2- or 3-conductor connection to enable meter reading or the internal nonvolatile memory of the meter are the only options available for logging static water meter usage.

Data Storage Capacity

It is essential that a recorder or meter's internal memory has adequate data storage capacity to enable the recorder to store the total number of entries for the duration of logging. As discussed in greater detail in the "Data Storage Interval" section, flow data must be logged into memory in small time increments if accurate maximum and minimum flow rate data is to be ensured. The potential factor of difference in the observed maximum flow rate between a 10-s and a 60-s data storage interval monitoring the exact same flow is 6:1. The potential factor of difference in the observed maximum flow rate between a 10-s and a 300-s (5 min) data storage interval monitoring the exact same flow is 30:1. In other words, if a solitary flow usage of 200 gal occurred for just 10 s at a rate of 1,200 gpm, the 10-s data storage interval could detect this high flow rate of 1,200 gpm, whereas the 300-s data storage interval would observe a maximum flow rate of just 40 gpm because the 200 gal would get averaged over 5 min rather than averaged over 10 s.

This difference could have serious implications for a meter size selection. Frequently, users choose to collect and store premise water-use data for one week when assessing the size of a commercial user's meter to ensure that a representative sample of flow data is gathered. If a user is to store 10-s interval data for one week, the recorder must be able to continuously store a minimum of 60,480 intervals of data. For other applications, such as cost-of-service studies and hydraulic modeling, a smaller data storage capacity is required for meter sizing. If the same data is to be used most efficiently, however, the storage capacity should provide for high-resolution data so that the same data may be used effectively for other applications.

Data Storage Interval

This interval is the period over which a flow recorder counts pulses before that interval's pulse count is logged into memory. The interval determines the resolution of the raw data file from which all subsequent graphs and reports are generated: the shorter the interval, the greater the detail possible in subsequent graphs and reports. Because of the quick

Table 3-1 Meter maximum flowrate range example

Sample Frequency	Recorded Peak GPM	Recorded Average GPM	Absolute Error %
1 s	7.18		0.0
5 s	7.18	7.10	-1.2
10 s	7.18	7.07	-1.7
30 s	7.18	6.77	-5.7
60 s	7.18	6.72	-6.5
5 min	7.18	5.97	-16.9
30 min	7.18	2.95	-59.0
1 h	7.18	2.79	-61.2

Source: Courtesy of F.S. Brainard and Co.

nature of maximum flow events, the data log interval should be sufficiently small to detect these maximum flow events. Table 3-1 shows the analysis of meter data with various time intervals. Resampling this master data set to create new data sets at different time intervals illustrates the absolute error that would be seen with too large a data storage interval. From the table, any time interval larger than 60 s pushes the absolute error beyond 10 percent of the actual maximum flowrate.

Keeping the data storage interval small is essential for accurately determining maximum flow rates. To ensure the accurate identification of a maximum flow rate, the data storage interval cannot exceed 50 percent of the duration of a maximum flow event. For example, if an industrial customer has a particular operation that occurs just once each 30 min, lasts 30 s, and uses 500 gal of water (i.e., a demand of 1,000 gpm for 30 s), identification of the 1,000-gpm flow rate can only be assured if data is logged into memory at least once each 15 s. If the data storage interval is between 15 s and 30 s, there is an increasing likelihood that the maximum flow rate will be understated because no data storage interval is guaranteed to begin and end within the 30-s event. If the data storage interval is more than 30 s, the true maximum flow rate will not be detected; the maximum flow rate will be understated. In this example, a data storage interval of 15 s or less would show the 1,000-gpm flow rate.

There are disadvantages to making the data storage interval too small. This interval defines the size of the downloaded data file and the length of time that one can record before running out of recorder memory. The same test recorded with a 5-s interval will use six times more memory than one stored with a 30-s interval. Generally, a 10–60 s interval provides adequate detail and recording time for most applications. If one is making a long recording (multiple weeks) and a 10-s interval would use up all the logger's memory before the recording is completed, lengthen the data storage interval. Another problem with too short an interval is discussed in the following section, "Meter Pulse Resolution." Briefly, if too short an interval is used on a meter with slow-moving drive magnets (or sweep hand, in the case of optical sensors), skewing (exaggeration) of maximum and minimum flow rates can occur because there is too little data for accurate calculations. A recorder's operating instructions should identify such meters so that care is taken when selecting intervals for data presentation. Software design can also provide some correction when downloading raw data from a recorder.

Meter Pulse Resolution

This resolution is defined as the number of pulses generated by a meter that equates to a unit of liquid measure. For magnetic pick-ups, the resolution is the number of meter

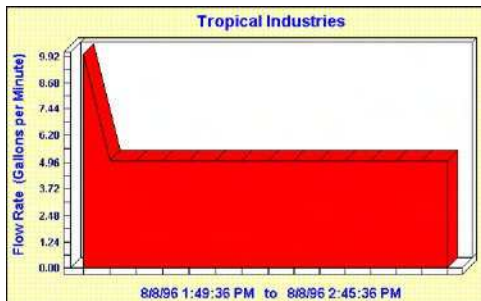
magnet poles (as the internal drive magnets rotate) that equate to a unit of liquid measure. It is desirable that the internal magnets revolve as fast as possible without degrading the reliability of the meter; accordingly, the higher the number of magnet poles per unit of measure, the better. For optical pick-ups, the same considerations apply to the speed of sweep hand rotation. When logging from a meter's encoder output, the resolution will equal the digit value of the least significant wheel position included in the encoder output. The available resolution on a particular meter is due to several factors, including meter age, type, and how it was ordered from the factory. It is possible to have a meter register that displays six digits but is only programmed to transmit four of them. If using the internal memory of the meter, the data log resolution may differ from the transmitted resolution. This requires due diligence on the part of the logger operator to make sure that the correct data is being collected.

The pulse resolution (or factor) is especially important when determining maximum and minimum flow rates. The issues are similar to those discussed in the preceding section, "Data Storage Interval." Concerning maximum flow rates, if a magnet (or sweep hand) is rotating slowly, a large, short-term usage could take place without any evidence of its occurrence. For example, if a 6-in. turbo meter generates just one magnetic pulse for each 500 gal, while another 6-in. turbo generates one pulse for each 2 gal, the 250 gal usage at 1,000 gpm described in the preceding section might not even be identified by a recorder attached to the 6-in. turbo with the slow-moving magnets, while the 6-in. turbo with the fast-moving magnets would have provided 125 pulses to the recorder. Furthermore, if the recorder attached to the meter with the slow-moving magnets did detect one pulse within a 10-s interval, the recorder technology might erroneously assume that 500 gal were used during that 10-s interval, which would equate to a flow rate of 3,000 gpm. If one pulse is logged in 10 s, this is the equivalent of six pulses per min, and six pulses per min multiplied by 500 gal per pulse equals 3,000 gpm. Accordingly, a meter with fast-moving magnets can provide continuously accurate data throughout the flow ranges, whereas a meter with slow-moving magnets cannot. Likewise, using optical sensors, the faster the rotation of the sweep hand, the more accurate the resultant data. As previously noted, intelligent software design can recognize and account for such circumstances.

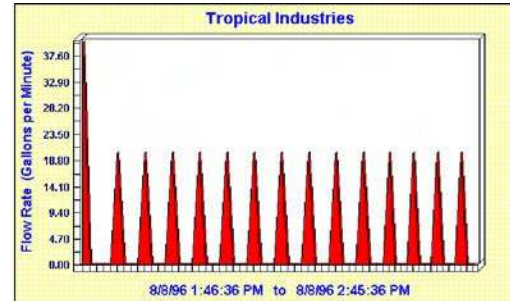
Minimum flow rates identify leakage rates and impact the selection of turbo versus compound meters in larger flow rate applications. To ensure the accurate identification of minimum flow rates, as with maximum flow rates, a user must know which meters have slow-moving drive magnets. For example, if a meter's magnets are providing just one pulse for each 20 gal, and the current flow rate is a steady rate of 5 gpm, only one pulse will be generated each 4 min. If one observes the data in time increments smaller than once each 4 min, the flow rate will appear to vary between zero and some amount greater than the actual flow rate of 5 gpm. As an illustration, if a 1-min data storage interval is used, the flow rate will appear to equal zero for 3 of each 4 min, and 20 gpm for 1 of each 4 min, because each pulse, equaling 20 gal apiece, will appear just once each 4 min when a steady flow rate of 5 gpm is occurring. If a 4-min time interval is used to observe the data, it will appear as if a steady flow rate of 5 gpm is occurring.

The two graphs shown in Figures 3-3a and 3-3b represent the scenario just described. Both graphs were generated from the same data, but the time increments used to view the data are 4 min and 1 min, respectively. Each pulse from the meter equals 20 gal, and they were spaced 4 min apart (except during the initial interval shown). Software design can help by evaluating the data to determine the likelihood that raw pulse data should be averaged over longer periods of time.

Unless someone is at the meter site watching the meter at the time of the event, it is not possible to know with certainty whether a periodic use of 20 gal is occurring or a steady flow rate of 5 gpm is occurring. If each pulse from the meter equaled a smaller amount of water, such as one gallon, the recorder technology would be able to consistently display more accurate data.



(a) Storage interval of 4 min



(b) Storage interval of 1 min

Source: Courtesy of F.S. Brainard and Co.

Figure 3-3 Depiction of 4-min and 1-min data storage intervals



Source: Courtesy of F.S. Brainard and Co.

Figure 3-4 Compound adapter and sensor

The key to getting accurate flow data is generating a sufficient number of pulses per time interval while keeping the storage interval as small as possible. In the case of magnetic pulses, most 2-in. and smaller positive displacement and some singlejet and multijet meters provide a good pulse resolution, such that the data can be observed in time increments as small as 10 s. Because some turbo meters have magnets that rotate relatively slowly, low flow rates are difficult to accurately observe.

Accordingly, adapters that increase the magnetic pulse resolution can be useful in determining accurate flow rate data because the flow data may be accurately logged and viewed in smaller time increments. One compound adapter, for example, can increase the resolution by a factor of 12 on various compound- and turbo-type meters (Figures 3-4 and 3-5). The adapter installs easily and enables the existing register to continue functioning normally. The same considerations also apply when using optical sensors.



Source: Courtesy of F.S. Brainard and Co.

Figure 3-5 Recording demand profiles from large compound meters may require an adapter.

RECORDING DATA

Length of Record

As previously discussed, many recorder users choose to store data from commercial sites for one week because certain high-rate water uses, e.g., a manufacturing operation, may only occur on a particular day each week. If possible, water usage should be discussed with a customer before storing data to ensure that the duration of the recording period is sufficient to get a representative sample of the full range of flow data. In the case of multitenant residential sites or hotels/motels, 24 h of data may be sufficient if the data is collected during hot weather for residential sites and during high occupancy for hotels/motels. Understanding a user's water use characteristics is important when selecting the optimum length of the data storage period. Experience with different types of users over time will also provide an indication as to the optimum record length for different classes of users.

Customer Water-Use Patterns

Data should be recorded during a period in which the user experiences typical peak, average, and minimum flow rates and for a duration sufficient to capture those rates. For example, data should not be recorded at a school or factory during a vacation period. Similarly, as previously mentioned, utility personnel may want to record data for at least a week at an industrial site if there is evidence that the customer performs different operations on different days of the week. Seasonal cycles are as important to consider as weekly ones. Weather at different times of the year may substantially alter demand patterns, especially if outdoor irrigation use is recorded through the same meter. If a customer uses a lot more water on a hot summer day, data on such a day should be recorded to capture peak flow data for meter typing, sizing, and accuracy evaluations.

Potential changes in demand patterns should be anticipated. At a residential development, the number of additional units currently under construction should be considered. Commercial lease space can have a high rate of turnover. A bottling company could be replaced by a warehousing or distribution company with substantially lower water usage. An elementary school may be converted into an apartment complex. If the appropriate type of meter is not installed and/or resized to reflect this change, the new user could be the beneficiary of a lot of free water that is inaccurately measured at low flow rates. This results in an increased volume of apparent water loss and reduces billable revenue.

Meter Accuracy

A flow recorder is generally only as accurate as the meter from which it is recording. When a flow recorder is used, it is typically assumed that the meter being monitored is accurate. A flow recorder cannot determine meter accuracy, but it can help determine the proper meter type and size for an existing setting. Because a flow recorder is only as accurate as the meter to which it is attached, routine meter testing is important when using recorders to determine the appropriate meter size. Since most meter inaccuracy involves under-registration of usage, a flow recorder on an under-registering meter can result in the selection of an undersized meter.

Ideally, a meter should be tested for accuracy—and repaired/recalibrated if testing indicates that it is not accurate—before recording data for meter-sizing purposes. As discussed in the section, “Meter Maintenance Considerations,” a demand profile performed in conjunction with a flow test may indicate that all the flow is occurring in an accurate range of the meter, even though the meter is not accurate throughout the flow ranges. If

this is the case, the meter does not need to be repaired/recalibrated because no revenue is being lost.

Flow recorders should be considered a valuable companion tool as part of a meter test program. As referred to previously, a flow recorder can identify the percentage of flow in low-, medium-, and high-flow ranges. With this information, testing can be focused on the ranges in which most of the usage is occurring, and unnecessary and costly repairs can be avoided. If a flow recorder indicates that all the flow at an oil refinery or brewery is occurring in a high-flow range, whether the meter is accurate at low and medium flow rates is not relevant.

Verifying Data Accuracy

A principal advantage of recording flow data directly from water meters rather than using alternative technologies, such as ultrasonic devices, is that the resultant flow data is based on and may be verified against the meter's registration. Graphs and reports generated from the data may be used with confidence because a water meter is the most accurate and reliable means to measure potable water use. However, if the accuracy of the data generated with a flow recorder is not verified by comparing the total volume observed by the flow recorder to the total volume registered by the water meter itself during the data storage period, this key advantage is lost.

Verification of data accuracy is critical and is accomplished by (a) requiring the user to enter the beginning and ending meter readings when downloading data, and (b) having an accurate meter magnetic-pulse factor database so that the total volume registered by the meter may be compared to the total volume registered by the flow recorder. This procedure also requires the operator to take care when making a record of the meter readings so that the numbers are accurate and include digits down to the decimal. To read a meter down to the decimal, a digit for all rotating dials and painted-on zeros must be read.

The sample software screen shown in Figure 3-6 requires the user to compare the meter's register volume to the flow recorder's observed volume. The numbers should either be extremely close or differ by an explicable margin. The software calculates register volume by subtracting the meter's beginning register reading from the ending register reading. This example is based on a magnetic pick-up. It calculates the recorder volume by multiplying the total magnetic pulse count for the entire recording period by the magnetic pulse factor for that meter in the software's database. An explicable difference between the two total volumes would include differences due to change gears used in some meters

Volume Comparison	
Ending Meter Reading:	632,324.000
Beginning Meter Reading:	631,029.000
Volume from Meter Readings:	1,295.000
Meter-Master Recorded Volume:	1,291.801
Delta (should be < 15%):	0.247 %

Volume Correction	
Conversion Factor:	1.00000
☐ Automatic ☐ Manual ☒ None	

Source: Courtesy of F.S. Brainard and Co.

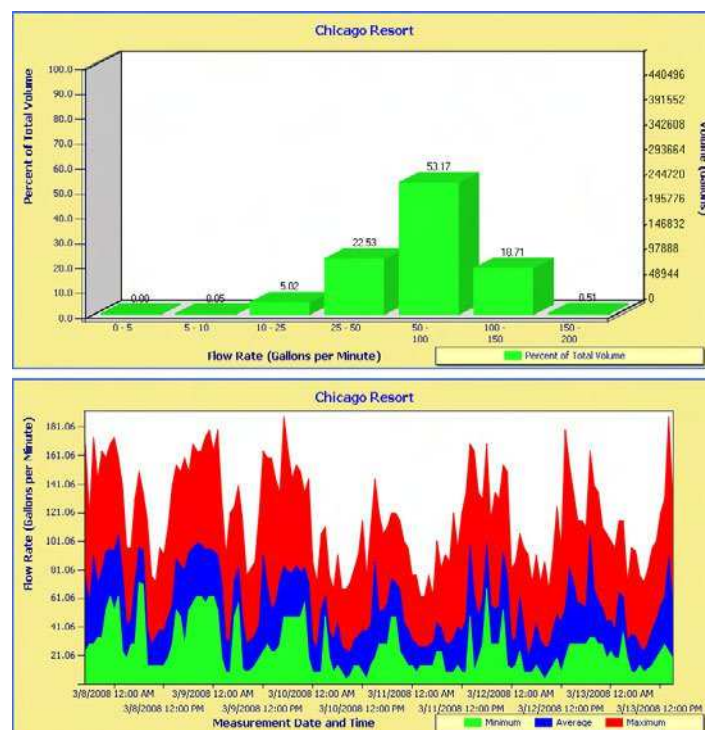
Figure 3-6 Verification of data accuracy

for calibration purposes. Because the change gears are used to speed up and slow down the register to match the activity in the meter's chamber, the recorder's volume could differ from the register's volume by as much as 15 percent, even though both the meter and the recorder may have functioned 100 percent accurately. The software screen shown in Figure 3-6 includes an automatic data conversion factor option so that the recorder's volume can automatically be calibrated to match the meter's volume 100 percent. These changes should only be performed by professionals with experience recording and analyzing water meter data.

Presentation Options

Data can be presented in many formats and styles, as shown in Figure 3-7. Generally, the flow recorder results should provide the following analysis:

- Seasonality volume trend
 - Illustrates the proper choice of data logging study time
- Volume data over the study period
- Max/Avg/Min flow rate
- Volume transported at different flow rates
- Comparison across meter types
 - Meter size
 - Service type
 - Example: Healthcare, industrial, or bulk transport



Source: Courtesy of F.S. Brainard and Co.

Figure 3-7 Data presentation options

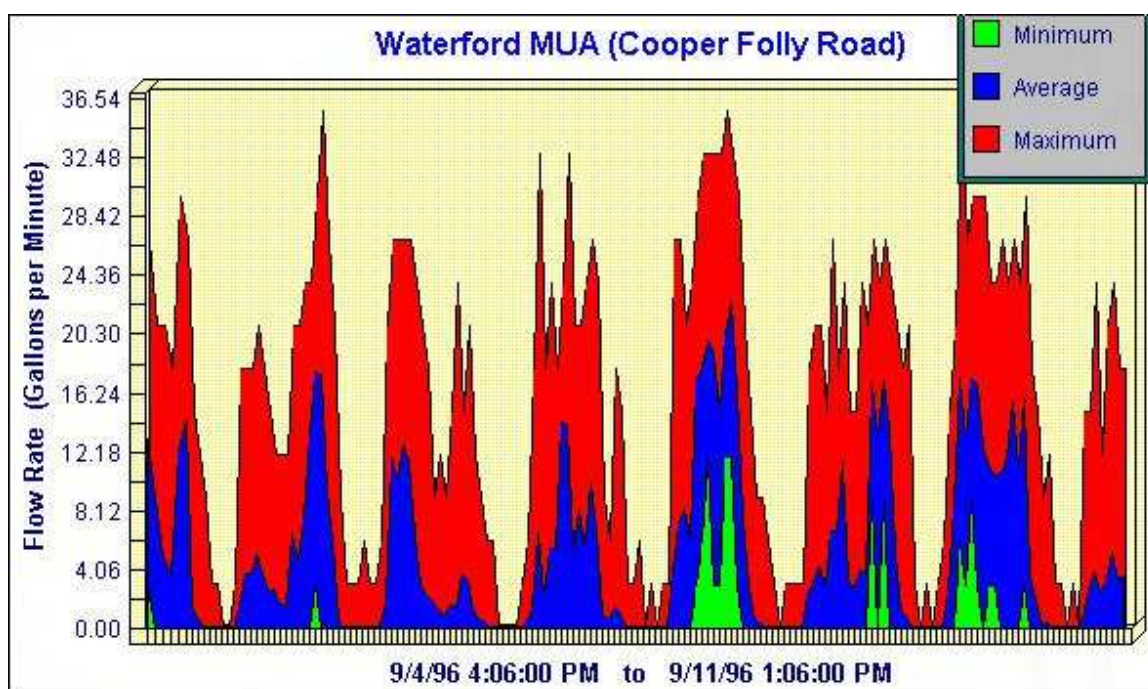
USING CUSTOMER USAGE DATA

Summary of Meter Sizing Benefits

The use of demand profiles for meter sizing applies to all users except single-family residential. Standard meter size and water-use patterns characterize single-family residential customers. With users other than single-family residential, each customer generates a unique demand profile, and the meter should be sized accordingly. Although generic demand data can be developed for various customer class groups based on demographic and business information, the cost of gathering customer-specific demand data is minimal when compared to the revenue and community relations benefits associated with maximizing meter accuracy and water use accountability.

Multifamily residential meters (e.g., apartment buildings) are the most consistently oversized meters because of both traditional fixture count methods of sizing and the advent of efficient, low-flow-rate fixtures. The graph displayed in Figure 3-8 is from an 8-in. wholesale connection serving a residential community. Although the specified accuracy range for an 8-in. turbo meter is approximately 40–3,500 gpm, the flow rate never exceeded 40 gpm at this site. The customer received much free water. Replacement of the meter with one that is properly sized will result in both greater meter accuracy and higher and more accurate billed water revenue. The revenue gain is further increased by higher sewer revenues whenever the sewer charge is a function of water usage.

Before downsizing a meter at an apartment complex or any potentially large variable-use facility, the utility should make sure that the meter does not serve any fire-suppression systems. If the meter does serve such a system, the meter may not be a good candidate for downsizing because of fire flow requirements. Moreover, either a UL-listed (Underwriters' Laboratories) or FM-approved (FM Global/Factory Mutual Insurance Company) meter should be installed in this setting—preferably a fire service or comparable type of meter that is designed to accurately register usage across a wide range of flows, especially at flow rates below 7 gpm.



Source: Courtesy of F.S. Brainard and Co.

Figure 3-8 Flow data from an apartment building served by oversized 8-in. turbo meter

Accurate meter sizing has positive residual effects with other programs mentioned in this manual. For example, a cost-of-service study in support of a rate-structure design can only be fair and equitable if all the sample sites have properly sized meters generating accurate usage data. Modern nonrevenue water management methods rely on accurate meter sizing. Customer-side leak-detection efforts are undermined if a meter is oversized—because low flows are not detected—and the meter’s pulse resolution is less than it would be with a smaller meter. Similarly, hydraulic models, conservation efforts, and other programs all benefit from accurate use registration, which depends on correct meter sizing.

Meter Maintenance Considerations

Another related use of customer usage data is meter maintenance programs—especially the larger ones. Some utilities consider demand profiles when making meter test, repair, and/or replacement decisions because the demand data enables the utility to perform an accurate cost-benefit analysis of these three maintenance options on a case-by-case basis. For example, if a 10-in. turbo meter tests 100 percent accurate in a high-flow range, 90 percent accurate in a medium-flow range, and 80 percent accurate in a low-flow range, the conventional wisdom would average the three accuracies, which would equal 90 percent, and recommend repair. If a demand profile indicates that the flow rate never drops below 1,000 gpm, the in-service meter accuracy for the subject application would equal 100 percent because all flow is occurring in a high-flow range. With the advantage of a demand profile, costly and unnecessary service interruption and repair costs can be avoided. Proper check-valve operation in a compound meter setting can also be evaluated by ensuring that the turbo side does not move unless the bypass chamber side exceeds a specified flow rate.

Water meters, like any piece of machinery, have optimum performance ranges, and projected test requirements can be related to a user’s demand profile. If a 4-in. meter is constantly being driven at a flow rate close to its high-end performance rating, more frequent repair requirements can be anticipated.

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- Edgar, T. 1995 (1st ed.). *Large Water Meter Handbook*. Dillsboro, N.C.: Flow Measurement Publishing.

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Chapter **4**

Estimating Peak Water Demands for Service Lines and Meters

INTRODUCTION

Hunter's Curve

To properly size service lines and water meters, it is essential to know the peak demand. Chapter 3 discussed approaches for measuring peak demand from existing customers. For customers requiring a new service connection and meter, the peak demand must be calculated based on building characteristics. This problem was investigated during the 1920s and 1930s by Dr. Roy Hunter, a research physicist at the National Bureau of Standards. Recognizing that water use is a random process, Hunter (1940) applied probability principles to predict peak demand as a function of the number of fixtures in a building.

Hunter formulated his approach using the binomial distribution, a probability model for random trials with two outcomes. In the case of a plumbing fixture, it is either “on” or “off.” Hunter focused on the three groups of fixtures that exerted the greatest load-bearing effect on plumbing systems in the 1930s—namely, the flush-valve toilet, the flush-tank toilet, and the bathtub. Hunter reasoned that the probability a fixture is on (running water)

depended on the ratio of two factors: (1) the average duration of flow when the fixture is operating and (2) the average time between successive operations.

Estimates for time between successive operations were based on the key assumption that all fixtures experienced *congested service*. Hunter defined congestion as the maximum practical rate at which fixtures can be used continuously in actual service. This implies there are users waiting in queue for each fixture so that when one user is finished, another immediately engages the fixture. In this manner, each fixture is continuously occupied, thus maximizing the probability that the fixture is running water. Such a scene is common for restroom use during breaks at a concert or halftime at a sporting event. From observations made at a few locations, Hunter determined the probability of use for the three key fixtures was 0.030 for a flush-valve toilet, 0.200 for a flush-tank toilet, and 0.067 for a bathtub.

With these three probability parameters, it was relatively straightforward for Hunter to develop individual design curves showing peak water demand versus fixture count for each of the three fixture groups. The challenge, then, was how to combine the individual curves into a single design graph that reflected the peak water demand in a building where all fixture groups could operate simultaneously. Hunter recognized that it was not legitimate to simply add the peak flow from each individual design curve. Hunter's ingenious solution was to introduce the *fixture unit* concept, effectively collapsing the individual fixture design curves into a single composite graph giving the peak demand (gpm) versus total fixture units for any combination of indoor end uses. The final result, called "Hunter's curve," is the basis for plumbing codes in the United States and across the globe. Before this historic development, there was no uniform method among plumbing codes to estimate the peak water demand in a building. Hunter's work established the standard for satisfactory service.

It is beyond the scope of this manual to replicate Hunter's derivation of fixture units (interested readers should consult Hunter's 1940 report). The key point is that fixture units provided the common currency that enabled any assortment of indoor plumbing fixtures to be combined and expressed as a single metric, which in turn mapped directly to a single estimate of the peak demand in the building. Hunter's curve gives the 99th percentile of peak period water demand. This means there is only a 1 percent chance that the actual peak period demand will exceed the load estimated from Hunter's design chart. Thus, in a properly designed system, peak flows are expected to exceed Hunter's curve 1 percent of the time and to fall below it 99 percent of the time during the period of peak use.

Hunter's iconic curve reflected good engineering judgment for water use habits in the mid-1900s. By 1970, however, there was a growing consensus among practicing engineers that Hunter's method led to overdesign of the water supply system in new buildings (USNCCIB 1974; Benazzi et al. 1976; Steele 1982; Jack and Whorlow 2017; Hobbs et al. 2019). There were two main reasons for this. First, the assumption of congested service often did not hold. Second, flow rates based on plumbing fixtures from the 1930s did not apply to the new generation of water-conserving fixtures. The disparity between peak water demands observed in the field and predicted by Hunter's curve widened with passage of the 1992 federal Energy Policy Act (EPAct) and adoption of other green plumbing codes.

Changes to Hunter's Curve

The profession has pursued two different paths to address these issues. One route, taken by plumbing-code committees, follows Hunter's original formulation. The basic strategy is to list additional building-occupancy types along with their corresponding modified fixture-unit values. Often these modifications stem from engineering judgment rather than observable data, resulting in discrepancies among fixture-unit values posted in various plumbing codes (Cole 2012).

The other course of action involves collecting water use readings at various buildings to generate new empirical peak demand curves. For instance, previous editions of AWWA M22 (1975, 2004, 2014) include a family of peak demand curves for different end-use categories: residential suburbs; commercial and institutional; and residential apartments and condominiums. In a subtle departure from Hunter's fixture unit concept, measured peak flows are plotted against the sum of all fixture flow rates (known as the combined *fixture value*) in a given building. A fixture value is defined as "the maximum discharge in gpm of a fixture when it is used individually without the intervention of any fixture at 60 psi" (AWWA 2004). The chief shortcomings of these empirical M22 curves are the small sample size and outdated water use readings. The field measurements were collected at just a few buildings in the United States and Canada in the early 1970s, years before the 1992 EPAAct legislation. Refer to Chapters 2 and 3 for further discussion of US legislation and its impact on water fixture demands.

Besides the AWWA M22 manual, organizations such as the International Association of Plumbing and Mechanical Officials (IAPMO) and the International Code Council (ICC) publish the Uniform Plumbing Code (UPC) and International Plumbing Code (IPC), with curves of peak demand versus fixture values or fixture units. The UPC, the IPC, and M22 are standard references for sizing service lines and water meters in North America. Although the UPC and the IPC use the same design curves, there are important differences between their approaches for estimating peak demand. Fixture units are assigned differently in the UPC and the IPC, and neither is equivalent to the fixture value calculation presented in M22.

In one area, the three methods agree: the UPC, the IPC, and M22 all include separate demand curves for buildings equipped predominantly with (1) flush-tank toilets or (2) flush-valve toilets. This important distinction between tank and valve toilets was also noted by Hunter. For design purposes, Hunter provided two curves in situations where the fixture unit sum is less than 1,000: Curve 1 where flush-valve toilets predominate and Curve 2 where flush-tank toilets predominate. When the fixture unit sum exceeds 1,000 on Hunter's chart, both curves merge into a single line for estimating peak water demand irrespective of toilet type.

The need for two curves in small-scale settings arises from the different hydraulic operation of flush-valve and flush-tank toilets. Valve-operated fixtures lack a reservoir of stored water and, when used, produce a brief but high demand for water on the premise plumbing. For instance, a single flush of a valve fixture may last only a few seconds while drawing up to 25 gpm. In contrast, tank-type toilets include a reservoir of stored water that is used to produce the flush. It is the refilling of this tank that produces the demand for water on the plumbing system. The refilling process may take 30–60 s with a draw in the range of 2–3 gpm. This distinction generally divides residential (flush tank) buildings from nonresidential (flush valve) buildings. In practice, small nonresidential buildings often install flush-tank toilets to reduce the meter size requirement and save money on connection fee charges.

Recent Studies of Peak Indoor Water Demand

Since publication in 2014 of the third edition of M22, a pair of independent but complementary investigations of peak indoor water use have been completed. The first study, performed from 2011 to 2017 under the auspices of IAPMO, the American Society of Plumbing Engineers (ASPE), and the Water Quality Association (WQA), developed a probabilistic model to estimate peak demands in residential buildings with water-conserving fixtures. The second study, performed from 2016 to 2019 under the auspices of the Water Research Foundation (WRF), compared high-resolution water-use readings against the rated capacity of existing meters at a wide variety of buildings, each with water-conserving fixtures. Both studies produced valuable information and insights that are used to update and revise the peak flow charts in this 4th edition of M22.

First study (2011 to 2017). IAPMO and ASPE in collaboration with WQA convened a task group to review methods for estimating peak demands in buildings. This initiative was in response to the increased use of water-conserving plumbing fixtures, fixture fittings, and appliances and the subsequent decreased demand for water in commercial buildings and private residences. The charge of the task group was to develop a probability model for predicting peak indoor water demand at single- and multifamily dwellings having water-conserving plumbing fixtures. Six types of indoor household fixtures were considered: bathtubs, clothes washers, dishwashers, faucets (kitchen and bathroom), showers, and toilets. The task group analyzed high-resolution (10-s) indoor water demands collected for two weeks at over 1,000 single-family homes in 62 US cities. The analysis led to the Water Demand Calculator (WDC), discussed later in this chapter as the recommended method for estimating peak demand in residential buildings. The WDC provides an estimate of the 99th percentile of peak indoor water use in single-family homes and multifamily apartments, based on the number and type of water fixtures in each household as specified by the user. In contrast to previous peak flow estimators, the WDC does not use fixture units or fixture values. Instead, the WDC uses “p-values” which represent the probability of fixture use during the hour of peak water demand. The WDC was incorporated into the 2018 Uniform Plumbing Code (IAPMO 2018b). It is available as an Excel spreadsheet from IAPMO’s website (www.iapmo.org/water-demand-calculator/) and as a smartphone app. The WDC is the recommended method for estimating peak water demand in residential buildings and is demonstrated later in this chapter.

Second study (2016 to 2019). The Water Research Foundation sponsored WRF project 4689, “Assessing Water Demand Patterns to Improve Sizing of Water Meters and Service Lines” (Mayer et al. 2020). The research project had two primary goals. The first was to collect peak demand flow data, fixture counts, and other pertinent information from large buildings with water-efficient plumbing fixtures (80 percent had 1–2-in. meters; 18 percent had a 3-in. meter; and 2 percent had a 4-in. meter). The second goal was to compare the measured peak water demand against the rated meter capacity and service line size at each building. Over 140 buildings were monitored by participating water utilities in three cities: Scottsdale, Ariz.; Denver, Colo.; and Westminster, Colo. The research team correlated high-resolution (10-s) flow data (from Scottsdale and Denver) and hourly flow data (from Westminster) to water meter sizes, building use, and the numbers and types of fixtures in multifamily and nonresidential buildings. The expected peak water use for buildings was estimated according to several different building codes and compared against observed water demands. In addition, the observed instantaneous peak water demands from residential buildings provided an independent data set to assess and verify the performance of peak flow predictions from the WDC. Among the key findings from this study, two are particularly relevant to M22:

- Measured peak flows in the buildings were well below the rated meter capacity.
- Demands from meter sizing design curves usually greatly exceeded measured flows.

ESTIMATING PEAK DEMAND FOR NONRESIDENTIAL BUILDINGS

Updated Demand Curves

This section provides guidelines for using the M22 approach to determine peak water demands in nonresidential buildings. The peak flow data collected during WRF project 4689 (Mayer et al. 2020) were used to update the existing water demand curves in the third edition of M22. Figure 4-1 shows more than 50,000 data points representing the top 1 percent of flows measured in 98 buildings for which fixture values were available at study sites in Denver, Scottsdale, and Westminster. The orange data points show