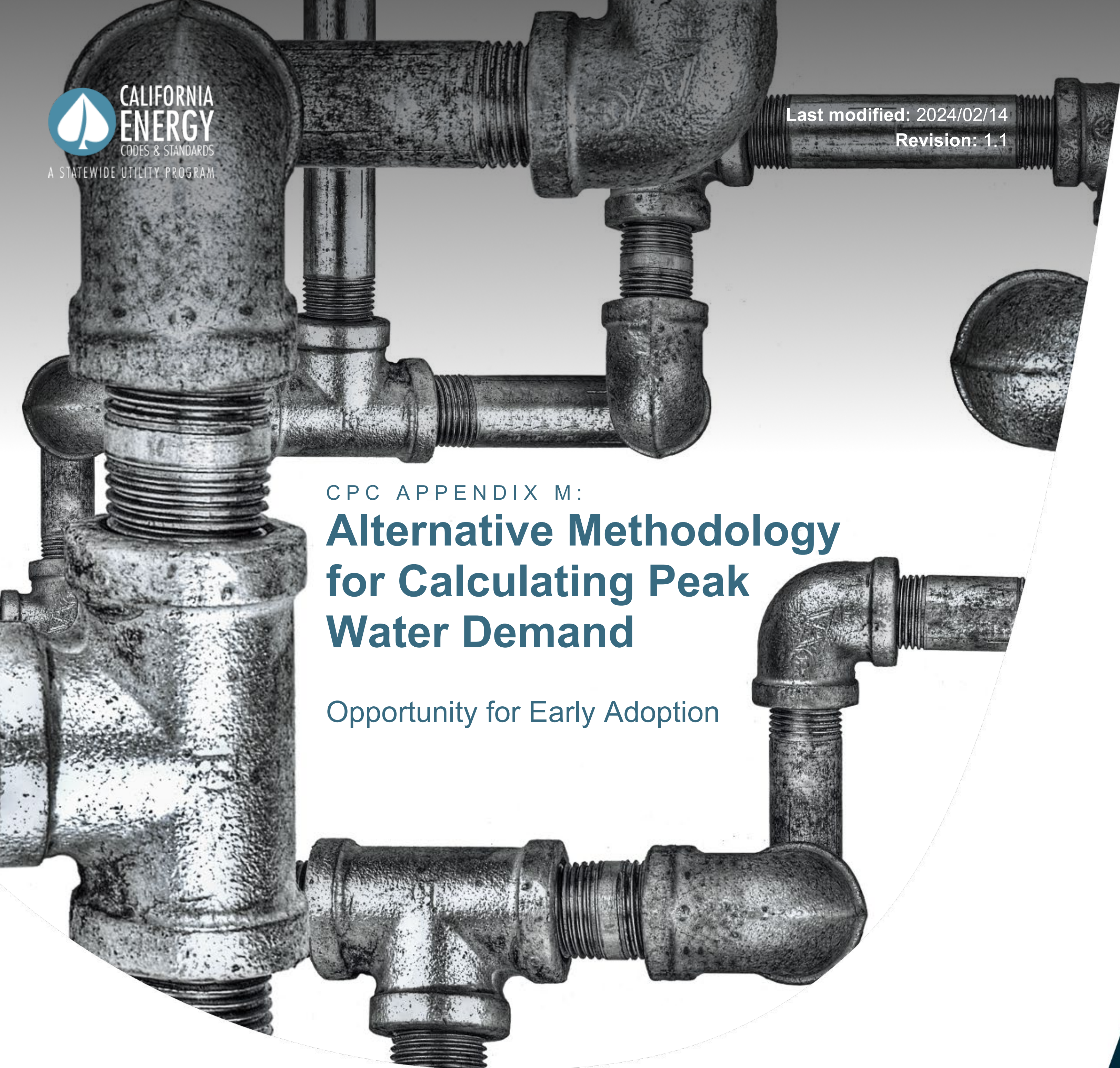

CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

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CPC APPENDIX M:

Alternative Methodology for Calculating Peak Water Demand

Opportunity for Early Adoption

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Pacific Gas and Electric Company

SOUTHERN CALIFORNIA EDISON
Energy for What's Ahead

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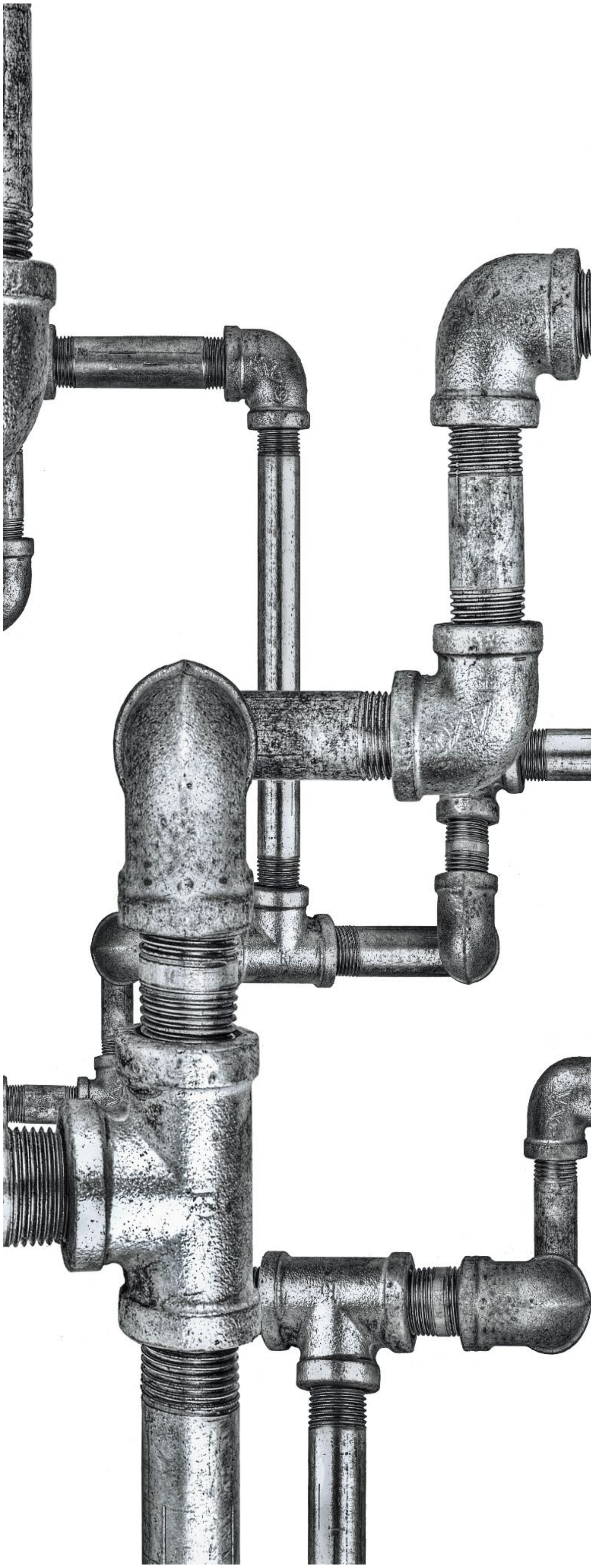

Acronym List

CBECC – California Building Energy Code Compliance

CBSC – California Building Standards Commission

CEC – California Energy Commission

CPC – California Plumbing Code

DHW – Domestic Hot Water

IAPMO – International Association of Plumbing and Mechanical Officials

gpm – Gallons per Minute

UPC – Uniform Plumbing Code

WDC – IAPMO Water Demand Calculator

WSFU – Water Supply Fixture Unit

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Executive Summary

In California, it is standard practice to determine peak water demand and supply pipe sizing for a building using the California Plumbing Code (CPC) Appendix A. CPC Appendix A is based on the Uniform Plumbing Code (UPC) Appendix A model code, which in turn uses the Hunter's curve developed in 1940 to estimate the water demand load. UPC Appendix M "Peak Water Demand Calculator" offers an alternative methodology for estimating the peak water demand (in gallons per minute) for the building supply, principal branches, and risers. The peak water demands derived using UPC Appendix M inform the recommended diameter of water supply pipes in new single family and multifamily buildings. The alternative approach of using UPC Appendix M methodology in conjunction with CPC Appendix A for pipe sizing yields lower design flow rates and smaller distribution piping when compared to using only CPC Appendix A.

On August 1, 2023, the California Building Standards Commission approved the adoption of UPC Appendix M into the CPC, effective July 1, 2024. The statewide adoption of UPC Appendix M into the CPC enables the voluntary use of Appendix M for residential occupancies that fall within the jurisdiction of the California Department of Housing and Development. The statewide adoption makes it equally convenient to use CPC Appendix A or Appendix M for estimating peak water demand in single family and multifamily dwellings.

This report shows the results of analysis (Figure 1) comparing the monitoring data for hot water flow rates in 20 multifamily buildings to design estimates for the peak hot water demand based on 2022 CPC Appendix A (red crosshairs), 2021 International Plumbing Code (IPC) Appendix E (pastel red crosshairs), and 2022 CPC Appendix M (blue crosshairs).

The red crosshairs in Figure 1 demonstrate that peak water demand estimates calculated using the standard practice in CPC Appendix A are 5 to 27 times larger than the observed peak flow rates. The pastel red crosshairs in Figure 1 represent peak water demand estimates calculated according to 2021 International Plumbing Code (IPC) Appendix E and are included for additional comparison. Overestimating peak water flow rates results in pipe diameters that are much larger than needed for modern buildings.

The blue crosshairs in Figure 1 demonstrate that CPC Appendix M, referred to as the Water Demand Calculator (WDC), can be used to more accurately, but still conservatively, calculate peak water flow rates in residential occupancies. The design estimates calculated using CPC Appendix M are between 2 and 6 times the observed flow rates for the 20 multifamily buildings in our dataset.

Using the WDC in conjunction with CPC Appendix A for sizing water pipes in residential occupancies provides upfront and ongoing cost savings, water savings, embedded energy savings, and natural gas savings. The benefits of avoiding water pipe oversizing also include reduced public health and safety risk and improved water quality due to shorter water dwell times within plumbing systems as well as reduced embodied and operational carbon emissions due to material savings and energy reductions.

For single family and multifamily buildings, the conservative estimates of water savings range from 234 to 1,096 gal per dwelling unit per year, embedded electricity savings from 1.1 to 5.3 kWh per dwelling unit per year, and natural gas savings from 2.8 to 7.7 therms per dwelling unit per year depending on the residential building type. Conservatively, for multifamily buildings, upfront construction cost savings are estimated to be between $600 and $1,200 per dwelling unit.

With this statewide adoption, there is an opportunity for local jurisdictions to facilitate the use of the alternative methodology on construction projects and to evaluate whether mandatory use of CPC Appendix M for estimating peak water demands in residential buildings is appropriate within their jurisdiction.

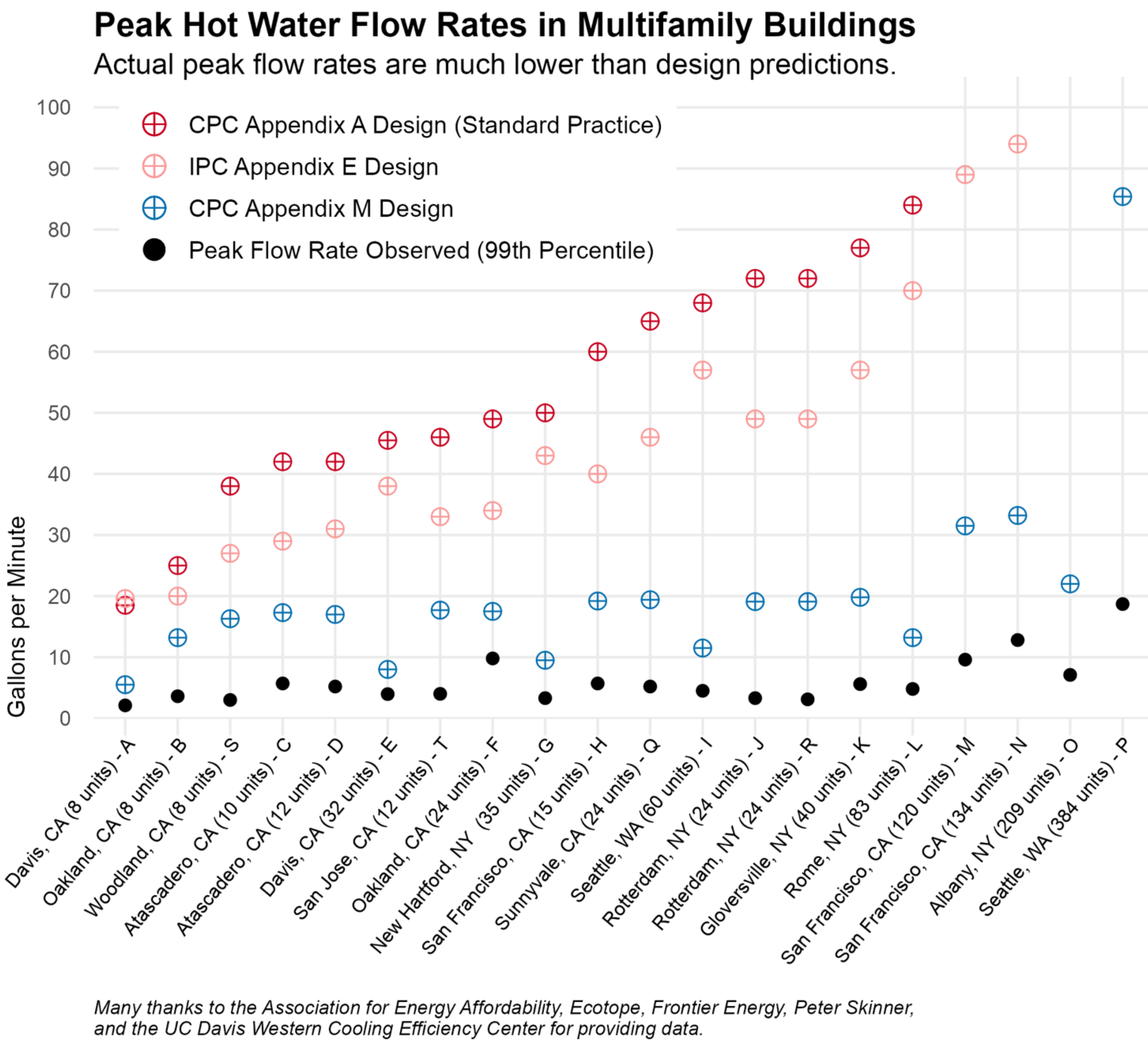

Figure 1. Comparison of Design Predictions to Actual Peak Flow Rates

Data for total of 20 multifamily buildings were collected during the period of 2019 to 2022. Monitoring period ranged from nine days to over two years depending on the building. Logging interval ranged from 1 to 60 seconds depending on the building. Buildings are ordered by CPC Appendix A design value. CPC Appendix A values for buildings M, N, O, and P exceeded 100 gallons per minute and are not included in this figure. Buildings Q, R, S, and T were added after the initial analysis, and appear alphabetically out of order.

1 Introduction

The engineering rules for sizing water supply piping were published by Roy Hunter in the early 1940s and incorporated into the model plumbing codes shortly thereafter. Modern plumbing fixtures and appliances operate with significantly less water. However, the rules for pipe sizing in the plumbing codes and engineering handbooks have not been updated to take account of modern materials and plumbing fixtures and appliances. The report explains the benefits of using the Water Demand Calculator (WDC) method to right-size the supply piping for our current plumbing materials and flow rates. The Additional Information and Analysis[1] section of the report contains details supporting the analysis and exploring related issues.

Design flow rates, necessary to determine pipe sizes for single family and multifamily dwellings, can be estimated by following the WDC procedure in CPC Appendix M. These flow rates, instead of those estimated using the current standard practice Water Supply Fixture Unit (WSFU) method in CPC Appendix A, are then incorporated into the pipe size selection method contained in the remainder of CPC Appendix A. This approach is summarized in the following clauses from CPC Appendix M:

> **M101.1 Applicability.** This appendix provides a method for estimating the demand load for the building water supply and principal branches for single- and multi-family dwellings with water-conserving plumbing fixtures, fixture fittings, and appliances.
>
> **M 102.2 Water Demand Calculator.** The estimated design flow rate for the building supply and principal branches and risers shall be determined by the IAPMO Water Demand Calculator available for download at https://www.iapmo.org/water-demand-calculator/
>
> **M 102.7 Size of Water Piping per Appendix A.** Except as provided in Section M 102.0 for estimating the demand load for single- and multi-family dwellings, the size of each water piping system shall be determined in accordance with the procedure set forth in Appendix A. After determining the permissible friction loss per 100 feet (30 480 mm) of pipe in accordance with Section A 104.0 and the demand flow in accordance with the Water Demand Calculator, the diameter of the building supply pipe, branches and risers shall be obtained from Chart A 105.1(1) through Chart A 105.1(7), whichever is applicable, in accordance with Section A 105.0 and Section A 106.0. Velocities shall be in accordance with Section A 107.0. Appendix I (IS 31), Figure 3 and Figure 4 shall be permitted when sizing PEX systems.

On August 1, 2023, the California Building Standards Commission approved the adoption of Uniform Plumbing Code (UPC) Appendix M into the California Plumbing Code (CPC). UPC Appendix M is available for statewide use effective July 1, 2024. The statewide adoption of UPC Appendix M into the CPC enables the voluntary use of Appendix M for residential occupancies that fall within the jurisdiction of the California Department of Housing and Development. The statewide adoption makes it equally convenient to use CPC Appendix A or Appendix M for estimating peak water demand in residential water pipes.

This adoption is a culmination of an advocacy effort that started in January 2021. In November 2021, the Statewide Utility Codes and Standards Team submitted a Title 24 Petition to adopt UPC Appendix M into the CPC during the 2022 Intervening Code Adoption Cycle. The petition was accompanied by letters of support from 20 organizations including the California State Legislature, building design firms, water districts, and water efficiency advocates.

[1] This report refers to "Additional Information and Analysis" in place of traditional "Appendices" to reduce confusion with frequent references to Appendices found in the Uniform Plumbing Code (UPC) and California Plumbing Code (CPC).

2 Benefits of Using the Water Demand Calculator

2.1 Overview

Using CPC Appendix M to calculate peak water demand for the building supply, principal branches, and risers and then subsequently using these peak demand values in CPC/UPC Appendix A when sizing water pipes provides:

- Construction cost savings due to:
  - Smaller diameter pipes and fittings, valves, pumps, and other equipment,
  - Smaller inside diameter pipe insulation, and
  - Smaller water service entrance size, resulting in smaller water meter size with lower connection fees.
- Ongoing cost savings due to:
  - Water savings from faster hot water delivery, resulting in smaller monthly water service charges and lower associated volumetric sewer charges,
  - Energy savings due to decreased heat loss in the hot water distribution system, and
  - Embedded energy savings for the water and wastewater utilities due to customer indoor water savings.
- Reduced public health and safety risk and improved water quality due to:
  - Shorter water dwell times within plumbing systems. Each floor plan determines the distance between the mechanical room and the fixtures. CPC Appendix M does not change the length of the pipe, only the diameter. With the pipe diameter on each segment reduced, the pipe volume will be reduced.
- Reduced carbon emissions due to:
  - Material savings and energy reductions.

Other states adopted UPC Appendix M, including Nevada (2018), North Dakota (2020), Hawaii (2020), Oregon (2021), Montana (2022), New Mexico (2022), New Jersey (2022), Washington (2023). In Wisconsin (2022), the Water Demand Calculator was approved as an alternate standard through the end of May 2027 for single family and multifamily dwellings. In 2019, Foster City and San Jose, California, adopted the voluntary use of UPC Appendix M. Other California local jurisdictions followed: County of Santa Cruz (2022) and Oakland (2023).

As of this report’s writing, as part of the 2025 California Energy Code update cycle, the California Energy Commission (CEC) is considering a prescriptive requirement to estimate peak water demand in multifamily buildings with the use of CPC Appendix M. Also, as of this report’s writing, the City of Seattle is considering the adoption of mandatory use of UPC Appendix M in new construction multifamily buildings; the draft code language is in Draft 2021 Seattle Energy Code.

Plumbing designs based on CPC Appendix M result in smaller pipe diameters for the water supply and principal branches compared to the current standard practice in UPC/CPC Appendix A. Compact hot water distribution designs result in shorter pipe lengths to deliver hot water at a fixture. The addition of CPC Appendix M would be consistent with the existing requirements in California’s Appliance Efficiency Regulations (Title 20) that specify that plumbing fixtures, fixture fittings, and appliances sold in California be water efficient. It also complements the requirements for compact hot water distribution design in the California Energy Code (Title 24, Part 6) and the California Green Building Standards Code (Title 24, Part 11 or CALGreen).

2.2 Water and Energy Savings

Reducing the volume of water in the piping will result in structural savings of water and energy. If the pipe volume is reduced by half, there is half as much water to clear out of the hot water piping at the beginning of a hot water event, and there is half as much water that will cool down when the event is over. Water use is lowered by reducing the time users spend allowing water to flow while waiting for hot water to arrive. Energy savings will be achieved in three ways:

- Less hot water in the branch and in-unit piping that cools down between uses means less heat loss.
- Less energy is needed for keeping a smaller diameter recirculation loop from a central water heating system hot (applicable to multifamily buildings).
- Less water running down the drain while waiting for the hot water to arrive results in associated embedded electricity savings.

Table 1 summarizes preliminary conservative estimates for annual water and energy savings per dwelling unit. The five multifamily buildings included one building with data monitoring equipment deployed on the domestic hot water system and four prototype buildings that were based on designs documented in the 2022 Codes and Standards Enhancement (CASE) Report on Multifamily Domestic Hot Water (DHW) Distribution. For single family and multifamily buildings, the conservative estimates of water savings range from 234 to 1,096 gal per dwelling unit per year, embedded electricity savings from 1.1 to 5.3 kWh per dwelling unit per year, and natural gas savings from 2.8 to 7.7 therms per dwelling unit per year depending on the residential building type.

Table 1. Estimated Annual Water and Energy Impacts Per Dwelling Unit

Building Type	Water Savings (gal/Dwelling Unit per Year)	Embedded Electricity Savings (kWh/Dwelling Unit per Year)	Natural Gas Savings (therms/Dwelling Unit per Year)
Low-Rise Loaded Corridor, 3-story, 24-unit building in Sunnyvale, CA	404	2.0	7.1
Prototype Low-Rise Garden Style, two-story, eight-unit building	257	1.2	2.8 – 3.0
Prototype Mid-Rise Loaded Corridor, three-story, 36-unit building	320	1.6	3.7 – 4.0
Prototype Mid-Rise Mixed-Use, five-story, 96-unit building	234	1.1	4.0 – 4.5
Prototype High-Rise Mixed-Use, 10-story, 108-unit building	248	1.2	4.4 – 4.9
Single Family Dwelling	1,096	5.3	7.7

Section 5.2 Calculation Methodology for Estimating Water and Energy Savings provides more details on calculation methodology of these water and energy impacts. For an additional reference on water, energy, and carbon savings from applying the WDC, link to the 2023 Arup Report on Energy and Carbon Savings Opportunities is provided in Section 6 Additional Resources of this report.

2.3 Cost Savings

In 2020, Gary Klein and Associates, Inc. evaluated possible approaches to plumbing design of a 92-unit multifamily building in Seattle, Washington. Each apartment had one bathroom (shower, lavatory faucet, and toilet) and a kitchen (kitchen faucet only). He calculated the peak water flow rates using the methods in both UPC/CPC Appendix A and Appendix M and then used the UPC/CPC Appendix A methodology with each value to size the piping. The configuration of the plumbing was the same in both calculations. The differences in final pipe diameters were due to the different methods of estimating peak water flow rates. Water velocities and pressure drops were considered when selecting the pipe diameters from the building entrance to the branches to each apartment.

Table 2 shows the comparisons of peak flow rates and resulting pipe sizes for the building water supply and the hot water branch. The CPC Appendix M method predicts a significantly smaller peak water demand: both the building water supply and the hot water branch are predicted by Appendix M to experience more than nine times less demand than predicted by Appendix A. The CPC Appendix A predictions for pipe diameter result in 3-inch pipe for both the building water supply and the hot water branch. Using CPC Appendix M peak flow rates would result in these pipe diameters being right-sized down to 1-inch pipe. The corresponding reduction in internal pipe volume for the whole building is approximately more than 50%.

The reduction in construction costs from right-sizing the supply piping is approximately $600 to $1,200 per apartment. The operational cost savings due to less water and energy use will continue for the life of the building. Since smaller pipes means less cooled water in the pipes and less water wasted while waiting for hot water to arrive, water and associated sewer charges could be reduced.

Table 2. Comparison of Peak Water Demand and Pipe Size for a 92-unit Multifamily Building

	Building Water Supply		*Hot Water Branch*	
Sizing Method	**Peak Flow Rate (gpm)**	**Pipe Size (inches)**	**Peak Flow Rate (gpm)**	**Pipe Size (inches)**
CPC Appendix A	127	3	105	3
CPC Appendix M	14	1	11	1

Note: The unit of gpm stands for gallons per minute.

Please see Section 5.3 Additional Information on Estimated Cost Savings for more details on the approach to calculate cost savings. For additional references on cost savings, links to the 2020 Stantec Report and the 2021 Alliance for Water Efficiency Report are provided in Section 6 Additional Resources of this report.

3 Results of Comparing Design Predictions to Observed Peak Flow Rate Values

Figure 2 demonstrates that standard-practice design estimates (red line) consistently overpredict water demand compared to actual peak hot water flow rates in occupied multifamily buildings (black dots). Actual peak flow rate is defined in this report as the 99th percentile of non-zero flow rates observed over each study's duration. The 20 multifamily buildings analyzed range in size from 8 to 384 apartments, with each building illustrated as a black dot on the top graph in Figure 2. The bottom graph in Figure 2 zooms on the cluster of buildings with fewer than 300 WSFUs. Overestimating peak water flow rates results in pipe diameters that are much larger than needed for modern buildings. Table 4 provides the occupancy types and fixture counts for each building. The alphabetically labeled buildings continue to be referenced by letter in various tables and figures that follow in this report.

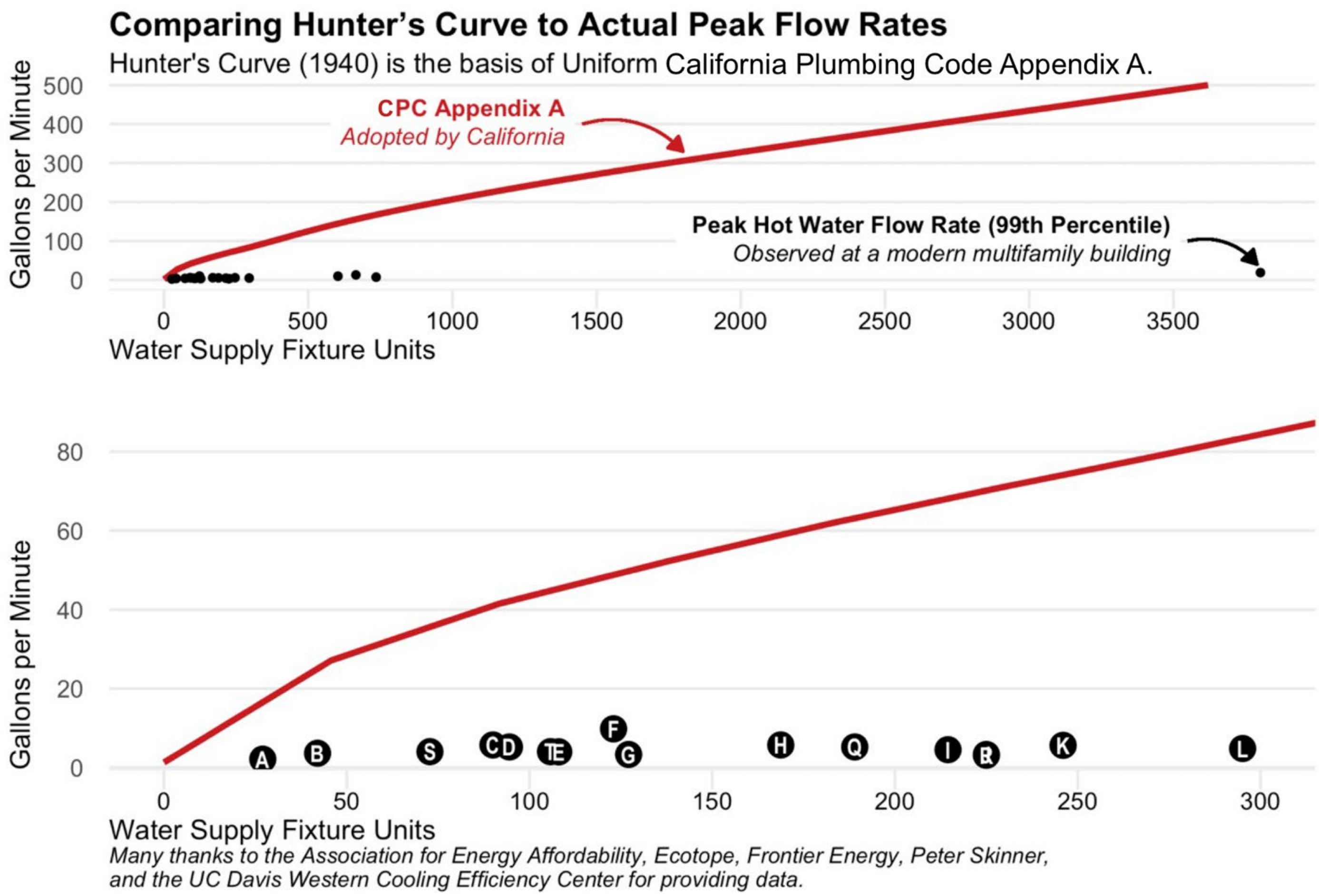

Figure 2. Comparing CPC Appendix A (Hunter's Curve) to Actual Peak Flow Rates in Multifamily Buildings

The top graph shows data for 20 multifamily buildings, ranging in size from 8 to 384 apartments, analyzed to date. The bottom graph zooms in on the cluster of buildings with fewer than 300 WSFUs. Actual Peak Flow Rate means 99th percentile of non-zero flows for all sampling intervals over the entire monitoring period.

Figure 3 compares the monitoring data for hot water flow rates in 20 multifamily buildings to design estimates for the peak hot water demand based on 2022 CPC Appendix A (red crosshairs), 2021 IPC Appendix E (pastel red crosshairs), and 2022 CPC Appendix M (blue crosshairs). CPC Appendix A values for buildings M, N, O, and P are out of scale and are provided in Figure 2 and Table 3.

The red crosshairs in Figure 3 demonstrate that peak water demand estimates calculated using the standard practice in CPC Appendix A are 5 to 27 times larger than the observed peak flow rates, as summarized in Table 3. The pastel red crosshairs in Figure 3 represent peak water demand estimates calculated according to IPC Appendix E and are included for additional comparison. IPC Appendix E methodology incorporates the Hunter's curve developed in 1940.

The blue crosshairs in Figure 3 demonstrate that CPC Appendix M, also referred to as the WDC, can be used to more accurately, but still conservatively, calculate peak water flow rates in residential occupancies. The design estimates calculated using CPC Appendix M are between 2 and 6 times the observed flow rates for the 20 multifamily buildings in our dataset.

Validating the WDC for multifamily buildings was of special interest because the probabilities of peak water use in the WDC were based on analyzing data for over 1,000 single family dwellings. Version 1 of the WDC used these unaltered probabilities for multifamily buildings. WDC Version 2 has some adjustments that slightly lower the probabilities of simultaneous use in multifamily buildings.

For additional details about the analyzed datasets, see Section 5.1 Details Included in the Analysis. For more details on peak flow rate metrics, see Section 5.5.4 Experimental and Analytical Considerations of Assessing Design Prediction Performance. For the overview of Hunter's methodology and the reasons the Hunter's curve is no longer relevant in modern buildings, refer to 2020 ASCE technical paper "Probability of Water Fixture Use during Peak Hour in Residential Buildings" by T. Omahomi et al.

The team primarily analyzed actual data for hot water flow rates because hot water data was more available from energy efficiency projects not related to water pipe sizing. For two similar multifamily buildings in a development complex in Rotterdam, New York, the team obtained not only hot but also cold water flow data. This data that is explored in Section 5.4 Comparing Cold Water and Total Water Use to Appendix M Estimates illustrated that the CPC Appendix M design values were not exceeded by peak water flow rates of hot, cold, or total water flow.

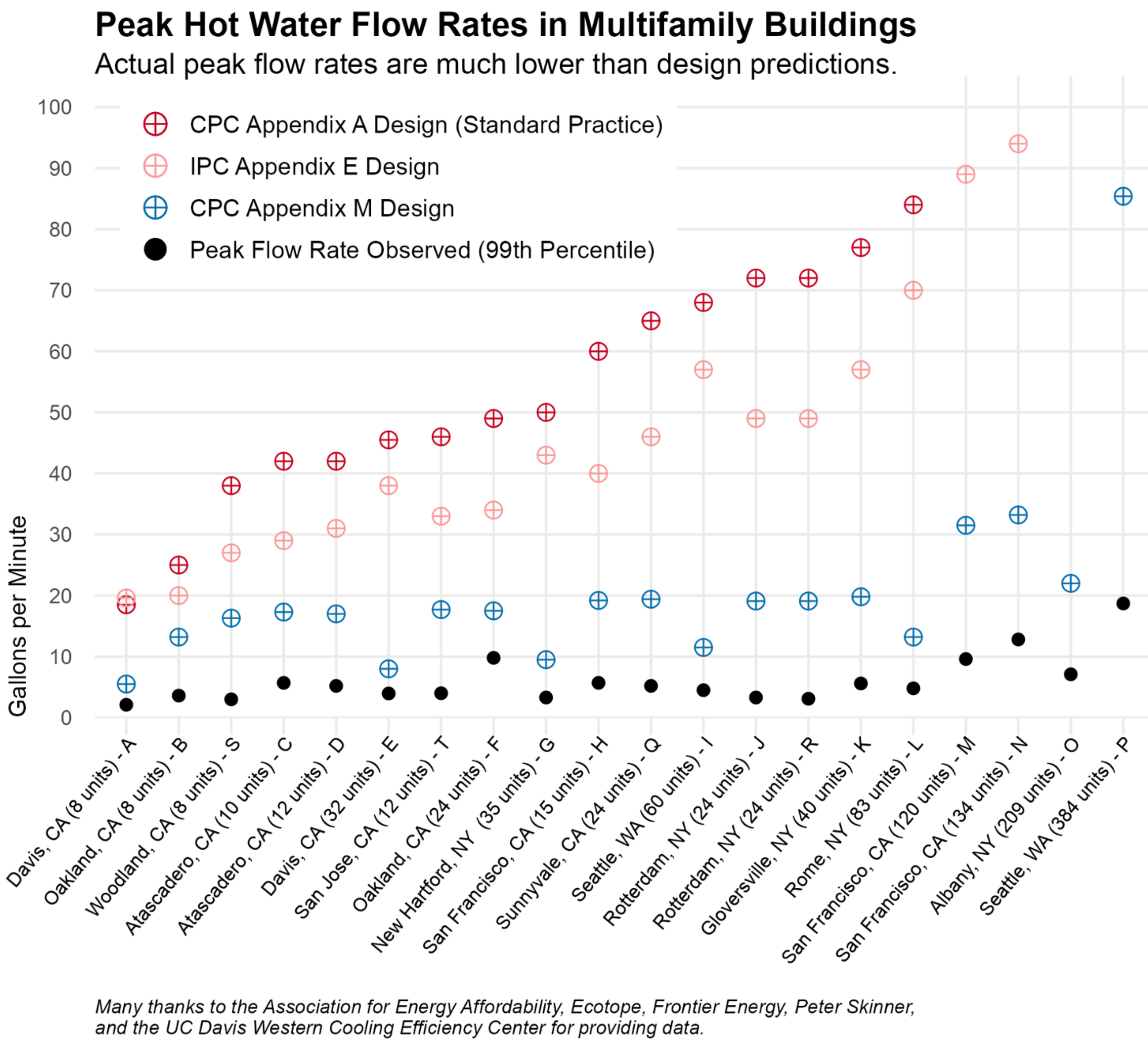

Figure 3. Comparison of Design Predictions to Actual Peak Flow Rates

Data for total of 20 multifamily buildings were collected during the period of 2019 to 2022. Monitoring period ranged from nine days to over two years depending on the building. Logging interval ranged from 1 to 60 seconds depending on the building. Buildings are ordered by CPC Appendix A design value. CPC Appendix A values for buildings M, N, O, and P exceeded 100 gallons per minute and are not included in this figure. Buildings Q, R, S, and T were added after the initial analysis, and appear alphabetically out of order.

Table 3. Summary of Detailed Data for the Analyzed Multifamily Buildings

		Monitoring Data					*CPC Appendix M*		*CPC Appendix A*		
	City	Monitored Apartments	Monitoring Period (day)	Logging Interval (sec)	Time at Zero Flow	Study Peak (gpm)	Design (gpm)	Design Relative to Study Peak	WSFU	Design (gpm)	Design Relative to Study Peak
A	Davis, CA	8	304	15	87%	2.1	6	3x	27	19	9x
B	Oakland, CA	8	10	1	-	3.6	13	4x	42	25	7x
C	Atascadero, CA	10	257	60	-	5.7	17	3x	94	42	7x
D	Atascadero, CA	12	257	60	-	5.2	17	3x	97	42	8x
E	Davis, CA	32	304	15	56%	4.0	8	2x	108	46	11x
F	Oakland, CA	24	14	1	48%	9.8	18	2x	123	49	5x
G	New Hartford, NY	35	26	60	69%	3.3	10	3x	127	50	15x
H	San Francisco, CA	15	9	1	-	5.7	19	3x	174	60	11x
I	Seattle, WA	60	823	60	-	4.5	12	3x	215	68	15x
J	Rotterdam, NY	24	18	60	38%	3.3	19	6x	234	72	22x
K	Gloversville, NY	40	12	60	-	5.6	20	4x	261	77	14x
L	Rome, NY	83	15	60	37%	4.8	13	3x	295	84	18x
M	San Francisco, CA	120	12	1	-	9.6	32	3x	603	143	15x
N	San Francisco, CA	134	12	1	38%	13	33	3x	665	155	12x
O	Albany, NY	209	21	60	-	7.1	22	3x	735	168	24x
P	Seattle, WA	384	609	60	8%	19	85	5x	3,946	500	27x
Q	Sunnyvale, CA	24	272	60	-	5.4	19	4x	198	65	12x
R	Rotterdam, NY	24	19	1	-	3.1	19	6x	234	72	23x
S	Woodland, CA	9	128	60	84%	4	16	4x	76	38	10x
T	San Jose, CA	12	59	60	72%	4	18	4x	110	46	12x
							Median	**3x**			**12x**

Notes: Study Peak is the 99th percentile of non-zero hot water flow rates observed during the monitoring period. WSFU stands for Water Supply Fixture Units. Percent Time with Zero Flow is not displayed where monitoring issues may have impacted the accuracy of the metric. For building P, the WSFU exceeds the CPC Appendix A design curve, therefore the last value on the design curve was used. Detailed information on building occupancy during the study periods for each building is not available. The requirement for a dataset to be included in this analysis was a minimum occupancy being greater than 80% during the study period.

Table 4. Summary of Fixture Counts for the Analyzed Multifamily Buildings

	City	Monitored Apartments	Occupancy Type	Combo Bath /Shower	Lavatory Faucet	Shower	Water Closets	Dish-washer	Kitchen Faucet	Clothes Washer	Total Fixtures
A	Davis, CA	8	MF Low Income	0	8	8	8	0	8	0	32
B	Oakland, CA	8	MF Market Rate (Rent Controlled)	8	8	0	8	0	8	1	33
C	Atascadero, CA	10	MF Low Income	18	18	0	18	10	10	0	74
D	Atascadero, CA	12	MF Low Income	18	18	0	18	12	12	0	78
E	Davis, CA	32	MF Low Income	0	32	32	32	0	32	0	128
F	Oakland, CA	24	MF Market Rate	24	24	0	24	0	24	2	98
G	New Hartford, NY	35	MF Senior	0	35	35	35	0	35	3	143
H	San Francisco, CA	15	MF Low Income	24	24	0	24	15	15	15	117
I	Seattle, WA	60	MF Senior Low Income	0	60	60	60	0	60	4	244
J	Rotterdam, NY	24	MF Net Zero (Mixed Occupancy)	24	28	4	28	24	24	24	156
K	Gloversville, NY	40	MF Low-and-Moderate Income	40	40	0	40	40	40	2	202
L	Rome, NY	83	MF Senior	0	83	83	83	0	83	5	337
M	San Francisco, CA	120	MF Low Income	120	120	0	120	0	120	6	486
N	San Francisco, CA	134	MF Low Income	134	134	0	134	0	134	4	540
O	Albany, NY	209	MF Senior	0	209	209	209	0	209	10	846
P	Seattle, WA	384	MF Market Rate	454	565	0	565	384	384	384	2,736
Q	Sunnyvale, CA	24	MF Low Income	36	36	0	36	24	24	0	189
R	Rotterdam, NY	24	MF Net Zero (Mixed Occupancy)	24	28	4	28	24	24	24	156
S	Woodland, CA	9	MF Low Income	14	14	0	14	9	9	0	60
T	San Jose, CA	12	MF Low Income	21	21	0	21	12	12	0	87

Notes: The CPC Appendix M design flow rate is determined based on fixture counts, probabilities of use, and fixture flow rates. The shower type in apartments in a multifamily building significantly impacts CPC Appendix M design flow rate. A building with combo bath/showers will have higher design flow rate compared to the same building with showers only. For hot water, design demand calculations exclude water closets since water closets use cold water only.

4 Conclusions and Recommendations

CPC Appendix M can be used to more accurately, but still conservatively, estimate peak water flow rates in residential occupancies. Using the WDC peak flow estimates for sizing water pipes in residential occupancies provides upfront and ongoing cost savings, water savings, embedded energy savings, and natural gas savings. The benefits of avoiding oversized water pipes also include reduced risk to public health and safety and reduced carbon emissions due to material savings and energy reductions.

On August 1, 2023, the California Building Standards Commission approved the adoption of UPC Appendix M into the CPC. UPC Appendix M will be available for statewide use, effective July 1, 2024. The statewide adoption of UPC Appendix M into the CPC enables the voluntary use of Appendix M for residential occupancies that fall within the jurisdiction of the California Department of Housing and Development.

With the statewide adoption, there is an opportunity for local jurisdictions to facilitate the use of the alternative methodology on construction projects and to evaluate whether mandatory use of CPC Appendix M is appropriate within their jurisdiction.

Jurisdictions interested in exploring the mandatory use of CPC Appendix M will benefit from following the implementation of proposed 2021 Seattle Energy Code that, if adopted, would mandate the use of UPC Appendix M in the City of Seattle. As of this report's writing, it is anticipated that the proposed measure in 2021 Seattle Energy Code will be adopted and become effective July 1, 2024.[2]

Recommendations for next steps include:

- Training Plan Checkers including 3rd Party Plan Checkers to ease the permitting process of plumbing designs that use the WDC.
- Implementing an outreach and educational program to raise awareness about this alternative methodology among stakeholders involved in construction industry such as building officials, plumbing designers, builders, etc.

Free educational resources include:

- Resources posted on Local Energy Codes website (this report, the report summary, and the fact sheet) at https://localenergycodes.com/content/reach-codes/energy-plus-water-1.
- Resources posted on the International Association of Plumbing and Mechanical Officials website (short videos, announcement of webinars and trainings on the WDC) at https://www.iapmo.org/we-stand/water-demand-calculator/water-demand-calculator-california/.

[2] Draft 2021 Seattle Energy Code: https://www.seattle.gov/documents/Departments/SDCI/Codes/ChangesToCodes/2021SeattleCodeAdoption/2021DraftSeattleEnergyCode.pdf
Updates on the code adoption status: https://www.seattle.gov/sdci/codes/changes-to-code/2021-seattle-code-adoption

5 Additional Information and Analysis

5.1 Additional Information on Calculating Design Flow Rates and Processing of Datasets

In standard practice (UPC/CPC Appendix A methodology), fixture counts are converted into Water Supply Fixture Units (WSFUs), which in turn are used to determine the design flow rate based on a lookup table codified in UPC/CPC. For our analysis, WSFUs were calculated based on the conversion factors in UPC/CPC Appendix A and are included in Table 5 for convenience. We also presented the WSFU to gpm conversion in graphical form in Figure 2 and Figure 3.

The concept of WSFUs is not used in the UPC/CPC Appendix M methodology; the design flow rate is determined based on fixture counts, probabilities of use, and fixture flow rates. For our analysis, default fixture flow rates from the WDC were used (except for two new construction buildings in Davis, California, and one new construction building in Sunnyvale, California) and are included in the table below for convenience. The two buildings in Davis have kitchen faucets rated at 1.8 gpm, so a value of 1.8 was used for kitchen faucet fixture flow when determining UPC Appendix M design estimate (conservative approach for comparing observed vs. predicted flow rates). For one building in Sunnyvale built in 2019, 1.8 gpm flow rate was used for kitchen faucets and 1.2 gpm for lavatory faucets in the WDC. These flow rates are currently the maximums allowed by Title 20 and CALGreen and should be used when designing with the WDC in California.

Datasets were assessed for irregularities with the intent of conservatively adjusting any monitoring issues that could lead to an underestimation of the peak flow rate. Some raw data demonstrated irregularities at low flow rates indicating leaks or issues with low flow rate calibration issues. Some data donors had previously assessed their data for irregularities and adjusted to compensate. In other cases, monitoring instrumentation design or placement limited precision and accuracy. Table 6 summarizes data quality issues found or reported in the analyzed datasets and the adjustments, if any, that were applied.

Table 5. Conversion factors for WSFUs and default flow rates from the WDC

	Conversion Factor to WSFU			*The WDC*
	Total Building Supply	**Hot Water Branch**	**Cold Water Branch**	**Default Fixture Flow Rate (gpm)**
Bathtub	4	3	3	5.5
Combination Bath/Shower	4	3	3	5.5
Lavatory Faucet	1	0.75	0.75	1.5
Shower	2	1.5	1.5	2.0
Water Closet (cold branch ONLY)	2.5	0	2.5	3.0
Dishwasher (hot branch ONLY)	1.5	1.5	0	1.3
Kitchen Faucet	1.5	1.125	1.125	2.2
Clothes Washer	4	3	3	3.5

Notes: Dishwasher is connected to hot water line only; water closet is connected to cold water line only. For the 20 buildings used in our analysis of hot water flows, water closets were not included.

Table 6. Summary of Data Quality Notes for the Analyzed Multifamily Buildings

	City	**(1) Monitoring data includes hot water use in common and/or utility areas.** *The CPC Appendix M design value does not include this additional water use.*	**(2) Raw data demonstrates irregularities at low flow rates.** *To limit underestimation of the peak flow rate, a lower-bound cut-off was applied. This either eliminated negative values or removed low-flow values deemed to be "noise."*	**(3) Raw data demonstrates irregularities at high flow rates.** *High outliers were removed either by the data donor or when deemed highly implausible given fixture counts.*	**(4) Data precision is limited.** * *to the ones unit* + *to 0.75 gpm increments*
A	Davis, CA			X	
B	Oakland, CA		X		
C	Atascadero, CA			X	
D	Atascadero, CA			X	
E	Davis, CA			X	
F	Oakland, CA				
G	New Hartford, NY	X	X		
H	San Francisco, CA		X		
I	Seattle, WA				X+
J	Rotterdam, NY	X			
K	Gloversville, NY	X	X		
L	Rome, NY				
M	San Francisco, CA		X		
N	San Francisco, CA				
O	Albany, NY	X	X		
P	Seattle, WA	X			X+
Q	Sunnyvale, CA		X		
R	Rotterdam, NY		X		
S	Woodland, CA			X	X*
T	San Jose, CA			X	X*

Note: Fixes applied for data quality issues (1) and (2) could lead to overestimation of the peak flow rate, while (3) could lead to underestimation of the peak flow rate. Fix (2) applied a cutoff of 0 or 0.1 gpm to marked buildings, except for building Q, where noise was significant and a 0.35-gpm cutoff was applied. This fix to building Q data increased the peak flow rate metric by 0.3 gpm.

5.2 Additional Information on Estimated Water and Energy Savings

The CPC Appendix M water demand sizing methodology yields lower design flow rates compared to the baseline case of using the CPC Appendix A demand sizing approach based on WSFUs. Lower design flow rates mean smaller distribution piping as well as energy and water savings.

The team estimated water and energy savings for six buildings listed in Table 7. The five multifamily buildings included one building with data monitoring equipment deployed on the domestic hot water system and four prototype buildings that were based on building designs documented in the 2022 Codes and Standards Enhancement (CASE) Report on Multifamily Domestic Hot Water (DHW) Distribution.

Table 7. Buildings Used to Estimate Water and Energy Savings

Building	DHW System	Units Served/ Monitored	Notes
Multifamily Sunnyvale Building (Not Prototype)	Simulated Central Gas Water Heating Plant	24	Water is distributed from the garage to risers, each with a return. Risers are thermally balanced with thermostatic balancing valves, and water is circulated via a pressure-based variable speed recirculation pump.
Multifamily Prototype: Low-Rise Garden	Same as above	8	Water is distributed from the ground level to risers, each with a return.
Multifamily Prototype: Low-Rise Loaded Corridor	Same as above	36	Water is distributed from the ground level to risers, each with a return.
Multifamily Prototype: Mid-Rise Mixed Use	Same as above	88	Water is distributed from the ground level to risers, each with a return.
Multifamily Prototype: High-Rise Mixed Use	Same as above	117	Water is distributed from two primary distribution loops on the ground floor and halfway up the building. Each primary distribution loop is connected to risers with returns.
Single Family Dwelling	Not applicable	Not applicable	1,290-square foot house with one bathroom, a laundry room, and a kitchen with a dishwasher; no recirculation loop.

The team used both methods – CPC Appendix A and CPC Appendix M – for each building to estimate the peak flow rate and used these values to determine the associated pipe diameters. Monitoring data from the Atascadero two buildings (Building C or D) was used to define draw patterns of hot water use since the team had individual unit DHW monitoring data for that building. Based on draw patterns measured at individual 2-bedroom and 3-bedroom apartments in Building C and D, the team derived the average number of hot water events per apartment. The team assumed the calculated average number of hot water events per apartment is applicable to apartments in all five multifamily buildings and the single family dwelling.

For all buildings (multifamily buildings and single family dwelling), the team calculated energy and water savings by comparing in-unit structural water and energy losses for pipe sizes derived using:

- The baseline approach (or WSFU method) of using CPC Appendix A methodology for sizing water demand and pipes and
- The alternative approach (or WDC method) of using CPC Appendix M in conjunction with CPC Appendix A (Appendix M for sizing water demand and Appendix A for sizing pipes).

Natural gas savings for recirculation loop heat loss were calculated and reported for the four prototype multifamily buildings previously in the 2022 CASE Report on Multifamily DHW Distribution. The reported natural gas savings vary based on climate zone. The team calculated natural gas savings from the recirculation loop for the Sunnyvale building. For the recirculation loop natural gas savings, the primary differences between reported savings in the 2022 CASE Report on Multifamily DHW Distribution for the prototype buildings and calculated savings for the Sunnyvale building are the location of the piping and assumed ambient temperatures. The Sunnyvale building has a parking garage on the ground floor, where the water heating system and a significant portion of distribution piping are located. The team used the average annual outdoor ambient temperature for any piping in the garage, whereas, in the 2022 CASE Report, all piping was assumed to be in the interior of the buildings. Some electricity savings from a recirculation pump are expected due to the reduction in water volume traveling throughout a central water heating system; however, those savings were not included in the analysis.

The estimated annual water and energy savings per dwelling unit are summarized in Table 8. The estimated water savings range from 234 to 1,096 gal per dwelling unit per year, embedded electricity savings from 1.1 to 5.3 kWh per dwelling unit per year, and natural gas savings from 2.8 to 7.7 therms per dwelling unit per year depending on the residential building type.

Table 8. Estimated Annual Water and Energy Savings Per Dwelling Unit

Building Type	In-Unit Water Savings (gal/Dwelling Unit per Year)	In-Unit Embedded Electricity Savings (kWh/Dwelling Unit per Year)	Natural Gas Savings (therms/Dwelling Unit per Year)		
			In-Unit	Recirculation Loop	Total
Low-Rise Loaded Corridor, 3-story, 24-unit building in Sunnyvale, CA	404	2.0	2.9	4.2	7.1
Prototype Low-Rise Garden Style, two-story, eight-unit building	257	1.2	1.8	1.0 - 1.2*	2.8 - 3.0
Prototype Low-Rise Loaded Corridor, three-story, 36-unit building	320	1.6	2.3	1.4 - 1.7*	3.7 - 4.0
Prototype Mid-Rise Mixed-Use, five-story, 96-unit building	234	1.1	1.7	2.3 - 2.8*	4.0 - 4.5
Prototype High-Rise Mixed-Use, 10-story, 108-unit building	248	1.2	1.8	2.6 - 3.1*	4.4 - 4.9
Single Family Dwelling	1,096	5.3	7.7	Not applicable	7.7

Notes: Embedded electricity in water is assumed to be 4,848 kWh/million gallons of water for indoor water use. Natural gas savings in a recirculation loop for four multifamily prototype buildings (denoted with * in the table) are from 2022 CASE Report on Multifamily DHW Distribution and depend on the climate zone.

5.2.1 Estimating In-Unit Water and Energy Savings (All Multifamily Buildings and Single-Family Dwelling)

Larger than needed pipe sizes result in:

- Longer wait times for hot water delivery,
- Increased volume of water wasted down the drain while waiting for hot water, and
- Larger volume of hot water that is trapped within uncirculated in-unit piping and ultimately cooled below acceptable hot water delivery temperature.

Using average hot water draw patterns for different unit types, an average number of hot water events per year was calculated to be 5,794, or roughly 16 hot water events per day. For this calculation, a hot water event was defined as a measured flow on the cold water make up line to a water heater for two consecutive 1-minute time intervals (i.e., a draw lasting over a minute). The team assumed that a draw lasting over a minute indicates that hot water was desired by the user. Also, the selected threshold eliminated events when the user did not wait for hot water.

In-unit pipe sizes were determined using CPC Appendix A and combined Appendix A and M methodologies and then converted to volume of water. The difference between volume of water for each method in the uncirculated piping was multiplied by the number of hot water events per year for each unit type and resulted in the annual gallons of water saved.

For the saved water, corresponding in-unit natural gas savings were calculated since, in larger hot water pipes, this usable hot water would cool in the uncirculated in-unit pipes. It was assumed that all water trapped in uncirculated hot water piping after a draw event cools down below an acceptable hot water delivery temperature. The efficiency factor of a water heater was assumed to be 82%. The inlet water temperature increase was assumed to be 70°F (60°F to 130°F) based on the measured data at the Sunnyvale building. The following equation was used to calculate annual in-unit natural gas savings.

$$Annual\ In\text{-}Unit\ Natural\ Gas\ Savings\ (therms) = \frac{\mathrm{c} * \mathrm{m} * \Delta T * a}{\mathrm{EF}} * \ annual\ hot\ water\ savings\ (gal)$$

Where:
c = specific heat of water at 100°F and 1 atm = 0.998 BTU/lb-°F
m = mass of water at 100°F and 1 atm = 8.29 lb/gal
ΔT = temperature change (°F)
a = energy unit conversion factor = 100,000 BTU/therm
EF = efficiency factor of water heater

Embedded electricity savings were calculated based on the calculated water savings. Embedded electricity in water was assumed to be 4,848 kWh/million gallons of water for indoor water use based on California Public Utilities Commission Rulemaking 13-12-011.

$$Annual\ In\text{-}Unit\ Embedded\ Electricity\ Savings\ (kWh) = annual\ water\ savings\ (gal) * \frac{4{,}848\ kWh}{1{,}000{,}000\ \mathrm{gal}}$$

For the single family dwelling, water and energy savings were estimated using the same method as for calculating in-unit savings for the multifamily buildings. The use patterns and draw frequencies from the Sunnyvale building were applied to the single family dwelling. The inlet water temperature increase was assumed to be 70°F (60°F to 130°F). The dwelling used for the calculations is 1,290 square feet, considerably smaller than the 2,100-square foot, single family, one-story prototype used in the CEC's CBECC-Res. The analyzed house has one bathroom, a laundry room, and a kitchen with a dishwasher. The house does not have a recirculation loop. A 2,100-square foot house is likely to have at least two bathrooms. Both the size of the house and the number of fixtures make the estimated savings conservative since the larger house is likely to have larger volume of hot water in pipes cooling below acceptable hot water delivery temperature between hot water events.

5.2.2 Estimating Recirculation Loop Natural Gas Savings (Sunnyvale Building Only)

For the Sunnyvale building, the natural gas savings from installing distribution piping sized in accordance with CPC Appendix M design flow rates were calculated using the measured thermal characteristics of water, theoretical heat loss of the recirculation loops for UPC Appendix A and Appendix M pipe sizes, and measured heat loss with existing UPC Appendix A pipe sizing. The water temperature in the pipes was averaged based on monitored supply and return water temperatures. For ambient temperature of pipes located indoors (i.e., risers), the team used assumptions from the CEC 2022 Residential Alternative Calculation Method Manual (i.e., 68°F for each hour of the day specified for heat pump heating). For ambient temperature of pipes located outdoors and garage, the team used the value of 59°F, an average of hourly temperatures over a full year. The team sourced those hourly temperatures for the building location from EnergyPro software, CEC-approved alternative compliance method for performance simulations.

Using the equation below, distribution system heat loss was calculated for two cases: 1) existing actual pipe sizes and lengths installed in the Sunnyvale building and 2) alternative pipe sizes derived using Appendix M. The calculated percent reduction in heat loss between these two cases was applied to the measured distribution heat loss at the Sunnyvale building to determine the reduction of heat loss more accurately for the case of alternatively sized piping. To be conservative, the calculation of natural gas savings from the recirculation loop did not account for boiler efficiency; this simplification lowers the estimate of savings. The in-unit piping is not recirculated and as such was not included in calculating natural gas savings from the recirculation loop.

Heat loss for DHW piping with insulation was calculated with the following equation for both baseline and alternative pipe sizing cases:

$$Q = 2 * Pi * \frac{L(T_1 - T_2)}{\frac{Ln(\frac{r_2}{r_1})}{k} + \frac{Ln(\frac{r_s}{r_1})}{k_s}}$$

Where:

Q = Heat Loss (Btu/hr)
Pi = constant = 3.14
k = Thermal Conductivity of Pipe (Btu/(hr°F/ft))
k_s = Thermal Conductivity of Insulation (Btu/(hr°F/ft))
T_1 = Fluid Temperature (°F)
T_2 = Ambient Temperature of Pipe (°F)
L = Length of Pipe (ft)
r_1 = Inner Radius (ft)
r_2 = Exterior Radius (ft)
r_s = Exterior Radius of Insulation (ft)

5.3 Additional Information on Estimated Cost Savings

Table 9 compares the first costs of the piping for the 92-unit multifamily building in Seattle, Washington, using both methods for pipe sizing: one based on WSFUs and one based on the WDC. The total pipe length is 2,314 feet in both cases; the difference is the lengths of each pipe diameter. When using the WDC, the building no longer needs pipes larger than 1-inch nominal diameter. The cost savings for the pipe alone are estimated to be about $6,000 for the whole building. There are additional first cost savings estimated to be at least $6,000 for the fittings, valves, hangers, and pipe insulation throughout the building, as well as the pumps and other major equipment in the mechanical room.

Table 9. Comparison of Piping Costs for a 4-story, 92-unit Multifamily Building in Seattle, Washington

	Water Supply Fixture Unit Method			*Water Demand Calculator Method*		
Nominal Diameter (in)	**Total (ft)**	**Cost per Foot ($)**	**Cost per Dimension ($)**	**Total (ft)**	**Cost per Foot ($)**	**Cost per Dimension ($)**
3	20	$22.87	$457	0	$22.87	$0
2.5	90	$16.90	$1,521	0	$16.90	$0
2	114	$12.86	$1,466	0	$12.86	$0
1.5	136	$6.43	$874	0	$6.43	$0
1.25	346	$5.53	$1,924	0	$5.53	$0
1	808	$2.23	$1,802	176	$2.23	$392
0.75	730	$1.24	$905	1908	$1.24	$2,366
0.5	70	$0.72	$50	230	$0.72	$166
Total	**2,314**		**$9,001**	**2,314**		**$2,924**

Notes: Each unit has one bathroom, building has 12 clothes washers. Prices are for PEX piping taken from www.ferguson.com on September 29, 2022. The table shows only the differences in the cost of the pipe for both hot and cold. For the WDC method, the WDC version 2.1 was used.

In addition to the cost savings in the piping and related equipment, since the WDC method predicts that the peak hot water demand will be more than nine times smaller compared to the WSFU method, the water heater can be sized much smaller as well. For a 35-unit multifamily building in New York State built in 2020 using UPC Appendix M method to size the pipes where there was only a factor of four decrease in peak hot water demand, the builder was able to save about $20,000 on the water heaters. We estimated the savings to be $30,000 for this building.

A smaller building water supply (based on the smaller peak water demand) should result in a smaller water meter. Connection fees and development charges vary widely, but the savings ranged from $16,000-$68,000 for the 92-unit building in Seattle. Assuming that the water meter can be reduced in size to better match the diameter of the building water supply, the monthly service charge based on meter size would also be reduced.

In sum, for this 92-unit building, the cost savings are estimated to be in the range of $58,000 to $110,000 per building, or approximately $600 to $1,200 per dwelling unit.

5.4 Comparing Cold Water and Total Water Use to CPC Appendix M Estimates

The team obtained not only hot but also cold-water flow data for two similar multifamily buildings in a development complex in Rotterdam, New York. Figure 4 and Figure 5 illustrate the cumulative distribution of observed flow rates (represented by dots, with a vertical solid line indicating the study peak flow rate of each flow type) and compare those observed values with design CPC Appendix M values (vertical dashed lines to the far right). The total flow was calculated by adding the hot and cold-water flow data. The comparison shows that CPC Appendix M is a conservative estimator of peak water flow rates for hot, cold, and total water flow.

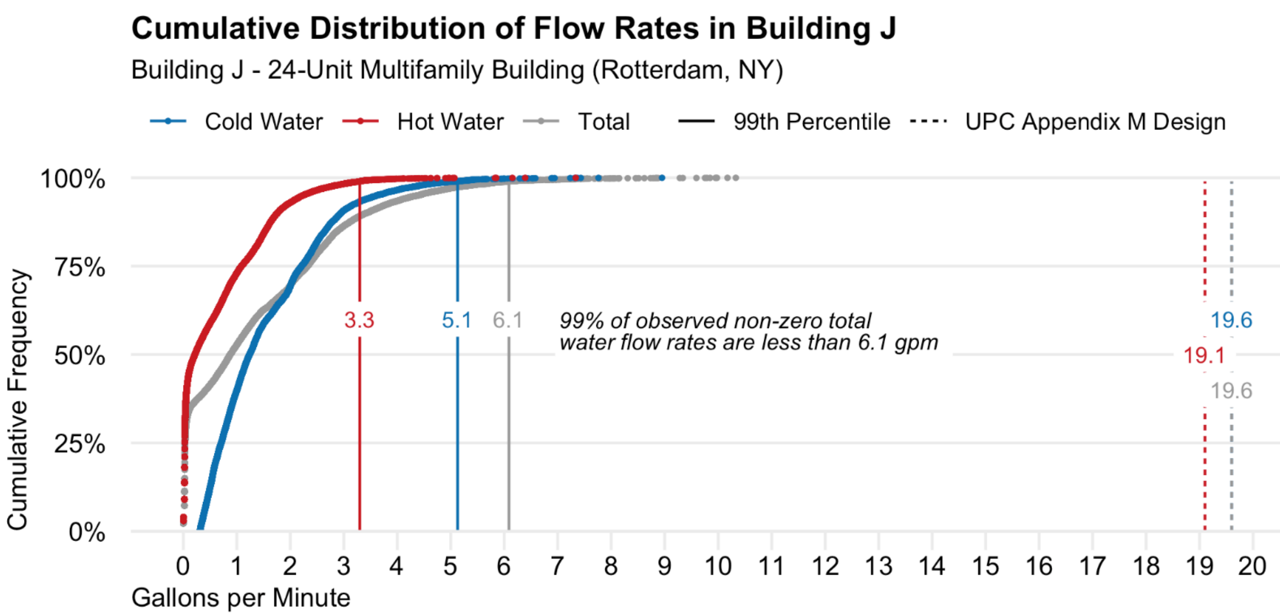

Figure 4. Cumulative Distribution of Flow Rates in Building J

Solid vertical lines indicate 99th percentile of observed non-zero flow rates (for hot, cold, and total). Dashed vertical lines indicate design flow rates based on UPC/CPC Appendix M method (for hot, cold, and total). Fixtures and fittings in Building J (total of 156): 24 combination bath/showers, 28 lavatory faucets, 4 showers, 28 water closets, 24 dishwashers, 24 kitchen faucets, and 24 clothes washers. The logging interval was 60 seconds. The monitoring period was 18 days. Data provided by Peter Skinner.

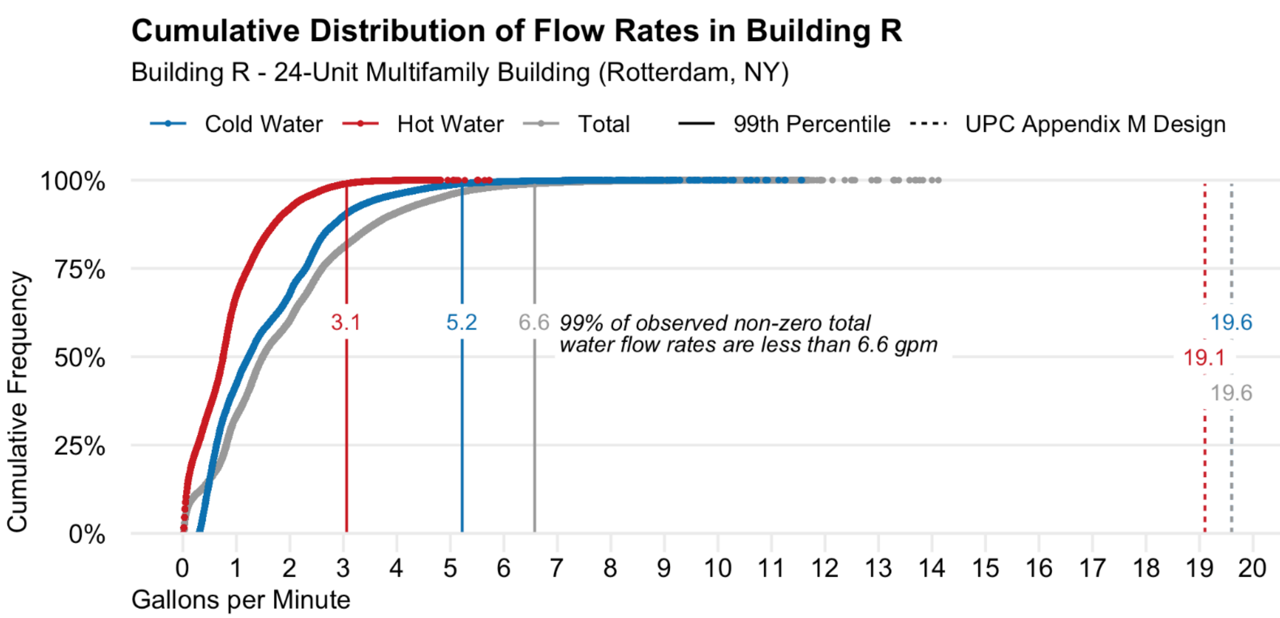

Figure 5. Cumulative Distribution of Flow Rates in Building R

Solid vertical lines indicate 99th percentile of observed non-zero flow rates (for hot, cold, and total). Dashed vertical lines indicate design flow rates based on UPC/CPC Appendix M method (for hot, cold, and total). Fixtures and fittings in Building R (total of 156): 24 combination bath/showers, 28 lavatory faucets, 4 showers, 28 water closets, 24 dishwashers, 24 kitchen faucets, and 24 clothes washers. The logging interval was 1 second. The monitoring period was 19 days. Data provided by Peter Skinner.

5.5 Insights on Monitoring Period Duration, Logging Interval, and Exceedances

Discussions with subject matter experts during the preparation of this report revealed an unexplored possibility of underestimating the true peak flow rate due to various experimental and analytical design parameters. The team explored four areas of ambiguity to ensure that the safety margin between observed peak flow rates and the CPC Appendix M design value was not simply due to limitations in experimental or analytical design.

The analysis detailed in Section 5.5.1 Estimating the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods assesses the effect of short-term monitoring periods on peak hot water flow rates. Seven datasets with a monitoring period greater than six months were selected for the analysis. Shorter monitoring periods of one week, two weeks, four weeks, one quarter, six months (and, where study length allowed, one year) were simulated by a rolling window of data, advancing one datapoint at a time. The peak flow rate for each window was calculated and compared to the peak of the much longer study. The analysis found that a 1-week study could underestimate the “true” long-term peak by 17% to 45% (median of 31%) and could overestimate the “true” long-term peak by a median of 23%.

The analysis detailed in Section 5.5.2 Estimating the Risk of Underestimating the Peak Flow Rate due to Long Logging Intervals explores the impact of longer logging intervals of flow rate data on the resolution of instantaneous peak water flow rate. For six datasets, 10-, 15-, 20-, 30- and 60-second logging interval datasets were simulated by grouping 1-second observations by each new logging interval and recording the mean of those measurements as the observation for the longer interval at that time. The peak hot water flow rate for the original 1-second dataset was compared to the peak flow rate of each simulated logging interval. The median for underestimation of study peak ranged from 2 to 10% of study peak depending on the length of simulated logging interval.

Designing for the 99th percentile peak flow rate means that a building may infrequently experience water demand exceeding a design value. While the CPC Appendix M design value was never exceeded by the calculated peak flow rate (again, defined as 99th percentile of non-zero water flow rates observed during the monitoring period), four of the 20 buildings experienced individual readings of flow rates that exceeded the design value (“exceedances”) at least once during their monitoring periods. Section 5.5.3 Summary of CPC Appendix M Exceedances in Four Multifamily Buildings summarizes all instances when observed hot water flow rate exceeded the design value of the CPC Appendix M.

Hunter’s method of defining peak flow rate is commonly used for assessing peak flow rates in plumbing, but in other areas of building systems peak flow rate is defined as the 99th percentile. This difference is discussed in Section 5.5.4 Experimental and Analytical Considerations of Assessing Design Prediction Performance.

5.5.1 Estimating the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods

Often the flow rate data available for a building is limited to two weeks or less of monitoring. A shorter monitoring period could happen to fall on a week or two with anomalous patterns of water use, leading to an observed peak flow rate that is higher or lower than the “true” longer-term peak flow rate of the building. This effect would impact the accuracy of conclusions drawn from short datasets. This analysis explores examples of possible misrepresentation of the peak flow rate to quantify the magnitude of underestimation likely by shorter studies, and if they could be underestimating long-term Appendix M exceedances.

Data collection for many of the analyzed buildings overlap with the beginning of the COVID-19 pandemic in the United States. Stay-at-home orders (many beginning in early 2020) significantly changed occupant routines, correlating with a downward trend in peak flow rates. Simultaneity of hot water fixture use likely decreased due to water use spreading out on any given day. Typical cyclical trends were likely obscured by this effect, meaning that these datasets are not good candidates for determining the effects due to seasonality of water use or those due to the general probability of over/underestimation. The presented analysis is conservative; the effect of stay-at-home orders may have exaggerated short-term study peak underestimates, as peaks from periods of stay-at-home use patterns are not differentiated from peaks from periods of pre-COVID patterns.

To assess the effect of short-term monitoring periods on peak hot water flow rates, seven datasets with a monitoring period greater than six months were selected for analysis. Shorter monitoring periods of one week, two weeks, four weeks, one quarter, six months (and where study length allowed, 1 year) were simulated by a rolling window cropping the timeseries data. The peak flow rate for each window was calculated and compared to the peak of the much longer study. Of particular interest is the most extreme short-term underestimation of the long-term peak.

Figure 6 illustrates the short-term peak flow rate values possible to observe during subsets of the longer monitoring period for building D. When the short-term peak (black line) dips below the study peak (red line), the short-term peak flow rate is an underestimation of the long-term peak. The short-term peak flow rates marked with a blue arrow are the worst-case underestimations for simulated monitoring periods of that length, and are reported for all buildings in Table 10 with long-term data. The one-week simulated monitoring period yields the most variable reported peak flow rates in the studied monitoring periods, resulting in peak flow rates being underestimated by as much as 45%.

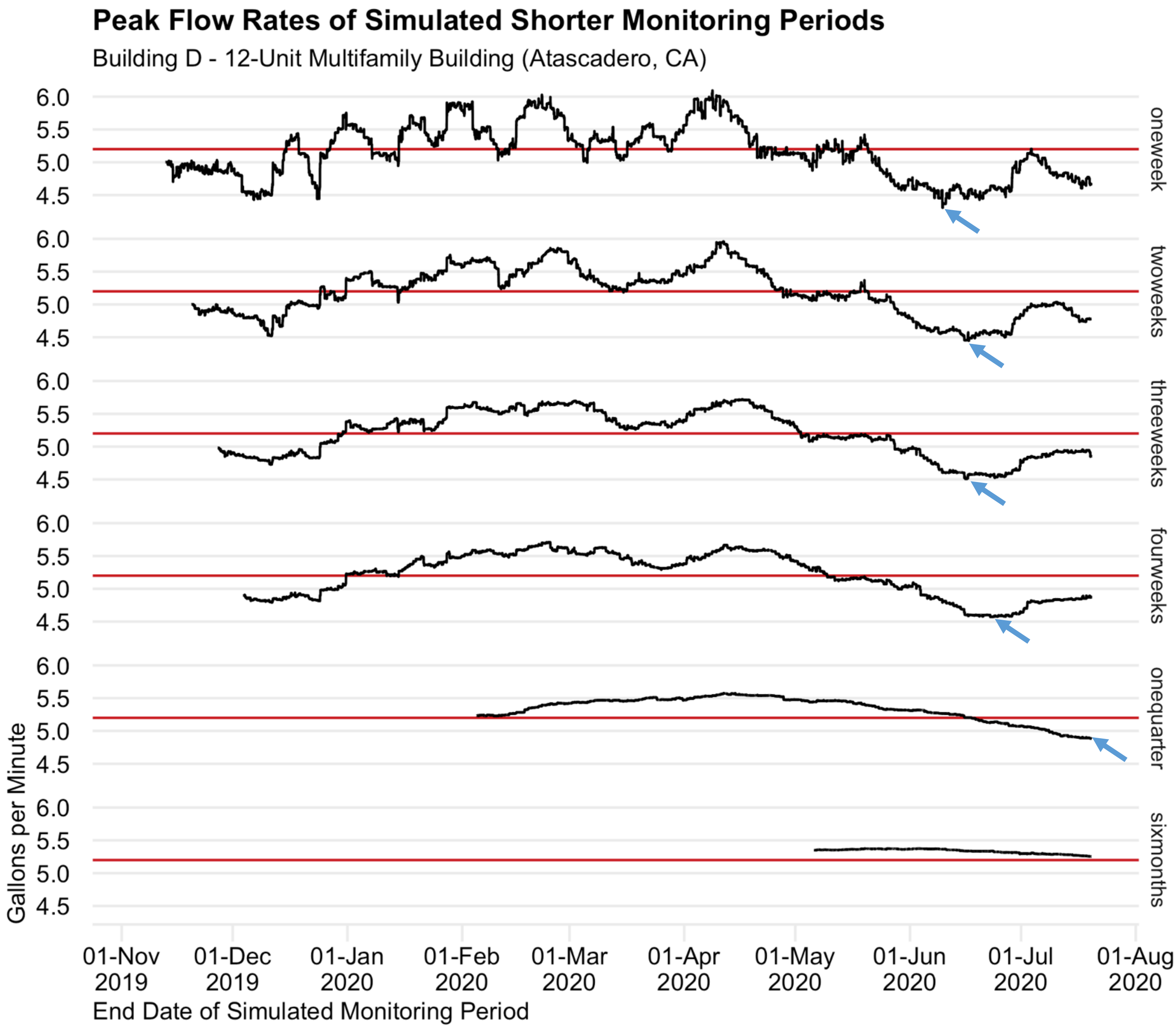

Figure 6. Peak Flow Rates of Simulated Shorter Monitoring Periods in Building D

Time series of 99th percentile flow rates observed in intervals of one week, two weeks, three weeks, four weeks, one quarter, and 6 months for building D, in Atascadero, CA (12 units monitored, 30 units total in building). The horizontal red line marks the 99th percentile flow rate logged over the entire monitoring period (5.2 gpm over 257 days). The CPC Appendix M design value for the 12 monitored units in this building was 17 gpm. The short-term peak flow rates marked with a blue arrow are the worst-case underestimations for that simulated monitoring period and are reported for all long-term buildings in Table 10.

For the buildings with monitoring period of less than 30 days, the team considered a possibility of underestimation by assuming the most extreme worst-case scenario of 45% underestimation. For a 45% underestimation of an unknown "true" peak, the adjustment factor applied to the observed short-term value would be 1 / (1 - 45%) = 1.82. We call this the "conservative multiplier for short monitoring periods." Table 11 shows that even when adjusted by the conservative multiplier, the adjusted peak flow rates remain well under their CPC Appendix M design value. Building F's adjusted peak flow rate comes closest, only 0.2 gpm below the CPC Appendix M design.

Table 10. Worst-Case Possible Underestimation of Peak Flow Rate in Shorter Monitoring Periods

	City	Monitored Apartments	Monitoring Period (day)	Study Peak (gpm)	***Worst-Case Underestimation of Study Peak*** *During Simulated Monitoring Periods* 1 wk	2 wk	3 wk	4 wk	1 qtr	6 mo	1 y
A	Davis, CA*	8	304	2.1	45%	42%	41%	11%	8%	3%	-
C	Atascadero, CA	10	257	5.7	22%	15%	14%	12%	8%	0%	-
D	Atascadero, CA	12	257	5.2	17%	14%	13%	12%	6%	1%	-
E	Davis, CA*	32	304	4.0	28%	25%	23%	23%	14%	3%	-
I	Seattle, WA	60	823	4.5	34%	34%	34%	17%	0%	0%	0%
P	Seattle, WA	384	609	19	31%	20%	20%	16%	16%	12%	8%
Q	Sunnyvale, CA	24	272	5.4	38%	36%	20%	16%	10%	3%	-
				Median	**31%**	**25%**	**20%**	**16%**	**8%**	**3%**	**-**
				Maximum	**45%**	**42%**	**41%**	**23%**	**16%**	**12%**	**-**

Notes: Study Peak is defined as the 99th percentile of non-zero hot water flow rates observed. The logging interval for buildings denoted with * was 15 seconds; all other buildings had logging increments of 60 seconds.

Table 11. Adjusted Study Peaks for Possible Underestimation due to Short Monitoring Periods

	City	Monitoring Period (days)	Study Peak (gpm)	CPC App. M Design (gpm)	Conservatively Adjusted Study Peak (gpm)	CPC App. M Design Relative to Conservatively Adjusted Study Peak
B	Oakland, CA	10	3.6	13	6.6	2.0x
F	Oakland, CA	14	9.8	18	17.8	1.0x
G	New Hartford, NY	26	3.3	10	6.0	1.6x
H	San Francisco, CA	9	5.7	19	10.4	1.9x
J	Rotterdam, NY	18	3.3	19	6.0	3.2x
K	Gloversville, NY	12	5.6	20	10.2	1.9x
L	Rome, NY	15	4.8	13	8.7	1.5x
M	San Francisco, CA	12	9.6	32	17.5	1.8x
N	San Francisco, CA	12	13	33	23.3	1.4x
O	Albany, NY	21	7.1	22	12.9	1.7x
R	Rotterdam, NY	19	3.1	19	5.6	3.4x
					Median	**1.8x**
					Minimum	**1.0x**

Notes: “Most Conservative Estimate of Study Peak” is equal to the “Study Peak” multiplied by 1.82. When the “CPC Appendix M Design Relative to Conservatively Adjusted Study Peak” is 1.0x, the adjusted peak flow rate is equal to the design value. Study Peak is defined as the 99th percentile of non-zero hot water flow rates observed. Buildings with monitoring periods longer than 30 days are not shown in this table, but the median and minimum shown below are equivalent to when they are included.

5.5.2 Estimating the Risk of Underestimating the Peak Flow Rate due to Long Logging Intervals

Flow rate meters typically take continuous measurements and record the mean of these continuous measurements at a user-specified logging interval, i.e., one averaged observation is recorded every 1, 15, 30, or 60 seconds. Longer logging intervals lead to loss of resolution of instantaneous peak water flow rate. This analysis examines whether the magnitude of this loss could produce an observed peak flow rate that masks a true peak exceeding the CPC Appendix M design value.

Six buildings with 1-second logging intervals were selected for the analysis. From these datasets, 10-, 15-, 20-, 30- and 60-second logging interval datasets were simulated by grouping 1-second observations by each new logging interval and recording the mean of those measurements as the observation for the longer interval at that time. The peak hot water flow rate for the original 1-second dataset was compared to the peak flow rate of each simulated logging interval, and the percent underestimation is reported in Table 12. The median for underestimation of study peak ranged from 2 to 10% of study peak depending on the length of simulated logging interval. Buildings H and M have the highest two underestimations in Table 12. They are also the two buildings in this set which had the 0.1 gpm cutoff applied to the data in the data validation phase. This treatment, which conservatively elevates the study peak, is also exaggerating the underestimation of the study peak in this analysis. The values are left in place to represent a conservative extreme possible study peak underestimation by longer logging intervals.

Table 12. Underestimation of Peak Flow Rates due to Longer Logging Intervals

					Worst-Case Underestimation of Study Peak *with Simulated Logging Interval*				
	City	**Monitored Apartments**	**Monitoring Period (day)**	**Study Peak (gpm)**	**10 sec**	**15 sec**	**20 sec**	**30 sec**	**60 sec**
B	Oakland, CA	8	10	3.6	1%	2%	3%	3%	5%
F	Oakland, CA	24	14	9.8	1%	1%	2%	3%	6%
H	San Francisco, CA*	15	9	5.7	6%	10%	15%	21%	27%
M	San Francisco, CA*	120	12	9.6	3%	4%	5%	7%	12%
N	San Francisco, CA	134	12	12.8	1%	2%	3%	5%	9%
R	Rotterdam, NY	24	19	3.1	3%	4%	5%	6%	10%
				Median	**2%**	**3%**	**4%**	**6%**	**10%**
				Max	**6%**	**10%**	**15%**	**21%**	**27%**

Notes: Study Peak is defined as the 99th percentile of non-zero hot water flow rates. Buildings denoted with * had a 0.1 gpm cutoff applied to flow data due to data quality issues.

For the buildings with logging intervals of 10 seconds or longer, the most extreme peak underestimation scenario was a 27% underestimation. For a 27% underestimation of an unknown “true” peak, the adjustment factor applied to the observed short-term value would be 1 / (1 – 27%) = 1.37. We call this the “conservative multiplier for longer logging intervals.” Table 13 shows that even when adjusted by the conservative multiplier, the adjusted peak flow rates remain well under their CPC Appendix M design value. Building E’s adjusted peak flow rate comes closest, 2.6 gpm below the CPC Appendix M design.

Data collected to date is not suitable for an examination of interaction effects between length of logging intervals and monitoring periods.

Table 13. Study Peaks for Possible Underestimation due to Longer Logging Intervals

	City	Logging Interval (seconds)	Study Peak (gpm)	CPC App. M Design (gpm)	Conservatively Adjusted Study Peak (gpm)	CPC App. M Design Relative to Conservatively Adjusted Study Peak
A	Davis, CA	15	2.1	6	2.9	1.9x
C	Atascadero, CA	60	5.7	17	7.8	2.2x
D	Atascadero, CA	60	5.2	17	7.1	2.4x
E	Davis, CA	15	4.0	8	5.4	1.5x
G	New Hartford, NY	60	3.3	10	4.5	2.1x
I	Seattle, WA	60	4.5	12	6.2	1.9x
J	Rotterdam, NY	60	3.3	19	4.5	4.2x
K	Gloversville, NY	60	5.6	20	7.7	2.6x
L	Rome, NY	60	4.8	13	6.6	2.0x
O	Albany, NY	60	7.1	22	9.7	2.3x
P	Seattle, WA	60	18.7	85	25.6	3.3x
Q	Sunnyvale, CA	60	5.2	19	7.1	2.7x
S	Woodland, CA	60	4.0	16	5.5	3.0x
T	San Jose, CA	60	4.0	18	5.5	3.2x
					Median	**2.6x**
					Minimum	**1.5x**

Notes: “Most Conservative Estimate of Study Peak” is equal to the “Study Peak” multiplied by 1.37. When the “CPC Appendix M Design Relative to Conservatively Adjusted Study Peak” is 1.0x, the adjusted peak flow rate is equal to the design value. Study Peak is defined as the 99th percentile of non-zero hot water flow rates observed. Buildings with logging intervals of less than 15 seconds (all 1 second) are not shown in this table.

5.5.3 Summary of CPC Appendix M Exceedances in Four Multifamily Buildings

It is understood that a building may infrequently experience water demand exceeding the CPC Appendix M design value. By either the CPC Appendix A or Appendix M method, this would be a flow rate greater than the 99th percentile. Four buildings experienced flow rates that exceeded the design value ("exceedances") during their monitoring periods. This section reviews the instances when the observed flow rate exceeded the design value of the CPC Appendix M.

Two types of exceedance events were observed: short exceedances that seemed to fit the surrounding pattern of use and prolonged exceedances that are anomalous in their magnitude and duration. Figure 7 shows examples of these two types of design exceedance events.

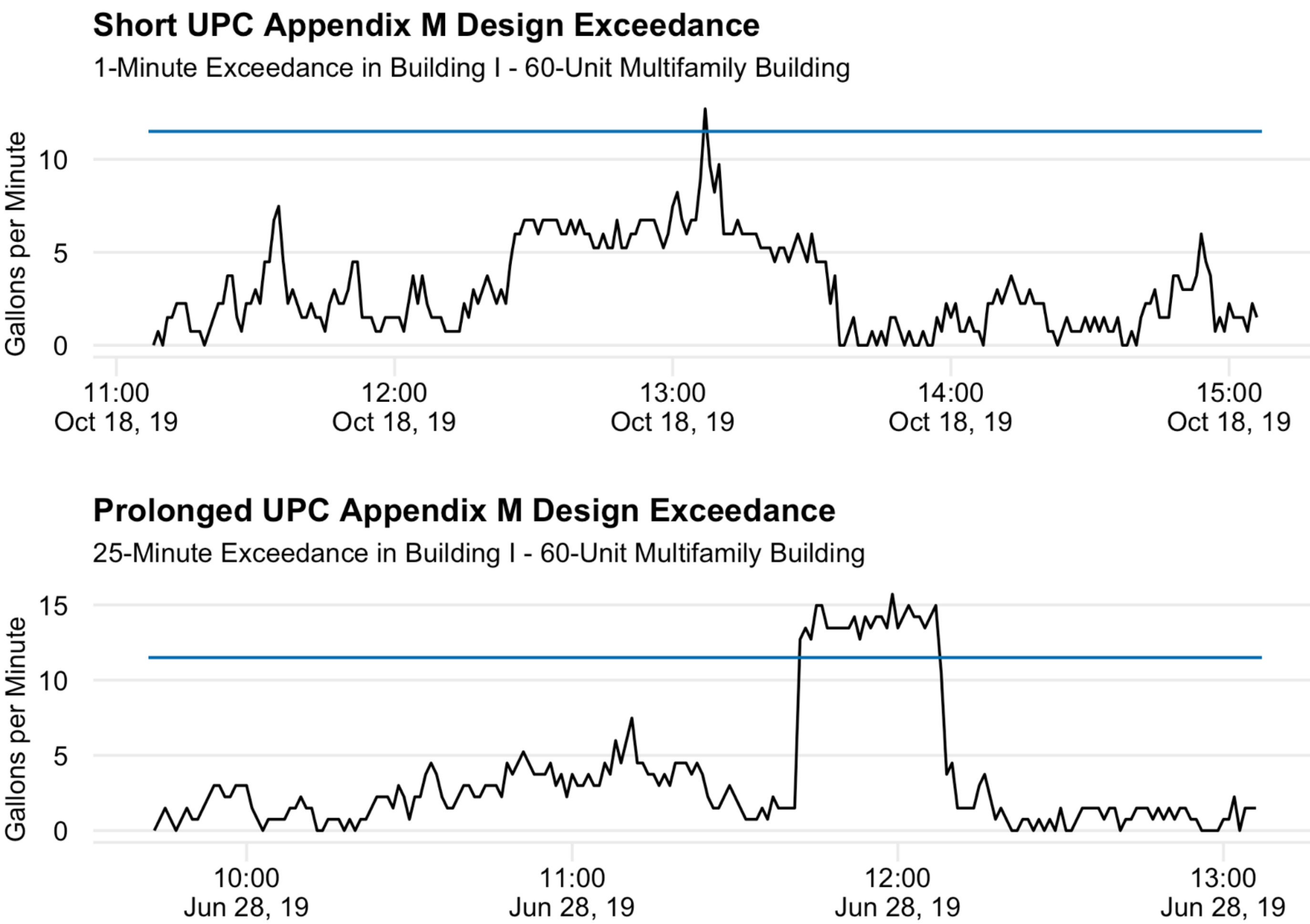

Figure 7. Examples of Short and Prolonged Exceedances in Building I

The CPC Appendix M design value (11.5 gpm) is marked as a blue line on both plots.

All short exceedances observed in the monitored buildings are summarized in Table 14. Short exceedance events in building A were most common during the 7am hour, followed by the 3pm and 4pm hours. Building A's 115 short exceedance events, totaling 29 minutes, were spread between days of the week with the most exceedances falling on Thursdays. The median time between exceedance events in building A was 1.2 days. Exceedance events in building E were most common during the 7am hour, followed by the 11am and 3pm hours. Building E's 428 short exceedance events, totaling 108 minutes, were spread between every day of the week, with the most exceedances falling on Sundays. The median time between exceedance events in building E was 0.5 days. For both buildings A and E exceedance events were more concentrated in the winter months, although neither monitoring period covered a complete year. Six discrete short exceedance events were observed in building F totaling 8 minutes over a 14-day monitoring period, with a median of 2.1 days between exceedance events. The duration of these events ranged from 1 second to 4 minutes. Building F is the only building with short exceedances lasting over one minute, with two such occurrences. Building I had a single short exceedance event, lasting 1 minute.

Prolonged exceedances were observed only in buildings A and I, summarized in Table 15. The team was not able to identify explanations for the prolonged exceedance events.

Table 14. Summary of Short Flow Events Exceeding CPC Appendix M Design Values

	City	Monitored Apartments	Monitoring Period (day)	Cumulative Time in Short Exceedances of App. M (min)	CPC App. M Design (gpm)	Max Flow Rate (gpm)	Max Event Length (min)
A	Davis, CA	8	304	29	6	10	< 0.3
E	Davis, CA	32	304	108	8	16	0.3
F	Oakland, CA	24	14	8	18	25	4.3
I	Seattle, WA	60	823	1	12	13	< 1.0

Note: Data logging intervals were 60 seconds in building I, 15 seconds in buildings A and E, and 1 second in building F.

Table 15. Summary of Prolonged Flow Events Exceeding CPC Appendix M Design Values

	City	Monitored Apartments	Monitoring Period (day)	Event Count	CPC App. M Design (gpm)	Median Flow Rate (gpm)	Max Flow Rate (gpm)	Event Length (min)
A	Davis, CA	8	304	1	6	7	8	43
I	Seattle, WA	60	823	1	12	14	16	25

Note: Data logging intervals were 60 seconds in building I and 15 seconds in building A.

5.5.4 Experimental and Analytical Considerations of Assessing Design Prediction Performance

A right-sized plumbing design aims to avoid issues from oversizing pipes and equipment including wasted building materials, inaccurate water meter measurements, increased time-to-tap, and water residence times large enough to allow bacterial growth. It also aims to avoid issues from under sizing such as user dissatisfaction with low flow rates. In his seminal work on rightsizing for expected plumbing demand load, Methods of Estimating Loads in Plumbing Systems (1941), Roy Hunter proposed to calculate the design flow rate as the flow rate with a specific probability of being exceeded. Hunter accepted that 1% of flows in a period of “congested condition of service” could be expected to exceed his peak flow rate estimate. CPC Appendix M adapts this methodology, providing updated probabilities of fixture use and estimates the 99th percentile flow rate in the single hour with the highest cumulative demand of water by volume. We refer to this hour of maximum volume as the “congested hour” and the predicted 99th percentile within that population of flow rates as the “congested hour peak.”

For the analysis of observed flow rates, our team took a different approach than the predictive methods described above. Our analysis looked at the 99th percentile of non-zero flows over the entire monitoring period, which we call the “peak flow rate,” or when necessary to differentiate from other predictive metrics, the “study peak flow rate.”

Comparing these two approaches across buildings, the team found that neither metric consistently exceeded the other. In the 20 multifamily buildings in our sample, the study peak flow rate was observed to measure from 4.5 gpm above to 3.0 gpm below the congested hour metric, with a median of 0.7 gpm below. Neither metric was above that predicted by Appendix M. Table 16 displays these two metrics alongside the CPC Appendix M design value, with the study peak highlighted in yellow when it exceeded the congested hour peak.

Table 16. Comparison of Two Metrics to Assess Peak Water Flows in Multifamily Buildings

					Peak Flow Observed in…		
	City	**Monitored Apartments**	**Monitoring Period (days)**	**Congested Hour (24h)**	**Congested Hour (gpm)**	**Study (gpm)**	**CPC App. M Design (gpm)**
A	Davis, CA	8	304	18	2.1	2.1	6
B	Oakland, CA	8	10	11	3.5	3.6	13
C	Atascadero, CA	10	257	17	6.4	5.7	17
D	Atascadero, CA	12	257	16	6.0	5.2	17
E	Davis, CA	32	304	11	3.9	4.0	8
F	Oakland, CA	24	14	21	12.5	9.8	18
G	New Hartford, NY	35	26	9	4.2	3.3	10
H	San Francisco, CA	15	9	7	4.5	5.7	19
I	Seattle, WA	60	823	9	5.2	4.5	12
J	Rotterdam, NY	24	18	9	3.8	3.3	19
K	Gloversville, NY	40	12	8	6.5	5.6	20
L	Rome, NY	83	15	10	5.0	4.8	13
M	San Francisco, CA	120	12	18	11.6	9.6	32
N	San Francisco, CA	134	12	18	15.8	13	33
O	Albany, NY	209	21	0	2.6	7.1	22
P	Seattle, WA	384	609	20	20.9	19	85
Q	Sunnyvale, CA	24	272	20	7.0	5.4	19
R	Rotterdam, NY	24	19	13	3.1	3.1	19
S	Woodland, CA	9	128	3	3	4	16
T	San Jose, CA	12	59	4	5	4	18

Notes: The “Congested Hour” metric calculates the 99th percentile of non-zero flow rates within a single peak hour. The “Study” metric calculates the 99th percentile of non-zero flow rates over the entire monitoring period.

6 Additional Resources

2022 CPC, Appendix M “Peak Water Demand Calculator”
https://epubs.iapmo.org/2022/CPC/#p=550 https://www.uniformcodes.org/water-demand-calculator
https://www.iapmo.org/water-demand-calculator/

2017 Study on Peak Water Demand by S. Buchberger et al. (basis for the WDC)
https://www.iapmo.org/media/3857/peak-water-demand-study-executive-summary.pdf

2020 ASCE Technical Paper on Probability of Water Fixture Use during Peak Hour in Residential Buildings by T. Omaghomi et al.
https://ascelibrary.org/doi/10.1061/%28ASCE%29WR.1943-5452.0001207

2020 Study on Water Demand Calculator by Stantec (assessment of cost savings from using the WDC)
https://www.iapmo.org/group/update/stantec-wdc-savings-study
https://www.iapmo.org/media/25276/water_demand_calculator_report_summary.pdf

2021 Report on Connection Fees and Service Charges by Meter Size by Alliance for Water Efficiency (assessment of cost savings from downsizing meters)
https://www.iapmo.org/media/25939/awe-meter-size-connection-fee-research.pdf

2023 Report on Energy and Carbon Savings Opportunities by Arup (assessment of water, energy, and carbon savings from applying the WDC)
https://www.iapmo.org/media/31469/iapmo_energy_savings_arup_report.pdf

Case Study on Applying the WDC on a Project in the State of New York
https://www.phcppros.com/articles/11971-practically-perfect-plumbing-in-multifamily

2022 and 2025 California Energy Code (Title 24, Part 6), Proposed Measures related to the WDC
https://title24stakeholders.com/measures/cycle-2022/multifamily-domestic-hot-water/
https://title24stakeholders.com/measures/cycle-2025/multifamily-domestic-hot-water/

Proposed Mandatory Use of UPC Appendix M in 2021 Seattle Energy Code
https://www.seattle.gov/documents/Departments/SDCI/Codes/ChangesToCodes/2021SeattleCodeAdoption/2021DraftSeattleEnergyCode.pdf

Adoption of UPC Appendix M into Foster City Municipal Code
https://www.codepublishing.com/CA/FosterCity/?FosterCity15/FosterCity1516.html&?f

Adoption of UPC Appendix M into San Jose Municipal Code
https://library.municode.com/ca/san_jose/codes/code_of_ordinances?nodeId=TIT24TECO_CH24.04PLCO_PT1ADCPPR

Adoption of UPC Appendix M into County of Santa Cruz
https://www.codepublishing.com/CA/SantaCruzCounty/#!/SantaCruzCounty12/SantaCruzCounty1210.html#12.10.235

Adoption of UPC Appendix M into Oakland Municipal Code
https://library.municode.com/ca/oakland/codes/code_of_ordinances?nodeId=TIT15BUCO_CH15.04OAAMCAMOBUCOCO_PT5CAPLCONMITEAM_15.04.3.50652022CPAPMAD

Adoption of UPC Appendix M into 2022 California Plumbing Code
https://www.dgs.ca.gov/BSC/Rulemaking/2022-Intervening-Cycle/Commission-Mtgs-List-v2/2023-08-01-CommMtg

Adoption of UPC Appendix M into 2018 Hawaii Plumbing Code
https://up.codes/viewer/hawaii/upc-2018

Adoption of UPC Appendix M into 2022 Montana Plumbing Code
https://rules.mt.gov/gateway/RuleNo.asp?RN=24%2E301%2E301

Adoption of UPC Appendix M into 2018 Nevada Plumbing Code
https://up.codes/viewer/nevada/upc-2018/chapter/M/peak-water-demand-calculator#M

Adoption of the WDC into 2021 New Jersey National Standard Plumbing Code
https://epubs.iapmo.org/NSPC/NJ2021/

Adoption of UPC Appendix M into 2021 New Mexico Plumbing Code
https://www.rld.nm.gov/wp-content/uploads/2022/03/14.8.2_Integrated-003.pdf

Adoption of UPC Appendix M into 2018 North Dakota Plumbing Code https://casetext.com/regulation/north-dakota-administrative-code/title-62-state-board-of-plumbing/article-62-031-plumbing-installation-standards/chapter-62-031-01-administration/section-62-031-01-01-effective-412020conformance-with-the-north-dakota-plumbing-code

Adoption of UPC Appendix M into 2021 Oregon Plumbing Specialty Code
https://epubs.iapmo.org/2021/OPC/

Adoption of UPC Appendix M into 2024 Washington State Plumbing Code
https://app.leg.wa.gov/WAC/default.aspx?cite=51-56-003

Approval of UPC Appendix M as Alternate Standard by Wisconsin Department of Safety and Professional Services
https://dsps.my.salesforce.com/sfc/p/#t0000000LAz5/a/8y000004t1kG/h62oQttBGrkNbyAB2wU1XneBnVcRwHSmw0_TTTASPGY

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