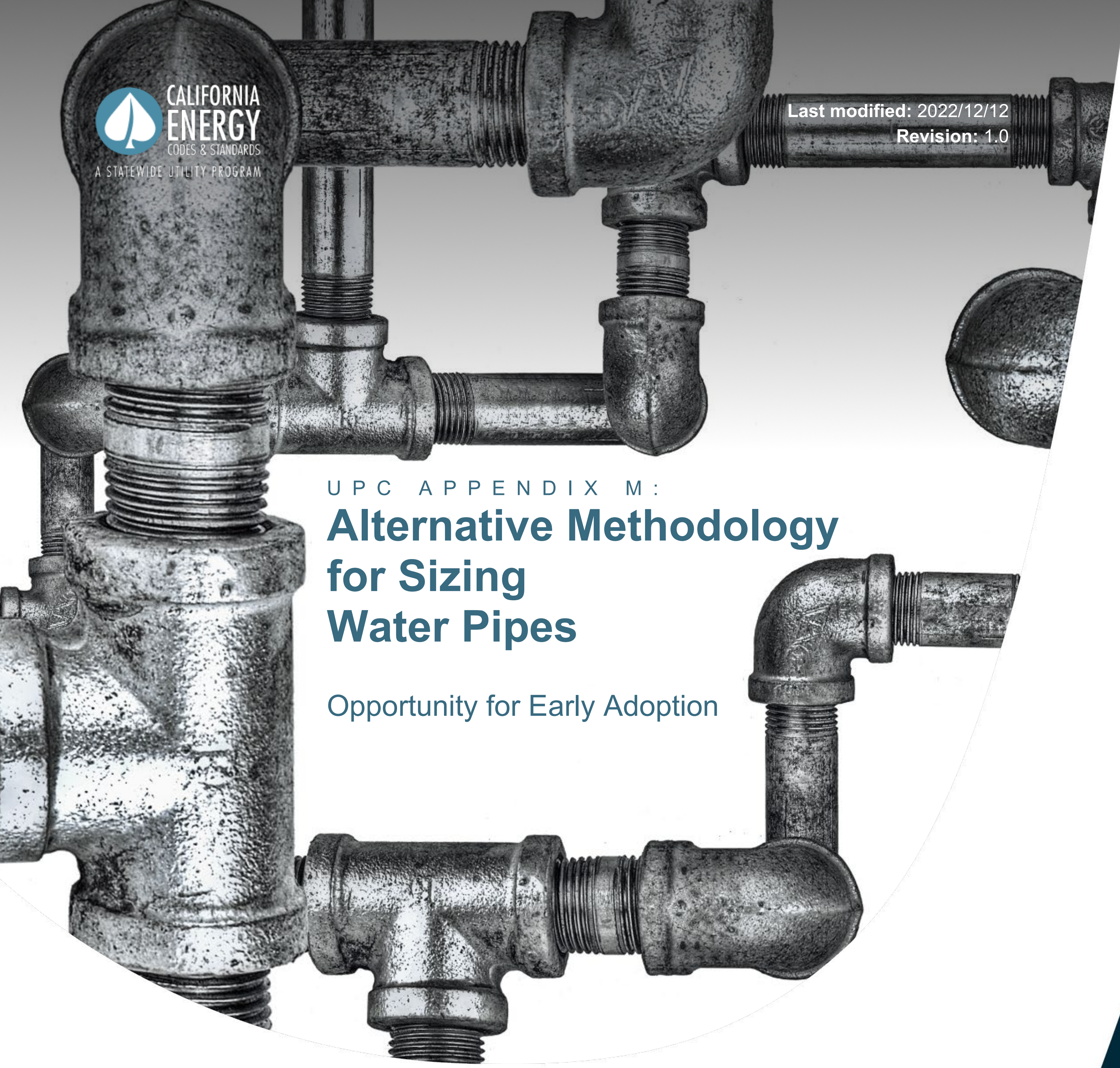

CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

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UPC APPENDIX M:

# Alternative Methodology for Sizing Water Pipes

## Opportunity for Early Adoption

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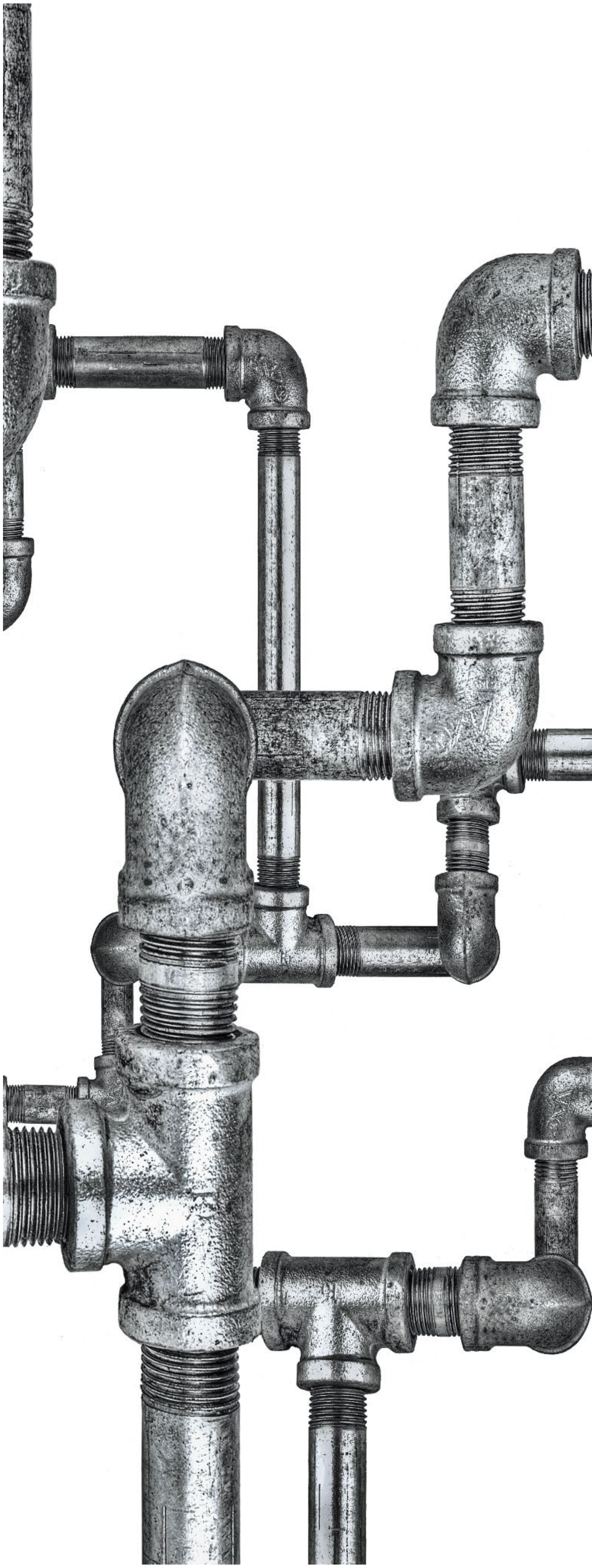

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## Acronym List

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

## Acknowledgements

The team thanks the following people and organizations for contributing data used in the presented analysis (in alphabetical order by organization name):

- Amy Dryden (Association for Energy Affordability),
- John MacArthur (Beardsley Architects + Engineers),
- Peter Skinner (E2G Solar),
- Adria Banks and Shawn Oram (Ecotope),
- Marc Hoeschele, Stephen Chally, and James Haile (Frontier Energy),
- Hugh Henderson (Owahgena Consulting), and
- Caton Mande (UC Davis Western Cooling Efficiency Center).

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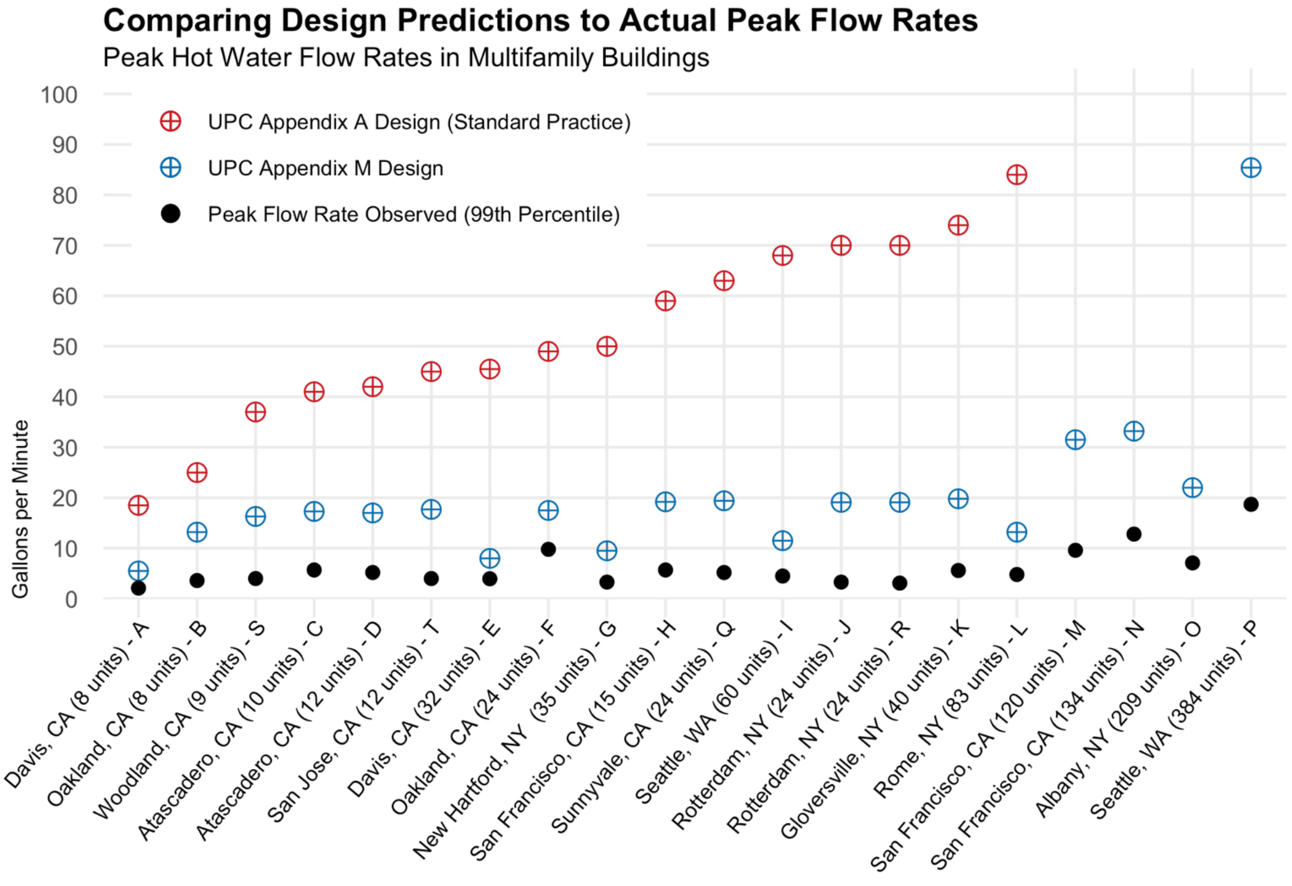
# Executive Summary

In California, it is standard practice to determine peak water demand and 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 is in turn based on the Hunter's curve developed in 1940. UPC Appendix M "Peak Water Demand Calculator" offers an alternative methodology for sizing water pipes (building supply, principal branches, and risers) in new single family and multifamily buildings.

Figure 1 shows the results of our analysis comparing UPC Appendix A and M design predictions to actual data for hot water flow rates in 20 multifamily buildings. The team primarily analyzed actual data for hot water flow rates because hot water data was readily available from data collection efforts serving energy efficiency projects not related to water pipe sizing. The design estimates calculated using the standard practice (red markers) are 5 to 27 times larger than the observed peak flow rates. Overestimating peak water flow rates results in pipe diameters that are much larger than needed for modern buildings.

The blue markers in Figure 1 demonstrate that UPC 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 UPC Appendix M are between 2 and 6 times the observed flow rates for the 20 multifamily buildings in our dataset. Note that UPC Appendix A values for buildings M, N, O, and P are out of scale and are provided in Figure 2 and Table 3.



*Many thanks to the Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and the UC Davis Western Cooling Efficiency Center for providing data.*

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

*Total of 20 multifamily buildings. Monitoring period ranged from 9 days to over 2 years, and logging interval ranged from 1 to 60 seconds. Buildings are ordered by UPC Appendix A design value. UPC Appendix A values for buildings M, N, O, and P are out of scale and are not included in this figure. Buildings Q, R, S, and T were added after the initial analysis, and thus appear alphabetically out of order.*

Using the WDC 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 not oversizing water pipes also include reduced risk to public health and safety and reduced 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. All of these benefits will be available to early adopters.

# 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. Virtually nothing flushes, fills, or flows at the flow rates that were present at that time. 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 body of this 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. This report refers to "Attachments" in place of traditional "Appendices" to reduce confusion with frequent references to Appendices found in the Uniform Plumbing Code (UPC). These Attachments contain 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 UPC Appendix M. These flow rates, instead of those estimated using the current standard practice Water Supply Fixture Unit (WSFU) method in UPC Appendix A, are then incorporated into the pipe size selection method contained in the remainder of UPC Appendix A. This approach is summarized in the following clauses from UPC 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.

The Statewide Utility Codes and Standards Team submitted a Title 24 Petition to adopt UPC Appendix M into the California Plumbing Code (CPC) during the 2022 Intervening Code Adoption Cycle. If adopted, UPC Appendix M would serve as an alternative methodology to UPC/CPC Appendix A for sizing water pipes in new single family and multifamily buildings. The petition was submitted to California Buildings Standards Commission, the California Department of Housing and Community Development, and the California General Services Administration Division of State Architect staff members in November of 2021. Statewide adoption of UPC Appendix M into the CPC would enable the voluntary use of Appendix M for all residential occupancies that fall within the jurisdictions of adopting state agencies. Statewide adoption would make it equally convenient to use Appendix A or Appendix M.

If UPC Appendix M is adopted by California state agencies during the 2022 Intervening Code Cycle, statewide adoption will be effective July 1, 2024. In the meantime, there is an opportunity for early adoption of UPC Appendix M by local jurisdictions to facilitate the use of the alternative pipe sizing methodology on construction projects.

# 2 Benefits of Using the Water Demand Calculator

## 2.1 Overview

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

- 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. UPC 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 and local jurisdictions have taken the lead in adopting UPC Appendix M, including Nevada (2018), North Dakota (2020), Hawaii (2020), Oregon (2021), New Mexico (2022), and City of Seattle and King County, Washington (2021). In 2019, Foster City, California, adopted the voluntary use of UPC Appendix M as a mitigation measure in conjunction with the Bay Area Water Supply and Conservation Agency drought contingency plan. San Jose, California, adopted UPC Appendix M as well. The California Energy Commission (CEC) plans to implement a new compliance credit in the 2022 CBECC software for projects using UPC Appendix M for pipe sizing in multifamily dwellings.

Plumbing designs based on UPC 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 UPC 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 on 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 cut in 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 will be saved 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. *Attachment 5.2 Calculation Methodology for Estimating Water and Energy Savings* provides more details on calculation methodology of these water and energy impacts.

## 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 |

## 2.3 Cost Savings

In 2020, Gary Klein 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 Appendix A and Appendix M and then used the UPC 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 UPC 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 UPC Appendix A predictions for pipe diameter result in 3-inch pipe for both the building water supply and the hot water branch. Using UPC 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 somewhat more than 50 percent.

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

*The unit of gpm stands for gallons per minute.*

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

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

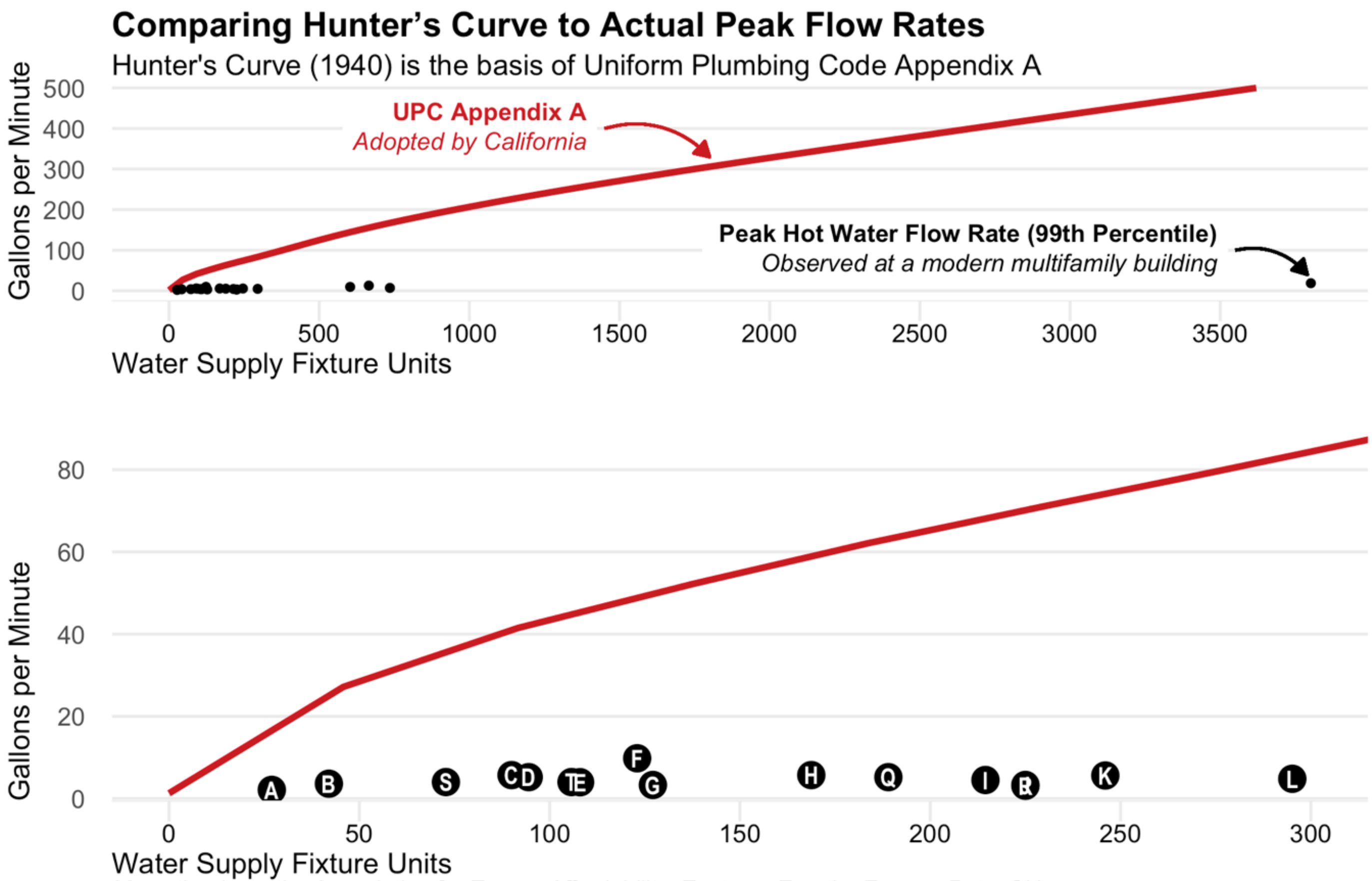
Please see Attachment 5.3 Additional Information on Estimated Cost Savings for more details, and the 2020 Stantec Report and the 2021 Alliance for Water Efficiency Report in the Reference Documents section for their analysis of the cost savings.

# 3 Comparison of Design Predictions to Observed Peak Flow Rate Values

## 3.1 Results

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 analyzed multifamily buildings range in size from 8 to 384 apartments. The standard-practice UPC Appendix A design estimates are 5 to 27 times larger than the observed peak flow rates, as summarized in Table 3. 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.

Note that the alphabetically labeled buildings continue to be referenced by letter in various tables, figures, and attachments that follow in this report. For additional details about the analyzed datasets, see *Attachment 5.1 Details Included in the* Analysis. Please see *Attachment 5.5.4 Experimental and Analytical Considerations of Assessing Design Prediction Performance* for more details on peak flow rate metrics.



*Many thanks to the Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and the UC Davis Western Cooling Efficiency Center for providing data.*

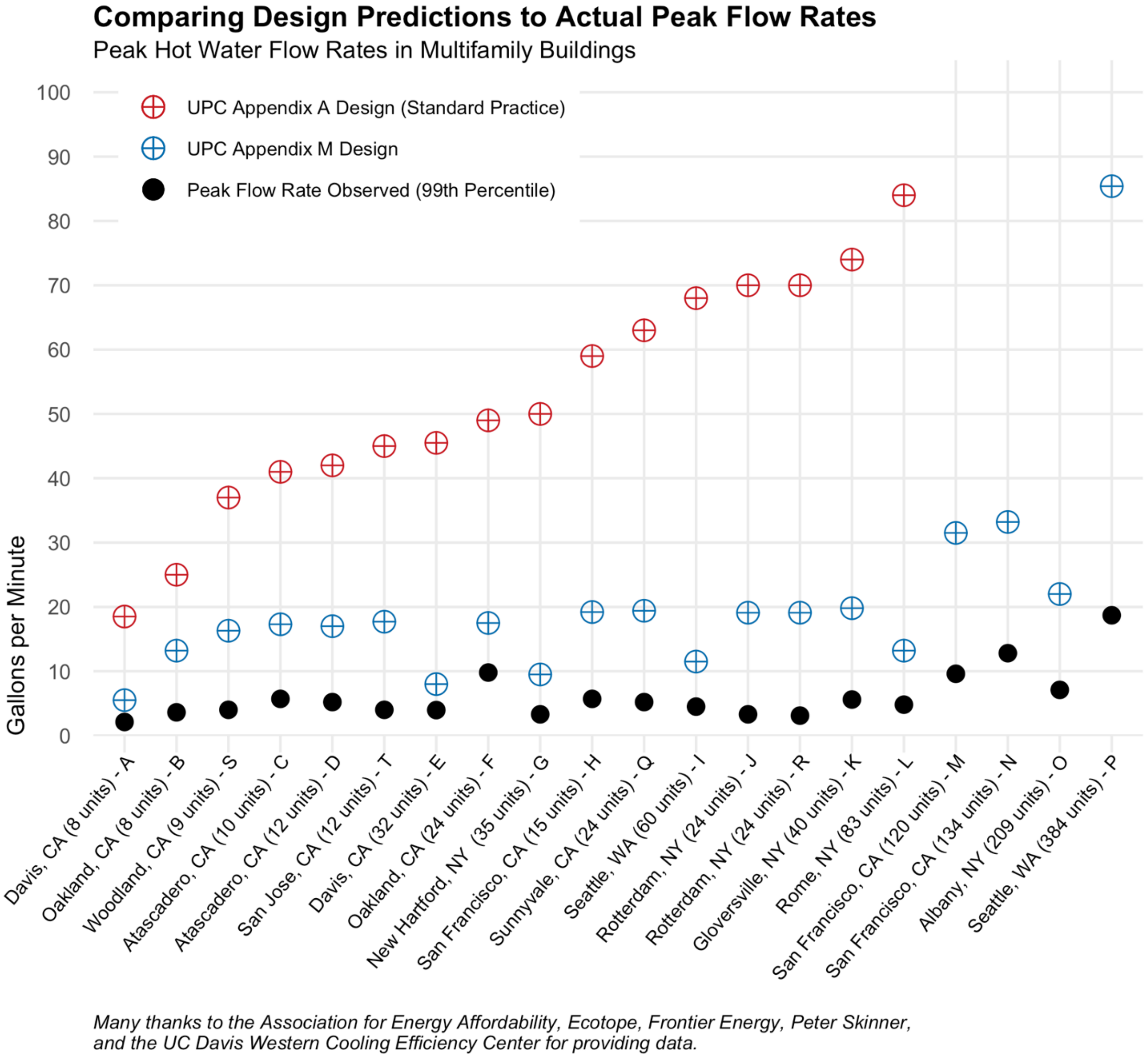
**Figure 2. Comparing UPC Appendix A (Hunter's Curve) to Actual Peak Flow Rates in Multifamily Buildings**

*Figure 2A shows data for 20 multifamily buildings, ranging in size from 8 to 384 apartments, analyzed to date. Figure 2B zooms in on the cluster of buildings with fewer than 300 WSFUs. Actual Peak Flow Rates means 99th percentile of non-zero flows for all sampling intervals over the entire monitoring period.*

Figure 3 compares the monitoring data from the 20 multifamily buildings to the peak hot water flow rate estimates based on UPC Appendix A (red crosshairs) and UPC Appendix M (blue crosshairs). This comparison shows that UPC Appendix M is a more accurate, but still conservative, approach to estimating peak water flow rates; Table 3 shows that UPC Appendix M design values are at least 1.8 times and no more than 6.2 times the observed peak flow rates in multifamily buildings.

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.

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. This data that is explored in *Attachment 5.4 Comparing Cold Water and Total Water Use to Appendix M Estimates* illustrated that the UPC Appendix M design value was not exceeded by peak water flow rates of hot, cold, or total water flow.



*Many thanks to the Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and the UC Davis Western Cooling Efficiency Center for providing data.*

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

*Total of 20 multifamily buildings. Monitoring period ranged from 9 days to over 2 years, and logging interval ranged from 1 to 60 seconds depending on the building. Buildings are ordered by UPC Appendix A design value. UPC Appendix A values for buildings M, N, O, and P are out of scale and are provided in Table 3. Buildings Q, R, S, and T were added after the initial analysis, and thus appear alphabetically out of order.*

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

*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 UPC Appendix A design curve; the last value on the design curve was used. The detailed information on building occupancy during the study period 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.*

| | | | *Monitoring Data* | | | | *UPC Appendix M* | | *UPC 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 | 2.6x | 27 | 19 | 8.8x |
| **B** | Oakland, CA | 8 | 10 | 1 | - | 3.6 | 13 | 3.7x | 42 | 25 | 6.9x |
| **C** | Atascadero, CA | 10 | 257 | 60 | - | 5.7 | 17 | 3.0x | 90 | 41 | 7.2x |
| **D** | Atascadero, CA | 12 | 257 | 60 | - | 5.2 | 17 | 3.3x | 95 | 42 | 8.1x |
| **E** | Davis, CA | 32 | 304 | 15 | 56% | 4.0 | 8 | 2.0x | 108 | 46 | 11.5x |
| **F** | Oakland, CA | 24 | 14 | 1 | 48% | 9.8 | 18 | 1.8x | 123 | 49 | 5.0x |
| **G** | New Hartford, NY | 35 | 26 | 60 | 69% | 3.3 | 10 | 2.9x | 127 | 50 | 15.2x |
| **H** | San Francisco, CA | 15 | 9 | 1 | - | 5.7 | 19 | 3.4x | 169 | 59 | 10.4x |
| **I** | Seattle, WA | 60 | 823 | 60 | - | 4.5 | 12 | 2.6x | 215 | 68 | 15.1x |
| **J** | Rotterdam, NY | 24 | 18 | 60 | 38% | 3.3 | 19 | 5.8x | 225 | 70 | 21.2x |
| **K** | Gloversville, NY | 40 | 12 | 60 | - | 5.6 | 20 | 3.5x | 246 | 74 | 13.2x |
| **L** | Rome, NY | 83 | 15 | 60 | 37% | 4.8 | 13 | 2.8x | 295 | 84 | 17.5x |
| **M** | San Francisco, CA | 120 | 12 | 1 | - | 9.6 | 32 | 3.3x | 603 | 143 | 14.9x |
| **N** | San Francisco, CA | 134 | 12 | 1 | 38% | 13 | 33 | 2.6x | 665 | 155 | 12.1x |
| **O** | Albany, NY | 209 | 21 | 60 | - | 7.1 | 22 | 3.1x | 735 | 168 | 23.6x |
| **P** | Seattle, WA | 384 | 609 | 60 | 8% | 19 | 85 | 4.6x | 3802 | 500 | 26.7x |
| **Q** | Sunnyvale, CA | 24 | 272 | 60 | - | 5.4 | 19 | 3.7x | 189 | 63 | 12.1x |
| **R** | Rotterdam, NY | 24 | 22 | 1 | - | 3.1 | 19 | 6.2x | 225 | 70 | 22.6x |
| **S** | Woodland, CA | 9 | 128 | 60 | 84% | 4 | 16 | 4.1x | 73 | 37 | 9.3x |
| **T** | San Jose, CA | 12 | 59 | 60 | 72% | 4 | 18 | 4.4x | 106 | 45 | 11.3x |
| | | | | | | | **Median** | **3.3x** | | | **12.1x** |

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

*The UPC 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 UPC 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.*

| | 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 | 46 |
| **T** | San Jose, CA | 12 | MF Low Income | 21 | 21 | 0 | 21 | 12 | 12 | 0 | 66 |

## 3.2 Conclusions and Recommendations

If UPC Appendix M is adopted by California state agencies during the 2022 Intervening Code Cycle, statewide adoption will be effective July 1, 2024. In the meantime, there is an opportunity for early adoption of UPC Appendix M by local jurisdictions to facilitate the use of the alternative pipe sizing methodology on construction projects.

UPC Appendix M can be used to more accurately, but still conservatively, calculate peak water flow rates in residential occupancies.

Using the WDC 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 not oversizing water pipes also include reduced risk to public health and safety and reduced carbon emissions due to material savings and energy reductions.

In addition to the early adoption, the authors recommend implementing an outreach and educational program to raise awareness about this alternative pipe sizing methodology among building officials, plumbing designers, builders, etc.

# 4 Reference Documents

**2021 UPC, Appendix M "Peak Water Demand Calculator"**
http://epubs.iapmo.org/2021/UPC/#p=453
https://www.uniformcodes.org/water-demand-calculator
**2017 Study on Peak Water Demand by S. Buchberger et al. (basis for Water Demand Calculator)**
https://www.iapmo.org/media/3857/peak-water-demand-study-executive-summary.pdf
**2020 Study on Water Demand Calculator by Stantec (assessment of cost savings from using Water Demand Calculator)**
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
**Case Study on Applying Water Demand Calculator on a Project in the State of New York**
https://www.phcppros.com/articles/11971-practically-perfect-plumbing-in-multifamily
**2022 California Energy Code (2022 Title 22, Part 6), Proposed Measure C "CPC Appendix M Sizing"**
https://title24stakeholders.com/measures/cycle-2022/multifamily-domestic-hot-water/

**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 2018 Seattle Plumbing Code**
https://www.seattle.gov/Documents/Departments/SDCI/Codes/PlumbingCode/2018SeattlePlumbingCode.pdf

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

# 5 Attachments

## 5.1 Details Included in the Analysis

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 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 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 1.8 value 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 Water Supply Fixture Units and default flow rates from Peak Water Demand Calculator**

*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.*

| | *Conversion Factor to WSFU* | | | *Water Demand Calculator* |
|---|---|---|---|---|
| | **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 | 1.875 | 3.0 |
| Dishwasher (hot branch ONLY) | 1.5 | 1.125 | 0 | 1.3 |
| Kitchen Faucet | 1.5 | 1.125 | 1.125 | 2.2 |
| Clothes Washer | 4 | 3 | 3 | 3.5 |

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

*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.*

| | **City** | **(1) Monitoring data includes hot water use in common and/or utility areas.** *The UPC 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 of 0 or 0.1 gpm was applied.* | **(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.**<br>** to the ones unit*<br>*+ 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* |

## 5.2 Calculation Methodology for Estimating Water and Energy Savings

The UPC Appendix M pipe sizing methodology yields lower design flow rates and smaller distribution piping when compared to the baseline case of using the UPC Appendix A pipe sizing approach. Smaller pipes in a distribution system result in 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 Ecotope 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** | 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. |
| **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 – UPC Appendix A and UPC 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 UPC Appendix A and Appendix M pipe sizes. 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

*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.*

| Building Type | In-Unit Water Savings (gal/Dwelling Unit per Year) | In-Unit Embedded Electricity Savings (kWh/Dwelling Unit per Year) | Natural Gas Savings from (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 |

### 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, thus 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 calculated using UPC Appendix A and Appendix M methodologies and 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.

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

For the Sunnyvale building, the natural gas savings from installing Appendix M sized distribution piping 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, the team followed temperature assumptions in the CEC 2022 Residential Alternative Calculation Method Manual depending on pipe location unless ambient temperatures were recorded in relevant locations.

Theoretical heat loss was calculated for the existing pipe sizes and Appendix M pipe sizes by using the equation below. A percentage of heat loss reduction was derived based on the theoretical heat loss for the two pipe size cases. This percentage reduction 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 Appendix M sized piping. 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 UPC Appendix A and Appendix M sized piping:

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

Where:

Q = Heat Loss (Btu/hr)
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 UPC Appendix M, the building no longer needs pipe larger than 1-inch nominal diameter. The cost savings for just the pipe are estimated to be about $6,000 for the whole building. There are additional estimated first cost savings of at least $6,000 for the fittings, valves, hangers and pipe insulation throughout the building, and 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

*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, WDC version 2.1 was used.*

| | *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** |

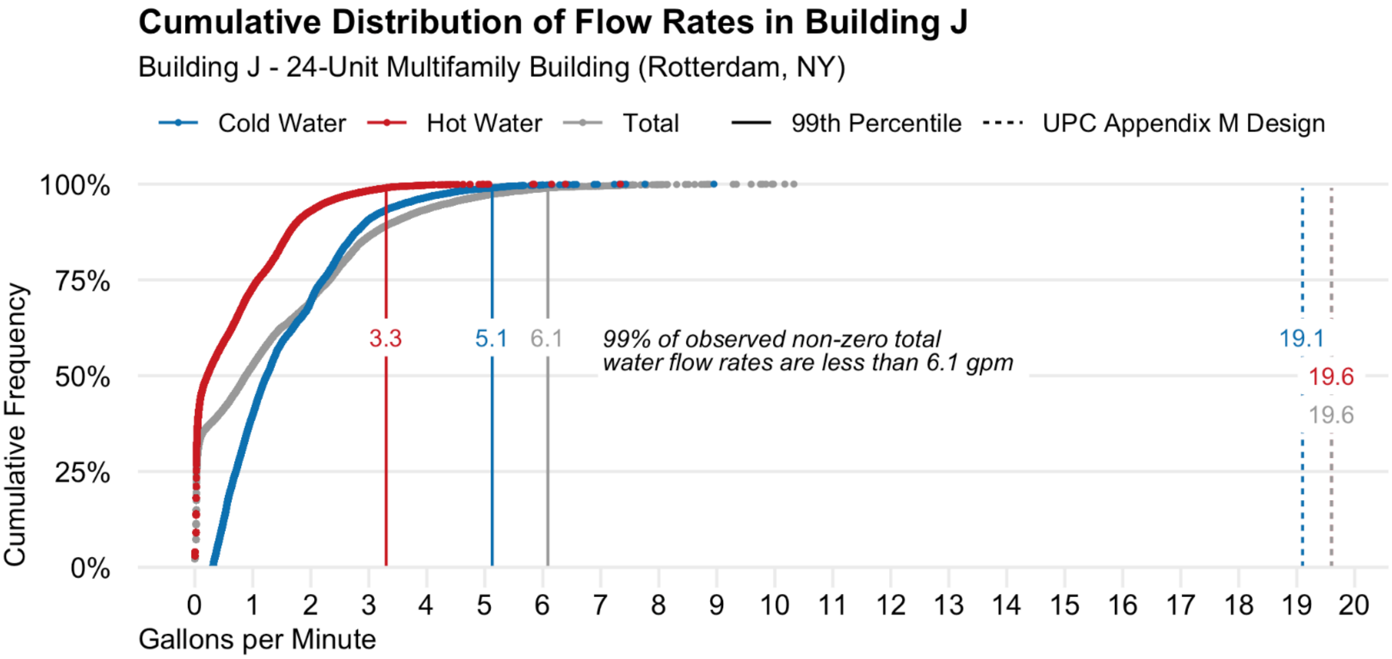
In addition to the cost savings in the piping and related equipment, since the WDC method predicts that the peak hot water demand will be more than nine times smaller compared to the WSFU method, the water heater can be sized much smaller as well. For a 35-unit multifamily building in New York State 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.

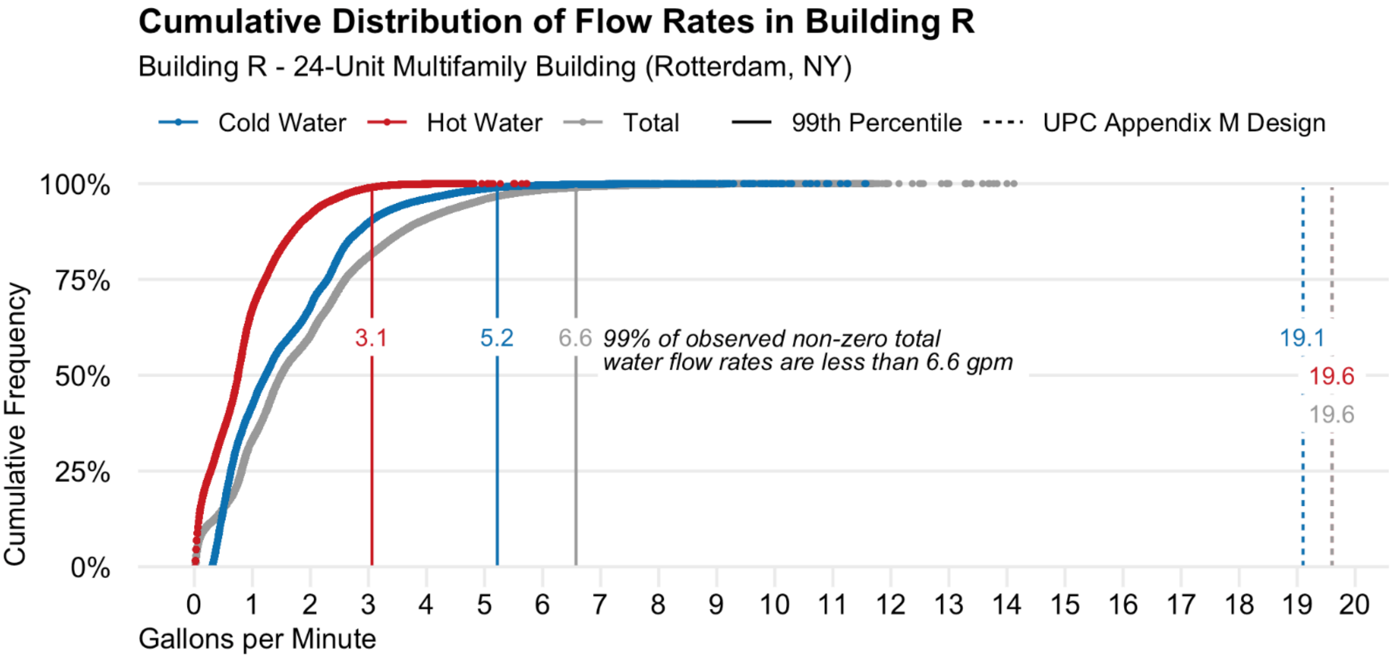
## 5.4 Comparing Cold Water and Total Water Use to Appendix M Estimates

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 UPC 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 UPC 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

*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

*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 22 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 ambiguous 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 UPC Appendix M design value was not simply due to limitations in experimental or analytical design.

The analysis detailed in Attachment 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 cropping the timeseries data. 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 Attachment 5.5.2 Estimating the Risk of Underestimating the Peak Flow Rate due to Long Logging Intervals 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 UPC 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. *Attachment 5.5.3 Summary of UPC Appendix M Exceedances in Four Multifamily Buildings* summarizes all instances when observed hot water flow rate exceeded the design value of the UPC 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 *Attachment 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 that simulated monitoring period and are reported for all long-term buildings in Table 10. The one-week monitoring period yields the most variable peak flow rates in the studied monitoring periods, resulting in peak flow rates being underestimated by as much as 45 percent.

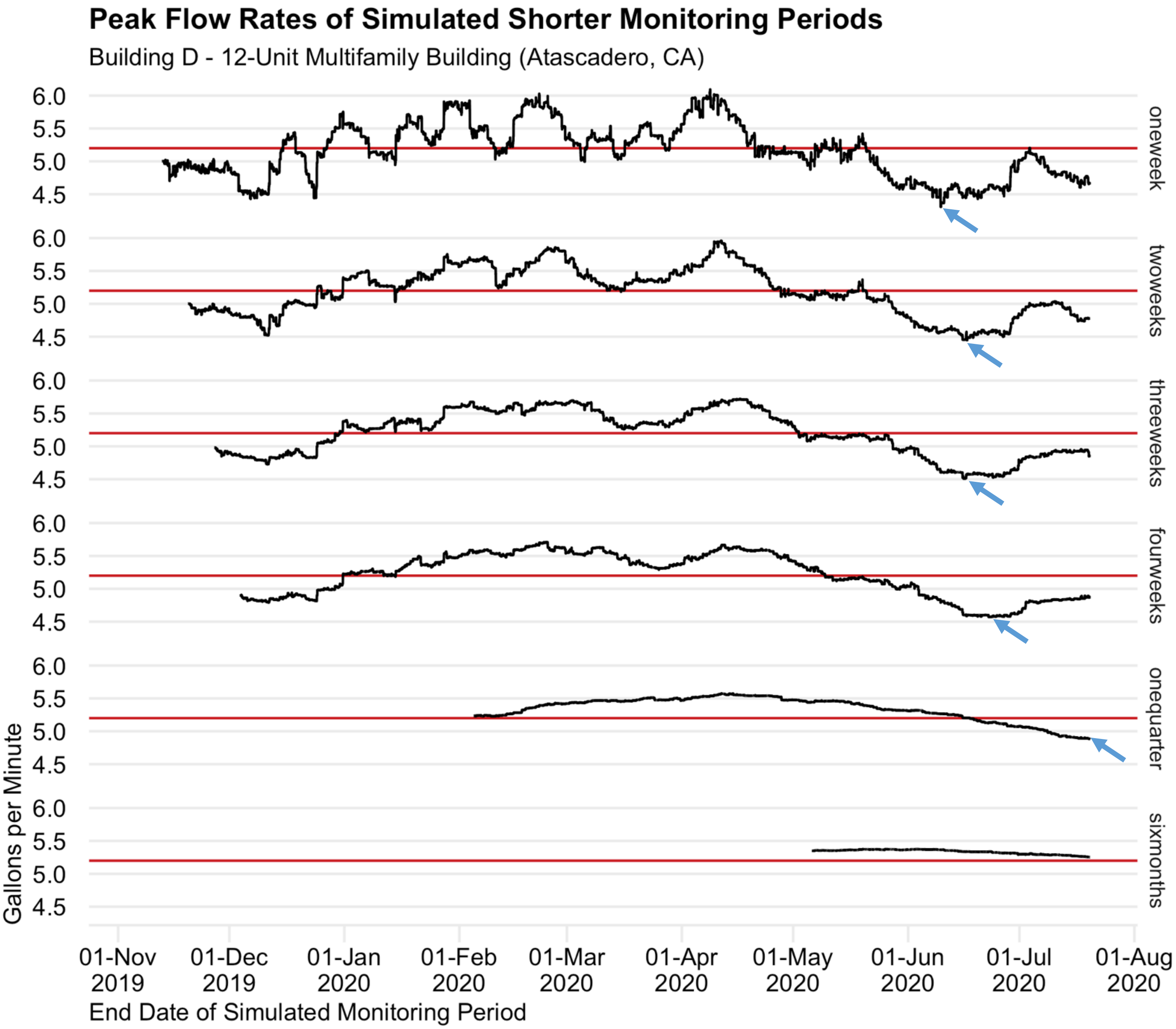


**Figure 6. Peak Flow Rates of Simulated Shorter Monitoring Periods in Building D**

*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 UPC 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 UPC Appendix M design value. Building F’s adjusted peak flow rate comes closest, only 0.2 gpm below the UPC Appendix M design.

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

*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.*

| | | | | | ***Worst-Case Underestimation of Study Peak*** *During Simulated Monitoring Periods* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **City** | **Monitored Apartments** | **Monitoring Period (day)** | **Study Peak (gpm)** | **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 | 18.7 | 31% | 20% | 20% | 16% | 16% | 12% | 8% |
| **Q** | Sunnyvale, CA | 24 | 272 | 5.2 | 38% | 36% | 20% | 16% | 10% | 3% | - |
| | | | | **Median** | **31%** | **25%** | **20%** | **16%** | **8%** | **3%** | - |
| | | | | **Maximum** | **45%** | **42%** | **41%** | **23%** | **16%** | **12%** | - |

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

*“Most Conservative Estimate of Study Peak” is equal to the “Study Peak” multiplied by 1.82. When the “UPC 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.*

| | **City** | **Monitoring Period (days)** | **Study Peak (gpm)** | **UPC App. M Design (gpm)** | **Conservatively Adjusted Study Peak (gpm)** | **UPC 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 | 22 | 3.1 | 19 | 5.6 | 3.4x |
| | | | | | **Median** | **1.8x** |
| | | | | | **Minimum** | **1.0x** |

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

Flow rate monitors 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 UPC 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**

*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.*

| | | | | | ***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 | 22 | 3.1 | 3% | 4% | 5% | 6% | 10% |
| | | | | **Median** | **2%** | **3%** | **4%** | **6%** | **10%** |
| | | | | **Max** | **6%** | **10%** | **15%** | **21%** | **27%** |

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 UPC Appendix M design value. Building E’s adjusted peak flow rate comes closest, 2.6 gpm below the UPC 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

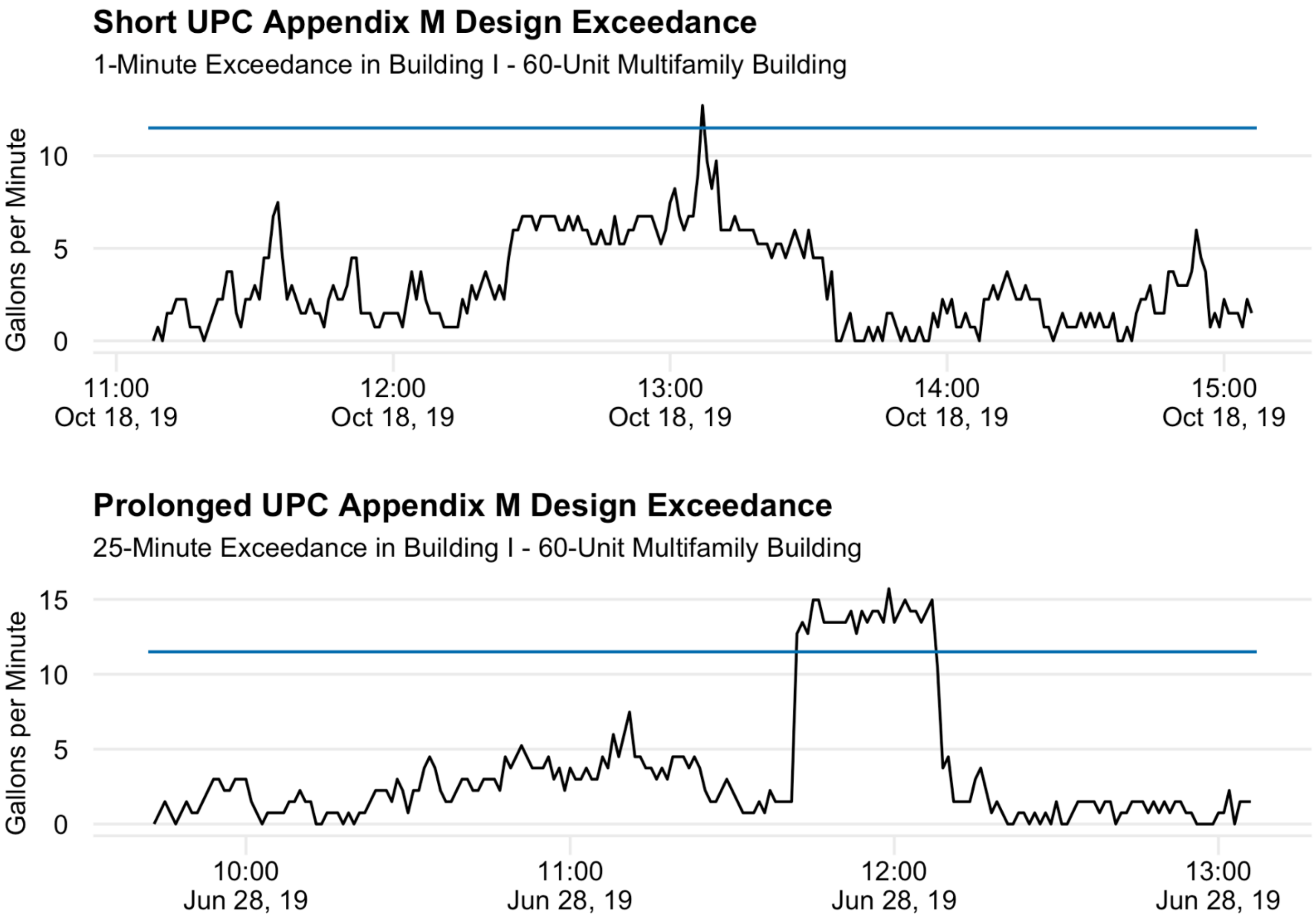
*"Most Conservative Estimate of Study Peak" is equal to the "Study Peak" multiplied by 1.37. When the "UPC Appendix M Design Relative to Conservatively Adjusted Study Peak" is 1.0x, the adjusted peak flow rate is equal to the design value. Study Peak is defined as the 99th percentile of non-zero hot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

| | City | Logging Interval (seconds) | Study Peak (gpm) | UPC App. M Design (gpm) | Conservatively Adjusted Study Peak (gpm) | UPC 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** |

### 5.5.3 Summary of UPC Appendix M Exceedances in Four Multifamily Buildings

It is understood that a building may infrequently experience water demand exceeding the UPC Appendix M design value. By either the UPC 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 UPC 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 event.



**Short UPC Appendix M Design Exceedance**

1-Minute Exceedance in Building I - 60-Unit Multifamily Building

**Prolonged UPC Appendix M Design Exceedance**

25-Minute Exceedance in Building I - 60-Unit Multifamily Building

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

*The UPC 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 UPC Appendix M Design Values

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

| | City | Monitored Apartments | Monitoring Period (day) | Cumulative Time in Short Exceedances of App. M (min) | UPC 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 |

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

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

| | City | Monitored Apartments | Monitoring Period (day) | Event Count | UPC 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 |

### 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. UPC 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 UPC 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

*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.*

| | | | | | *Peak Flow Observed in…* | | |
|---|---|---|---|---|---|---|---|
| | **City** | **Monitored Apartments** | **Monitoring Period (days)** | **Congested Hour (24h)** | **Congested Hour (gpm)** | **Study (gpm)** | **UPC 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 | 22 | 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 |

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