What Have We Learned About Using the WDC?

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Prepared for ICC 815 Meeting #4, 26 June 2023
Updated 13 July 2023 with feedback.

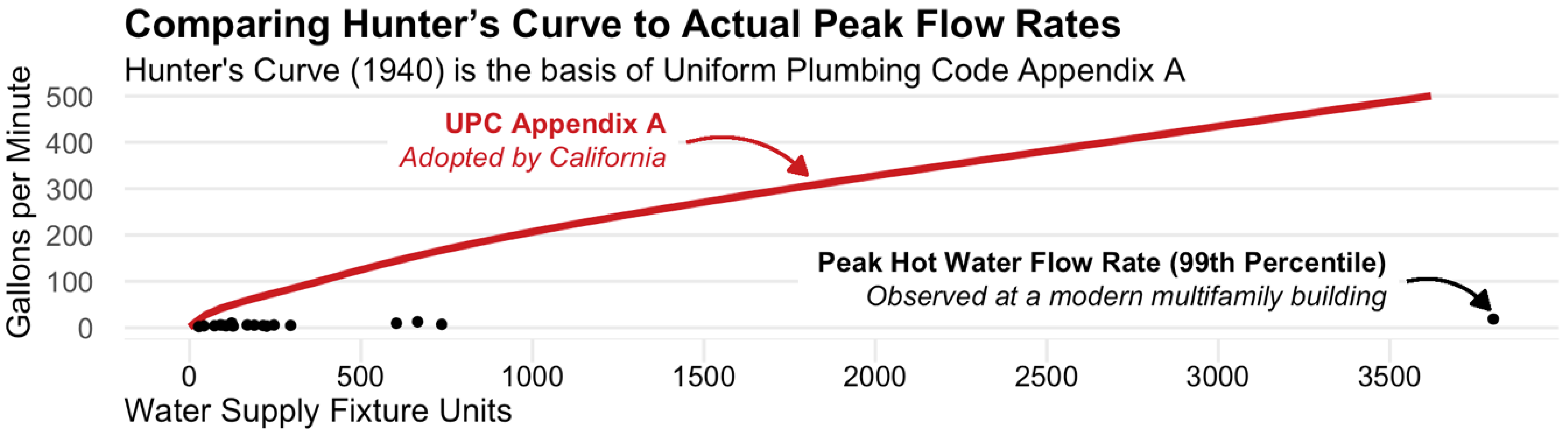
Special thanks to:

Gary Klein, Gary Klein and Associates, Inc.

Steffi Becking, 2050 Partners, Inc.

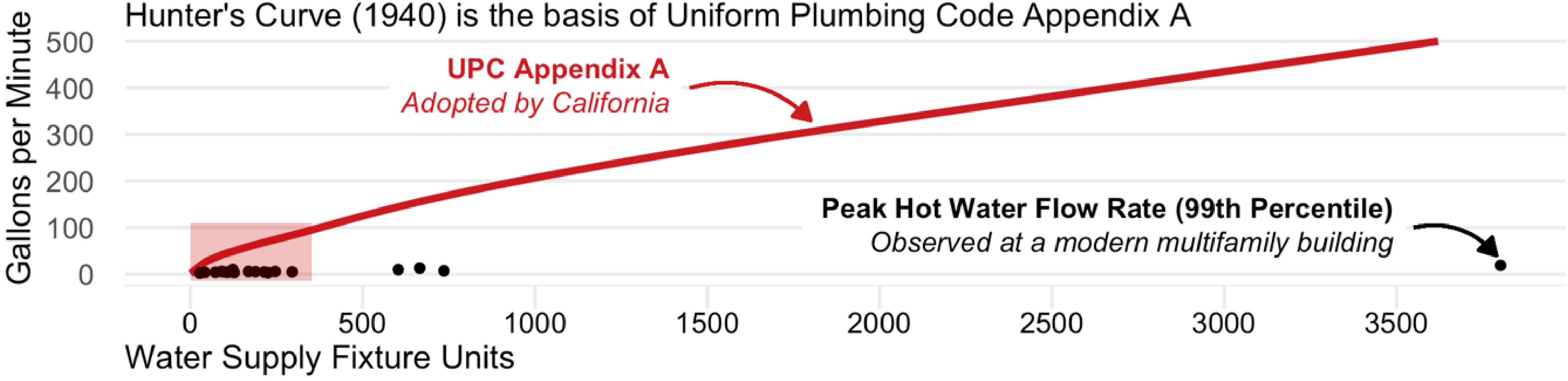
Amy Dryden and Jack Aitchison, Association for Energy Affordability

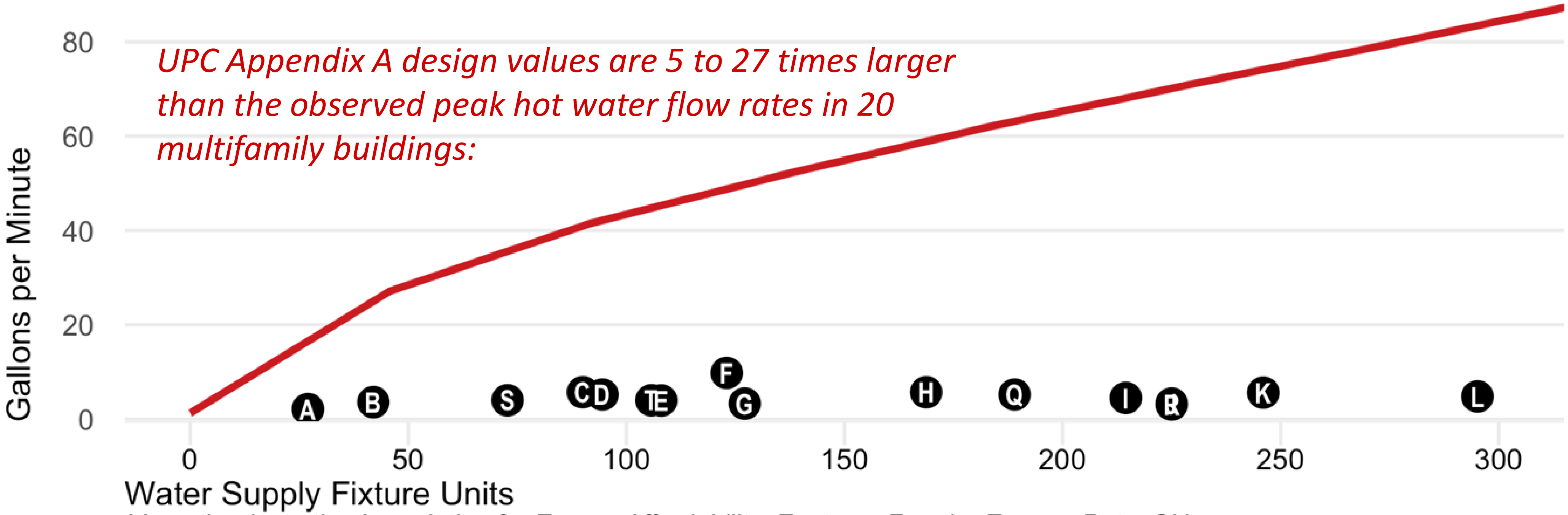
Kelly Cunningham, Codes and Standards Program, Pacific Gas and Electric Company


Comparing Hunter's Curve to Actual Peak Flow Rates
Hunter's Curve (1940) is the basis of Uniform Plumbing Code Appendix A
Gallons per Minute
500
400
300
200
100
0
UPC Appendix A
Adopted by California
Peak Hot Water Flow Rate (99th Percentile)
Observed at a modern multifamily building
0
500
1000
1500
2000
2500
3000
3500
Water Supply Fixture Units

Comparing Hunter's Curve to Actual Peak Flow Rates

Hunter's Curve (1940) is the basis of Uniform Plumbing Code Appendix A

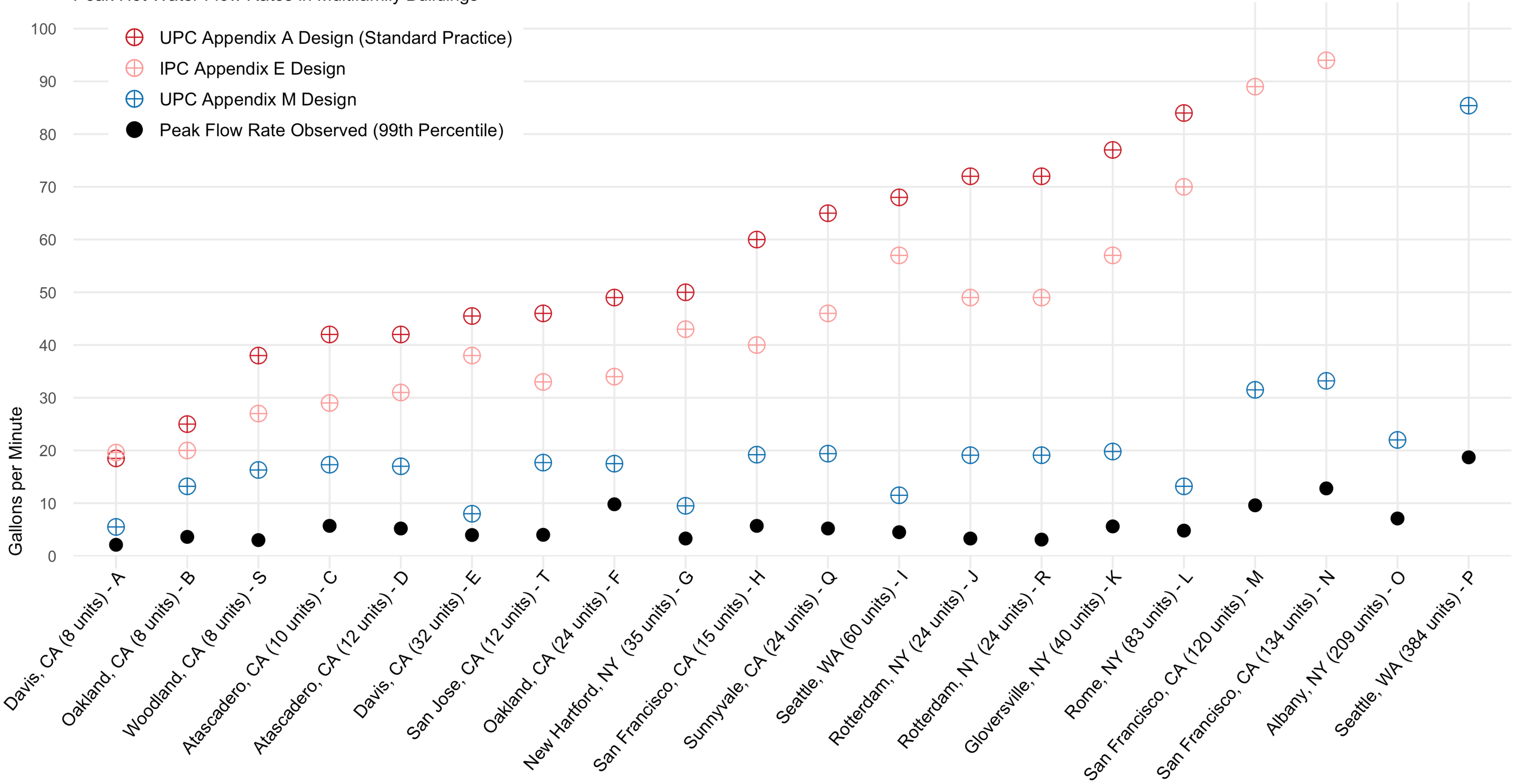




Many thanks to the Association for Energy Affordability, Ecotope, Frontier Energy, Peter Skinner, and the UC Davis Western Cooling Efficiency Center for providing data.

UPC Appendix M design values are between 2 and 6 times the observed peak hot water flow rates

Peak Hot Water Flow Rates in Multifamily Buildings



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

			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	3x	27	19	9x

Summary of Detailed Data for the Analyzed Multifamily Buildings

			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	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	12x
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	3946	500	27x
Q	Sunnyvale, CA	24	272	60	-	5.4	19	4x	198	65	13x
R	Rotterdam, NY	24	22	1	-	3.1	19	6x	234	72	23x
S	Woodland, CA	9	128	60	84%	4	16	4x	76	38	13x
T	San Jose, CA	12	59	60	72%	4	18	4x	110	46	12x
							Median	**3x**			**13x**

Summary of Detailed Data 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	46
T	San Jose, CA	12	MF Low Income	21	21	0	21	12	12	0	66

Summary of Fixture Counts for the Analyzed Multifamily Buildings

What Else Have We Learned?

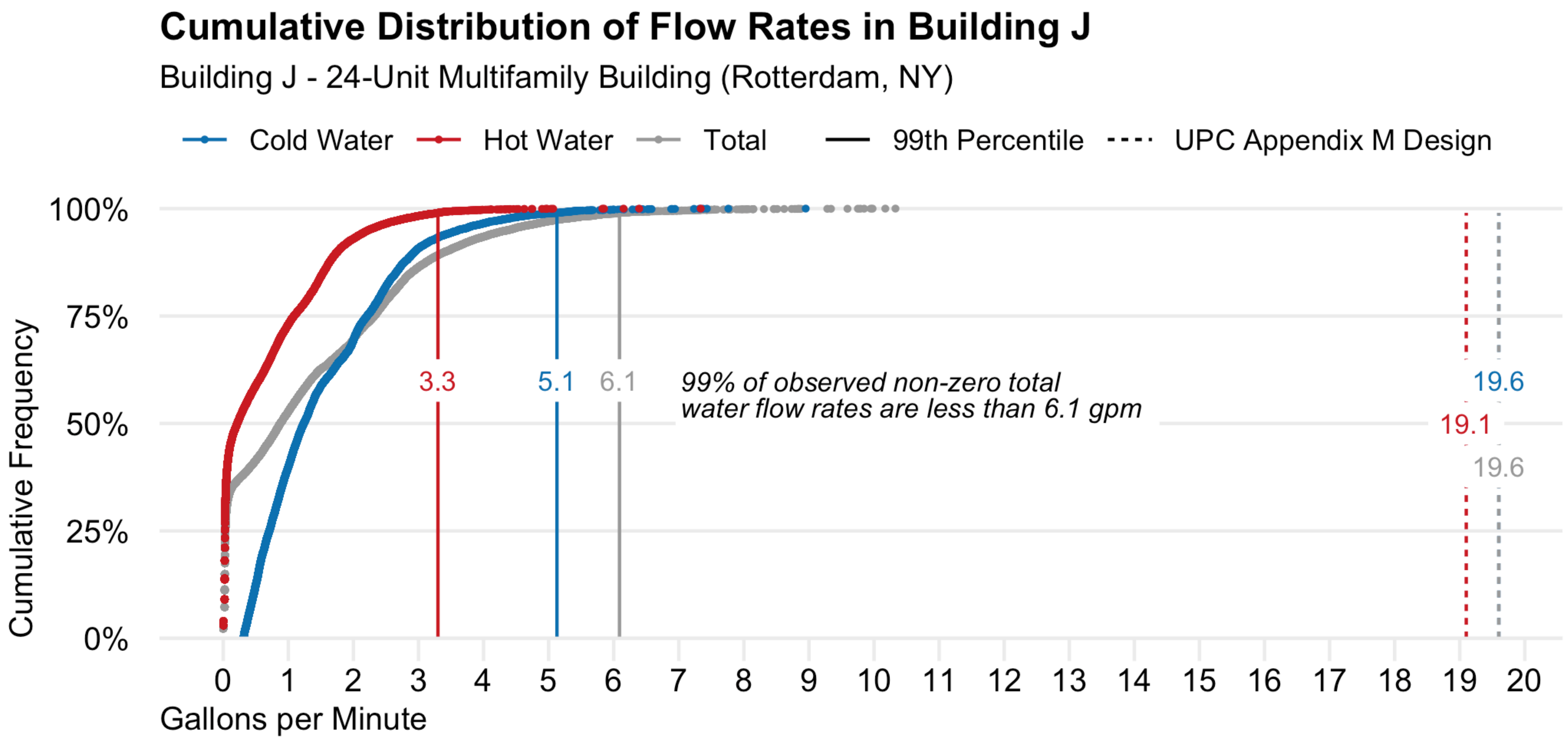
1. How do WDC Estimates for the Cold Water Branch Compare to Actual Cold Water Flow Rates?

2. What is the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods?

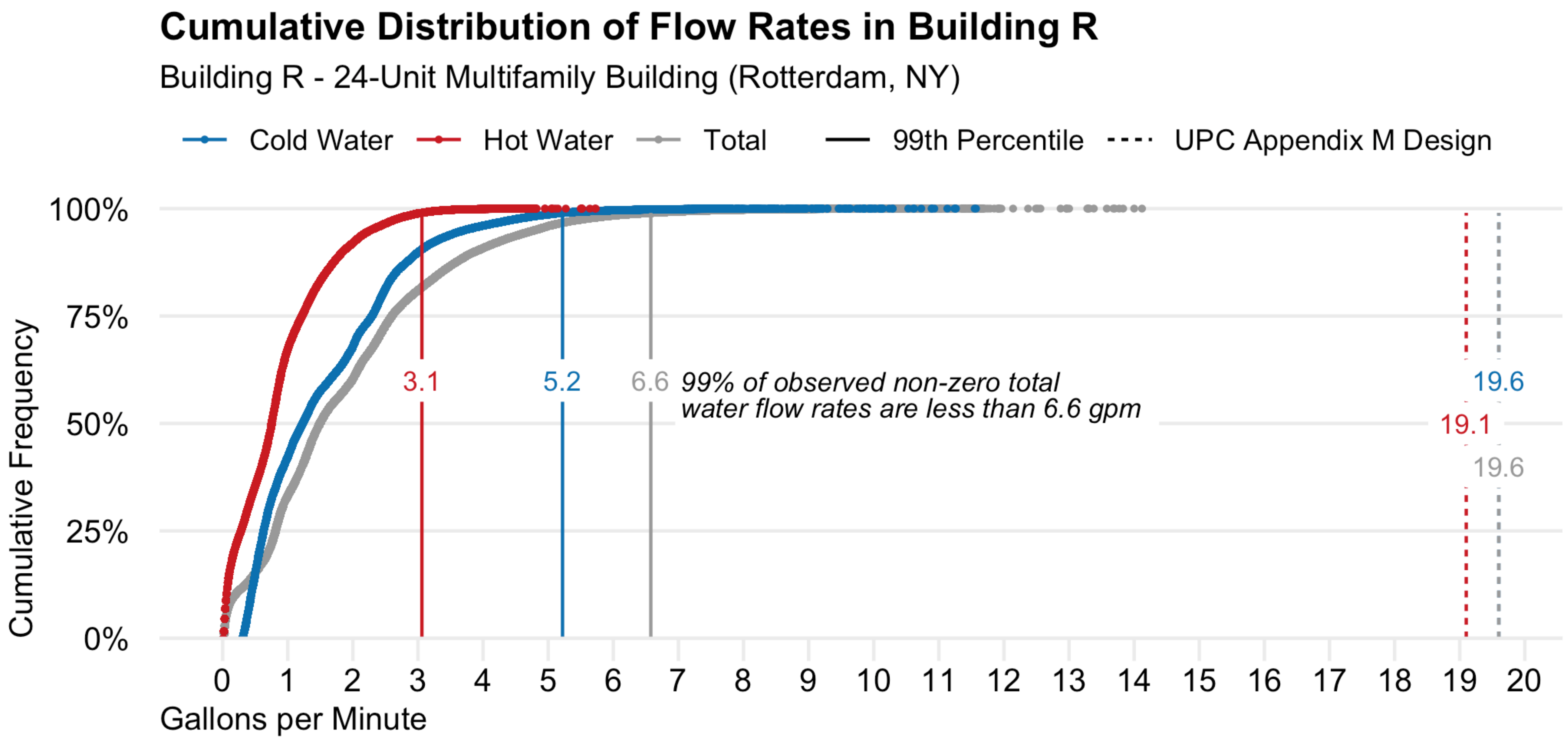
3. What is the Risk of Underestimating Peak Flow Rates due to Longer Logging Intervals?

4. How often were WDC Design Estimates Exceeded?

5. How do Metrics to Assess Peak Water Flows in Multifamily Buildings Compare?



So, What About Hot, Cold and Total?



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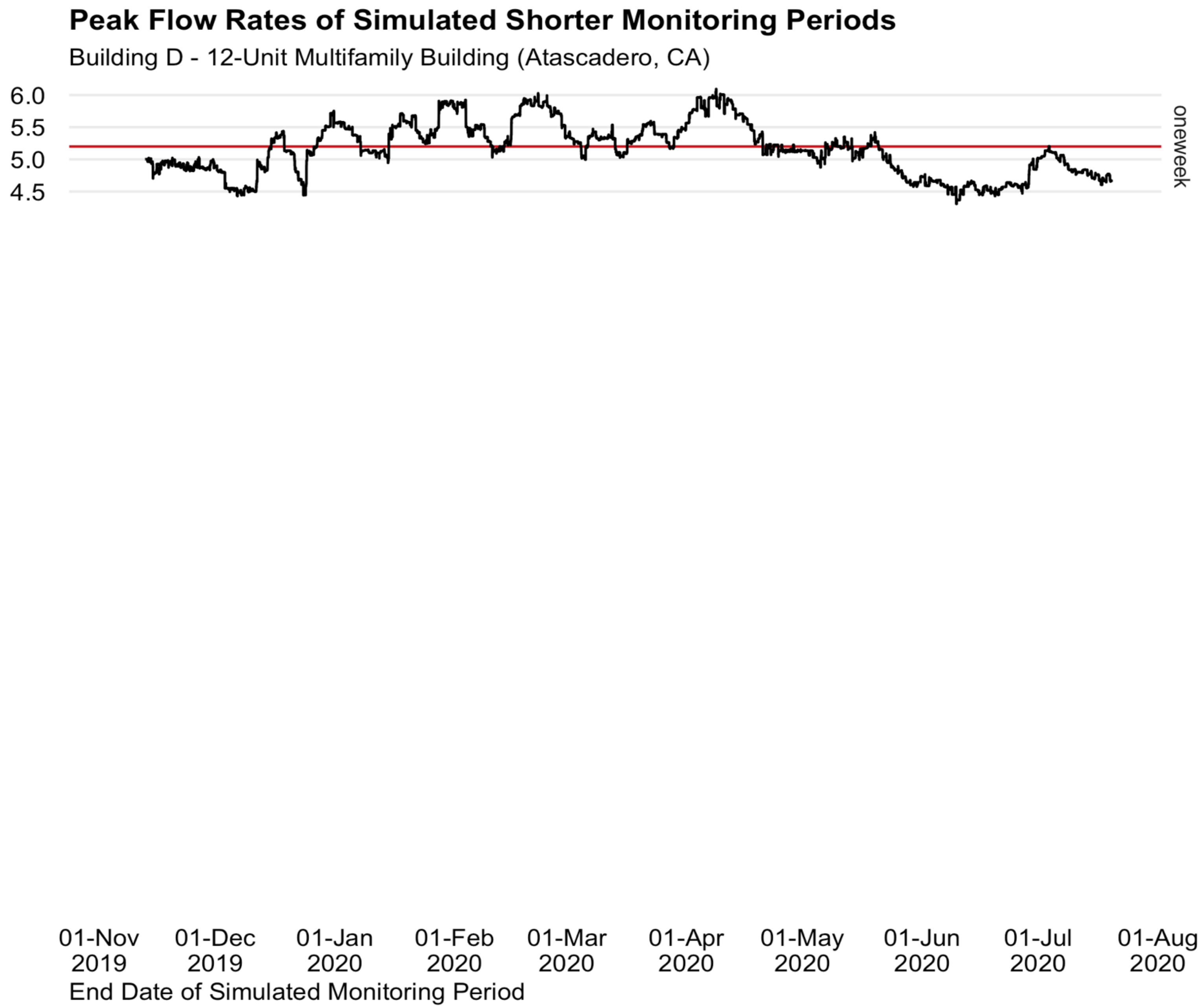
Estimating the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods



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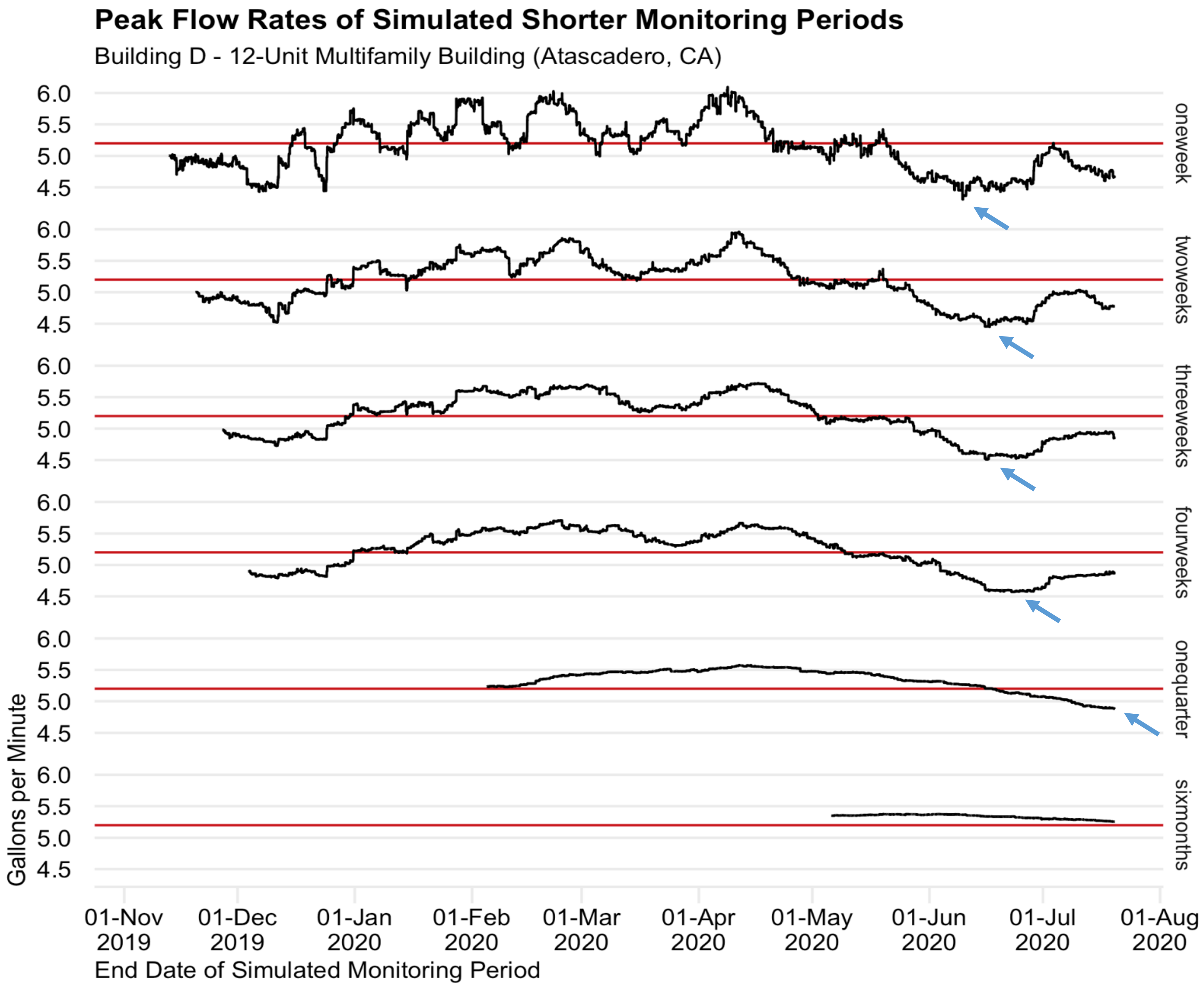


Estimating the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods

	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	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%**	-

Conservative Multiplier for Short Monitoring Periods: 1 / (1 - 45%) = 1.82

Adjusted Study Peaks for Possible Underestimation due to Short Monitoring Periods

	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**

What Else Have We Learned?

1. How do WDC Estimates for the Cold Water Branch Compare to Actual Cold Water Flow Rates?

2. What is the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods?

3. What is the Risk of Underestimating Peak Flow Rates due to Longer Logging Intervals?

4. How often were WDC Design Estimates Exceeded?

5. How do Metrics to Assess Peak Water Flows in Multifamily Buildings Compare?

Underestimation of Peak Flow Rates due to Longer Logging Intervals

	City	Monitored Apartments	Monitoring Period (day)	Study Peak (gpm)	**Worst-Case Underestimation of Study Peak** *with Simulated Logging Interval* 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%**
				Minimum	**6%**	**10%**	**15%**	**21%**	**27%**

Conservative Multiplier for Longer Logging Intervals: 1 / (1 – 27%) = 1.37

Study Peaks for Possible Underestimation due to Longer Logging Intervals

	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**

What Else Have We Learned?

1. How do WDC Estimates for the Cold Water Branch Compare to Actual Cold Water Flow Rates?

2. What is the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods?

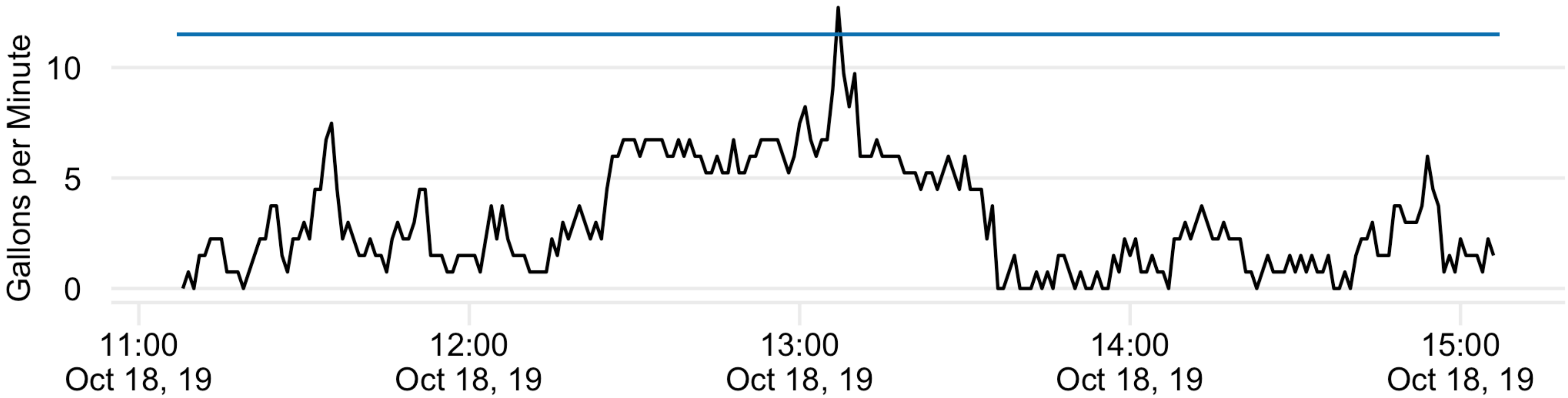
3. What is the Risk of Underestimating Peak Flow Rates due to Longer Logging Intervals?

4. How often were WDC Design Estimates Exceeded?

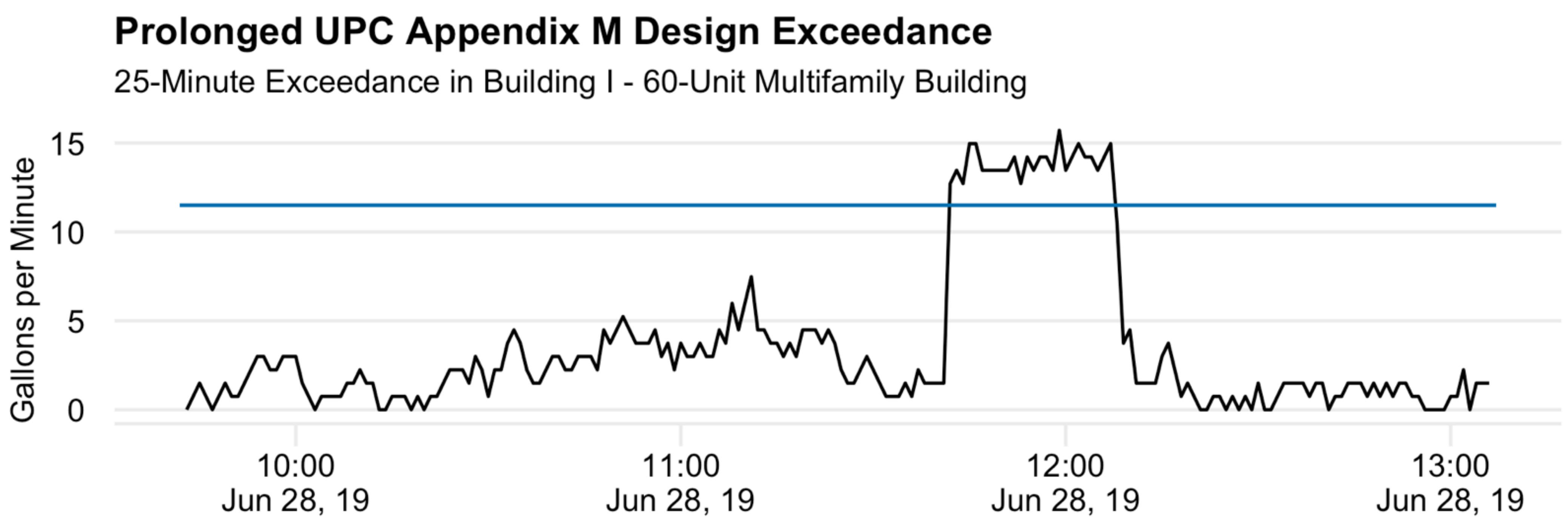
5. How do Metrics to Assess Peak Water Flows in Multifamily Buildings Compare?

Short UPC Appendix M Design Exceedance

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



	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



	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

What Else Have We Learned?

1. How do WDC Estimates for the Cold Water Branch Compare to Actual Cold Water Flow Rates?

2. What is the Risk of Underestimating the Peak Flow Rate due to Short Monitoring Periods?

3. What is the Risk of Underestimating Peak Flow Rates due to Longer Logging Intervals?

4. How often were WDC Design Estimates Exceeded?

5. How do Metrics to Assess Peak Water Flows in Multifamily Buildings Compare?

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

	City	Monitored Apartments	Monitoring Period (days)	Congested Hour (24h)	*Peak Flow Observed in…* 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

What Have We Learned?

1. WDC Estimates for the Cold-Water Branch also Exceed Actual Cold Water Flow Rates.

2. Worst-case Scenarios for Underestimating the Peak Flow Rate with Short Monitoring Periods range from 12% to 45%.

3. Worst-case Scenarios for Underestimating Peak Flow Rates due to Longer Logging Intervals range from 6% to 27%.

4. WDC Design Estimates were exceeded very rarely in 4 of the 20 buildings observed.

5. Peak Water Flow Metrics differ, but not enough to impact conclusions about Appendix M efficacy.

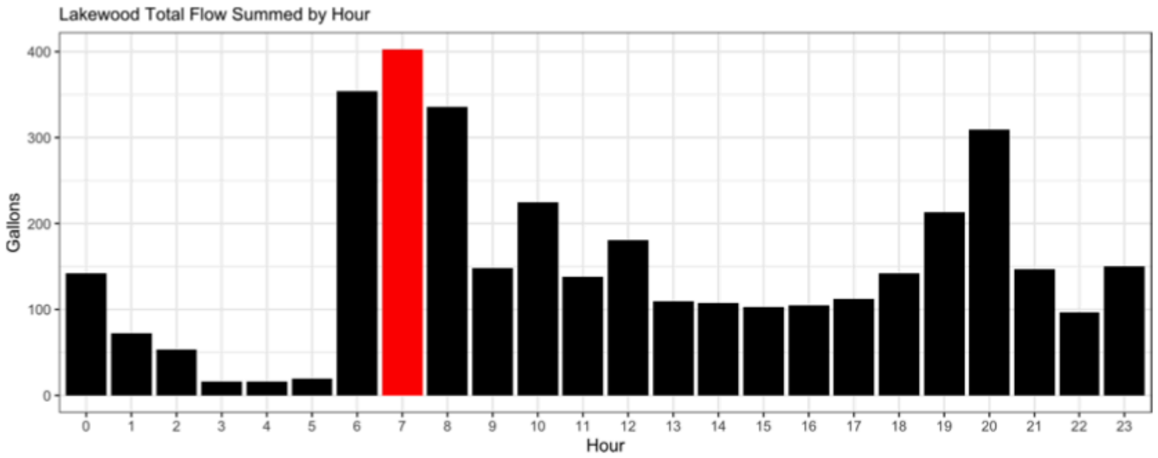
Thank you.

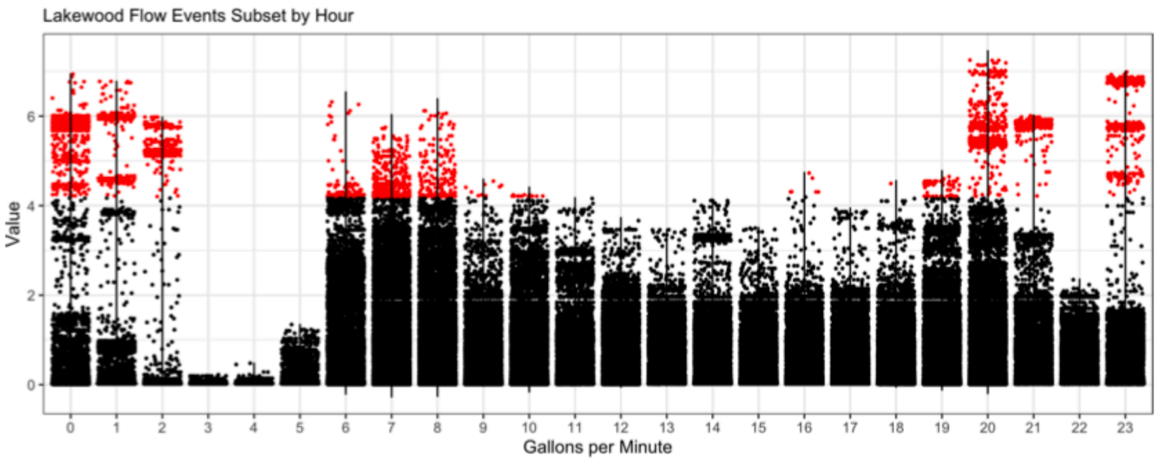
Building H

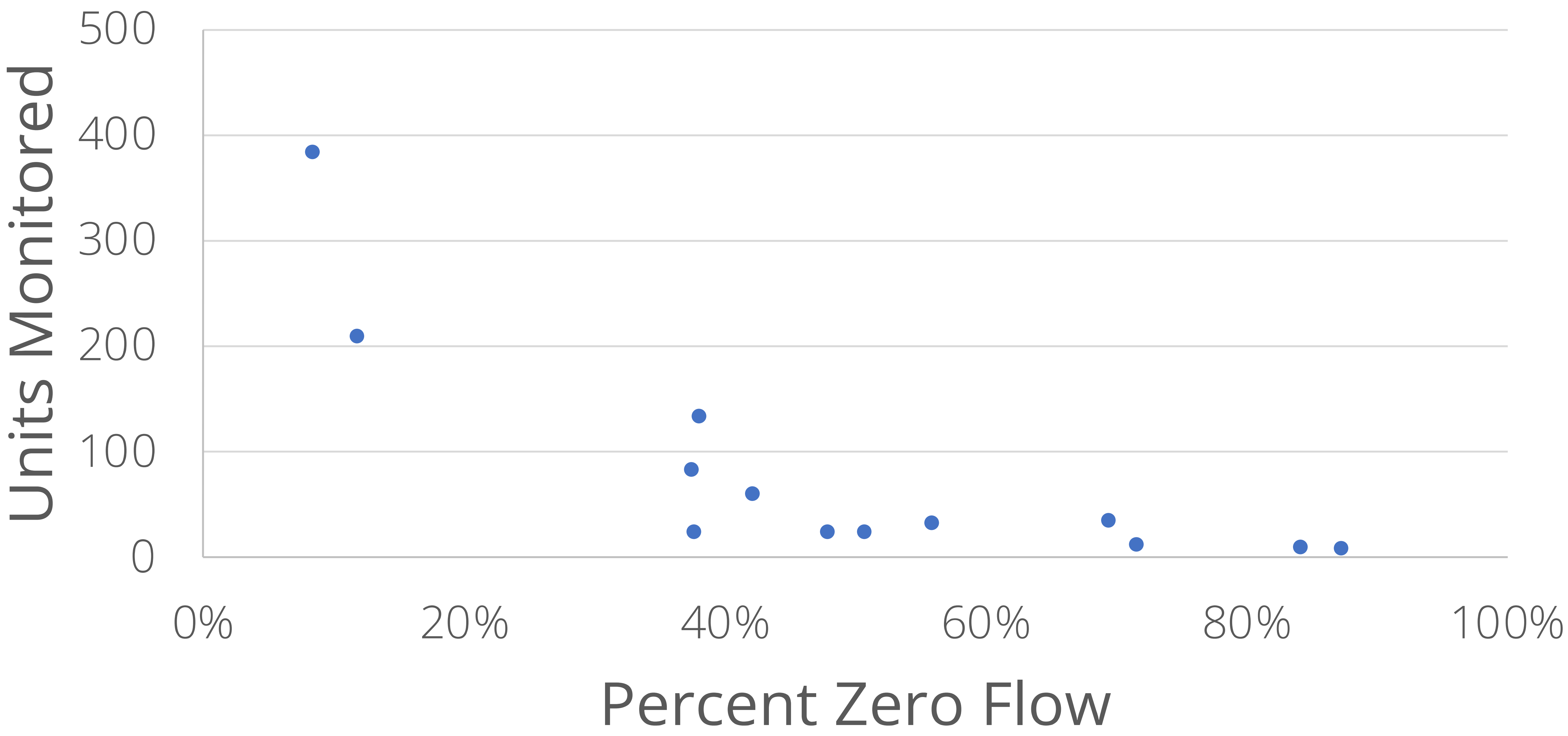
Summarize by Hour

Table 4: Peak Hour

Hour	Gallons	99th Percentile (gpm)
7	402.44	4.2






Units Monitored
500
400
300
200
100
0
0%
20%
40%
60%
80%
100%
Percent Zero Flow