Water Research Foundation – 4689

Assessing Water Demand Patterns to Improve Sizing of Water Meters and Service Lines

Water Research Foundation℠

WaterDM DEMAND MANAGEMENT

METERING TECHNOLOGY CONSULTANTS, INC.

UNIVERSITY OF Cincinnati

DENVER WATER

WESTMINSTER

SCOTTSDALE WATER

Badger Meter

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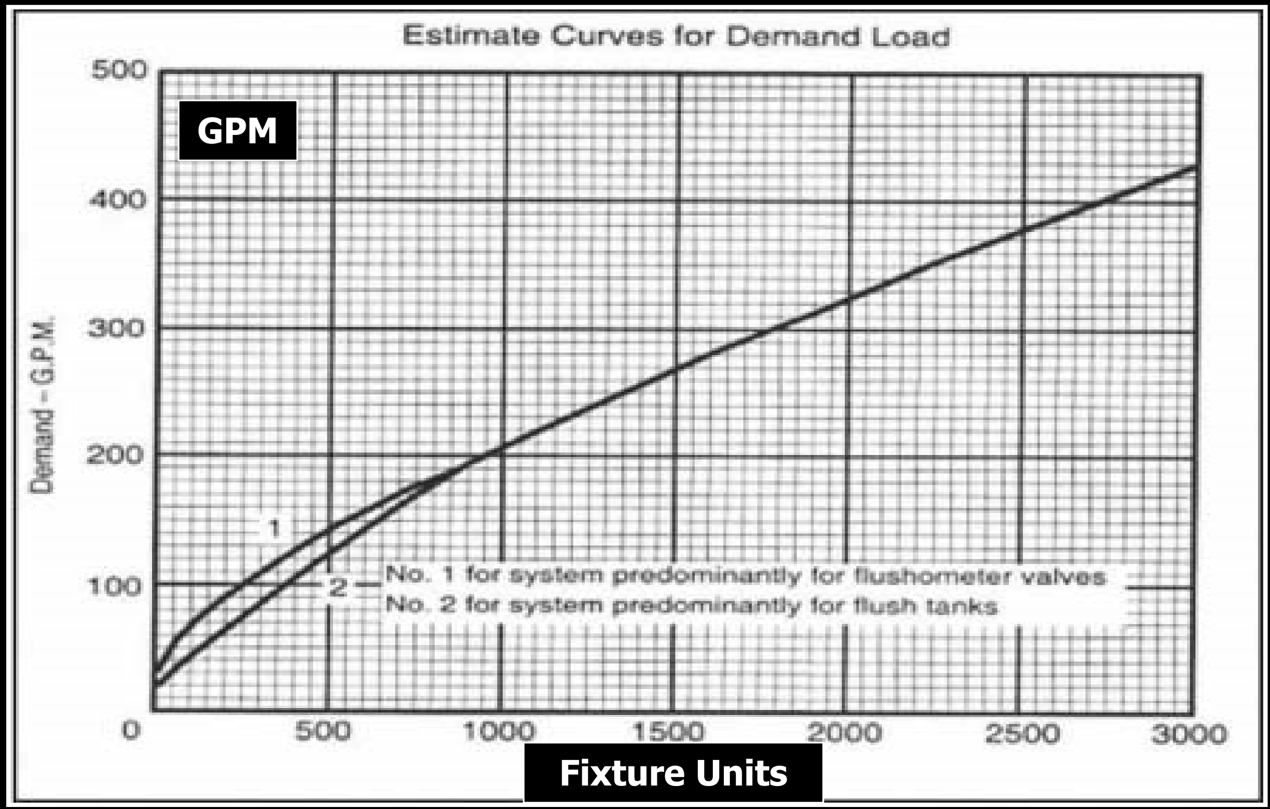
WRF – 4689 Tailored Collaboration

$175,000 – cash & in-kind
May 2016 start
Oct 2018 draft report
Mid-2019 publication

Water Research Foundation
WaterDM Demand Management
METERING TECHNOLOGY CONSULTANTS, INC.
University of Cincinnati
Denver Water
Westminster
Scottsdale Water
Badger Meter

20th Century Design Legacy: Hunter's Curve (BMS Report 65, 1940)



The original Hunter's Curve to estimate peak water use in buildings, (Hunter, 1940).

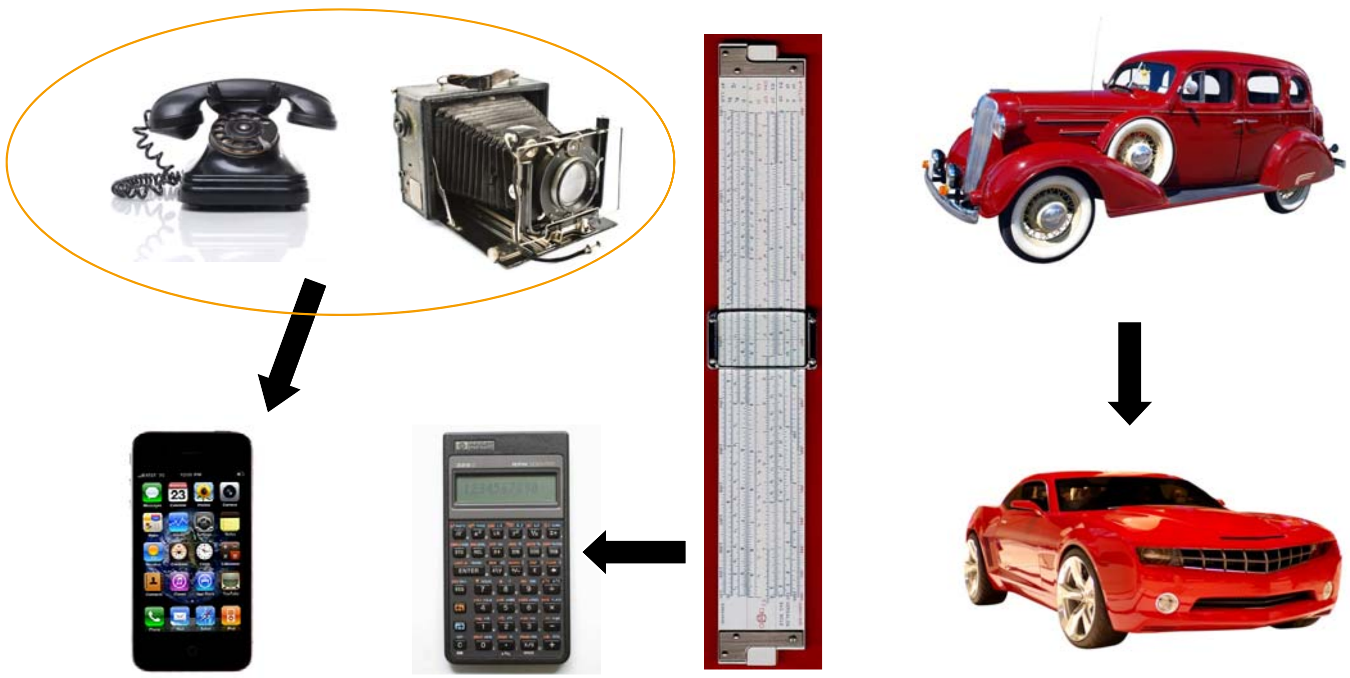
Life in 1940

Population = 2.3B

Gas = $0.18/gal

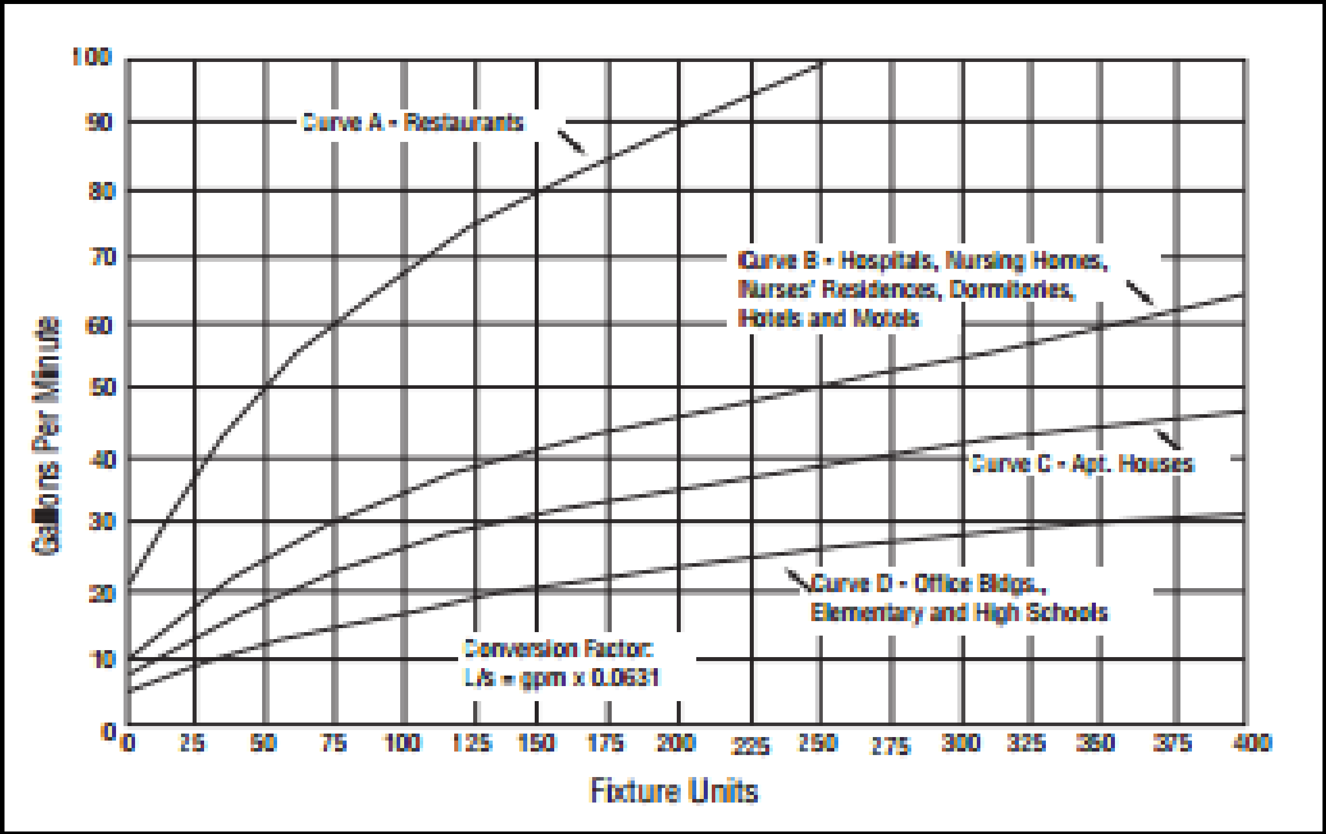
Life in 2018



Population = 7.0B

Gas = $2.8/gal

The Problem: Sizing Meters for Modern Buildings



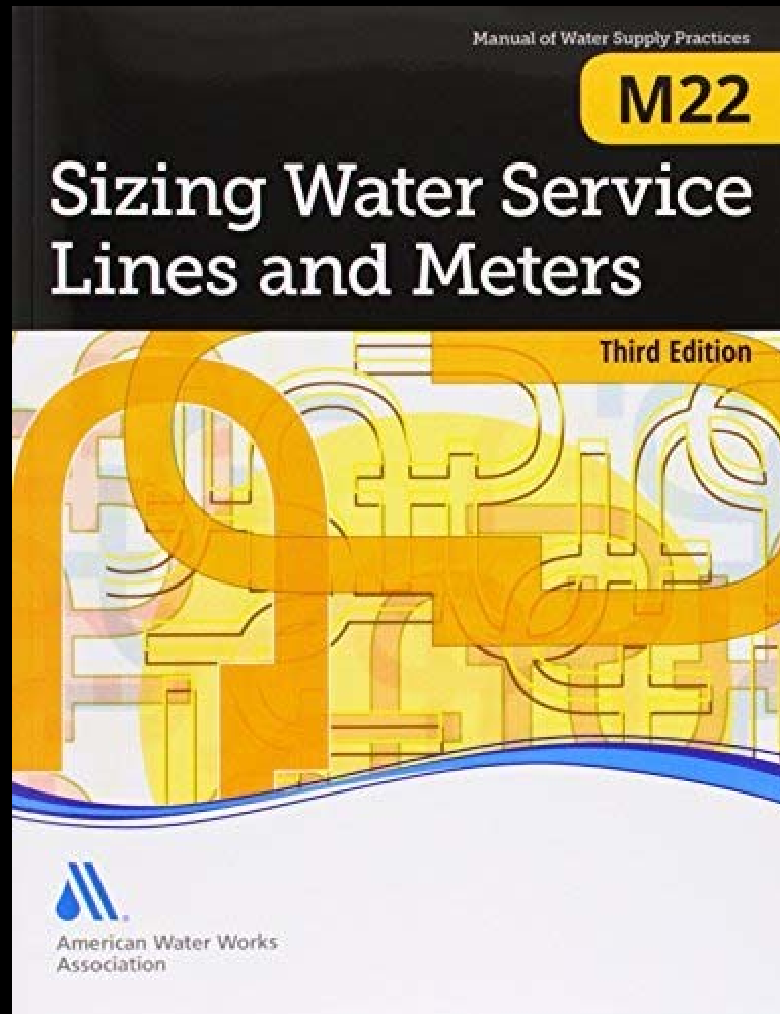
Family of design curves to estimate peak water use in various buildings (from Armstrong Hot Water Group, 2014).

M22, 3rd Ed.

3rd Edition - 2014
2nd Edition – 2004
1st Edition - 1975

3rd. Edition - four year effort of the Customer Metering and Practices Committee.

4th Edition slated for 2021



Study Goals

Collect and analyze water demand pattern data for the purpose of sizing water meters and service lines.

Project Tasks

- **Task 1 – Collect and Analyze Utility Billing Data and Meter Sizing Methods (100% done)**
- **Task 2 – Collect Short Interval/High Resolution AMI Data and Customer Level Data (90% done)**
- **Task 3 – Prepare Database and Analyze Flow Data (60% done)**
- **Task 4 – Prepare Demand Curves (20% done)**
- **Task 5 – Prepare Final Report and Database (40% done)**

Draft final report submitted to PAC, Oct. 1, 2018

Presentations at WaterSmart Innovations 2018, ACE 2019

Research Focus

- Meters 1” and larger
- New/equipped with water efficient fixtures
- Non-Residential
- Multifamily

Westminster Buildings

Property	Count
Retail	17
Restaurant	11
Multifamily	8
Office	7
Medical Facility	5
School	5
Misc	5
Senior/Nursing	4
Hotel	4
Hospital	2
Child Care	1
Church	1
Clubhouse	1
Event Center	1
Grocery	1
Car Wash	1
Medical Center	1
Storage	1
Movie Theater	1
Irrigation	1

WESTMINSTER
COLORADO

*Not the actual buildings, but these are similar to some of the buildings.


Badger Recordall PD Meters – 1”, 1.5”

Robust and reliable hourly data recording method. 2.4 years of hourly consumption were made available for this study.

Badger Recordall Turbo – 2”, 3” & 4” & E series

Schools and Multifamily

Radcom Flow recorders

10 second data

Retrofit Schools

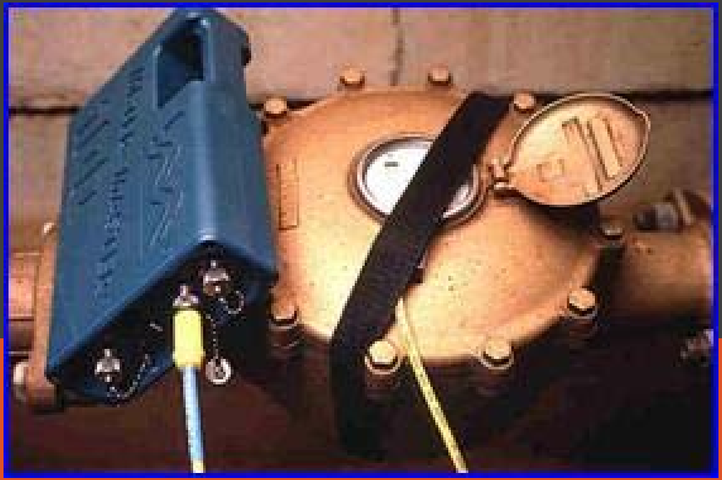
Retrofit Multifamily

Summary of 19 Denver Sites

- Schools (10)
  - Variety of student ages
  - Variety of enrollment numbers
  - Variety of meter sizes
  - 10-sec and 15-sec data
- Multifamily (9)
  - 2 Complexes
  - 9 Buildings
  - All 1.5-inch meters
  - 10-sec data
  - 14 days

Summary of Sites				
ID	Type	Enrollment	MeterSize	Make
1	Elementary School	593	4“x3/4” Compound	Badger
2	ECE-8 School	941	3"x5/8" Compound	Neptune
3	Elementary School	564	3"x5/8" Compound	Neptune
4	Middle School	471	3"x5/8" Compound	Neptune
5	High School	1403	4" Turbine	Badger
6	Middle School	471	3"x3/4" Compound	Neptune
7	High School	1672	3"x5/8" Compound	Neptune
8	Elementary School	628	2" Disc	Badger
9	Middle School	792	2" Disc	Neptune
10	ECE-12 School	319	2" Disc	Badger
11	Multifamily	N/A	1.5" disc	Neptune
12	Multifamily	N/A	1.5" disc	Neptune
13	Multifamily	N/A	1.5" disc	Neptune
14	Multifamily	N/A	1.5" disc	Neptune
15	Multifamily	N/A	1.5" disc	Badger
16	Multifamily	N/A	1.5" disc	Badger
17	Multifamily	N/A	1.5" disc	Badger
18	Multifamily	N/A	1.5" disc	Badger
19	Multifamily	N/A	1.5" disc	Badger

Scottsdale, Arizona



Summary of 30 Scottsdale Sites

- 30 sites, various uses (no schools)
- 2-week study window at each site
- 23 Sites with 10-sec data
- 7 Sites with 30-sec data

- 10 Sites with 2-inch meters
- 20 Sites with 3-inch meters
- 3700 sites with 2 or 3 inch meters
- < 1% of large meter users

Overview of Meter Specifications

Size	Make	Model	SMOC (gpm)	Typical Min. Flow (gpm)
2"	Badger	M170	170	2.5
3"	Badger	Turbo450	550	5
3"x5/8"	Badger	3x5/8Compound	450	0.5
3"	Sensus	W-350	450	5

SMOC = Safe Maximum Operating Capacity

Overview of Scottsdale Sites

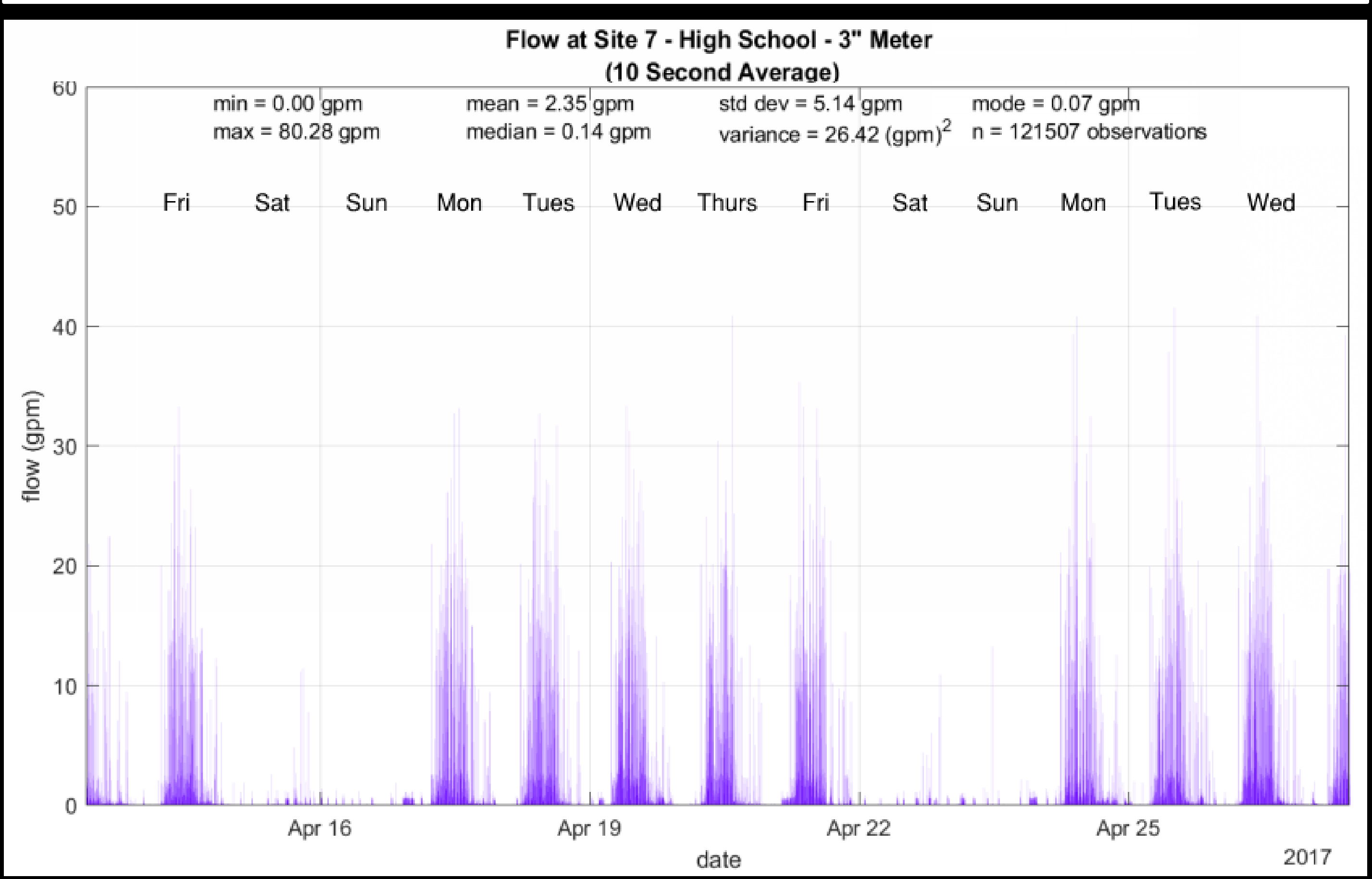
Grocery	1
Home Owners Association	4
Hotel	3
Ice Rink	1
Medical Center	2
Multi-Family	9
Multi-Office	1
Office	1
Senior Living	3
Shopping Center	1
To be Categorized	4

Water Research Foundation Project 4689

Summary of High Resolution Denver Meter Data
Summary of High Resolution Scottsdale Meter Data
27 March 2018

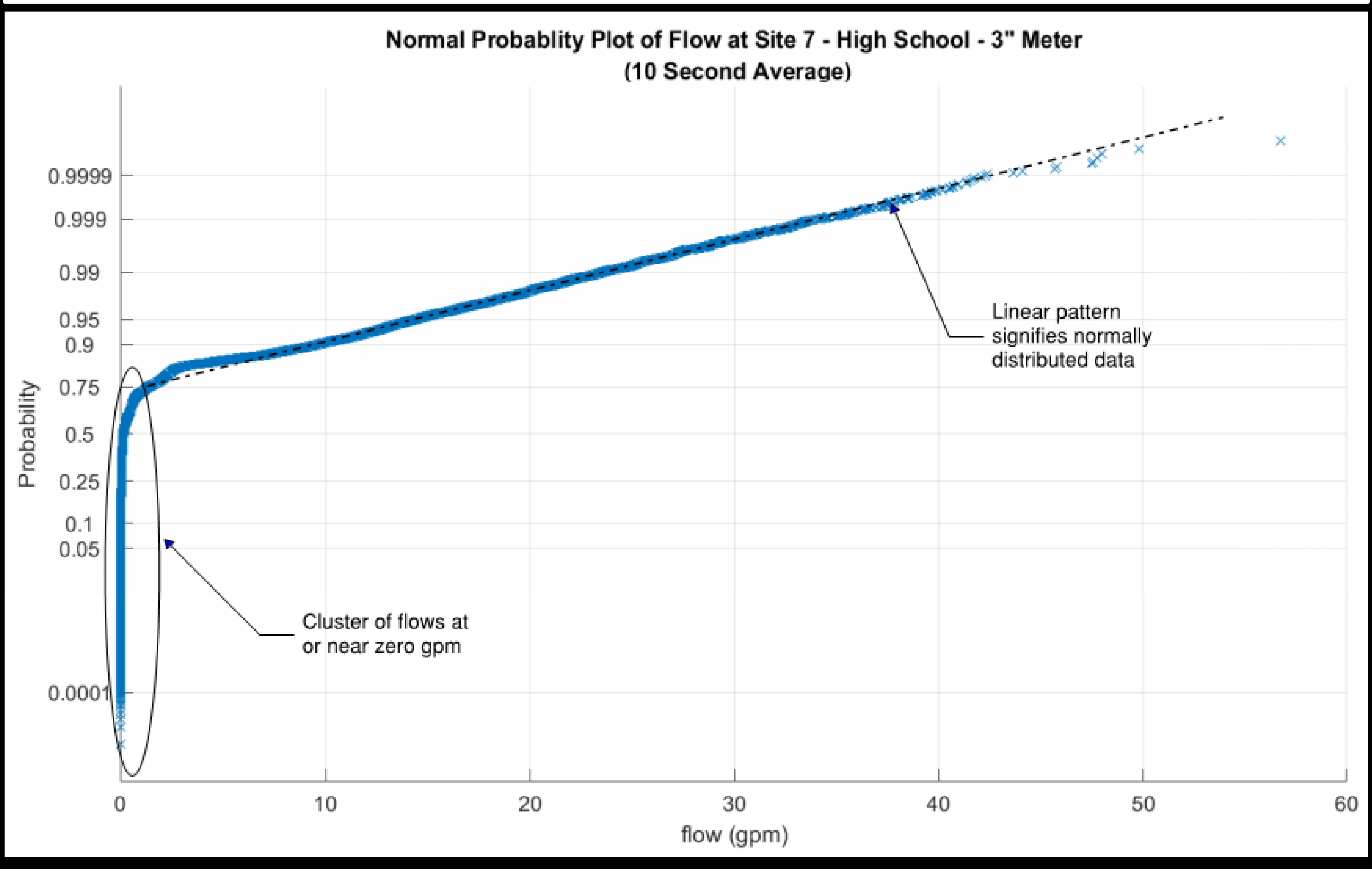
Denver Schools – Full, Well-Behaved Dataset (14 days)

Clear weekday patterns
Predictable use as expected from a school with a constant schedule



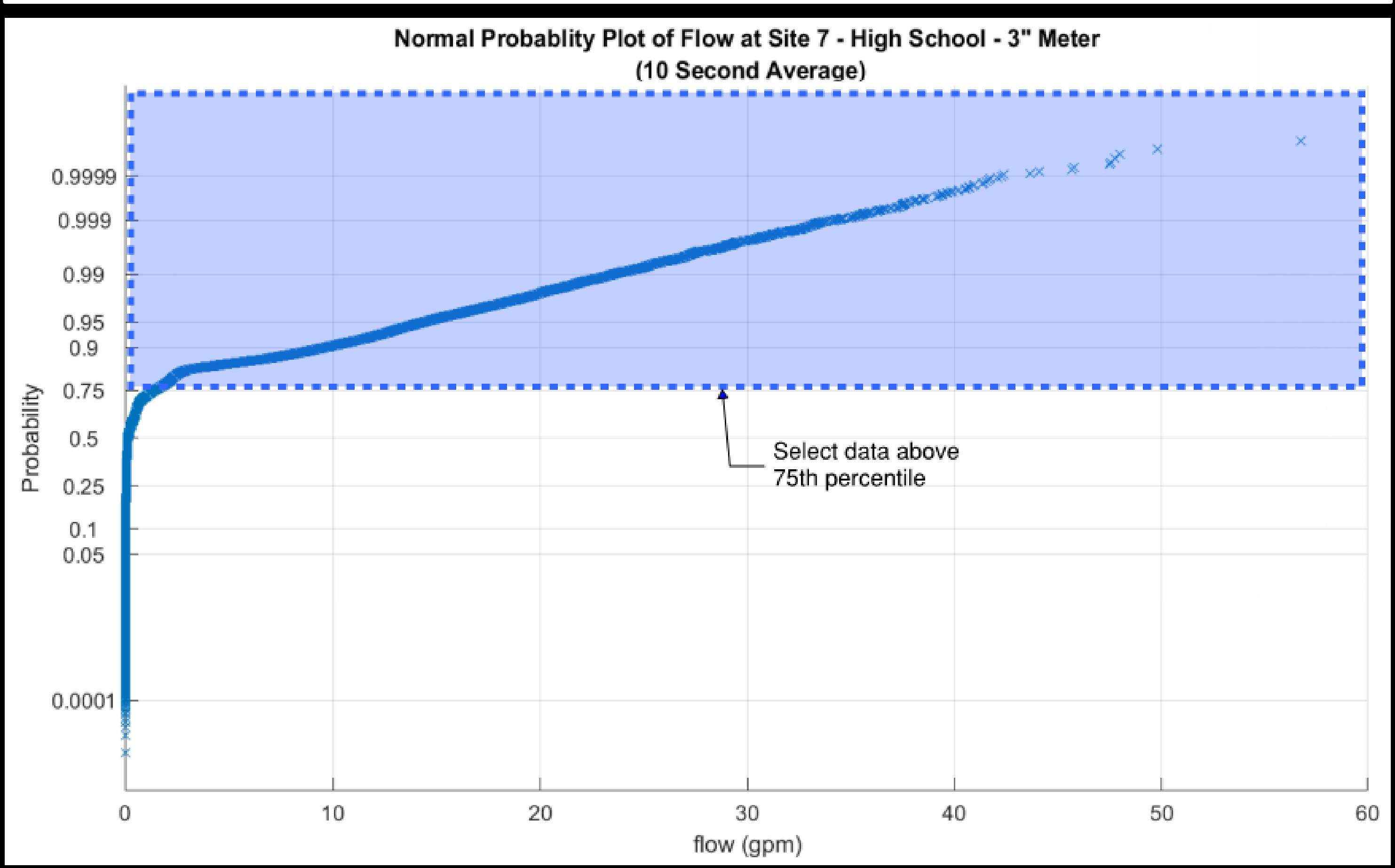
Denver Schools – Full, Well Behaved Dataset (14 days)

Most flows are "low"; n=121,507
Clean, normal distribution above 75th percentile



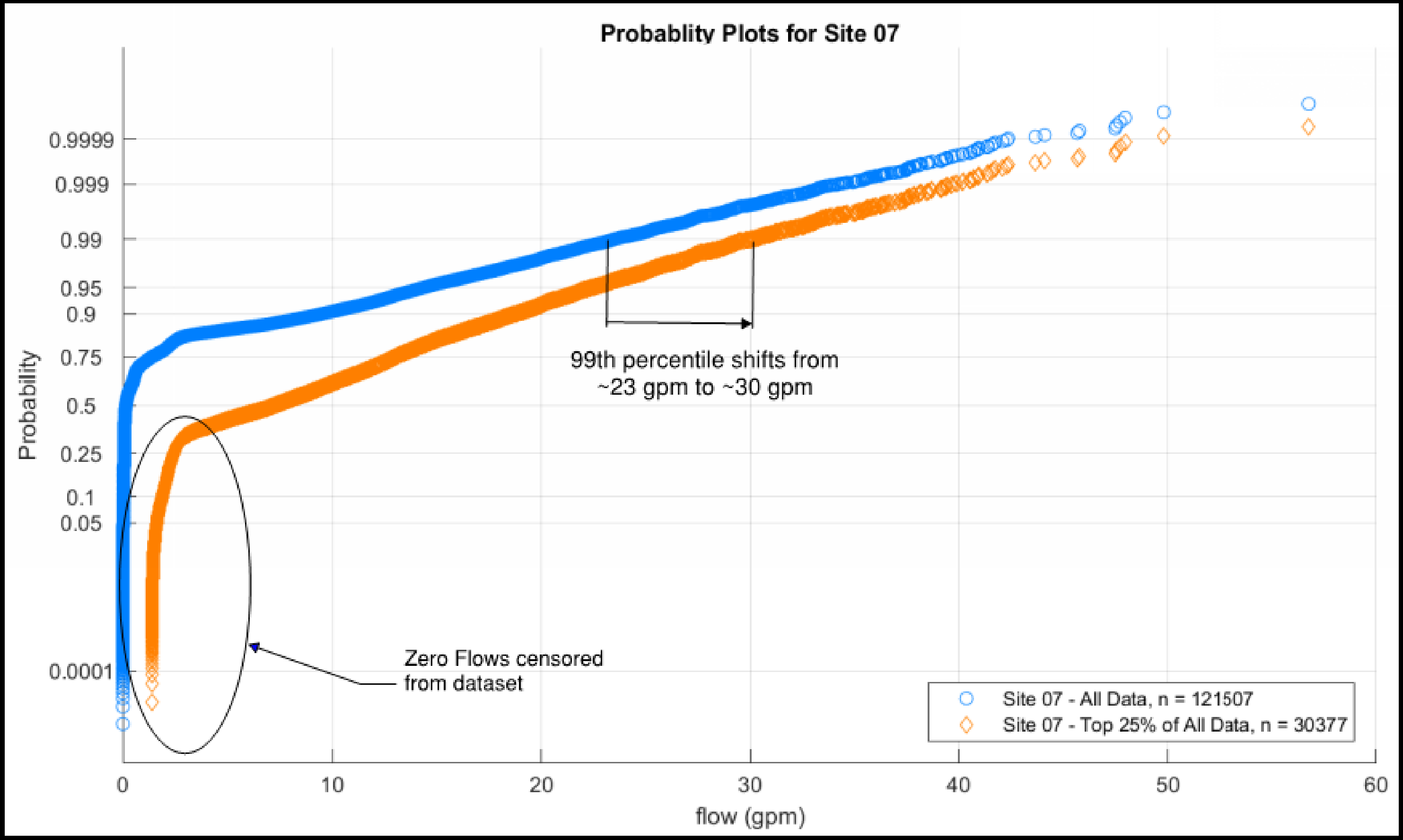
Denver Schools – Full, Well Behaved Dataset

What happens if we look at the flows above the 75th percentile?



Denver Schools – Top 25% of Full Dataset at Site 7

The general shape is similar to the full dataset
Everything shifts right – zero flows are gone and 99th percentile increases



Heat Map of Water Use at Denver Site 7

Number of flows Equal to or Greater than the 99th Percentile at Site 7																									
	Hour of Day																								
Date	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	SUM
Thursday, April 13, 2017	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	1	0	0	0	0	0	0	0	0	7
Friday, April 14, 2017	0	0	0	0	0	1	0	1	4	18	23	26	14	11	5	1	0	0	0	0	1	0	0	0	105
Saturday, April 15, 2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sunday, April 16, 2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monday, April 17, 2017	0	0	0	0	0	1	0	5	8	19	28	23	24	22	13	1	1	0	0	0	0	0	0	0	145
Tuesday, April 18, 2017	0	0	0	0	0	0	0	1	16	16	25	21	24	18	5	2	0	0	0	0	0	0	0	0	128
Wednesday, April 19, 2017	0	0	0	0	0	2	0	5	20	13	26	11	18	8	19	3	0	0	0	1	0	0	0	0	126
Thursday, April 20, 2017	0	0	0	0	0	1	0	3	27	10	21	16	37	9	7	3	1	0	1	0	1	0	0	0	137
Friday, April 21, 2017	0	0	0	0	0	1	1	5	12	25	24	19	26	26	13	0	0	0	0	0	0	0	0	0	152
Saturday, April 22, 2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Sunday, April 23, 2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monday, April 24, 2017	0	0	0	0	0	1	0	4	13	20	23	26	19	13	7	0	0	0	0	0	1	0	0	0	127
Tuesday, April 25, 2017	0	0	0	0	0	1	0	2	16	19	18	12	24	17	11	1	0	0	1	0	0	0	0	0	122
Wednesday, April 26, 2017	0	0	0	0	0	0	0	1	19	6	20	19	14	17	15	1	0	0	0	0	0	0	0	0	112
Thursday, April 27, 2017	0	0	0	0	0	1	0	0	9	15	21	8	0	0	0	0	0	0	0	0	0	0	0	0	54
SUM	0	0	0	0	0	9	1	27	144	163	231	183	200	141	95	13	2	0	3	1	3	0	0	0	1216

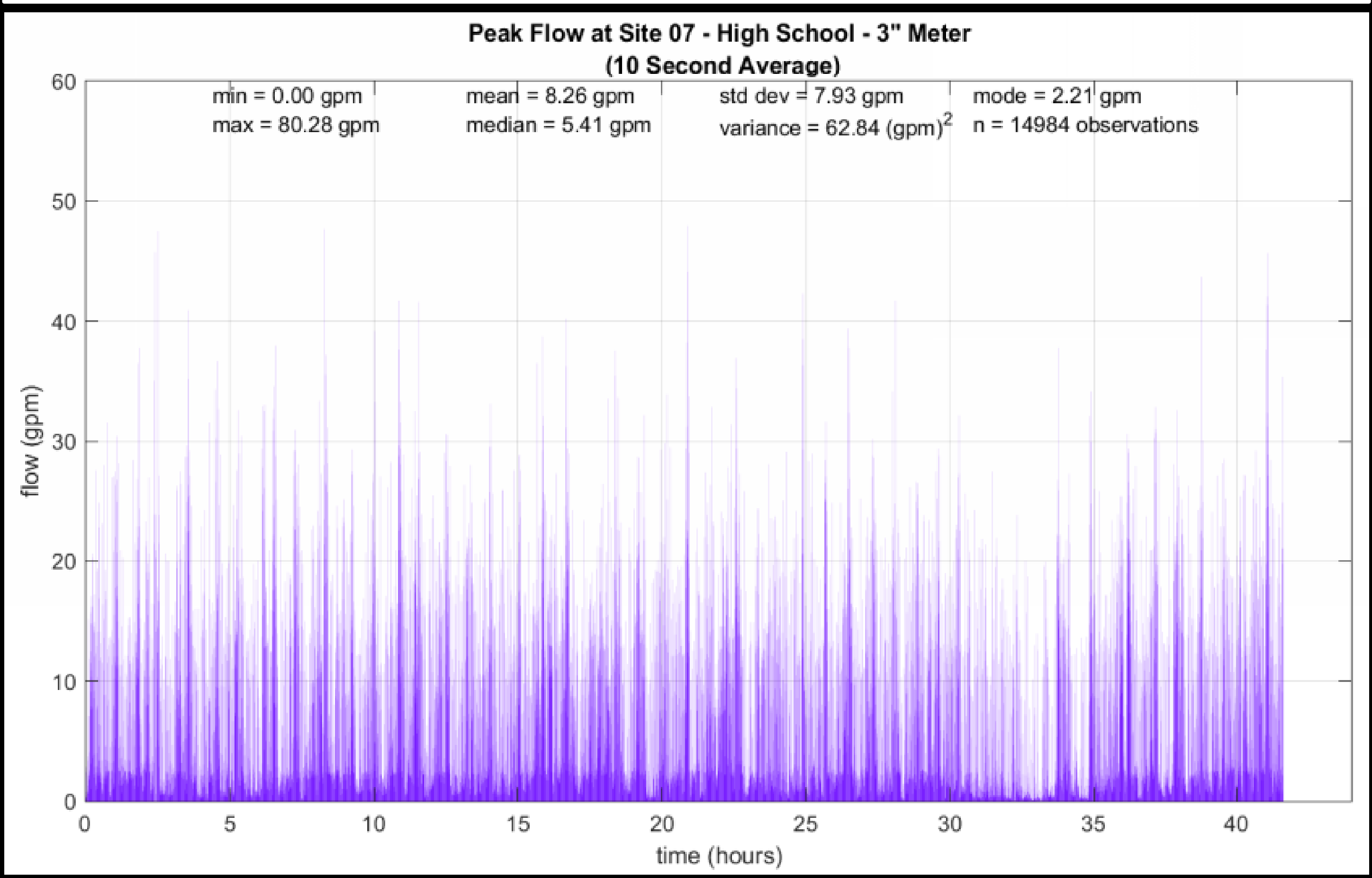
Comments:

[1] Exclude all weekend days from analysis. Only 1 observation is above the 99th percentile.

[2] Exclude Thursday, April 13th from analysis. Three hours are tied for the most observations (2 per hour). Adding all three hours will unnecessarily deflate the 99th percentile.

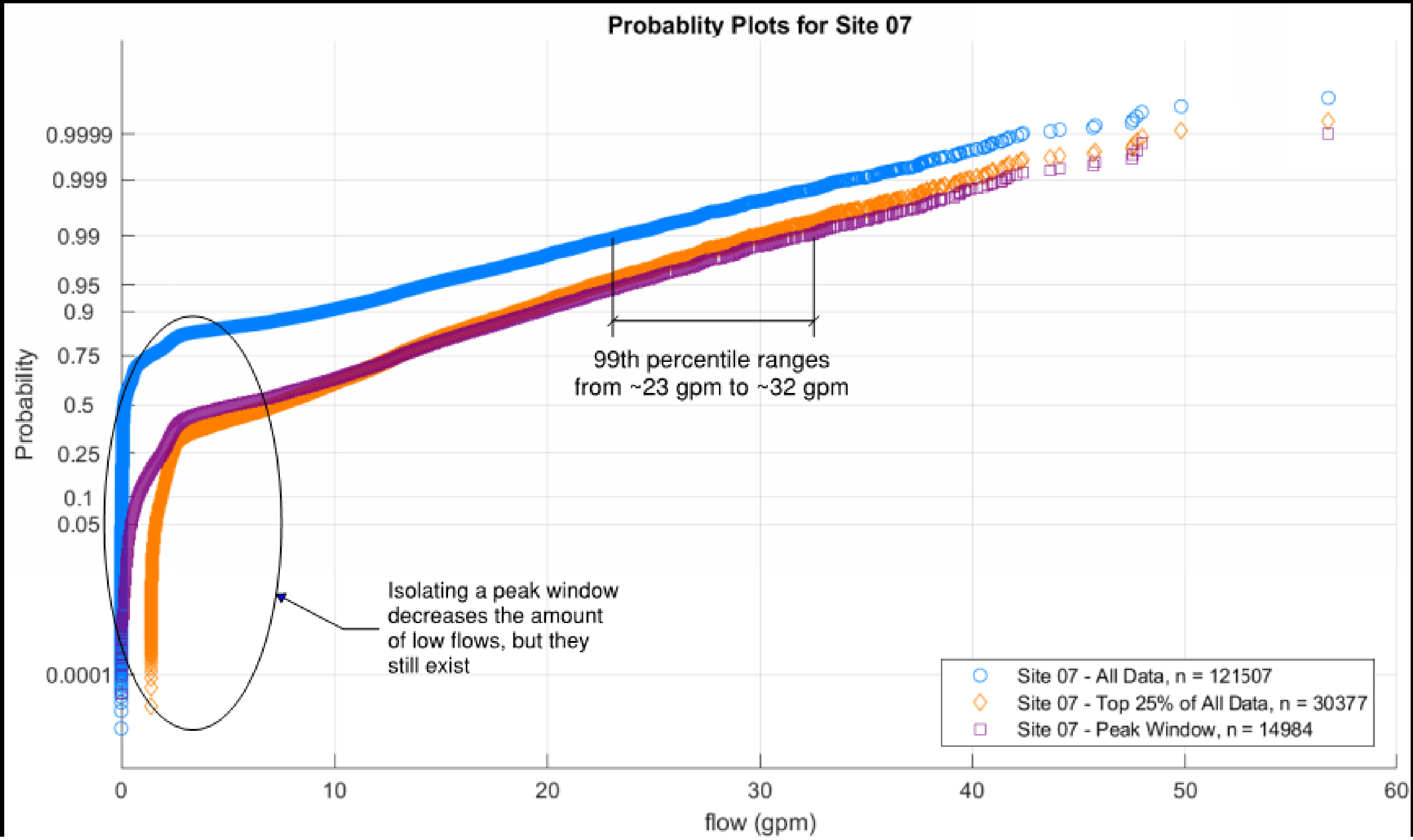
9 am – 1pm Peak Window at Denver Site 7

Highlights peak usage at Denver Site 7
Strings together every school day from 09:00:00 – 12:59:50

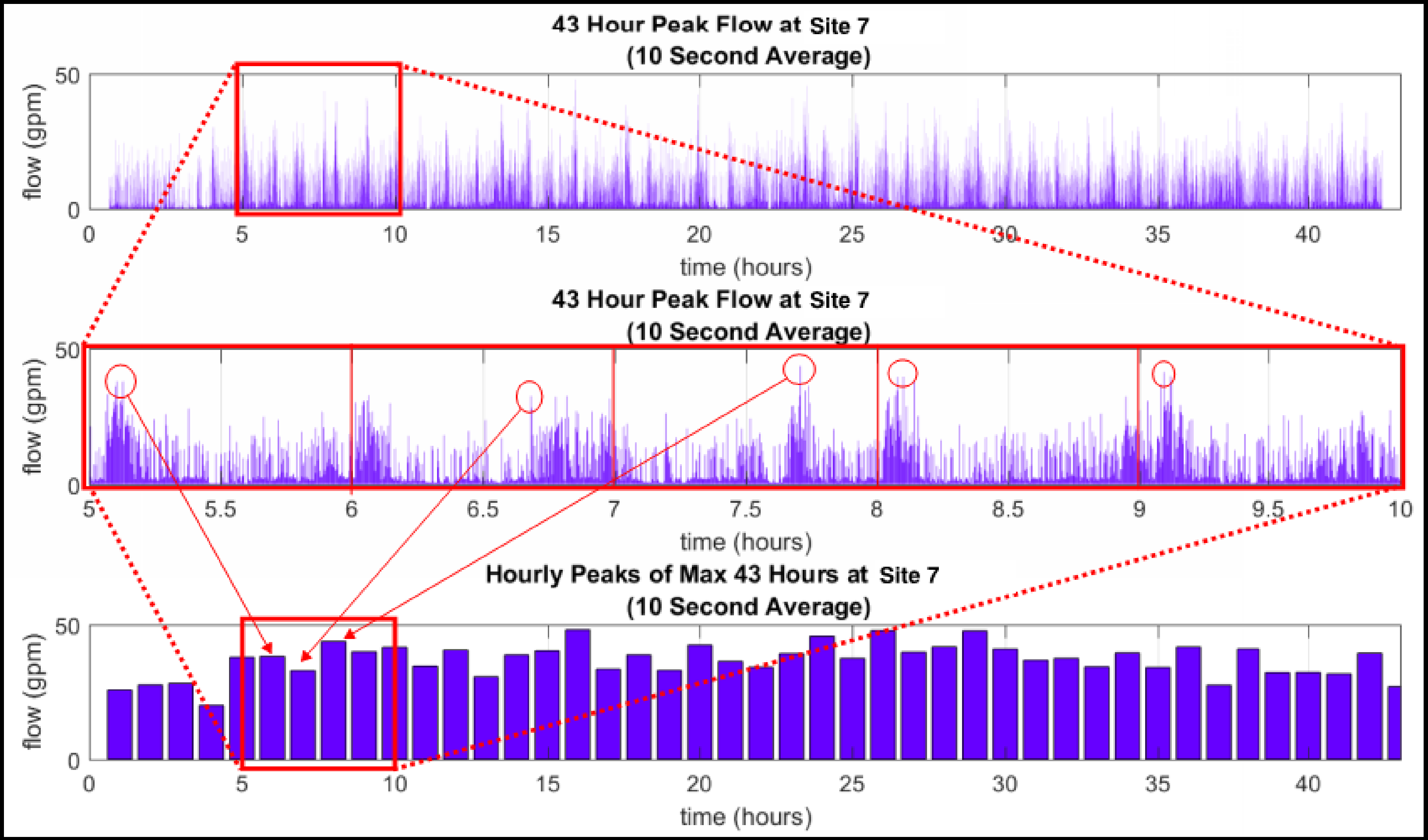


9 am – 1pm Peak Window at Site 07

"Inactive period" is between using the full dataset and the top 25% of the full dataset
99th percentile increases from ~23 gpm on the full dataset to ~32 gpm
Shape of each curve is very similar

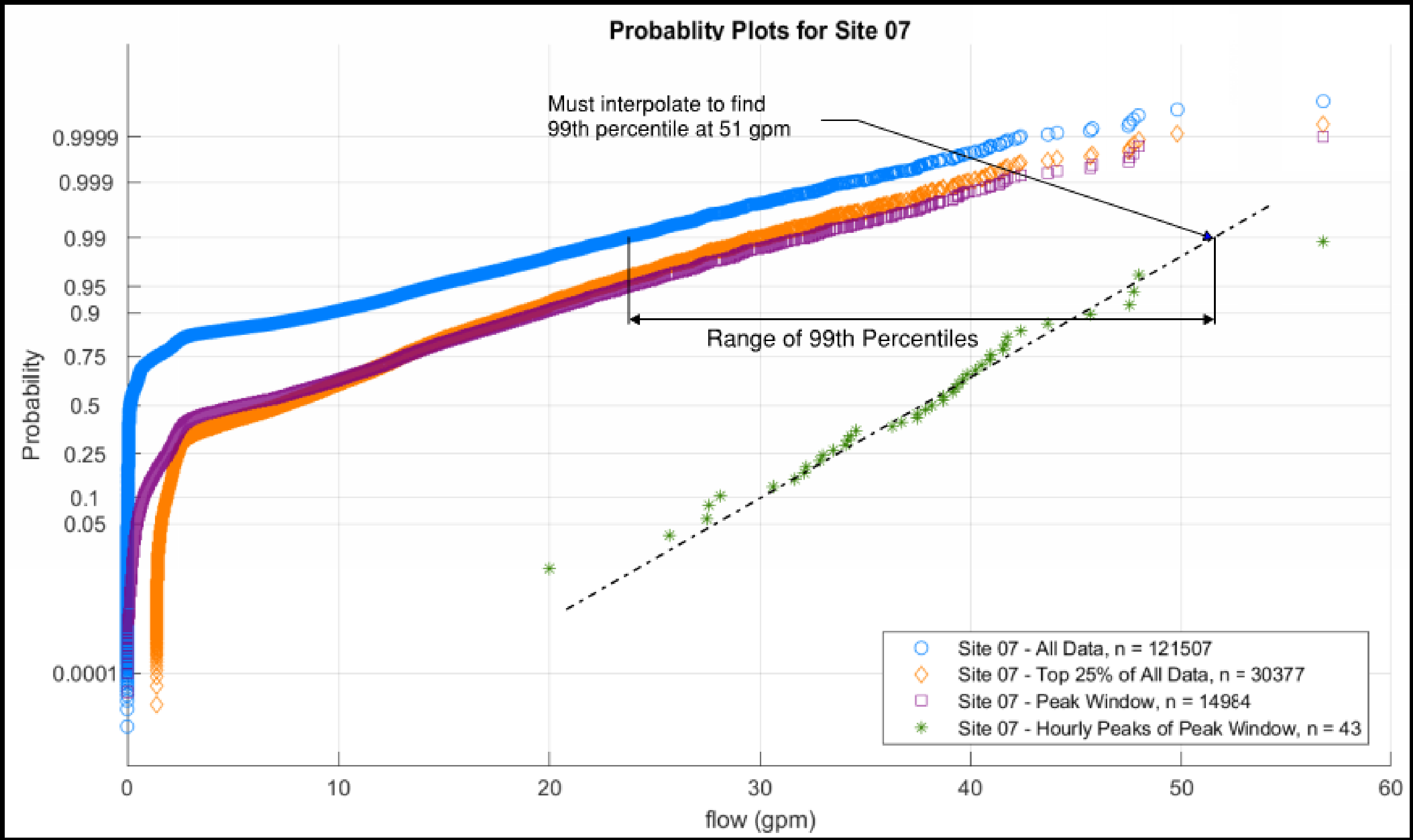


Developing Peak Hourly Flows from Peak Flow

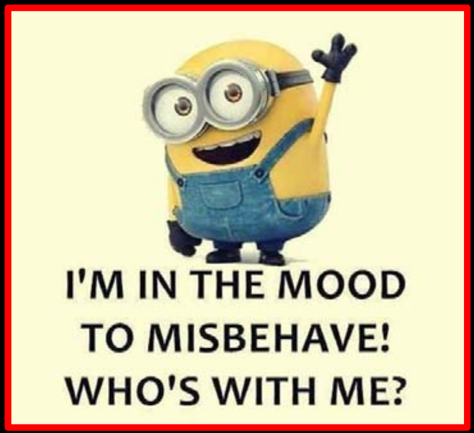


Peak Hourly Flows of Peak Window

Virtually no inactive period using Hourly Peaks of Peak Window
New 99th percentile is 51 gpm – almost double the observed 23 gpm using full dataset

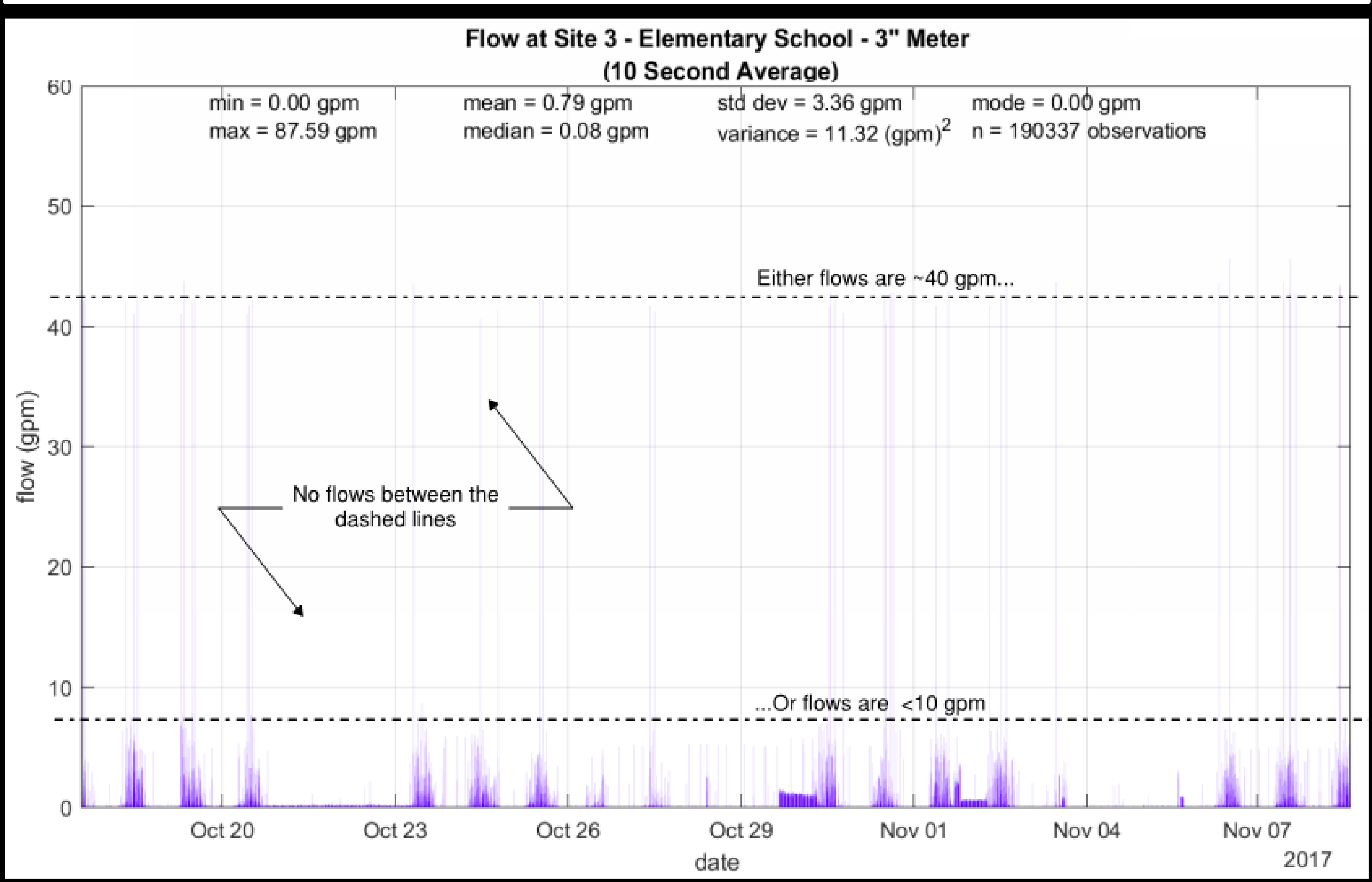


Data That Behave Badly



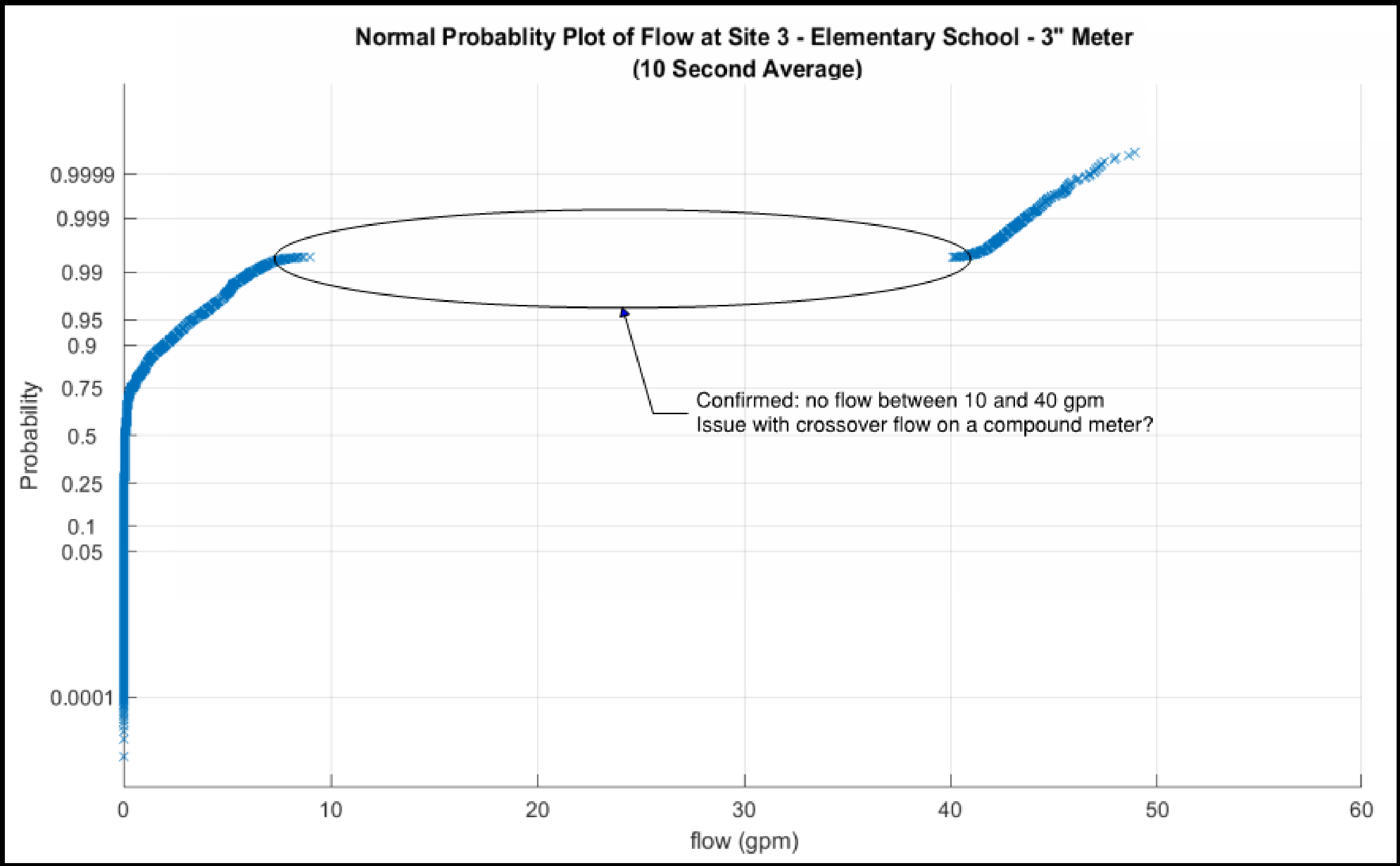
Denver Schools – Full, Poorly Behaved Dataset (14 days)

Weekday peaks are visible
No flows exist between 10 and 40 gpm



Denver Schools – Full, Poorly Behaved Dataset (14 days)

Probability plot confirms gap in flows



30 Study Sites in Scottsdale

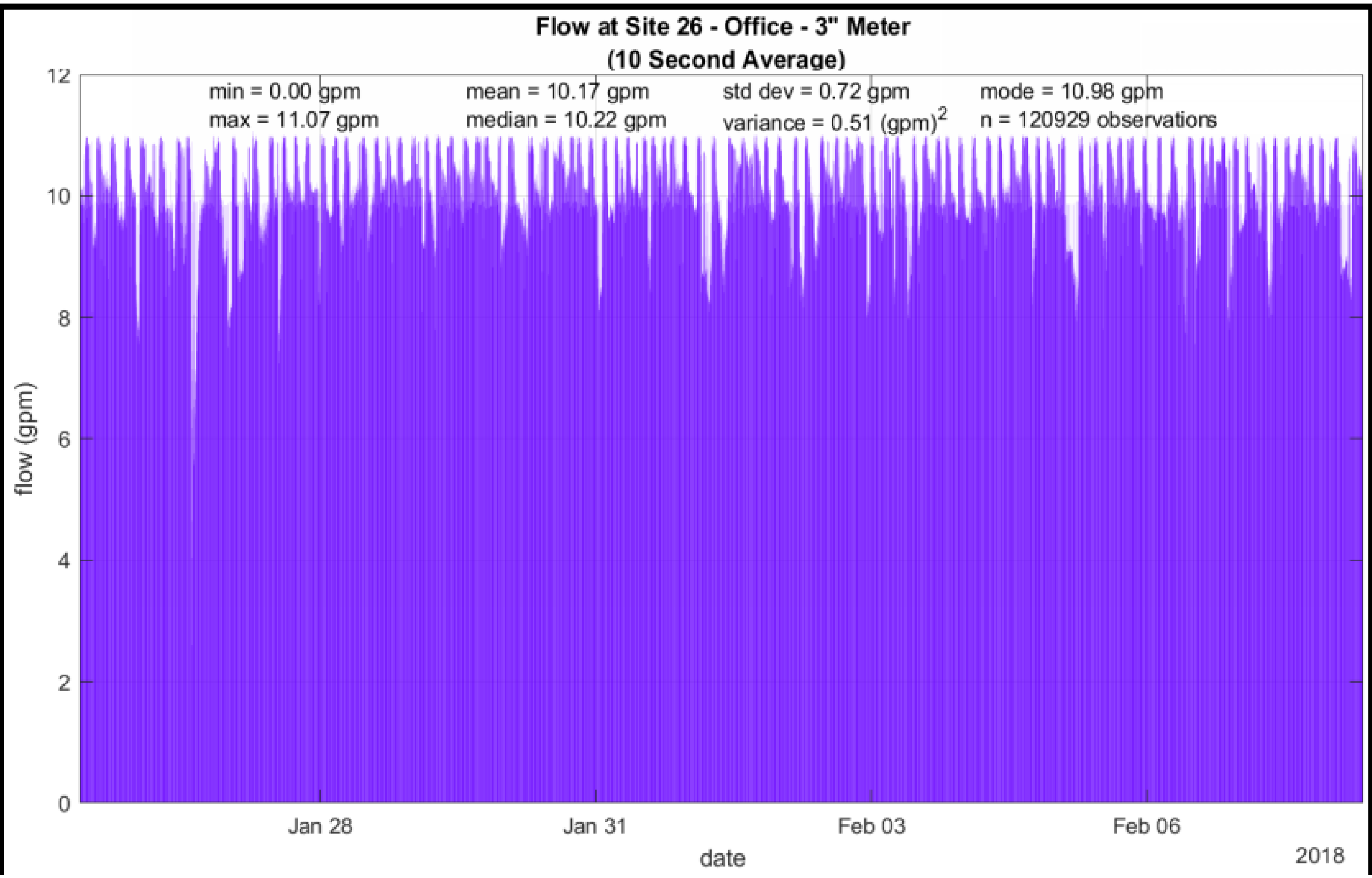
ID	Building Type	Meter Size (in)	Meter Make	Data Interval	Overall Grade
1	Grocery	3	Sensus	10 second	Well Behaved
2	Multi Family	2	Badger	10 second	Questionable
3	MultiFamily	2	Badger	10 second	Questionable
4	HOA	2	Badger	10 second	Questionable
5	Senior Living	3	Badger	30 second	Well Behaved
6	HOA	2	Badger	10 second	Questionable
7	Multi Family	3	Sensus	10 second	Well Behaved
8	Multi Family	2	Badger	10 second	Well Behaved
9	Westminster Village	3	Sensus	30 second	Well Behaved
10	Unknown	3	Sensus	10 second	Well Behaved
11	Medical Center	2	Badger	30 second	Poorly Behaved
12	Unknown	3	Sensus	10 second	Questionable
13	MultiFamily	2	Badger	10 second	Questionable
14	Multi Family	3	Sensus	30 second	Well Behaved
15	Shopping Center	3	Sensus	30 second	Well Behaved

ID	Building Type	Meter Size (in)	Meter Make	Data Interval	Assessment
16	Multi Family	2	Badger	10 second	Poorly Behaved
17	HOA	2	Badger	10 second	Well Behaved
18	Multi Family	2	Badger	10 second	Well Behaved
19	Hotel	3	Sensus	10 second	Well Behaved
20	HOA	3	Sensus	30 second	Questionable
21	Multi Family	3	Sensus	30 second	Well Behaved
22	Multi Office	3	Sensus	10 second	Questionable
23	Medical Center	3	Sensus	10 second	Well Behaved
24	Senior Living	3	Sensus	10 second	Questionable
25	Ice Rink	3	Sensus	10 second	Well Behaved
26	**Office**	**3**	**Badger**	**10 second**	**Poorly Behaved**
27	Hotel	3	Badger	10 second	Questionable
28	Unknown	3	Badger	10 second	Poorly Behaved
29	Senior Living	3	Badger	10 second	Poorly Behaved
30	Hotel	3	Badger	10 second	Well Behaved

- 15 “Well Behaved” sites (data seems ready to analyze as-is)
- 10 “Questionable” sites (data might contain outliers or simply does not behave as expected and requires investigation)
- 5 “Poorly Behaved” sites (data should either be relogged or excluded from analysis due to logger malfunction)

Questionable Data – Office (site 26)

Compound meter where only the low side of demand was collected for 14 days
Flow is cut off around 11 gpm (crossover flow is rated for 12 gpm)



Questionable Data – Office (site 26)

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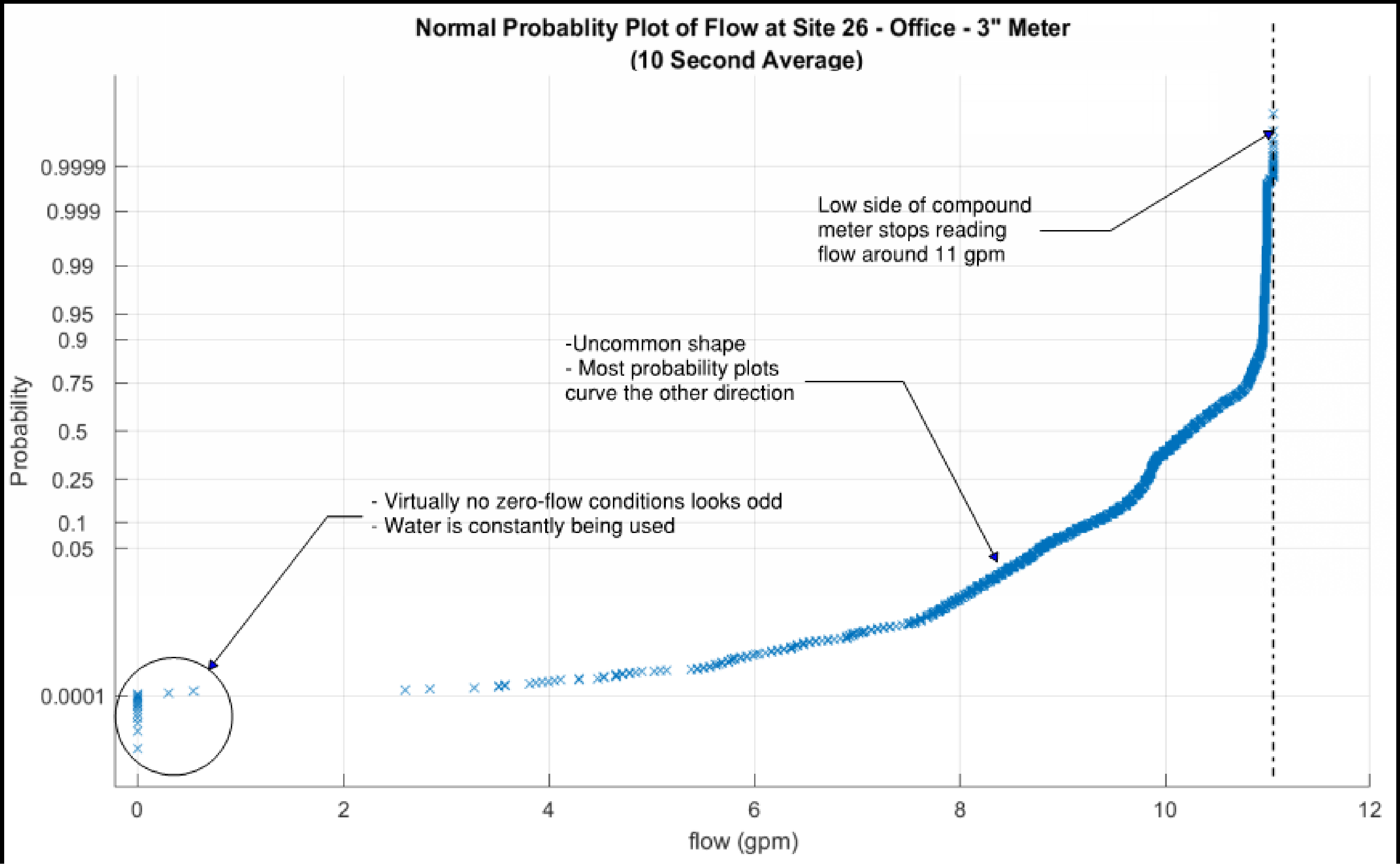
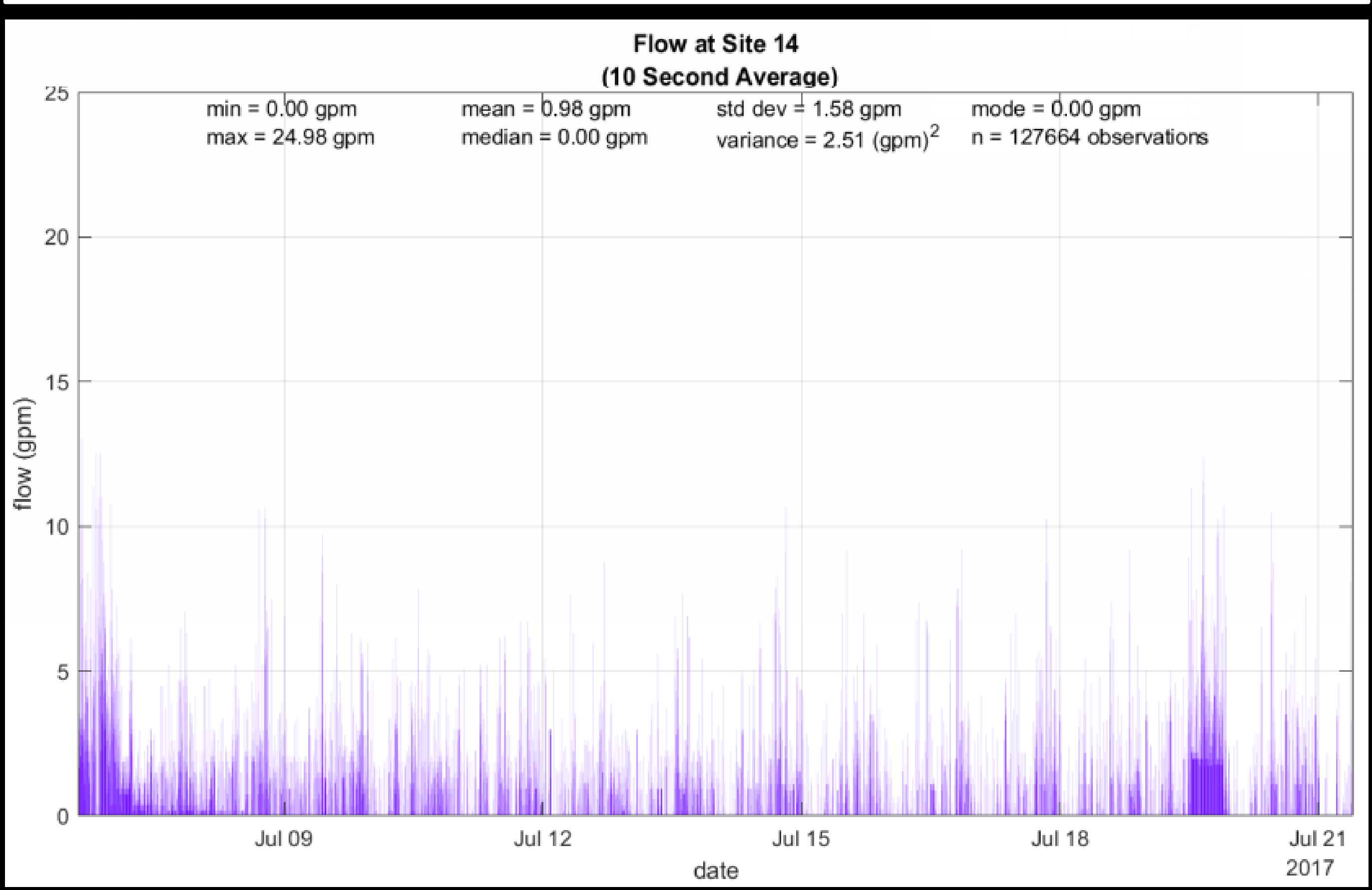


Multifamily Data - Apartments in Denver & Scottsdale

(Behaving well again, for now)

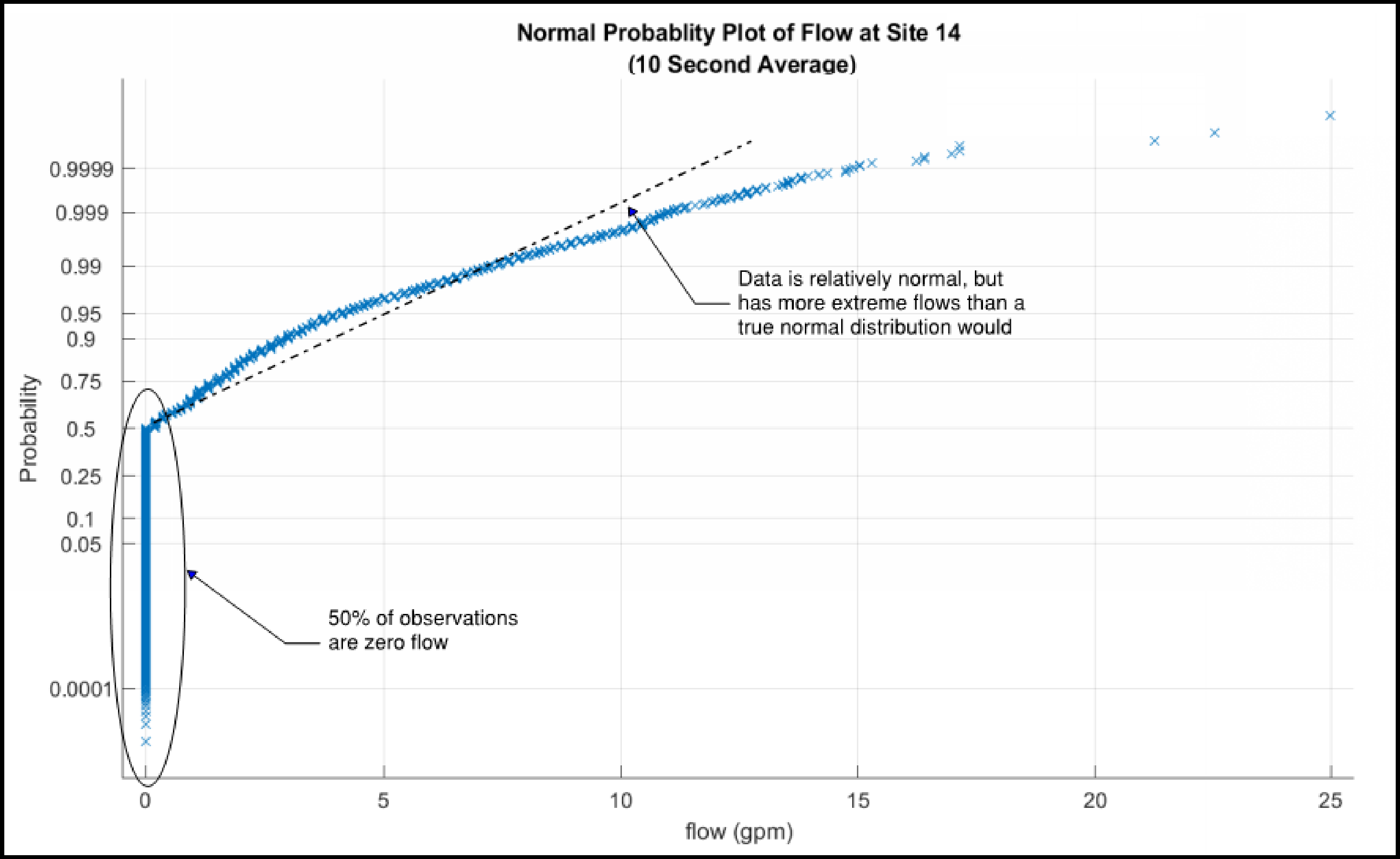
Denver Multifamily Data – Full Data Set (14 days)

Daily patterns are visible, but not as clear as at the schools
Resembles single family residences (23 units)



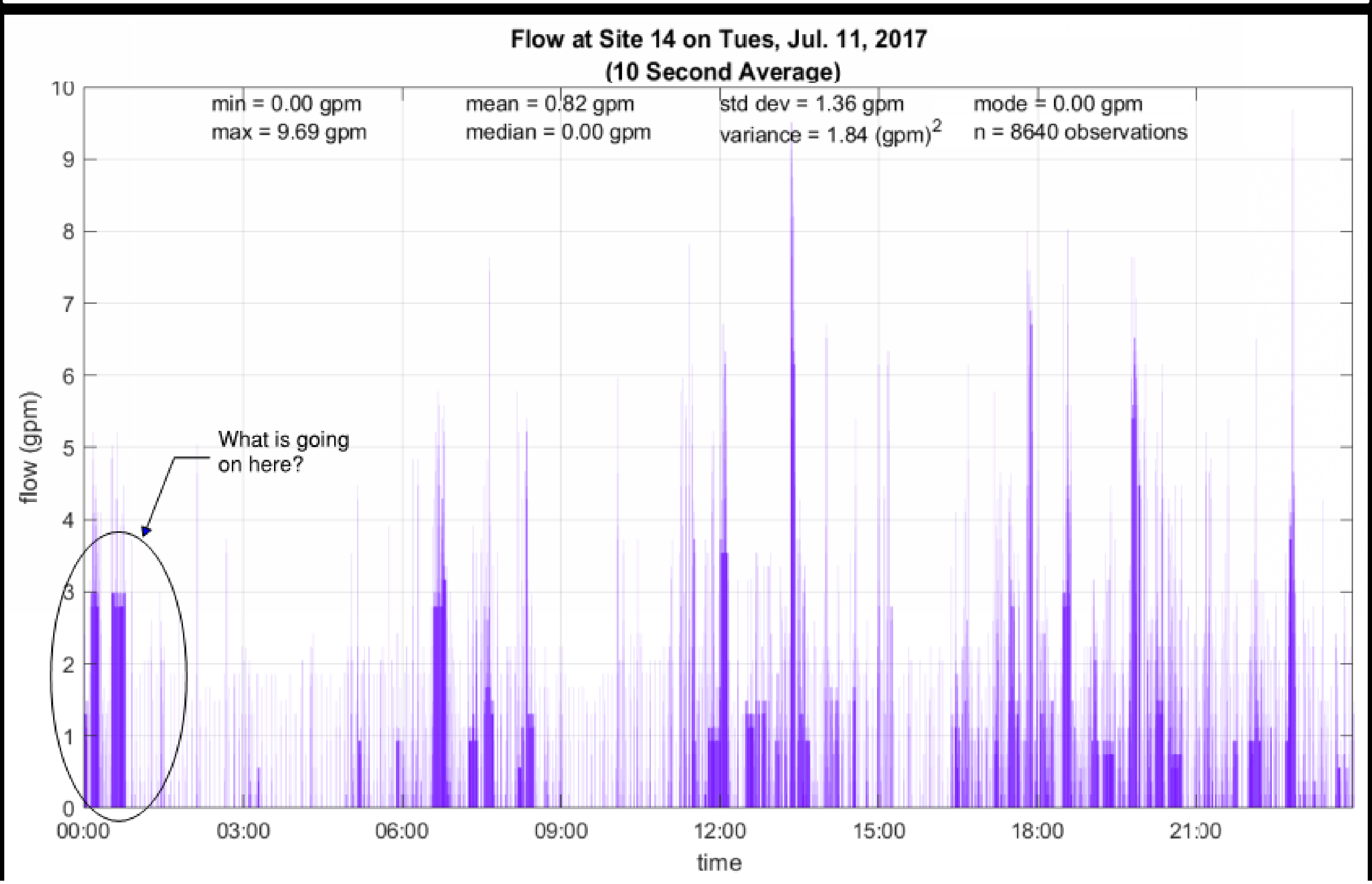
Denver Multifamily Data – Full Data Set (14 days)

50% zero flow resembles single family residences (23 units)
Data is relatively normal above 50th percentile



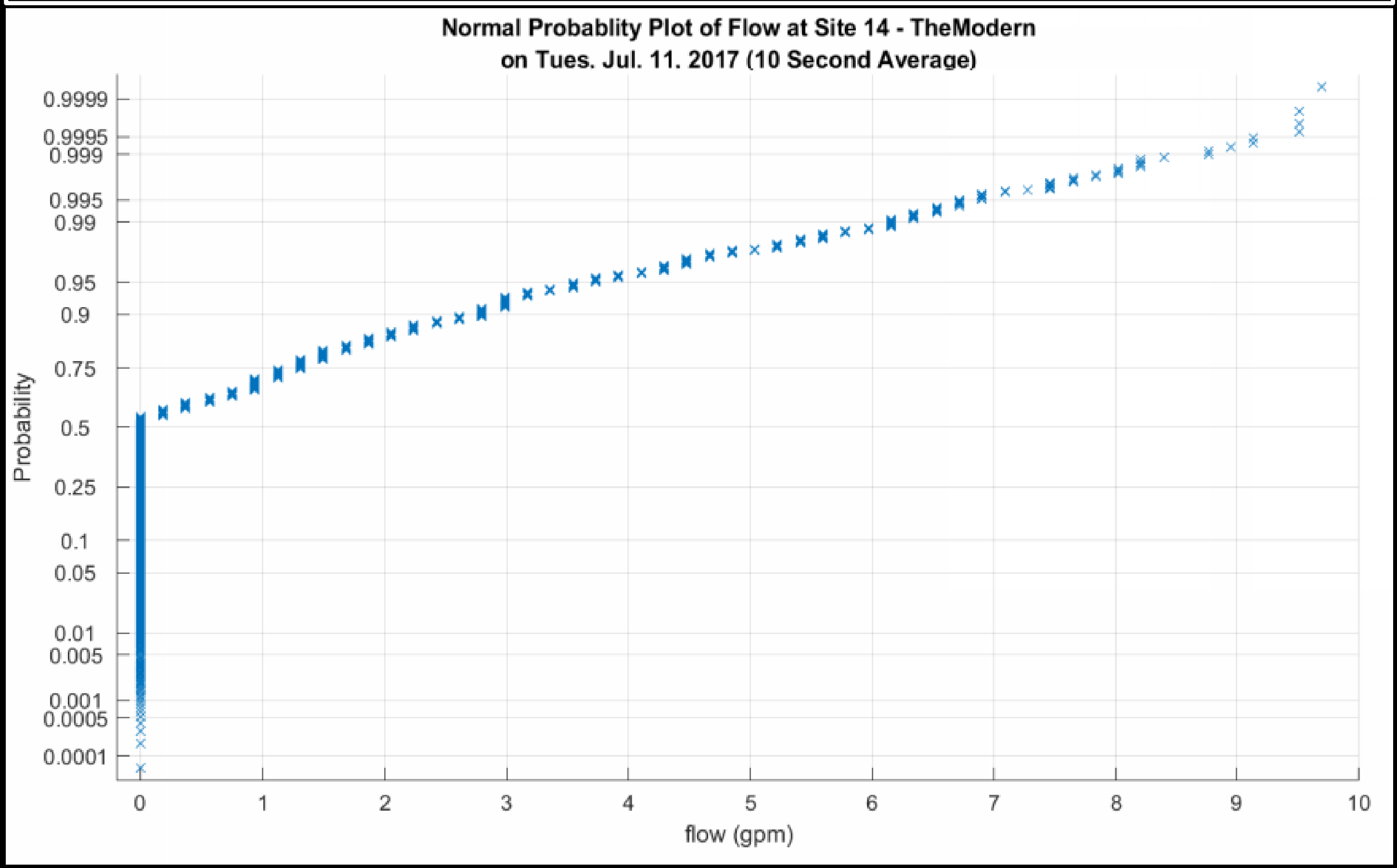
Denver Multifamily Data – Tuesday July 11th

Morning, lunch, and evening use is apparent (23 units)
What goes on at midnight?



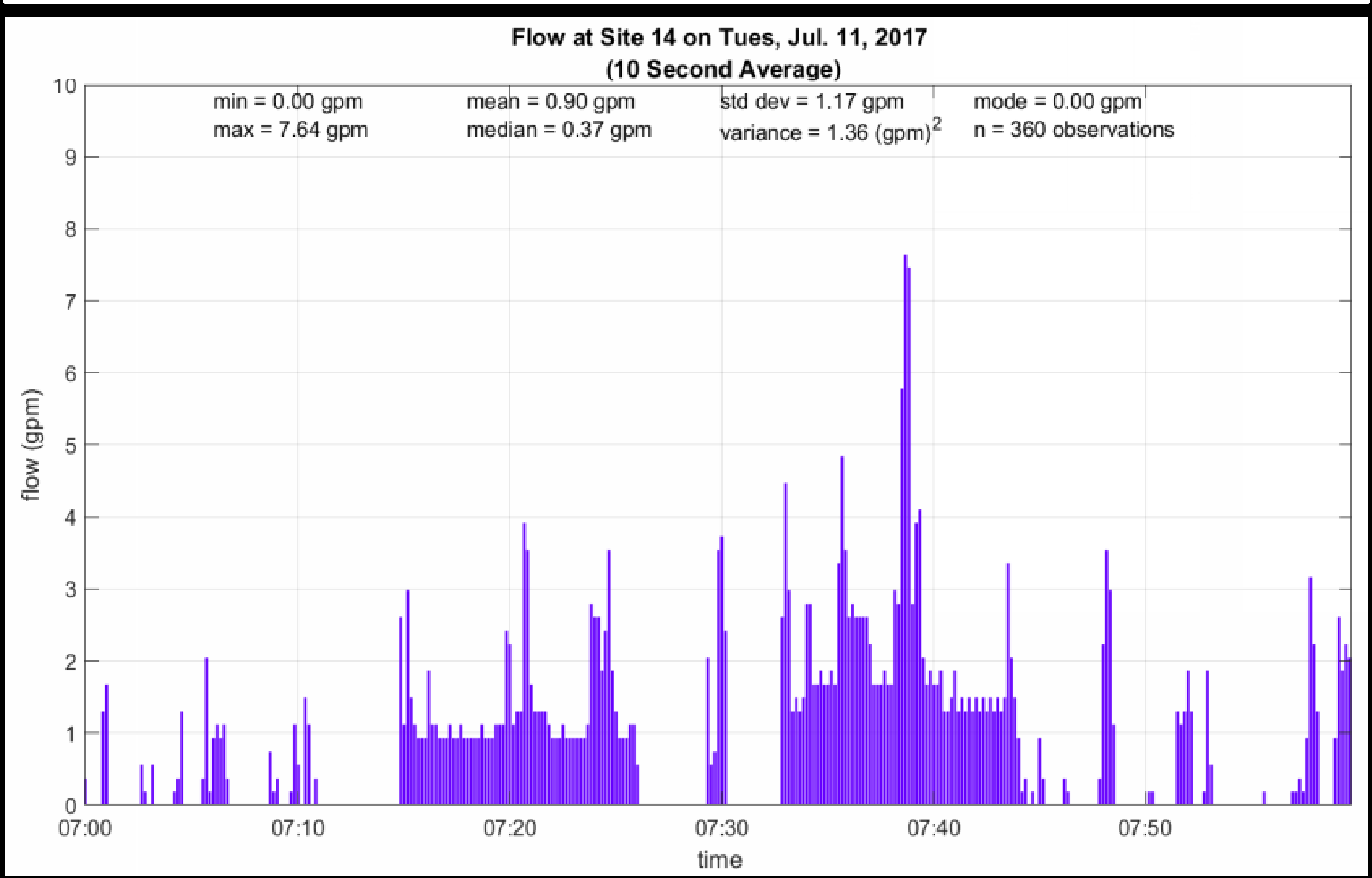
Denver Multifamily Data – Tuesday July 11th

Probability plot showing one day of data looks similar to all of the data
Usage is likely to be consistent each day (23 units)



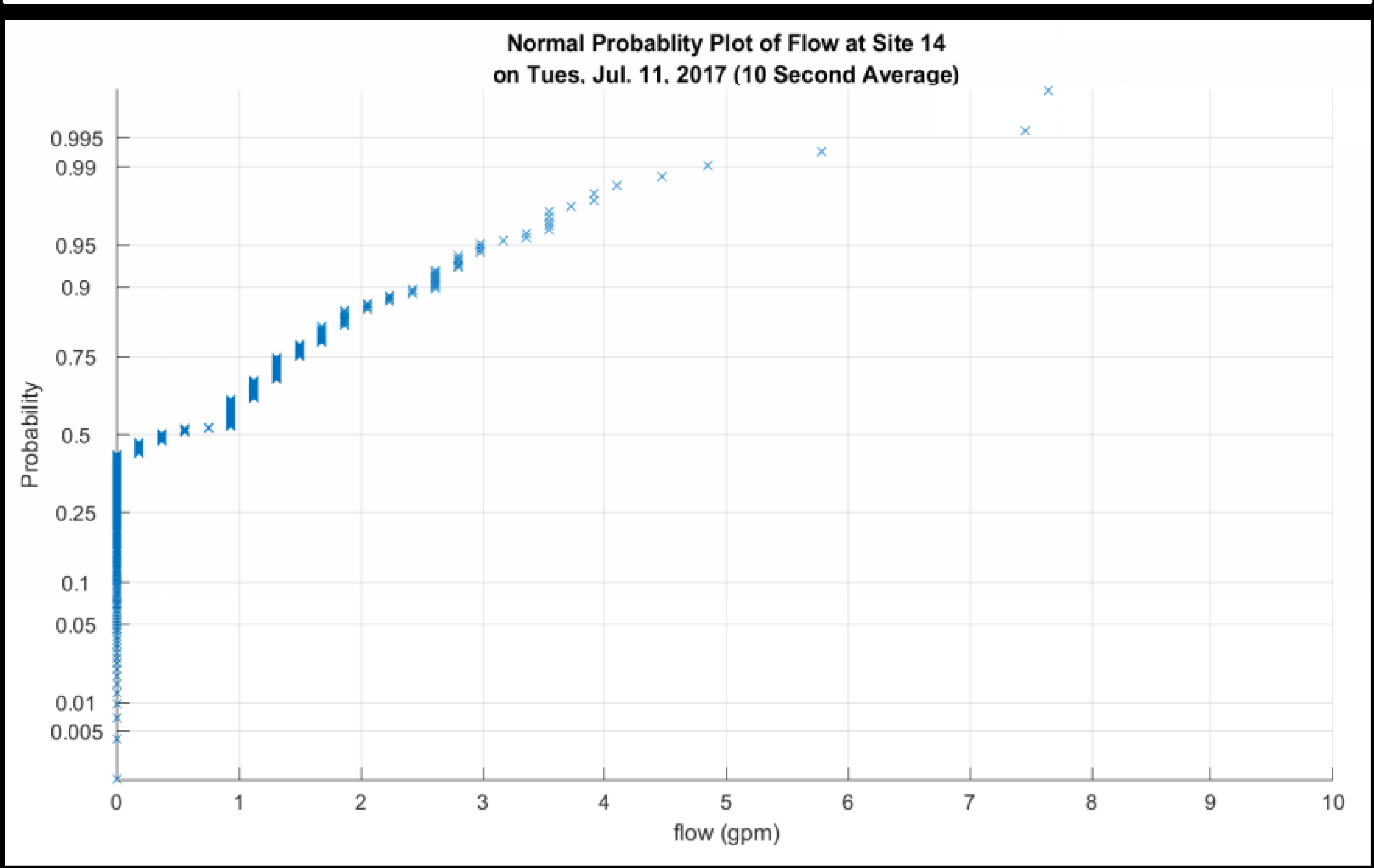
Denver Multifamily Data – July 11th, 7:00-8:00 a.m.

Zero in on the 7 o'clock hour (23 units)



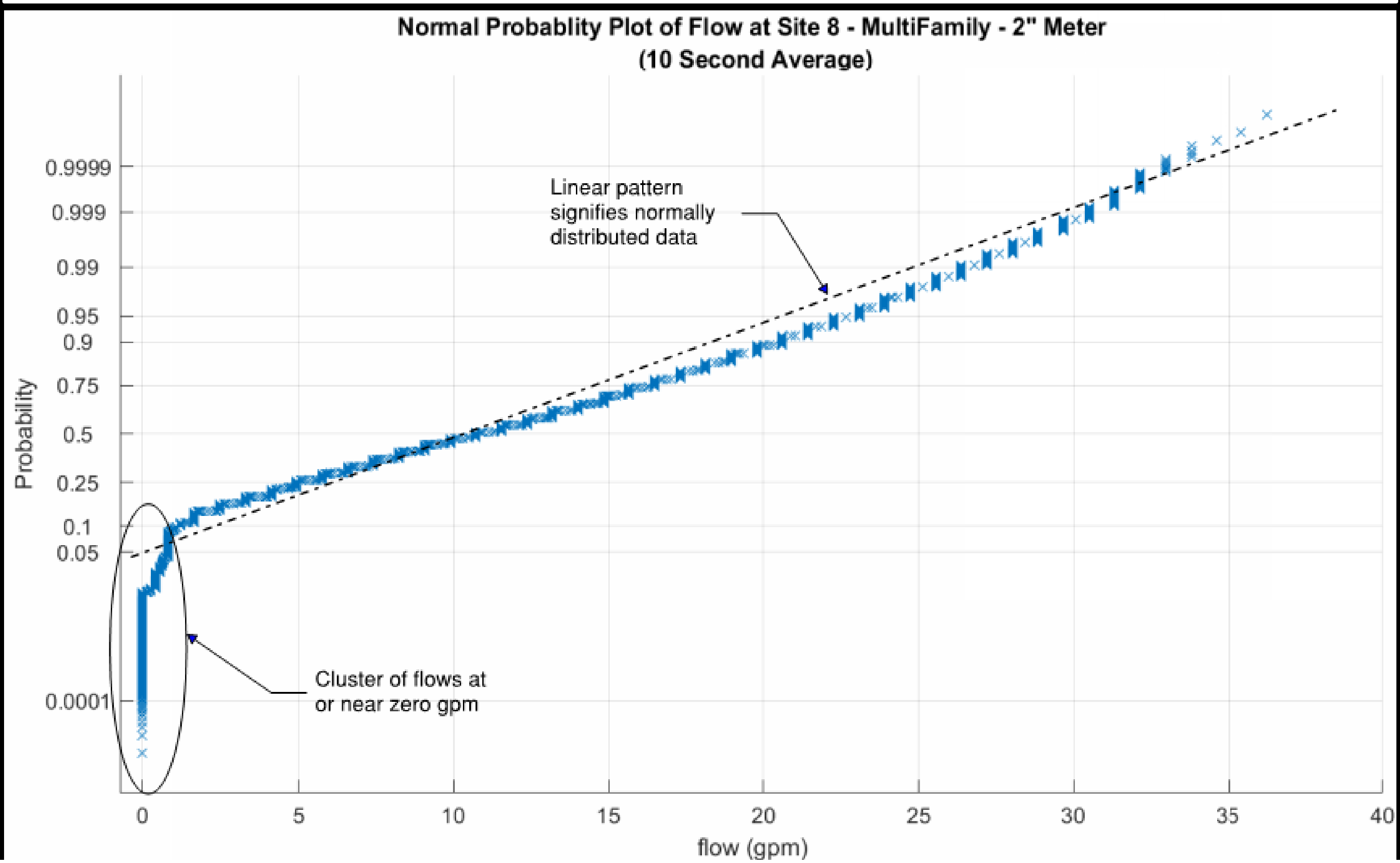
Denver Multifamily Data – July 11th, 7:00-8:00 a.m.

One hour of data does not look the same as one day or two weeks of the data



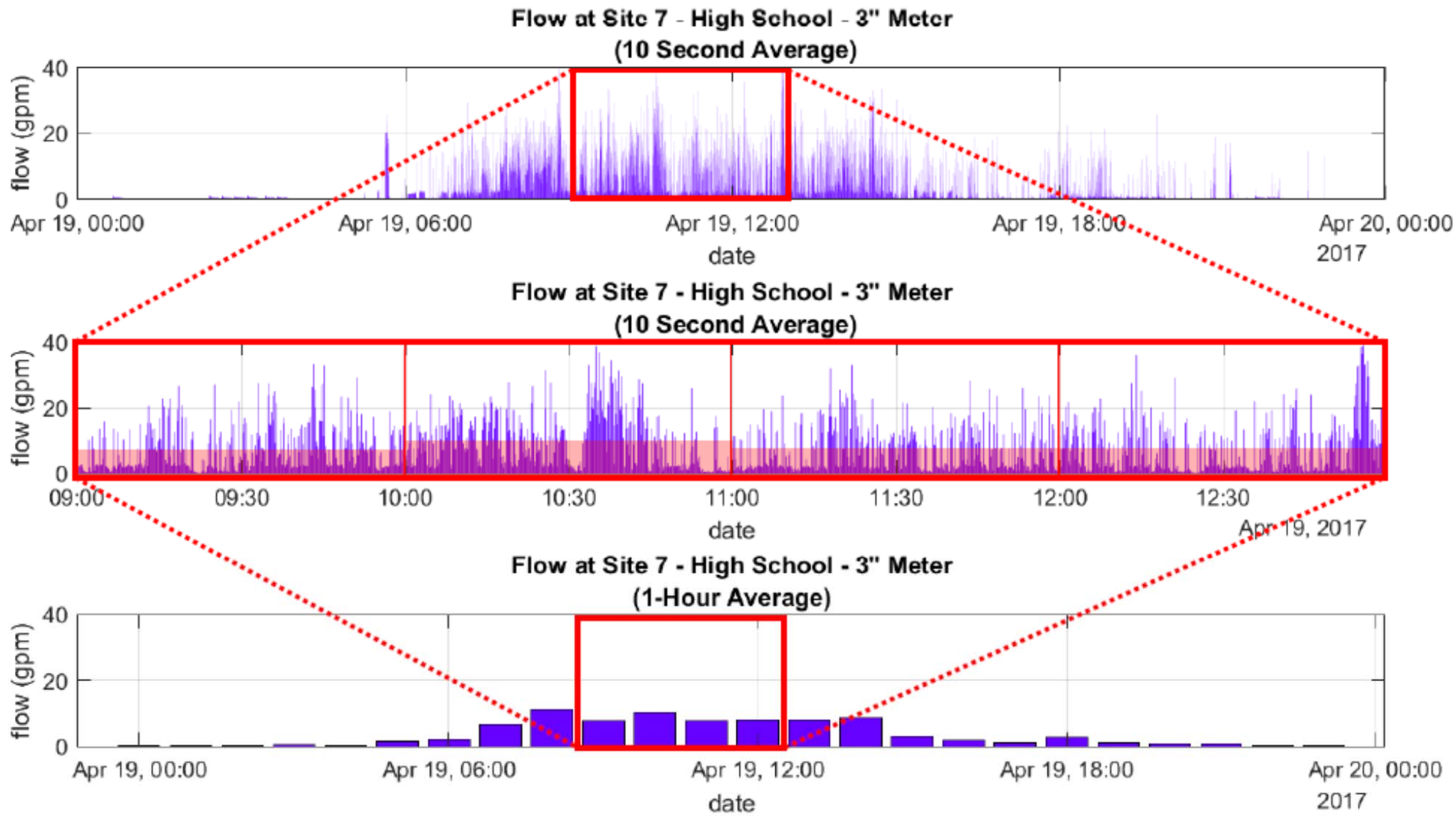
Scottsdale Multifamily – Full Data Set

10% chance of flow <1 gpm
Flows above 1 gpm are normally distributed (number of units?)



Question: What is the proper time step for characterizing meter flows?

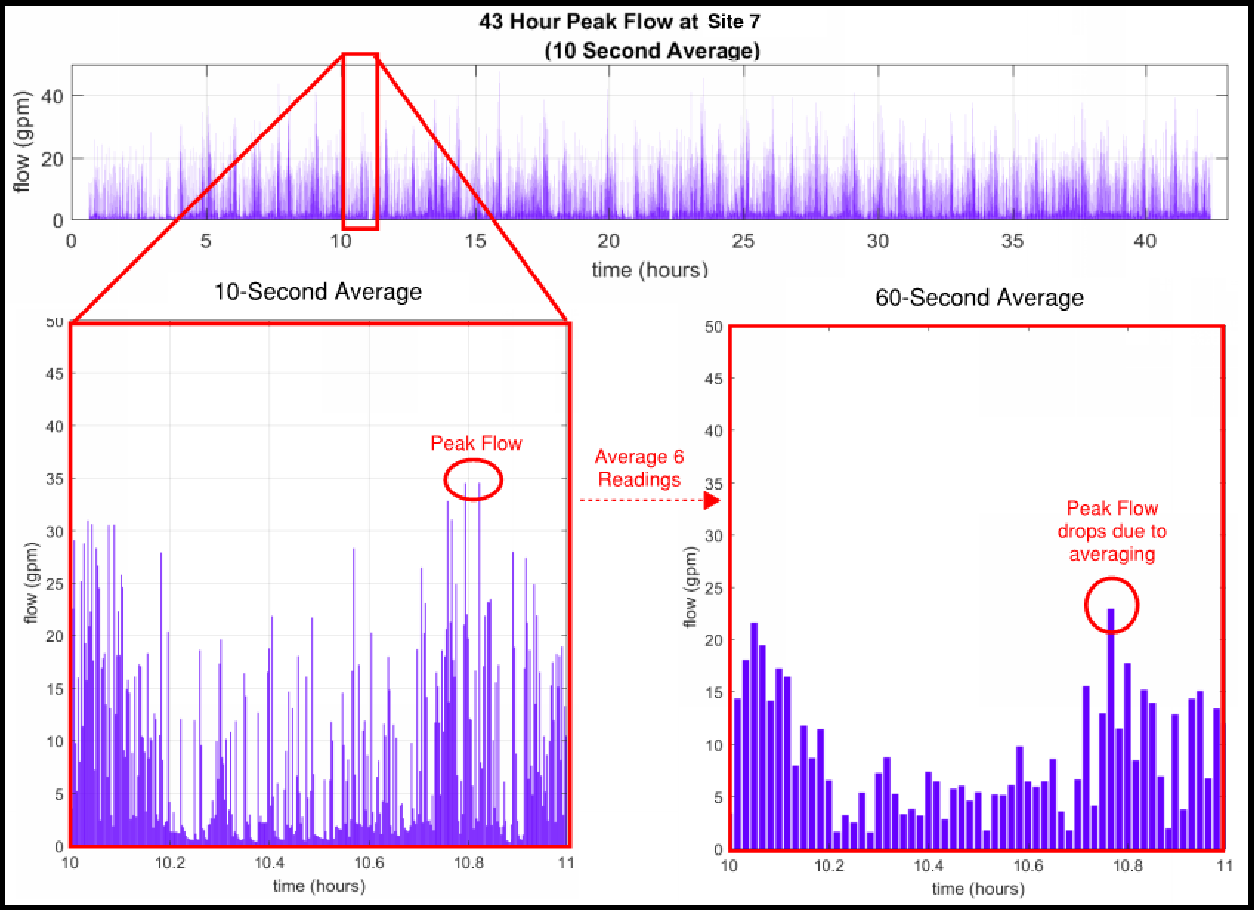
Corollary: Why does it matter (how does time step impact peak demands?)



Flow at Site 7 - High School - 3" Meter
(10 Second Average)
flow (gpm)
40
20
0
Apr 19, 00:00
Apr 19, 06:00
Apr 19, 12:00
Apr 19, 18:00
Apr 20, 00:00
2017
date
Flow at Site 7 - High School - 3" Meter
(10 Second Average)
flow (gpm)
40
20
0
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
Apr 19, 2017
date
Flow at Site 7 - High School - 3" Meter
(1-Hour Average)
flow (gpm)
40
20
0
Apr 19, 00:00
Apr 19, 06:00
Apr 19, 12:00
Apr 19, 18:00
Apr 20, 00:00
2017
date

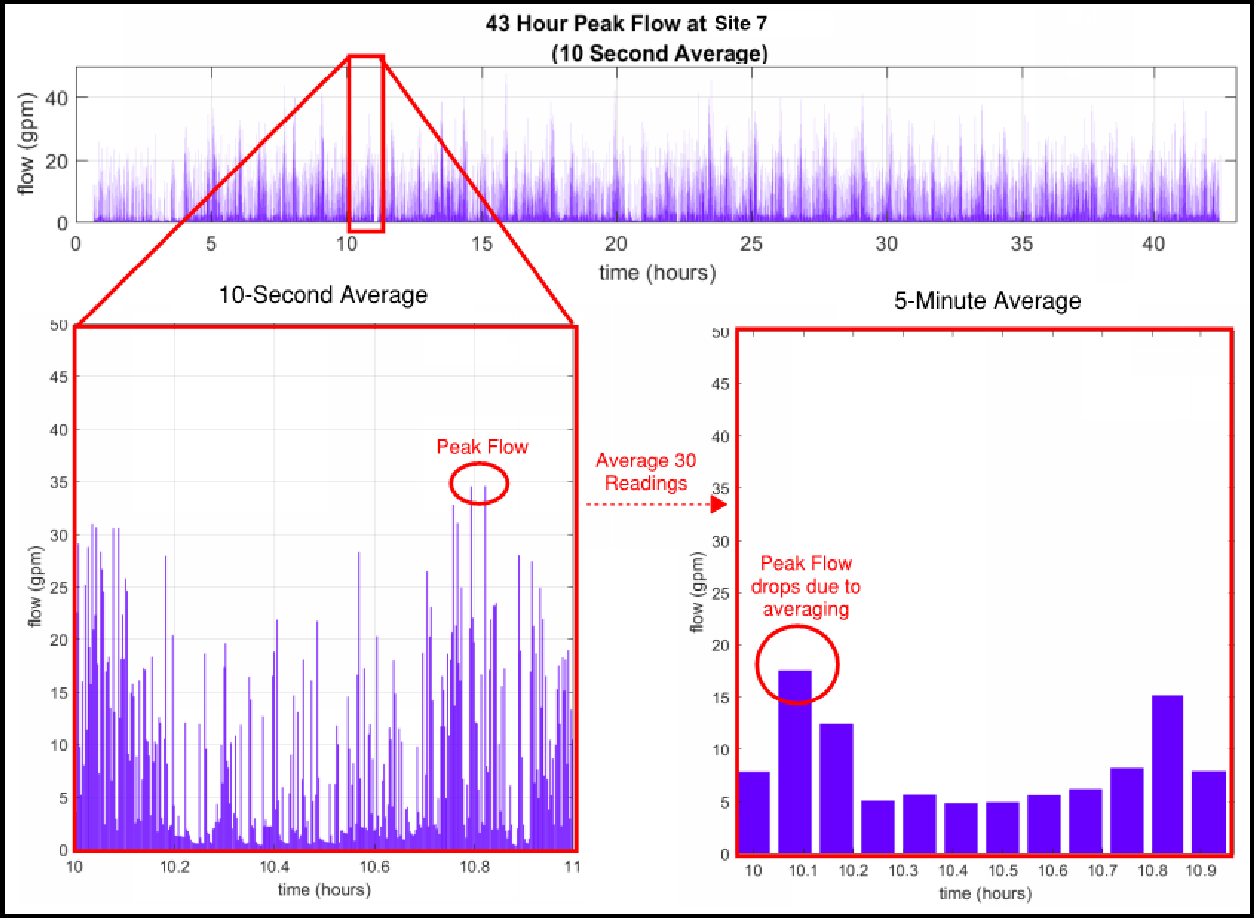
Effects of Averaging Data – 1-minute Resolution

As data points are averaged, the peak flow decreases from 35 to 23 gpm



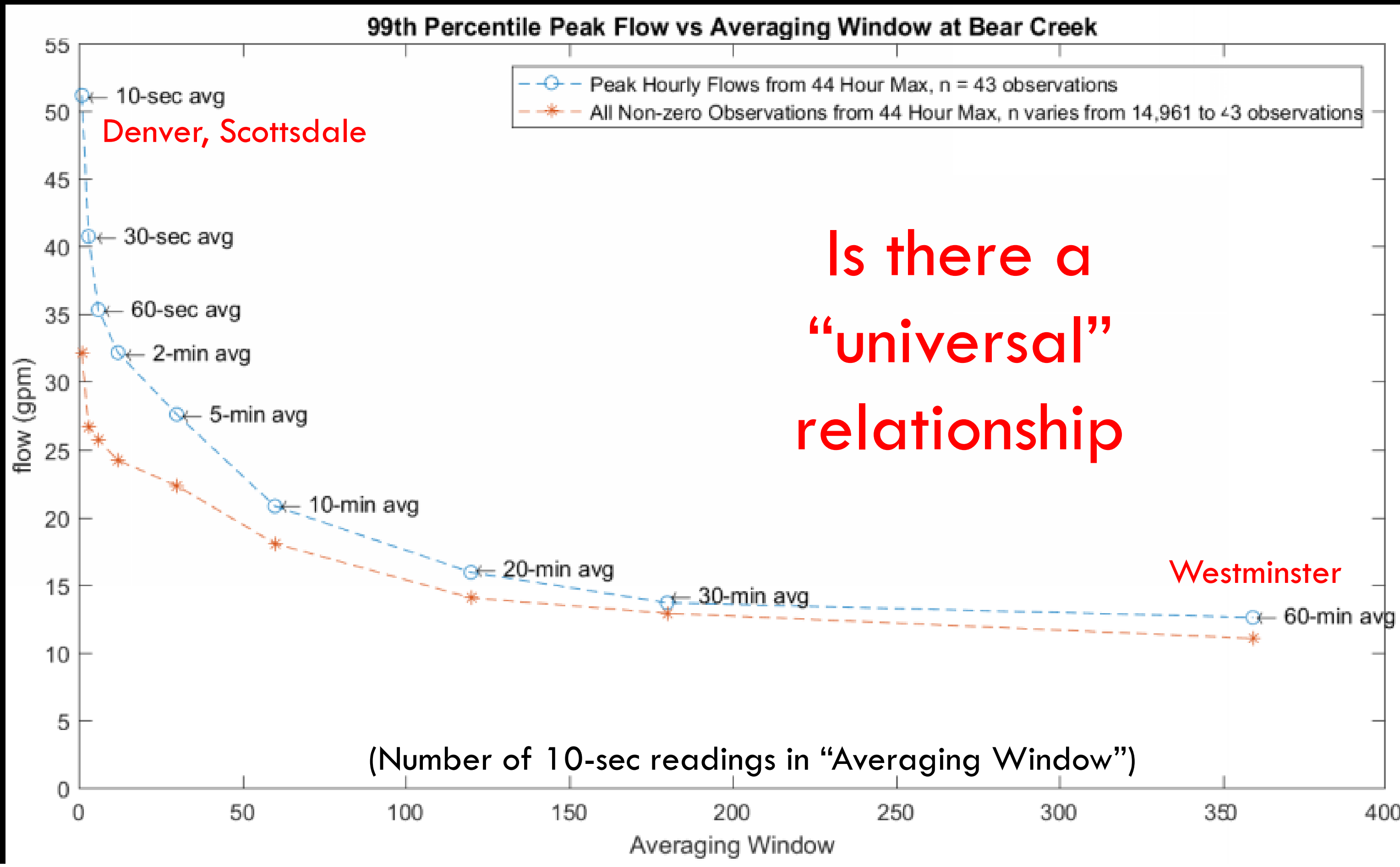
Effects of Averaging Data – 5-minute Resolution

5-minute window shows even lower peak (19 gpm)



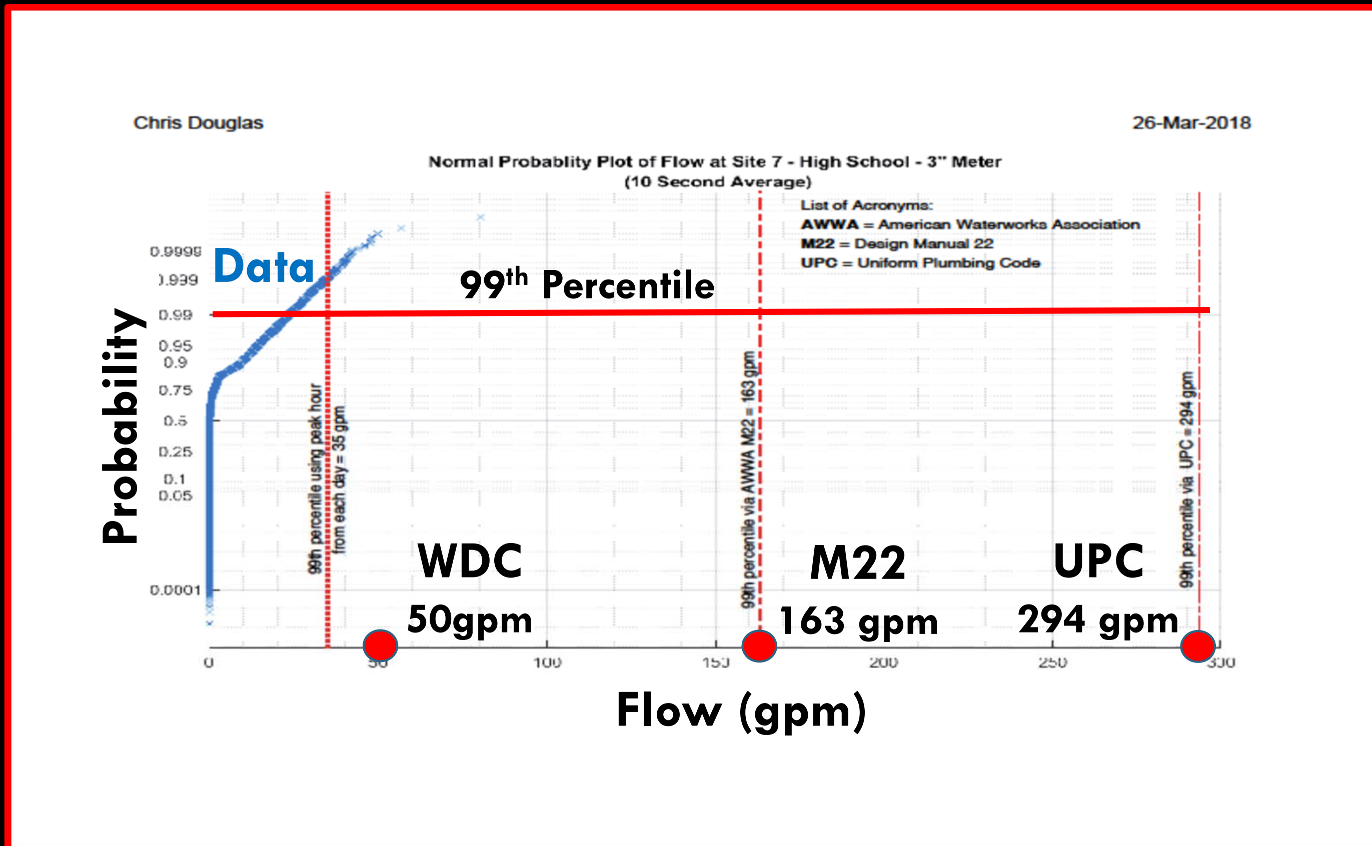
Change in 99th Percentile with Averaging Window

Peak flows get big quickly when the averaging window is small
This change is critical to deciding the 99th percentile for design purposes

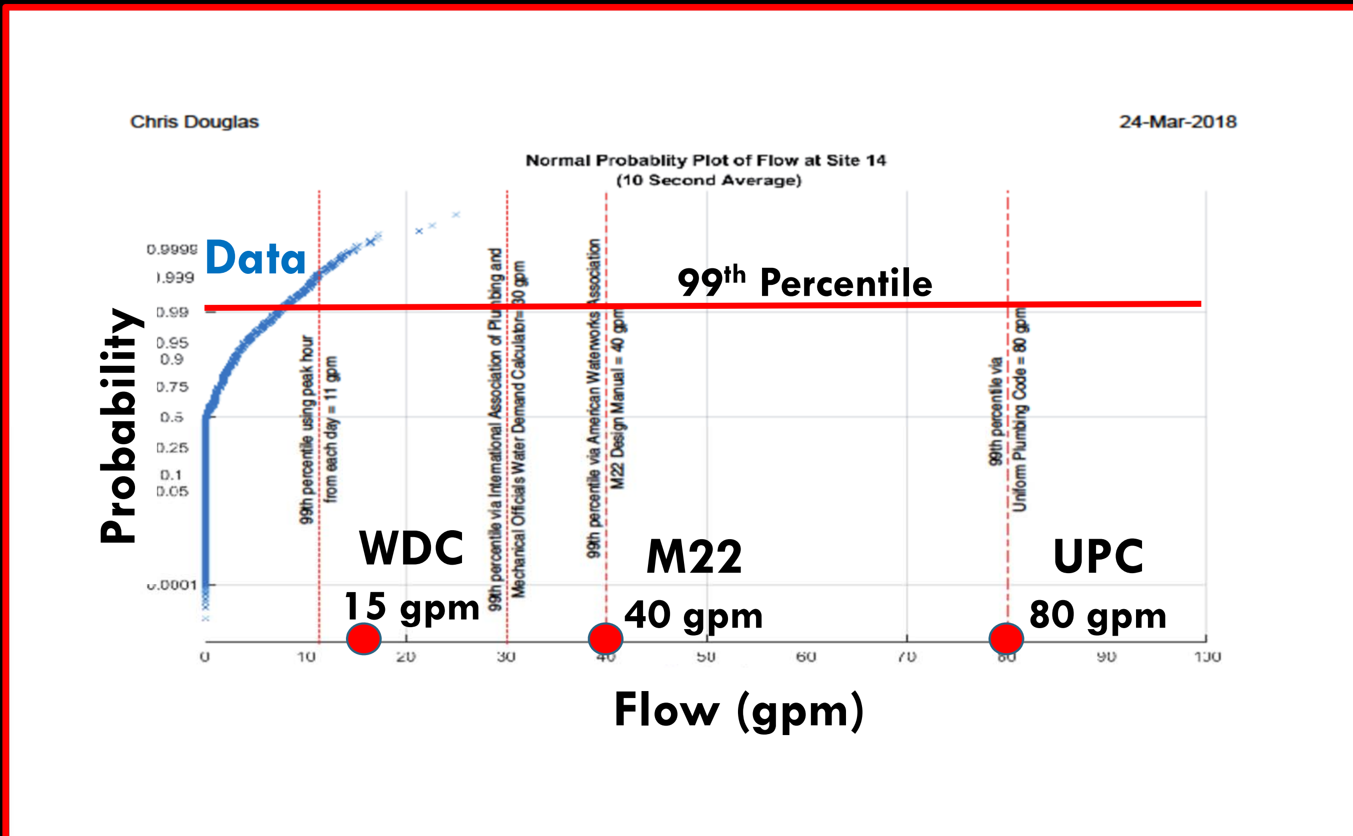


Estimating the Design Flow (using a 10-sec averaging step)

Design Flow Comparison: School (site 7)

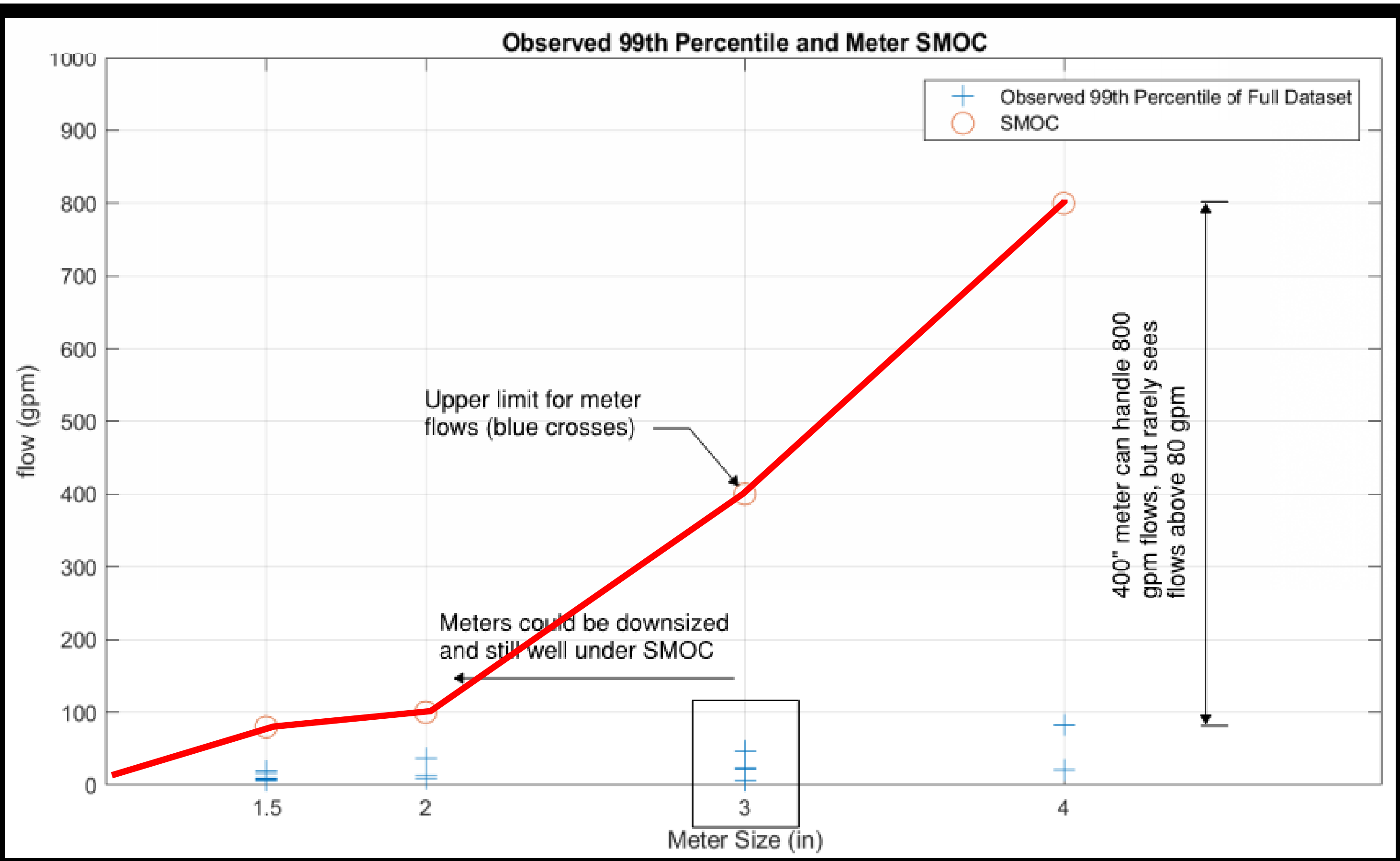


Design Flow Comparison: Apartments (site 14)



SMOC Flows and Observed 99th Percentiles

Preliminary Finding for all Denver Sites (Schools and Multifamily)
Virtually all meters could be downsized and stay below SMOC
Considers 99th percentile of a full dataset.



Key Nuggets

1. Performing "EDA" on a unique massive data set
2. Getting detailed glimpse of non-residential water use behavior
3. 99^{th} percentile may be a "good" design threshold for meter sizing
4. What is proper time step for peak flow duration…10 sec, 1 min?
5. What is the rule for flow variance reduction as time step grows?

Closing on Two Cautiously Optimistic Notes

1. Next edition of M22 (circa 2021) will allow smaller meters for buildings with water conserving fixtures.
2. Soon we will have a 21st century update to Hunter's Curve, but without the need for those mysterious fixture units.

See : www.iapmo.org/Pages/WaterDemandCalculator.aspx