Water Research Foundation – 4689
Assessing Water Demand Patterns to Improve Sizing of Water Meters and Service Lines
Research Team

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Stu Feinglas,
City of Westminster
WRF – 4689
Tailored Collaboration

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


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

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*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

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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

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<th>Size</th>
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SMOC = Safe Maximum Operating Capacity

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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

**Flow at Site 7 - High School - 3" Meter**
(10 Second Average)

- min = 0.00 gpm
- max = 80.28 gpm
- mean = 2.35 gpm
- median = 0.14 gpm
- std dev = 5.14 gpm
- variance = 26.42 (gpm)^2
- mode = 0.07 gpm
- n = 121507 observations
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 75\textsuperscript{th} percentile?

![Normal Probability Plot of Flow at Site 7 - High School - 3" Meter (10 Second Average)](image)

Select data above 75th percentile
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

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#### 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 – 1 pm 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

Peak Flow at Site 07 - High School - 3" Meter
(10 Second Average)

- min = 0.00 gpm
- max = 80.28 gpm
- mean = 8.26 gpm
- median = 5.41 gpm
- std dev = 7.93 gpm
- variance = 62.84 (gpm)^2
- mode = 2.21 gpm
- n = 14984 observations

flow (Gpm)

0 10 20 30 40 50 60

time (hours)

0 5 10 15 20 25 30 35 40
9 am – 1pm Peak Window at Site 07

“Inactive period” is between using the full dataset and the top 25% of the full dataset. The 99th percentile increases from ~23 gpm on the full dataset to ~32 gpm. The shape of each curve is very similar.
Developing Peak Hourly Flows from Peak Flow

43 Hour Peak Flow at Site 7
(10 Second Average)

Hourly Peaks of Max 43 Hours at Site 7
(10 Second Average)
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

I'M IN THE MOOD TO MISBEHAVE!
WHO'S WITH ME?
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

Normal Probability Plot of Flow at Site 3 - Elementary School - 3" Meter
(10 Second Average)

Confirmed: no flow between 10 and 40 gpm issue with crossover flow on a compound meter?
### 30 Study Sites in Scottsdale

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

- **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).

Flow at Site 26 - Office - 3" Meter
(10 Second Average)

- min = 0.00 gpm
- max = 11.07 gpm
- mean = 10.17 gpm
- median = 10.22 gpm
- std dev = 0.72 gpm
- variance = 0.51 (gpm)^2
- mode = 10.98 gpm
- n = 120929 observations
Questionable Data – Office (site 26)

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

Normal Probability Plot of Flow at Site 26 - Office - 3" Meter
(10 Second Average)

- Virtually no zero-flow conditions looks odd
- Water is constantly being used

- Uncommon shape
- Most probability plots curve the other direction

Low side of compound meter steps reading flow around 11 gpm
Multifamily Data - Apartments in Denver & Scottsdale

(Behaving well again, for now)
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

Normal Probability Plot of Flow at Site 14
(10 Second Average)

50% of observations are zero flow

Data is relatively normal, but has more extreme flows than a true normal distribution would
Denver Multifamily Data – Tuesday July 11th

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

Flow at Site 14 on Tues, Jul. 11, 2017
(10 Second Average)

- min = 0.00 gpm
- max = 9.69 gpm
- mean = 0.82 gpm
- median = 0.00 gpm
- std dev = 1.36 gpm
- variance = 1.84 (gpm)^2
- mode = 0.00 gpm
- n = 6840 observations

What is going on here?
Probability plot showing one day of data looks similar to all of the data
Usage is likely to be consistent each day (23 units)
Zero in on the 7 o’clock hour (23 units)

Flow at Site 14 on Tues, Jul. 11, 2017
(10 Second Average)

- min = 0.00 gpm
- max = 7.64 gpm
- mean = 0.90 gpm
- median = 0.37 gpm
- std dev = 1.17 gpm
- variance = 1.36 (gpm)^2
- mode = 0.00 gpm
- n = 360 observations
One hour of data does not look the same as one day or two weeks of the data.

Normal Probability Plot of Flow at Site 14
on Tues. Jul. 11, 2017 (10 Second Average)
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?)
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)
Peak flows get big quickly when the averaging window is small. This change is critical to deciding the 99th percentile for design purposes.

Is there a "universal" relationship?

Denver, Scottsdale

Westminster
Estimating the Design Flow (using a 10-sec averaging step)
Design Flow Comparison: School (site 7)

- **WDC**: 50 gpm
- **M22**: 163 gpm
- **UPC**: 294 gpm

99th Percentile

Data
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. 99th 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