Estimating Peak Water Demands in Buildings with Efficient Fixtures: Progress and Prognosis

Steven Buchberger
Emerging Water Technology Symposium
May 15, 2018
The Problem

The Progress

The Prognosis
Time History of Water Demand (21 units)
BUILDING MATERIALS and STRUCTURES

REPORT BMS65

Methods of Estimating Loads in Plumbing Systems

by

ROY B. HUNTER

ISSUED DECEMBER 16, 1940
3 Key Fixture Characteristics ($n, p, q,$)

$n$: Fixture Count

$q$: Fixture Flow Rate

$p$: Fixture Probability of Use

$$p = \frac{\sum t_i}{T}$$
Hunter’s Big Three

Flush Valve | Flush Tank | Bathtub
---|---|---
$p = 0.030$ | $p = 0.200$ | $p = 0.067$
$q = 27$ gpm | $q = 4$ gpm | $q = 8$ gpm
$\text{FU} = 10$ | $\text{FU} = 5$ | $\text{FU} = 4$

$\text{FU} = \text{“Fixture Unit”}$
A Building with $n=100$ Flush Tanks

Binomial Distribution

probability

BUSY FIXTURES

$0.1$

$0.08$

$0.06$

$0.04$

$0.02$

$0$

$0$ $20$ $40$ $60$ $80$ $100$
Hunter’s Criterion: Design for 99\textsuperscript{th} Percentile

Binomial Distribution

\[ n=100, \ p=0.20 \]

Simultaneous demands
Building with **100 flush tanks** + **100 red fixtures**

Binomial Distribution

![Graph showing probability distribution](image)

- **n=100, p=0.20**
- **n=100, p=0.40**

Q(0.99) → 30 busy fixtures
Q(0.99) → 52 busy fixtures
Hunter’s Curve Predicts Peak Flow (99\textsuperscript{th} percentile)

Hunter’s 1940 Curve has withstood the test of time; it is the basis for plumbing codes around the globe today.

(Hunter .vs. Moody)
Today **Hunter’s Curve** is often faulted for overly conservative design....Why?

[1] **Simplicity is seductive.** Hunter’s curve has been applied to many situations for which it was not intended.

[2] **Times have changed.** Water use fixtures (hot and cold) have become much more efficient since Hunter’s pioneering work. Water use habits have changed, too.
Hunter’s Approach Assumed “Congestion”
Modified Hunter’s Curve(s)

Different curve for different end users
Consequences of Obsolete Guidelines

Obsolete design guidelines produce over-sized premise plumbing and improperly-sized water meters, heaters and softeners.

This, in turn, leads to a host of water/energy problems including: inflated costs of construction, inaccurate metering and water billing, wasted energy and lost water through inefficient water heating, and increased potential health hazards from risk of microbial contamination (Legionella) (ANSI/ASHRAE 2015)
The Problem

The Progress

The Prognosis
Task Group Sponsors and Members

Daniel Cole, Chair, IAPMO, Mokena, IL
Jason Hewitt, CB Engineers, San Francisco, CA
Timothy Wolfe, TRC Worldwide Engineering MEP, Indianapolis, IN
Toritseju Omaghomi, College Engr & Applied Science, Univ of Cincinnati, Cincinnati, OH
Steven Buchberger, College Engr & Applied Science, Univ of Cincinnati, Cincinnati, OH
“...will work singularly to develop the probability model to predict peak demands based on the number of plumbing fixtures of different kinds installed in one system.”

Bring Hunter into 21st Century
Database: Location of Homes

- Survey 1996-2011
- MS database
- 62 cities
- 9 states
- 1,038 households
- 2,800 residents
- 11,350 home-days
- 863,000 events
## Recommended $p$-values and $q$-values

<table>
<thead>
<tr>
<th>FIXTURE GROUP</th>
<th>DESIGN P-VALUE (%)</th>
<th>MAXIMUM DESIGN FLOW RATE (GPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar Sink</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Bathtub</td>
<td>1.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Bidet</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Clothes Washer</td>
<td>5.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Combination Bath/Shower</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>0.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Kitchen Faucet</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Laundry Faucet</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Lavatory Faucet</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Shower, per head</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Water Closet, 1.28 GPF Gravity Flush Tank</td>
<td>1.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

- Hunter 1940: $6.7; 8.0$
- $20; 4.0$
Hunter Number: $H(n,p) = \Sigma n_k p_k$
Dimensionless Hunter Number, $H$

Fixture Count: $n = 100$
Probability of Use: $p = 0.20$
Hunter Number: $H = np = 20$

$H$ is “expected number” of flush tanks in simultaneous use during the peak demand period.
Peak Period Probability of Stagnation

Hunter Number $H(n,p) = \Sigma H_k = \Sigma n_k p_k \quad k=1,2,...,K$

$\text{Prob[zero demand]} = P_0 \approx \exp[-H(n,p)]$
Probability of Fixture Use, p (%)

Number of Fixtures, n

Yellow box is region for single dwelling;
Blue box is region for multiple dwellings.

$P_0 = 0.78$

$P_0 = 0.29$

$P_0 = 0.01$
Algorithm for Zone D: Wistort Method (1994)
Algorithm for Zone D: Wistort Method (1994)

Binomial Distribution

\[ n=100, \ p=0.20, \ H(n,p)=20 \]

\[
Q_{99} = \sum_{k=1}^{K} q_k n_k p_k + z_{99} \sqrt{\sum_{k=1}^{K} q_k^2 n_k p_k (1 - p_k)}
\]

Design for the 99th percentile!

BUSY FIXTURES

simultaneous demands

probability

0 20 40 60 80 100
0
0.02
0.04
0.06
0.08
0.1
Algorithm for Zone D: Wistort Method (1994)

Binomial Distribution

\[ n=100, \ p=0.20, \ H(n,p)=20 \]

\[ Q_{99} = \sum_{k=1}^{K} q_k n_k p_k + z_{99} \sqrt{\sum_{k=1}^{K} q_k^2 n_k p_k (1-p_k)} \]

Design for the 99th percentile!

Normal approximation for binomial distribution
Zones A&B Algorithm: Exhaustive Enumeration
Algorithm for Zones A&B: Exhaustive Enumeration

EXEN Outcomes Grows as $2^n$

$n=1$ fixture
2 outcomes
0
a

$n=2$ fixtures
4 outcomes
0
a, b
a+b

$n=3$ fixtures
8 outcomes
0
a, b, c
a+b, a+c, b+c
a+b+c

$n=7$ fixtures
128 outcomes
0
a, b, c, d, e, f, g
a+b, a+c, a+d ..... 
....etc......
a+b+c+d+e+f+g
Example CDF from EXEN for n=4 Fixtures
Exhaustive Enumeration Grows as $2^n$
$P_0 = 0.78$  $P_0 = 0.29$  $P_0 = 0.01$

Yellow box is region for single dwelling; Blue box is region for multiple dwellings.

$H(n, p) = 0.25$  $H(n, p) = 1.25$  $H(n, p) = 5.00$
Algorithm for Zone A only: Q1+Q3

**STEP 1:** Rank fixture demands from maximum to minimum.

**STEP 2:** Add rank 1 and rank 3 demands (largest and 3rd largest).

“Q1+Q3” works reasonably well in single family homes (n ≤ 12).
Transition from One to Many Fixtures

- Limiting Case is Deterministic (n=1)
- Discrete Random Variables
- Single Family Homes
- Small Hunter’s Number, $H(n,p)$
- High chance of stagnation $P[0]$
- One water fixture can have a big influence

- Limiting Case is Stochastic (n>>1)
- Continuous Random Variables
- Multi-Family Developments
- Large Hunter’s Number, $H(n,p)$
- Little chance of stagnation, $P[0]$
- One water fixture has little (if any) influence
WDC: Water Demand Calculator

Basic Template

![Water Demand Calculator](image-url)
Zone A Example: Single Family Home

### WDC: Water Demand Calculator-2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bar Sink</td>
<td>0</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>2 Bathtub</td>
<td>0</td>
<td>1.0</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>3 Bidet</td>
<td>0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4 Clothes Washer</td>
<td>1</td>
<td>5.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>5 Combination Bath/Shower</td>
<td>2</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>6 Dishwasher</td>
<td>1</td>
<td>0.5</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>7 Kitchen Faucet</td>
<td>1</td>
<td>2.0</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>8 Laundry Faucet</td>
<td>1</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>9 Lavatory Faucet</td>
<td>3</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>10 Shower, per head</td>
<td>0</td>
<td>4.5</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>11 Water Closet: 1.28 GPF Gravity Tank</td>
<td>3</td>
<td>1.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>12 Other Fixture 1</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
<tr>
<td>13 Other Fixture 2</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
<tr>
<td>14 Other Fixture 3</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

**Total Number of Fixtures**: 12

**99th PERCENTILE DEMAND FLOW**: 11.0 GPM

**RUN WATER DEMAND CALCULATOR**

12 Fixtures

UPC gives 18.2 gpm

40% reduction

1” line

¾” line
Zone D Example: Multi-Family Complex

WDC: Water Demand Calculator

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Bar Sink</td>
<td>0</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>2 Bathtub</td>
<td>0</td>
<td>1.0</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>3 Bidet</td>
<td>0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4 Clothes Washer</td>
<td>100</td>
<td>5.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>5 Combination Bath/Shower</td>
<td>200</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>6 Dishwasher</td>
<td>100</td>
<td>0.5</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>7 Kitchen Faucet</td>
<td>100</td>
<td>2.0</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>8 Laundry Faucet</td>
<td>100</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>9 Lavatory Faucet</td>
<td>300</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>10 Shower, per head</td>
<td>0</td>
<td>4.5</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>11 Water Closet 1.28 GPF Gravity Tank</td>
<td>300</td>
<td>1.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>12 Other Fixture 1</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
<tr>
<td>13 Other Fixture 2</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
<tr>
<td>14 Other Fixture 3</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Total Number of Fixtures: 1200

99th PERCENTILE DEMAND FLOW = **155.4** GPM

1200 Fixtures
UPC gives 397 gpm
62% reduction

5” line
↓
3” line
Precautionary Note on Fixture Retrofits

<table>
<thead>
<tr>
<th>Method</th>
<th>Peak Flow (gpm)</th>
<th>Pipe Size (inch)</th>
<th>Velocity (fps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPC</td>
<td>397</td>
<td>5</td>
<td>6.5</td>
</tr>
<tr>
<td>WDC</td>
<td>155</td>
<td>3</td>
<td>7.0</td>
</tr>
<tr>
<td>UPC, WDC</td>
<td>155</td>
<td>5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Velocity ratio 6.5/2.5 = 2.6 times slower moving water after retrofitting the original premise plumbing system. This almost certainly implies longer residence time for water in the premise plumbing system since the volume of water use also drops following retrofit.
The Problem

The Progress

The Prognosis
Design Flow Comparison: School (site 7)

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

99th Percentile
Design Flow Comparison: Apartments (site 14)

<table>
<thead>
<tr>
<th>Flow (gpm)</th>
<th>Probability</th>
<th>99th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDC</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>M22</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>UPC</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

Data:
- WDC: 15 gpm
- M22: 40 gpm
- UPC: 80 gpm

Flow (gpm):
- 0 to 100

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

24-Mar-2018

Chris Douglas
BIM: Building Information Model
Archive Fixture Values: (p,q)

- **Fixture Group K**
  - \( p = 0.05 \)
  - \( q = 1.2 \text{ gpm} \)

- **Fixture Group 2**
  - \( p = 0.05 \)
  - \( q = 1.2 \text{ gpm} \)

- **Fixture Group 1**
  - \( p = 0.05 \)
  - \( q = 1.2 \text{ gpm} \)
Universal Dimensionless Design Curve

(From Omaghomi and Buchberger, 2014).
Summary / Conclusions

❖ Introduced a new framework to estimate peak water demand in single/multi-family dwellings.
❖ Replaced fixture units with fixture counts.
❖ Runs on a spreadsheet.
❖ Recommended fixture $p$ and $q$ values.
❖ Can be applied to a wide spectrum of buildings.
❖ WDC is an appendix in the 2018 Code.
❖ Approach is amendable to BIM platforms.
Steven.Buchberger@uc.edu
University of Cincinnati