Estimating Peak Water Demands in Buildings with Efficient Fixtures

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INTERNATIONAL EMERGING TECHNOLOGY SYMPOSIUM

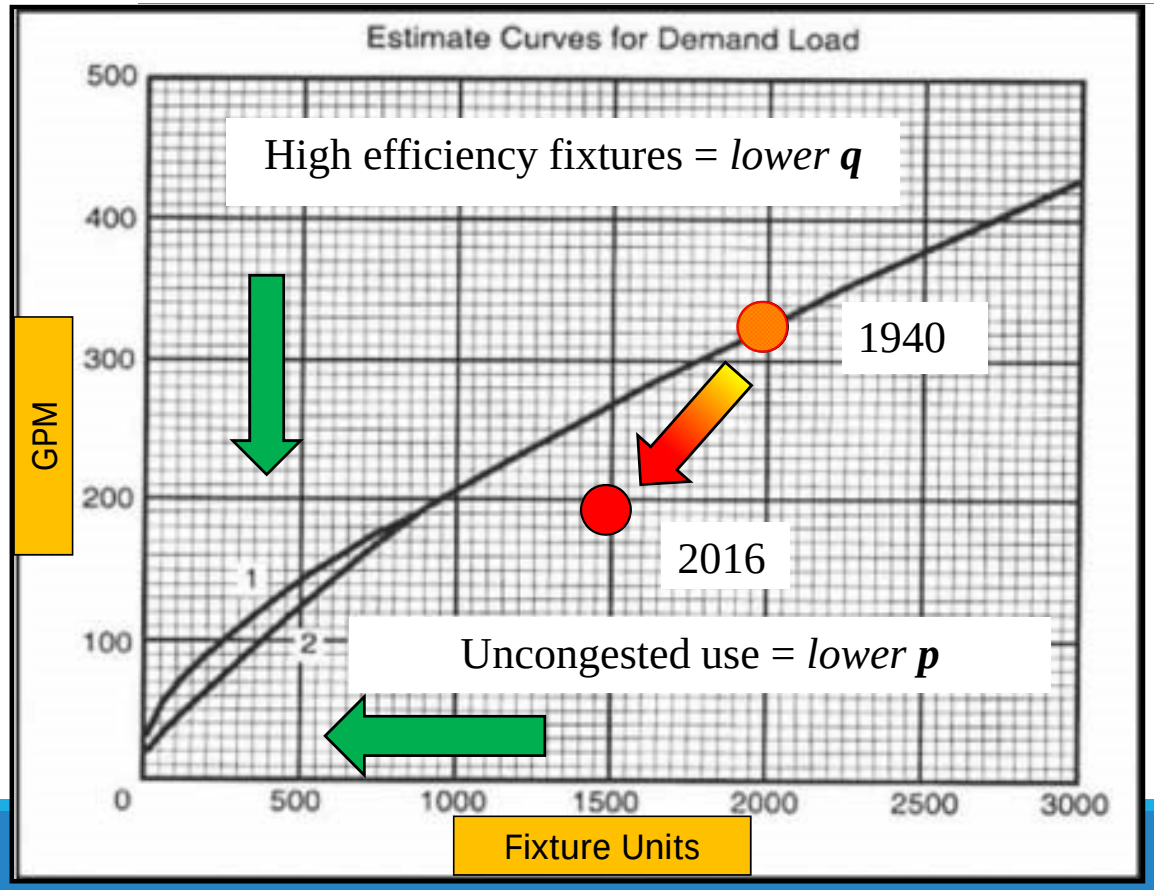
MAY 10, 2016

Outline

- [1] Background/Motivation
- [2] Water Use Database
- [3] Water Use Parameters
- [4] Water Use Model
- [5] Application
- [6] Conclusion

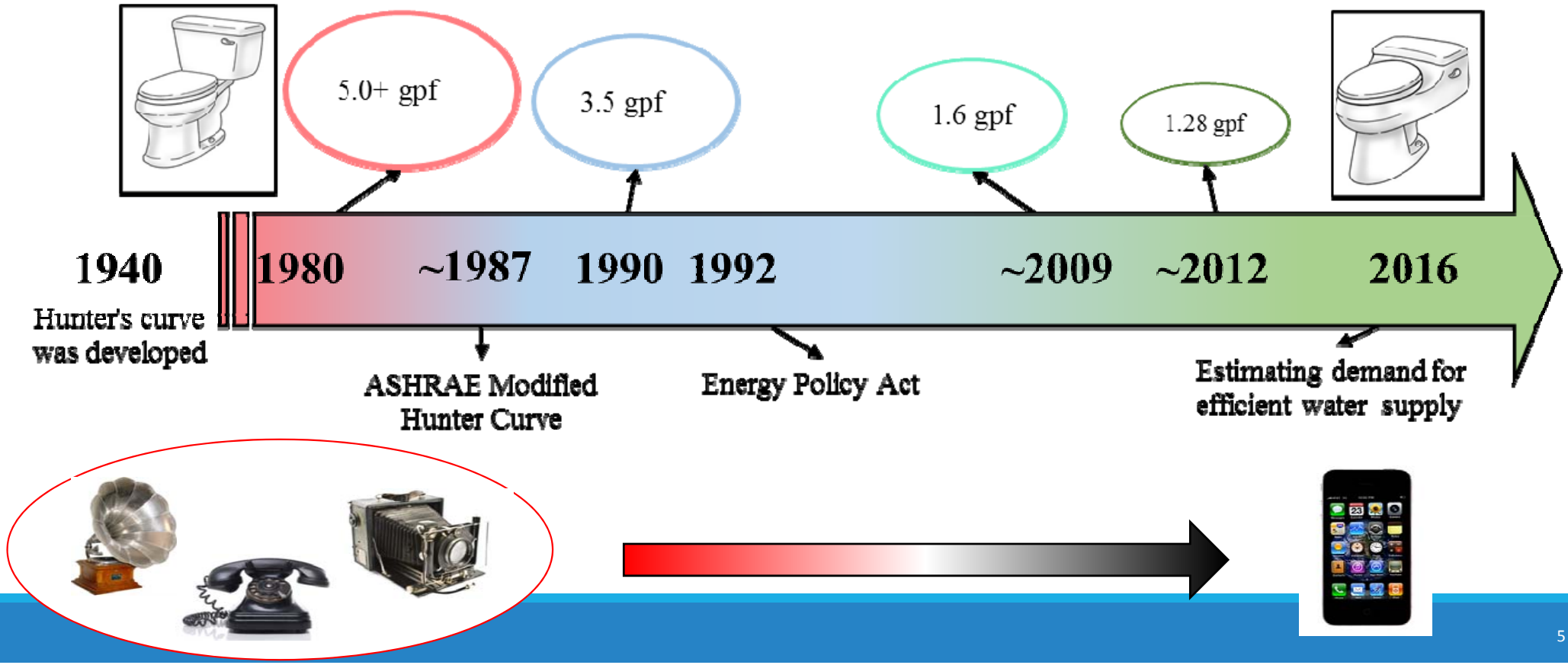
[1] BACKGROUND / MOTIVATION

Hunter's Curve

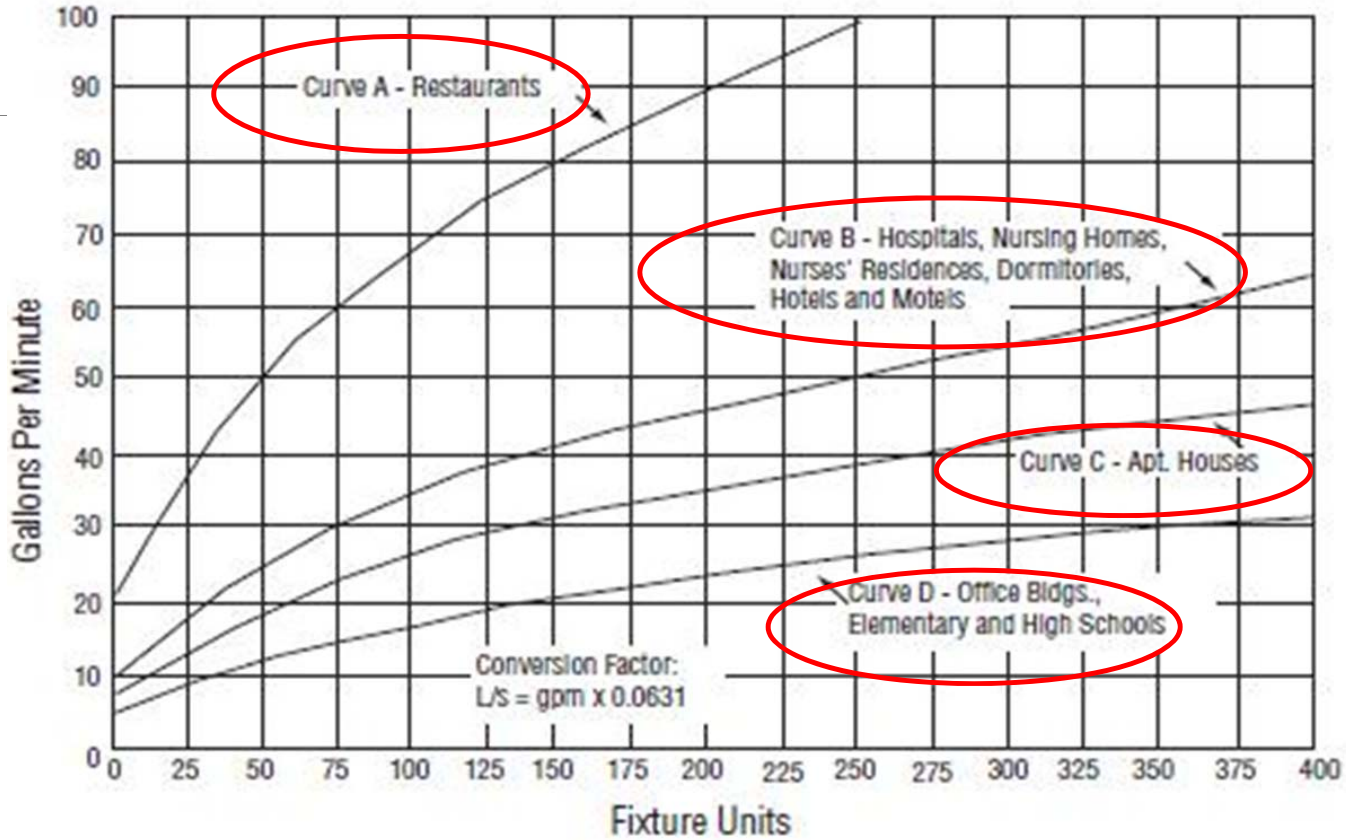


Today, **Hunter's curve** is often faulted for giving overly conservative designs….Why?

Changing Times



Modified Hunter's Curve(s)



Different curve for different end users

http://www.armstronginternational.com/files/products/wheaters/pdf/sizing%20chart.pdf

Task Group Sponsors and Members

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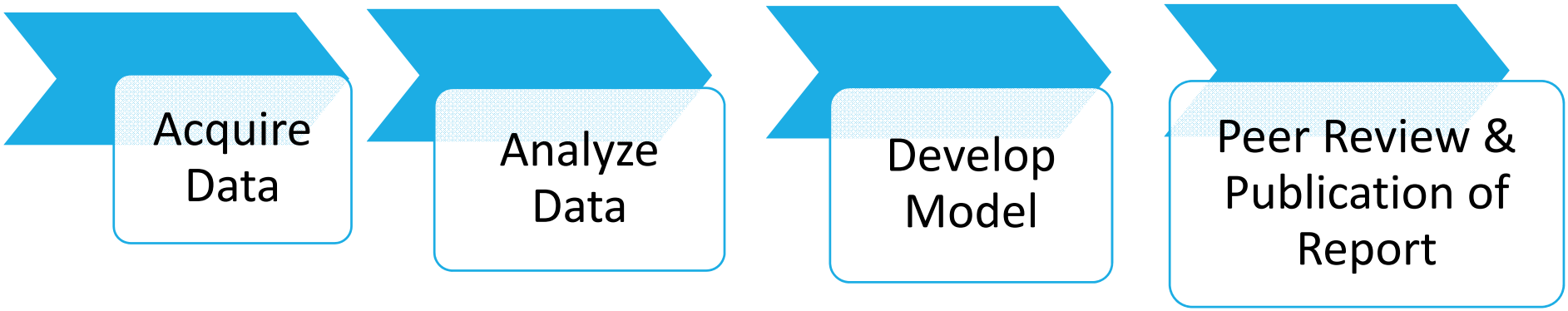
IAPMO Task Group Orders

"….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)

Project Activities

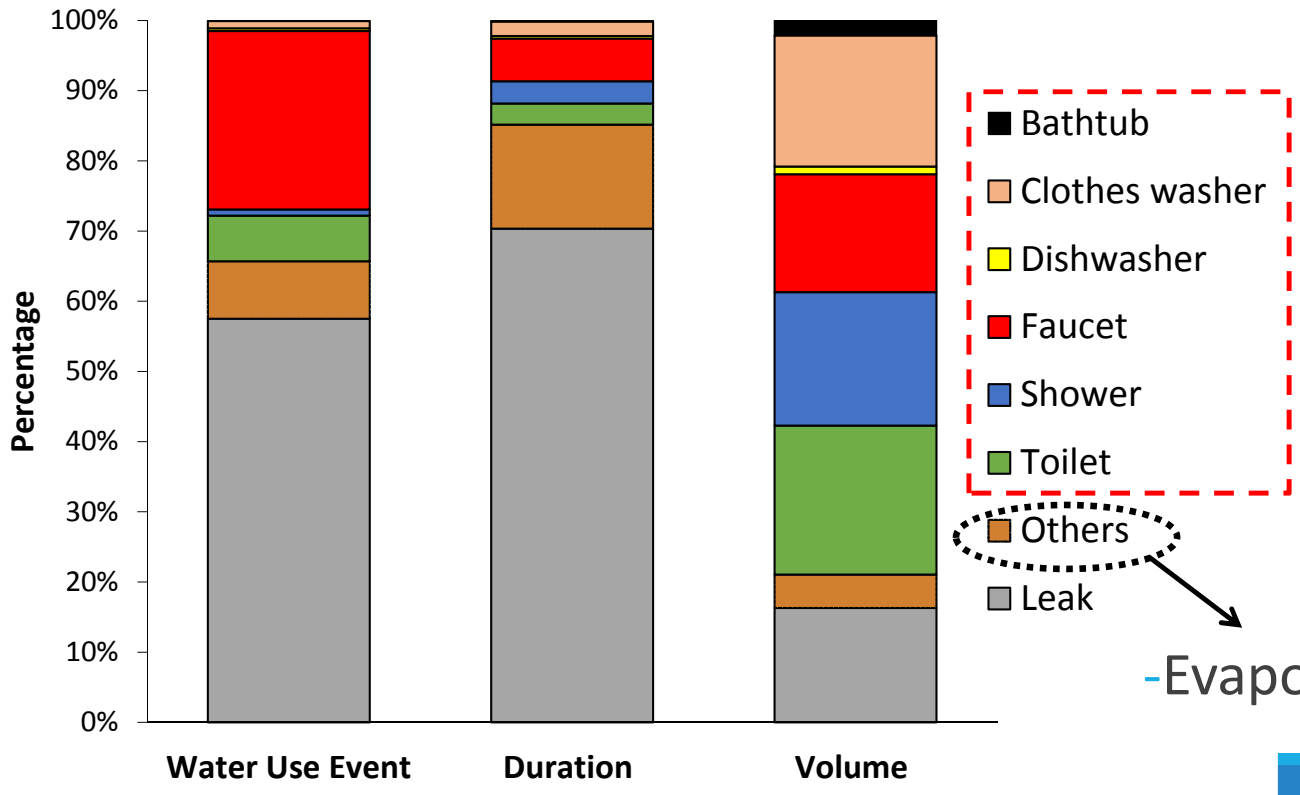


[2] WATER USE DATABASE

Database: Location of Homes

- Survey 1996-2011
- 1,038 households
- 2,800 residents
- 11,350 monitoring days
- MS Access DB

Database: Summary of Measured Data



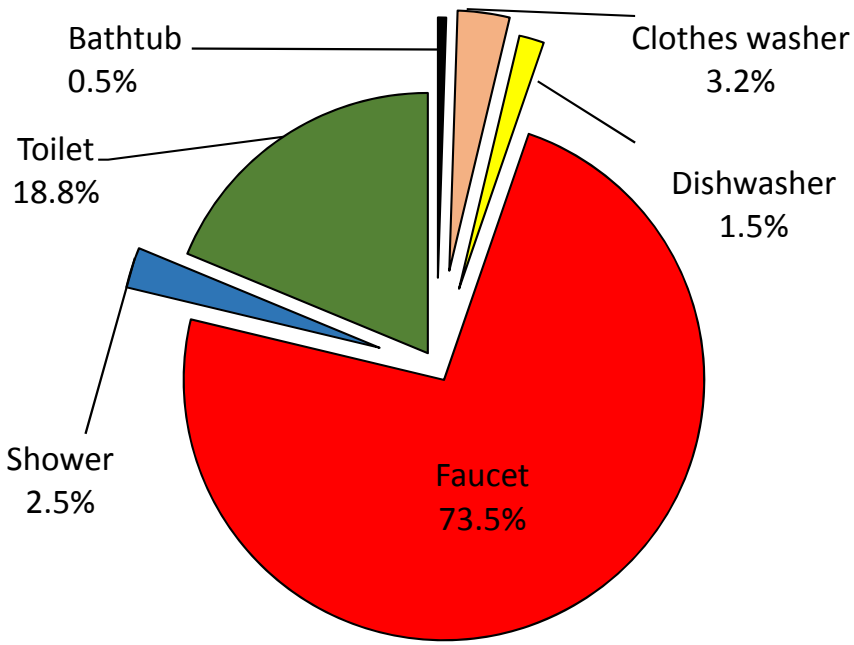
- Six unique fixtures
- 862,900 events*
- 1,591,700 gallons*
- 889,700 minutes*

*excluding leaks

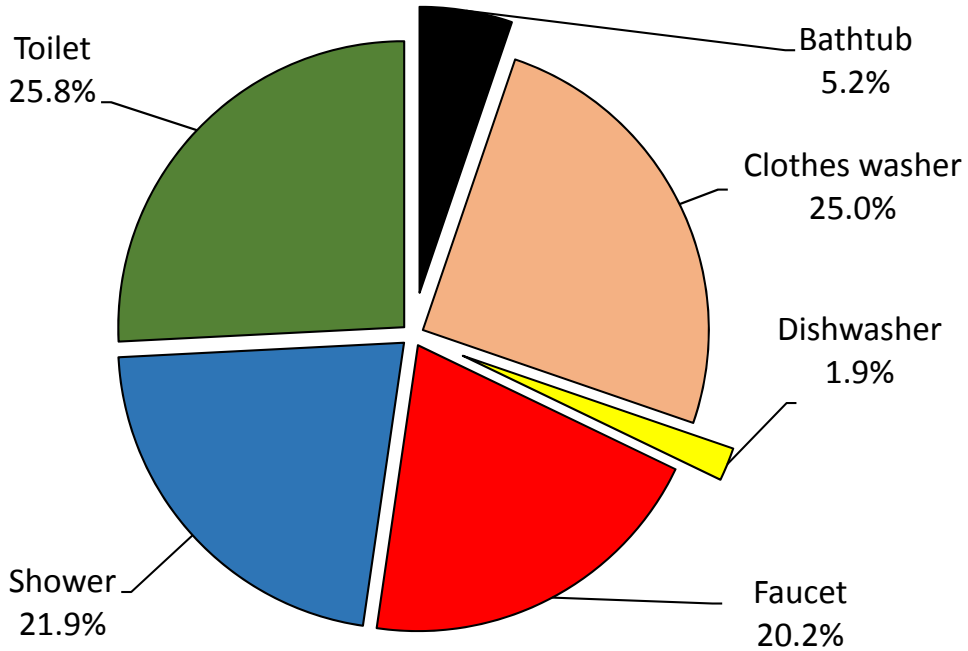
-Evaporative Cooler

Database: Details of Water Use at Fixture

NUMBER OF "HITS"



VOLUME OF WATER USE



Database: Residential Fixture Classification

Fixture*	Ultra-Efficient	Efficient	Inefficient
Clothes washer (gallons/load)	< 20	20 – 30	> 30
Dishwasher (gallons/cycle)	< 1.8	1.8 – 3.0	> 3.0
Shower (gallons/minute)	< 2.2	2.2 – 2.5	> 2.5
Toilet (gallons/flush)	< 1.8	1.8 – 2.2	> 2.2

***Bathtubs and faucets were excluded**

[3] WATER USE PARAMETERS

Key Fixture Characteristics

1 - n: Fixture Count

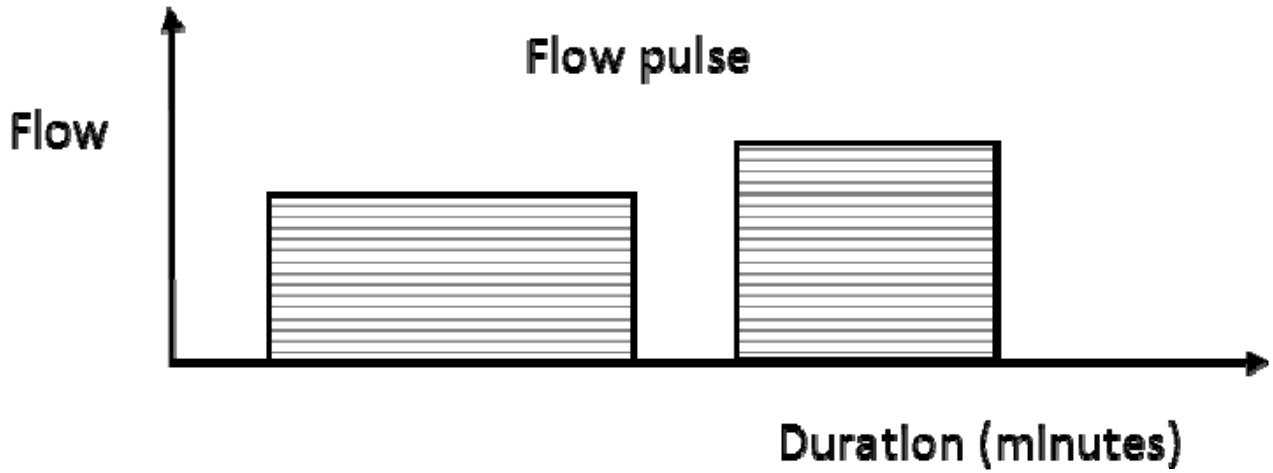
1 2 3 . . . x . . . . n

2 - q: Fixture Flow Rate

3 - p: Fixture Probability of Use

$$p = \frac{\sum t_i}{T}$$

Computed Fixture Flow Rate; $\boldsymbol{q}$

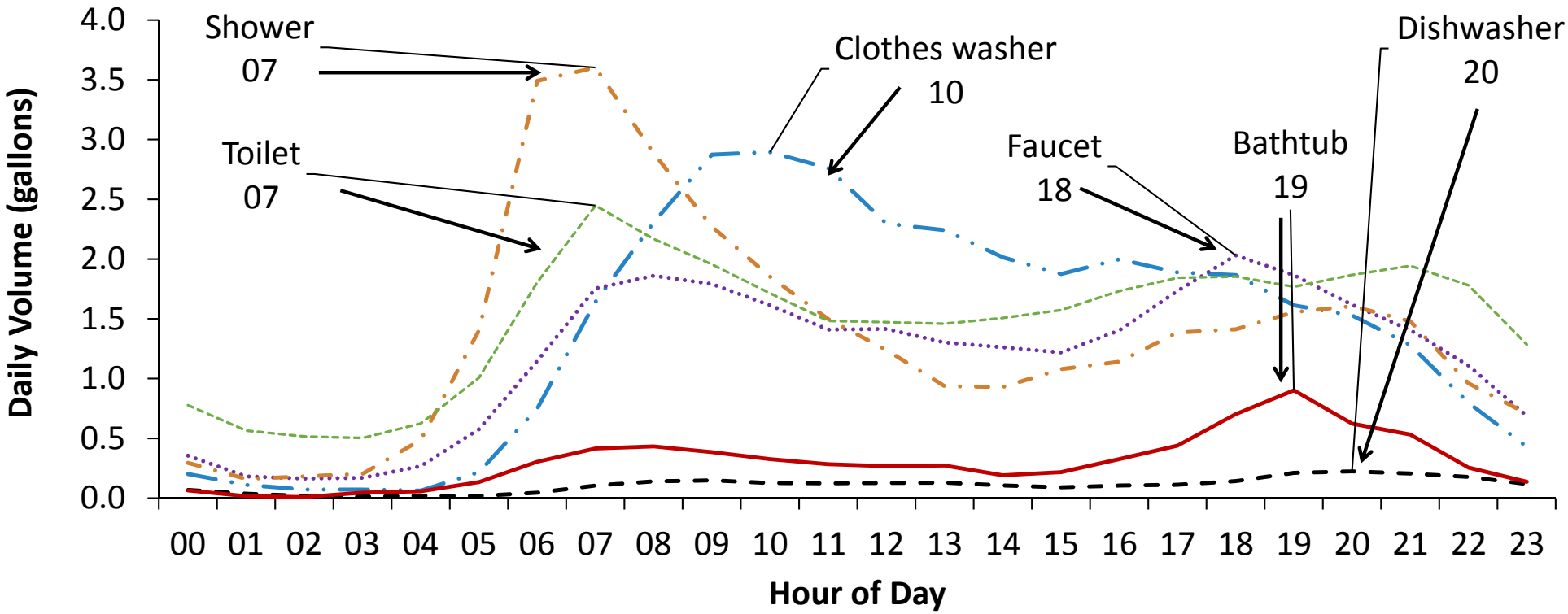


$$q = \frac{\sum Volume\, of\ each\ pulse\,(gallons)}{\sum Duration\, of\ each\ pulse\,(minutes)}$$

Summary of “Efficient” Fixture Flow Rate

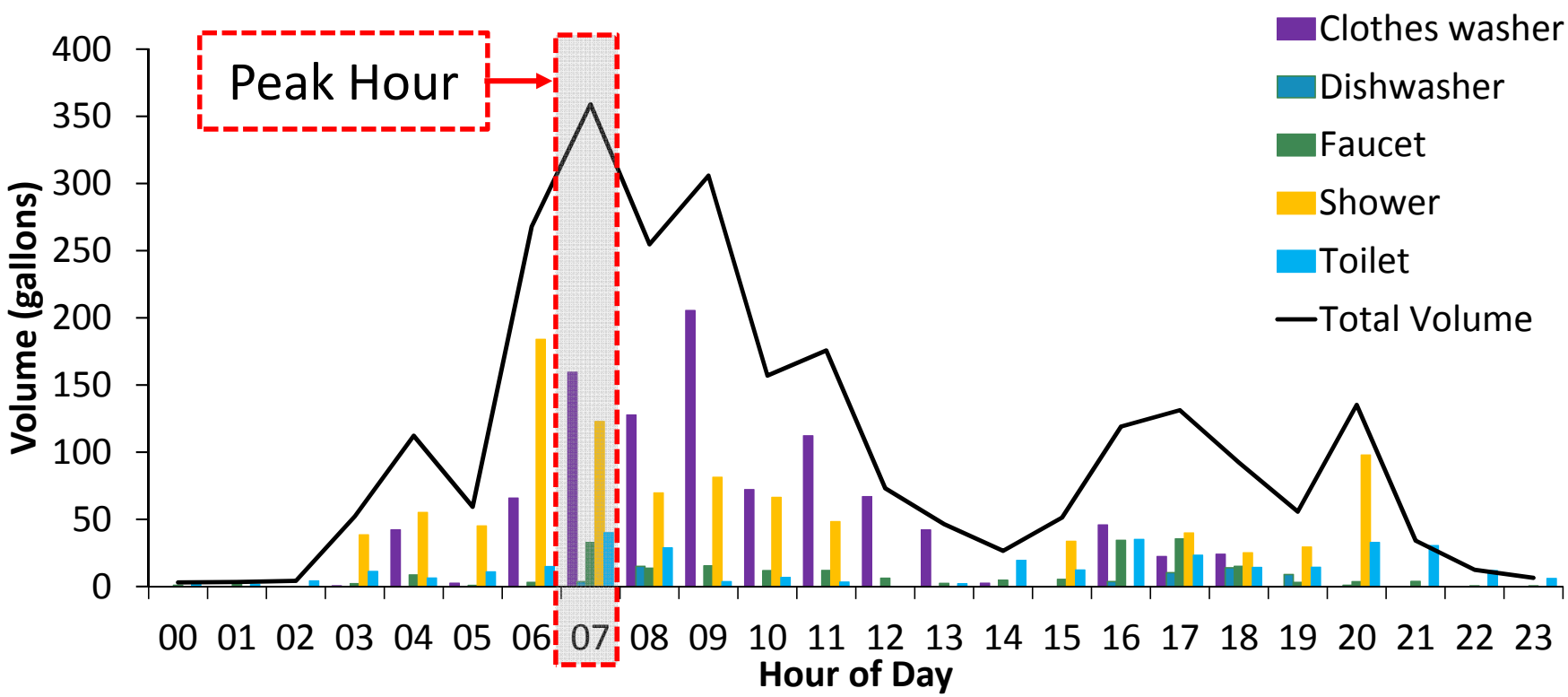
“Efficient” = Ultra-efficient and Efficient Fixtures

Hourly Fixture Use (Volume)

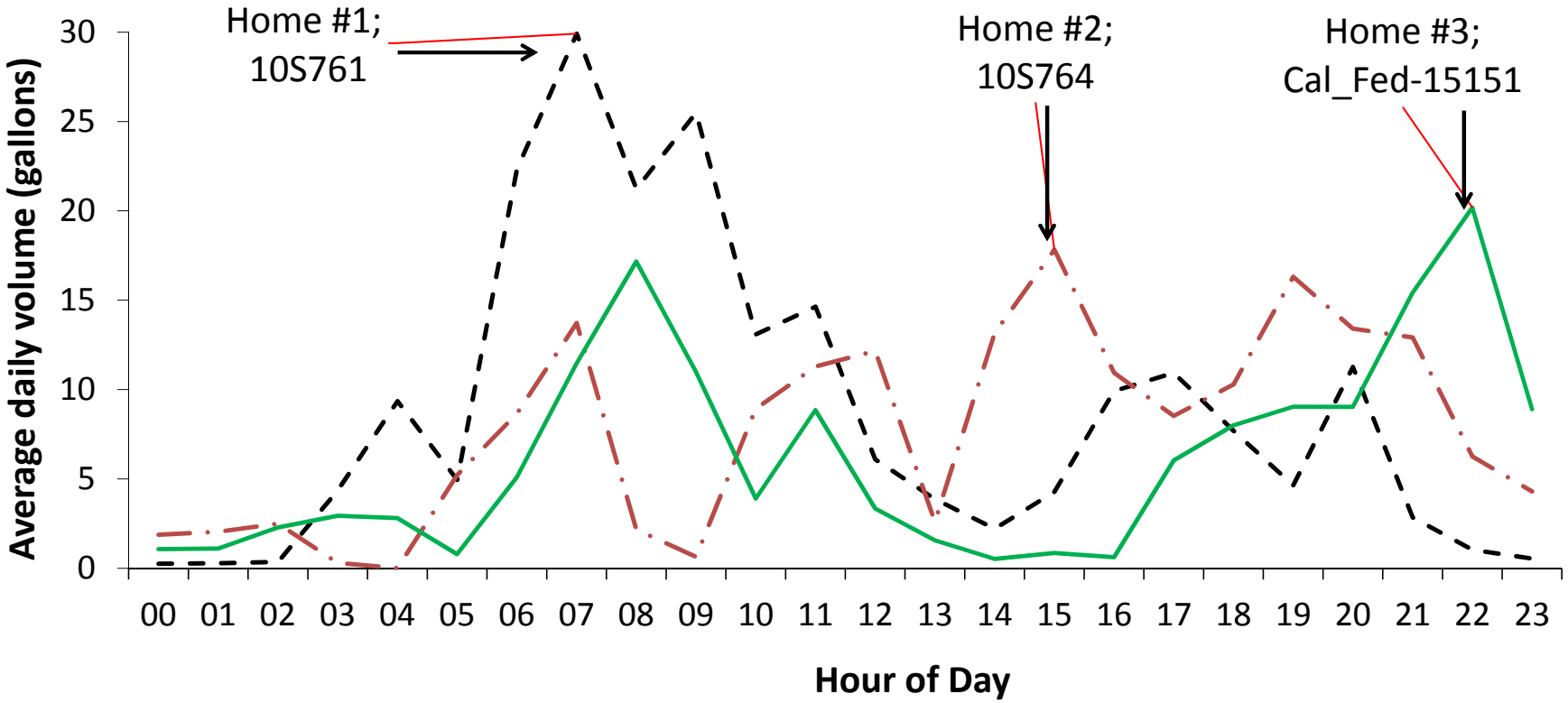


Average hourly volume of water use at a fixture per home per day

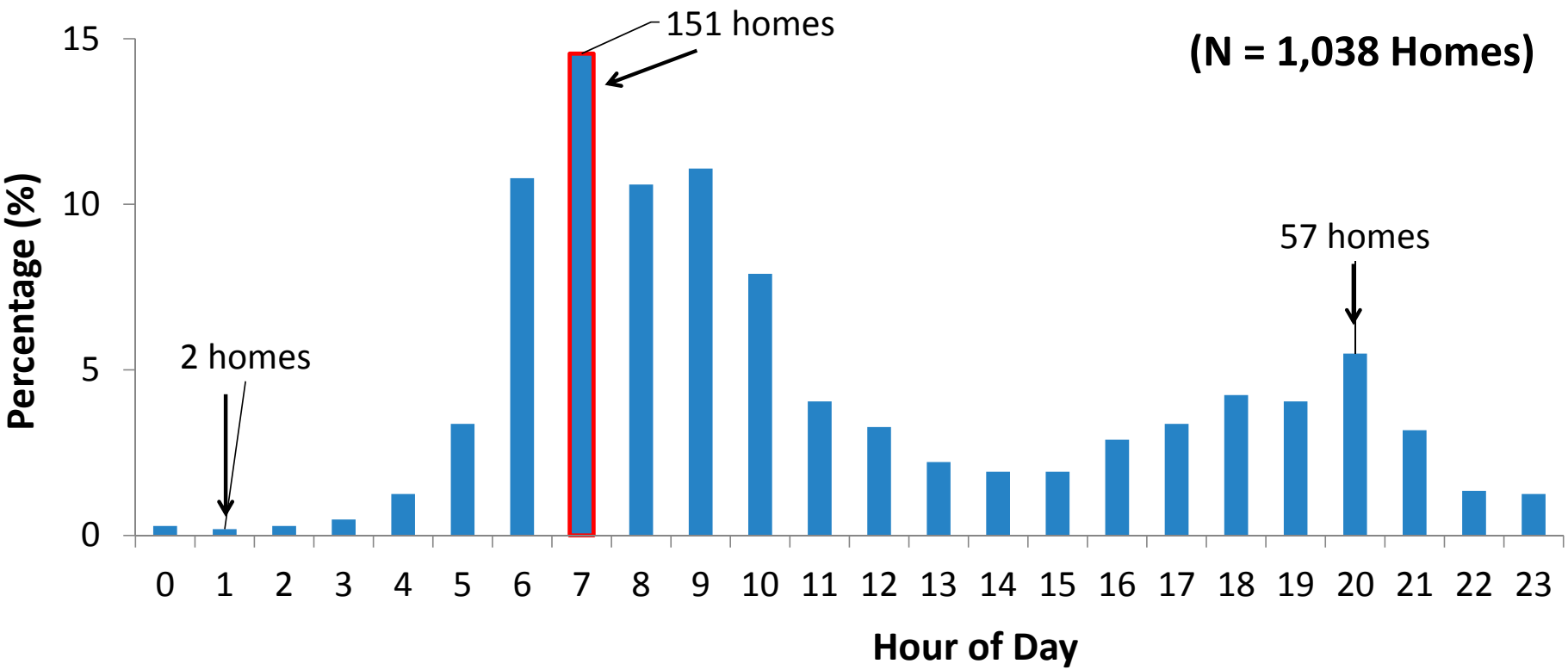
Single Home 12 Day Water Use Profile (10S761)



Multiple Homes Water Use Profile (by Volume)



Distribution of Peak Hour of Water Use



Probability of Fixture Use at Individual Homes

- Focused on only efficient fixtures

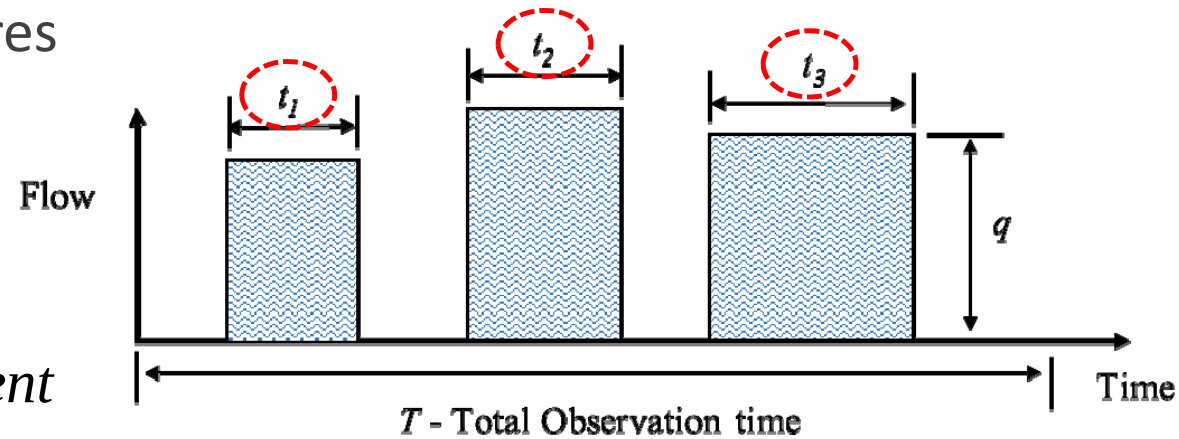
$$p = \frac{\sum_i t_i}{n \cdot D \cdot T}$$

t_i – *Duration of* i^{th} *water use event*

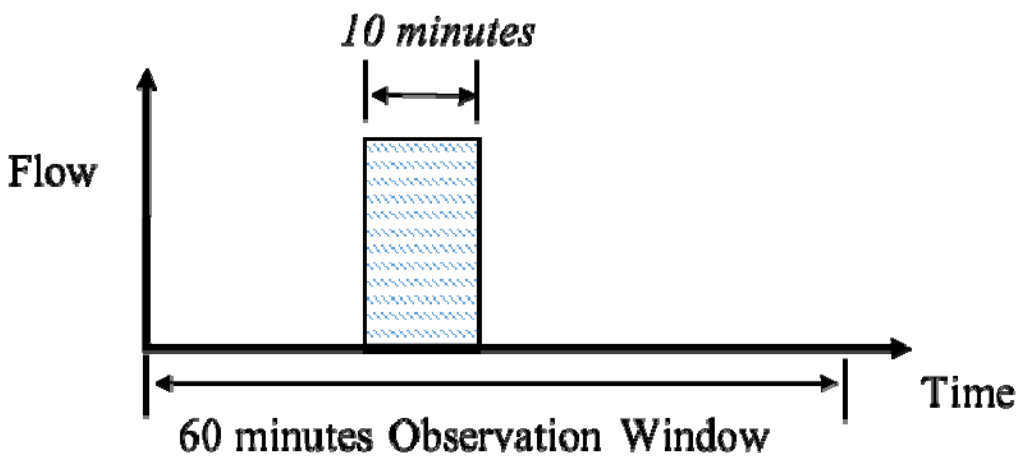
n – *Number of fixtures*

D – *Number of observation days*

T – *60 minutes (1 hour observation window)*



Probability of Fixture Use at Individual Homes

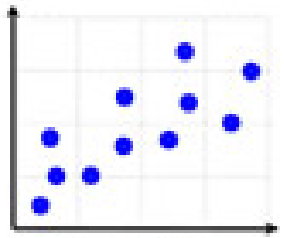


$$p = \frac{\sum_i t_i}{n \cdot D \cdot T}$$

$$p = \frac{10\,minutes}{1\,fixture \cdot 1\,day \cdot 60\,minutes} = 0.17$$

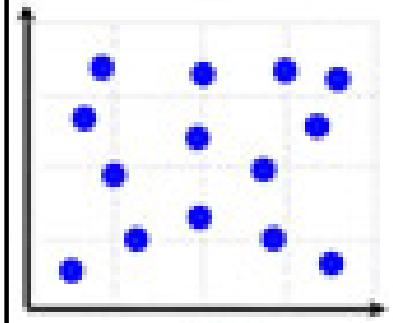
Considered only efficient fixtures

Probability of Fixture Use – Group of Homes



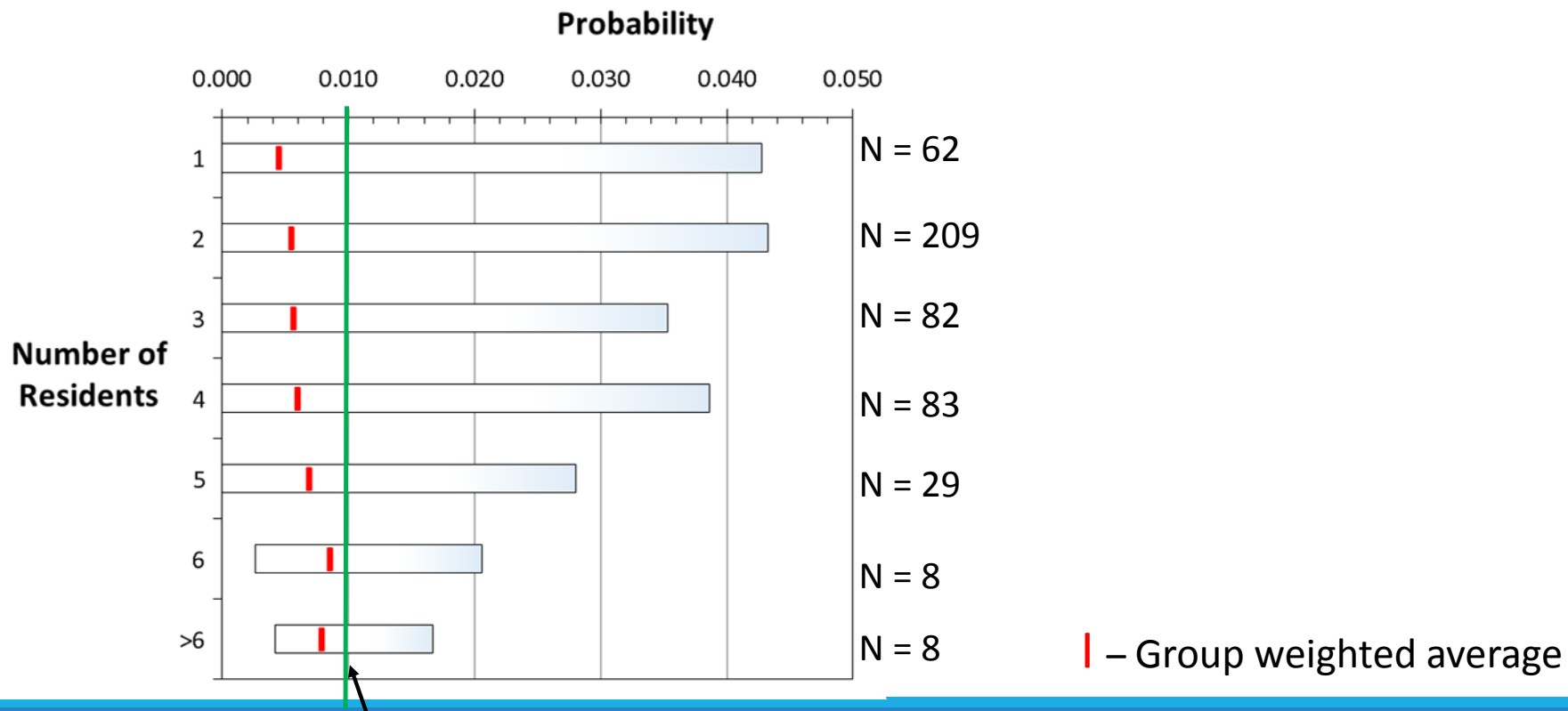
Positive Correlation

- Number of residents
- Number of bathrooms
- Number of bedrooms



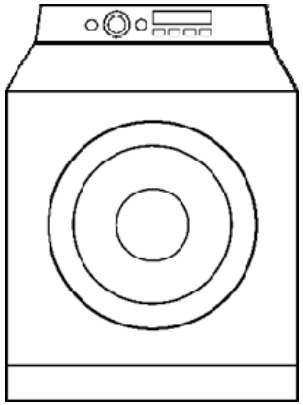
No Correlation

Probability of Toilet Use



Conservative Value

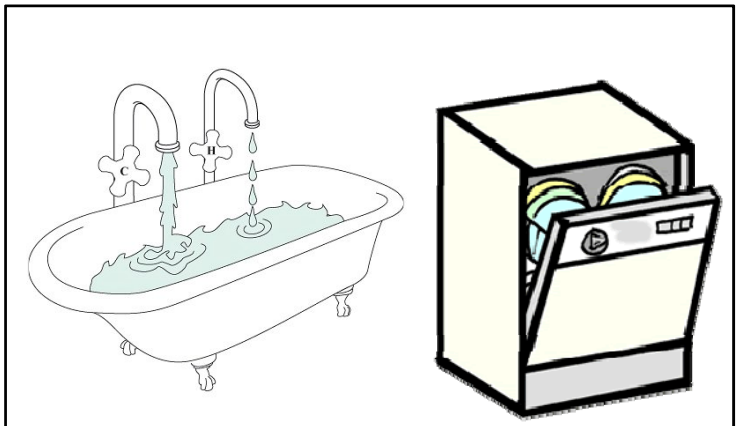
Design Fixture Probability Values



p = 0.050

p = 0.010

p = 0.025

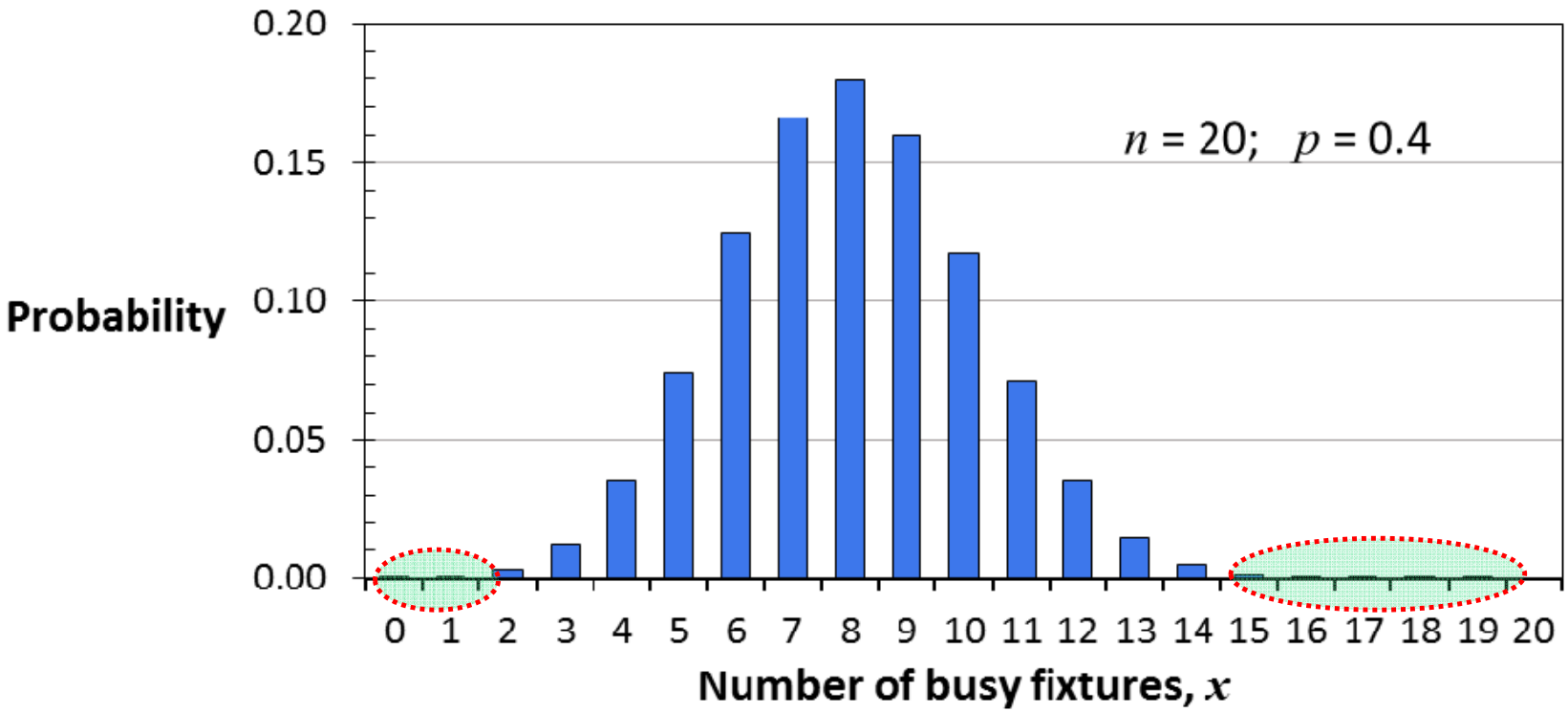


p = 0.005

[4] (PEAK) WATER USE MODEL

Binomial Model

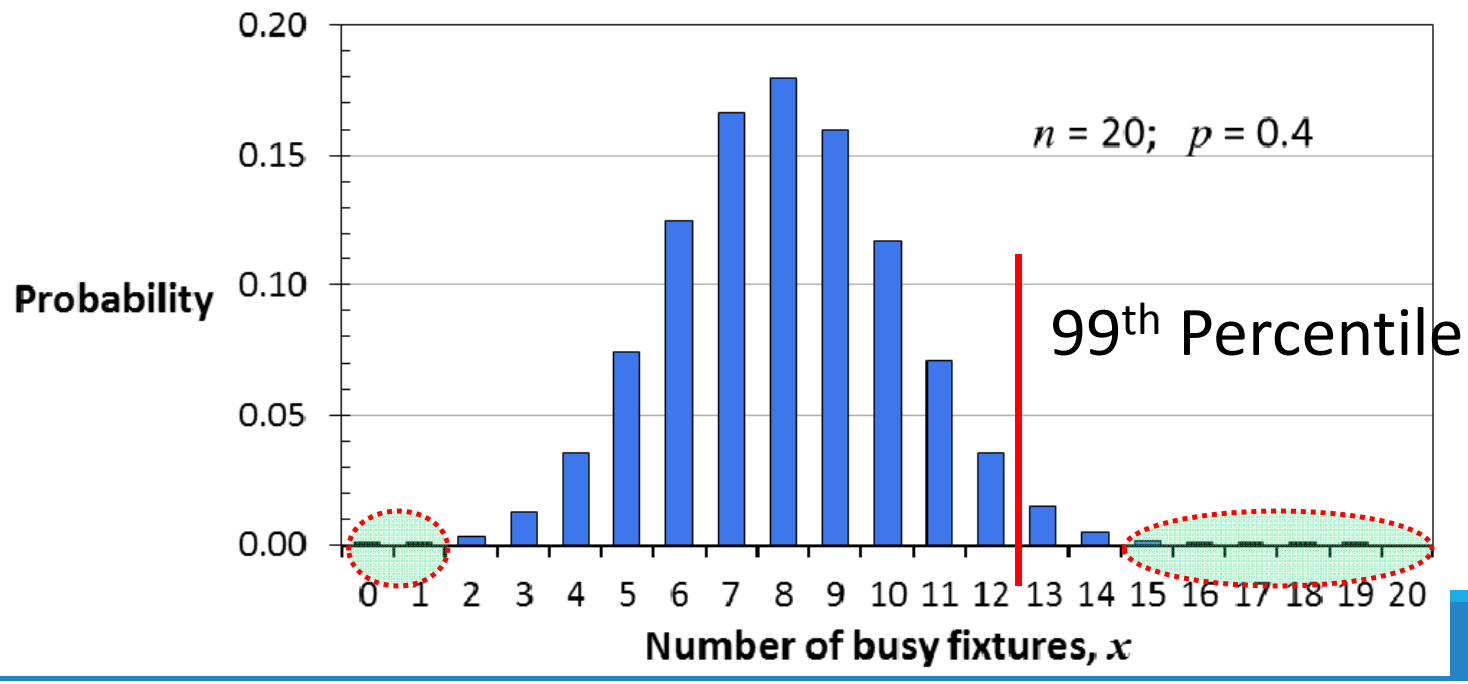
$$\Pr\begin{pmatrix}\text{exactly } x \text{ busy} \\ \text{out of } n \text{ fixtures}\end{pmatrix} = \binom{n}{x} p^x (1-p)^{n-x}$$



Hunter did this

“Frequency Factor” Approach

$$Q_{0.99} = Mean + \left(z_{0.99}\right) Standard\ Deviation$$

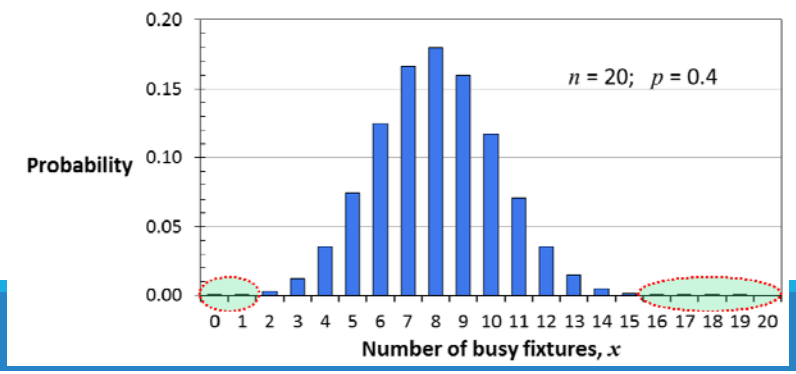


Normal Approximation

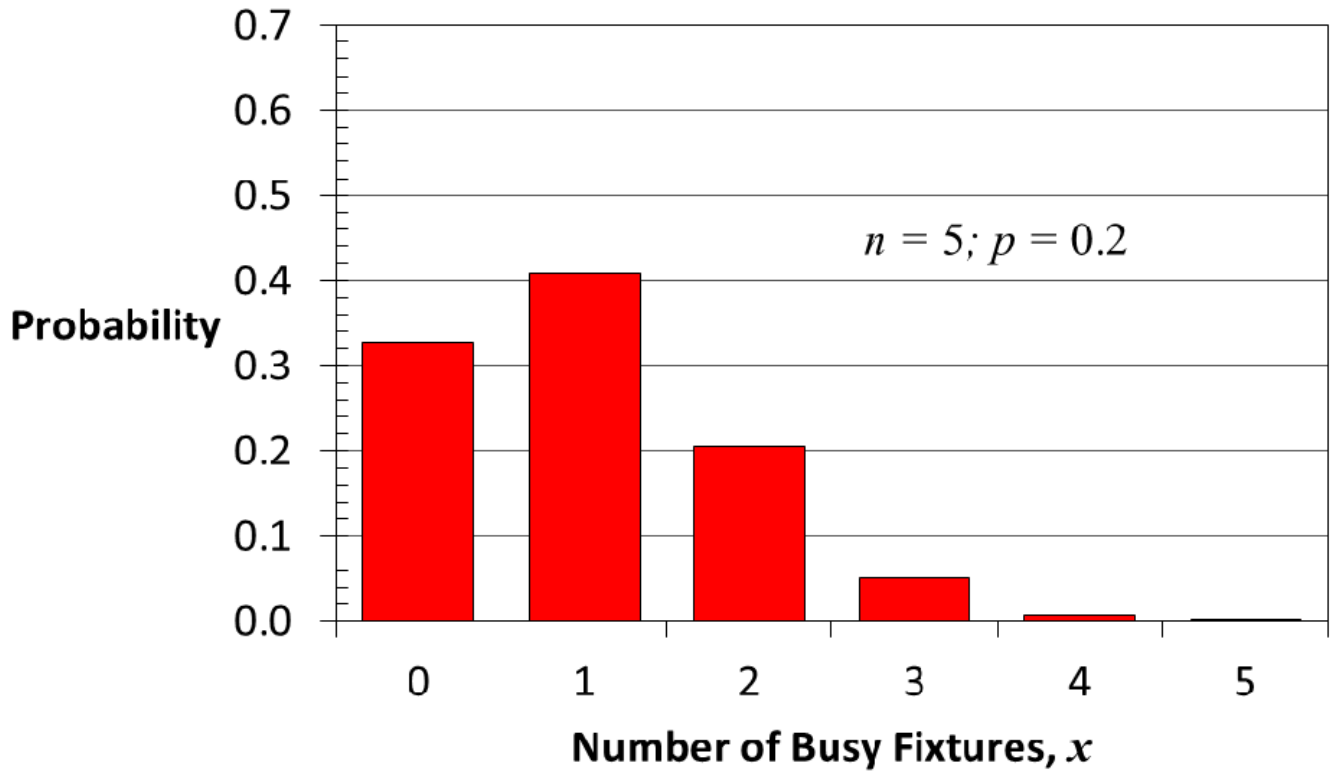
$$Q_{0.99} = \mu_q + (z_{0.99})\sigma_q$$

per Wistort (1995)

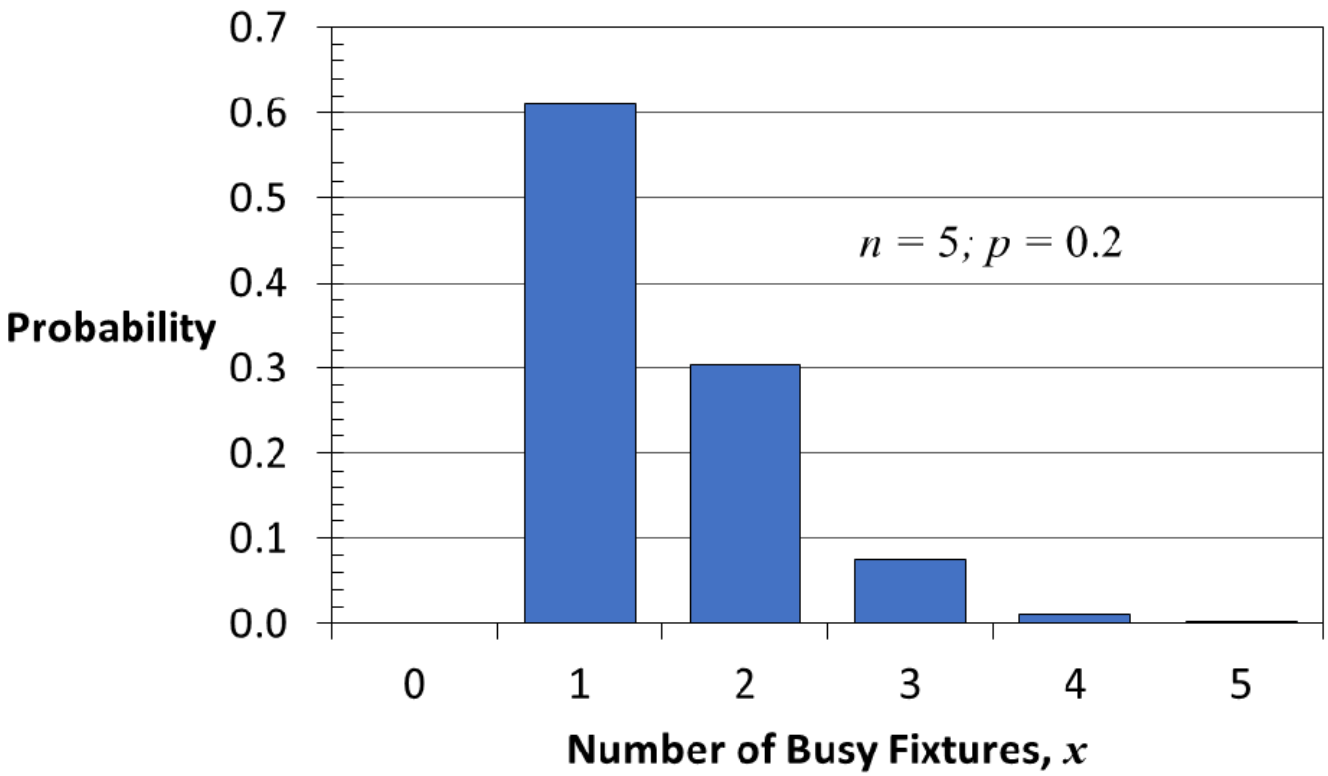
$$Q_{0.99} = \sum_{k=1}^{K} n_k p_k q_k + (z_{0.99})\sqrt{\sum_{k=1}^{K} n_k p_k (1 - p_k) q_k^2}$$



Binomial Distribution (small building)



Zero Truncated Binomial Distribution



Modified Wistort's Model

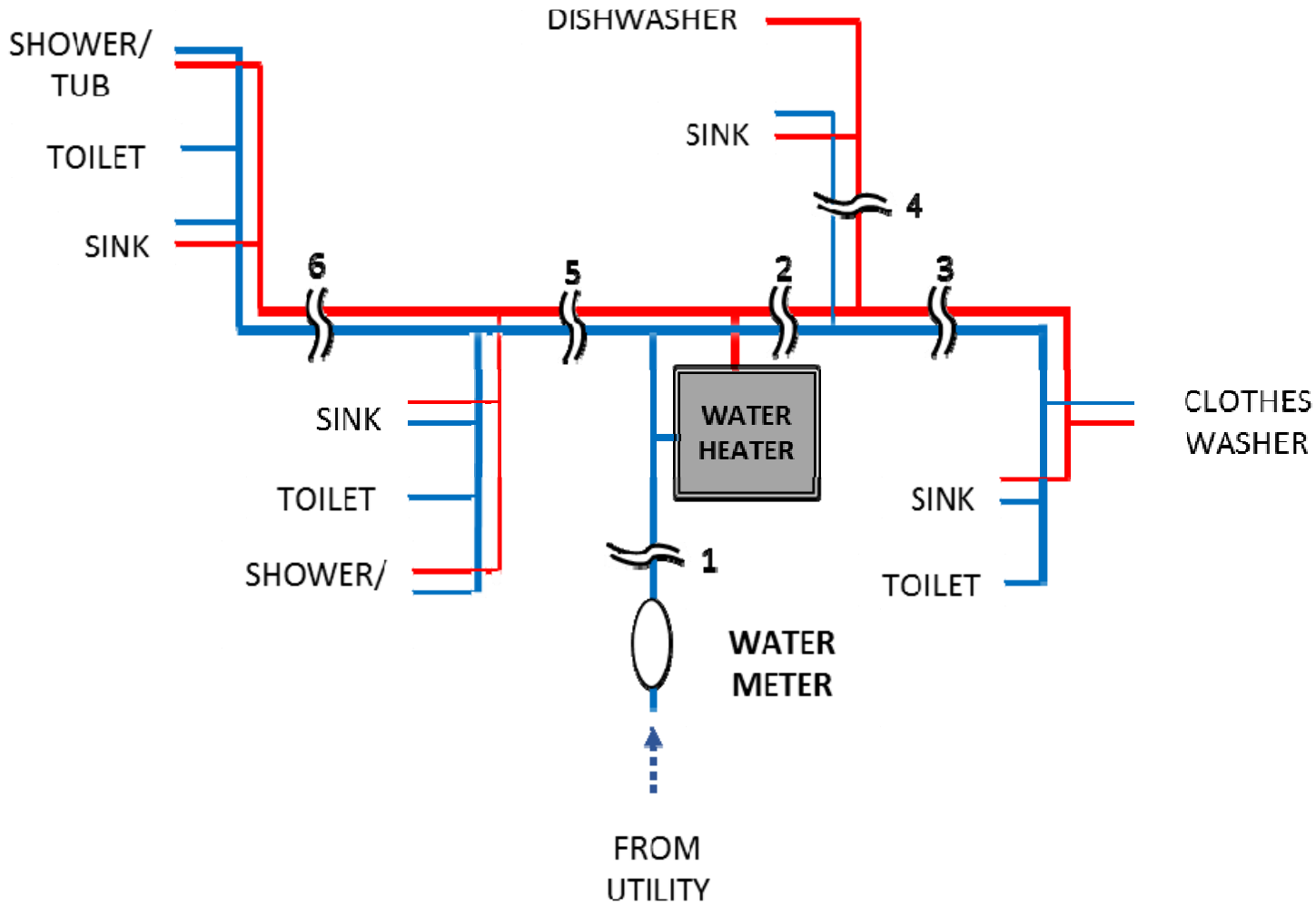
$$Q_{0.99} = \sum_{k=1}^{K} n_k p_k q_k + (z_{0.99}) \sqrt{\sum_{k=1}^{K} n_k p_k (1-p_k) q_k^2}$$

$$Q_{0.99} = \frac{1}{1-P_0} \left[\sum_{k=1}^{K} n_k p_k q_k + (z_{0.99}) \sqrt{\left[(1-P_0) \sum_{k=1}^{K} n_k p_k (1-p_k) q_k^2 \right] - P_0 \left(\sum_{k=1}^{K} n_k p_k q_k \right)^2} \right]$$

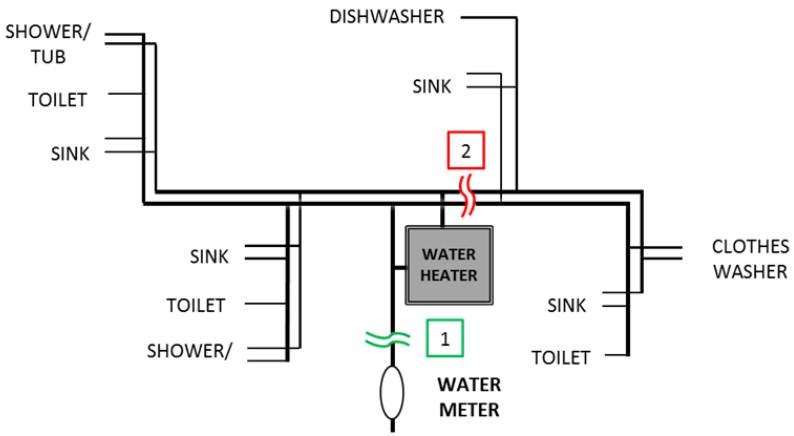
- Note:
  - $P_0 = \prod_{1}^{k} (1-p_k)^{n_k}$ is probability of stagnation in a home (i.e. no water use)
  - Addresses water demand in single family homes with high P_0
  - Transitions back to Wistort's model as P_0 approaches 0

[5] APPLICATION

Hypothetical Residential Building Pipe Layout



Peak Flow Calculations

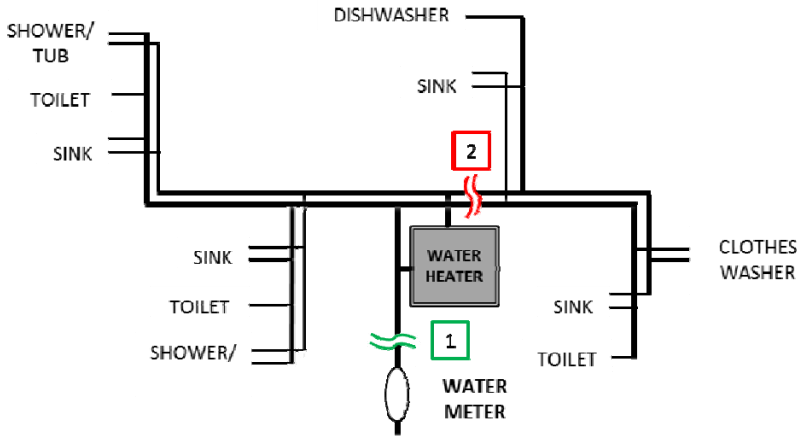


Example: 2.5 bath single family home

Section	UPC FU	UPC Method (gpm)	MW Method (gpm)
1	25.5	18.0	**11.8**
2	10.5	8.5	**6.9**

Sizing Pipes

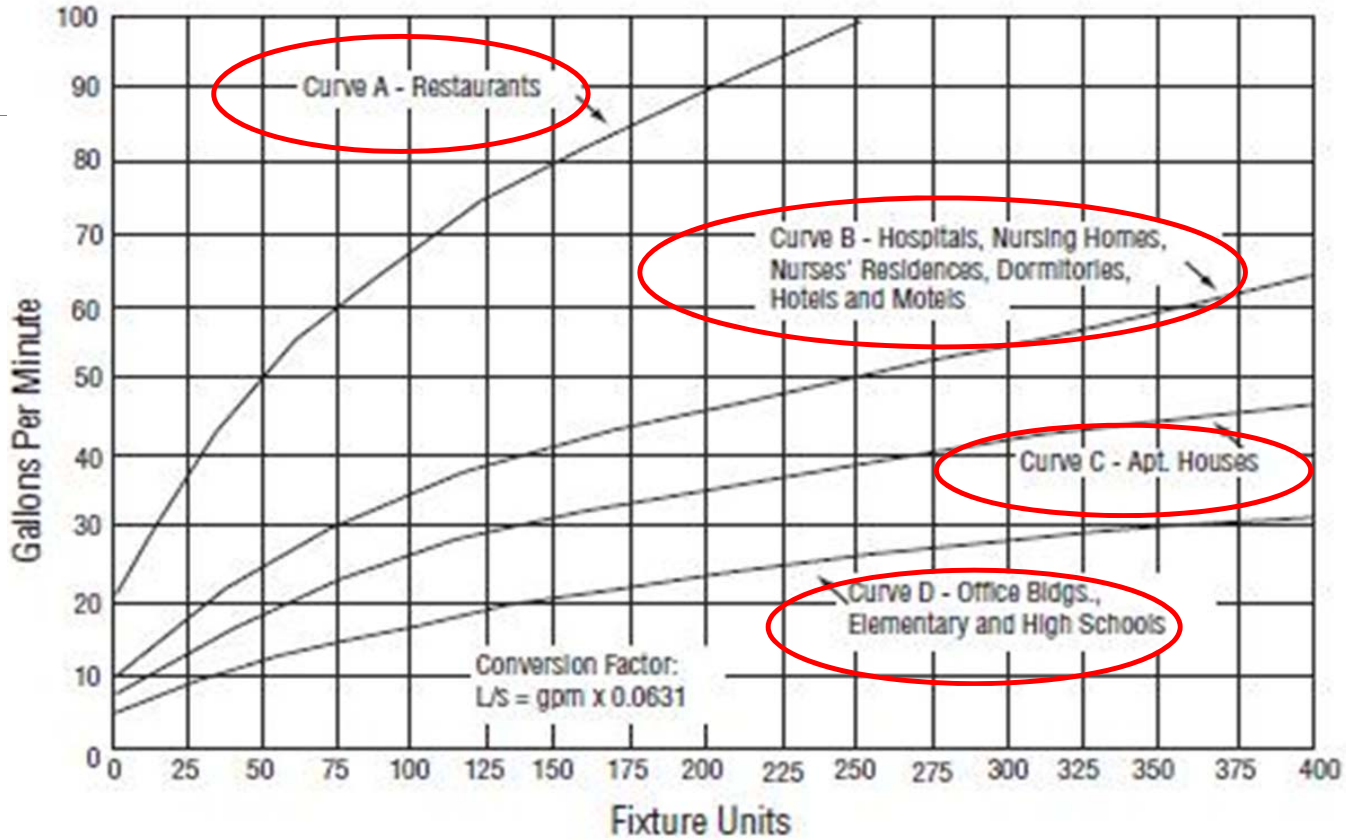
Example: 2.5 bath single family home



Section	UPC Method	Pipe Size*	MW Method	Pipe Size*
1	**18.0 gpm**	**1”**	**11.8 gpm**	**3/4"**
2	8.5 gpm	3/4"	6.9 gpm	3/4"

* Maximum flow rate at 8 f/s

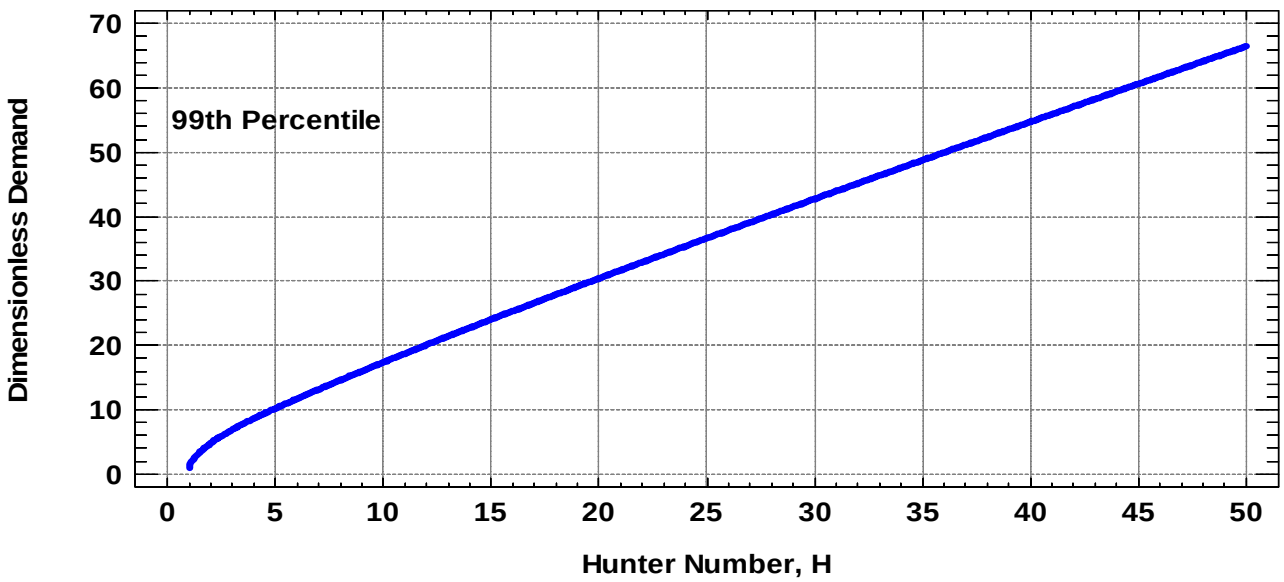
Modified Hunter's Curve(s)



Different curve for different end users

http://www.armstronginternational.com/files/products/wheaters/pdf/sizing%20chart.pdf

Universal Dimensionless Design Curve



Glimpse of the Future?

[6] CONCLUSION

Conclusion

- Introduced a new model to estimate peak water demand in single and multi-family dwellings.
- Replaced fixture units with fixture counts.
- Runs on a spreadsheet.
- Recommended fixture $\boldsymbol{p}$ and $\boldsymbol{q}$ values.
- Results are more sensitive to $\boldsymbol{q}$ than to $\boldsymbol{p}$.
- Can be applied to a wide spectrum of buildings.

Questions?

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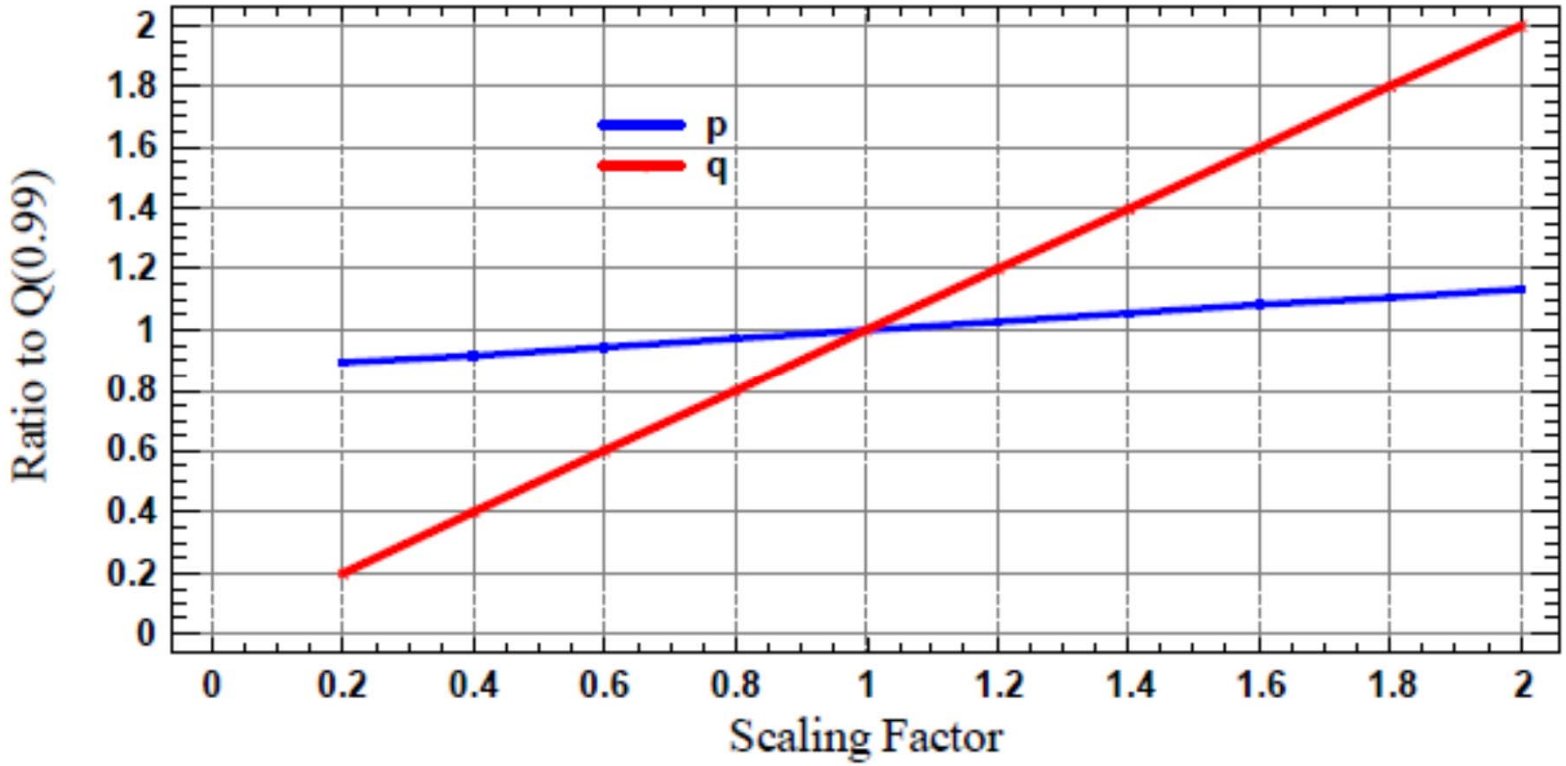
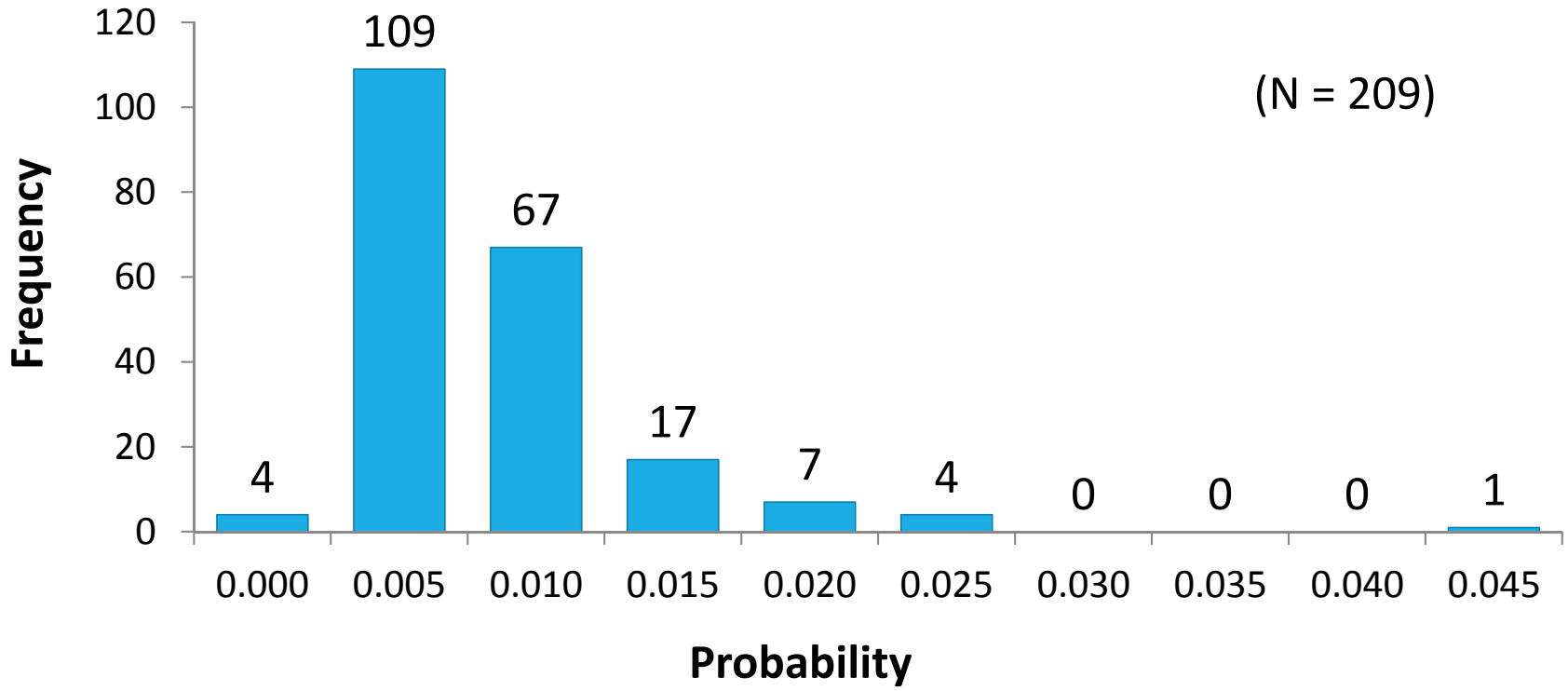
Demand Sensitivity to p and q values



Distribution of $\boldsymbol{p}$ values for home with 2 residents



Summary Probability of Fixture of Use

- Each fixture has a unique water use profile.
- Probability of fixture use depends on frequency and duration of use.
- Probability of fixture use increased as the number of residents increased.