Understanding the Application and Potential of the Water Demand Calculator

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EMERGING WATER TECHNOLOGY SYMPOSIUM

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Acknowledgments

- **IAPMO** – International Assoc of Plumbing & Mechanical Officials
- **ASPE** – American Society of Plumbing Engineers
- **WQA** – Water Quality Association
- **UC** – University of Cincinnati
- **NIST** – National Institute of Standards and Technology
- **NBS** – National Bureau of Standard (Dr. Roy Hunter, visionary)
- **IAPMO Task Group** Members (2012-2018):

Dan Cole, Tim Wolfe, Jason Hewitt, Toju Omaghomi

ACT I WDC HISTORY

ACT II WDC FUTURE

ACT III WDC Q/A

UNITED STATES DEPARTMENT OF COMMERCE · Jesse H. Jones, Secretary

NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

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*:** <u>Fixture</u> Count

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

***p*:** <u>Fixture</u> Probability of Use

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

***q*:** <u>Fixture</u> Flow Rate

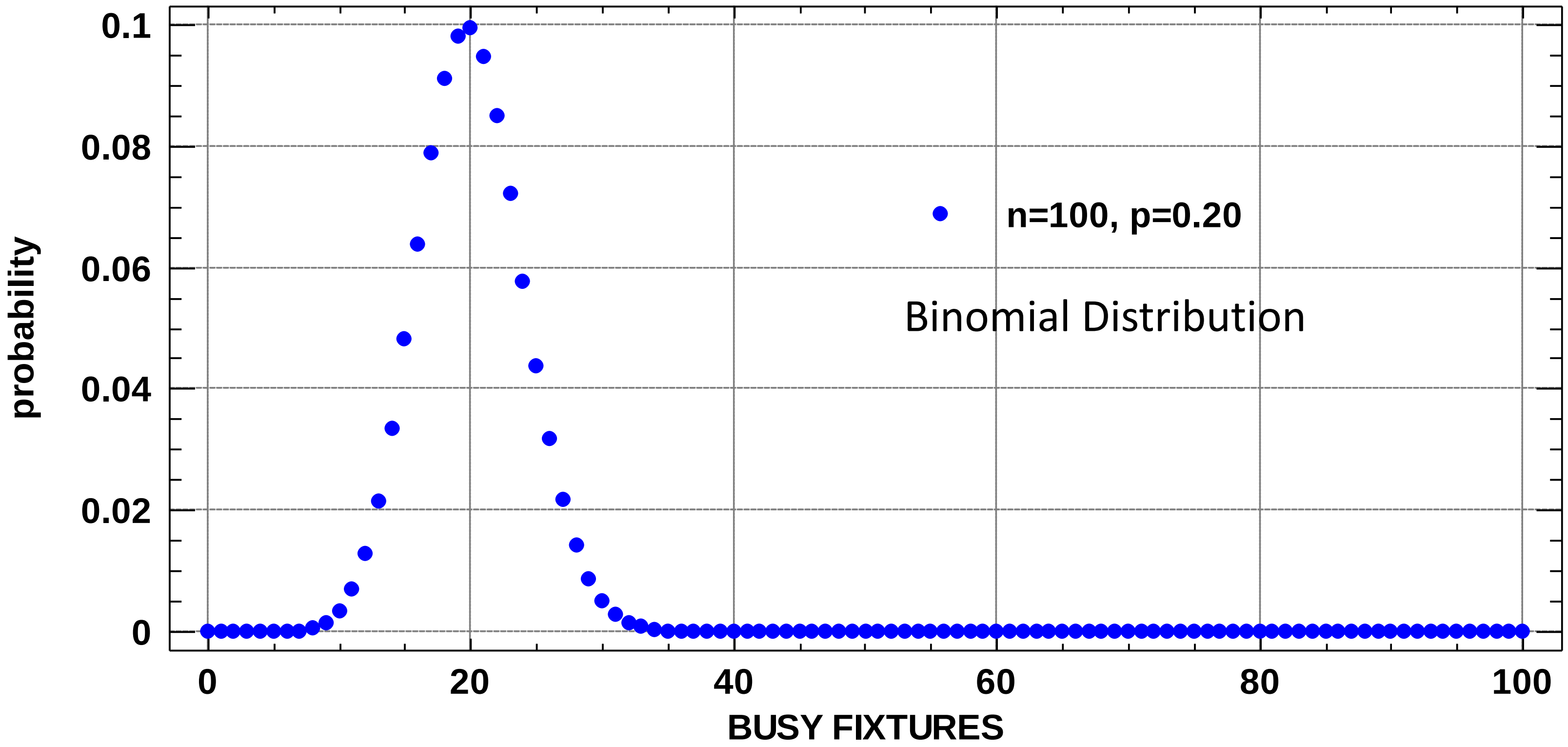
Hunter's Big Three (1940)

Dr. Roy Hunter

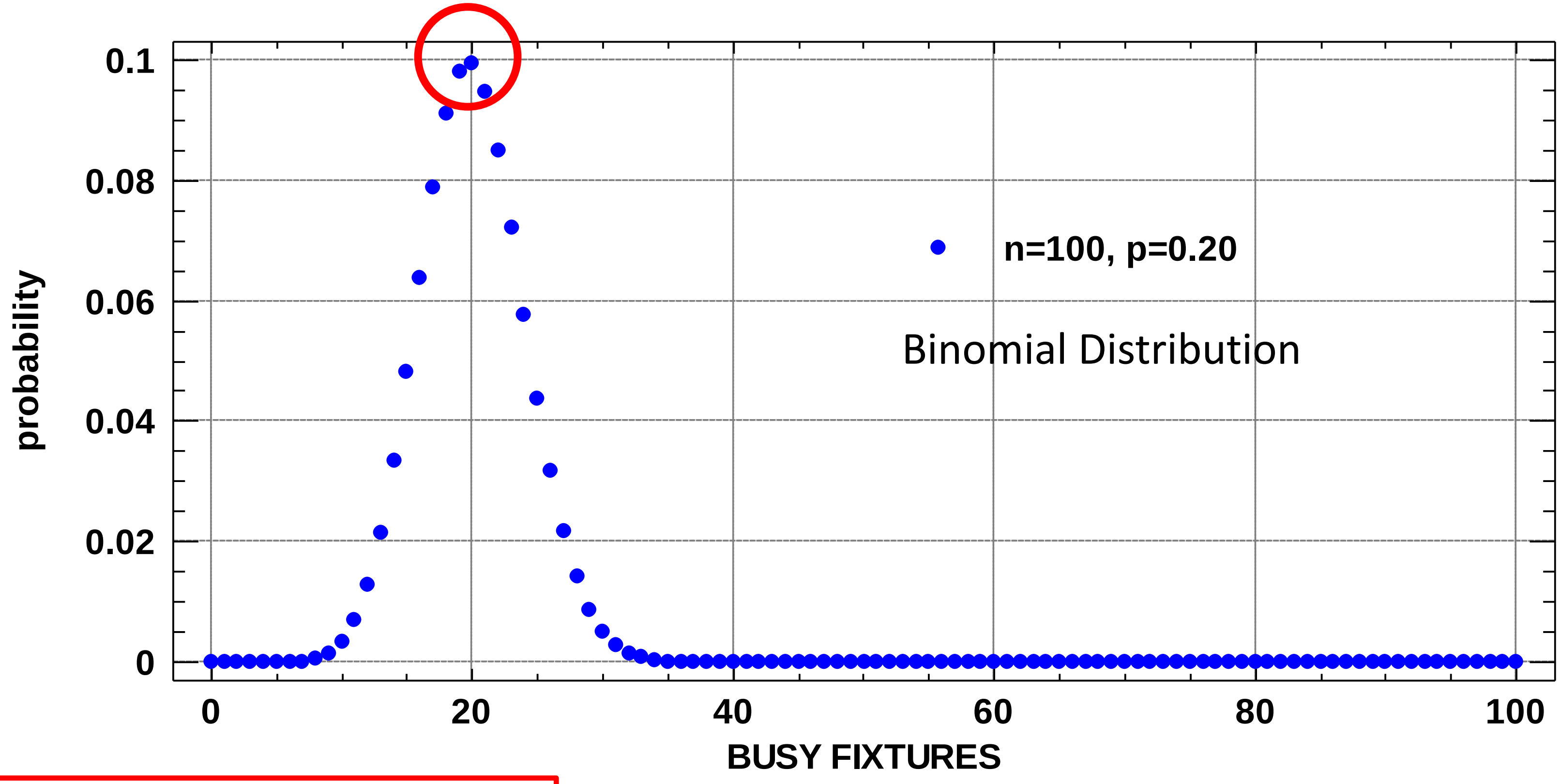
Flush Valve	Flush Tank	Bathtub
p = 0.030	***p*** = 0.200	***p*** = 0.067
q = 27 GPM	***q*** = 4 GPM	***q*** = 8 GPM
FU = 10	FU = 5	FU = 4

FU = "Fixture Unit"

Busy Fixtures in Building with n=100 Flush Tanks, p=0.20



Busy Fixtures in Building with n=100 Flush Tanks, p=0.20



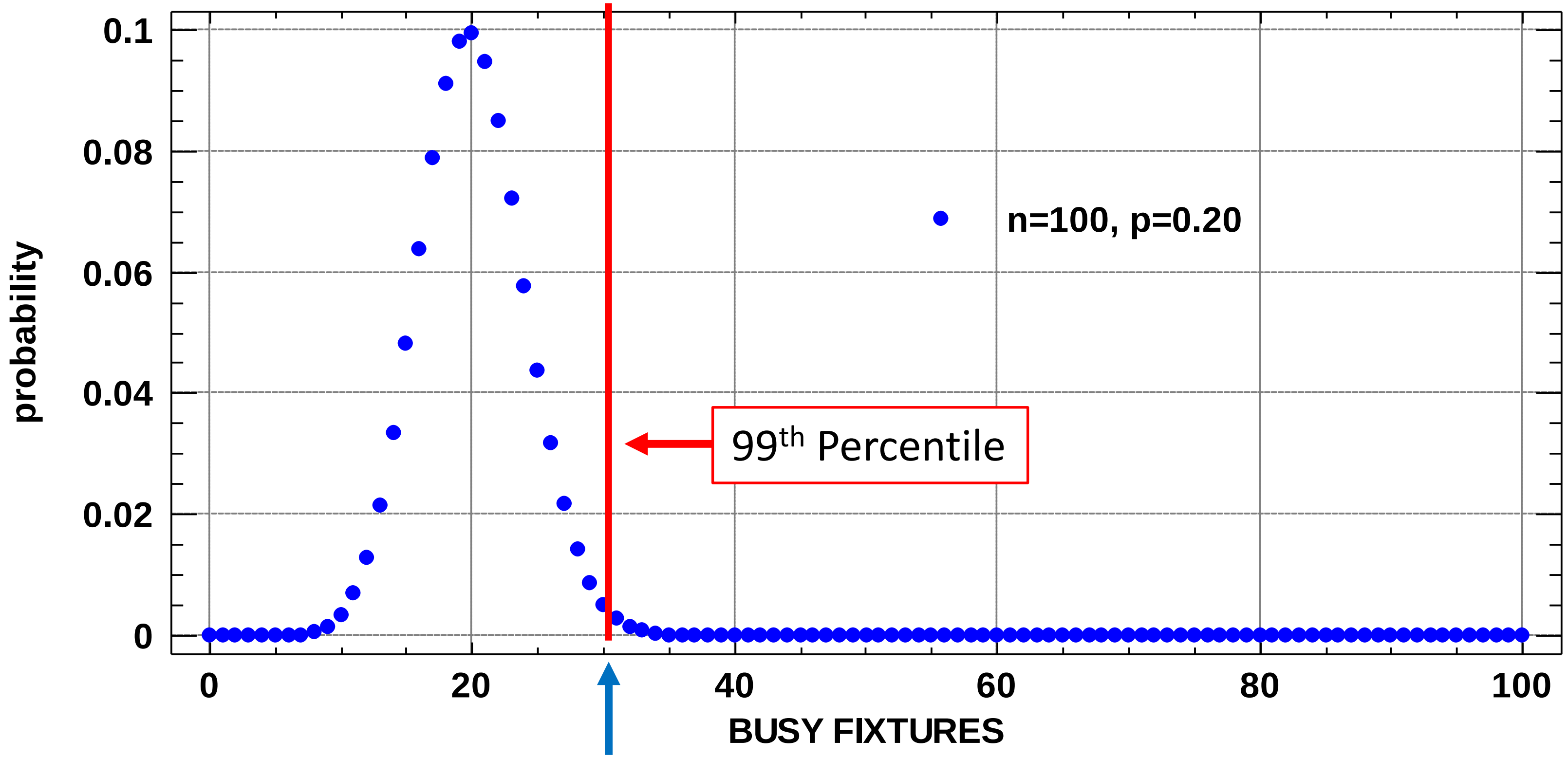
Hunter Number, H = np = 20

Dimensionless Hunter Number, **H**

Fixture Count:	$n = 100$
Probability of Use:	$p = 0.20$ (flush tank)
Hunter Number:	**$H = np = 20$**

H is "expected number" (average number) of fixtures in simultaneous use during the peak demand period.

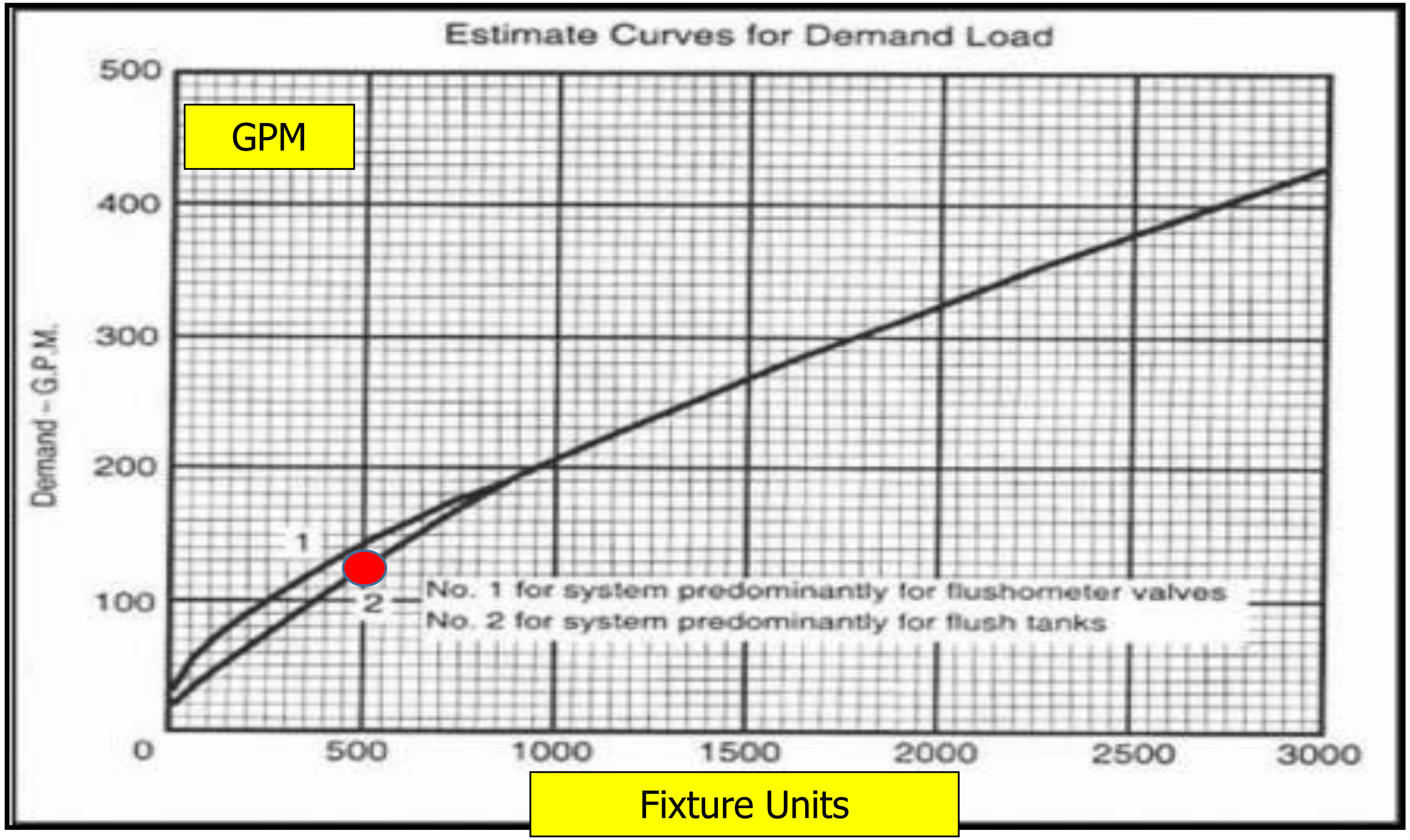
Hunter's Criterion: Design for 99th Percentile



30
simultaneous demands
(30 x 4 GPM = 120 GPM)

1 point on Hunter's Curve (n=100 flush tanks x 5 FU/flush tank = 500 FU)

Hunter's Curve Predicts Peak Flow (99th 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)

Main Issues

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.

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)

IAPMO Task Group Orders

International Association of Plumbing and Mechanical Officials

"....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

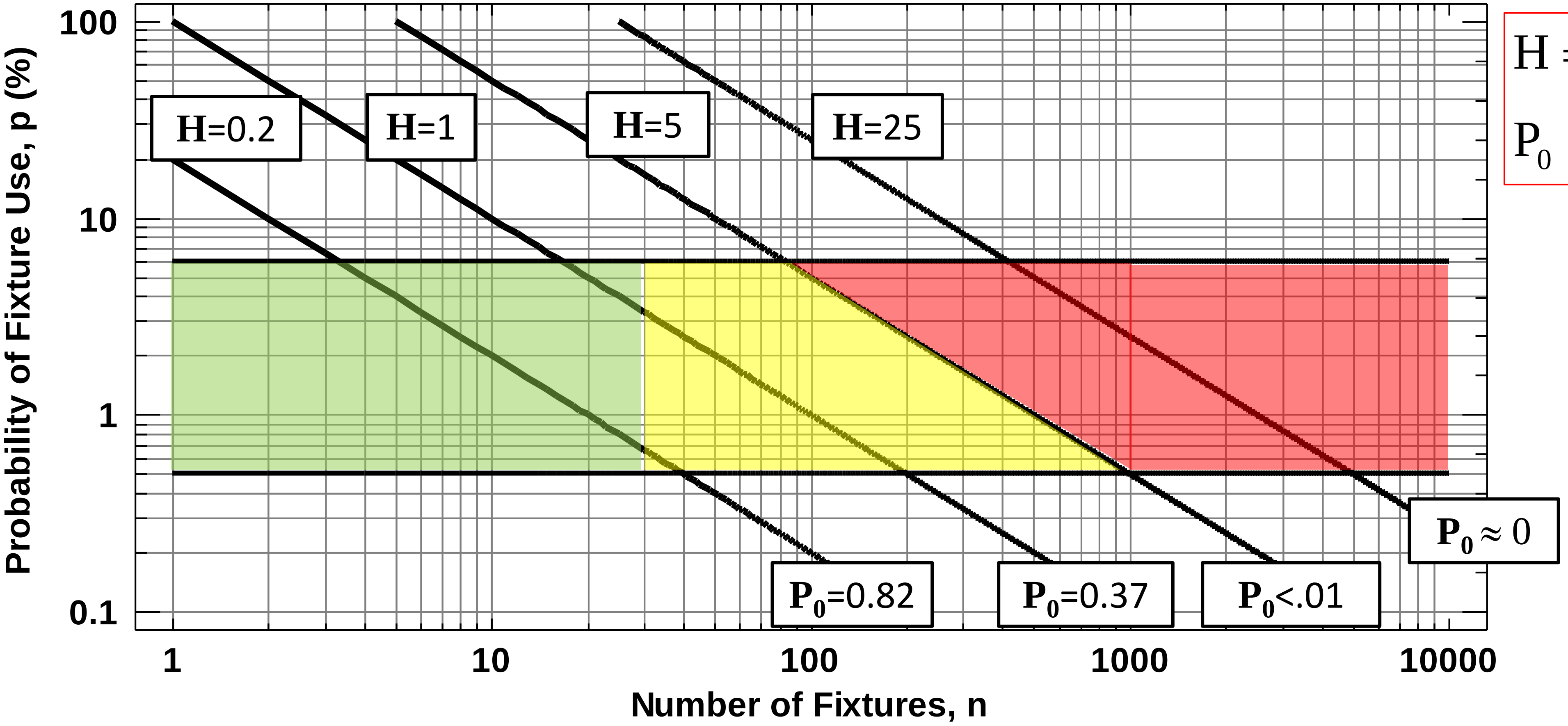
- 11,350 home-days
- 863,000 events

New *p*'s and *q*'s for Residential Buildings

Recommended **_p_** and **_q_** values: water conserving fixtures during peak hour of use. (IAPMO 2017)

Plumbing Fixture	Probability (p) (percent)	Flow Rate (q) (gpm)	Hunter (1940)
Bathtub	1.0	5.5	p = 6.7% q = 8 gpm
Clothes Washer	**5.5**	3.5	
Dishwasher	**0.5**	1.3	
Faucet	2.0	1.5 – 2.2	
Shower	4.5	2.0	
Toilet (flush tank)	1.0	3.0	p = 20% q = 4 gpm

(n,p) Diagram for Residential Buildings



$$H = \sum np$$

$$P_0 = \exp(-H)$$

Table 4-2 from AWWA M22 4th Edition, expected late 2022

Table 4-2. Methods to estimate peak demands in residential buildings with efficient fixtures.

Region in Figure 4-10	Building Size	Algorithm in Water Demand Calculator	Boundary Criteria	Probability of Peak Period Stagnation, P_0
Green 🟢	Small	Exhaustive Enumeration (ExEn)	$n \leq 30$	Very High
Yellow 🟡	Medium	Modified Wistort Method (MWM)	$n > 30$ $\mathbf{H} < 5$	Moderate
Red 🔴	Large	Wistort Method (WM)	$\mathbf{H} \geq 5$	Very Low

What is the Water Demand Calculator?

- **WDC** is a free downloadable EXCEL spreadsheet
- **WDC** resides on the IAPMO website
- **WDC** is part of the 2021 Uniform Plumbing Code
- **WDC** computes peak indoor water demands for residential buildings with efficient fixtures
- **WDC** is an e-version of “updated” Hunter’s Curve

Water Demand Calculator: Basic Template

Water Demand Calculator (WDC v2.0)

PROJECT NAME : - - - - -

Click for Drop-down Menu → **Single-Family Residence**

Wednesday, July 29, 2020
2:07 AM

FIXTURE GROUPS		FIXTURE	n	p	q	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	1.00	5.5	5.5
	2	Bidet	0	1.00	2.0	2.0
	3	Combination Bath/Shower	0	5.50	5.5	5.5
	4	Faucet, Lavatory	0	2.00	1.5	1.5
	5	Shower, per head (no Bathtub)	0	4.50	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	0	1.00	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.50	1.3	1.3
	8	Faucet, Kitchen Sink	0	2.00	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	0	5.50	3.5	3.5
	10	Faucet, Laundry	0	2.00	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	2.00	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.00	0.0	6.0
	13	Fixture 2	0	0.00	0.0	6.0
	14	Fixture 3	0	0.00	0.0	6.0

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS

Total No. of Fixtures in Calculation

99th Percentile Demand Flow

Hunter Number

Stagnation Probability

DOWNLOAD RESULT | **RESET WDC** | ↓ Select Units for Water Demand ↓ **GPM** **LPM** **LPS** | **RUN WDC** | ← CLICK BUTTON ←

Water Demand Calculator: "Red Zone", n=1200

Water Demand Calculator (WDC v2.0)

PROJECT NAME : Webinar Demo
Click for Drop-down Menu → Multi-Family Building

Total Number of Apartments in the Building→ 100
Total Apartments in this Calculation→ 100

Wednesday, July 29, 2020
2:22 AM

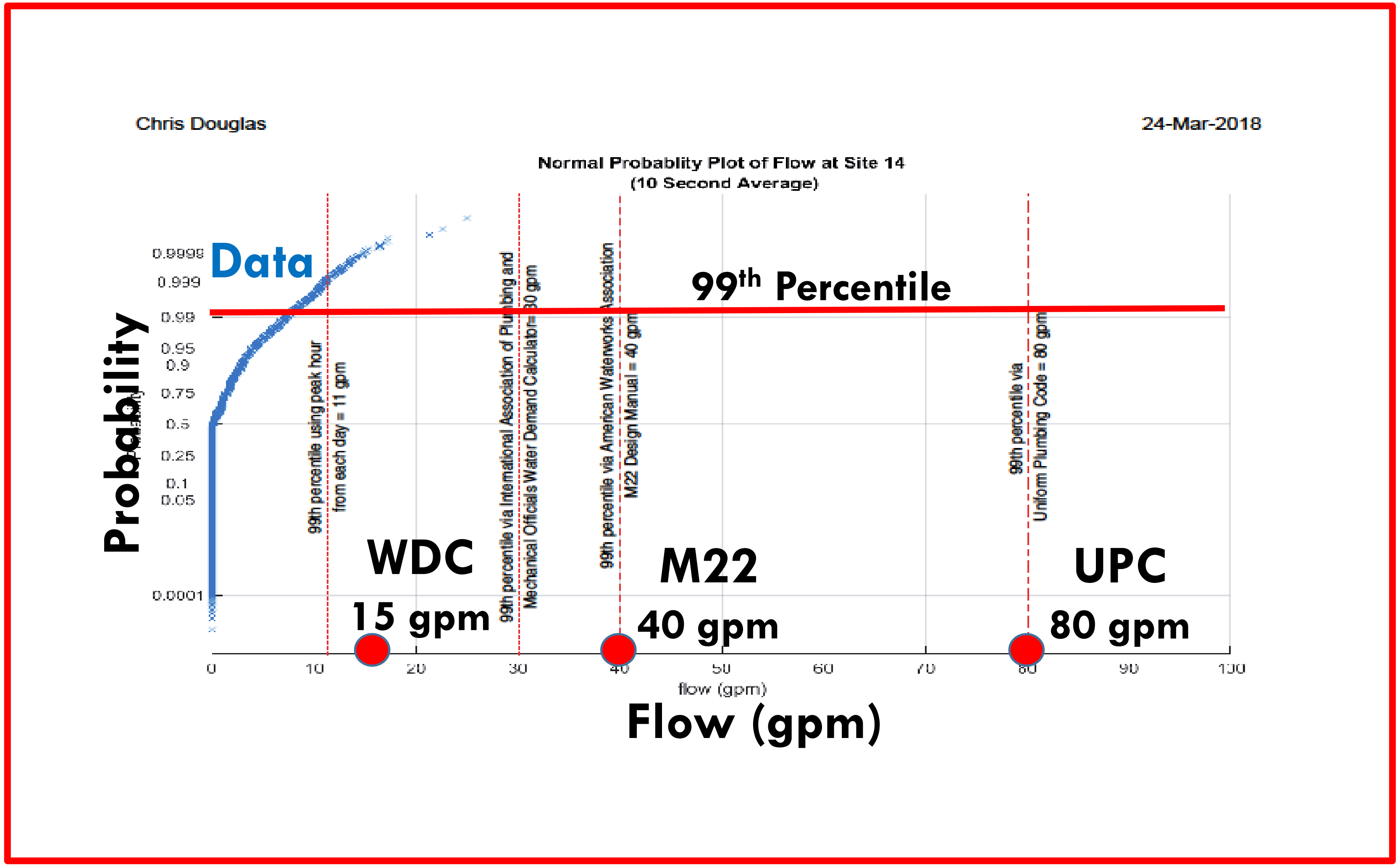
FIXTURE GROUPS		FIXTURE	n	p	q	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	0.38	5.5	5.5
	2	Bidet	0	0.54	2.0	2.0
	3	Combination Bath/Shower	200	1.39	5.5	5.5
	4	Faucet, Lavatory	300	1.10	1.5	1.5
	5	Shower, per head (no Bathtub)	0	0.93	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	300	0.54	3.0	3.0
Kitchen Fixtures	7	Dishwasher	100	0.32	1.3	1.3
	8	Faucet, Kitchen Sink	100	1.10	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	100	1.31	3.5	3.5
	10	Faucet, Laundry	100	1.10	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	1.10	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.00	0.0	6.0
	13	Fixture 2	0	0.00	0.0	6.0
	14	Fixture 3	0	0.00	0.0	6.0

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS
Total No. of Fixtures in Calculation
n = 1,200
99th Percentile Demand Flow
Q = 61.3 GPM
Hunter Number
H(n,p) = 12
Stagnation Probability
Pr[Zero Demand] = 0%

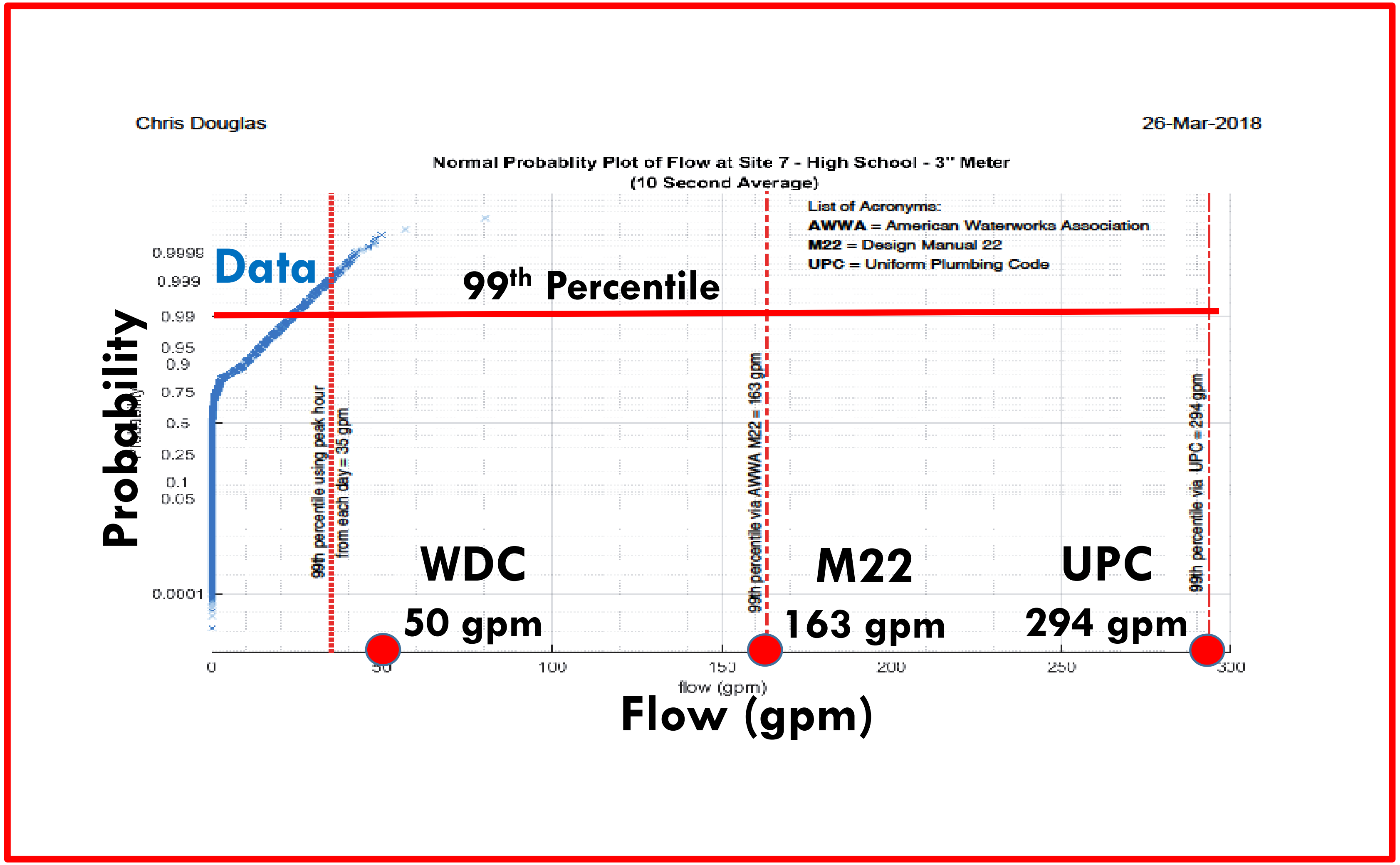
DOWNLOAD RESULT | RESET WDC | ↓ Select Units for Water Demand ↓ GPM | LPM | LPS | RUN WDC

UPC gives 388 GPM → 5" service line
WDC gives 62 GPM → 2" service line
84% reduction in peak flow

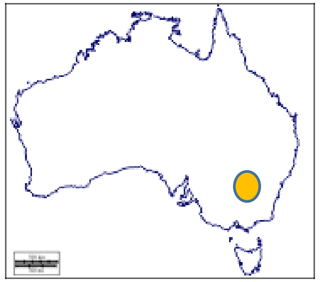
Design Flow Comparison: Apartments (site 14)

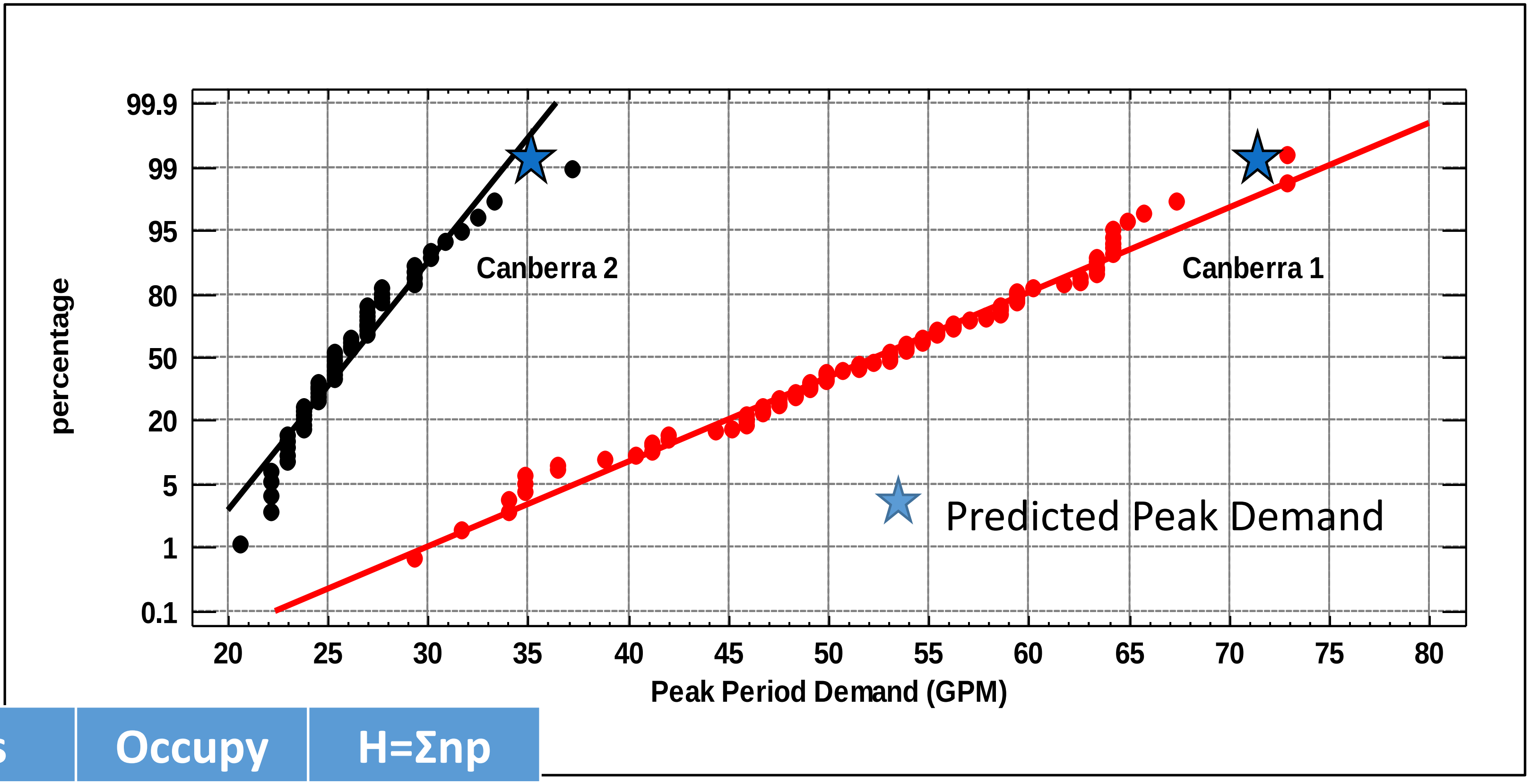


Design Flow Comparison: School (site 7)



Field Verification of WDC at New Residential Buildings in Canberra (2019-2020)





Site	Days	Apts	Occupy	H=Σnp
1	92	330	>95%	21
2	57	115	>95%	8

ACT I WDC HISTORY

ACT II WDC FUTURE

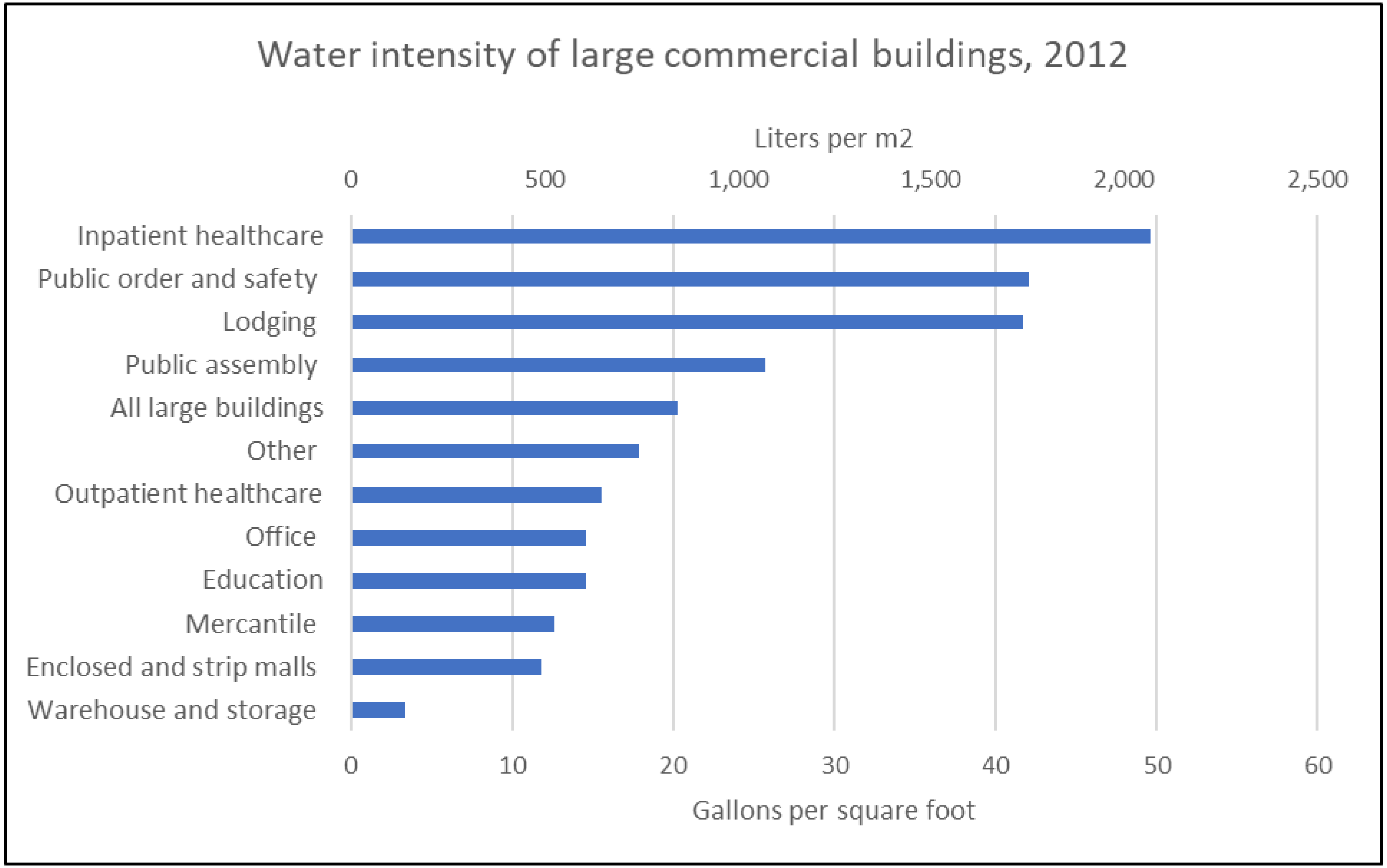
ACT III WDC Q/A

NIST Project: Extend WDC to Nonresidential


Research Questions (in search of "$\boldsymbol{p}$")

1. <u>What</u> types of buildings do we sample?
2. <u>Where</u> do we sample these buildings?
3. <u>How many</u> buildings do we sample?
4. <u>How</u> do we sample the selected buildings?

Research Question 1: What Buildings to Sample?



Building Types:

1. Education
2. Food Sales/Services
3. Healthcare
4. Lodging
5. Office
6. Mercantile
7. Public Assembly
8. Public Order and Safety
9. Religious Worship
10. Service
11. Warehouse and Storage
12. Other

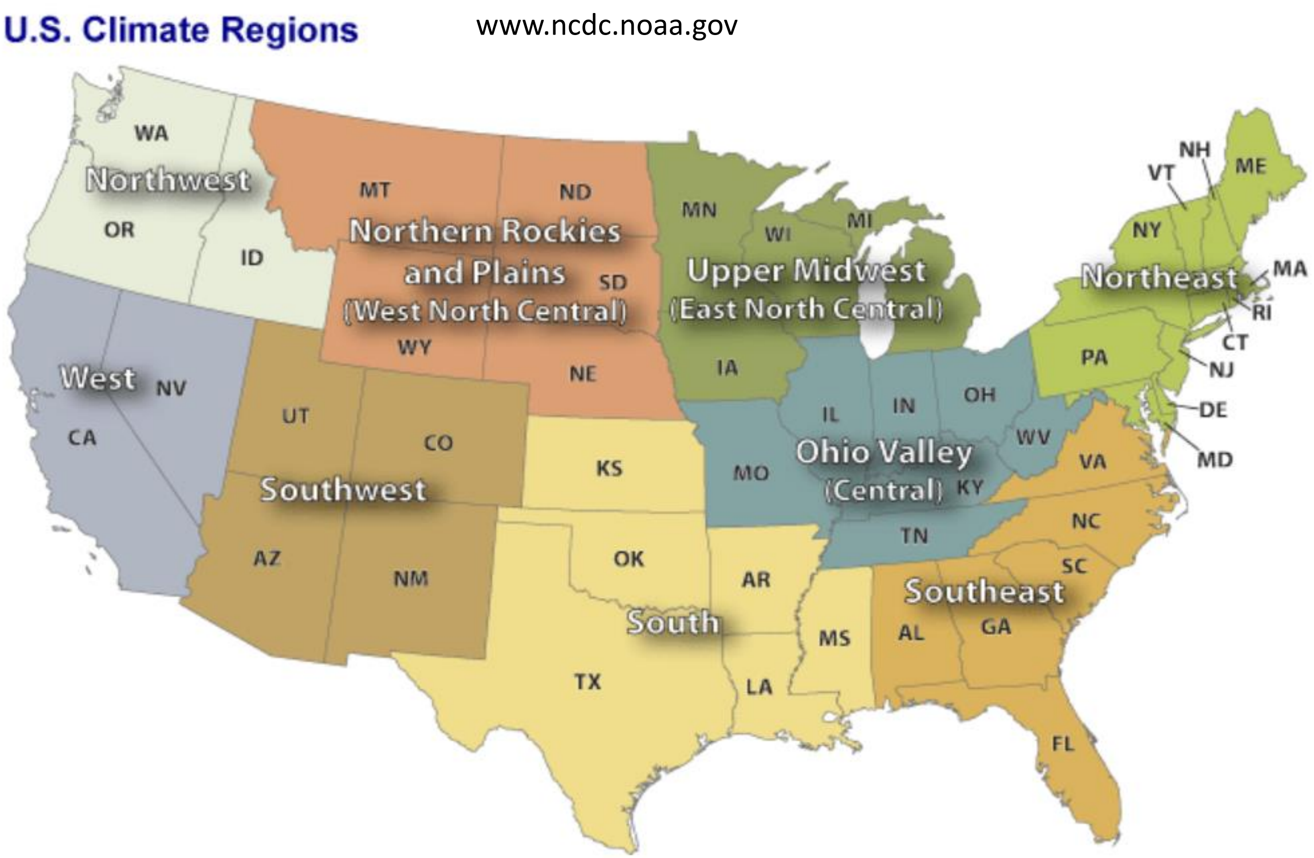
Hospitals, public order (prisons) and hotels have the largest annual water use per unit area among commercial buildings in the United States. *Source: Lewis 2017 (Energy Information Administration-CBECS)*

Research Question 2: Where to Sample?

Does indoor water use in commercial buildings vary by region, by season or by climate?

We hypothesize: **"No"**

(*i.e.*, Indoor water use does <u>not</u> vary by region, season or climate)



Research Question 3: Number of Buildings to Sample?

How many buildings (or **fixtures**) need to be sampled to compile a representative national data set?

$$n = \left(\frac{z}{e}\right)^2 p\,(1 - p)$$

n - *sample size*

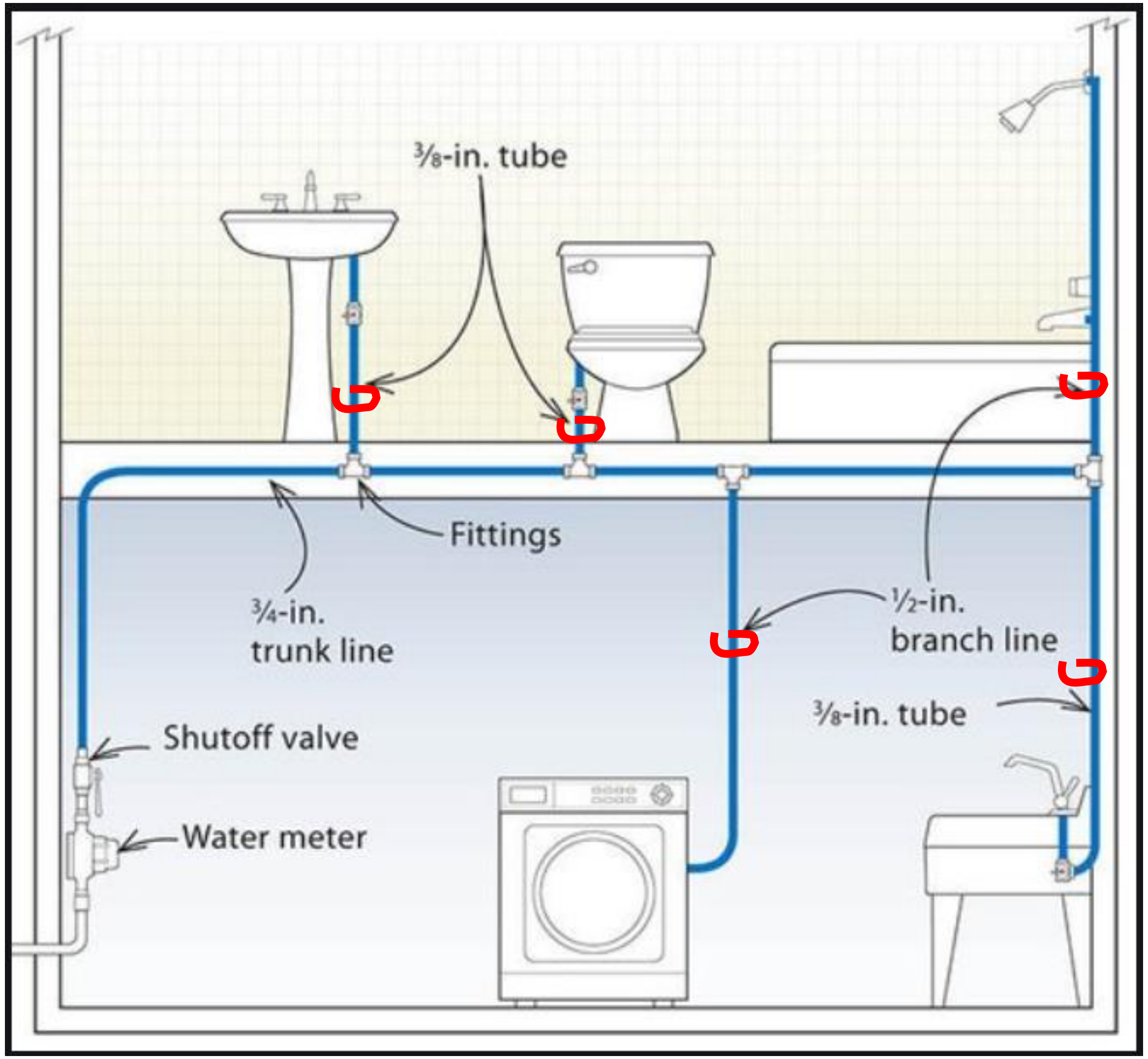
p - *fixture p-value*

z - *standard normal deviate*

e - *margin of error*

Reference: Cochran, W. G. (1977). Sampling techniques (3rd ed.). New York: John Wiley & Sons.

Research Question 4: How to Collect the Sample?



Wireless Sensor Network

- Select buildings to be surveyed
- Develop water sampling protocol
- Install sensors for sampling
- Collect, store, analyze data

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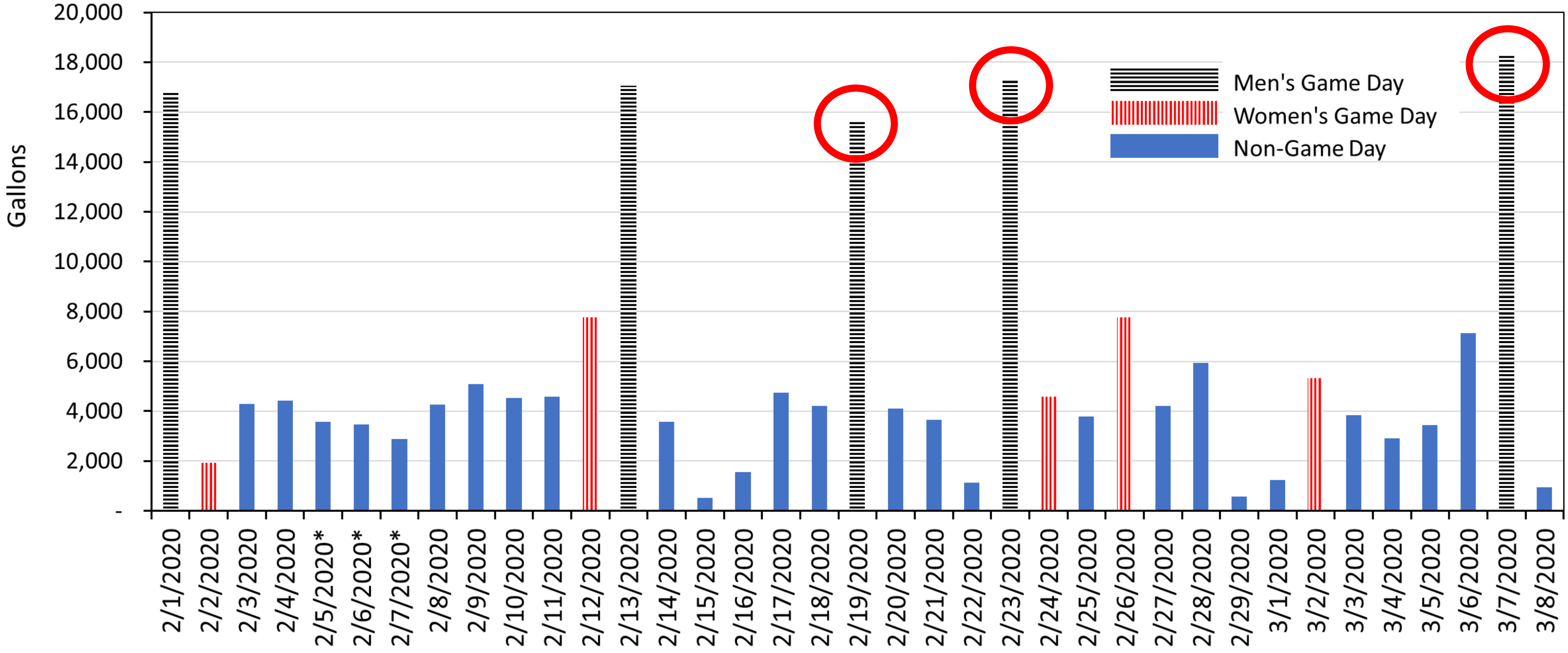
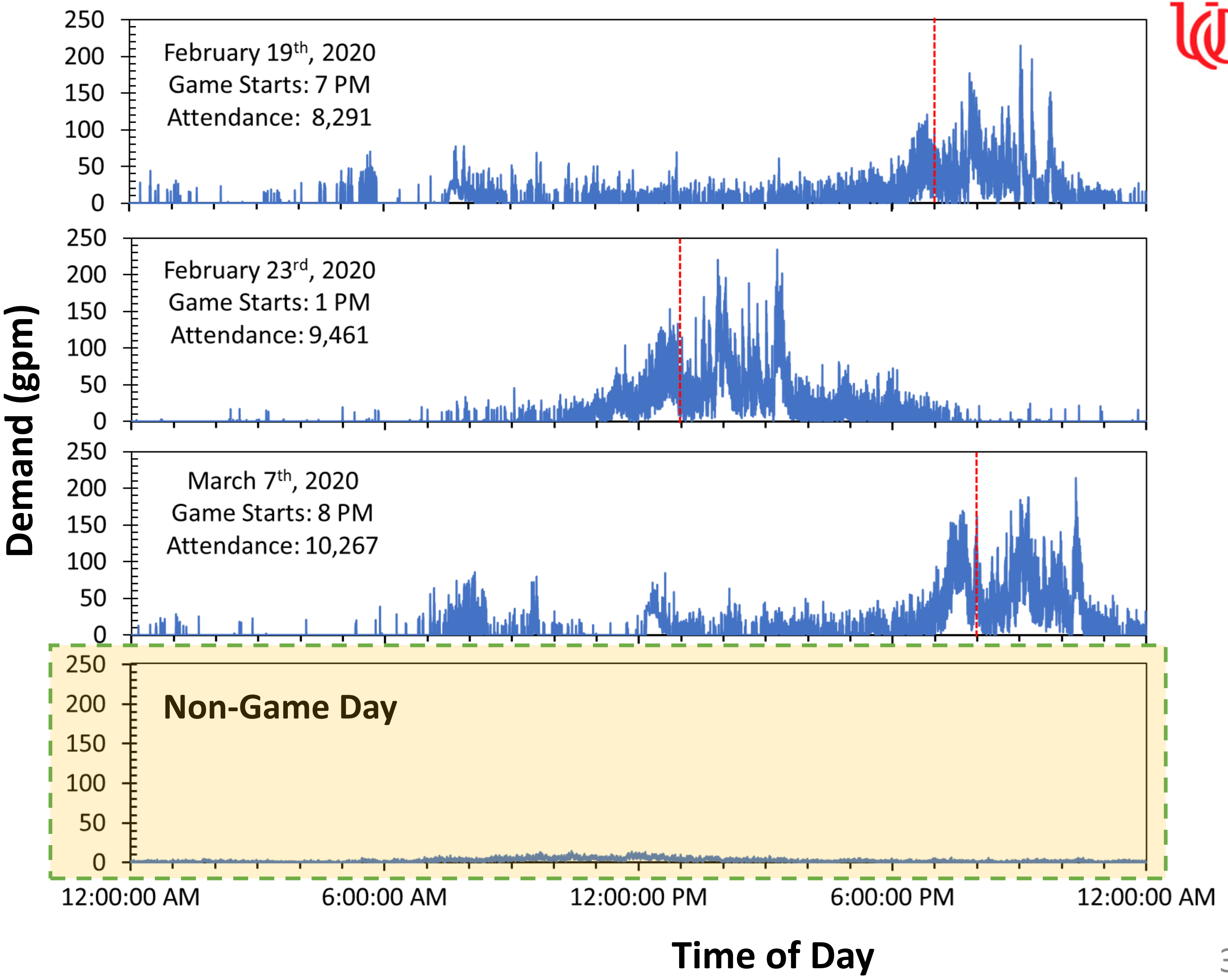
Daily Water Consumption at 5/3rd Arena
University of Cincinnati



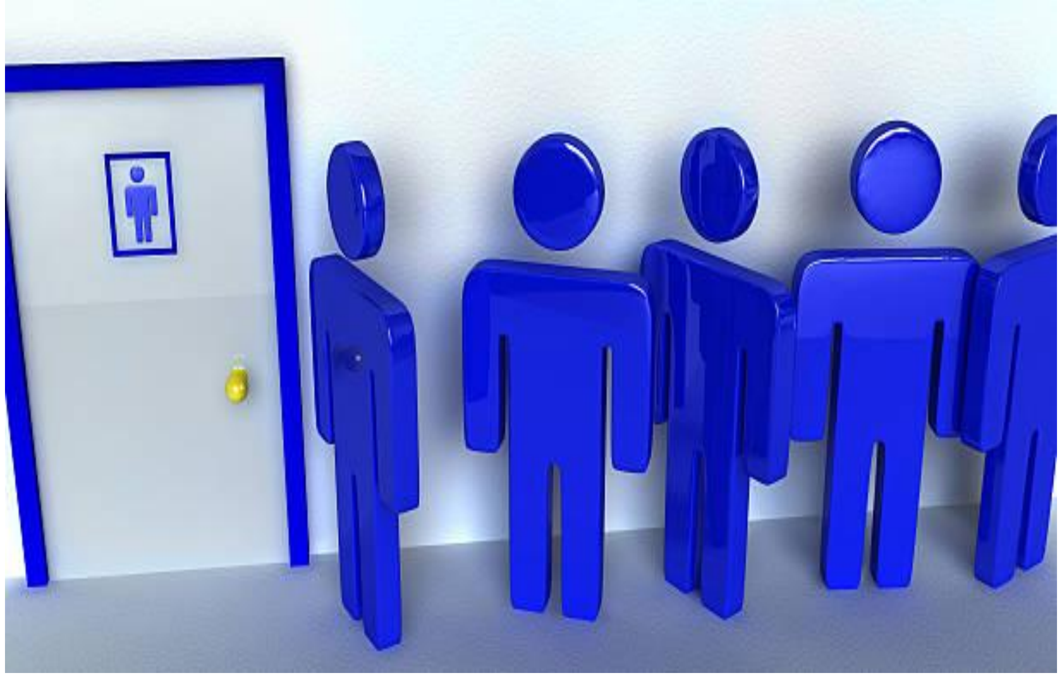
* Incomplete flow readings

3 Game Days Water Demand @5/3rd Arena University of Cincinnati



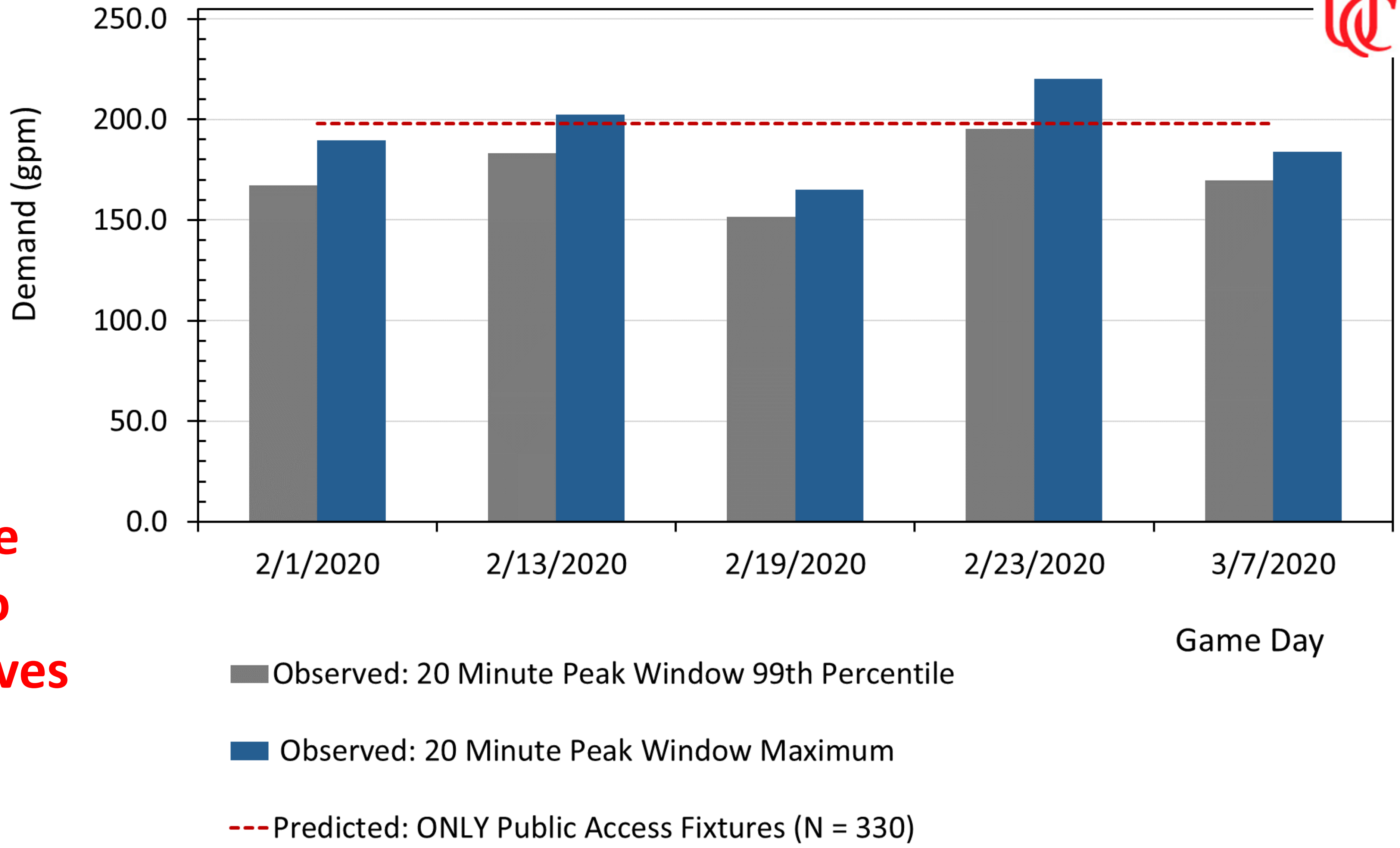
Probability of Fixture Use During "Congestion"

$$p = \left(\frac{N}{n}\right)\left(\frac{V/q}{T}\right)a$$



- N = Number of people exiting restroom
- n = Number of fixtures in restroom
- T = Observation period (minutes)
- V = Volume of flow per water use event (gal)
- q = Fixture flow rate (gpm)
- a = Percentage of people activating the fixture

5/3rd Arena: Predicted Peak Demand

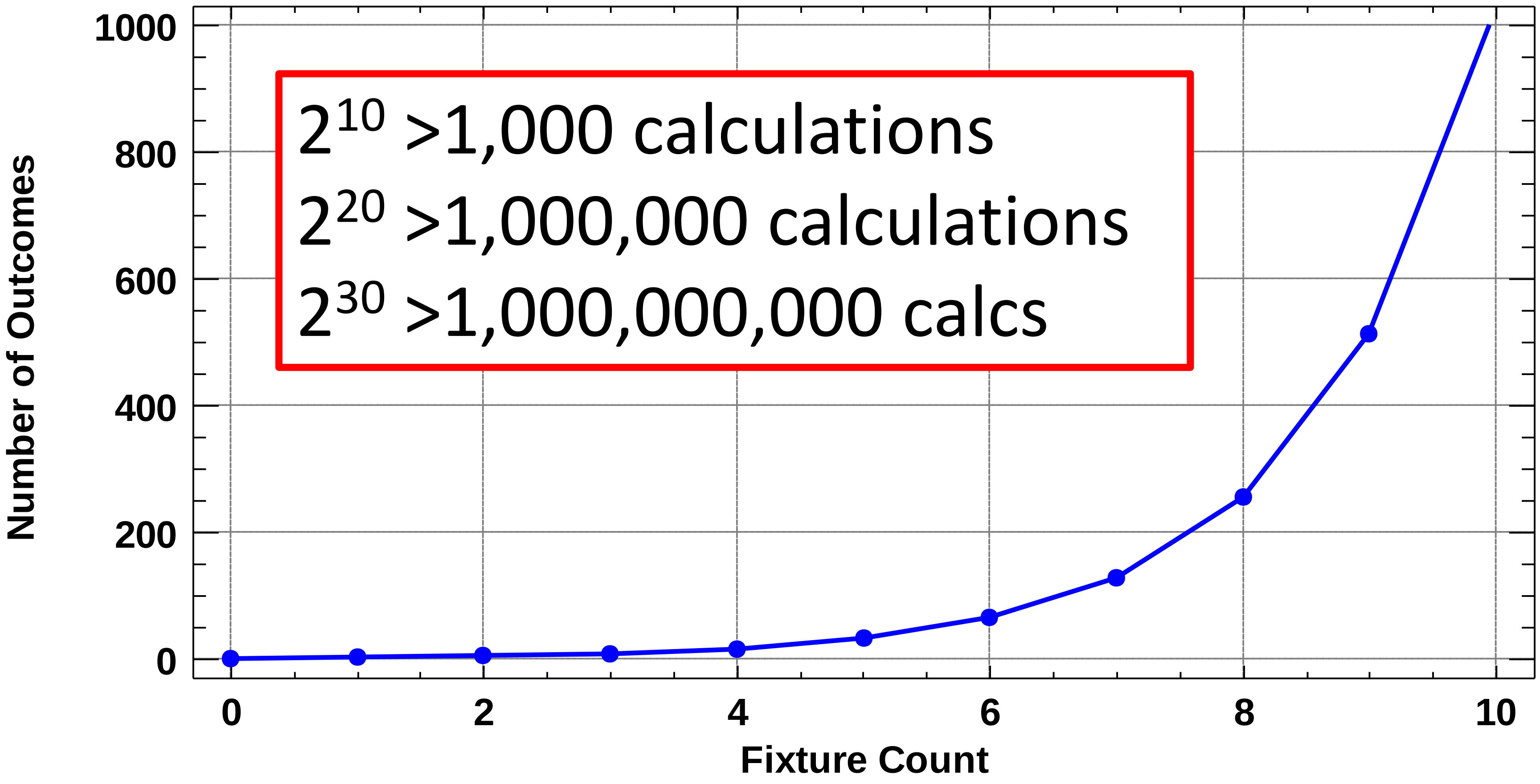


"Red Zone" example w/ p-values close to Hunter for flush valves

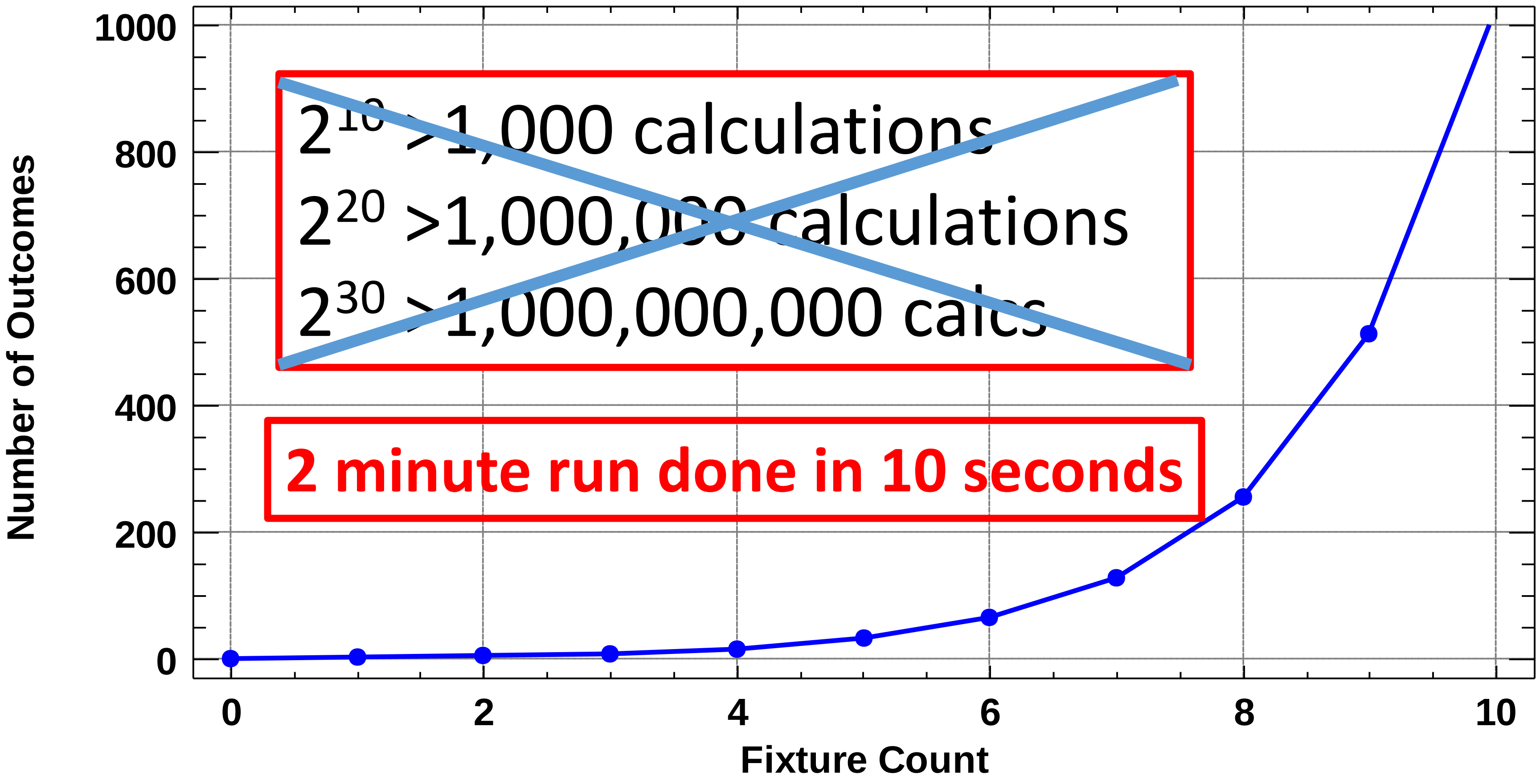
Wistort's Equation

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

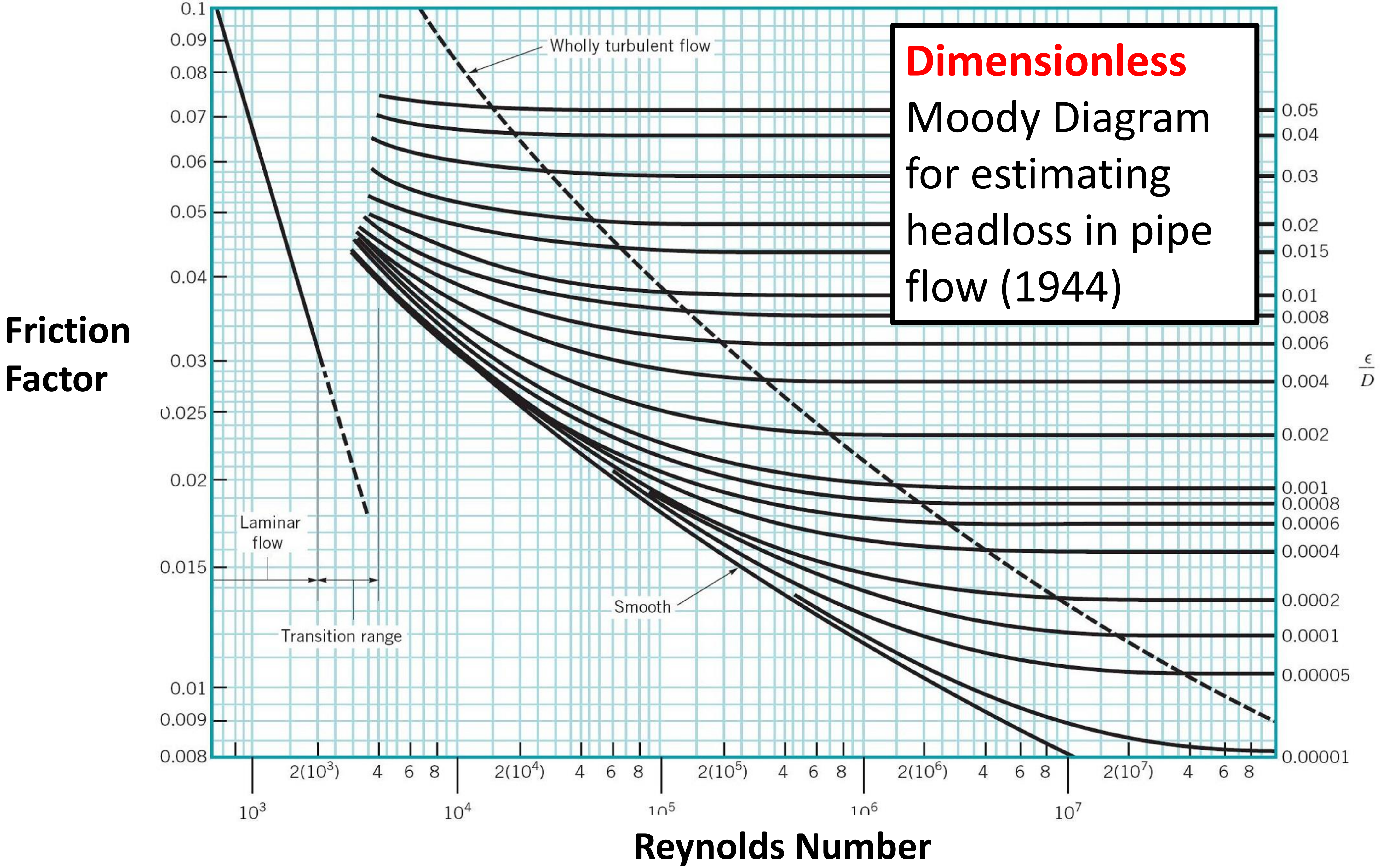
Green Zone: Exhaustive Enumeration Grows as 2^n



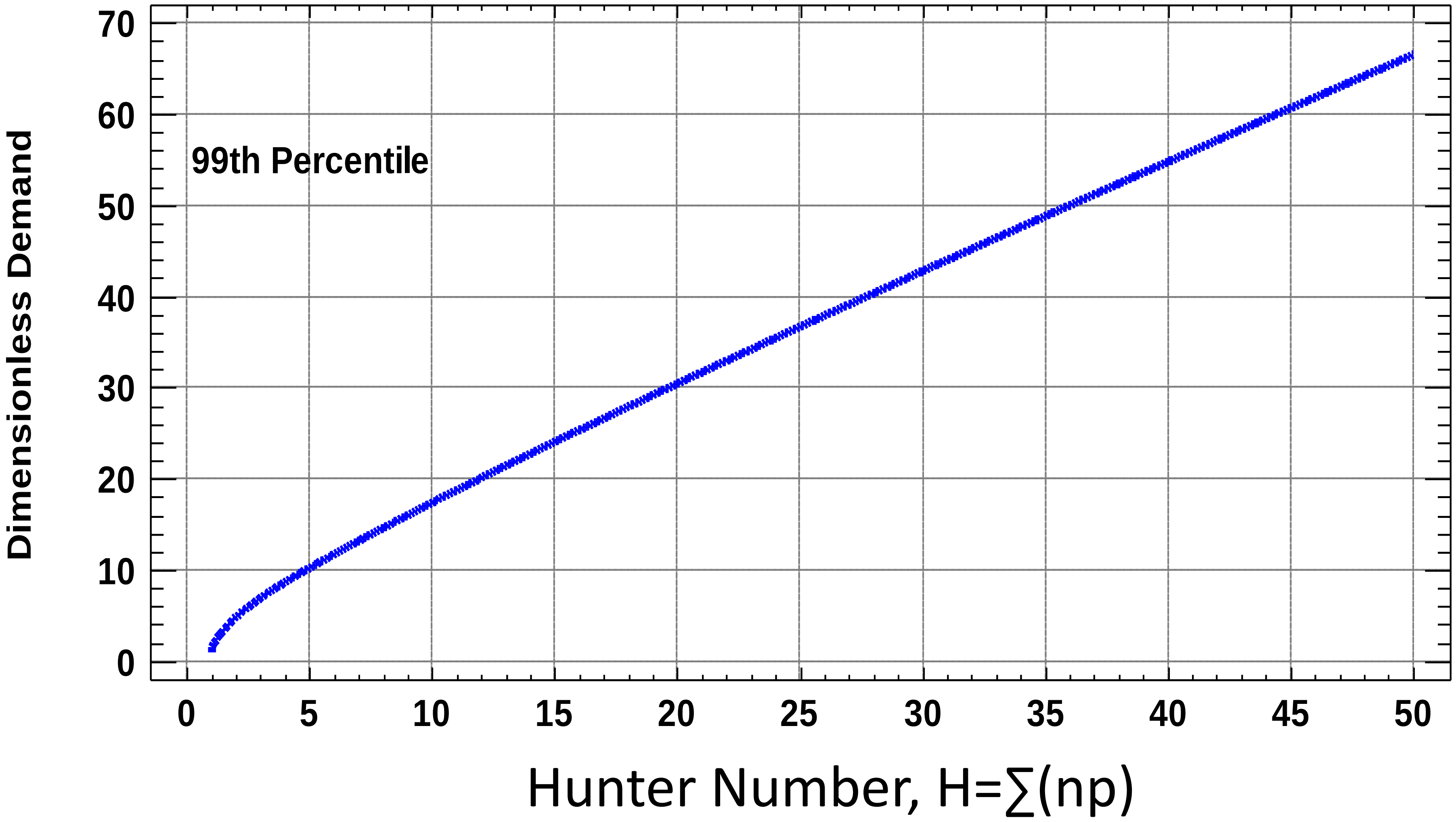
New Convolution Algorithm for Green Zone: Increase WDC Speed by Factor of 10



Dimensionless Moody Diagram for estimating headloss in pipe flow (1944)



Universal Dimensionless Hunter Curve



Summary / Conclusions

- WDC has performed well in field (US/Australia)
- New algorithm improves WDC **green** execution speed
- Working to extend WDC to commercial sector
- **Big Challenge**: Need fixture "p-values"
- Case study at UC 5/3rd arena is very encouraging
- Testing new sensors to detect water motion in pipes
- Sensor data will allow estimation of "p-values"
- Developing a universal dimensionless Hunter's Curve
- WDC is amendable to BIM platform

ACT I WDC HISTORY

ACT II WDC FUTURE

ACT III WDC Q/A

Contact Information

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Data Specs for <u>Entire Buildings</u>

- Assumption: Estimates of “$\boldsymbol{n}$” and “$\boldsymbol{q}$” are readily obtained. (fixture count and fixture flow).
- Objective: Measure peak indoor water demand at the building (especially flows during the peak hour)
- [1] Spatial scale: Monitor <u>service line</u>
- [2] Time scale: Logging frequency 1-3 seconds
- [3] Time stamp: Log exactly when readings are made
- [4] Time duration: Continuous readings for at least 30 days
- [5] Data signal: Flow rate as GPM or LPS

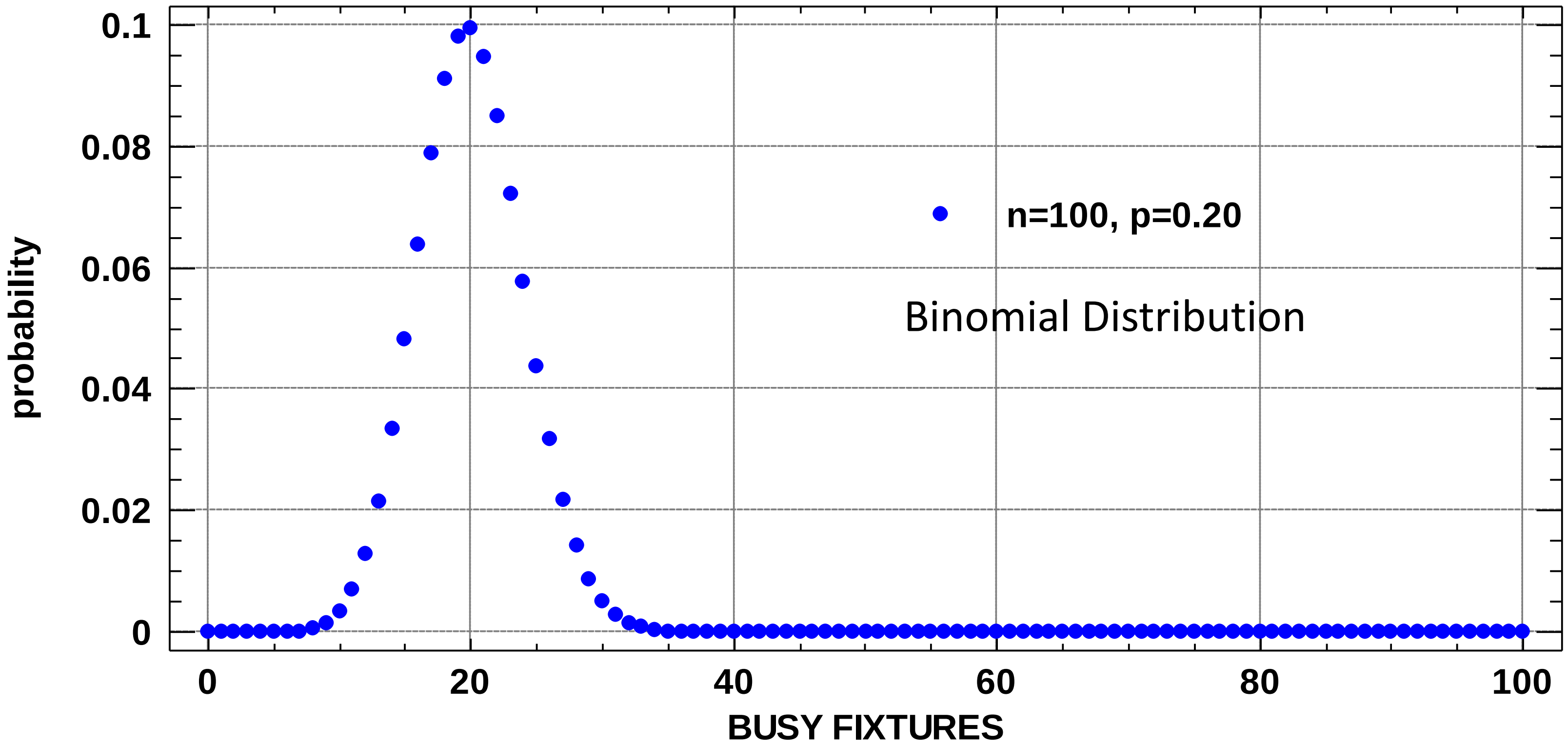
IAPMO Working Group C, data template available from UC…..data will help corroborate WDC predictions

Data Specs for Individual Fixtures

- Assumption: Estimates of "n" and "q" are readily obtained.
  (fixture count and fixture flow).
- Objective: Determine "p", the probability of fixture use (especially during the peak hour)
- [1] Spatial scale: Monitor individual fixtures
- [2] Time scale: Logging frequency 1-2 seconds (high frequency)
- [3] Time stamp: Log exactly when and where water is used
- [4] Time duration: Continuous readings for at least 30 days
- [5] Data signal: Binary (0 = fixture not used, 1 = fixture is used)

IAPMO Working Group C, data template available from UC…..data will help estimate fixture **p**-values

Busy Fixtures in Building
with n=100 Flush Tanks, p=0.20



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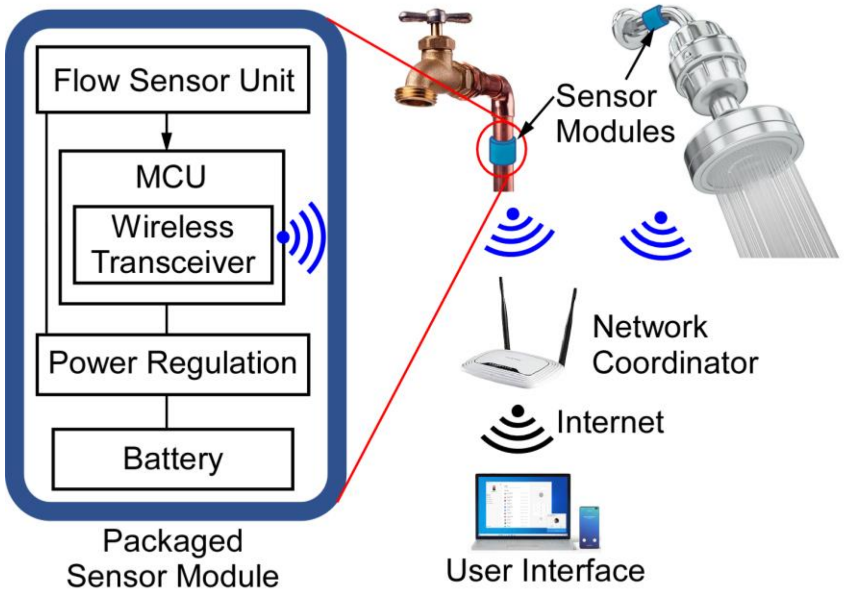
Wireless Sensor Network for Water Usage Monitoring



System Concept Diagram

- Goal: To develop and test a miniature wireless sensor module with
  - Low-cost
  - Battery power Noninvasive detection of flow in water delivery pipes
  - Capability to form wireless sensor network of multiple sensor modules
- To accurately monitor the incidence and patterns of water usage at various fixtures
- Provide information for determination of fixture p-values needed to estimates peak water demand

Technical Merits and Progress

- Existing technologies for noninvasive flow measurements are mostly based on ultrasonic sensors (sophisticated and highly costly)

Keyence's FD-Q10C Clamp-on Ultrasonic Flow Sensor

- Leverage commercially available matured microsensor technologies to provide a reliable and low-cost solution
- The innovations also include:
  - Integration and packaging approaches enabling a compact and reliable device with long operation lifetime.
  - Ease of deployment and operation.
- Sensors are currently in development and under field tests