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

Steven Buchberger

Emerging Water Technology Symposium

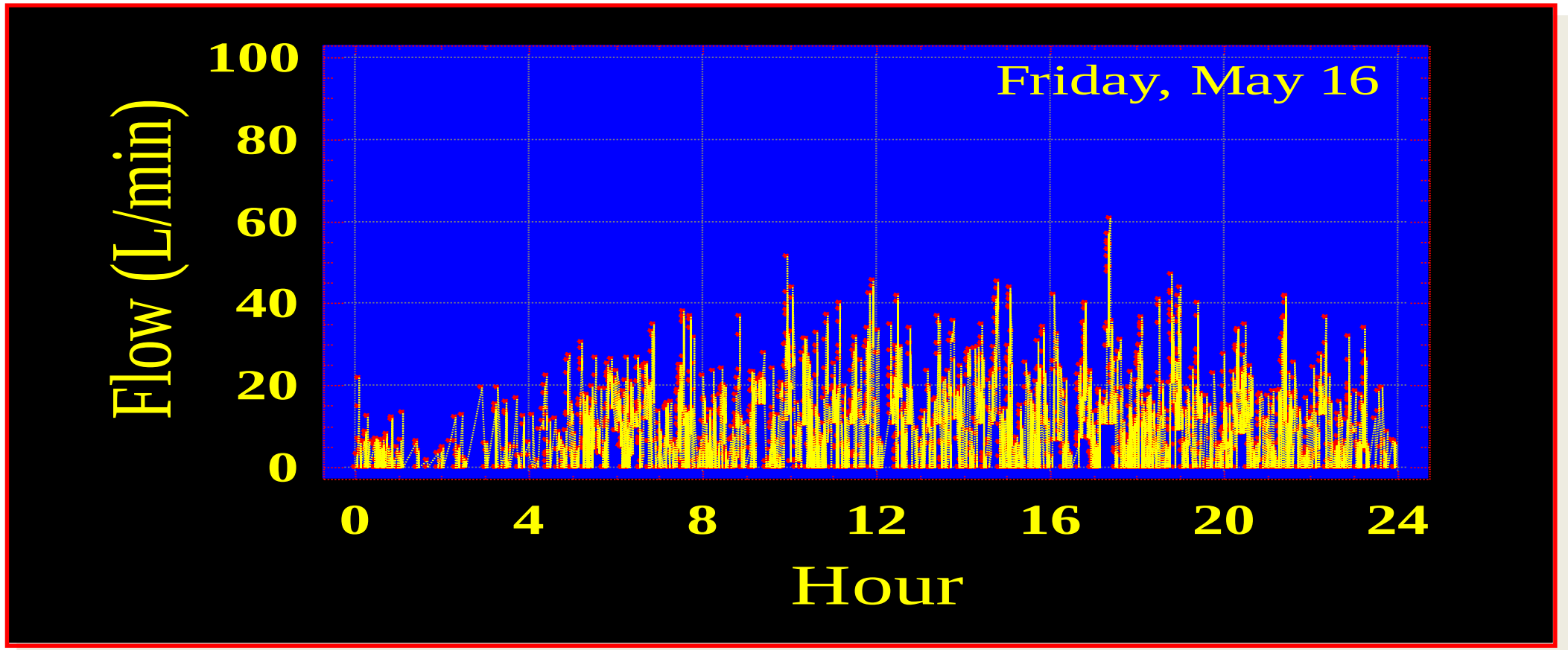
May 15, 2018

The Problem

The Progress

The Prognosis

Time History of Water Demand (21 units)



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: Fixture Count

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

q: Fixture Flow Rate

p: Fixture Probability of Use

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

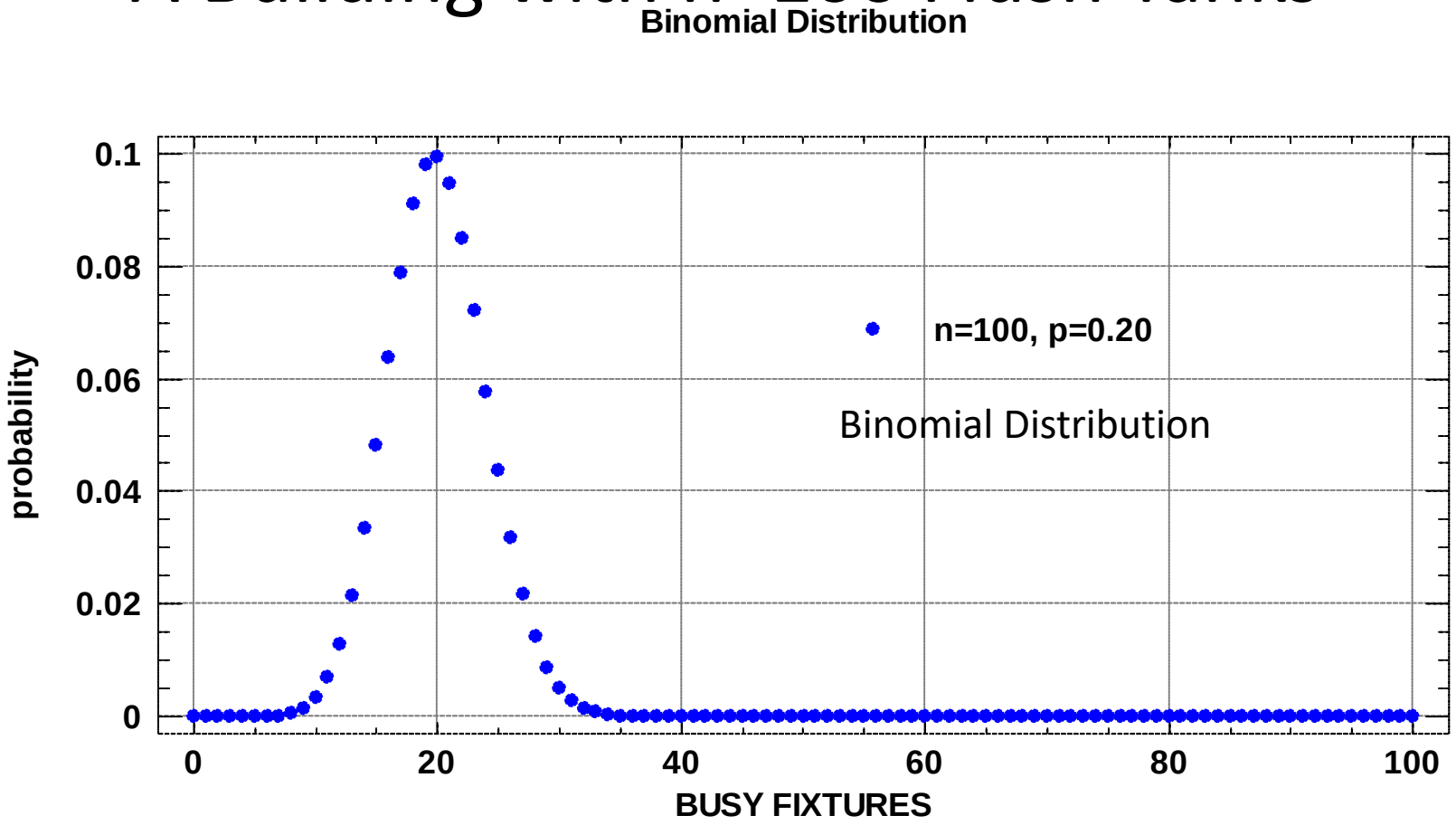
Hunter's Big Three

Dr. Roy B. Hunter

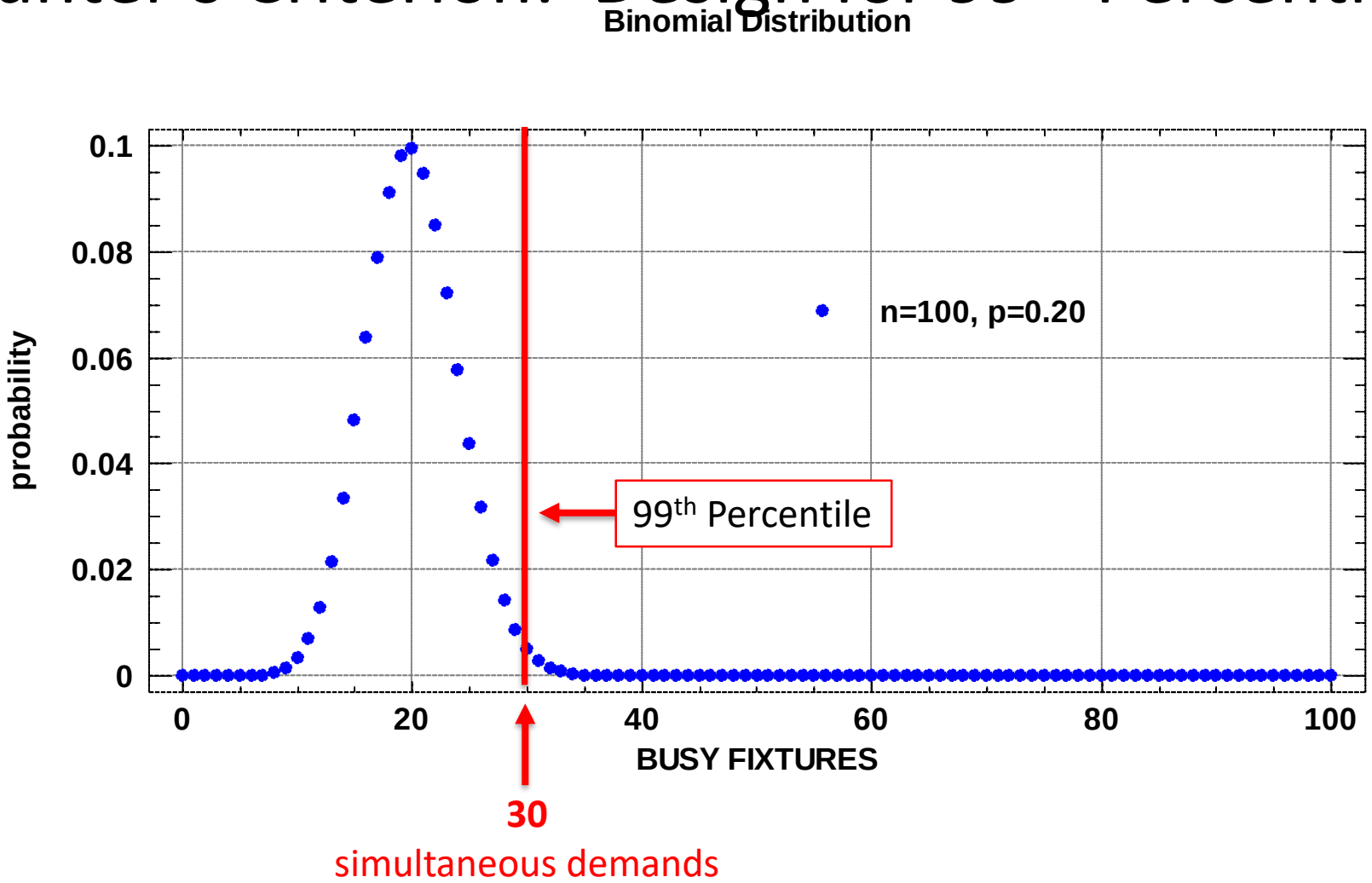
Flush Valve	Flush Tank	Bathtub
p = 0.030	p = 0.200	p = 0.067
q = 27 gpm	q = 4 gpm	q = 8 gpm
FU = 10	FU = 5	FU = 4

FU = "Fixture Unit"

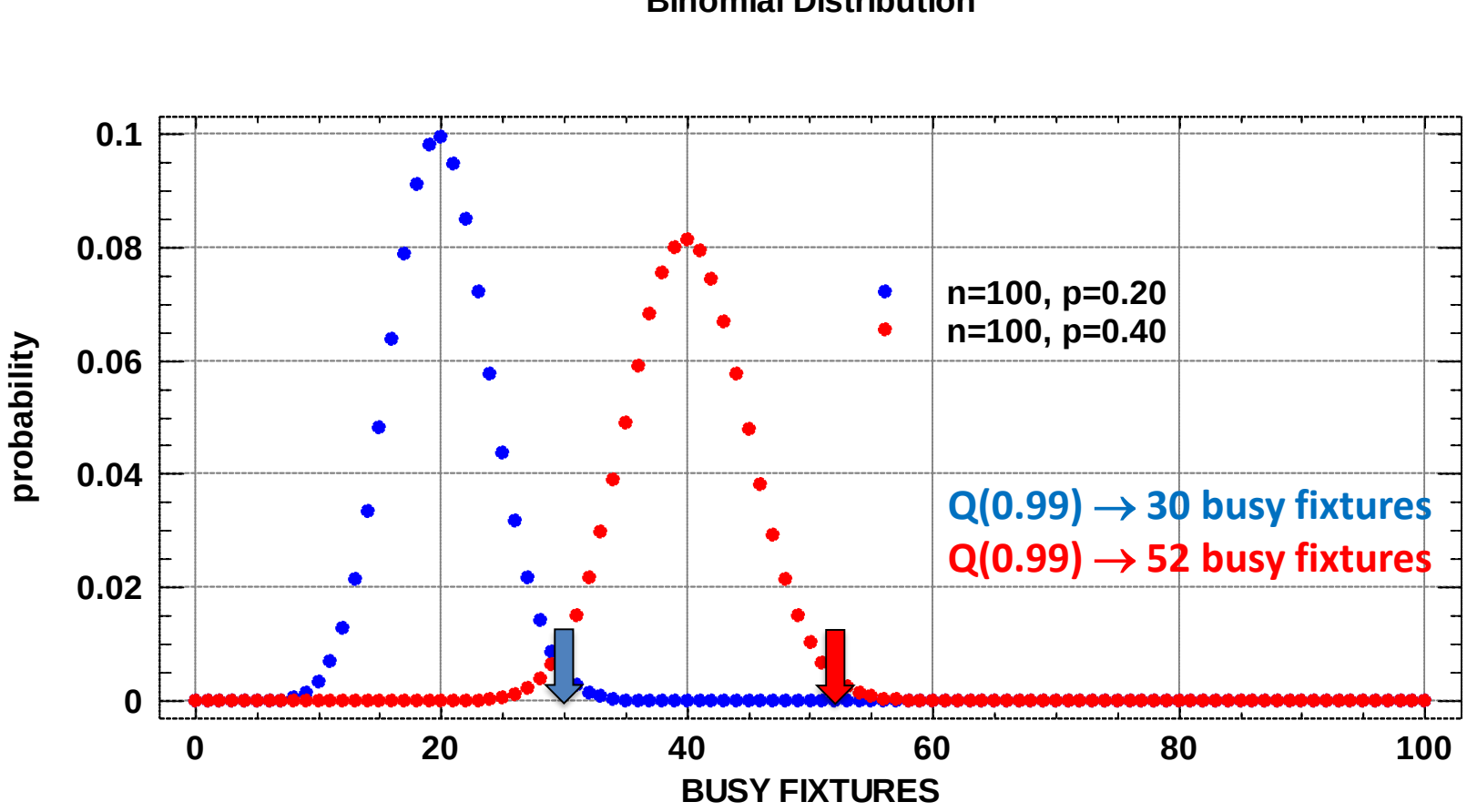
A Building with n=100 Flush Tanks



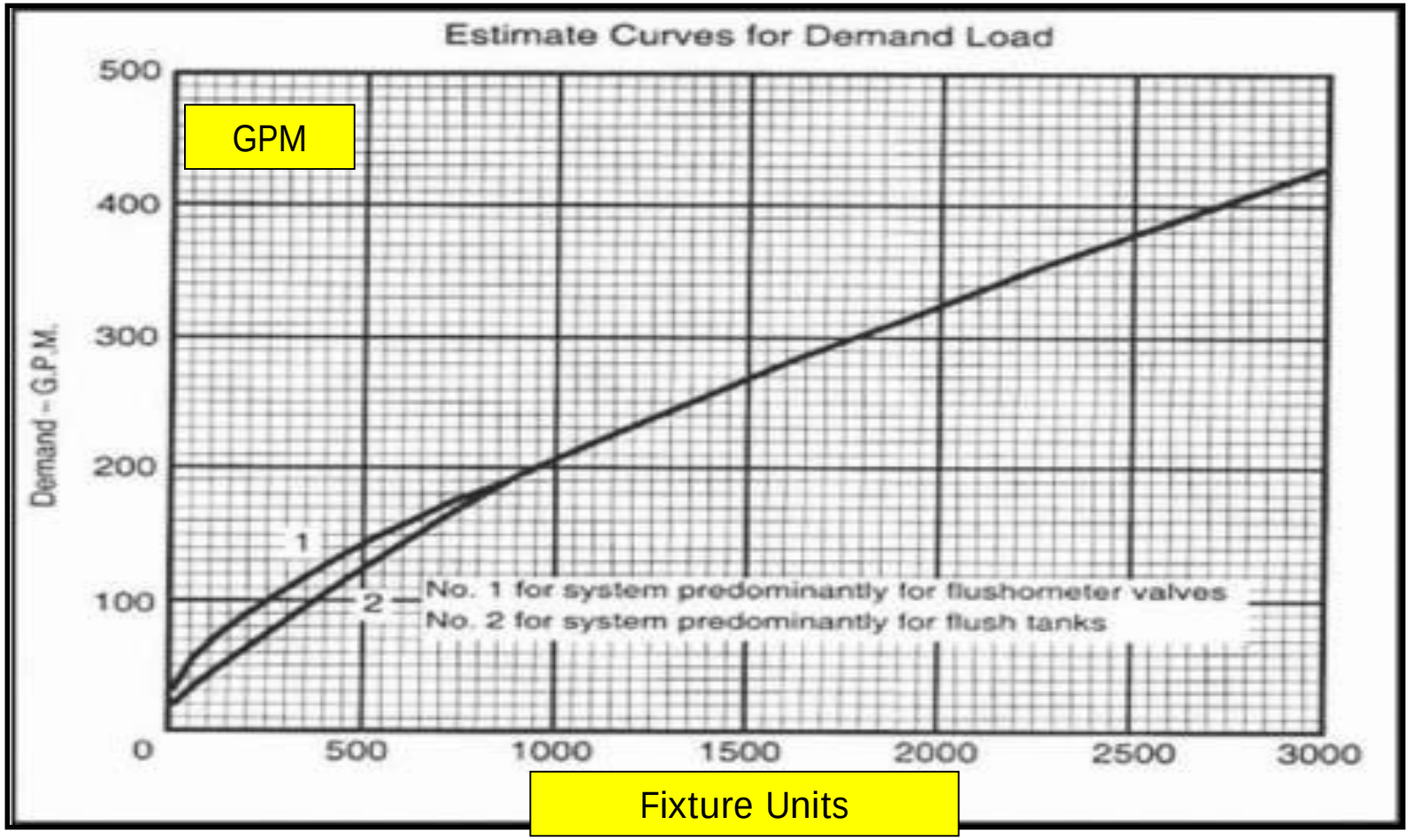
Hunter's Criterion: Design for 99th Percentile



Building with 100 flush tanks + 100 red fixtures



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

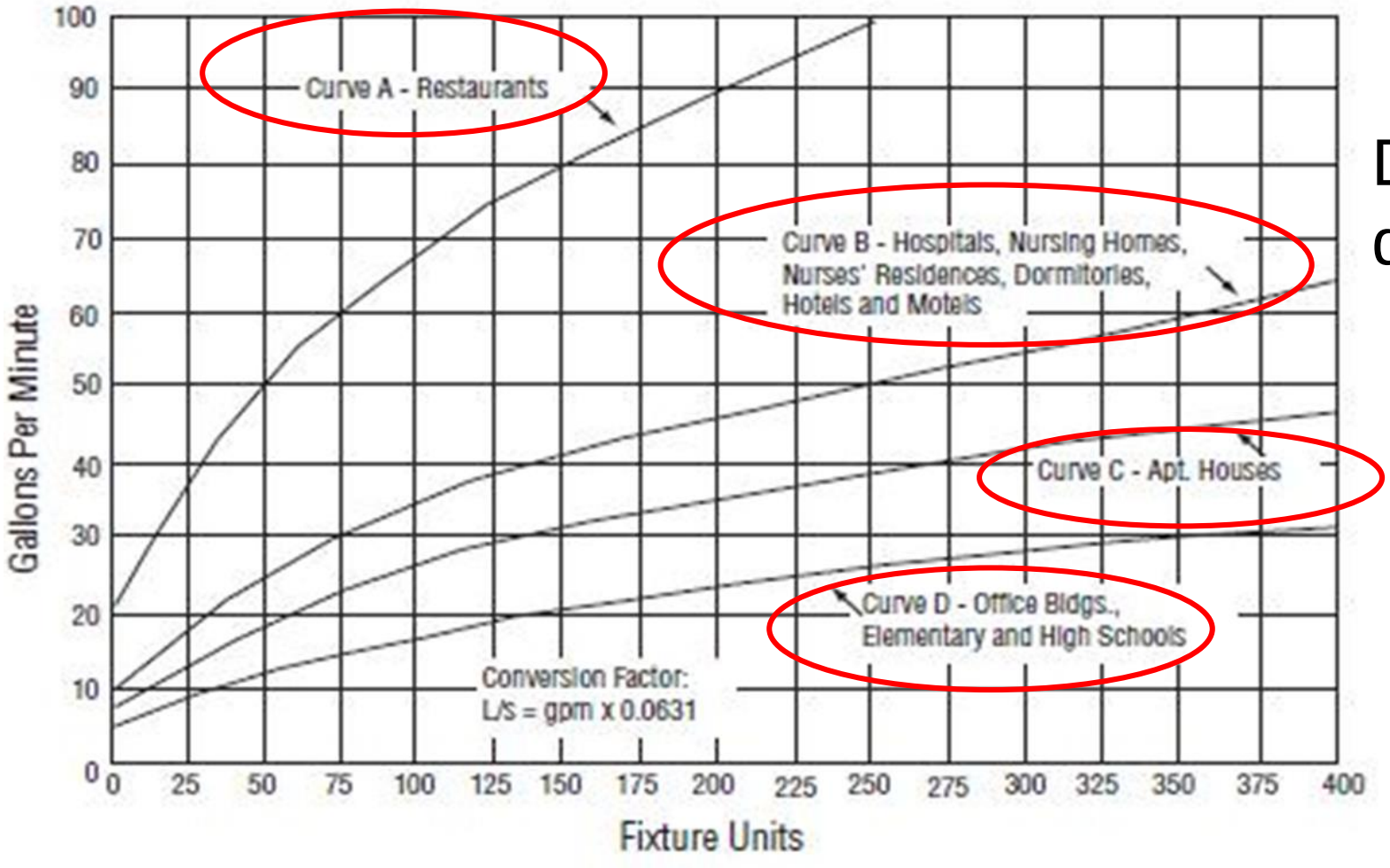
Today **Hunter's Curve** is often faulted for overly conservative design....Why?

[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.

Hunter's Approach Assumed "Congestion"

Modified Hunter's Curve(s)



Different curve for different end users

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

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

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

WATER USE DATABASE

Database: Location of Homes

- Survey 1996-2011
- MS database

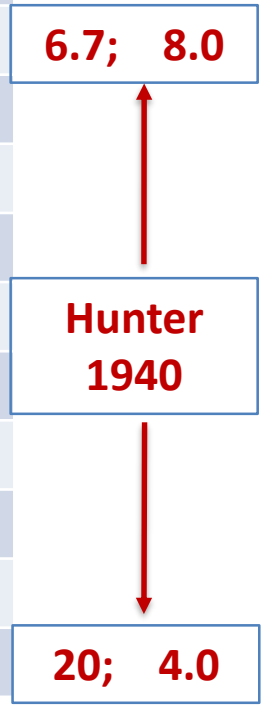
- 62 cities
- 9 states

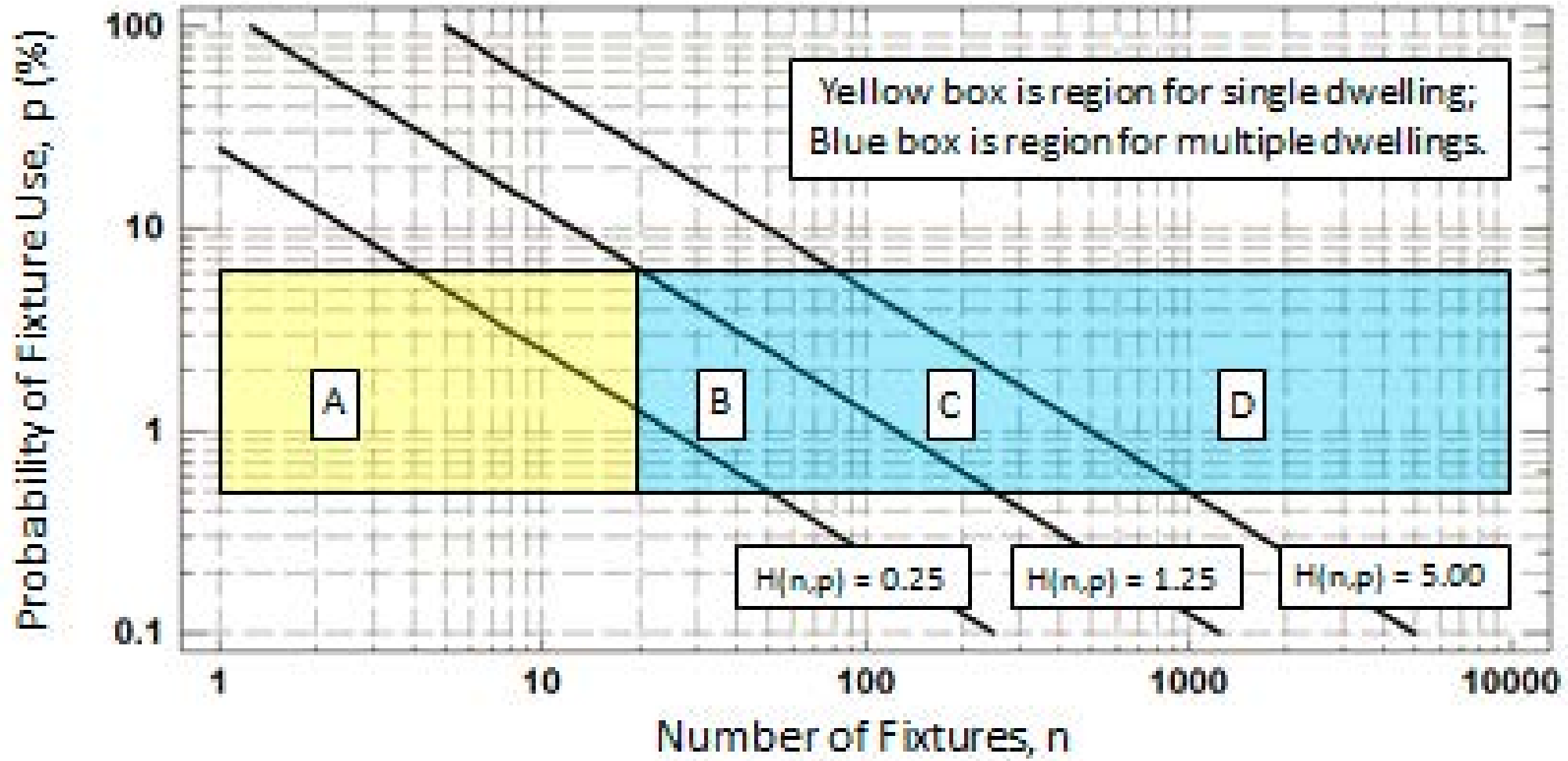
- 1,038 households
- 2,800 residents

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

Recommended *p*-values and *q*-values

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





Hunter Number: $H(n,p) = \Sigma n_k p_k$

Dimensionless Hunter Number, **H**

Fixture Count: n = 100

Probability of Use: p = 0.20

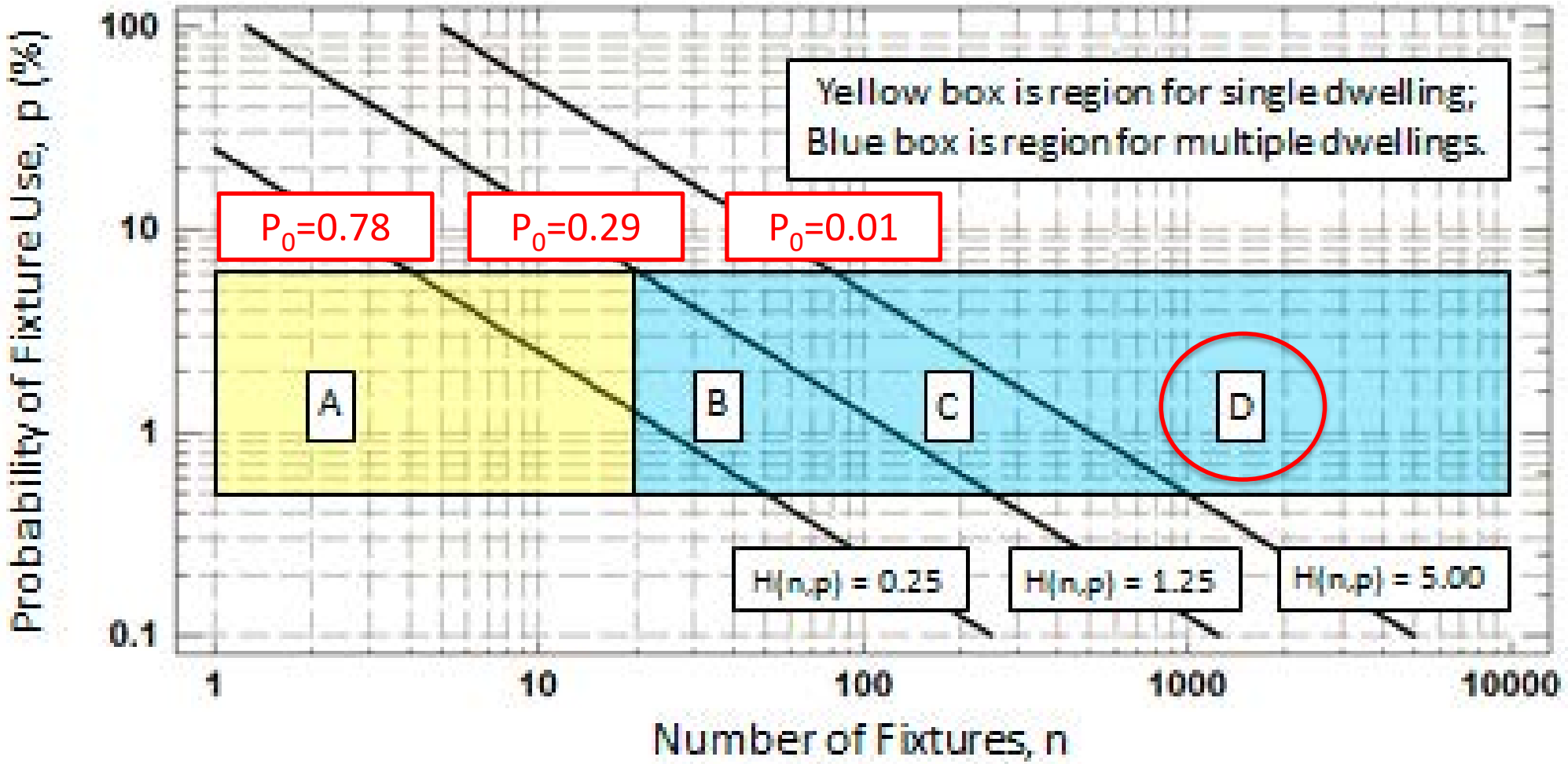
Hunter Number: **H** = np = 20

H is “expected number” of flush tanks in simultaneous use during the peak demand period.

Peak Period Probability of Stagnation

Hunter Number $\mathbf{H}(n,p) = \Sigma \mathbf{H}_k = \Sigma n_k p_k$ $\quad k=1,2,\ldots K$

Prob[zero demand] $= P_0 \approx \exp[-\mathbf{H}(n,p)]$


Probability of Fixture Use, p (%)
100
10
1
0.1
1
10
100
1000
10000
Number of Fixtures, n
Yellow box is region for single dwelling;
Blue box is region for multiple dwellings.
P0=0.78
P0=0.29
P0=0.01
A
B
C
D
H(n,p) = 0.25
H(n,p) = 1.25
H(n,p) = 5.00

Algorithm for Zone D: Wistort Method (1994)

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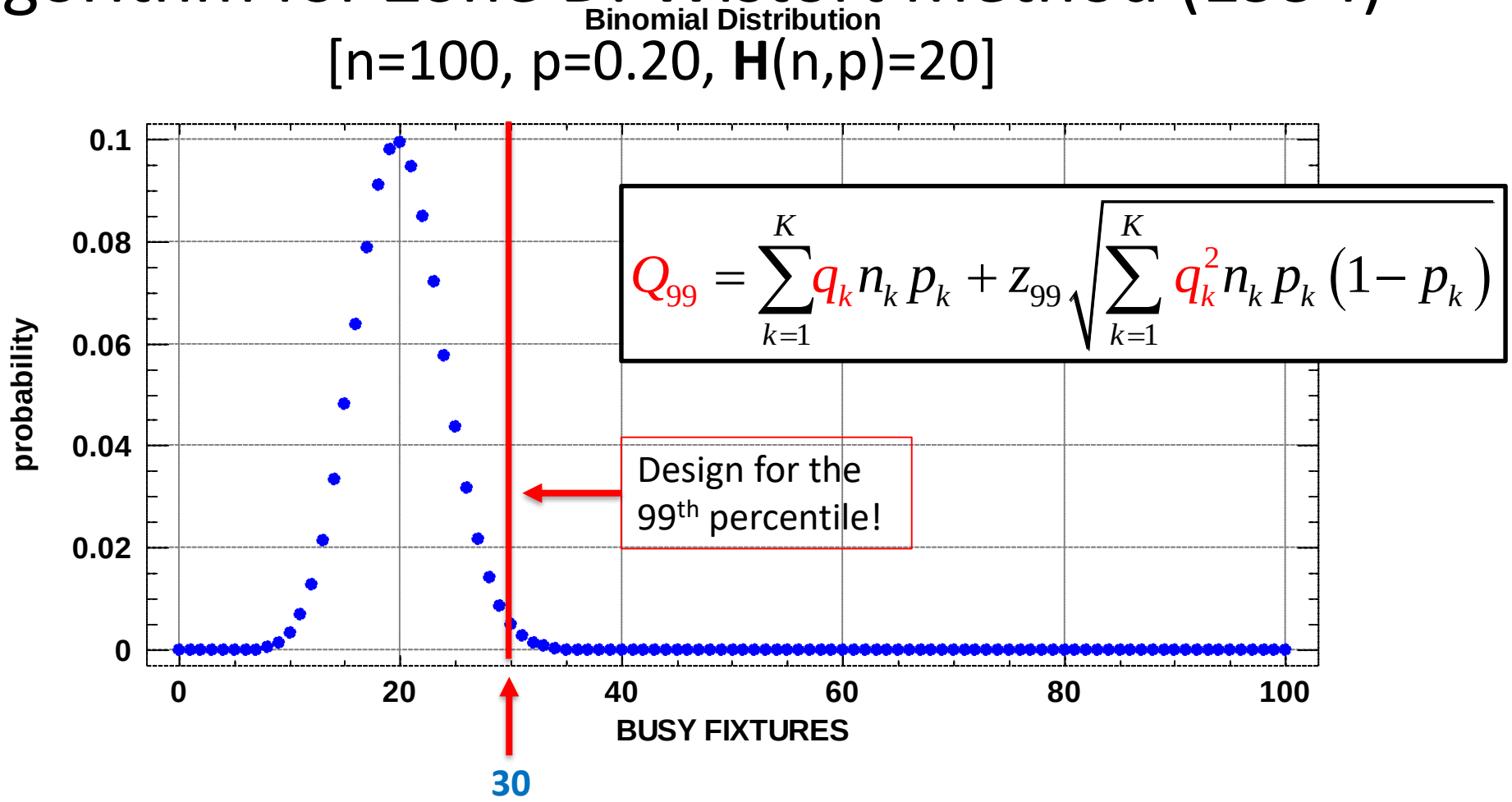

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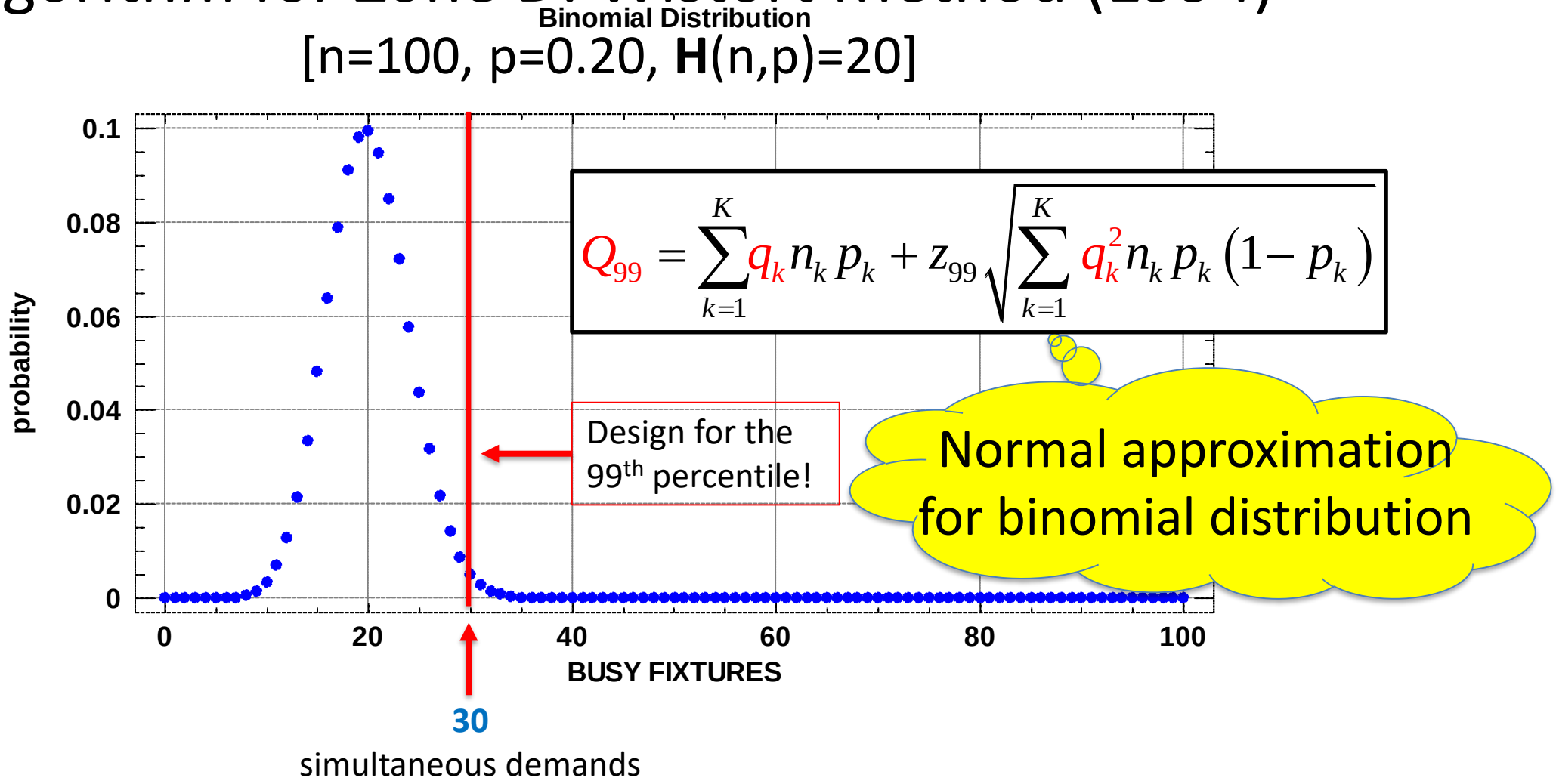

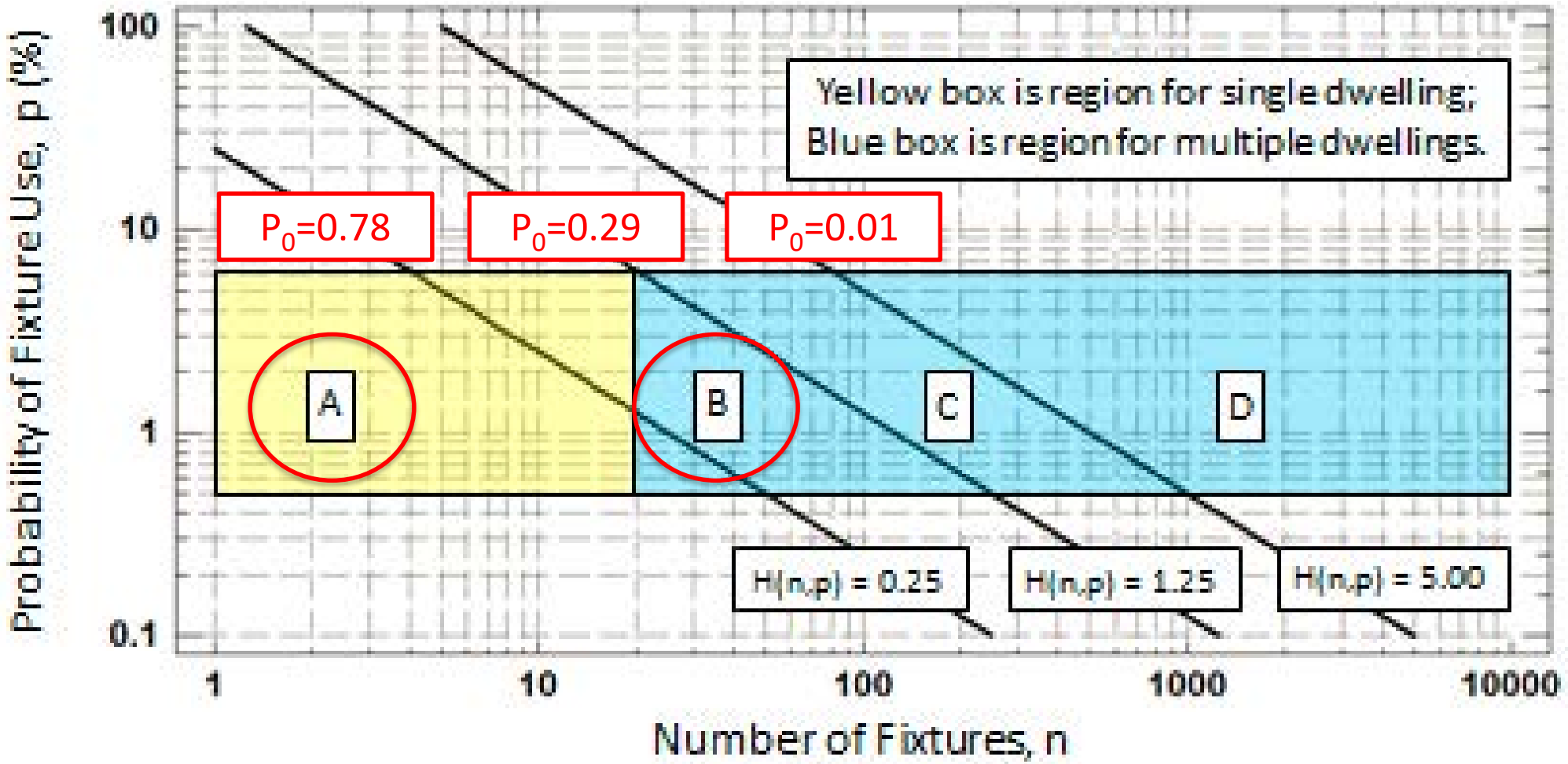
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Zones A&B Algorithm: Exhaustive Enumeration

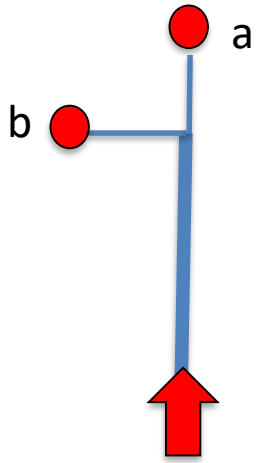
Algorithm for Zones A&B: Exhaustive Enumeration

n=**1** fixture

2 outcomes

0

a



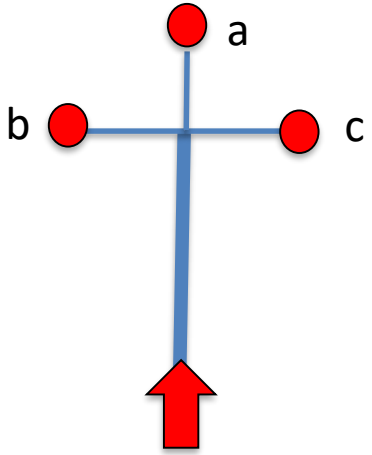
n=**2** fixtures

4 outcomes

0

a, b

a+b



n=**3** fixtures

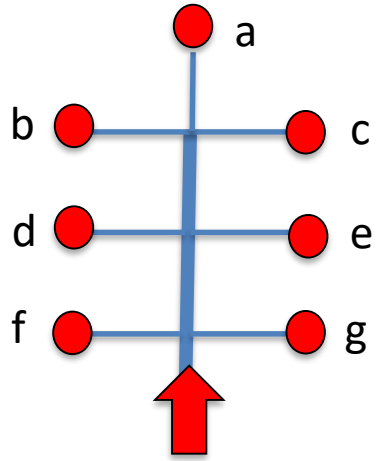
8 outcomes

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

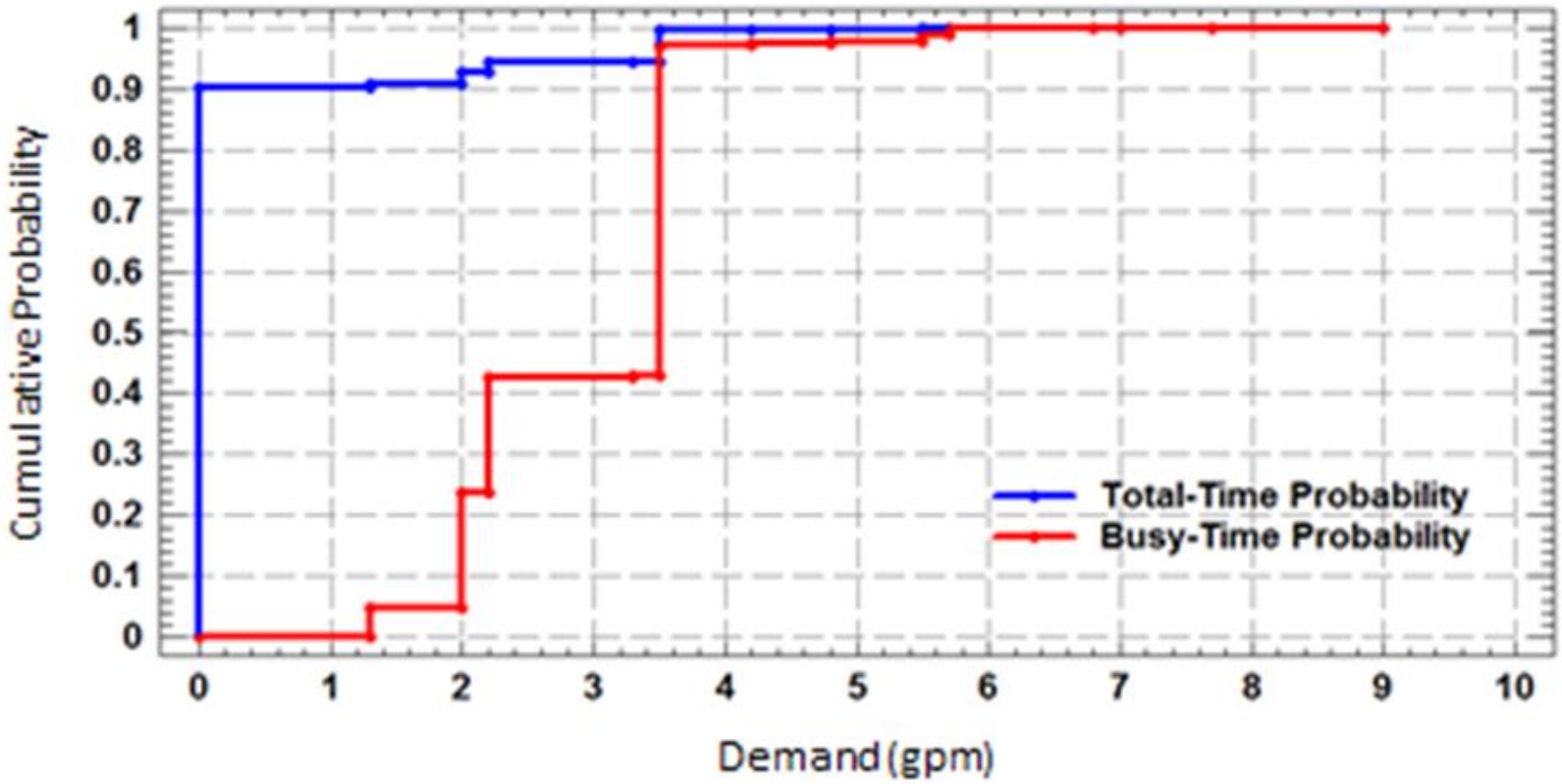
a+b, a+c, a+d …..

…….etc…….

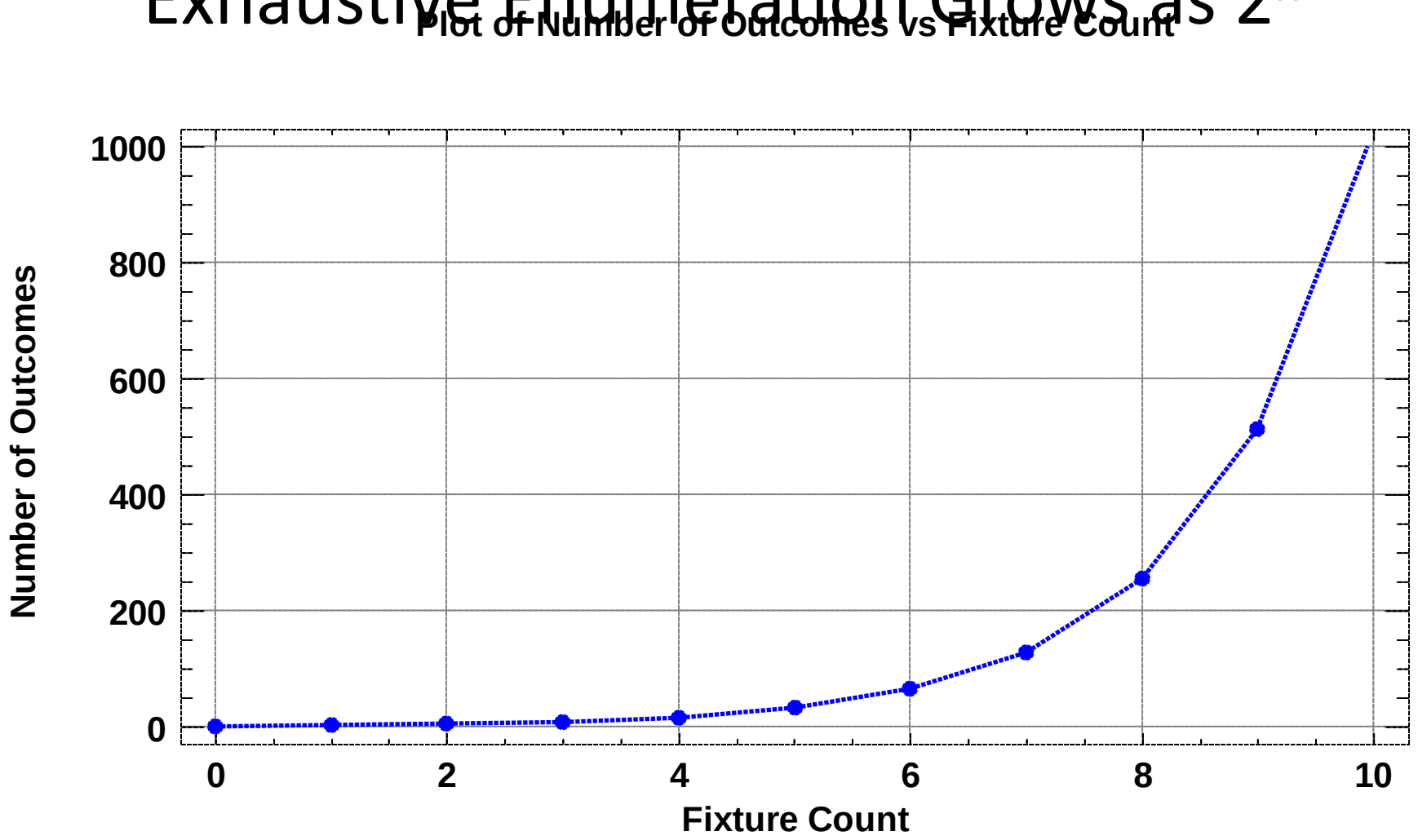
a+b+c+d+e+f+g

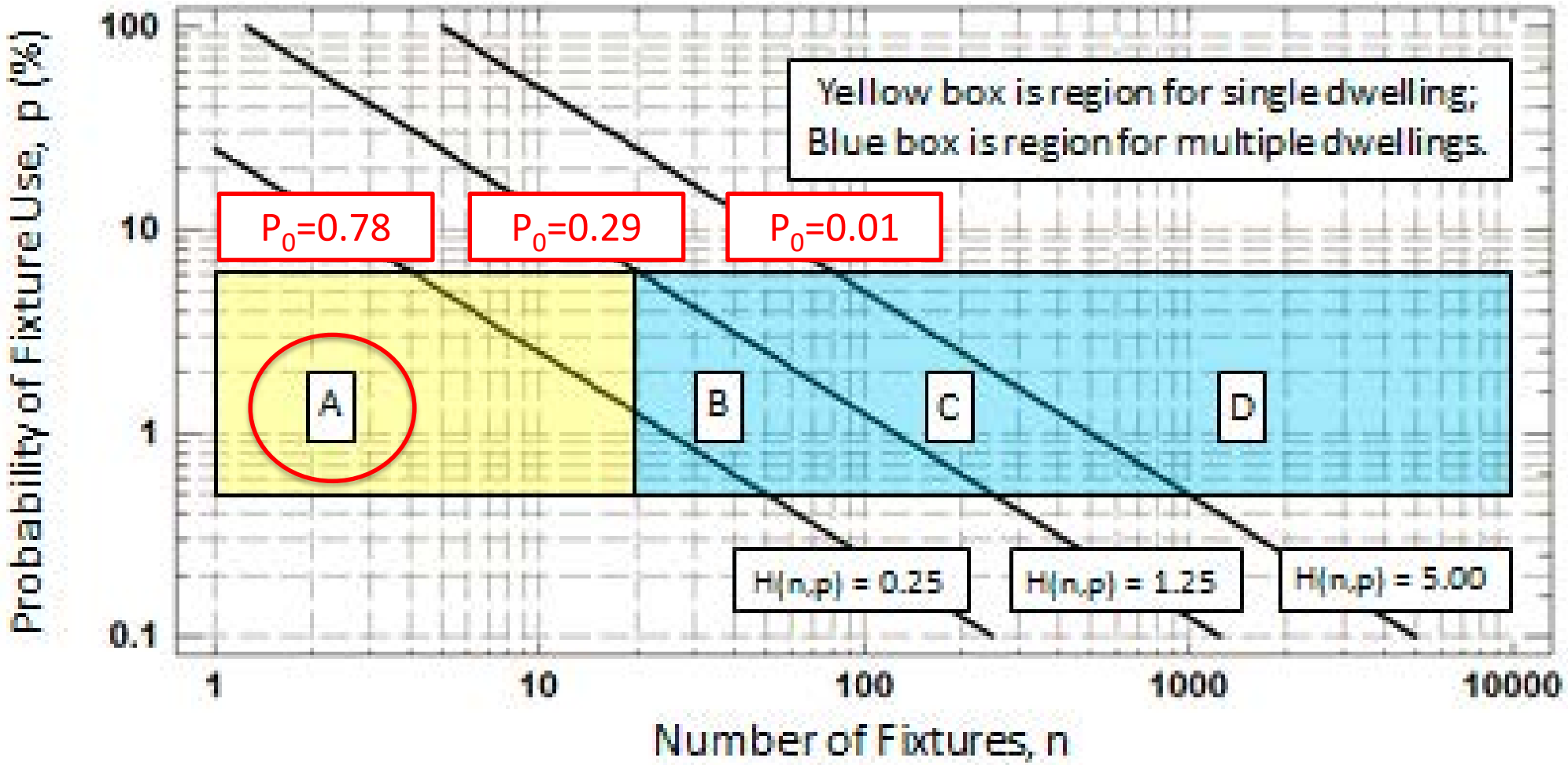
EXEN Outcomes Grows as 2^n

Example CDF from EXEN for n=4 Fixtures



Exhaustive Enumeration Grows as 2^n

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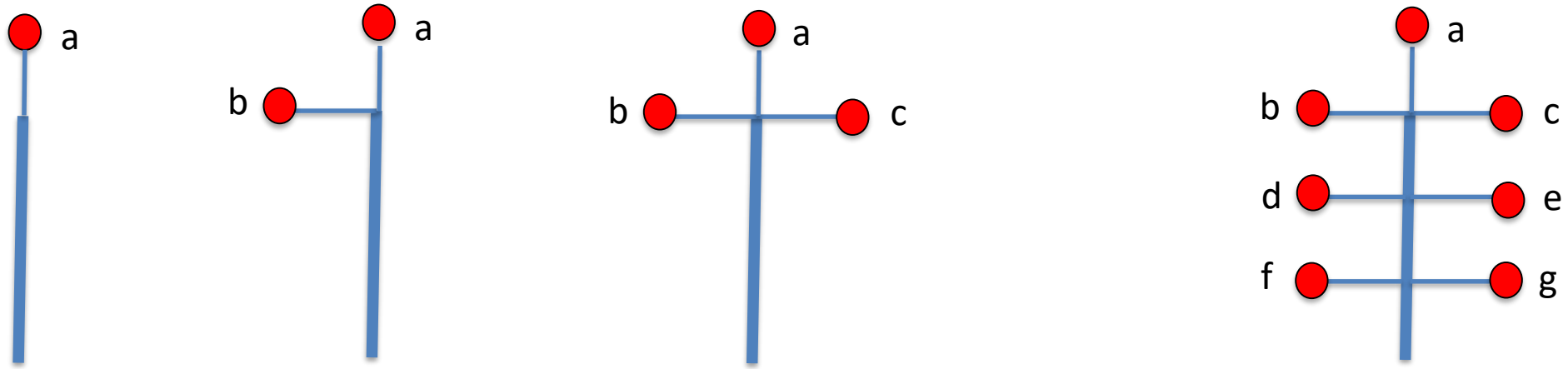
Algorithm for Zone A only: Q1+Q3



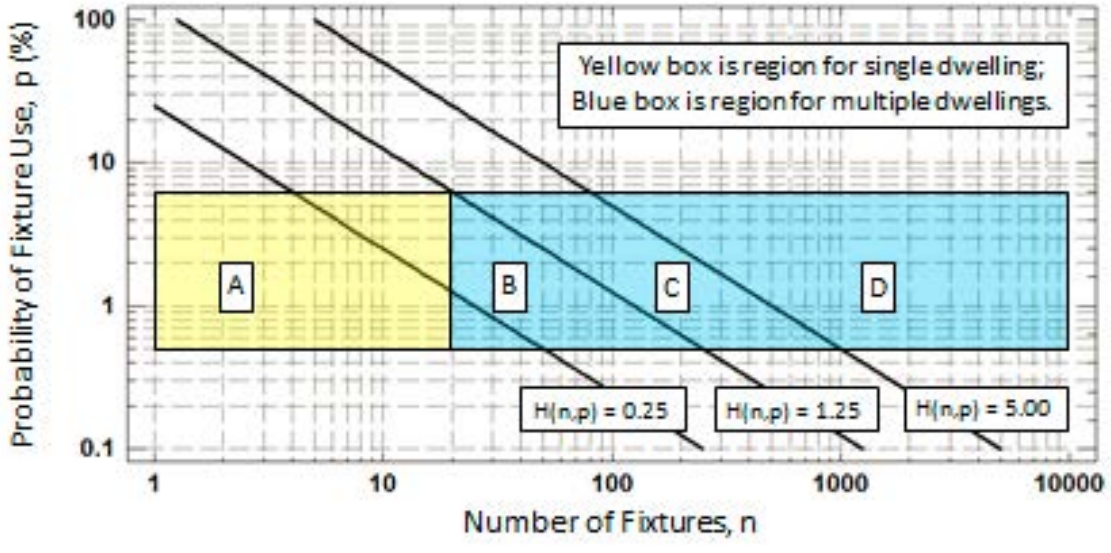
STEP 1: Rank fixture demands from maximum to minimum.

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

"**Q1+Q3**" works reasonably well in single family homes ($n \leq 12$).

Transition from One to Many Fixtures

ONE



MANY

- 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-1

	[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
1	Bar Sink	0	2.0	1.5	1.5
2	Bathtub	0	1.0	5.5	5.5
3	Bidet	0	1.0	2.0	2.0
4	Clothes Washer	0	5.5	3.5	3.5
5	Combination Bath/Shower	0	5.5	5.5	5.5
6	Dishwasher	0	0.5	1.3	1.3
7	Kitchen Faucet	0	2.0	2.2	2.2
8	Laundry Faucet	0	2.0	2.0	2.0
9	Lavatory Faucet	0	2.0	1.5	1.5
10	Shower, per head	0	4.5	2.0	2.0
11	Water Closet, 1.28 GPF Gravity Tank	0	1.0	3.0	3.0
12	Other Fixture 1	0	0.0	0.0	6.0
13	Other Fixture 2	0	0.0	0.0	6.0
14	Other Fixture 3	0	0.0	0.0	6.0

Total Number of Fixtures 0

99th PERCENTILE DEMAND FLOW = GPM

RESET

RUN WATER DEMAND CALCULATOR

↑ CLICK BUTTON ↑

Title Page | Key | DemandEstimate

Ready

70%

Basic Template

WDC: Water Demand Calculator-2

Zone A Example: Single Family Home

	[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
1	Bar Sink	0	2.0	1.5	1.5
2	Bathtub	0	1.0	5.5	5.5
3	Bidet	0	1.0	2.0	2.0
4	Clothes Washer	1	5.5	3.5	3.5
5	Combination Bath/Shower	2	5.5	5.5	5.5
6	Dishwasher	1	0.5	1.3	1.3
7	Kitchen Faucet	1	2.0	2.2	2.2
8	Laundry Faucet	1	2.0	2.0	2.0
9	Lavatory Faucet	3	2.0	1.5	1.5
10	Shower, per head	0	4.5	2.0	2.0
11	Water Closet, 1.28 GPF Gravity Tank	3	1.0	3.0	3.0
12	Other Fixture 1	0	0.0	0.0	6.0
13	Other Fixture 2	0	0.0	0.0	6.0
14	Other Fixture 3	0	0.0	0.0	6.0

Total Number of Fixtures 12

99th PERCENTILE DEMAND FLOW = 11.0 GPM

RESET

RUN WATER DEMAND CALCULATOR

Title Page | Key | DemandEstimate

Ready 70%

12 Fixtures

UPC gives 18.2 gpm

40% reduction

1” line ↓ ¾” line

WDC: Water Demand Calculator-3

Zone D Example: Multi-Family Complex

	[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
1	Bar Sink	0	2.0	1.5	1.5
2	Bathtub	0	1.0	5.5	5.5
3	Bidet	0	1.0	2.0	2.0
4	Clothes Washer	100	5.5	3.5	3.5
5	Combination Bath/Shower	200	5.5	5.5	5.5
6	Dishwasher	100	0.5	1.3	1.3
7	Kitchen Faucet	100	2.0	2.2	2.2
8	Laundry Faucet	100	2.0	2.0	2.0
9	Lavatory Faucet	300	2.0	1.5	1.5
10	Shower, per head	0	4.5	2.0	2.0
11	Water Closet, 1.28 GPF Gravity Tank	300	1.0	3.0	3.0
12	Other Fixture 1	0	0.0	0.0	6.0
13	Other Fixture 2	0	0.0	0.0	6.0
14	Other Fixture 3	0	0.0	0.0	6.0

Total Number of Fixtures 1200

99th PERCENTILE DEMAND FLOW = 155.4 GPM

RESET

RUN WATER DEMAND CALCULATOR

Title Page | Key | DemandEstimate

Ready 70%

1200 Fixtures

UPC gives 397 gpm

62% reduction

5” line ↓ 3” line

Precautionary Note on Fixture Retrofits

Method	Peak Flow (gpm)	Pipe Size (inch)	Velocity (fps)
UPC	397	5	6.5
WDC	155	3	7.0
UPC, WDC	155	5	2.5

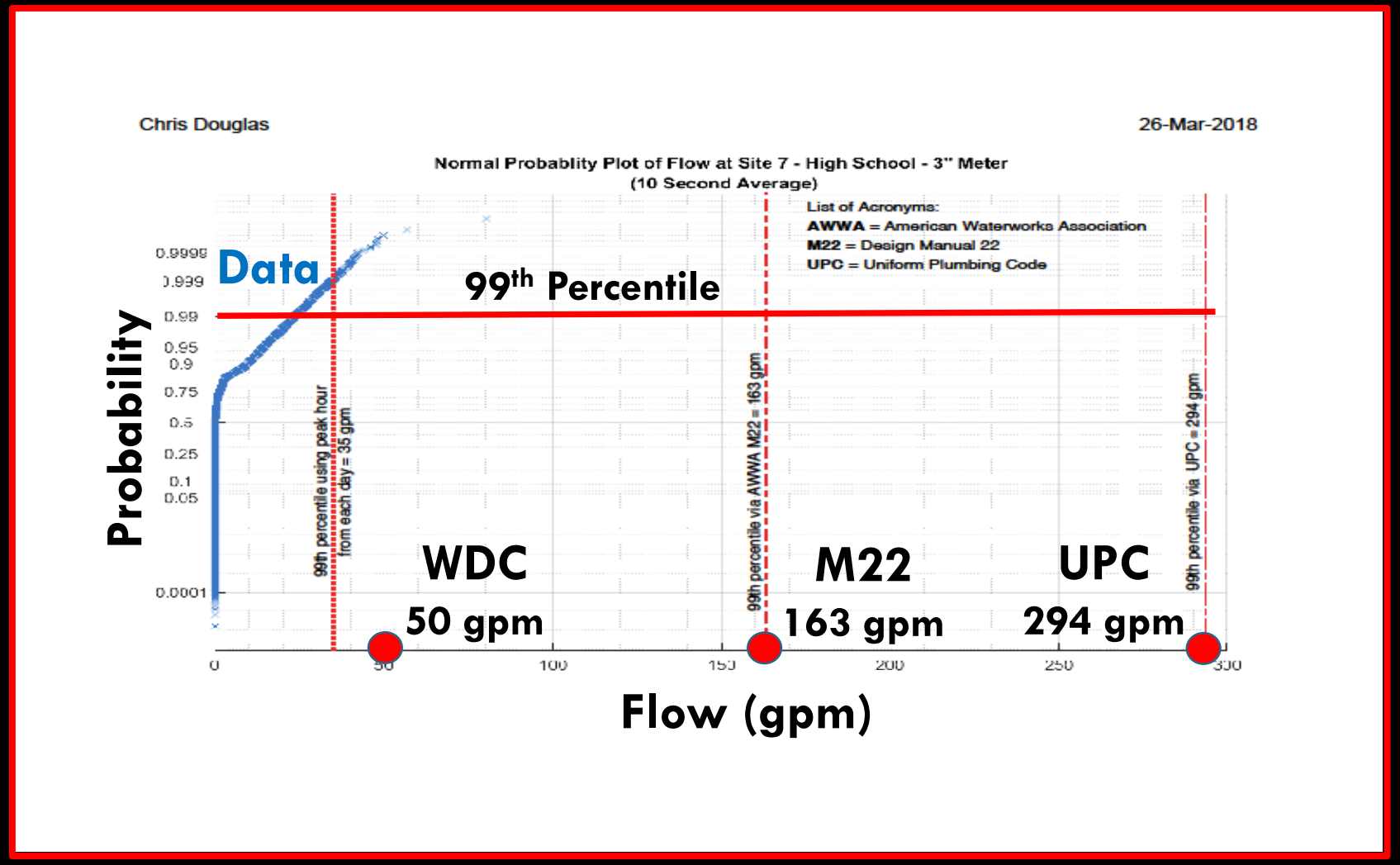
Velocity ratio 6.5/2.5 = 2.6 times slower moving water after retrofitting the original premise plumbing system. This almost certainly implies longer residence time for water in the premise plumbing system since the volume of water use also drops following retrofit.

The Problem

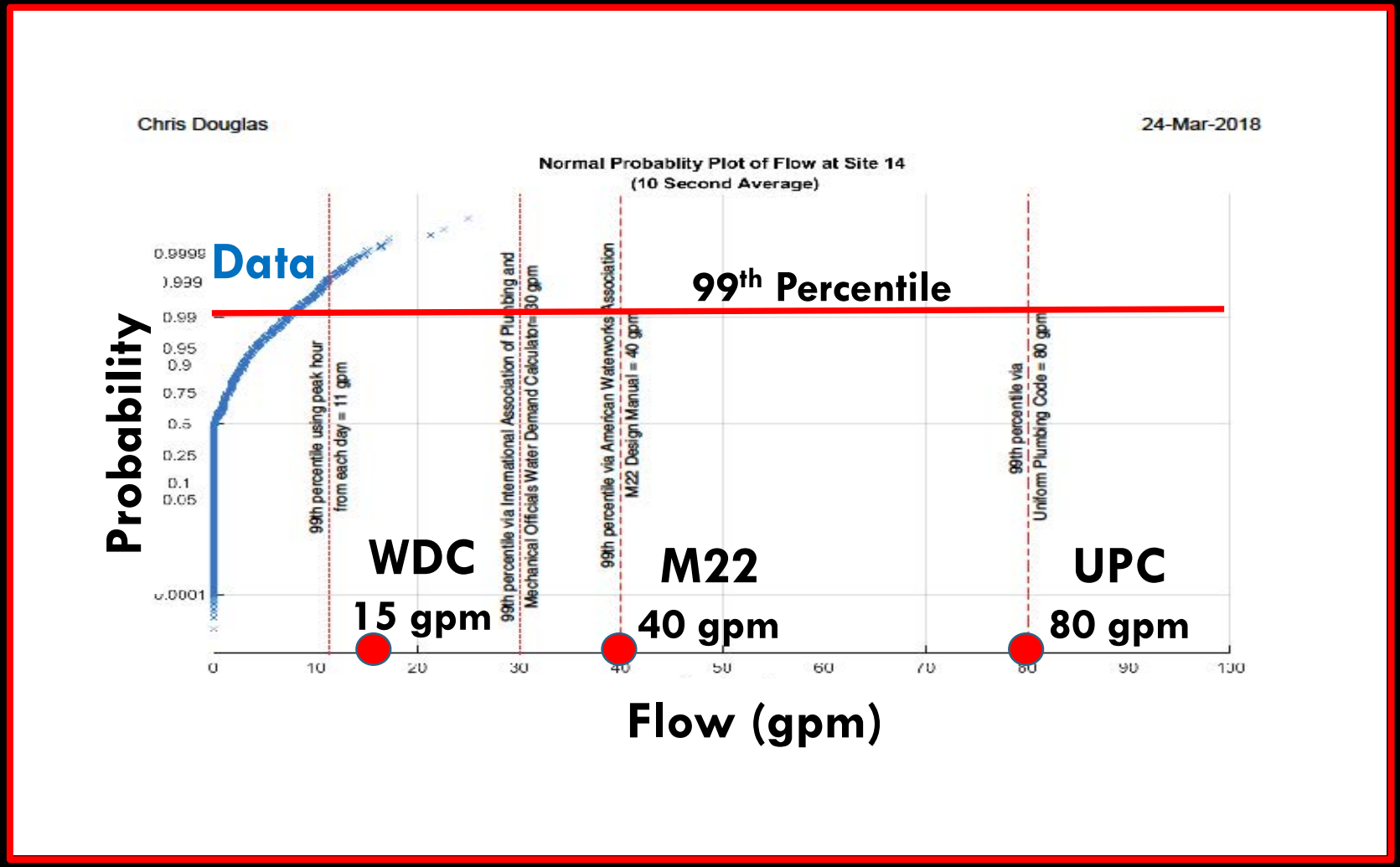
The Progress

The Prognosis

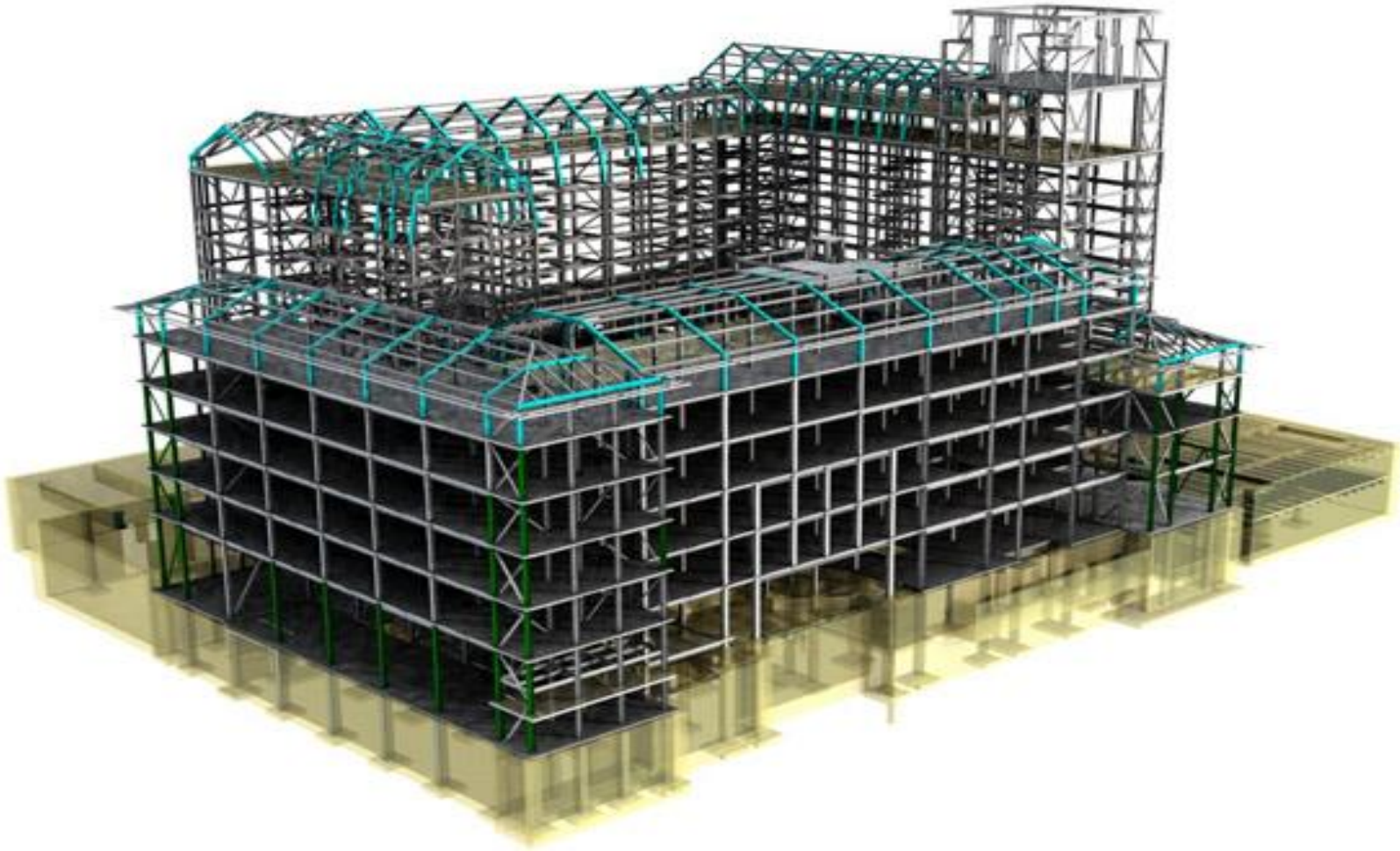
Design Flow Comparison: School (site 7)

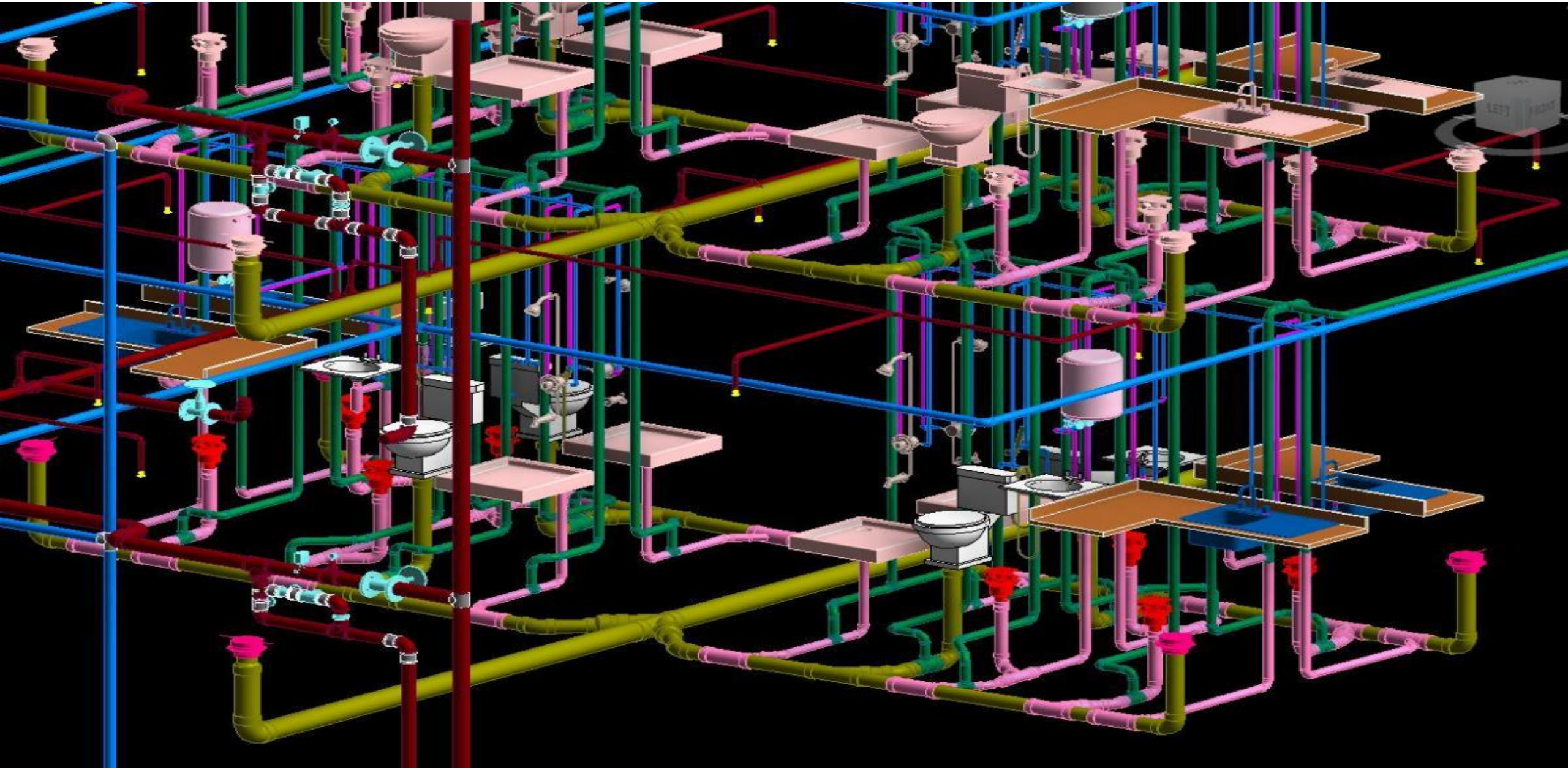


Design Flow Comparison: Apartments (site 14)

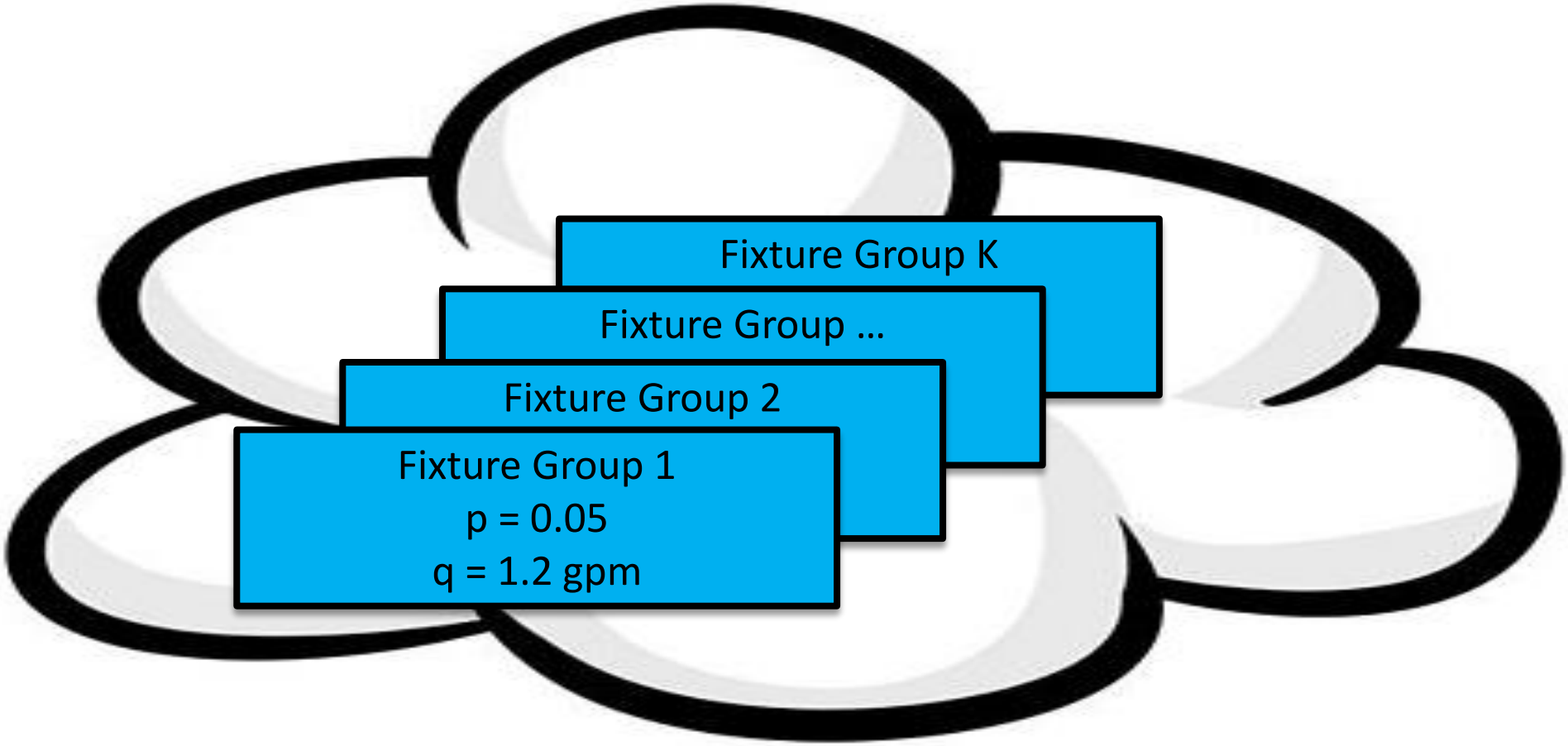


BIM: Building Information Model

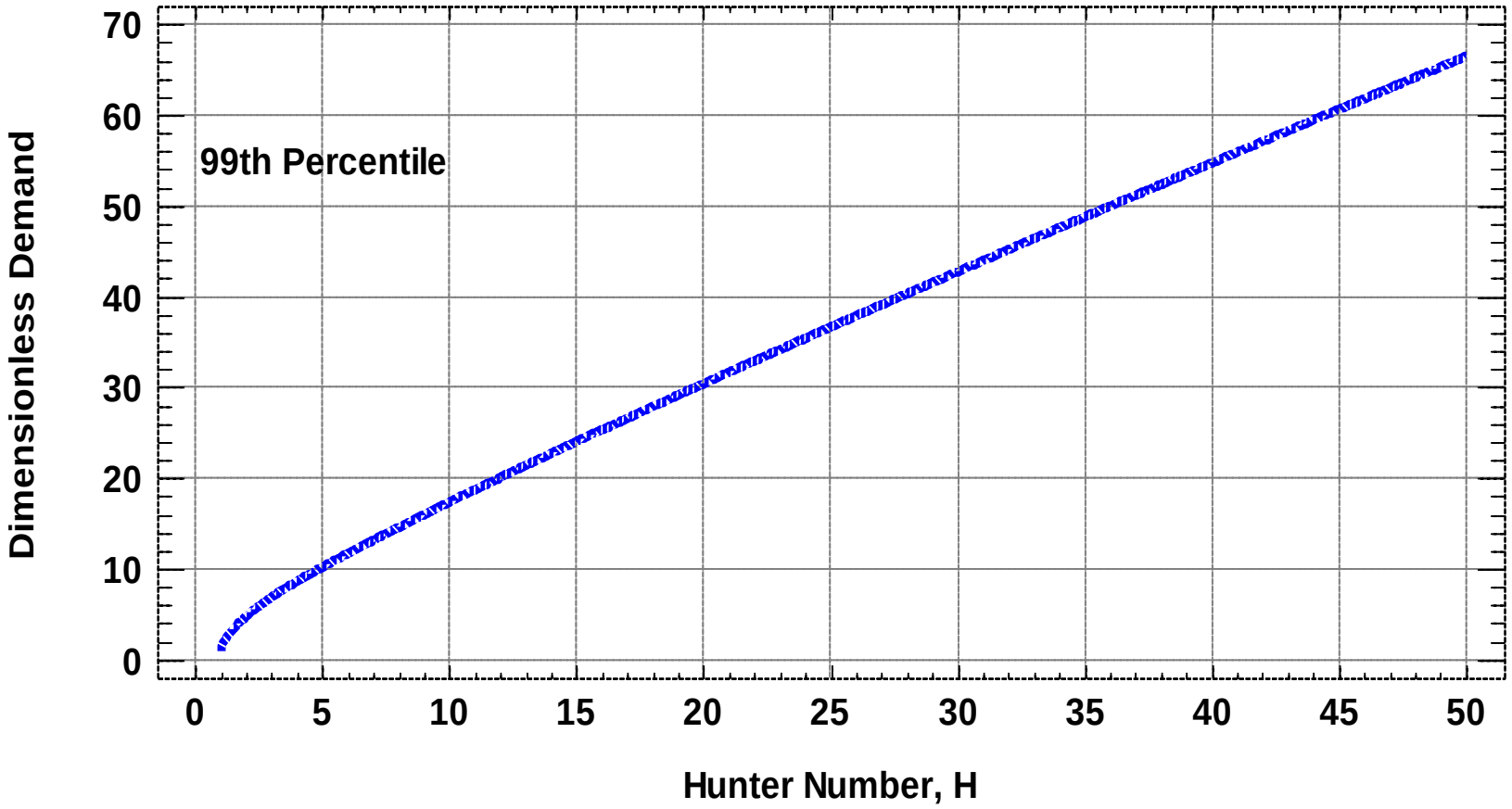




Archive Fixture Values: (p,q)



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 $\boldsymbol{p}$ and $\boldsymbol{q}$ values.
- Can be applied to a wide spectrum of buildings.
- WDC is an appendix in the 2018 Code
- Approach is amendable to BIM platforms.

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