# DOE Challenge Home

***- Tech Training Webinar Series***

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy


## Efficient Hot Water Distribution I – What's at Stake

U.S. DEPARTMENT OF ENERGY CHALLENGE HOME

# The Home of the Future….Today

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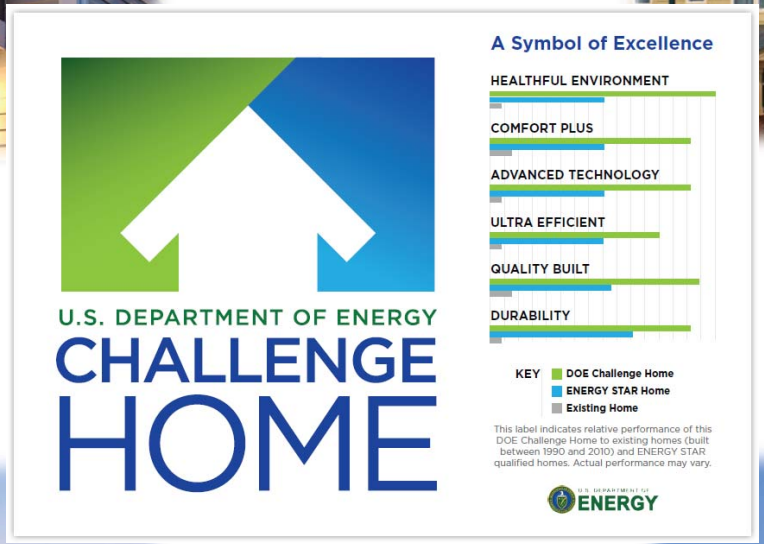


# DOE Challenge Home Resources

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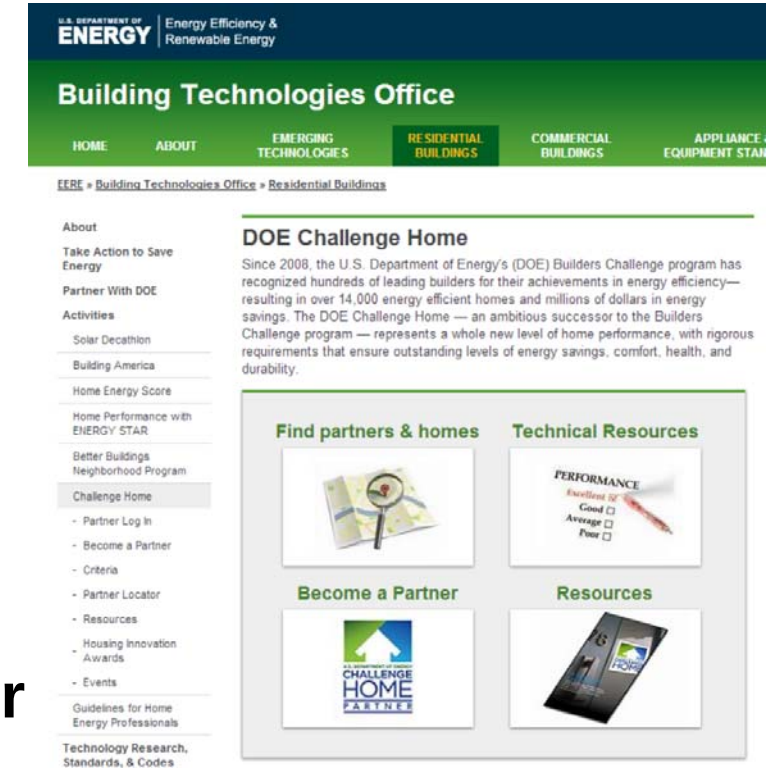
## Website

- www.buildings.energy.gov/challenge/
- Events:
  - Upcoming in-person ZERH Training
  - Technical Training webinars
- Partner Locator
- Program Specifications
- Webinar Recordings (coming soon)




## Building America Solution Center

- http://basc.pnnl.gov/

# DOE Challenge Home
## - Efficient Hot Water Distribution

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Based on EPA WaterSense Specifications:
  - No more than 0.5 gallons of water in any piping/manifold between the hot water source and any hot water fixture.
  - No more than 0.6 gallons of water shall be collected from the hot water fixture before hot water delivered.
  - Recirculation systems based only on a timer or a temperature sensor don't qualify
- Water heater efficiency (ENERGY STAR Level) is addressed in the Target Home
- Performance and system efficiency involve the inter-related components of the water heater, the distribution system, and the flow rates….

# Thank You

U.S. DEPARTMENT OF ENERGY CHALLENGE HOME

**Efficient Hot Water Distribution II – How to Get it Right**

**Thursday January 30, Noon – 1 p.m. Eastern**

## For More Information:

www.buildings.energy.gov/challenge/

## Email:

doechallengehome@newportpartnersllc.com

# Efficient Hot Water Distribution
# Part 1 – What's at Stake

## DOE Challenge Home
## Tech Training Webinars

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# Learning Objectives

1. Understand the relative size of water heating compared to other energy uses and to our budgets.
2. Learn about the magnitude and variability of hot water use patterns.
3. Know the meaning of the terms: “time-to-tap”, “volume-until-hot” and “it’s all about the feel”.
4. Compare the Challenge Home criteria to these performance metrics.
5. Gain insights into what it takes to increase customer satisfaction.

# Table of Contents

# How Big is Hot Water?

# Annual Energy Use for Hot Water?

## Residential

- Single family or individual units in multi-family
  - 10-20 gallons per person per day
  - Large variations within and between households
- Annual costs for a US median household of 3:
  - Approximately $150-300 – natural gas
  - Approximately $500-1,000 – electric resistance or propane
    - Variations depend on temperature rise, water heater or boiler efficiency and fuel price
    - What would operating a heat pump water heater cost?
    - A condensing gas water heater or boiler?
  - Approximately $130 for water and sewer combined

# How Big is Hot Water?

Water heating is the 1st or 2nd largest residential energy end-use: 15 – 30% of a house's total energy pie.

- What is number 1? Number 3?
- Percentage grows as houses and appliances get more efficient

How does this compare to your:

- Cell phone bill?
- Internet bill?
- Cable or Satellite bill?
- Designer coffee bill?

# Why Do I Work on Hot Water?

- Energy Intensity of Indoor Cold Water
  - Range from 5 to 25 kWh per 1000 gallons
- Energy Intensity of Hot Water

| | Electric | | Natural Gas | |
|---|---|---|---|---|
| | Resistance (85% Efficient) | Heat Pump (COP = 2) | (50% Efficient) | (95% Efficient) |
| kWh/1,000 Gallons | 2201 | 885 | 342 | 180 |
| Relative Energy Intensity compared to 5 kWh/1,000 gallons | 440 | 177 | 68 | 36 |

- Typically 40-68 times more energy intensive than indoor cold water.

The most valuable water to conserve
is hot water
at the top of the tallest building, with
the highest elevation,
in the area with the greatest
pressure drop.

# Issues We Face

- Flow rates have been reduced
- Distances to fixtures have increased
- Potential for simultaneous flow is generally overestimated
- Code requirements for minimum pipe diameters have not been revised since before flow rates were reduced
- Codes and efficiency and green programs generally focus on components, not the hot water system
- Others?

# Topics for Discussion

- Fixture fitting and appliance flow rates and fill volumes
- Pipe insulation
- Volume from source of hot water to uses
- Temperature maintenance systems
- Methods of controlling circulation loops
- Drain water heat recovery
- Water heater energy and water heater efficiency
- Vary requirements by type of occupancy
- Energy rating that takes into account reduced hot water use
- Others?

# What Are We Aiming For?

- People want the service of hot water, as efficiently as possible.
- It does not make sense to discuss efficiency until the desired service has been provided.

# The 2 Key Services…

Hot Water Now = “Instantaneousness”

- Need hot water available before the start of each draw.
  - A tank with hot water
  - Heated pipes
- Need the source of hot water close to each fixture or appliance
- Point of Use is not about water heater size, its about location

Never Run Out in My Shower = “Continousness”

- Need a large enough tank or a large enough burner or element
- Or, a modest amount of both

# The Key Components of a Hot Water System

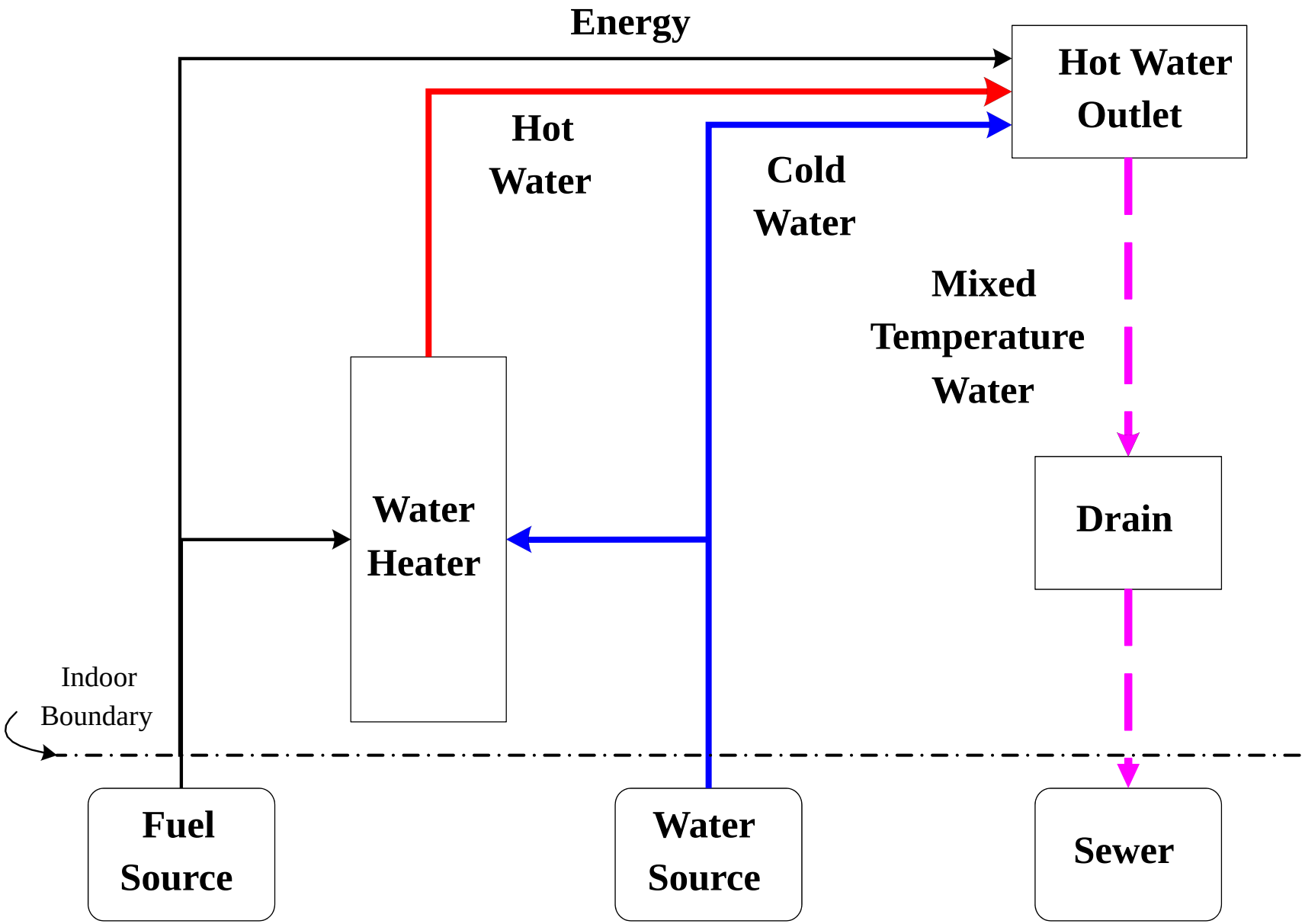
# The Hot Water System

- Treatment and Delivery to the Building
- Use in the Building
  - Water Heater
  - Piping
  - Fixtures, Fittings and Appliances
  - Behavior
  - Water Down the Drain
- Waste Water Removal and Treatment

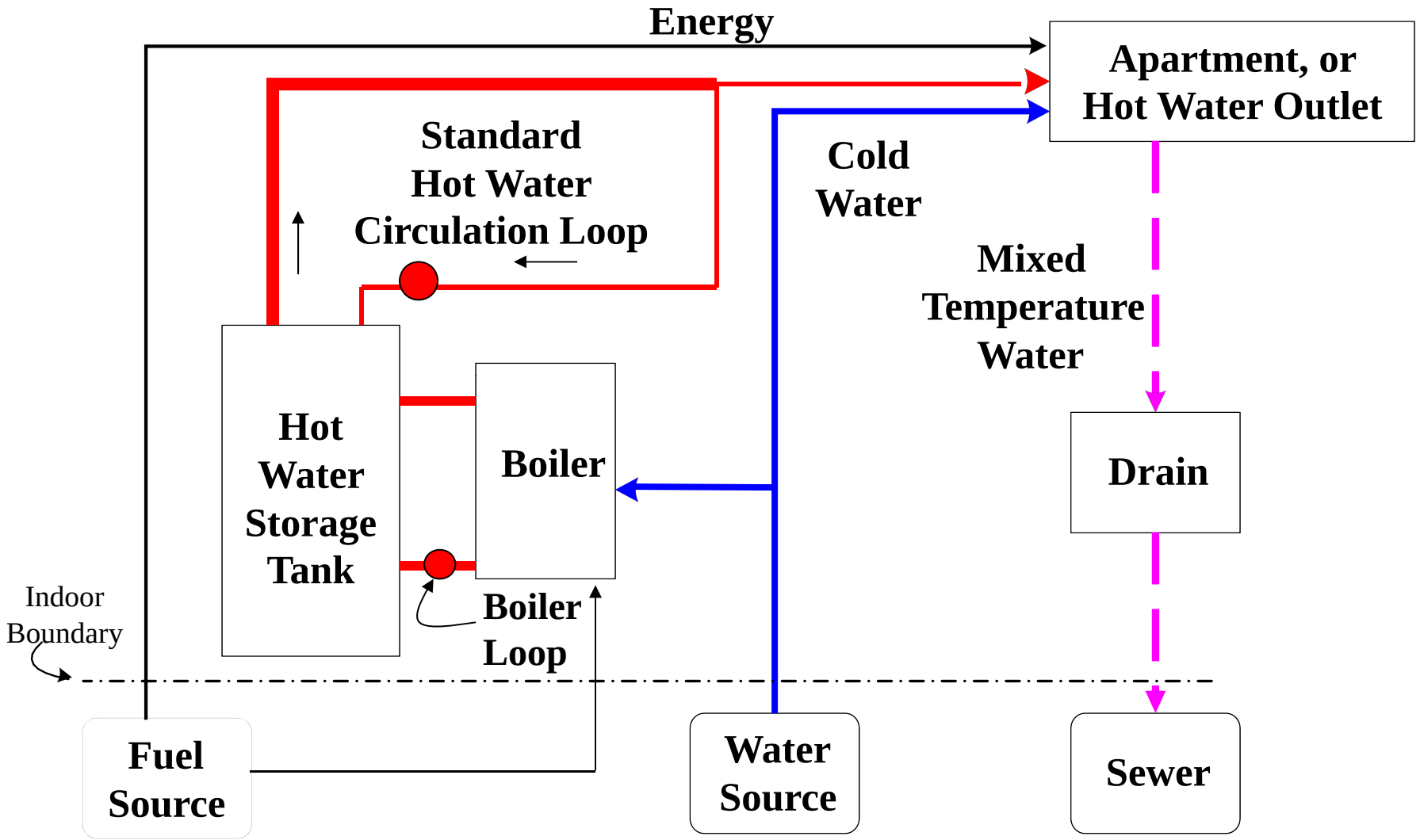
Which is the biggest ***variable*** in determining water and energy use?

How do the ***interactions*** among these components affect ***system*** performance?

# Typical “Simple” Hot Water System



# Typical Central Boiler Hot Water System



# Definitions for Water Supply Piping

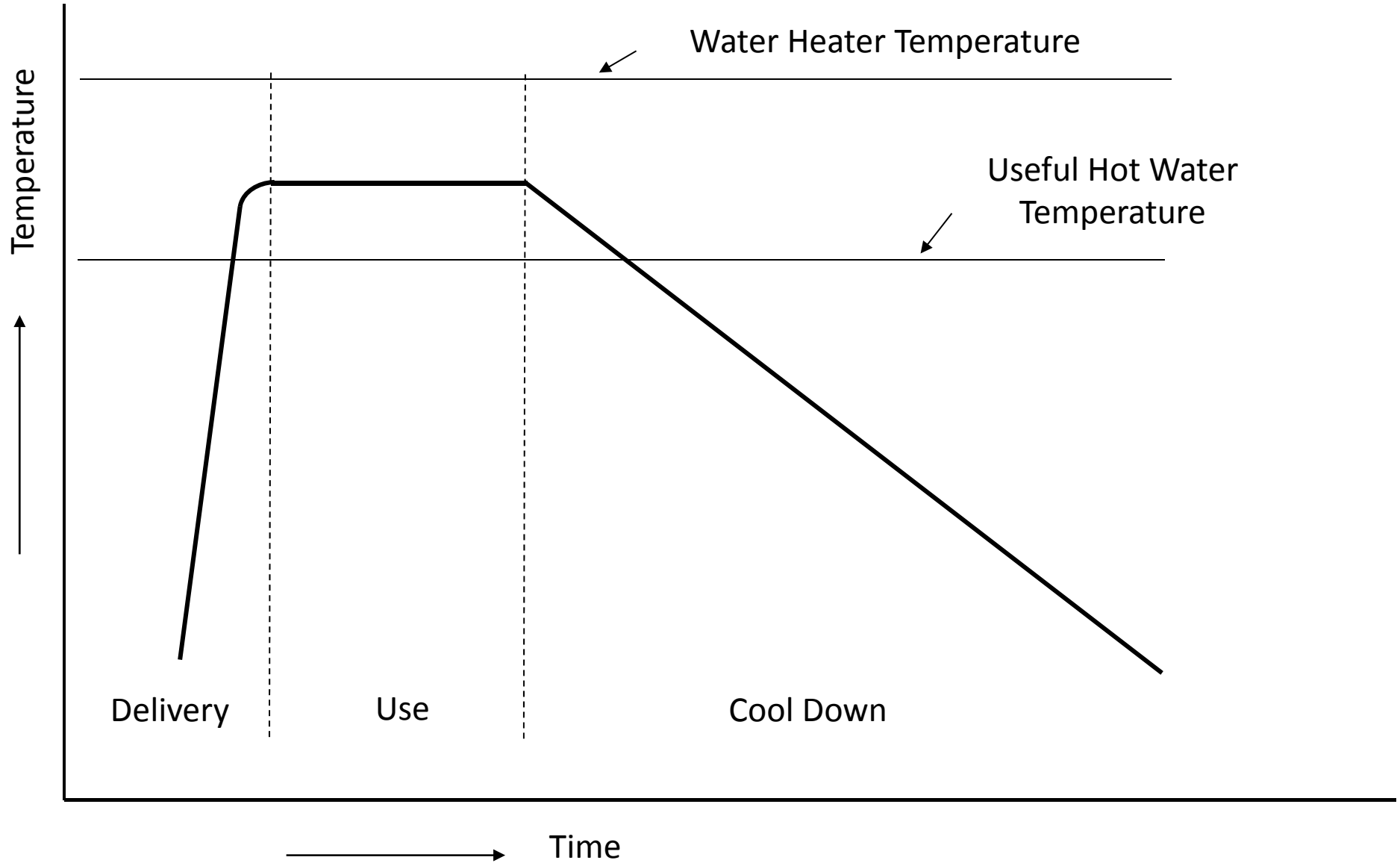
1. A Twig line serves one outlet or appliance.
   - The diameter of the twig should be determined by the flow rate of the outlet or appliance it serves and the pressure drop that will occur due to length, velocity and restrictions to flow (e.g. elbows and tees).
2. A Branch line serves more than one twig.
3. A Trunk line serves branches and twigs.
4. A Main line serves the building.
5. A hot water location contains one or more hot water outlets. Some cold ones too.

# What are Residential Hot Water Use Patterns?

# Do You Know:

- *Anyone who waits a long time to get hot water somewhere in their house? At their job? In their favorite restaurant?*
- Someone who has ever run out of hot water?
- *Any Communities that have a "you can't build unless you can guarantee a long term supply of water" ordinance?*
- Someone who has a "routine"' that they do while waiting for hot water to arrive at their shower? At the kitchen sink? For the dishwasher?
- *Anyone who wants instantaneous hot water?*
- Someone who thinks that a tankless water heater is instantaneous?
- *Anyone who thinks that a whole-house manifold plumbing system will save water?*
- Someone who is confused about how to implement the LEED, NAHB, Water Sense, Build-it-Green or other hot water distribution system credits?
- *Anyone who would like to learn how to get hot water to every fixture wasting no more than 1 cup waiting for the hot water to arrive?*
- Someone who wants to know "the answer"?

# Typical Hot Water Event



# Field Studies of Hot Water Use

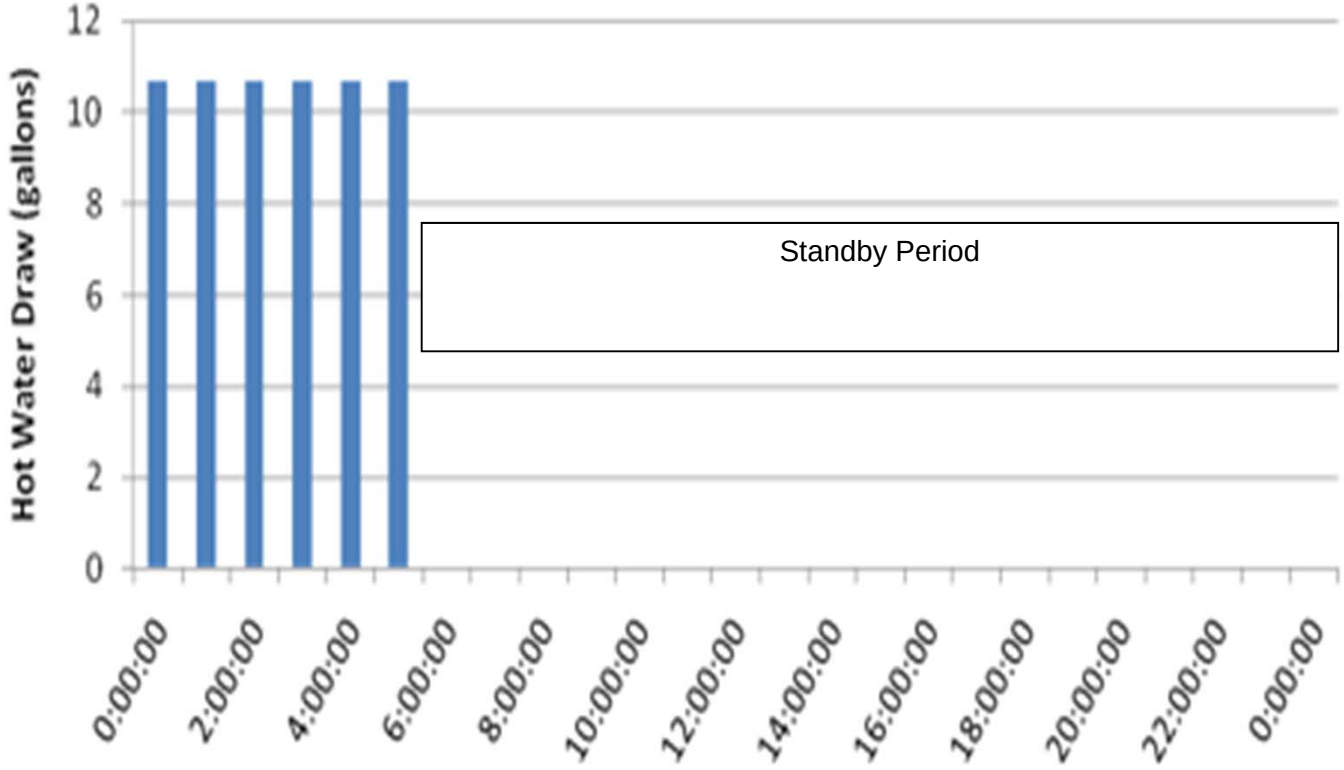
# Summary of Field Studies

- 12 studies
- 159 monitored houses,
- 250 monitored configurations of water heaters and hot water end uses
- 22,902 days of monitoring
- 21,491 days that included inlet water temperature
- 1,679,668 hot water draws
- > 73 draws per day

Source: Jim Lutz and Moya Melody, Typical Hot Water Draw Patterns Based On Field Data, Lawrence Berkeley National Laboratory, November 2012

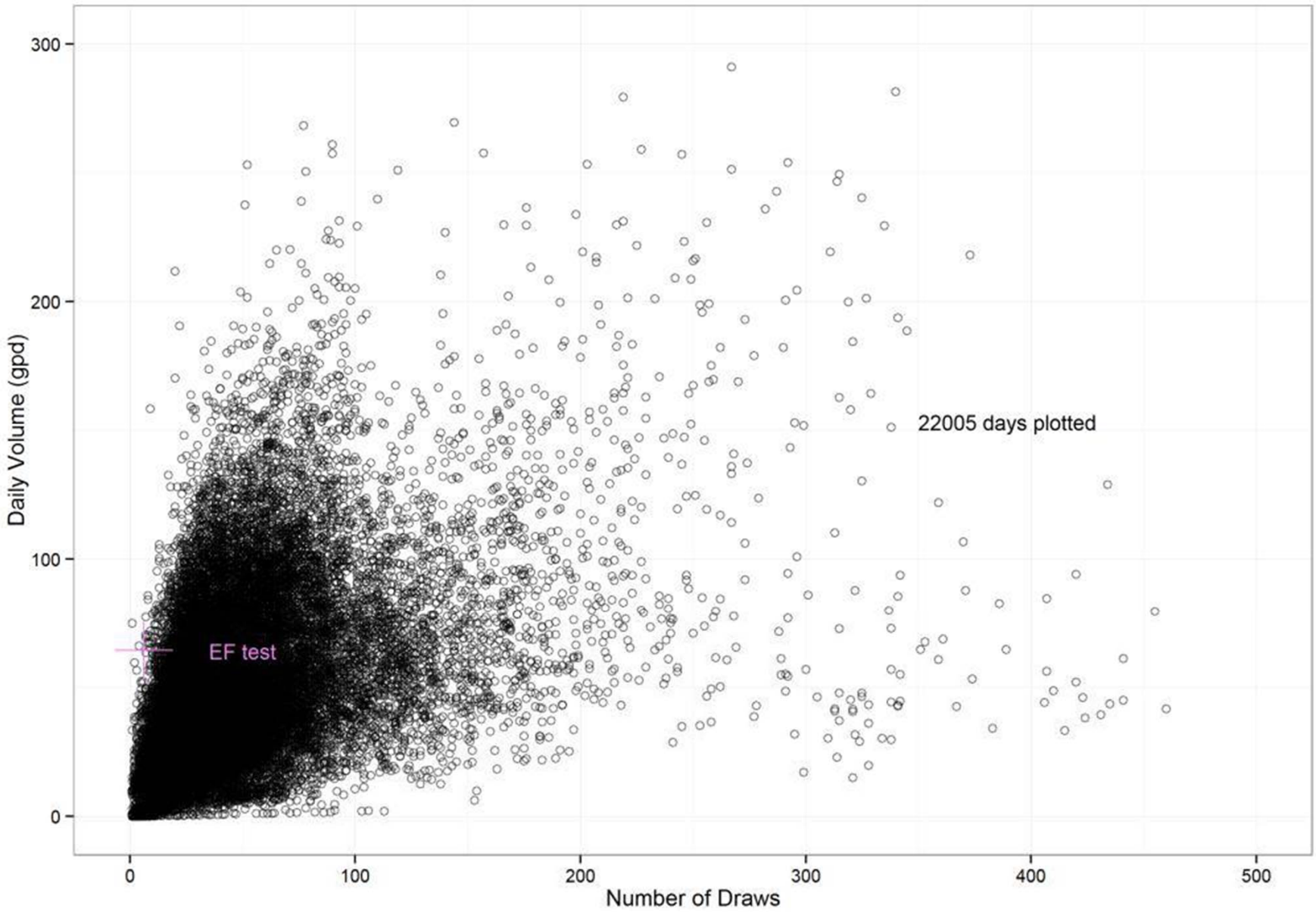
# Draw Patterns for Water Heater Tests

## DOE Test Pattern for Energy Factor

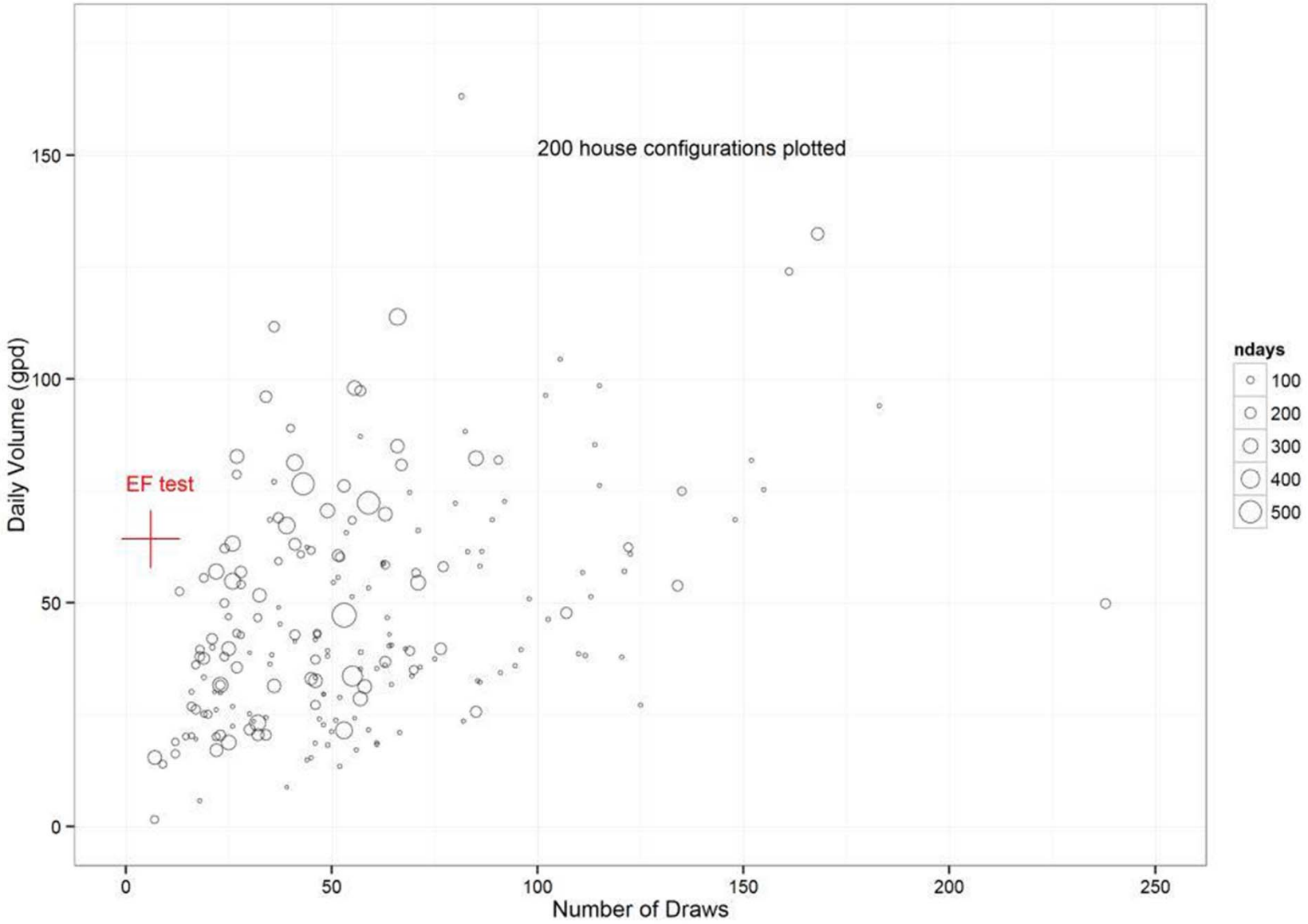



**64.3 gallons per day**
**6 equal draws, 10.72 gallons per draw**
**3 gallons per minute, 3.6 minutes per draw**

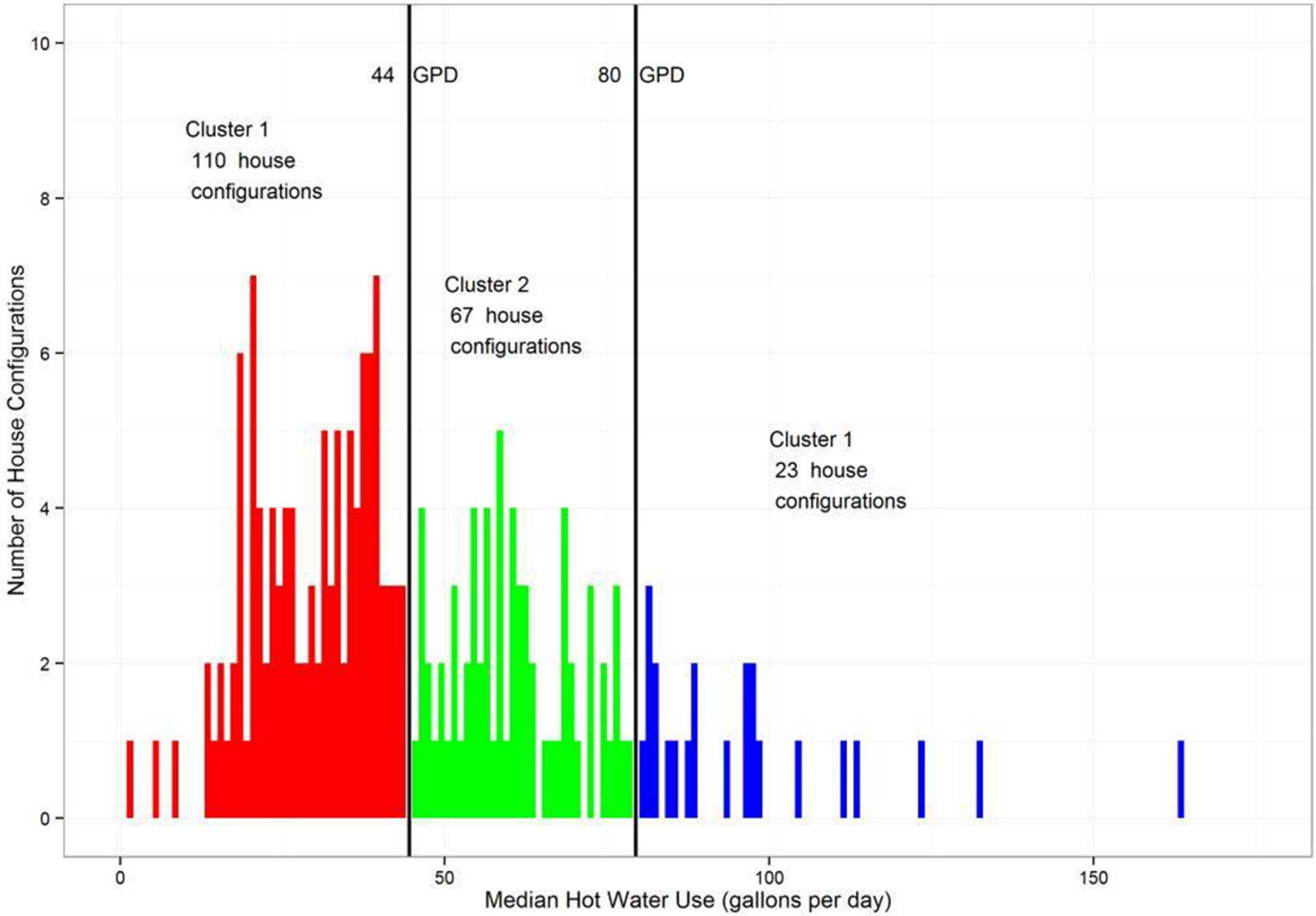
# Daily Hot Water Use



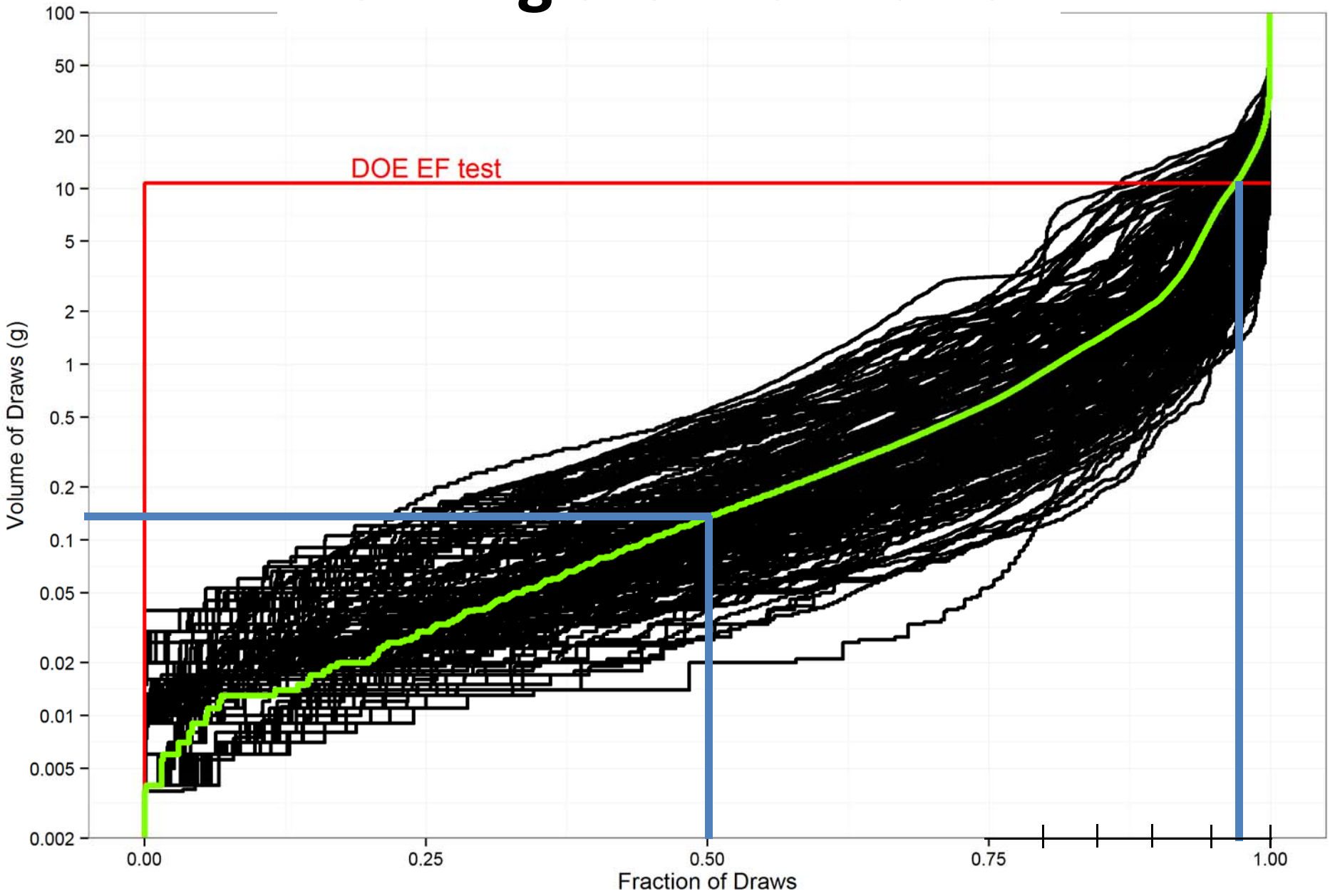
# Median Daily Hot Water Use



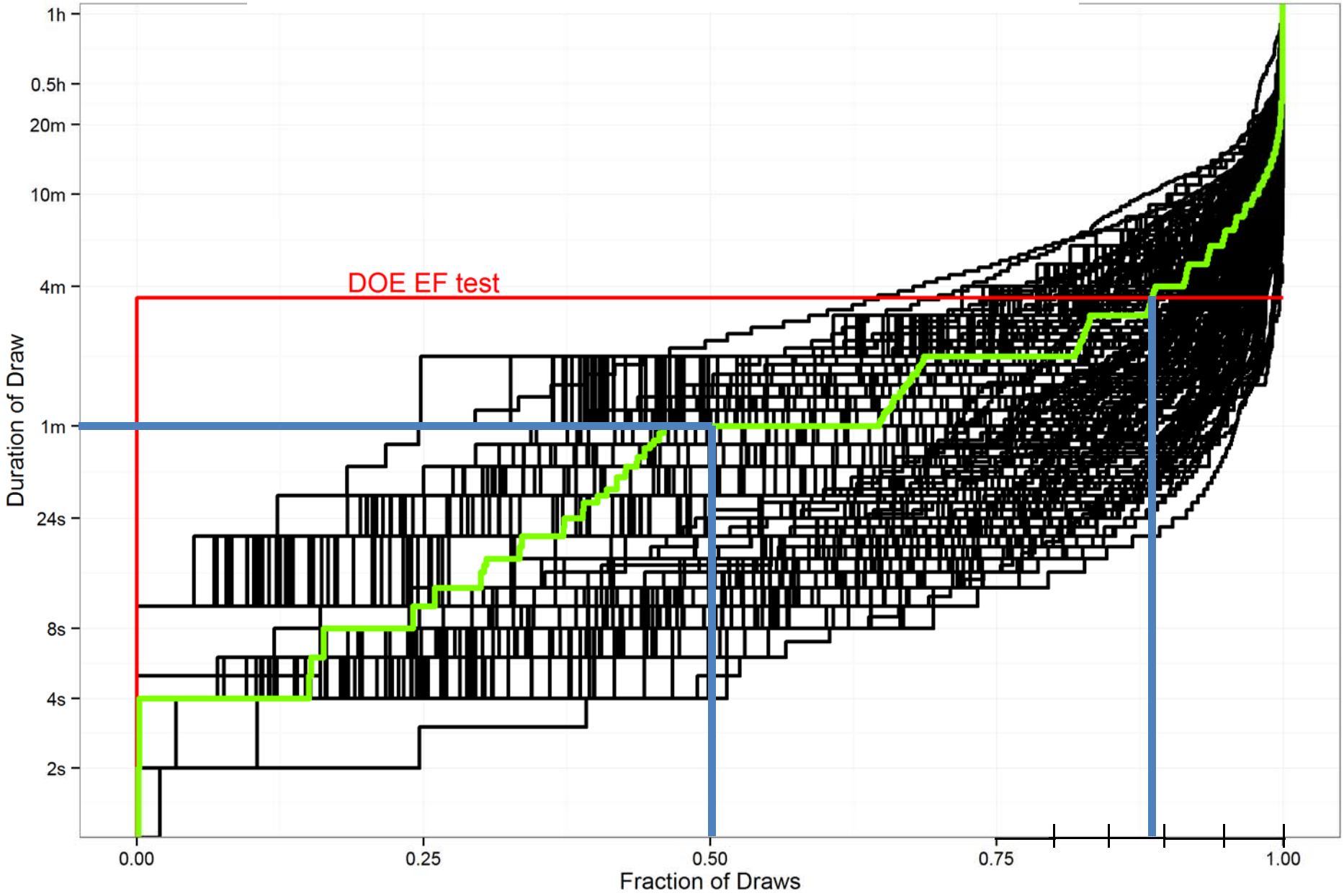
# Clustered Median Daily Hot Water Use



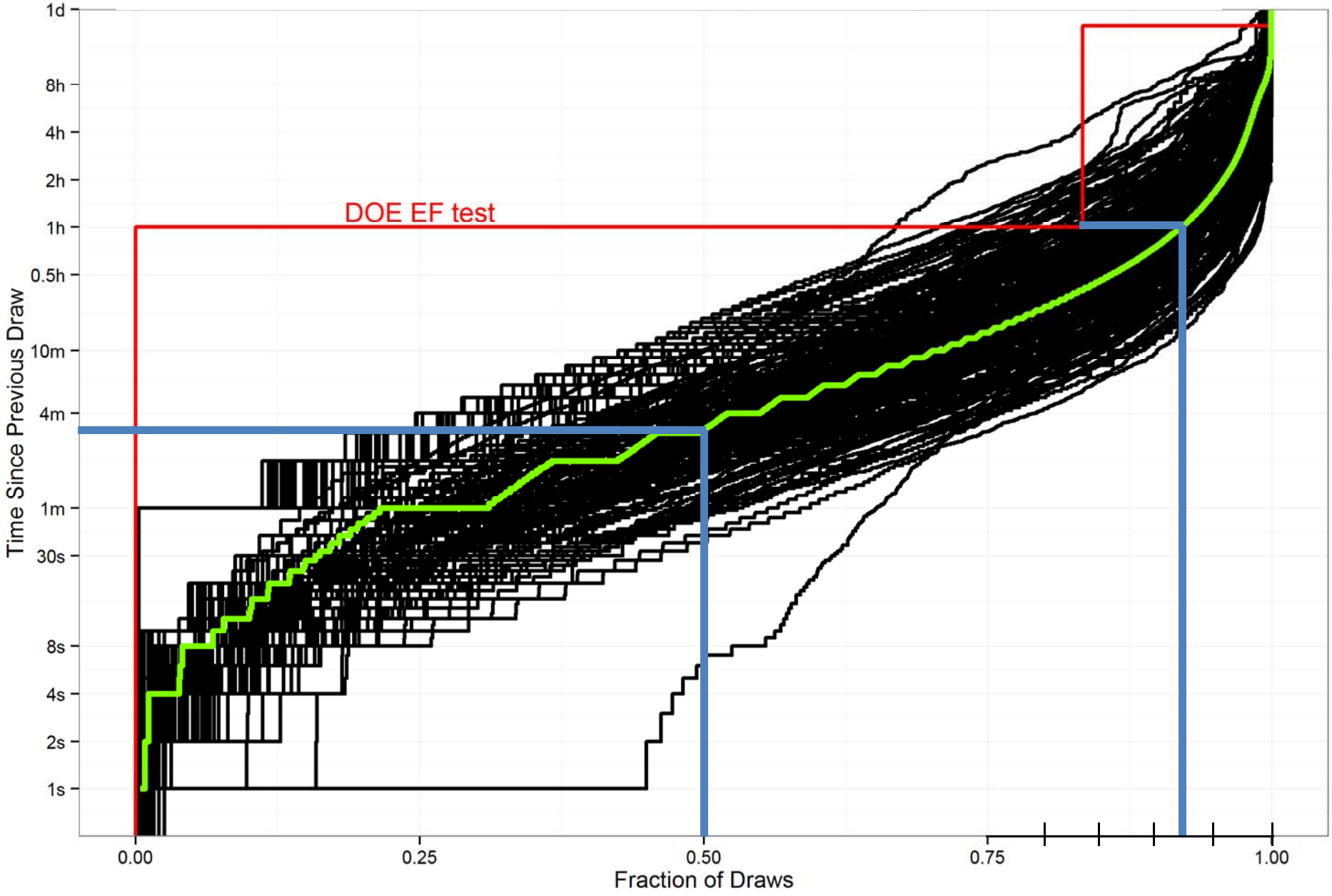
# How Big are the Draws?



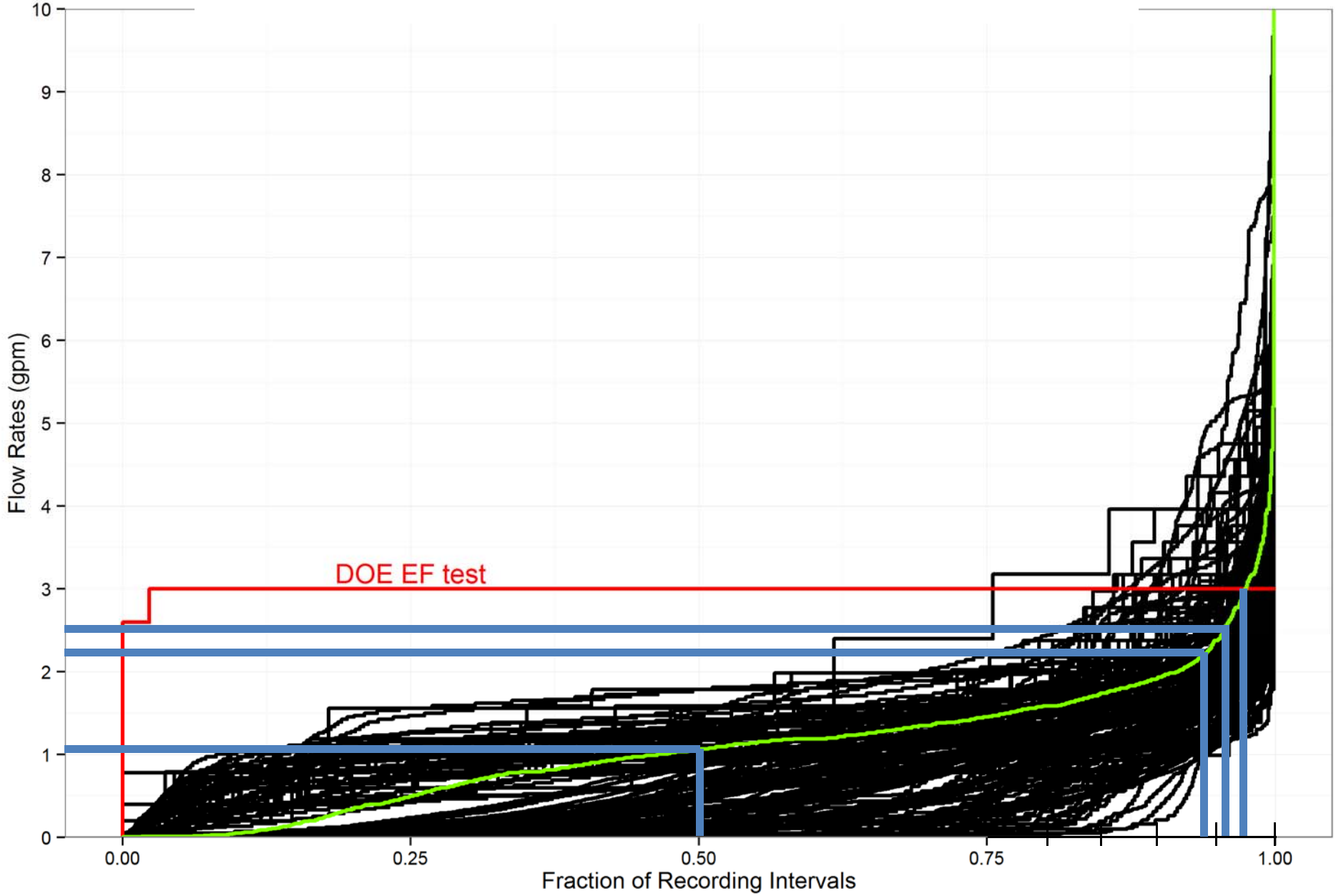
# How Long is Each Draw?



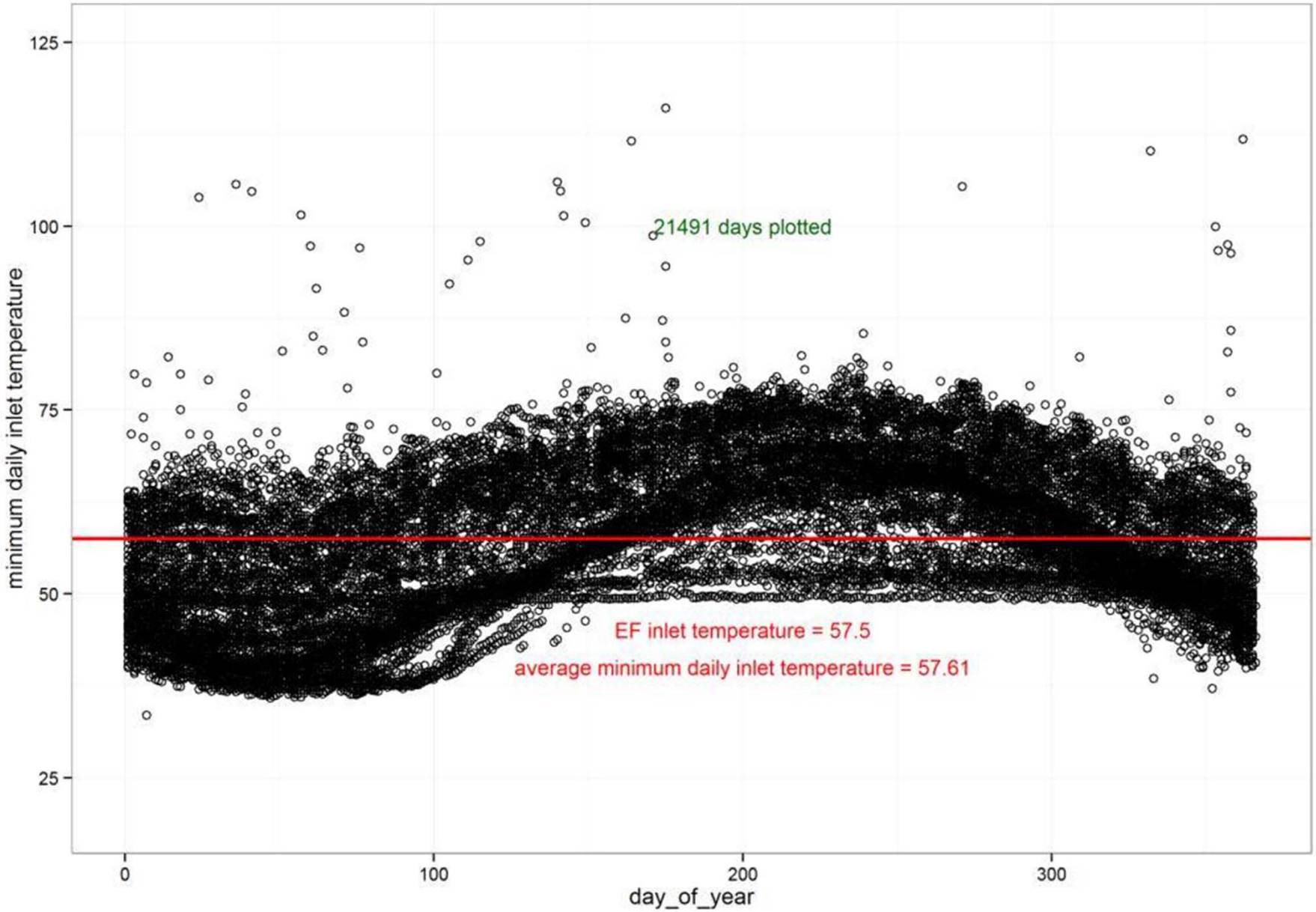
# How Much Time Between Draws?



# What are the Flow Rates?



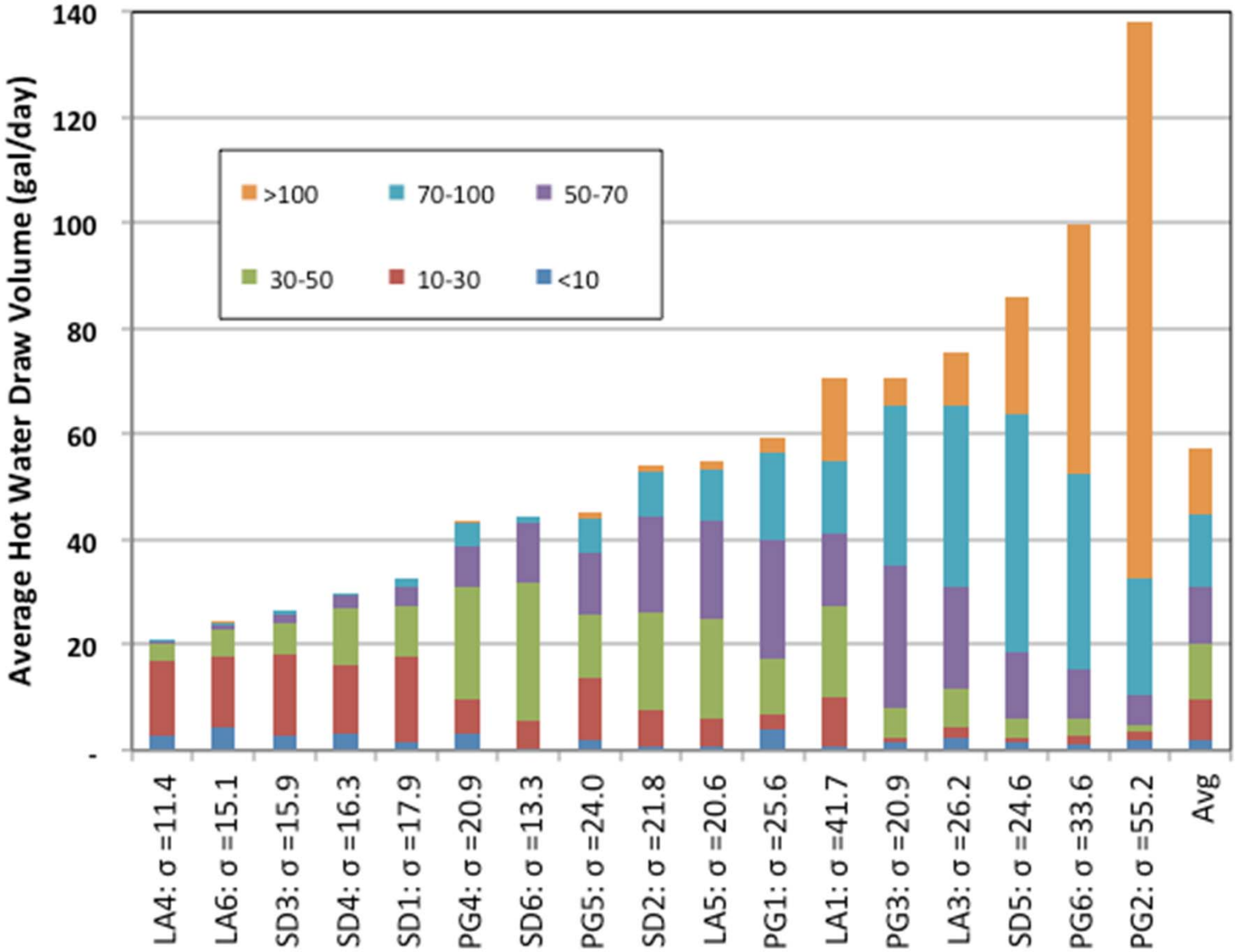
# Inlet Water Temperatures



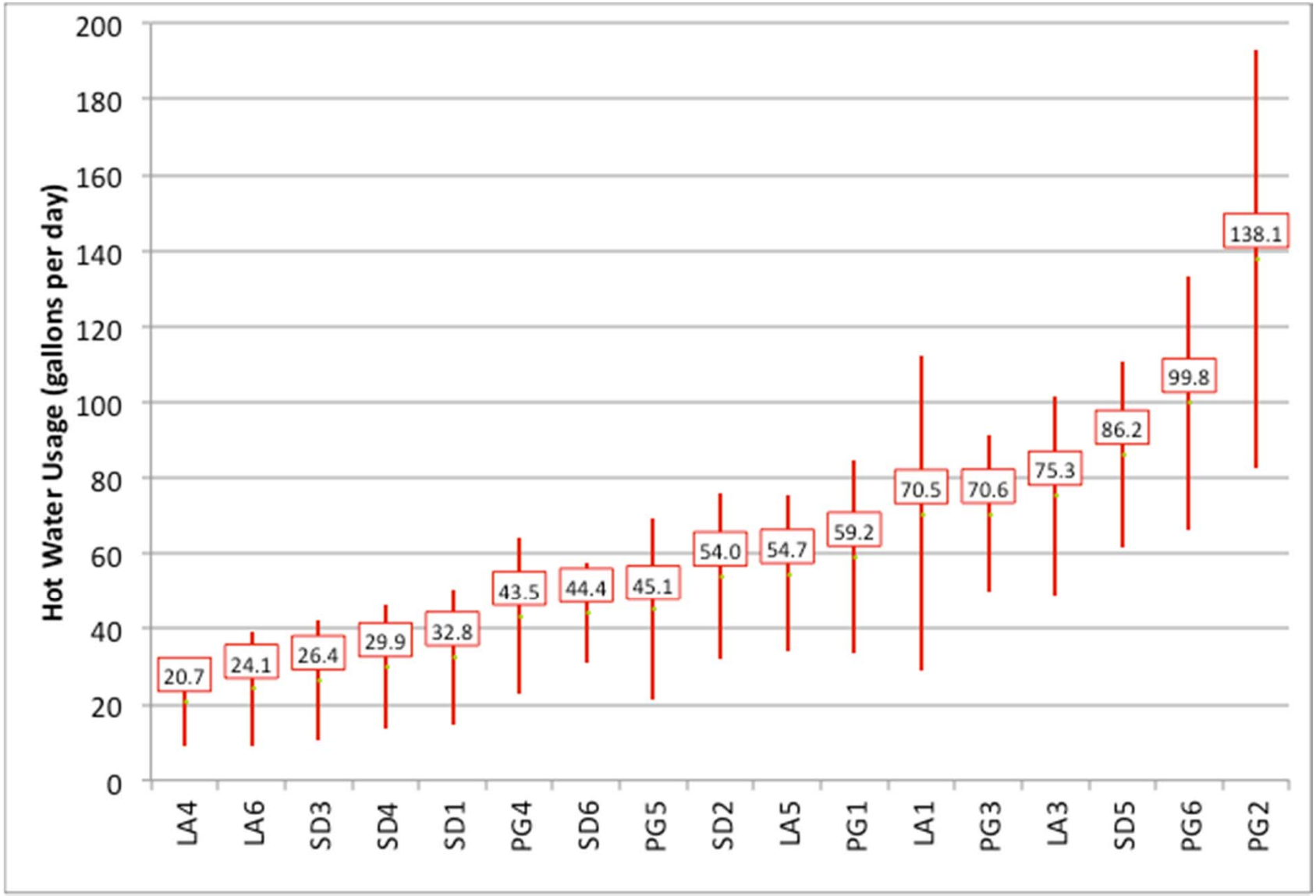
# California Hot Water Research

- Residential Water Heating Program, Prime Contractor – Gas Technology Institute
- Funded by California Energy Commission, CEC 500-08-060
- 36 month study
- Field Studies – hot water use in 18 homes, distribution piping in 100 homes, surveys
- Laboratory Studies – water heaters, distribution piping

# Daily Hot Water Use (Gallons)



# Daily Hot Water Use (Gallons)

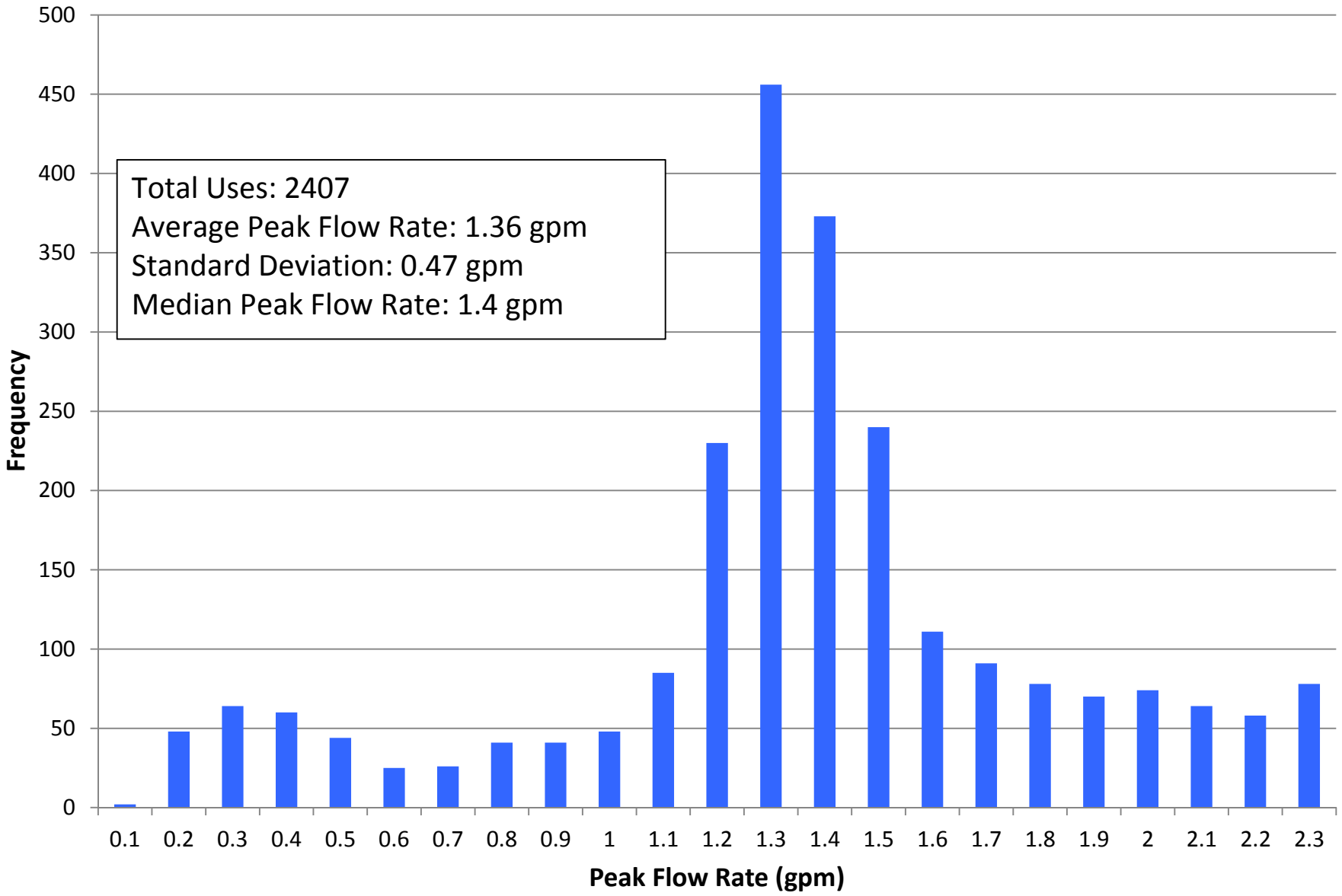


# How do we use hot water?

- Frequent short, low flow-rate draws
- Occasional long draws at low flow-rates
- High flow-rate and high volume draws are rare
- Draws are highly clustered

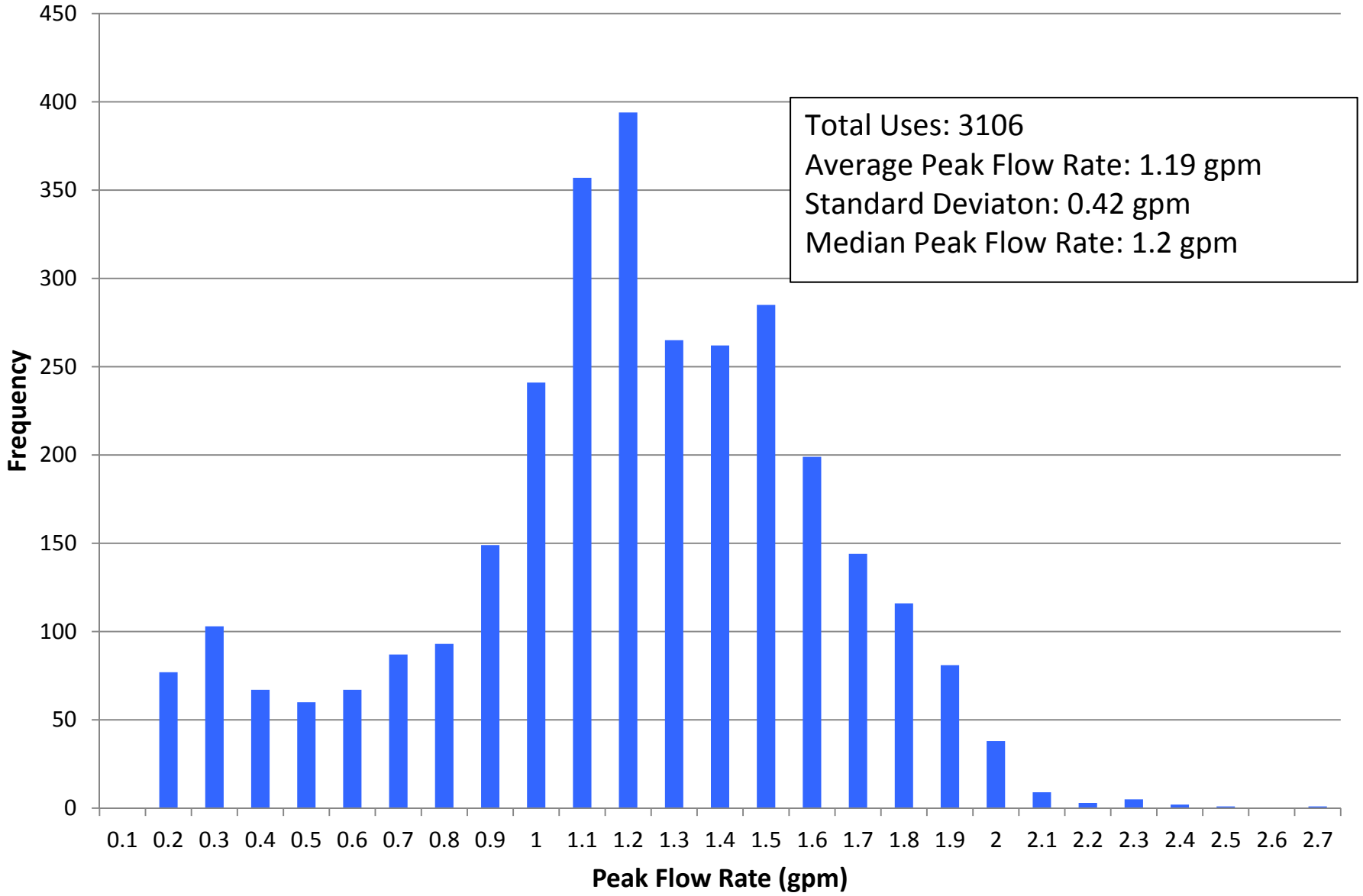
# What We Have Learned About Flow Rates, Volume-until-Hot and Time-to-Tap

# Kitchen Sink Peak Flow Rate Distribution



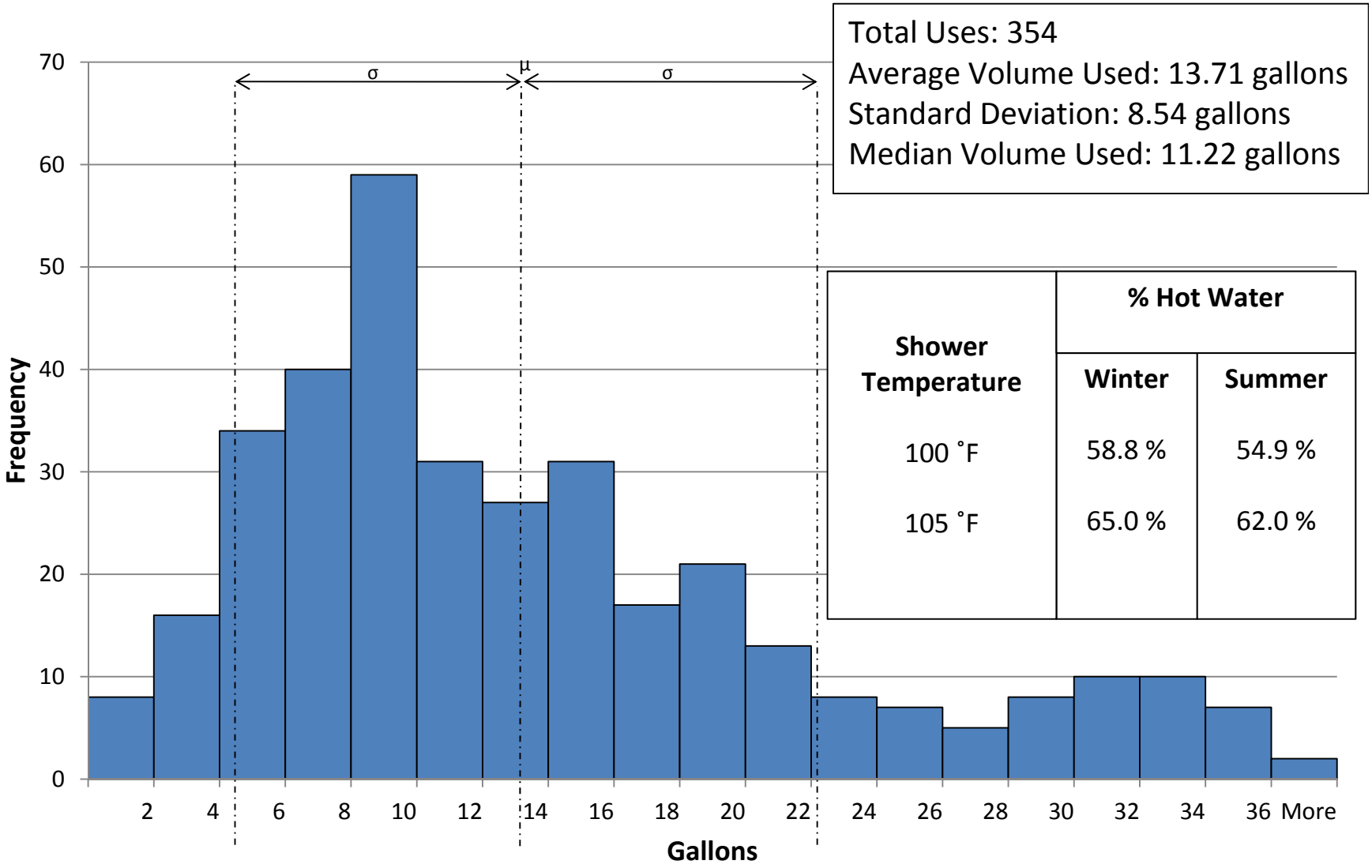

Source: Craig Selover, Masco

# Lavatory Faucet Peak Flow Rate Distribution




Source: Craig Selover, Masco

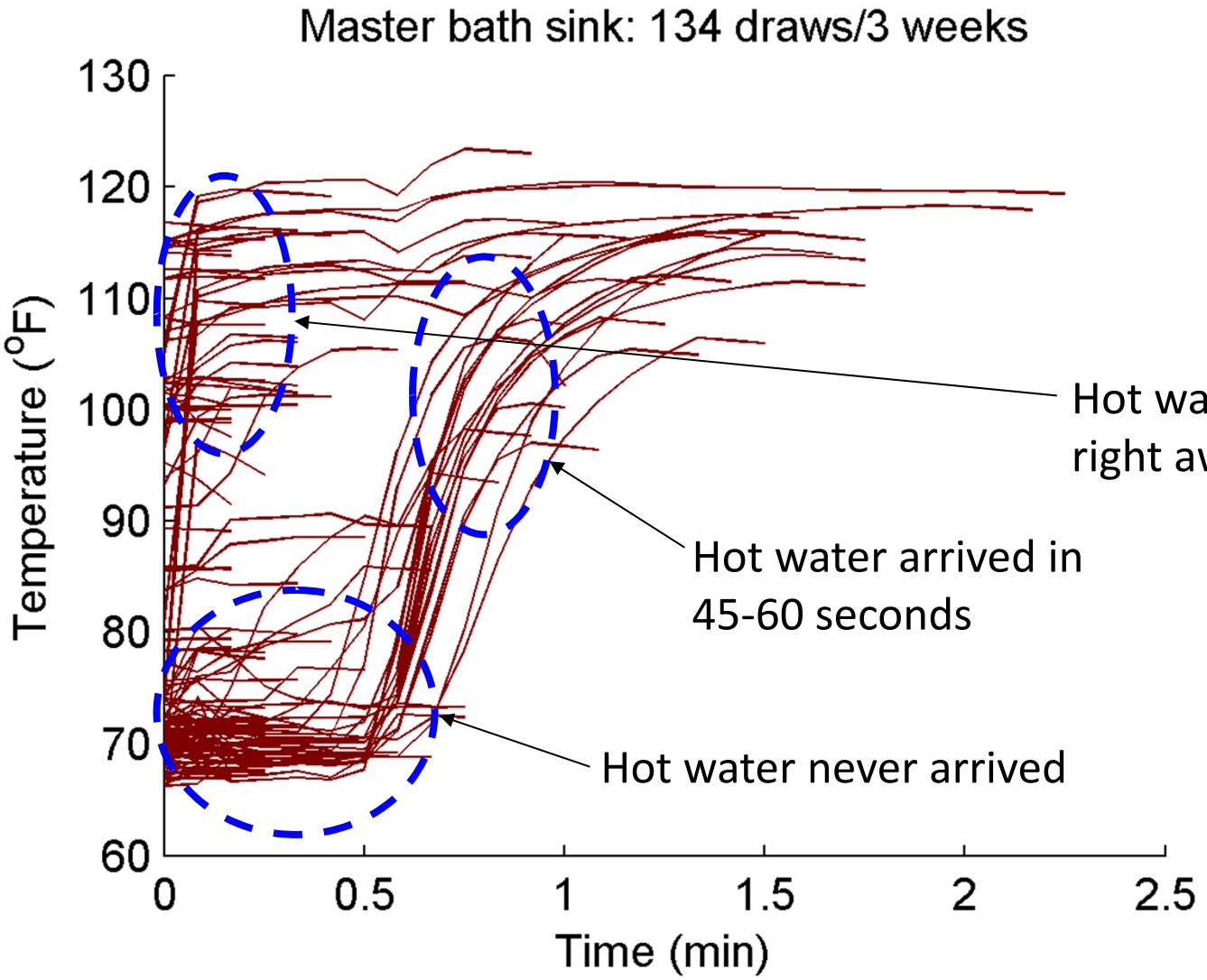
# Shower Uses




| Shower Temperature | % Hot Water | |
|---|---|---|
| | Winter | Summer |
| 100 ˚F | 58.8 % | 54.9 % |
| 105 ˚F | 65.0 % | 62.0 % |

Source: Craig Selover, Masco

# Time and Temperature at the Master Bath Sink




Average draw is 30 ± 29 seconds

Source: National Renewable Energy Laboratory

# How Long Should We Wait?

| Volume in the Pipe (ounces) | Minimum Time-to-Tap (seconds) at Selected Flow Rates | | | | | |
|---|---|---|---|---|---|---|
| | 0.25 gpm | 0.5 gpm | 1 gpm | 1.5 gpm | 2 gpm | 2.5 gpm |
| 2 | 4 | 1.9 | 0.9 | 0.6 | 0.5 | 0.4 |
| 4 | 8 | 4 | 1.9 | 1.3 | 0.9 | 0.8 |
| 8 | 15 | 8 | 4 | 2.5 | 1.9 | 1.5 |
| 16 | 30 | 15 | 8 | 5 | 4 | 3 |
| 24 | 45 | 23 | 11 | 8 | 6 | 5 |
| 32 | 60 | 30 | 15 | 10 | 8 | 6 |
| 64 | 120 | 60 | 30 | 20 | 15 | 12 |
| 128 | 240 | 120 | 60 | 40 | 30 | 24 |

**ASPE Time-to-Tap Performance Criteria**

| | | |
|---|---|---|
| | Acceptable Performance | 1 – 10 seconds |
| | Marginal Performance | 11 – 30 seconds |
| | Unacceptable Performance | 31+ seconds |

Source: Domestic Water Heating Design Manual – 2nd Edition, ASPE, 2003, page 234

# Water Waste as a Function of Flow Rate (Really Velocity)

| Flow Rate | ¾ inch Nominal Diameter Pipe | |
|---|---|---|
| | Relative Water Waste Percent | Approximate Velocity Feet per Second |
| Greater than 4 gpm | Just over 100% | Greater than 3 |
| 4 gpm | 110% | 2.65 |
| 3 gpm | 120% | 1.99 |
| 2 gpm | 130% | 1.33 |
| 1 gpm | 150% | 0.66 |
| 0.5 gpm | Roughly 200% | 0.33 |
| 0.25 gpm | ???? | 0.17 |

The velocity of 0.5 gpm in ¾ inch nominal pipe
is roughly equivalent to the velocity of
2 gpm in 1.5 inch nominal pipe

# Gallons Wasted as a Function of Time and Fixture Flow Rate

(Green < 2 cups), Red >1/2 Gallon)

| Flow Rate (GPM) \ Time-to-Tap (Seconds) | 1 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 105 | 110 | 115 | 120 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.25** | 0.004 | 0.021 | 0.042 | 0.063 | 0.083 | 0.104 | 0.125 | 0.15 | 0.17 | 0.19 | 0.21 | 0.23 | 0.25 | 0.27 | 0.29 | 0.31 | 0.33 | 0.35 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 | 0.48 | 0.5 |
| **0.5** | 0.008 | 0.042 | 0.083 | 0.125 | 0.17 | 0.21 | 0.25 | 0.29 | 0.33 | 0.38 | 0.42 | 0.46 | 0.50 | 0.54 | 0.58 | 0.63 | 0.67 | 0.71 | 0.75 | 0.79 | 0.83 | 0.88 | 0.92 | 0.96 | 1.0 |
| **0.75** | 0.013 | 0.063 | 0.125 | 0.19 | 0.25 | 0.31 | 0.38 | 0.44 | 0.50 | 0.56 | 0.63 | 0.69 | 0.75 | 0.81 | 0.88 | 0.94 | 1.0 | 1.1 | 1.1 | 1.2 | 1.3 | 1.3 | 1.4 | 1.4 | 1.5 |
| **1** | 0.017 | 0.083 | 0.17 | 0.25 | 0.33 | 0.42 | 0.50 | 0.58 | 0.67 | 0.75 | 0.83 | 0.92 | 1.0 | 1.1 | 1.2 | 1.3 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.8 | 1.9 | 2.0 |
| **1.25** | 0.021 | 0.104 | 0.21 | 0.31 | 0.42 | 0.52 | 0.63 | 0.73 | 0.83 | 0.94 | 1.0 | 1.1 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 |
| **1.5** | 0.025 | 0.125 | 0.25 | 0.38 | 0.50 | 0.63 | 0.75 | 0.88 | 1.0 | 1.1 | 1.3 | 1.4 | 1.5 | 1.6 | 1.8 | 1.9 | 2.0 | 2.1 | 2.3 | 2.4 | 2.5 | 2.6 | 2.8 | 2.9 | 3.0 |
| **1.75** | 0.029 | 0.15 | 0.29 | 0.44 | 0.58 | 0.73 | 0.88 | 1.0 | 1.2 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 | 2.0 | 2.2 | 2.3 | 2.5 | 2.6 | 2.8 | 2.9 | 3.1 | 3.2 | 3.4 | 3.5 |
| **2** | 0.033 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.0 | 1.2 | 1.3 | 1.5 | 1.7 | 1.8 | 2.0 | 2.2 | 2.3 | 2.5 | 2.7 | 2.8 | 3.0 | 3.2 | 3.3 | 3.5 | 3.7 | 3.8 | 4.0 |
| **2.25** | 0.038 | 0.19 | 0.38 | 0.56 | 0.75 | 0.94 | 1.1 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.4 | 2.6 | 2.8 | 3.0 | 3.2 | 3.4 | 3.6 | 3.8 | 3.9 | 4.1 | 4.3 | 4.5 |
| **2.5** | 0.042 | 0.21 | 0.42 | 0.63 | 0.83 | 1.0 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 | 2.7 | 2.9 | 3.1 | 3.3 | 3.5 | 3.8 | 4.0 | 4.2 | 4.4 | 4.6 | 4.8 | 5 |
| **3** | 0.05 | 0.25 | 0.50 | 0.75 | 1.0 | 1.3 | 1.5 | 1.8 | 2.0 | 2.3 | 2.5 | 2.8 | 3.0 | 3.3 | 3.5 | 3.8 | 4.0 | 4.3 | 4.5 | 4.8 | 5.0 | 5.3 | 5.5 | 5.8 | 6 |
| **3.5** | 0.058 | 0.29 | 0.58 | 0.88 | 1.2 | 1.5 | 1.8 | 2.0 | 2.3 | 2.6 | 2.9 | 3.2 | 3.5 | 3.8 | 4.1 | 4.4 | 4.7 | 5.0 | 5.3 | 5.5 | 5.8 | 6.1 | 6.4 | 6.7 | 7 |
| **4** | 0.067 | 0.33 | 0.67 | 1.0 | 1.3 | 1.7 | 2.0 | 2.3 | 2.7 | 3.0 | 3.3 | 3.7 | 4.0 | 4.3 | 4.7 | 5.0 | 5.3 | 5.7 | 6.0 | 6.3 | 6.7 | 7.0 | 7.3 | 7.7 | 8 |
| **4.5** | 0.075 | 0.38 | 0.75 | 1.1 | 1.5 | 1.9 | 2.3 | 2.6 | 3.0 | 3.4 | 3.8 | 4.1 | 4.5 | 4.9 | 5.3 | 5.6 | 6.0 | 6.4 | 6.8 | 7.1 | 7.5 | 7.9 | 8.3 | 8.6 | 9 |
| **5** | 0.083 | 0.42 | 0.83 | 1.3 | 1.7 | 2.1 | 2.5 | 2.9 | 3.3 | 3.8 | 4.2 | 4.6 | 5.0 | 5.4 | 5.8 | 6.3 | 6.7 | 7.1 | 7.5 | 7.9 | 8.3 | 8.8 | 9.2 | 9.6 | 10 |
| **5.5** | 0.092 | 0.46 | 0.92 | 1.4 | 1.8 | 2.3 | 2.8 | 3.2 | 3.7 | 4.1 | 4.6 | 5.0 | 5.5 | 6.0 | 6.4 | 6.9 | 7.3 | 7.8 | 8.3 | 8.7 | 9.2 | 9.6 | 10.1 | 10.5 | 11 |
| **6** | 0.100 | 0.50 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 10.0 | 10.5 | 11.0 | 11.5 | 12 |
| **6.5** | 0.108 | 0.54 | 1.1 | 1.6 | 2.2 | 2.7 | 3.3 | 3.8 | 4.3 | 4.9 | 5.4 | 6.0 | 6.5 | 7.0 | 7.6 | 8.1 | 8.7 | 9.2 | 9.8 | 10.3 | 10.8 | 11.4 | 11.9 | 12.5 | 13 |
| **7** | 0.117 | 0.58 | 1.2 | 1.8 | 2.3 | 2.9 | 3.5 | 4.1 | 4.7 | 5.3 | 5.8 | 6.4 | 7.0 | 7.6 | 8.2 | 8.8 | 9.3 | 9.9 | 10.5 | 11.1 | 11.7 | 12.3 | 12.8 | 13.4 | 14 |
| **7.5** | 0.125 | 0.63 | 1.3 | 1.9 | 2.5 | 3.1 | 3.8 | 4.4 | 5.0 | 5.6 | 6.3 | 6.9 | 7.5 | 8.1 | 8.8 | 9.4 | 10.0 | 10.6 | 11.3 | 11.9 | 12.5 | 13.1 | 13.8 | 14.4 | 15 |
| **8** | 0.13 | 0.67 | 1.3 | 2.0 | 2.7 | 3.3 | 4.0 | 4.7 | 5.3 | 6.0 | 6.7 | 7.3 | 8.0 | 8.7 | 9.3 | 10.0 | 10.7 | 11.3 | 12.0 | 12.7 | 13.3 | 14.0 | 14.7 | 15.3 | 16 |
| **8.5** | 0.14 | 0.71 | 1.4 | 2.1 | 2.8 | 3.5 | 4.3 | 5.0 | 5.7 | 6.4 | 7.1 | 7.8 | 8.5 | 9.2 | 9.9 | 10.6 | 11.3 | 12.0 | 12.8 | 13.5 | 14.2 | 14.9 | 15.6 | 16.3 | 17 |
| **9** | 0.15 | 0.75 | 1.5 | 2.3 | 3.0 | 3.8 | 4.5 | 5.3 | 6.0 | 6.8 | 7.5 | 8.3 | 9.0 | 9.8 | 10.5 | 11.3 | 12.0 | 12.8 | 13.5 | 14.3 | 15.0 | 15.8 | 16.5 | 17.3 | 18 |
| **9.5** | 0.16 | 0.79 | 1.6 | 2.4 | 3.2 | 4.0 | 4.8 | 5.5 | 6.3 | 7.1 | 7.9 | 8.7 | 9.5 | 10.3 | 11.1 | 11.9 | 12.7 | 13.5 | 14.3 | 15.0 | 15.8 | 16.6 | 17.4 | 18.2 | 19 |
| **10** | 0.17 | 0.83 | 1.7 | 2.5 | 3.3 | 4.2 | 5.0 | 5.8 | 6.7 | 7.5 | 8.3 | 9.17 | 10.0 | 10.8 | 11.7 | 12.5 | 13.3 | 14.2 | 15.0 | 15.8 | 16.7 | 17.5 | 18.3 | 19.2 | 20 |

# Gallons Wasted as a Function of Time and Fixture Flow Rate

(Green < 2 cups), Red >1/2 Gallon)

| Flow Rate (GPM) \ Time Until Hot Water Arrives (Seconds) | 1 | 2 | 3 | 4 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.08 | 0.13 | 0.17 | 0.21 | 0.25 | 0.29 | 0.33 | 0.38 | 0.42 | 0.46 | 0.50 |
| 1 | 0.02 | 0.03 | 0.05 | 0.07 | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.50 | 0.58 | 0.67 | 0.75 | 0.83 | 0.92 | 1.00 |
| 1.5 | 0.03 | 0.05 | 0.08 | 0.10 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 0.75 | 0.88 | 1.00 | 1.13 | 1.25 | 1.38 | 1.50 |
| 2 | 0.03 | 0.07 | 0.10 | 0.13 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.00 | 1.17 | 1.33 | 1.50 | 1.67 | 1.83 | 2.00 |
| 2.5 | 0.04 | 0.08 | 0.13 | 0.17 | 0.21 | 0.42 | 0.63 | 0.83 | 1.04 | 1.25 | 1.46 | 1.67 | 1.88 | 2.08 | 2.29 | 2.50 |
| 3 | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 | 2.25 | 2.50 | 2.75 | 3.00 |
| 3.5 | 0.06 | 0.12 | 0.18 | 0.23 | 0.29 | 0.58 | 0.88 | 1.17 | 1.46 | 1.75 | 2.04 | 2.33 | 2.63 | 2.92 | 3.21 | 3.50 |
| 4 | 0.07 | 0.13 | 0.20 | 0.27 | 0.33 | 0.67 | 1.00 | 1.33 | 1.67 | 2.00 | 2.33 | 2.67 | 3.00 | 3.33 | 3.67 | 4.00 |
| 4.5 | 0.08 | 0.15 | 0.23 | 0.30 | 0.38 | 0.75 | 1.13 | 1.50 | 1.88 | 2.25 | 2.63 | 3.00 | 3.38 | 3.75 | 4.13 | 4.50 |
| 5 | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.83 | 1.25 | 1.67 | 2.08 | 2.50 | 2.92 | 3.33 | 3.75 | 4.17 | 4.58 | 5.00 |
| 5.5 | 0.09 | 0.18 | 0.28 | 0.37 | 0.46 | 0.92 | 1.38 | 1.83 | 2.29 | 2.75 | 3.21 | 3.67 | 4.13 | 4.58 | 5.04 | 5.50 |
| 6 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 |
| 6.5 | 0.11 | 0.22 | 0.33 | 0.43 | 0.54 | 1.08 | 1.63 | 2.17 | 2.71 | 3.25 | 3.79 | 4.33 | 4.88 | 5.42 | 5.96 | 6.50 |
| 7 | 0.12 | 0.23 | 0.35 | 0.47 | 0.58 | 1.17 | 1.75 | 2.33 | 2.92 | 3.50 | 4.08 | 4.67 | 5.25 | 5.83 | 6.42 | 7.00 |
| 7.5 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 1.25 | 1.88 | 2.50 | 3.13 | 3.75 | 4.38 | 5.00 | 5.63 | 6.25 | 6.88 | 7.50 |
| 8 | 0.13 | 0.27 | 0.40 | 0.53 | 0.67 | 1.33 | 2.00 | 2.67 | 3.33 | 4.00 | 4.67 | 5.33 | 6.00 | 6.67 | 7.33 | 8.00 |
| 8.5 | 0.14 | 0.28 | 0.43 | 0.57 | 0.71 | 1.42 | 2.13 | 2.83 | 3.54 | 4.25 | 4.96 | 5.67 | 6.38 | 7.08 | 7.79 | 8.50 |
| 9 | 0.15 | 0.30 | 0.45 | 0.60 | 0.75 | 1.50 | 2.25 | 3.00 | 3.75 | 4.50 | 5.25 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 |
| 9.5 | 0.16 | 0.32 | 0.48 | 0.63 | 0.79 | 1.58 | 2.38 | 3.17 | 3.96 | 4.75 | 5.54 | 6.33 | 7.13 | 7.92 | 8.71 | 9.50 |
| 10 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.67 | 2.50 | 3.33 | 4.17 | 5.00 | 5.83 | 6.67 | 7.50 | 8.33 | 9.17 | 10.00 |

1 cup = 8 ounces = 1/16$^{th}$ gallon = 0.0625 gallon

# Gallons Wasted as a Function of Time and Fixture Flow Rate

(Green < 2 cups), Red >1/2 Gallon)

| Flow Rate (GPM) \ Time Until Hot Water Arrives (Seconds) | 1 | 2 | 3 | 4 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.08 | 0.13 | 0.17 | 0.21 | 0.25 | 0.29 | 0.33 | 0.38 | 0.42 | 0.46 | 0.50 |
| 1 | 0.02 | 0.03 | 0.05 | 0.07 | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.50 | 0.58 | 0.67 | 0.75 | 0.83 | 0.92 | 1.00 |
| 1.5 | 0.03 | 0.05 | 0.08 | 0.10 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 0.75 | 0.88 | 1.00 | 1.13 | 1.25 | 1.38 | 1.50 |
| 2 | 0.03 | 0.07 | 0.10 | 0.13 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.00 | 1.17 | 1.33 | 1.50 | 1.67 | 1.83 | 2.00 |
| 2.5 | 0.04 | 0.08 | 0.13 | 0.17 | 0.21 | 0.42 | 0.63 | [illegible] | 1.04 | 1.25 | 1.46 | 1.67 | 1.88 | 2.08 | 2.29 | 2.50 |
| 3 | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.50 | 0.75 | [illegible] | 1.25 | 1.50 | 1.75 | 2.00 | 2.25 | 2.50 | 2.75 | 3.00 |
| 3.5 | 0.06 | 0.12 | 0.18 | 0.23 | 0.29 | 0.58 | 0.88 | 1.17 | [illegible] | 1.75 | 2.04 | 2.33 | 2.63 | 2.92 | 3.21 | 3.50 |
| 4 | 0.07 | 0.13 | 0.20 | 0.27 | 0.33 | 0.67 | 1.00 | 1.33 | [illegible] | 2.00 | 2.33 | 2.67 | 3.00 | 3.33 | 3.67 | 4.00 |
| 4.5 | 0.08 | 0.15 | 0.23 | 0.30 | 0.38 | 0.75 | 1.13 | 1.50 | 1.88 | 2.25 | 2.63 | 3.00 | 3.38 | 3.75 | 4.13 | 4.50 |
| 5 | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.83 | 1.25 | 1.67 | 2.08 | 2.50 | 2.92 | 3.33 | 3.75 | 4.17 | 4.58 | 5.00 |
| 5.5 | 0.09 | 0.18 | 0.28 | 0.37 | 0.46 | 0.92 | 1.38 | 1.83 | 2.29 | 2.75 | 3.21 | 3.67 | 4.13 | 4.58 | 5.04 | 5.50 |
| 6 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 |
| 6.5 | 0.11 | 0.22 | 0.33 | 0.43 | 0.54 | 1.08 | 1.63 | 2.17 | 2.71 | 3.25 | 3.79 | 4.33 | 4.88 | 5.42 | 5.96 | 6.50 |
| 7 | 0.12 | 0.23 | 0.35 | 0.47 | 0.58 | 1.17 | 1.75 | 2.33 | 2.92 | 3.50 | 4.08 | 4.67 | 5.25 | 5.83 | 6.42 | 7.00 |
| 7.5 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 1.25 | 1.88 | 2.50 | 3.13 | 3.75 | 4.38 | 5.00 | 5.63 | 6.25 | 6.88 | 7.50 |
| 8 | 0.13 | 0.27 | 0.40 | 0.53 | 0.67 | 1.33 | 2.00 | 2.67 | 3.33 | 4.00 | 4.67 | 5.33 | 6.00 | 6.67 | 7.33 | 8.00 |
| 8.5 | 0.14 | 0.28 | 0.43 | 0.57 | 0.71 | 1.42 | 2.13 | 2.83 | 3.54 | 4.25 | 4.96 | 5.67 | 6.38 | 7.08 | 7.79 | 8.50 |
| 9 | 0.15 | 0.30 | 0.45 | 0.60 | 0.75 | 1.50 | 2.25 | 3.00 | 3.75 | 4.50 | 5.25 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 |
| 9.5 | 0.16 | 0.32 | 0.48 | 0.63 | 0.79 | 1.58 | 2.38 | 3.17 | 3.96 | 4.75 | 5.54 | 6.33 | 7.13 | 7.92 | 8.71 | 9.50 |
| 10 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.67 | 2.50 | 3.33 | 4.17 | 5.00 | 5.83 | 6.67 | 7.50 | 8.33 | 9.17 | 10.00 |

1 cup = 8 ounces = 1/16$^{th}$ gallon = 0.0625 gallon

# Gallons Wasted as a Function of Time and Fixture Flow Rate

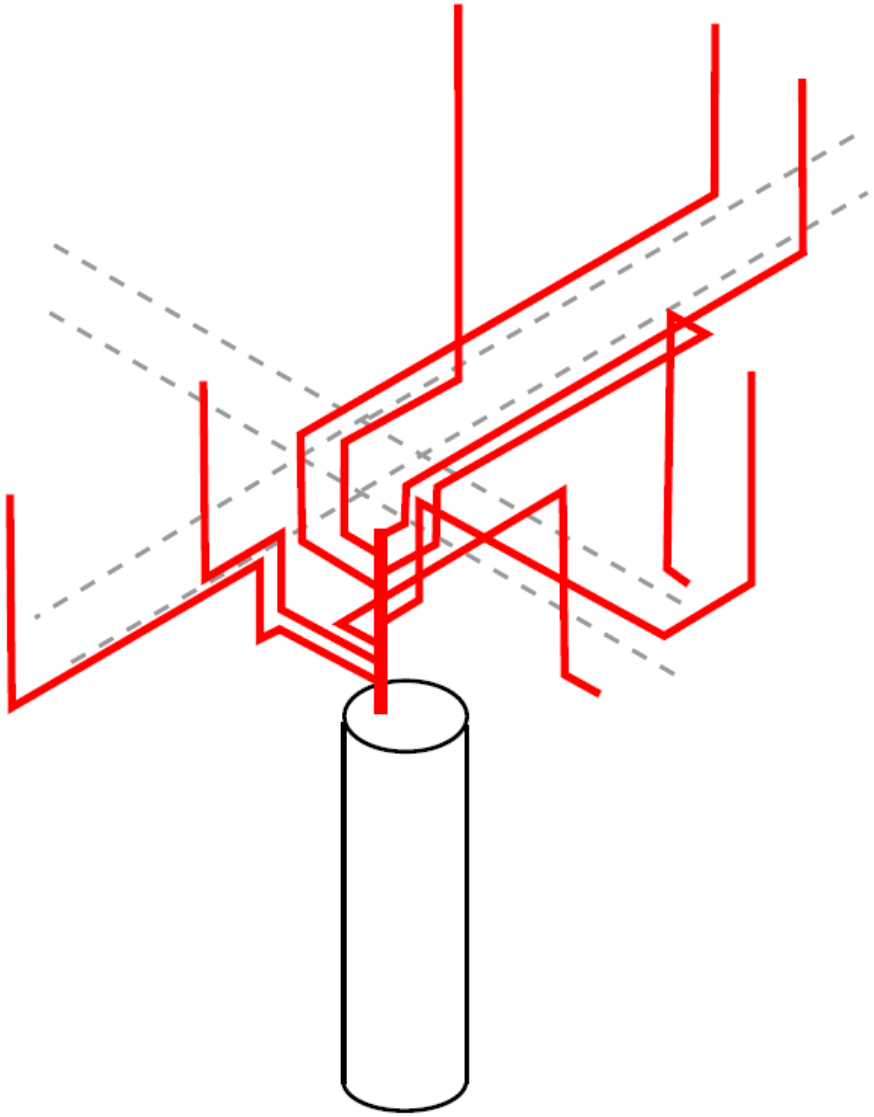
(Green < 2 cups), Red >1/2 Gallon)

| Flow Rate (GPM) \ Time Until Hot Water Arrives (Seconds) | 1 | 2 | 3 | 4 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.08 | 0.13 | 0.17 | 0.21 | 0.25 | 0.29 | 0.33 | 0.38 | 0.42 | 0.46 | 0.50 |
| 1 | 0.02 | 0.03 | 0.05 | 0.07 | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.50 | 0.58 | 0.67 | 0.75 | 0.83 | 0.92 | 1.00 |
| 1.5 | 0.03 | 0.05 | 0.08 | 0.10 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 0.75 | 0.88 | 1.00 | 1.13 | 1.25 | 1.38 | 1.50 |
| 2 | 0.03 | 0.07 | 0.10 | 0.13 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.00 | 1.17 | 1.33 | 1.50 | 1.67 | 1.83 | 2.00 |
| 2.5 | 0.04 | 0.08 | 0.13 | 0.17 | 0.21 | 0.42 | 0.63 | 0.83 | 1.04 | 1.25 | 1.46 | 1.67 | 1.88 | 2.08 | 2.29 | 2.50 |
| 3 | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 | 2.25 | 2.50 | 2.75 | 3.00 |
| 3.5 | 0.06 | 0.12 | 0.18 | 0.23 | 0.29 | 0.58 | 0.88 | 1.17 | 1.46 | 1.75 | 2.04 | 2.33 | 2.63 | 2.92 | 3.21 | 3.50 |
| 4 | 0.07 | 0.13 | 0.20 | 0.27 | 0.33 | 0.67 | 1.00 | 1.33 | 1.67 | 2.00 | 2.33 | 2.67 | 3.00 | 3.33 | 3.67 | 4.00 |
| 4.5 | 0.08 | 0.15 | 0.23 | 0.30 | 0.38 | 0.75 | 1.13 | 1.50 | 1.88 | 2.25 | 2.63 | 3.00 | 3.38 | 3.75 | 4.13 | 4.50 |
| 5 | 0.08 | 0.17 | 0.25 | 0.33 | 0.42 | 0.83 | 1.25 | 1.67 | 2.08 | 2.50 | 2.92 | 3.33 | 3.75 | 4.17 | 4.58 | 5.00 |
| 5.5 | 0.09 | 0.18 | 0.28 | 0.37 | 0.46 | 0.92 | 1.38 | 1.83 | 2.29 | 2.75 | 3.21 | 3.67 | 4.13 | 4.58 | 5.04 | 5.50 |
| 6 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 | 6.00 |
| 6.5 | 0.11 | 0.22 | 0.33 | 0.43 | 0.54 | 1.08 | 1.63 | 2.17 | 2.71 | 3.25 | 3.79 | 4.33 | 4.88 | 5.42 | 5.96 | 6.50 |
| 7 | 0.12 | 0.23 | 0.35 | 0.47 | 0.58 | 1.17 | 1.75 | 2.33 | 2.92 | 3.50 | 4.08 | 4.67 | 5.25 | 5.83 | 6.42 | 7.00 |
| 7.5 | 0.13 | 0.25 | 0.38 | 0.50 | 0.63 | 1.25 | 1.88 | 2.50 | 3.13 | 3.75 | 4.38 | 5.00 | 5.63 | 6.25 | 6.88 | 7.50 |
| 8 | 0.13 | 0.27 | 0.40 | 0.53 | 0.67 | 1.33 | 2.00 | 2.67 | 3.33 | 4.00 | 4.67 | 5.33 | 6.00 | 6.67 | 7.33 | 8.00 |
| 8.5 | 0.14 | 0.28 | 0.43 | 0.57 | 0.71 | 1.42 | 2.13 | 2.83 | 3.54 | 4.25 | 4.96 | 5.67 | 6.38 | 7.08 | 7.79 | 8.50 |
| 9 | 0.15 | 0.30 | 0.45 | 0.60 | 0.75 | 1.50 | 2.25 | 3.00 | 3.75 | 4.50 | 5.25 | 6.00 | 6.75 | 7.50 | 8.25 | 9.00 |
| 9.5 | 0.16 | 0.32 | 0.48 | 0.63 | 0.79 | 1.58 | 2.38 | 3.17 | 3.96 | 4.75 | 5.54 | 6.33 | 7.13 | 7.92 | 8.71 | 9.50 |
| 10 | 0.17 | 0.33 | 0.50 | 0.67 | 0.83 | 1.67 | 2.50 | 3.33 | 4.17 | 5.00 | 5.83 | 6.67 | 7.50 | 8.33 | 9.17 | 10.00 |

1 cup = 8 ounces = 1/16$^{th}$ gallon = 0.0625 gallon

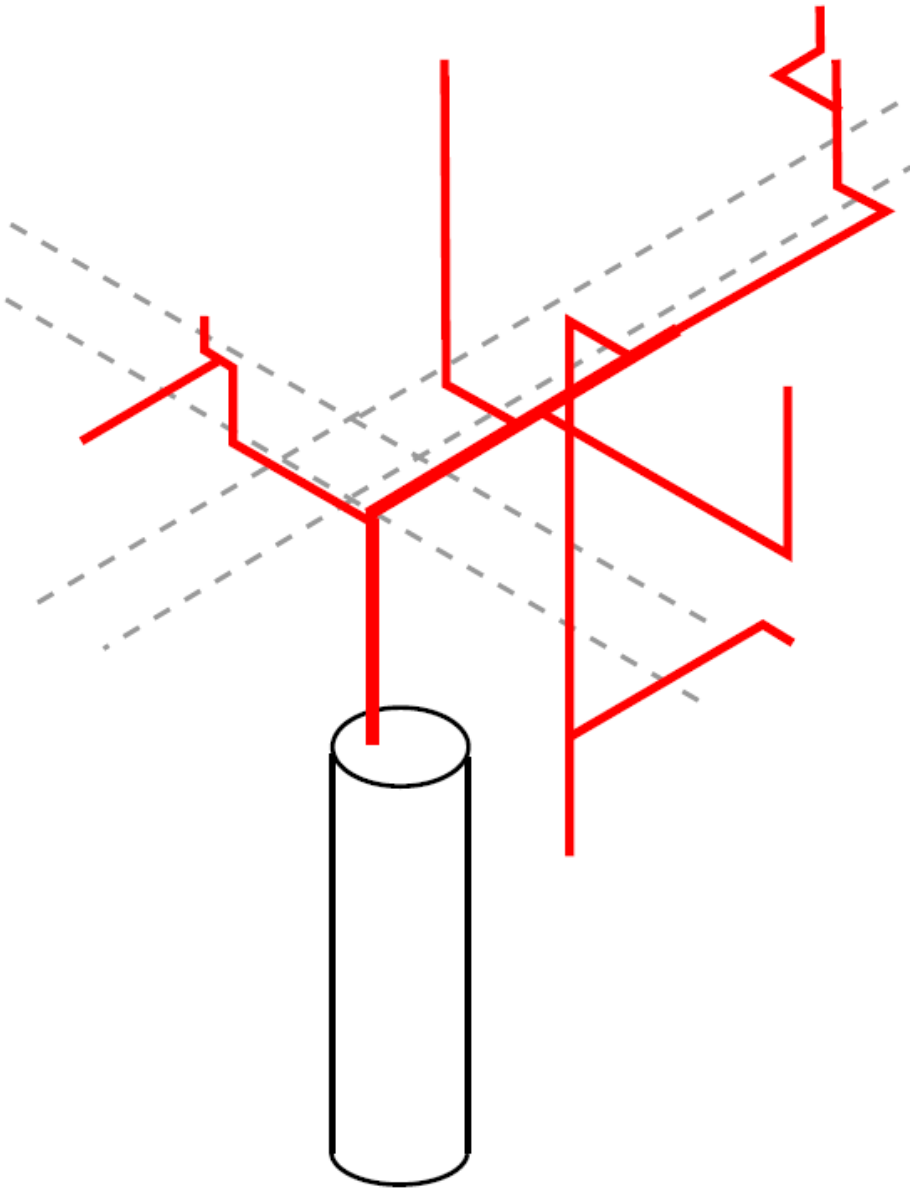
# 1- Quart Hot Water Distribution System

## Short Trunk – Long Twig



# 1- Quart Hot Water Distribution System

## Long Trunk – Short Twig



# What is the Future of Flow Rates?

Kitchen sinks – 0.5 to 2 gpm (hot only to left, pot fill)

Lavatory sinks – 0.5 gpm (hot only to left)

Showers – 1.5 gpm (water down drain)

Showers – 15 gallons (maximum volume per event)

What impact will these flow rates have on system performance?

Given these flow rates, what impact will the interactions with the rest of the system have on customer satisfaction?

# It’s All About the Feel!

**Not the pressure or flow rate**

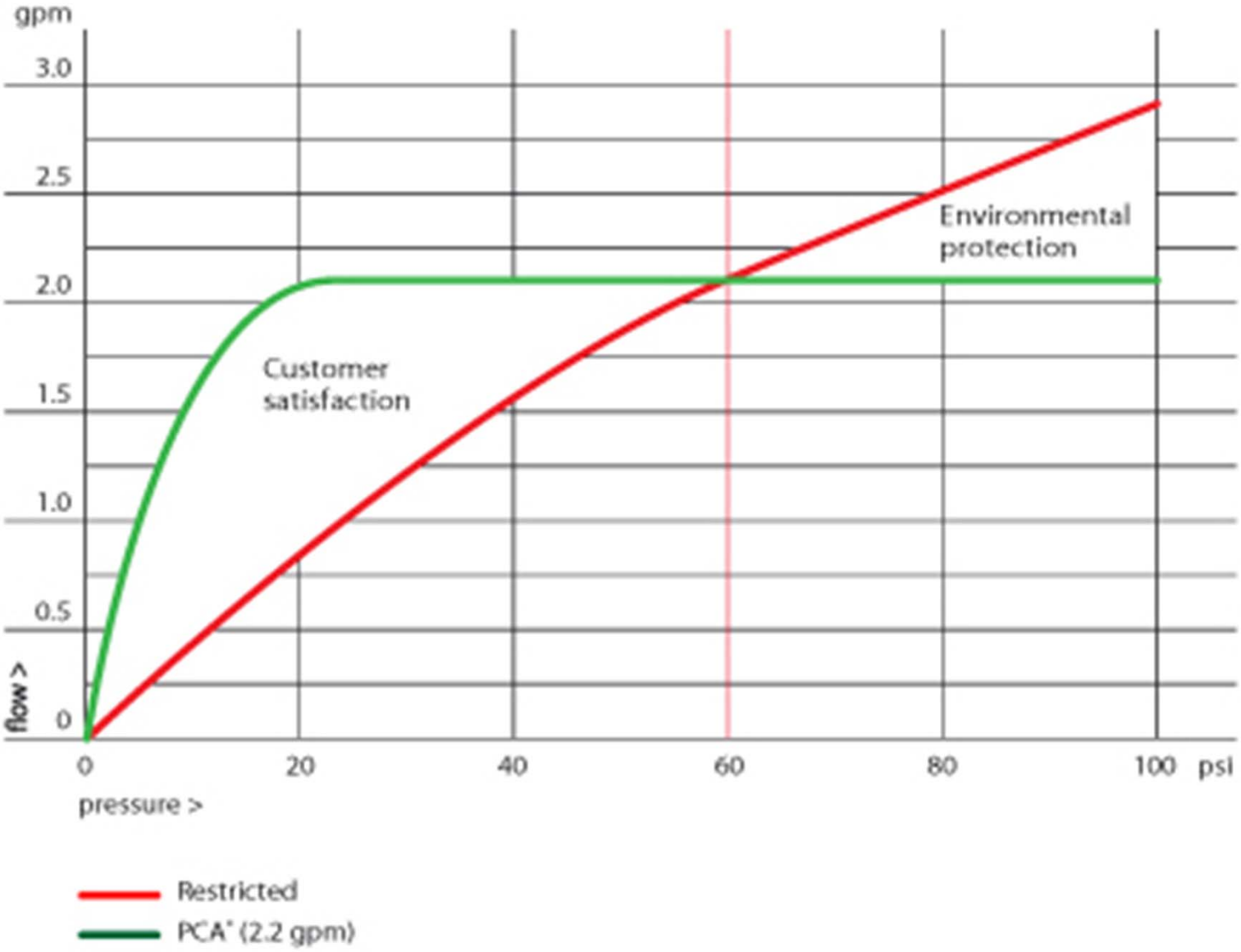
# Lavatory Faucet Stream Patterns

**Aerated stream** Aerators introduce air into the water stream to produce a larger and whiter stream soft to the touch and non-splashing. Aerators are the usual choice for residential faucet applications.

**Laminar stream** Laminar stream straighteners produce a non-aerated water stream. Ideal for high flow applications or health care facilities (no mix water/air) laminar spout-end devices deliver a crystal clear and non-splashing stream.

**Spray** When the flow rate is too low to produce an aerated or laminar stream, a spray device is used to produce a miniature shower pattern to provide full coverage of the hands during washing. Sprays are recommended for use in public lavatories.

# Pressure Compensating Aerators



# Thank You!

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