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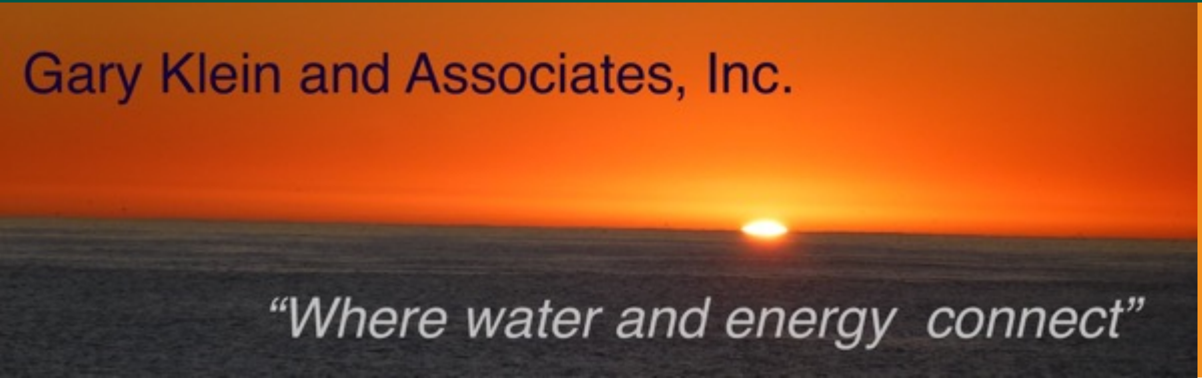
Why Your Shower Feels Wimpy:
And What You Can Do About It!



Gary K
Gary Klein and
gary@garyklein

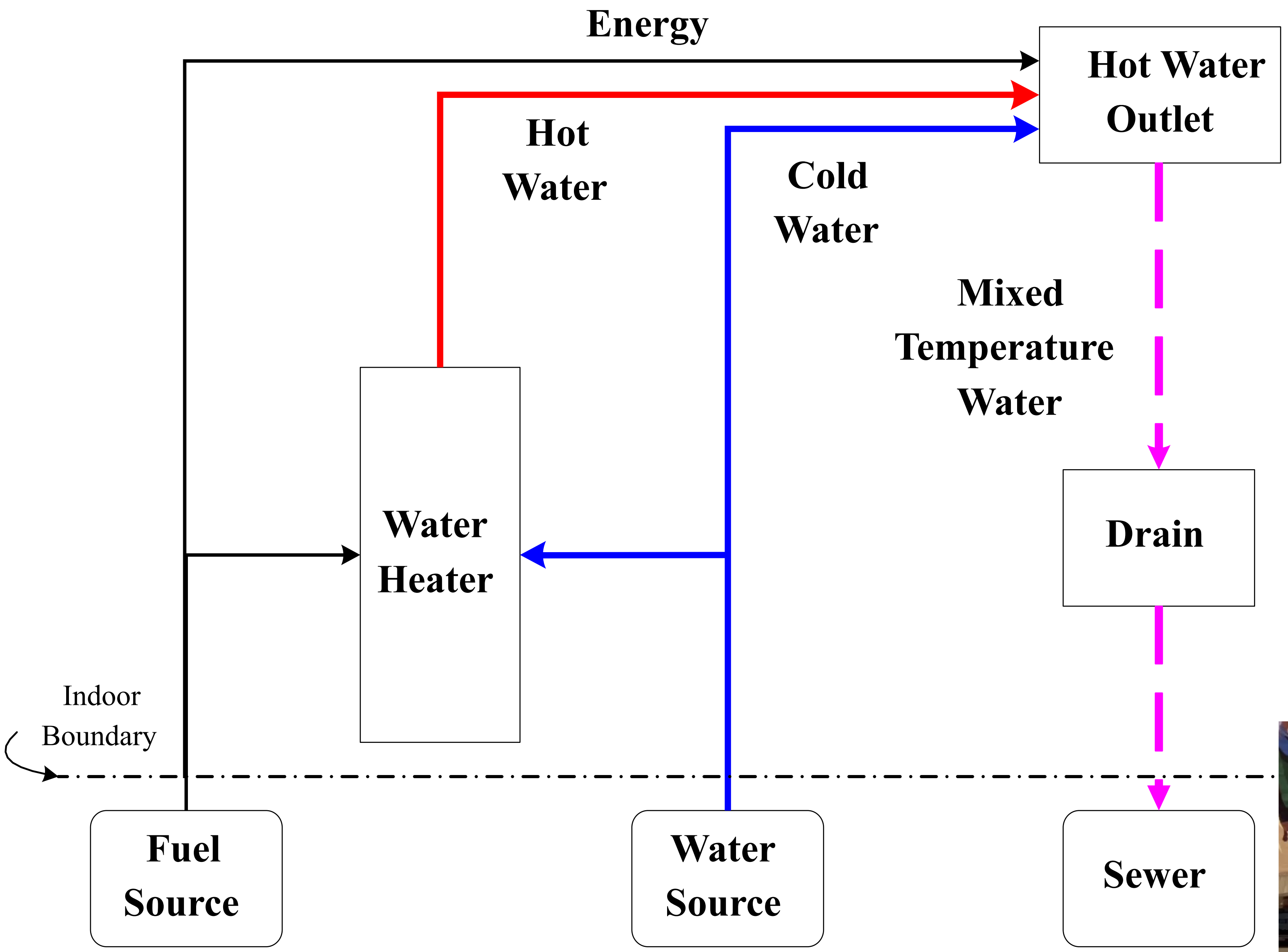
Topics

1. What Are We Aiming For?
2. Where Did All the Pressure Go?
3. (Hot) Water Flow in Buildings
4. Time-to-Tap and Volume-until-Hot
5. How Do We Increase Customer Satisfaction?
6. Discussion

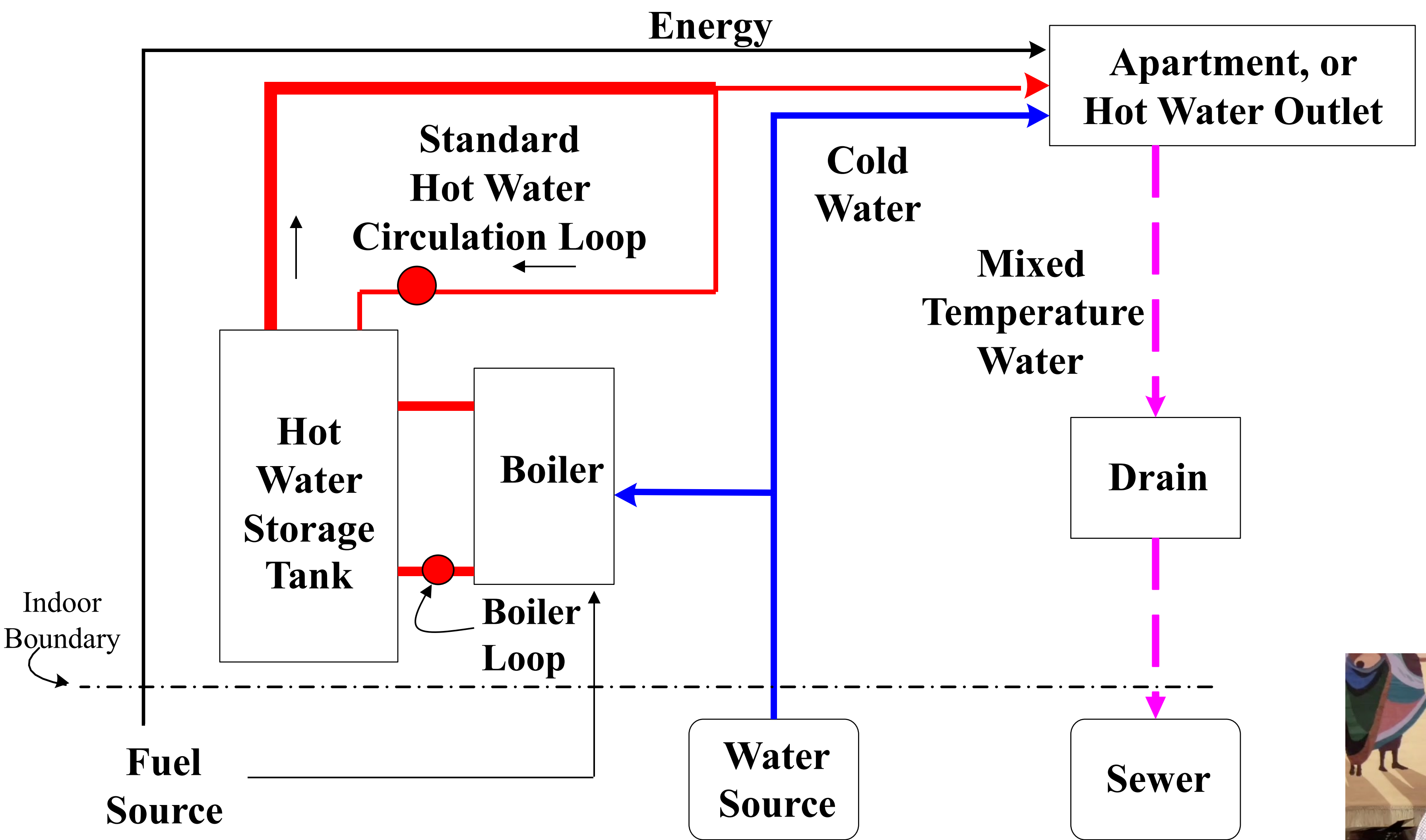
1. What Are We Aiming For?

- People want:
  - The water flowing from their showers and faucets to "feel" right.
  - Their toilets to flush first time, every time.
  - Clean clothes, dishes and bodies
  - The service of water, as efficiently as possible.
- It does not make sense to discuss efficiency until the desired service has been provided.

Typical "Simple" Hot Water System



Typical “Complex” Hot Water System



The 2 Key Services for Hot Water…

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, it’s about location

Never Run Out in My Shower = “Continuousness”

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

2. Where Did All the Pressure Go?

Let's Look at a 2nd Floor Shower

	PSI	PSI
Street Pressure	60	80
Go up 20 feet	- 9	- 9
Tub/Shower Valve	- 11	- 11
Losses in the piping	- 20	- 20
Total of the Pressure Losses	- 40	- 40
Available Pressure at the shower head	20	40

Shower head flow rates are determined at 80 psi.

For fixed orifice shower heads, the flow rate depends on the available pressure:

Flow rate at 40 psi = 0.7 * Flow Rated at 80 psi

Flow rate at 20 psi = 0.49 * Flow Rated at 80 psi

Similar reductions for faucets with flow rated at 60 psi

3. (Hot) Water Flow in Buildings

- What percent of the time does water flow through the meter into the building?
  - Most normal condition is off – zero flow!
    - Depending on occupancy, more than 96% of the time
  - 2nd most normal is 1 plumbing fixture or appliance
    - Probably a faucet, what percentage hot and cold?
    - Of the remaining 4%, this happens more than 3.9% of the time
    - Hot water is roughly half of this.
  - Flows greater than 3 gpm occur less than 0.1% of the time

3. (Hot) Water Flow in Buildings (cont.)

- Pipe sizing rules were written down in the 1940s
  1. Pressure and temperature balanced shower valves became widely available in the 1980s
  2. Pressure compensating orifices became widely available in the 2010s
- These two devices mitigate many of this issues that occurred with peak flow rates
  - Relatively constant, safe flow rates for showers and faucets
  - Little impact on the fill rates for toilets, tubs and machines.
- Let’s use these technologies to help with revising the rules for pipe sizing.

4. Time-to-Tap and Volume-until-Hot

- More water than is in a pipe comes out of it before hot water arrives. How much more?
  - Carl Hiller measured this in the early 2000s for 3/8 to 3/4-inch copper, CPVC and PEX piping
  - Yanda Zhang reviewed the data in 2018 and found that for flow rates of 0.5 to 2 gpm in 3/4-inch pipe, 1.5-2.5 times the pipe volume comes out before hot water (>105F) comes out the other end. Roughly 2:1.
- Conclusion: if you want hot water to arrive within 10 seconds, make sure there is no more than 5 seconds of volume in the pipe between the source of hot water and the use.

Calculating Time-to-Tap and Volume-to-Hot

Time-to-tap (seconds) = Feet * (Ounces/foot) *(1 gallon/128 ounces) / gpm * 1 minute/60 seconds

$$= \frac{\text{Feet} * \text{1 oz} * \text{1 gallon} * \text{1 minute} * \text{60 seconds}}{\text{1 foot} * \text{128 oz} * \text{1 gallon} * \text{1 minute}}$$

= 0.46875 * Feet * ounces/foot * gallons per minute

Volume-to-Hot (gallons)

$$= \frac{\text{Feet} * \text{1 oz} * \text{1 gallon}}{\text{1 foot} * \text{128 oz}}$$

Adjustment = Range of extra volume or time until hot is 1.5-2.5

≅ 2 * time in seconds based on pipe volume

≅ 2 * gallons in the pipe

5. How Do We Increase Customer Satisfaction?

1. Reduce the Time-to-Tap
   a) Reduce the Distance from the Source to the Use
   b) Right-Size the Piping based on Modern Flow Rates and Realistic Simultaneity
2. Reduce the Pressure Drop
   a) In the Pipe and Fittings
      1) Minimize the length
      2) Minimize the number of pressure-consuming fittings
   b) In the Faucets and Shower Valves
3. Install Pressure-Independent Faucet Aerators and Showerheads

5.1.a) Reduce the Distance from Source to Use

- The shorter the pipe, the less time it takes.
  - The smaller the pipe diameter, the less time it takes too!
- ***But***, the lower the flow rate, the longer it takes.
- How long is too long?
  - 5 seconds? 10 seconds? Longer? Shorter?

Water, energy and time efficient hot water systems start with deciding how long we want people to wait.

The decision on the location of the wet-room(s) and the mechanical room(s) is made by the architect.

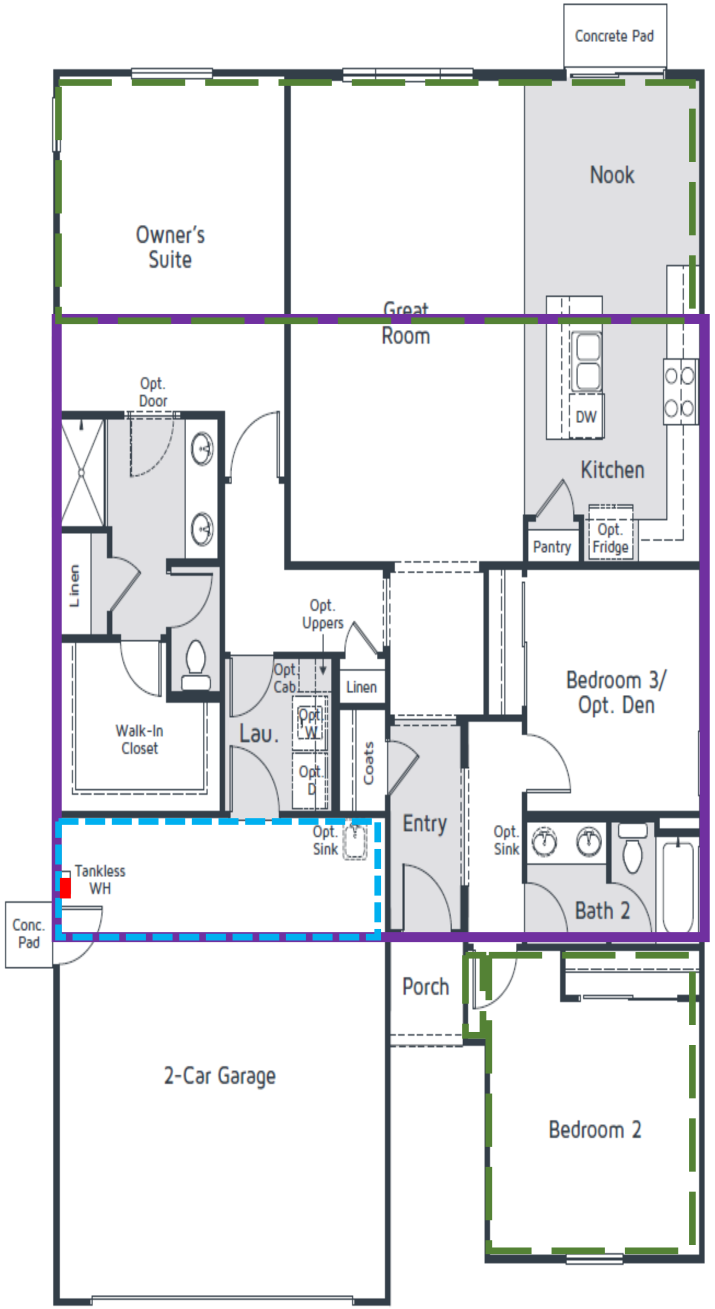
Better floor plans can lead to better hot water system performance.

Better floor plans decrease the residence time in the premise plumbing system (hot and cold) too!

Distance Between the Wet Rooms and the Water Heater

Example:

1 Story
3Br/2Ba
1,697 sq ft
Fresno, CA
~67% (1137 sq ft)



Relationship between the Hot Water System and the Floor Area – The Logical Worst Case

Number of Stories	Hot Water System/ Floor Area (%)
1-story	100%
2-story	50%
3-story	33.3%
4-story	25%
5-story	20%

Basements count as stories if they contain wet rooms.

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~~ 1	4	1.9	0.9	0.6	0.5	0.4
~~4~~ 2	8	4	1.9	1.3	0.9	0.8
~~8~~ 4	15	8	4	2.5	1.9	1.5
~~16~~ 8	30	15	8	5	4	3
~~24~~ 12	45	23	11	8	6	5
~~32~~ 16	60	30	15	10	8	6
~~64~~ 32	120	60	30	20	15	12
~~128~~ 64	240	120	60	40	30	24

Cut the pipe volume in half to get these times

ASPE Time-to-Tap Performance Criteria

(green)	**Acceptable Performance**	1 – 10 seconds
(orange)	**Marginal Performance**	11 – 30 seconds
(pink)	**Unacceptable Performance**	31+ seconds

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

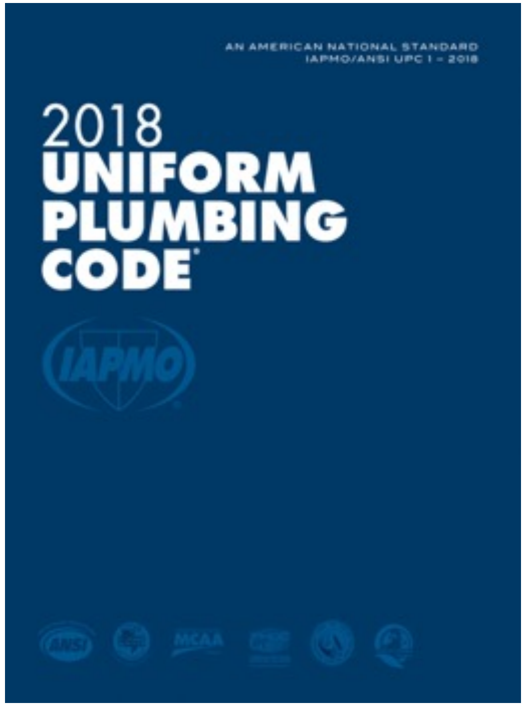
5.1.b Right-Size the Plumbing

Which Pipe Sizing Method(s) do you use?

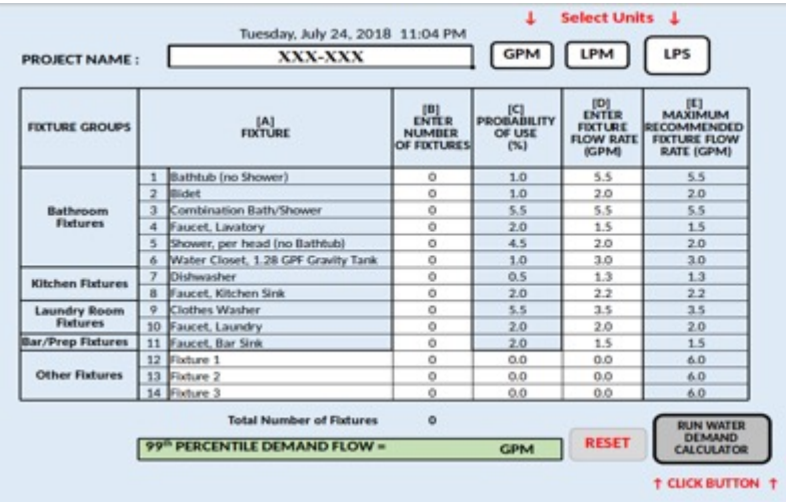
1. International Code Council (ICC)
    1. International Residential Code (IRC)
    2. International Plumbing Code (IPC)
    3. Local adoption as amended?
2. International Association of Plumbing and Mechanical Officials (IAPMO)
    1. Uniform Plumbing Code (UPC)
    2. Location adoption as amended?
3. American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE)
4. American Society of Plumbing Engineers (ASPE)
5. Others?

Estimating Peak Flow Rates

1. IPC/IRC and UPC Standard Method: Water Supply Fixture Units (WSFU)



2. Appendix M (IAPMO UPC): Water Demand Calculator



Select Units

Tuesday, July 24, 2018 11:04 PM

PROJECT NAME : XXX-XXX

GPM LPM LPS

FIXTURE GROUPS		[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	1.0	5.5	5.5
	2	Bidet	0	1.0	2.0	2.0
	3	Combination Bath/Shower	0	5.5	5.5	5.5
	4	Faucet, Lavatory	0	2.0	1.5	1.5
	5	Shower, per head (no Bathtub)	0	4.5	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	0	1.0	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.5	1.3	1.3
	8	Faucet, Kitchen Sink	0	2.0	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	0	5.5	3.5	3.5
	10	Faucet, Laundry	0	2.0	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	2.0	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.0	0.0	6.0
	13	Fixture 2	0	0.0	0.0	6.0
	14	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

https://www.iapmo.org/water-demand-calculator/

What if we used real data for different occupancies?

Pipe Sizing Comparison – PEX Piping

2018 IRC/IPC (WSFU)

1 unit

Hot: 7.9 gpm (3/4”)

Cold: 7.5 gpm (3/4”)

35 units

Hot: 51 gpm (2”)

Cold: 50 gpm (2”)

Total: 70 gpm (3”)

Appendix M (UPC)

1 unit

Hot: 3.6 gpm (1/2”)

Cold: 3.6 gpm (1/2”)

35 units

Hot: 12.0 gpm (1”)

Cold: 13.9 gpm (1”)

Total: 15.8 gpm (1.25”)

Measured 99th percentile peaks are < 3 gpm hot and 5 gpm cold.

Daily hot water use is 15-20 gallons per apartment per day

Pipe Sizing Using the Water Demand Calculator

1 Apartment

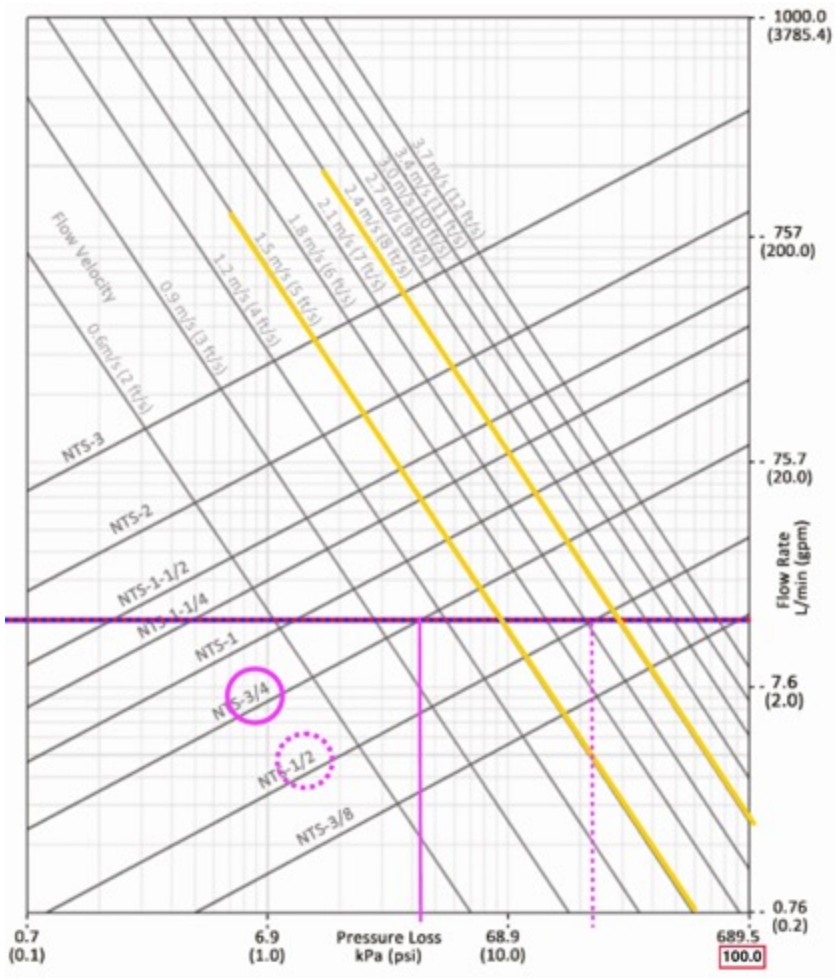


FIGURE 3
PRESSURE LOSS OF PEX TUBING AT 16 °C (60°F)
(See Section 10.6.2)

35 Apartments

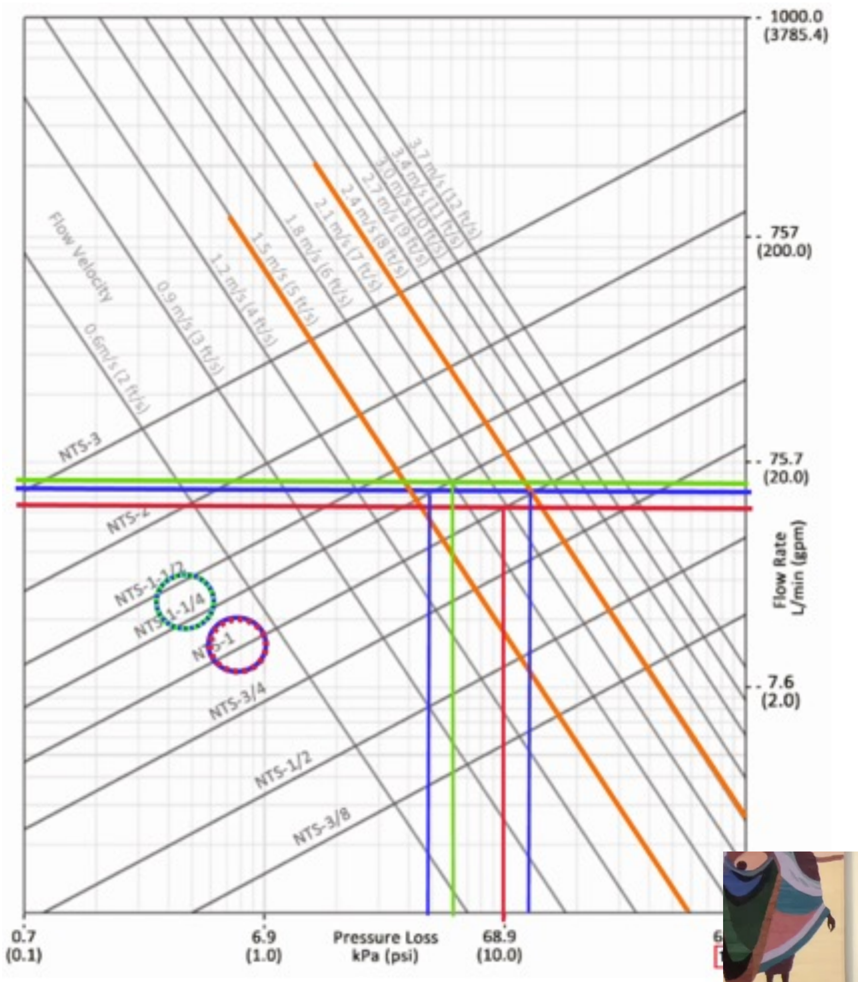


FIGURE 3
PRESSURE LOSS OF PEX TUBING AT 16 °C (60°F)
(See Section 10.6.2)

Nomographs are for PEX from 2018 UPC, Appendix I

Impact of Right-Sizing Pipe

	Seattle	Utica
Number of Apartments	114 units (96 1-bath, 18 2-bath, 29 clothes washers)	35 units (35 1-bath, 3 clothes washers)
Applicable Plumbing Code	Uniform Plumbing Code (UPC)	International Plumbing Code (IPC)
UPC Appendix A or IPC Appendix E	GPM: 260 Size: 4"	GPM: 80 Size: 3"
UPC or IPC with bathroom groups	GPM: 205 Size: 3.5"	GPM: 70 Size: 3”
Water Demand Calculator V1.4	GPM: 90 Size: 2.5"	GPM: 15.8 Size: 1.5"
Water Demand Calculator V2.0	GPM: 54 Size: 2"	GPM: 10.3 Size: 1"
Measured Peak Flow Rates		Hot: < 4 GPM Cold: < 5 GPM

https://www.iapmo.org/water-demand-calculator/

Comparing the Piping Costs

Pipe from the 4th Floor Mechanical Room to the 7th Floor Apartment Branches						
	As Designed			Proposed		
Nominal Dia. (in)	Total (feet)	Cost per Foot ($)	Cost per Dimension ($)	Total (feet)	Cost per Foot ($)	Cost per Dimension ($)
3	20	$ 18.75	$ 375.00	0	$ 18.75	$ -
2.5	90	$ 13.81	$ 1,242.90	0	$ 13.81	$ -
2	114	$ 10.55	$ 1,202.70	0	$ 10.55	$ -
1.5	136	$ 5.26	$ 715.36	56	$ 5.26	$ 294.56
1.25	346	$ 4.50	$ 1,557.00	120	$ 4.50	$ 540.00
1	808	$ 1.70	$ 1,373.60	144	$ 1.70	$ 244.80
0.75	730	$ 0.94	$ 686.20	1764	$ 0.94	$ 1,658.16
0.5	70	$ 0.57	$ 39.90	230	$ 0.57	$ 131.10
Totals	2314		$ 7,192.66	2314		$ 2,868.62
Prices are for PEX piping taken from www.ferguson.com on September 18, 2020. Table shows only the differences in the cost of the pipe for both hot and cold. There are additional, and significant savings in the fittings. There will be some labor savings. There will also be savings for the pipe insulation.						

And don't forget the water heater, the other equipment in the mechanical room, the water meter and the monthly service charges.

5.2 Reduce the Pressure Drop

What is it in Modern Pipe and Fittings?

- Many materials and types of fittings
- Calculations vs. measured data
- Are the data we use representative of present-day materials and fittings?

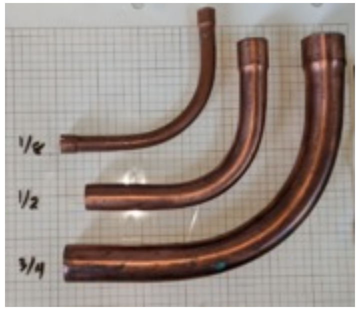
From the current ASHRAE Fundamentals Pipe Sizing chapter

- *Hegberg (1995) and Rahmeyer (1999a, 1999b) discuss the origins of some of the data shown in Tables 4 and Table 5.*
- *The Hydraulic Institute (1990) data appear to have come from Freeman (1941), work that was actually performed in 1892.*
- *The work of Giesecke (1926) and Giesecke and Badgett (1931, 1932a, 1932b may not be representative of current materials.*

Downey Lab

Arcata Lab

Elbows – Copper Type-L

Technology (Copper)	Image
Elbow (tight inside corner)	
Long Radius Sweep	
Swoop®	

Have also measured:
Copper Tees
CPVC Elbows and Tees

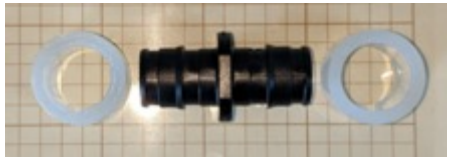
To date:
Measured more than
70 combinations of
3/8 and 1/2 pipe and fittings
in copper, CPVC and PEX

Elbows - PEX

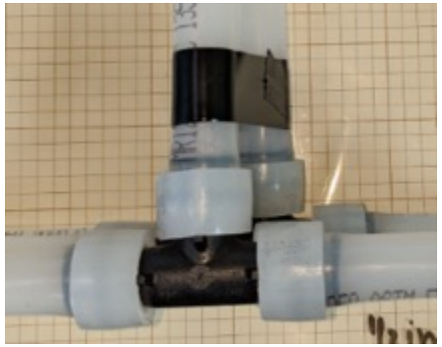
Technology (PEX)	Image
Poly Push to Connect Inner Seal ¾ in	 
Brass Push to Connect Outer Seal ¾ in	 
Brass Crimp ¾ in	
Poly Crimp ¾ in	

Technology (PEX)	Image
Brass Press ½ in	
Poly Press ½ in	
Bend Support	
Poly Expansion ¾ in	

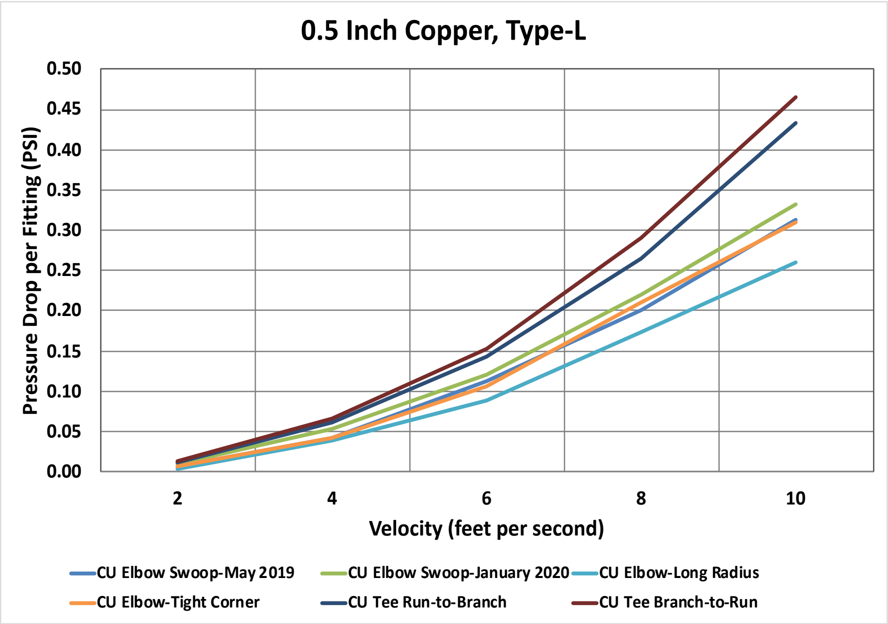
Couplings

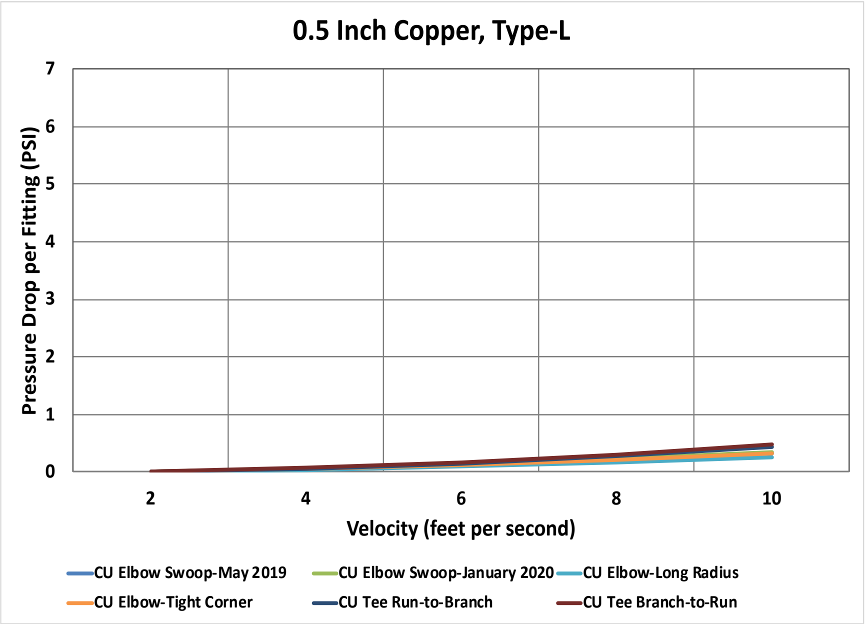
Technology (PEX)	Image
Poly Press ¾ in	
Brass Press ¾ in	
Poly Expansion ½ in	

Tees

Technology (PEX)	Image
Poly Press ½ in	
Brass Press ½ in	
Poly Expansion ½ in	

0.5 Inch Copper
Pressure Drop in Assorted Fittings

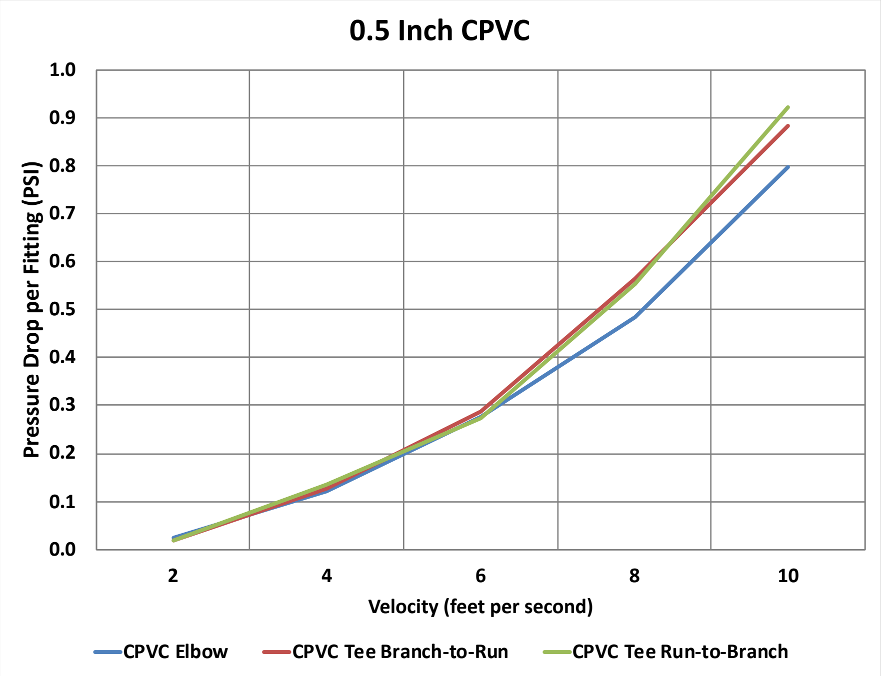


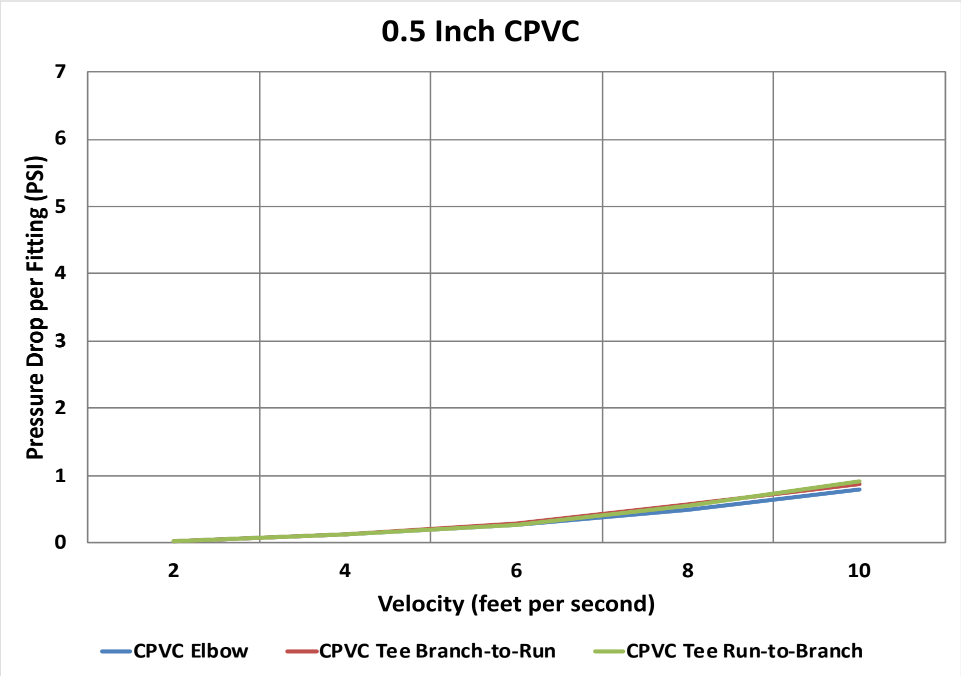


Target Flow Rates for 0.5 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.5 inch PEX	1.10	2.21	3.31	4.42	5.52
0.5 inch CPVC	1.15	2.30	3.45	4.61	5.76
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

At **4 feet/second**, the pressure drop is about 0.05 psi per fitting

0.5 Inch CPVC
Pressure Drop in Assorted Fittings





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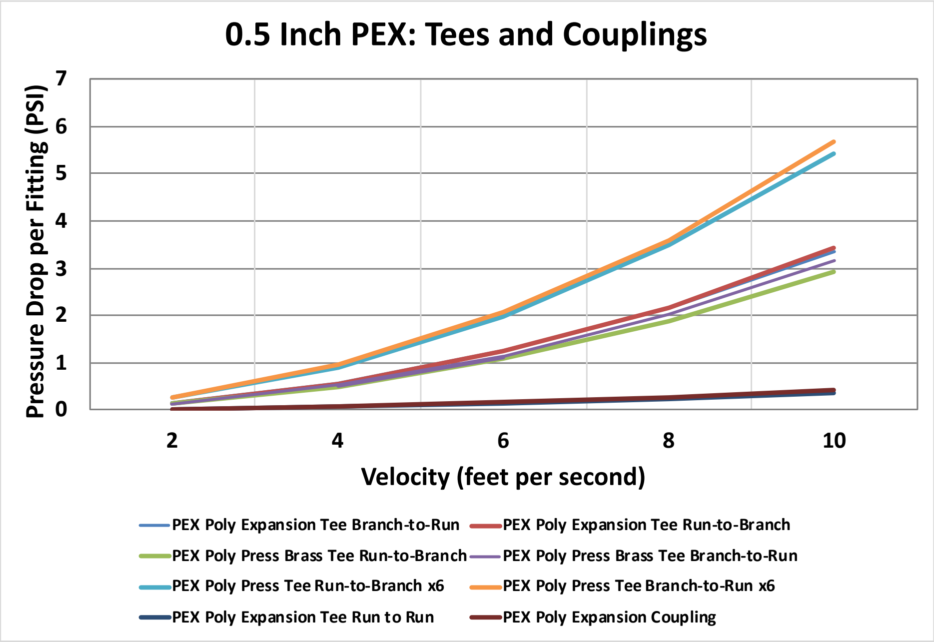
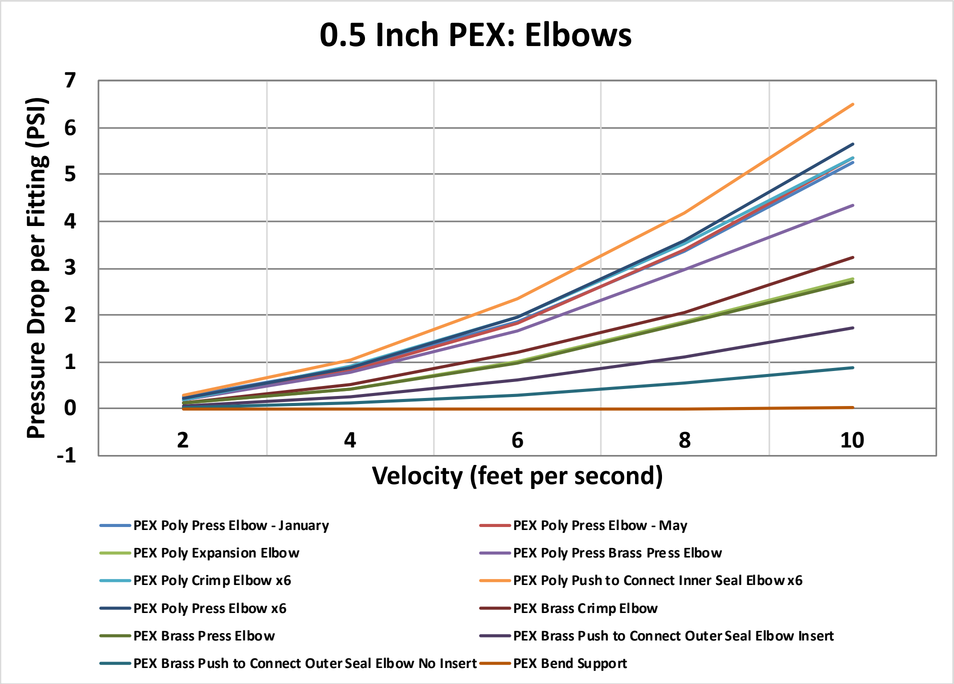
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

At 4 feet/second, the pressure drop is about 0.13 psi per fitting

0.5 Inch PEX
Pressure Drop in Assorted Fittings





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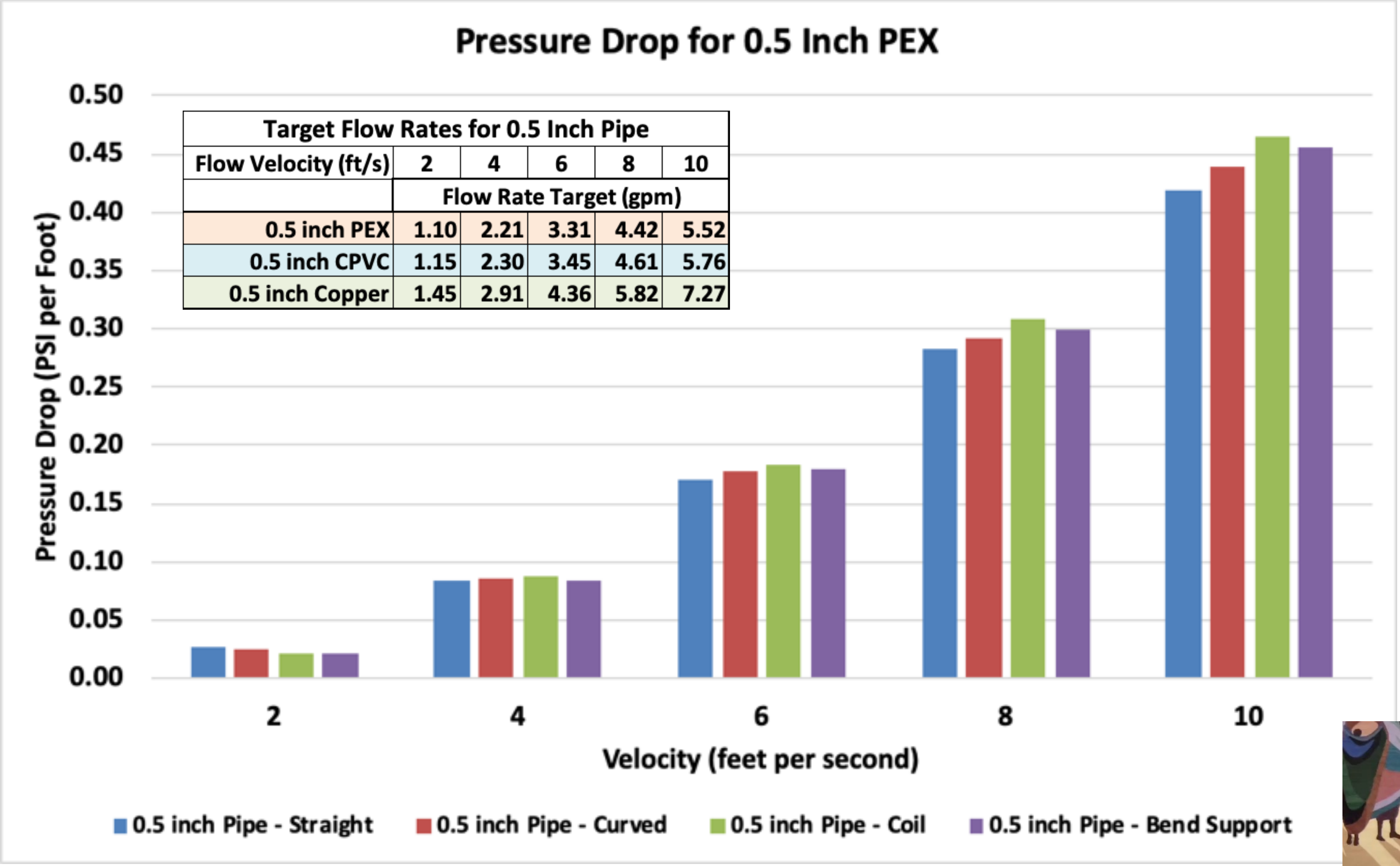
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

At 4 feet/second, the pressure drop ranges from 0 to 1 psi per fitting

Can Water Make a 90º Turn Without Losing Pressure?



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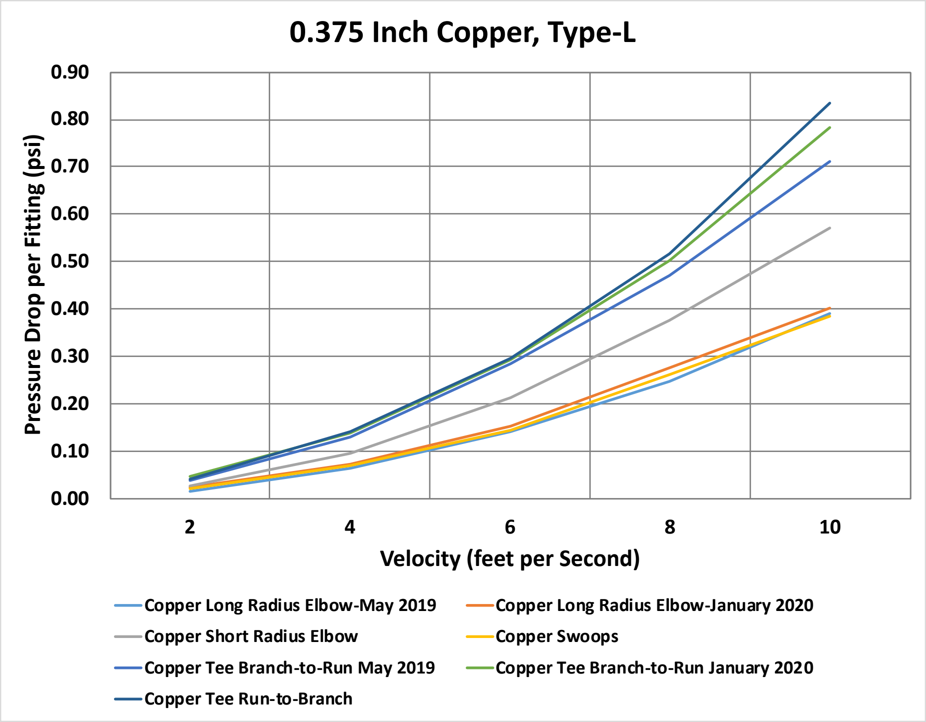
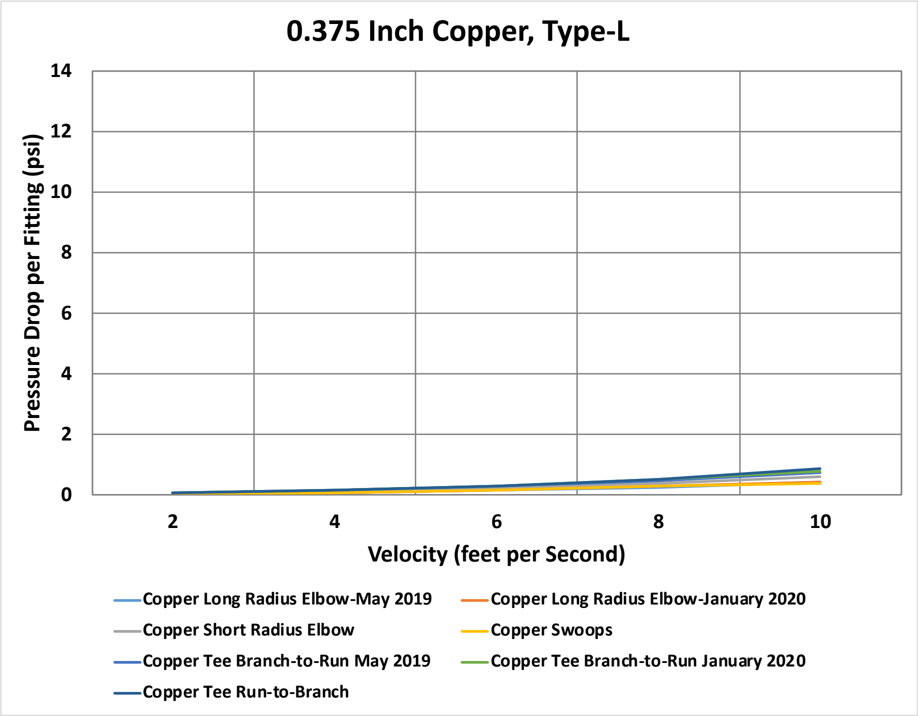
0.5 inch Copper	1.45	2.91	4.36	5.82	7.27

At 4 feet/second, the pressure drop is about 0.08 psi per foot

0.375 Inch Copper
Pressure Drop in Assorted Fittings

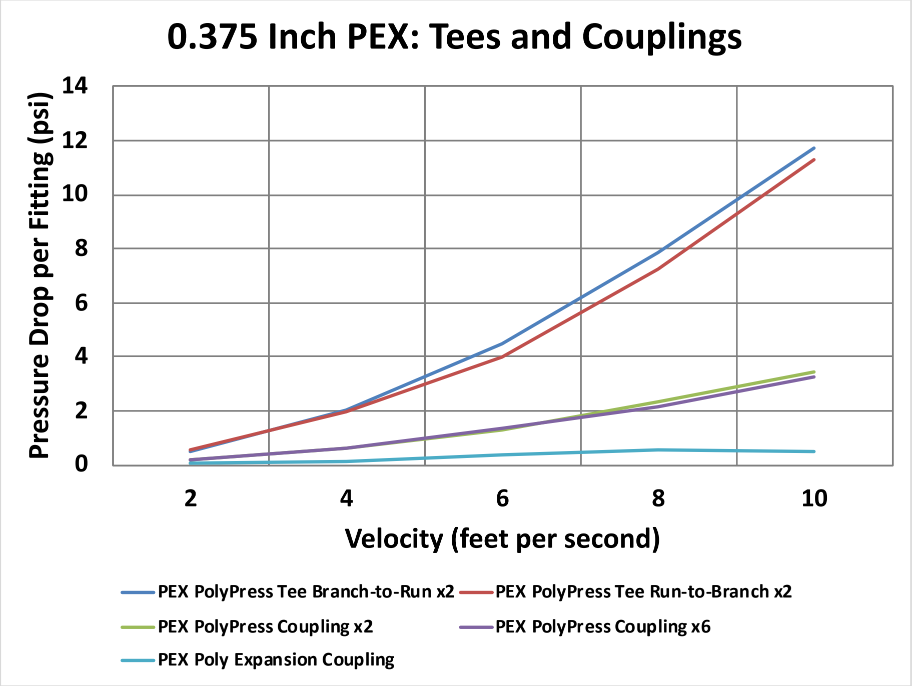


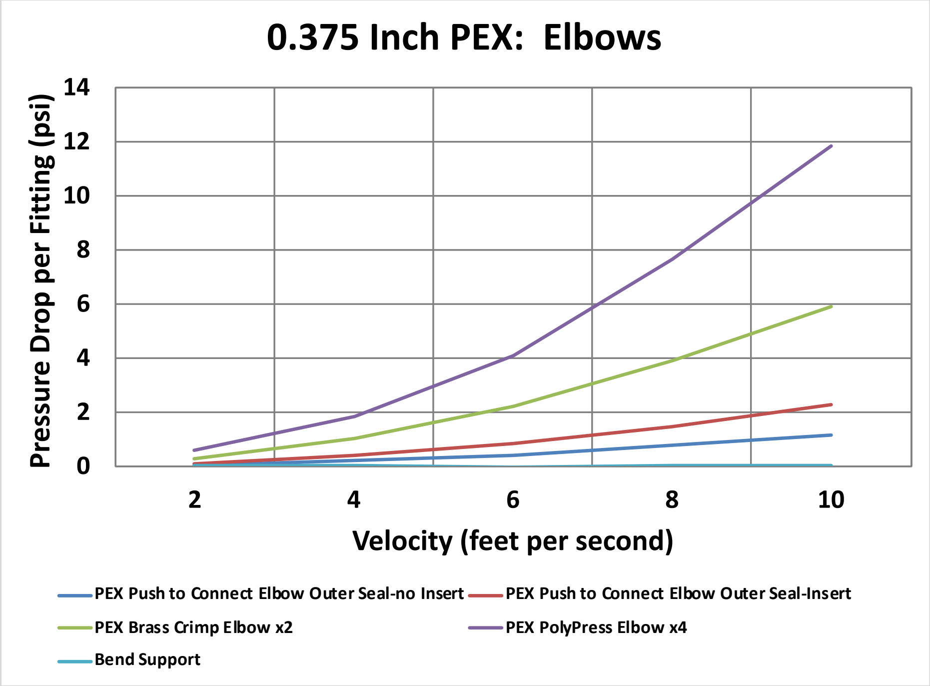


Target Flow Rates for 0.375 Inch Pipe					
Flow Velocity (ft/s)	2	4	6	8	10
	Flow Rate Target (gpm)				
0.375 inch PEX	0.60	1.20	1.80	2.40	3.00
0.375 inch CPVC	0.63	1.27	1.90	2.54	3.17
0.375 inch Copper	0.91	1.81	2.72	3.62	4.53

At 6 feet/second, the pressure drop ranges from 0.1 to 0.3 psi per fitting

0.375 Inch PEX
Pressure Drop in Assorted Fittings





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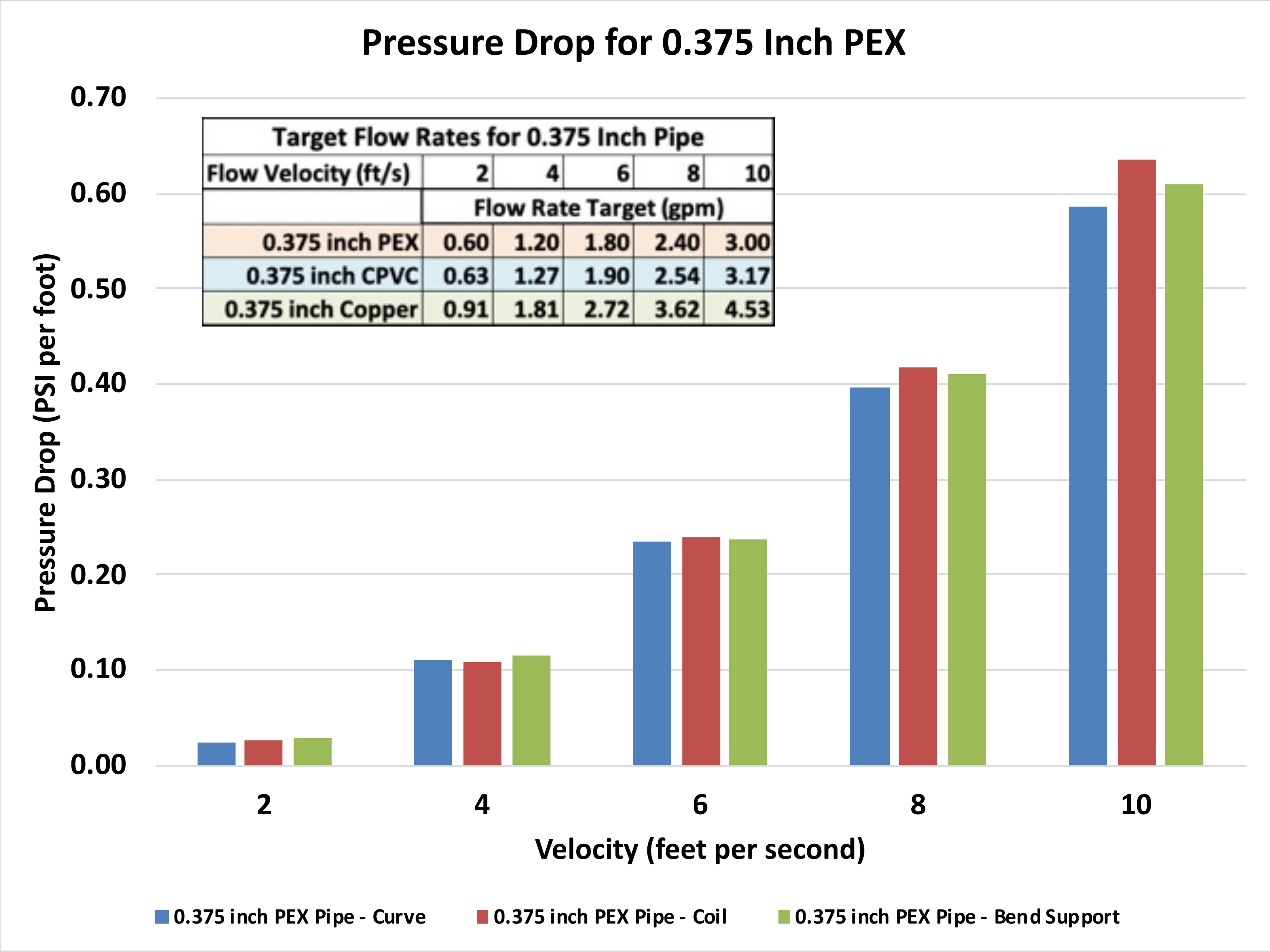
0.375 inch PEX	0.60	1.20	1.80	2.40	3.00
0.375 inch CPVC	0.63	1.27	1.90	2.54	3.17
0.375 inch Copper	0.91	1.81	2.72	3.62	4.53

At 8 feet/second, the pressure drop ranges from 0 to 8 psi per fitting

Can Water Make a 90º Turn Without Losing Pressure?



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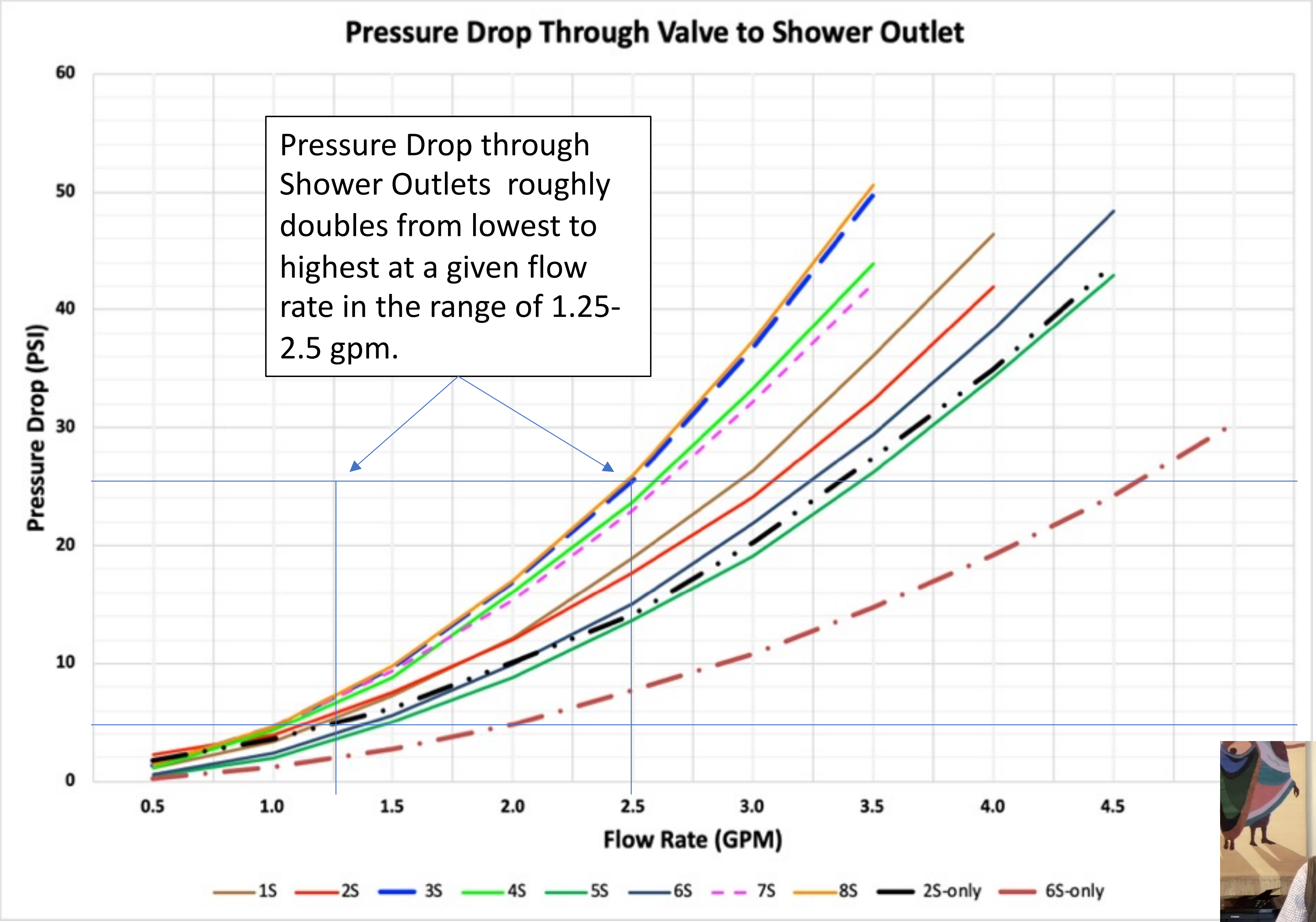
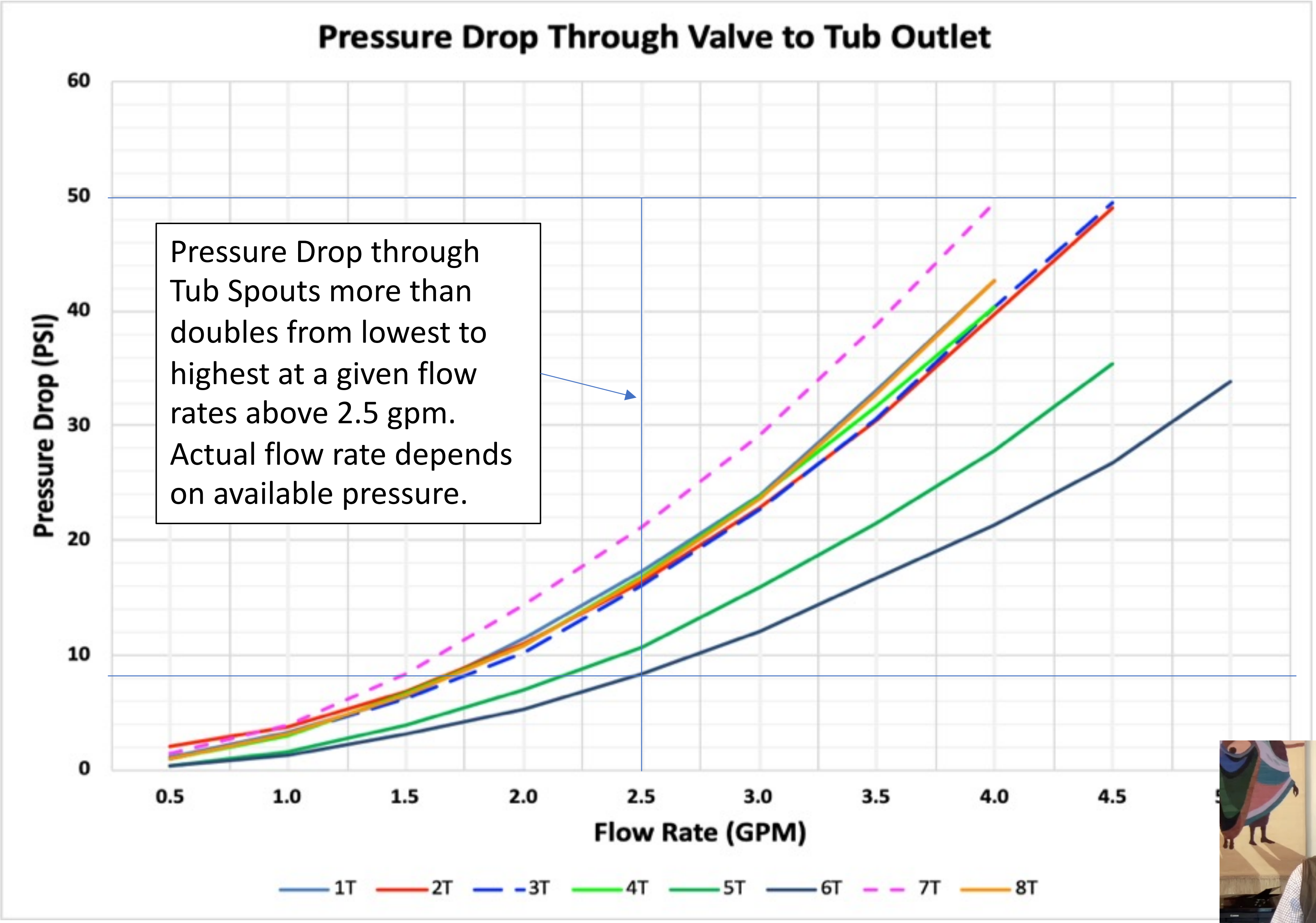
0.375 inch PEX	0.60	1.20	1.80	2.40	3.00
0.375 inch CPVC	0.63	1.27	1.90	2.54	3.17
0.375 inch Copper	0.91	1.81	2.72	3.62	4.53

At 8 feet/second, the pressure drop is about 0.4 psi per foot

Pressure Drop Through Tub/Shower and Shower Valves



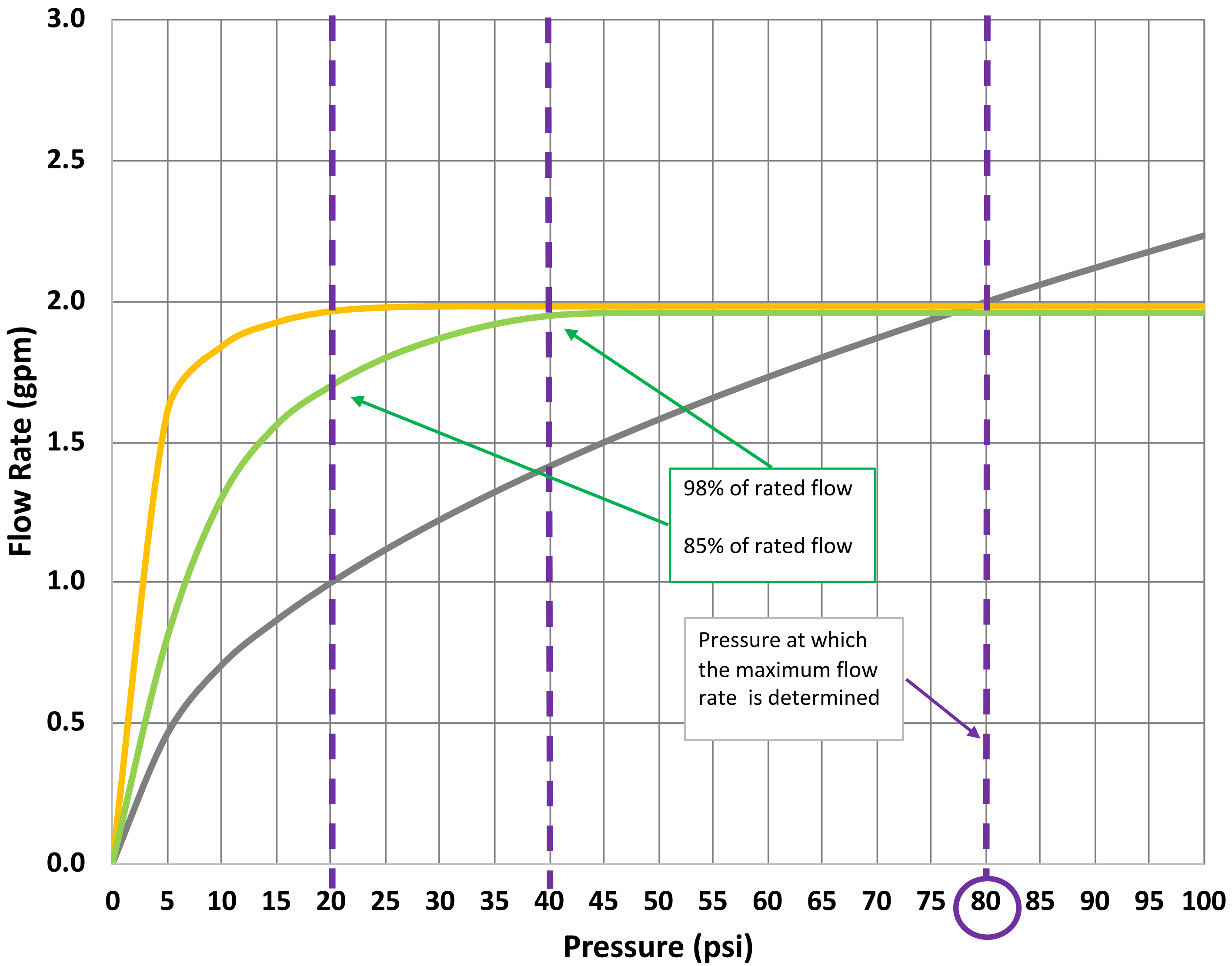
Pressure Drop Through Valve to Shower Outlet
Pressure Drop through Shower Outlets roughly doubles from lowest to highest at a given flow rate in the range of 1.25-2.5 gpm.
Pressure Drop (PSI)
60
50
40
30
20
10
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Flow Rate (GPM)
1S
2S
3S
4S
5S
6S
7S
8S
2S-only
6S-only


Pressure Drop Through Valve to Tub Outlet
Pressure Drop through Tub Spouts more than doubles from lowest to highest at a given flow rates above 2.5 gpm. Actual flow rate depends on available pressure.
Pressure Drop (PSI)
0
10
20
30
40
50
60
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Flow Rate (GPM)
1T
2T
3T
4T
5T
6T
7T
8T

5.3 Install Pressure – Independent Faucets and Showerheads

- **Fixed Orifice:**
  - High pressure: High flow rate
  - Low pressure: Low flow rate
  - Before 2000, practically all fixture fittings and appliances
- **Pressure Compensating Orifice:**
  - Adjusts flow rate to compensate for available pressure
  - Almost the same flow rate for all pressures above 20-25 psi
  - Ramped up from 2000-2012 for showerheads
  - Today more than 90% and many faucet aerators

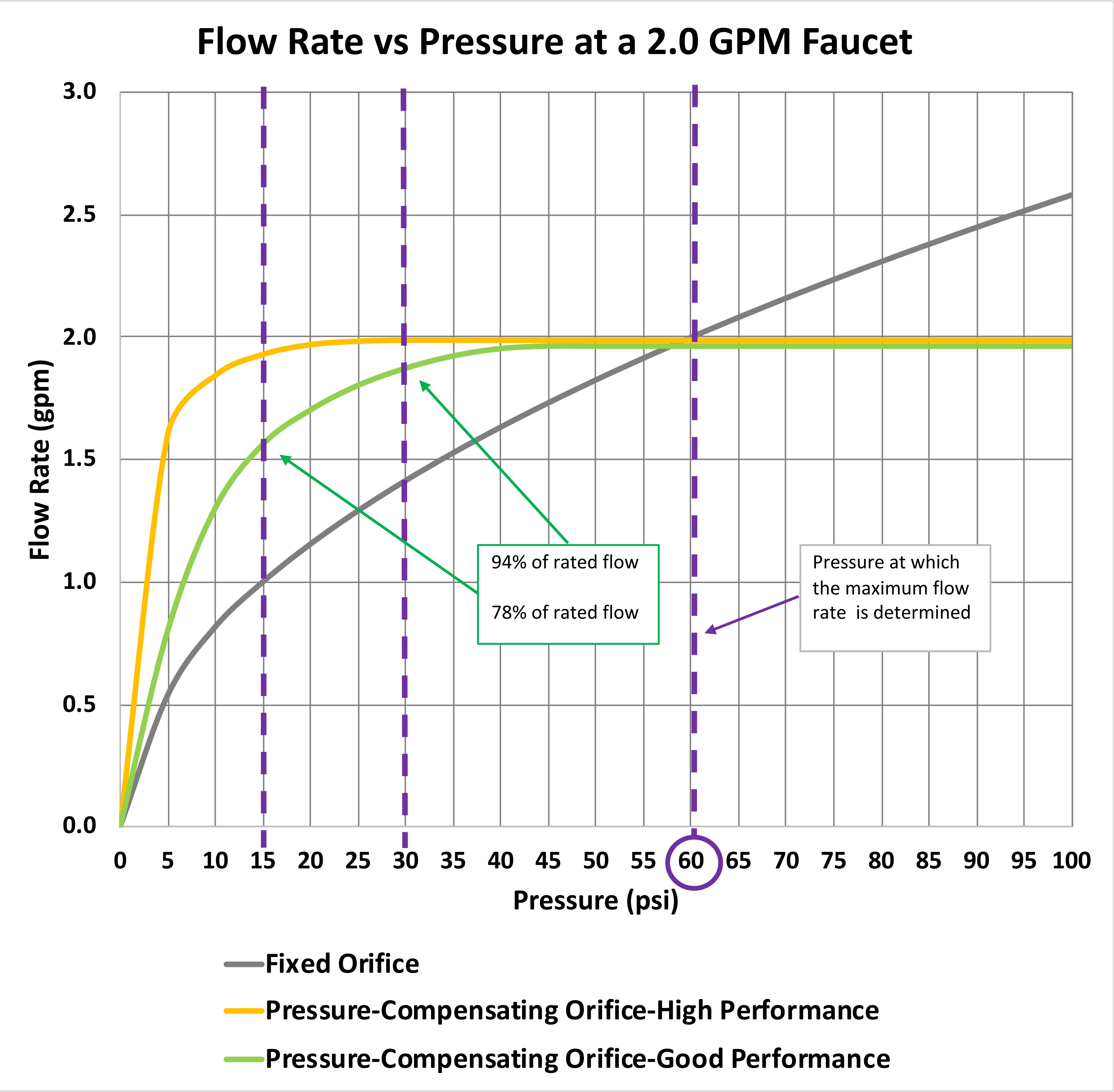
Flow Rate vs Pressure at a 2.0 GPM Showerhead



Fixed Orifice

Pressure-Compensating Orifice-High Performance

Pressure-Compensating Orifice-Good Performance



Flow Rate vs Pressure at a 2.0 GPM Faucet
Flow Rate (gpm)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Pressure (psi)
94% of rated flow
78% of rated flow
Pressure at which the maximum flow rate is determined
Fixed Orifice
Pressure-Compensating Orifice-High Performance
Pressure-Compensating Orifice-Good Performance

Given human nature,

it is our job

to provide the infrastructure

that supports efficient behaviors.

Questions?

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