What You Don’t Know You Don’t Know About (Hot) Water

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Goal of this Session:

- Identify at least 5 things you didn't know you didn't know about (hot) water
- Any specific topics you want me to address?
- Are you ready?

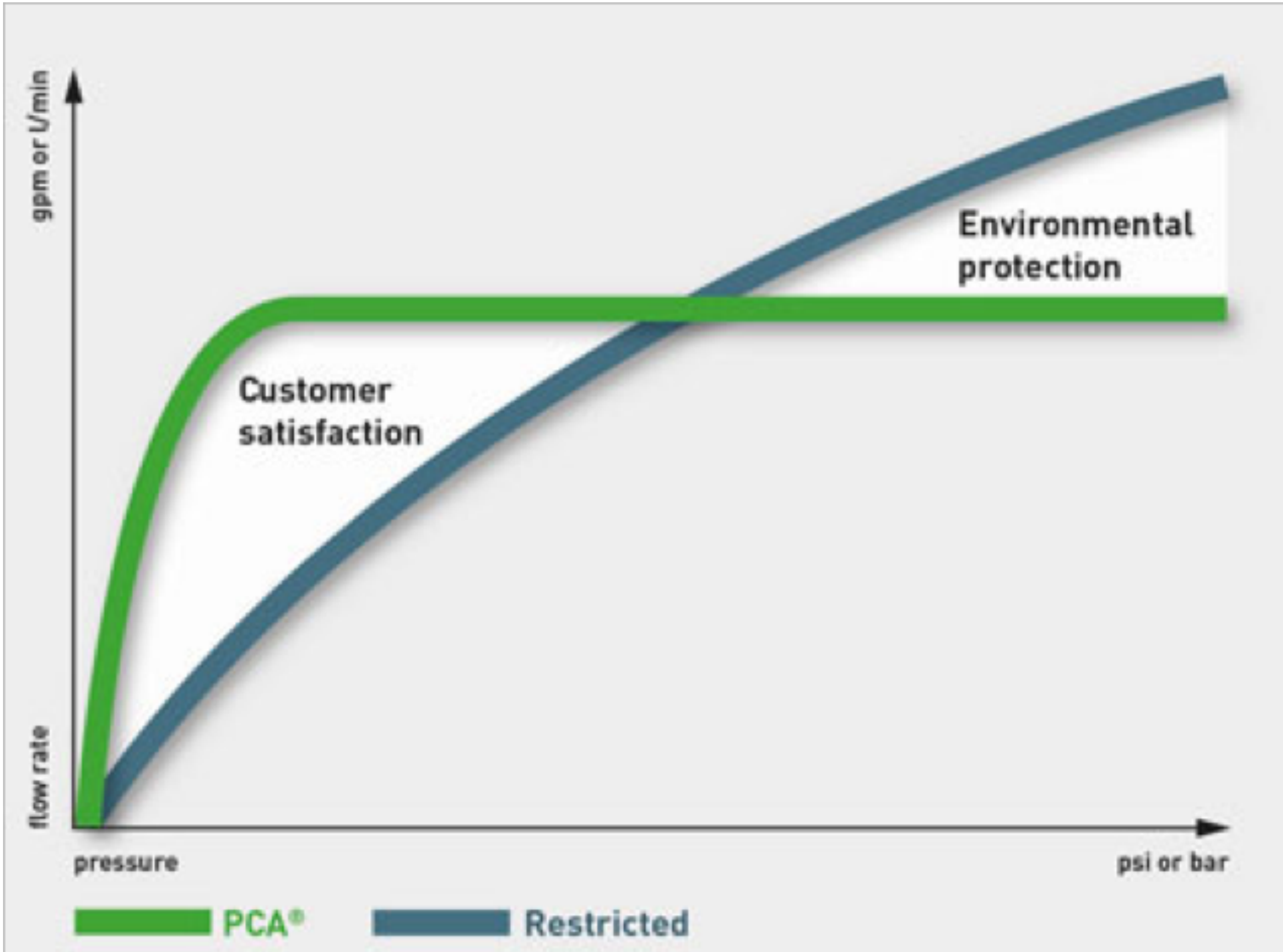
1. Water Heaters Have Air Filters

- Well, not all of them, but a very large and growing percentage
- Atmospheric Gas-fired Storage Heaters
  - Flammable Vapor Ignition Resistance (FVIR)
    - Closed combustion chamber, screen with tiny air holes, easily clogged with dust and lint
    - Large particle screen surrounds the bottom of the heater
- Electric Heat Pump Water Heaters
  - Filter on the inlet side of the air path through the heat pump coils.
- Filters need to be cleaned regularly!

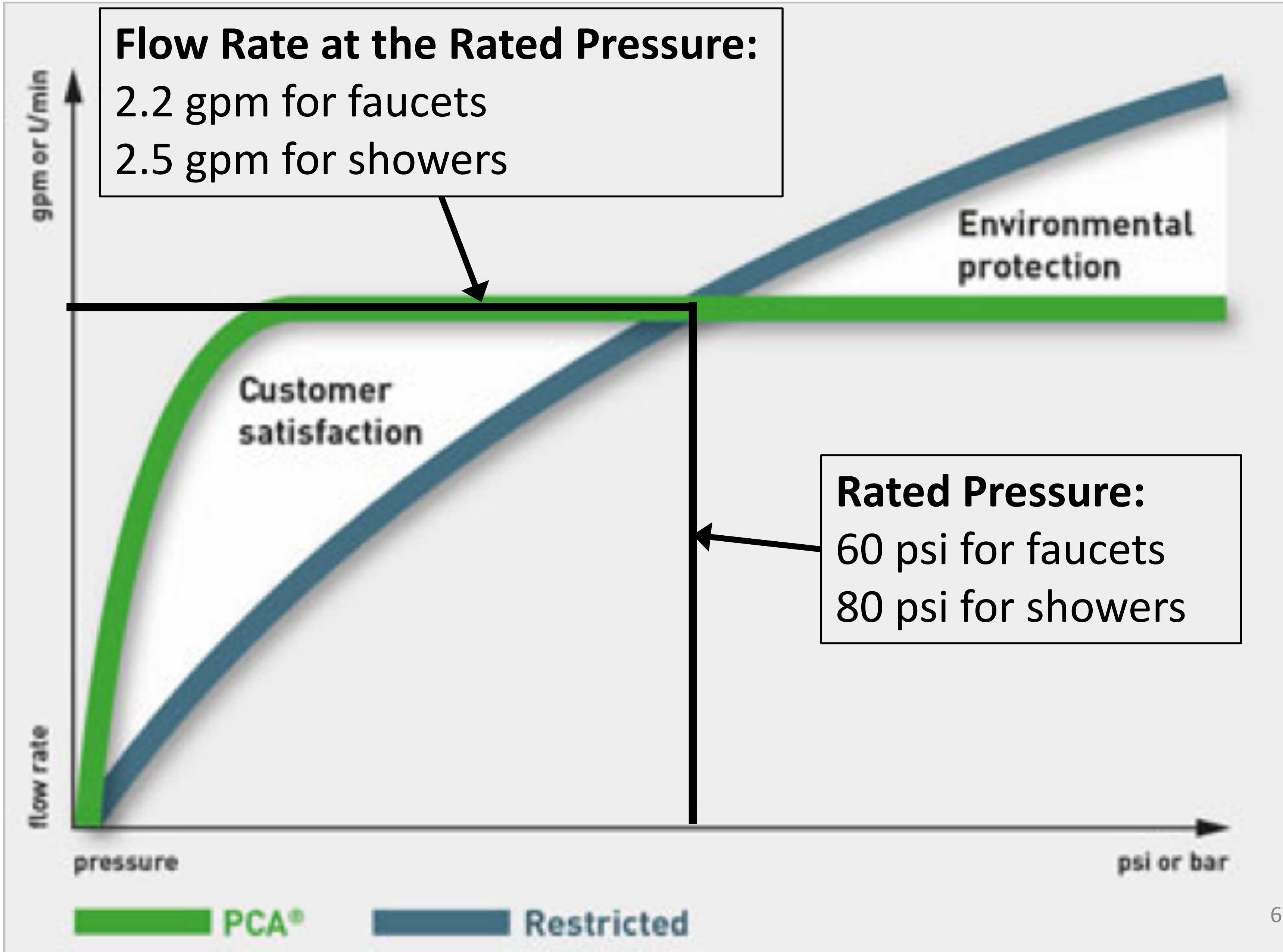
2. Fixed vs. Variable Orifices

- **Fixed Orifice:**
  - High pressure: High flow rate
  - Low pressure: Low flow rate
  - Before 2000, practically all fixture fittings and appliances
- **Pressure Compensating Aerators**
  - 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

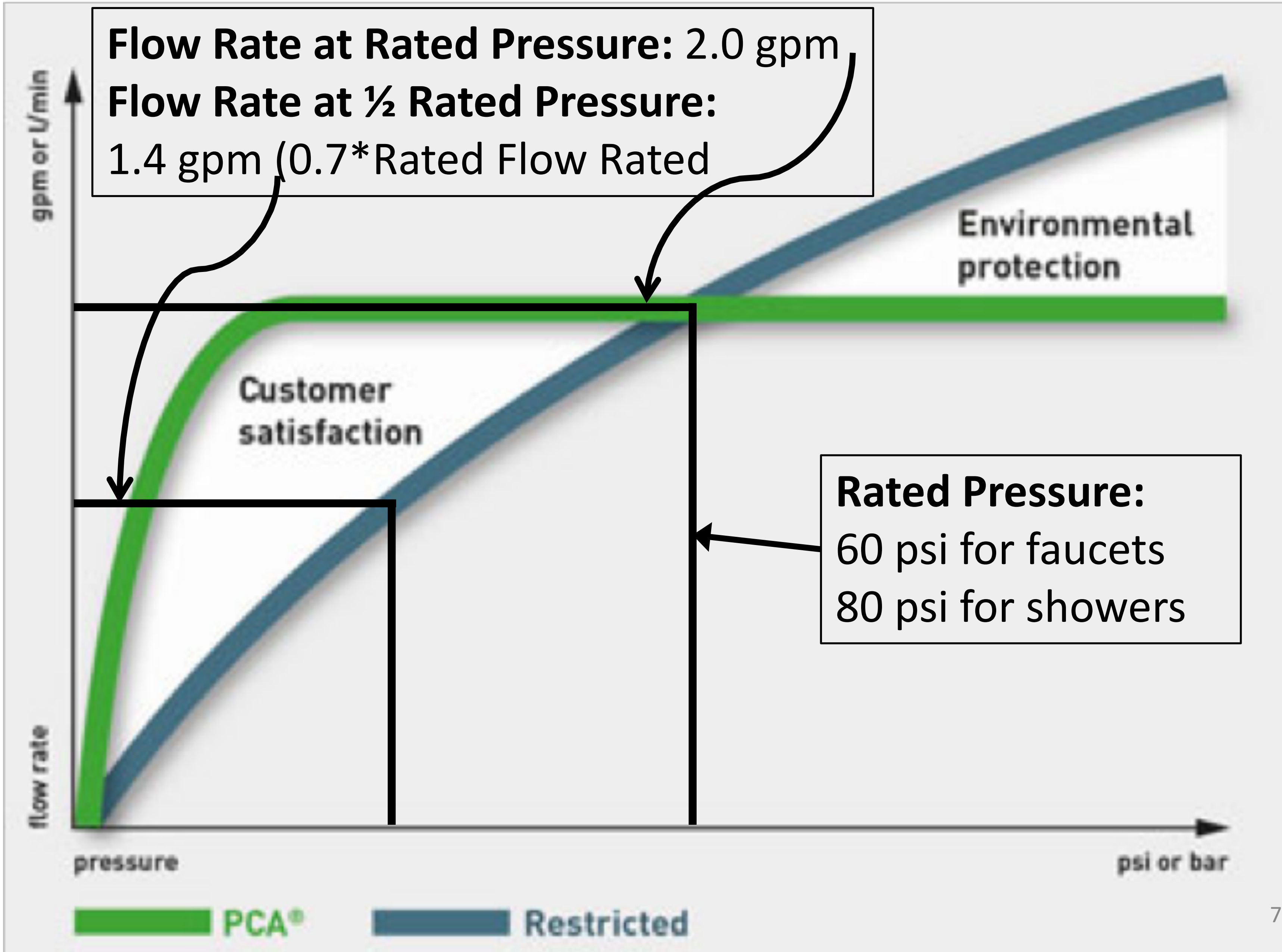
Pressure Compensating Aerators - 1



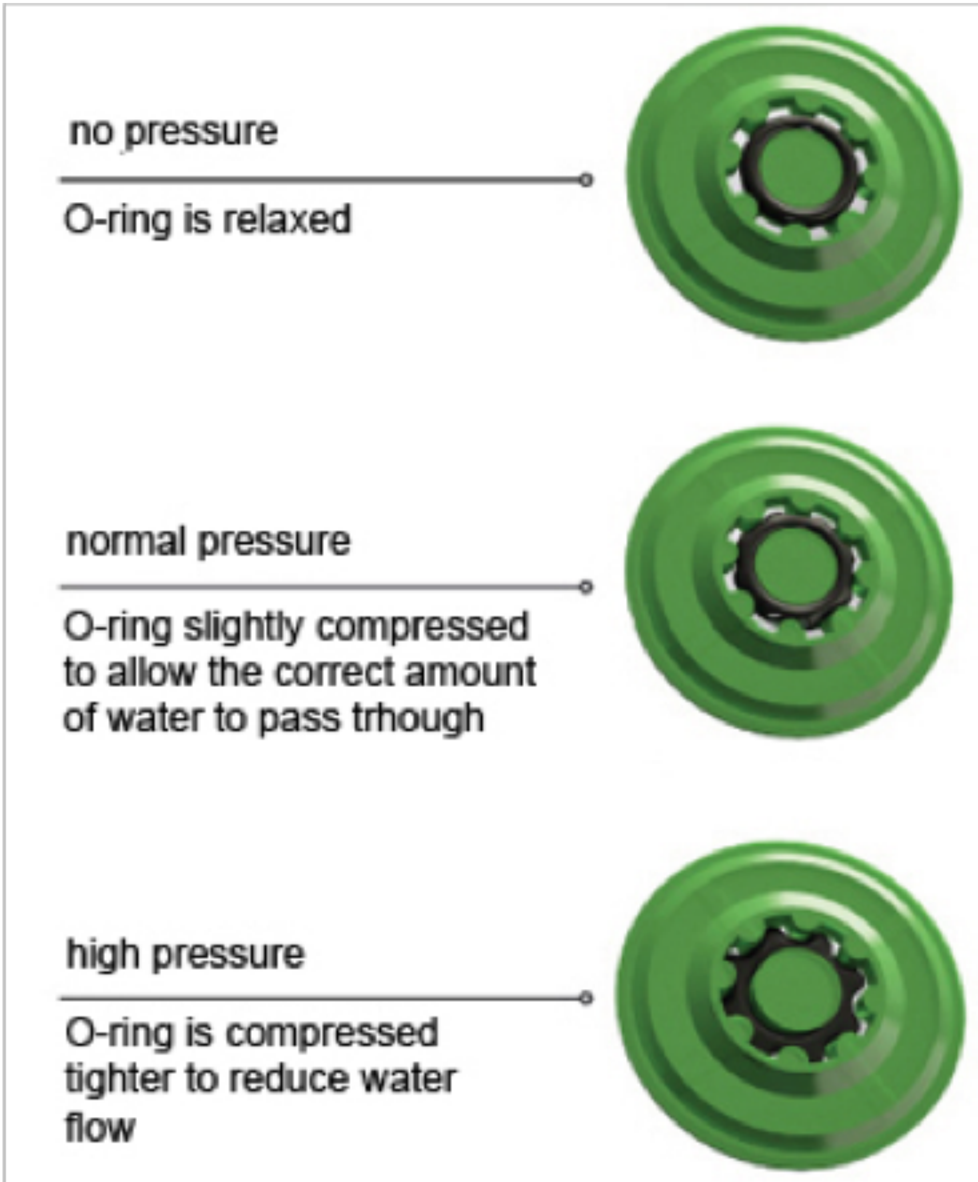
Pressure Compensating Aerators - 2



Pressure Compensating Aerators - 3



Pressure Compensating Aerators - 4



A pressure compensating flow regulator maintains a constant flow regardless of variations in line pressure thereby optimizing system performance and comfort of use at all pressures.

Source: Neoperl's website for this and the pressure-flow diagrams

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 fixture fitting or appliance
    - Probably cold, say a toilet
    - 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
  - Pressure and temperature balanced shower valves became widely available in the 1980s
  - 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.

Water Consumption 1980-2017

Water-using Fixture or Appliance	1980s Water Use (typical)	1990 Requirement (maximum)	EPAct 1992 Requirement (maximum)	2009 Baseline Plumbing Code (maximum)	"Green Code" Maximums (2017 CALGreen)	% Reduction in avg water use since 1980s
Residential Bathroom Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	2.2 gpm	1.2 gpm	66%
Showerhead	3.5+ gpm	3.5 gpm	2.5 gpm	2.5 gpm	1.8 gpm	49%
Residential ("private") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Commercial ("public") Toilet	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Urinal	1.5 to 3.0+ gpf	1.5 to 3.0+ gpf	1.0 gpf	1.0 gpf	0.125 gpf	96%
Commercial Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	0.5 gpm	0.5 gpm	86%
Food Service Pre-Rinse Spray Valve	5.0+ gpm	No requirement	1.6 gpm *(EPAct 2005)*	No requirement	1.3 gpm	74%
Residential Clothes Washing Machine	51 gallons per load	No requirement	26 gallons per load *(2012 std)*	No requirement	12.6 gallons per load *(Energy Star)*	75%
Residential Dishwasher	14 gallons per cycle	No requirement	6.5 gallons per cycle *(2012 std)*	No requirement	3.5 gallons per cycle *(Energy Star)*	75%

From 1980 to 2017: Reductions range from 49 to 96%

Source: *The Drainline Transport of Solid Waste in Buildings*, PERC 1 Report - J. Koeller, P. DeMarco

Right-size the Supply Piping

2018 IAPMO Uniform Plumbing Code (UPC)

- Appendix M, Peak Water Demand Calculator
- Single- and multi-family homes with water-conserving plumbing fixtures, fixture fittings and appliances
- In general, can expect reduction of one nominal diameter.
    - Going smaller than 0.5 inch nominal?
    - Pay attention to velocity and residual pressure
- http://www.iapmo.org/water-demand-calculator/

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
  - Zhang recently reviewed the data and has 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.

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

Cut the 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. Pressure Drop Through 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 1895.*
- *The work of Giesecke (1926) and Giesecke and Badgett (1931, 1932a, 1932b may not be representative of current materials.*

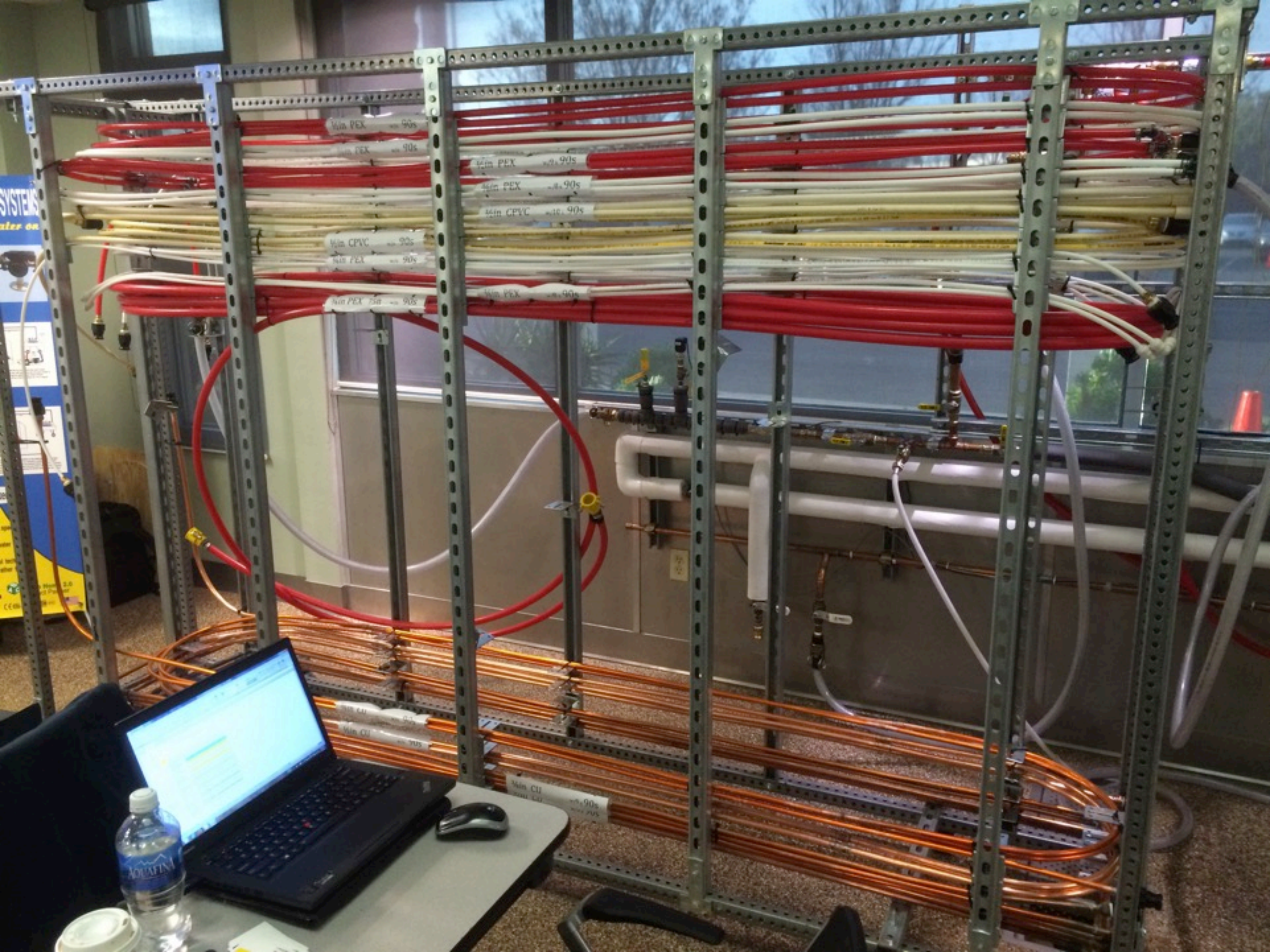
Pressure Drop - 1

- Elbows widely spaced and close together
- Velocities from 1-12 feet per second
- So far, we have not yet measured any published numbers
  - Are our measurements higher or lower than what is published? Yes!
  - Do our numbers have the same trends as what is published? No!
- It matters if we want to right-size piping systems.

Southern California Gas Company
Hot Water Demonstration Lab
Downey, CA


TOOL
BOX


Solar Water Heating System
Demonstration Unit
Windows 7
Copper Tubing
MADE IN USA

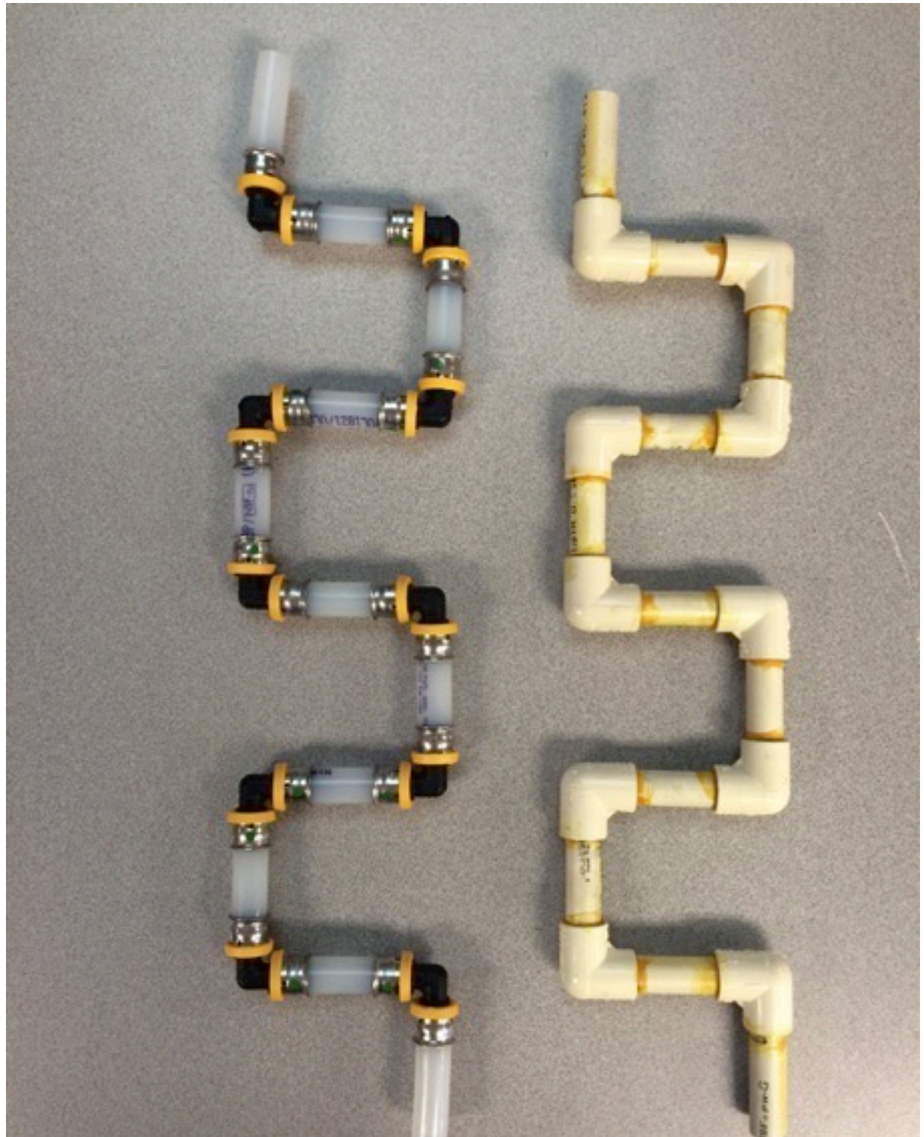

36in PEX
36in CPVC
36in CU
SYSTEMS
AQUAFINA

Pipe from ¼ inch to ¾ inch Nominal

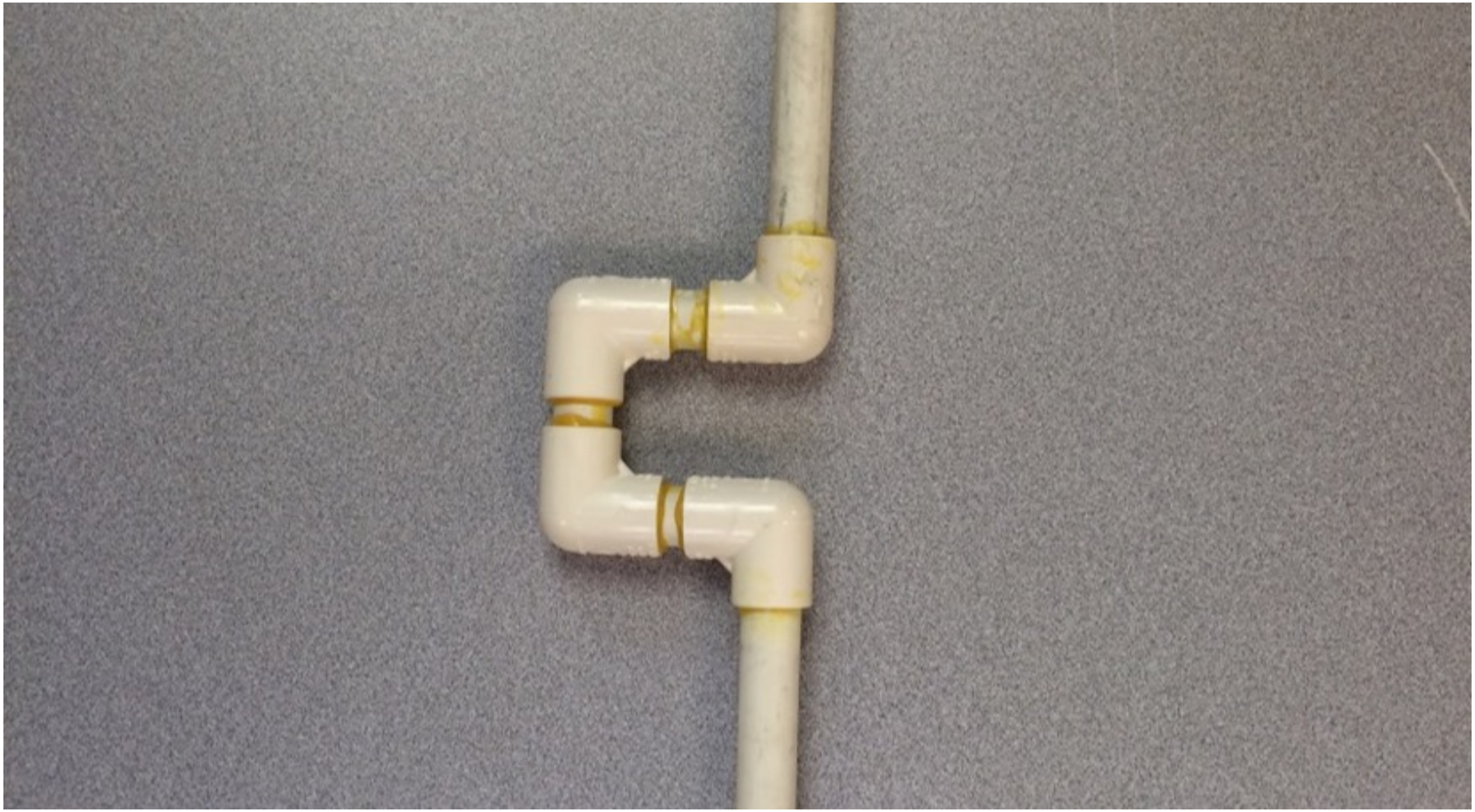
Pipe from ¼ inch to ¾ inch Nominal

90 Degree Elbows

Close-coupled Elbows



Even Closer



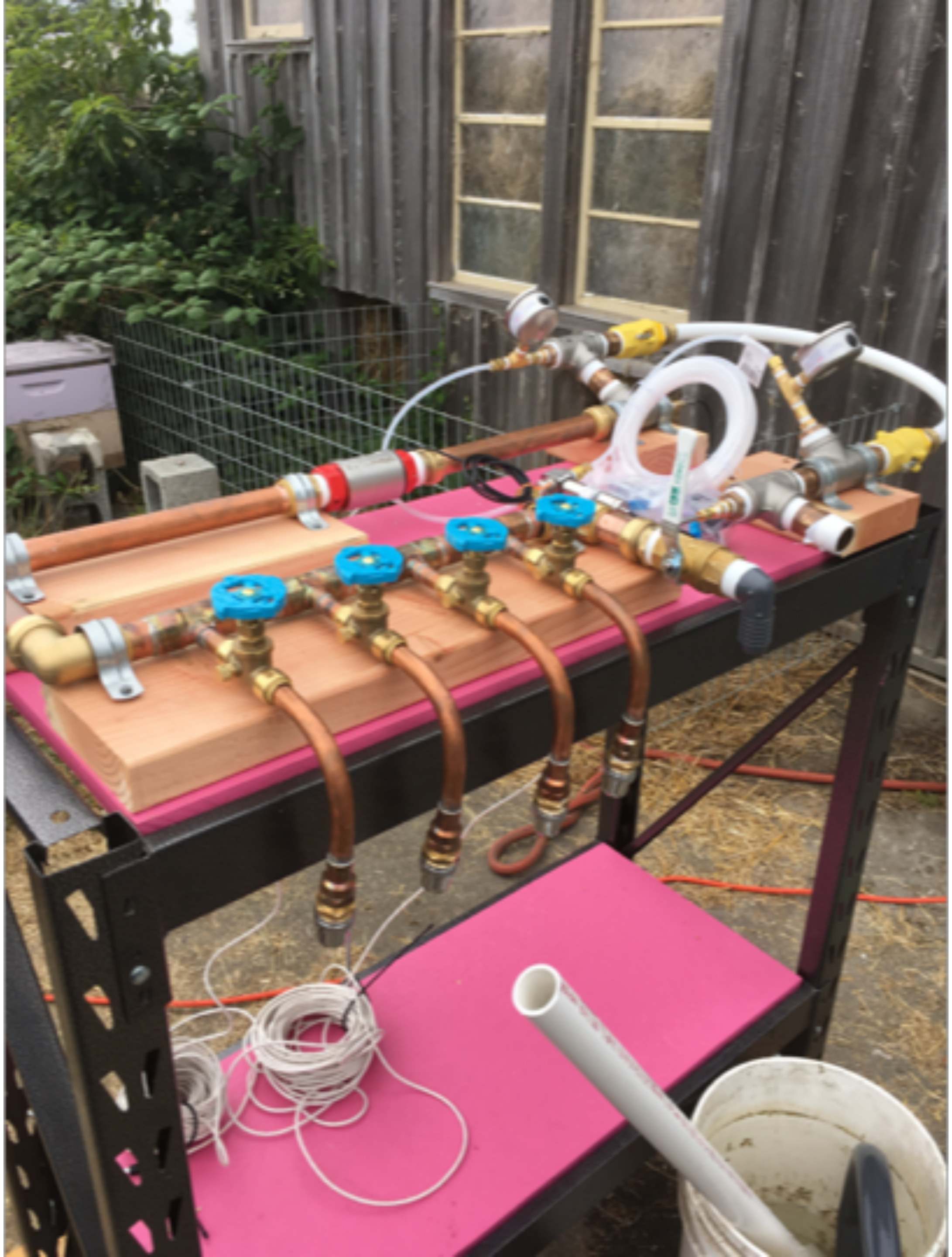
Pressure Drop Due to Elbows

	Equivalent Feet of 1/2" Tubing			
	Water Velocity in Tubing Feet per Second			
90° Elbow Type	2 FPS	4 FPS	5 FPS	8 FPS
PEX Crimp Insert	8.6	10.1	9.8	11.9
PEX Poly SS Press	7.9	8.9	8.9	9.6
PEX Cold Expansion	6.6	7.3	8.0	9.1
CPVC (Std Elb)	1.7	0.8	0.9	1.3
Copper (Std Tight Elb)	0.0	0.4	0.3	0.6

Pressure Drop Due to Elbows

Tight Spacing of Elbows	Equivalent Feet of 1/2" Tubing			
	Water Velocity in Tubing Feet per Second			
90° Elbow Type	**2 FPS**	**4 FPS**	**5 FPS**	**8 FPS**
PEX Poly SS Press	7.9		8.9	9.6
Tight Spacing	8.4		10.8	11.7
PEX Cold Expansion	6.6		8.0	9.1
Tight Spacing	7.9		9.3	9.4
CPVC (Std Elb)	1.7		0.9	1.3
Tight Spacing	0.7		1.3	1.5

Arcata Test Site




TRIATHLON

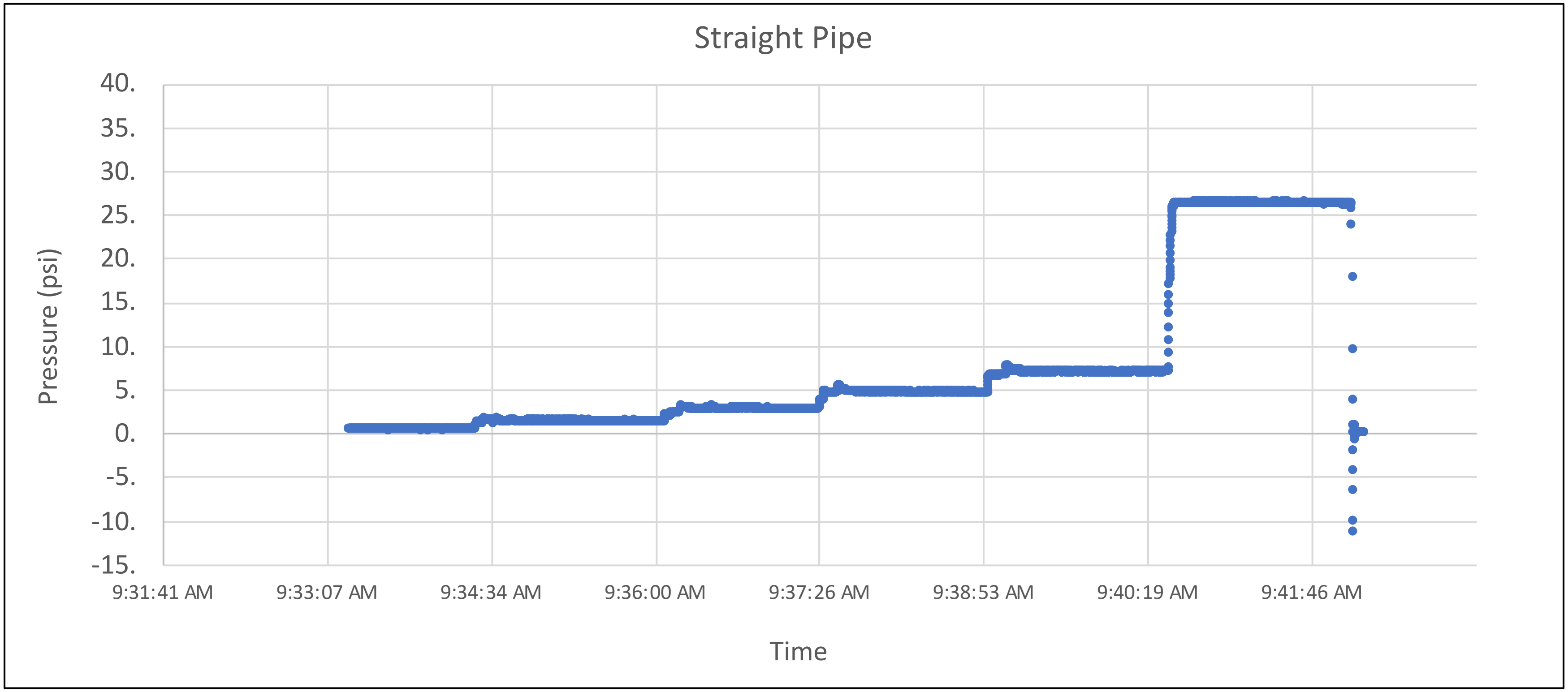

KANSAS

Brass Crimp Elbow

Plastic Crimp Elbow

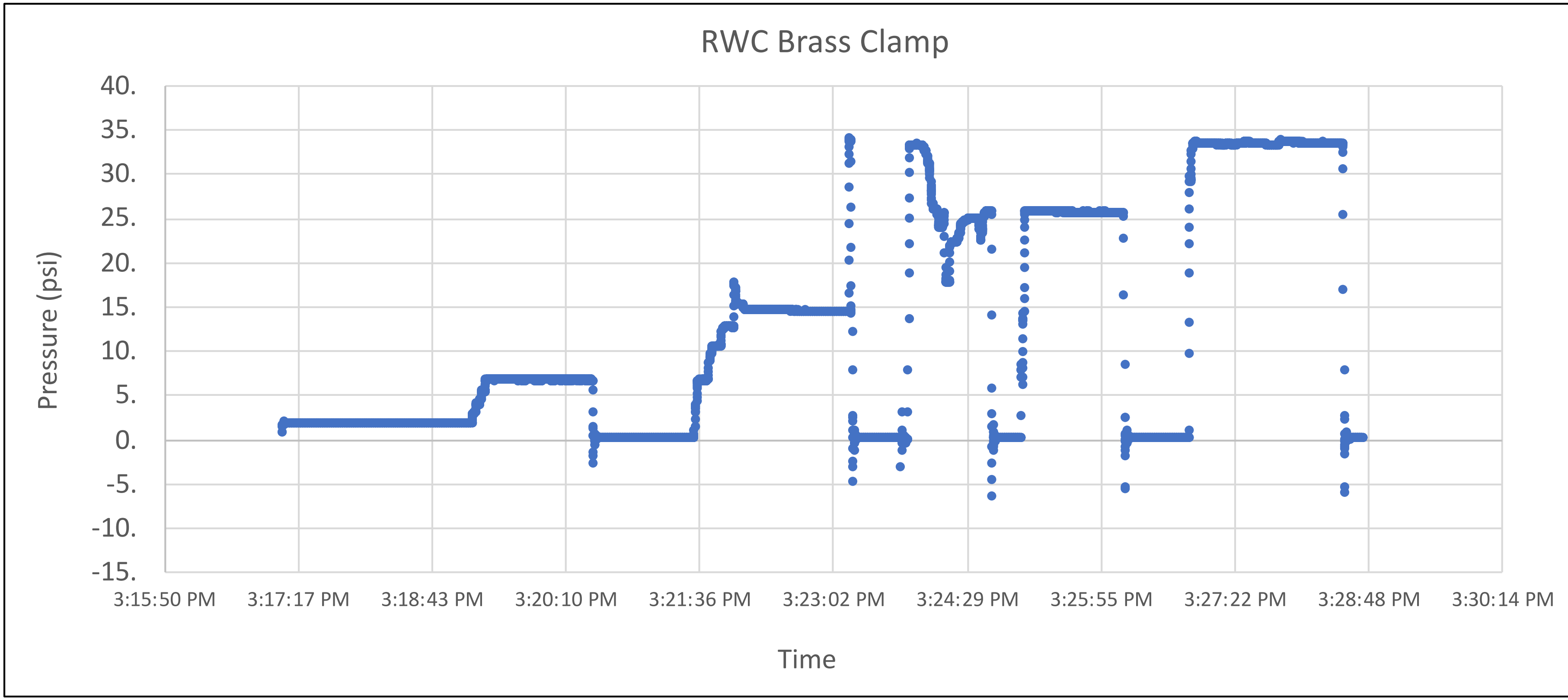
Plastic Evopex Elbow

Pressure Drop (PSI) (16.25 feet 0.5 inch PEX)



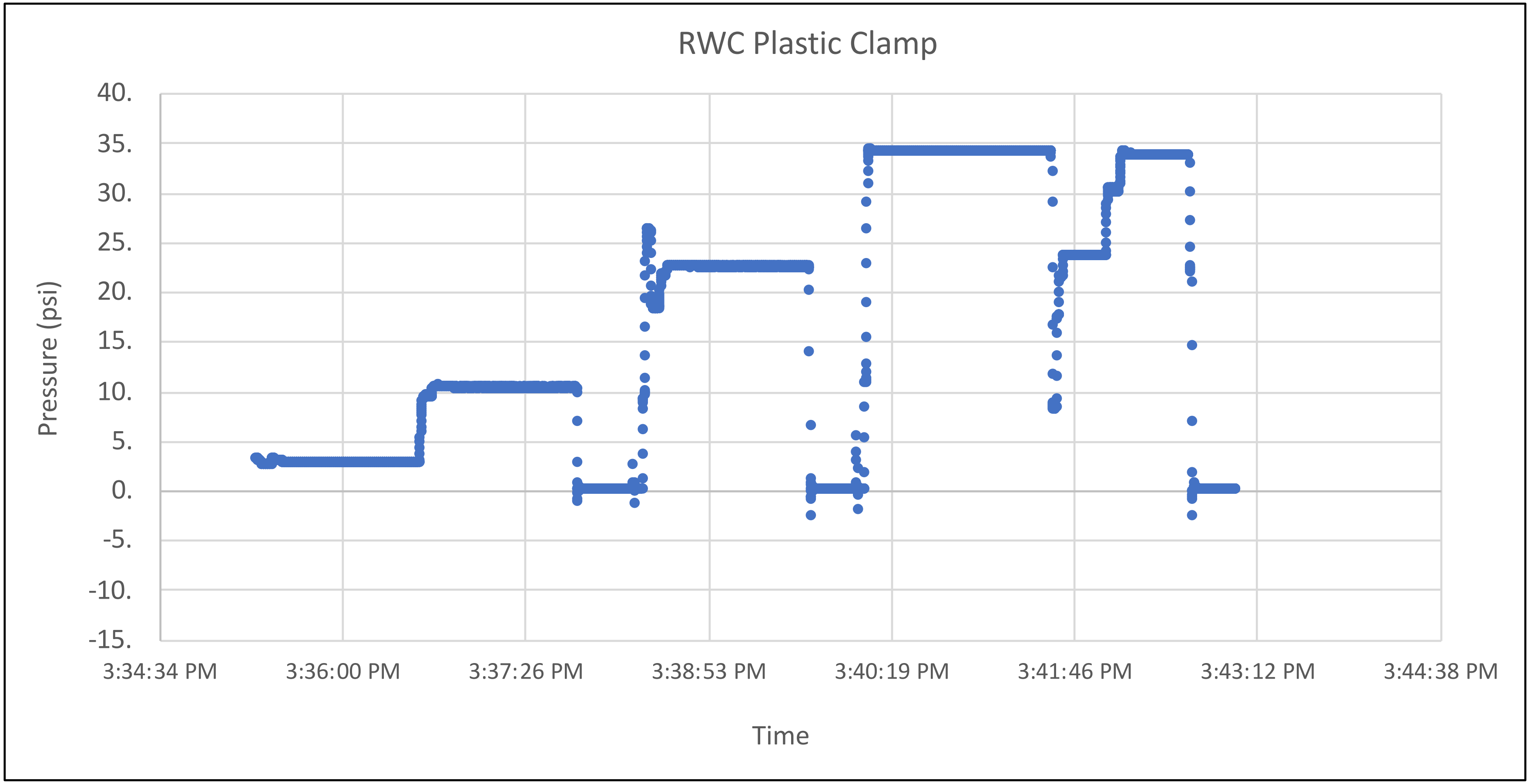
2 fps4 fps6 fps8 fps10 fps Max Flow

Pressure Drop (PSI) (0.5 inch Brass Elbow)



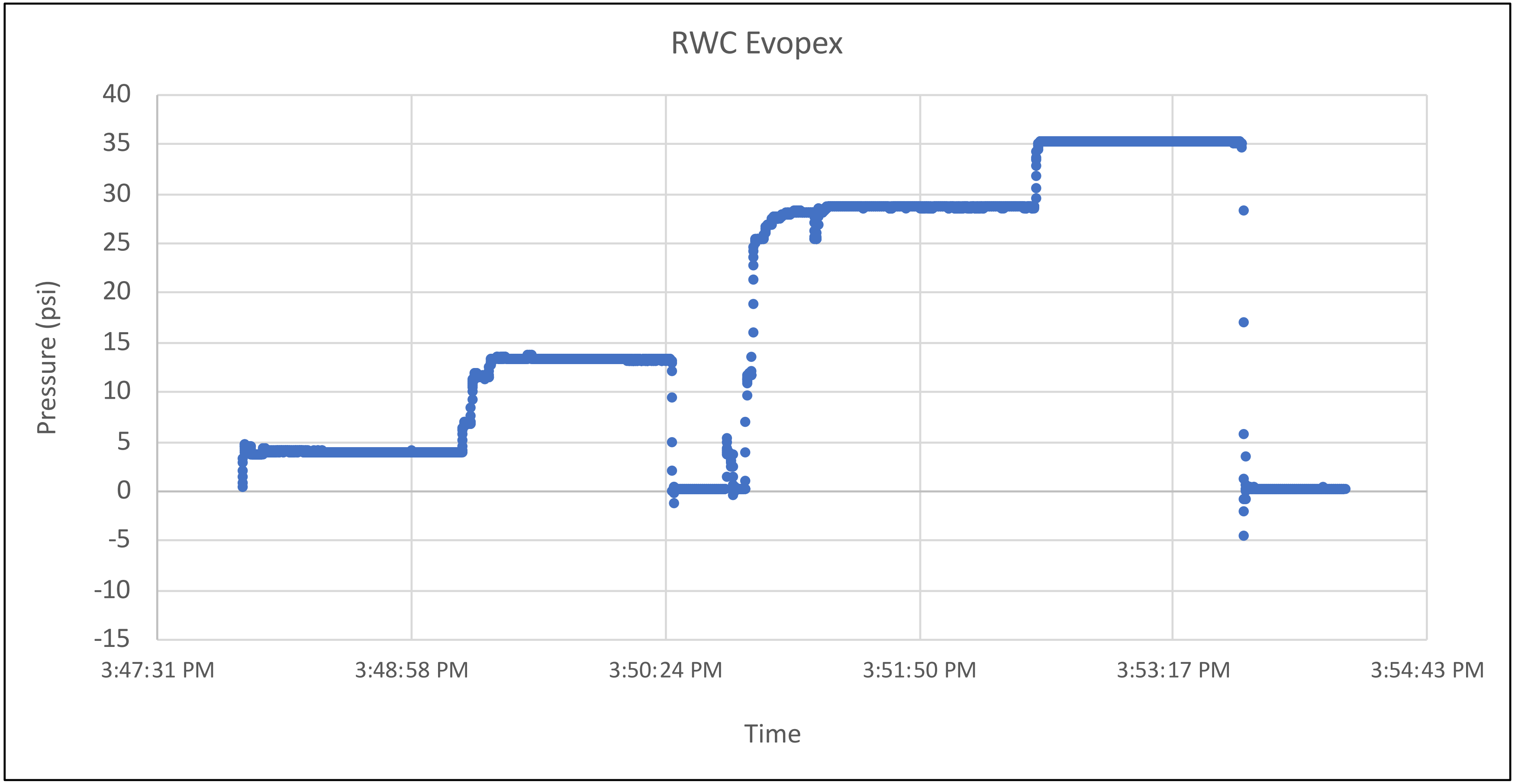
2 fps4 fps 6 fps 8 fps 10 fps

Pressure Drop (PSI) (0.5 inch Plastic Elbow)



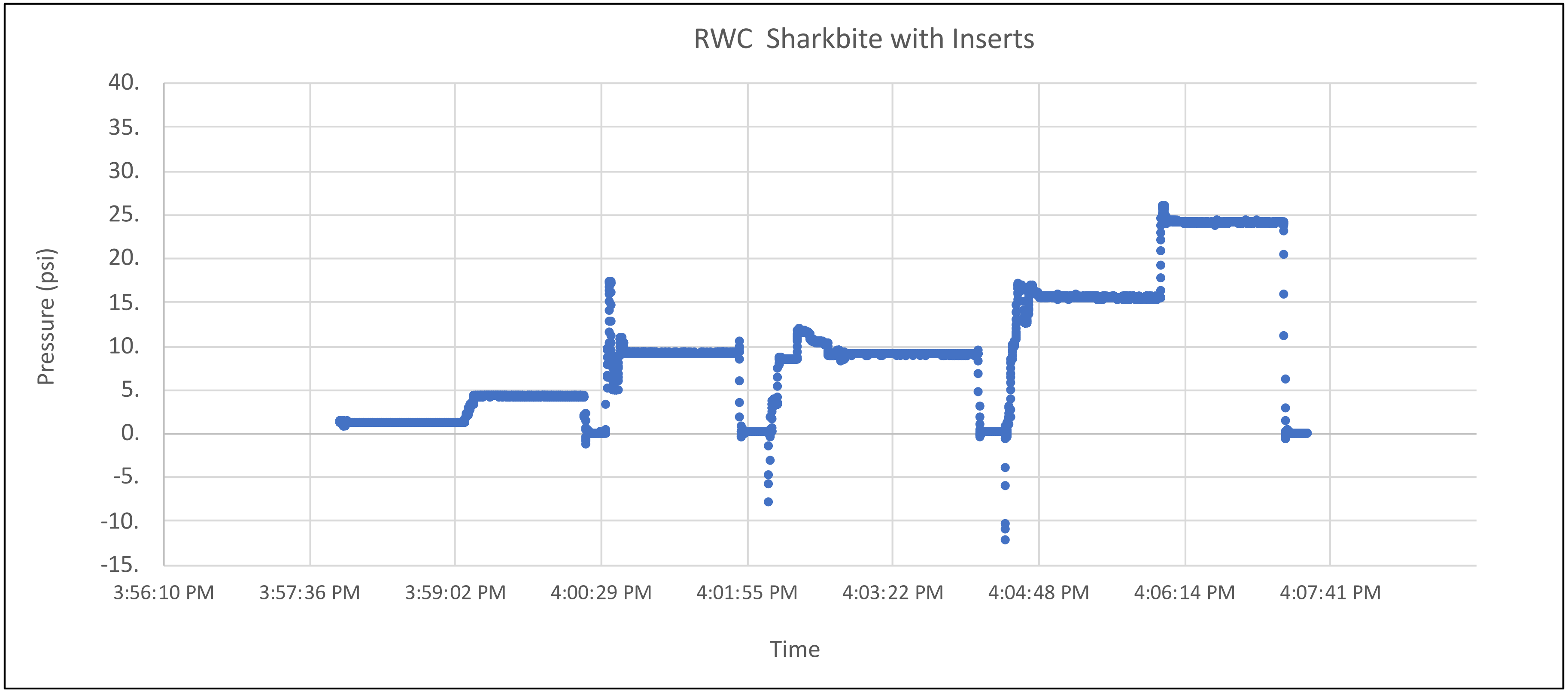
2 fps4 fps 6 fps 8 fps 10 fps

Pressure Drop (PSI) (0.5 inch Evopex)



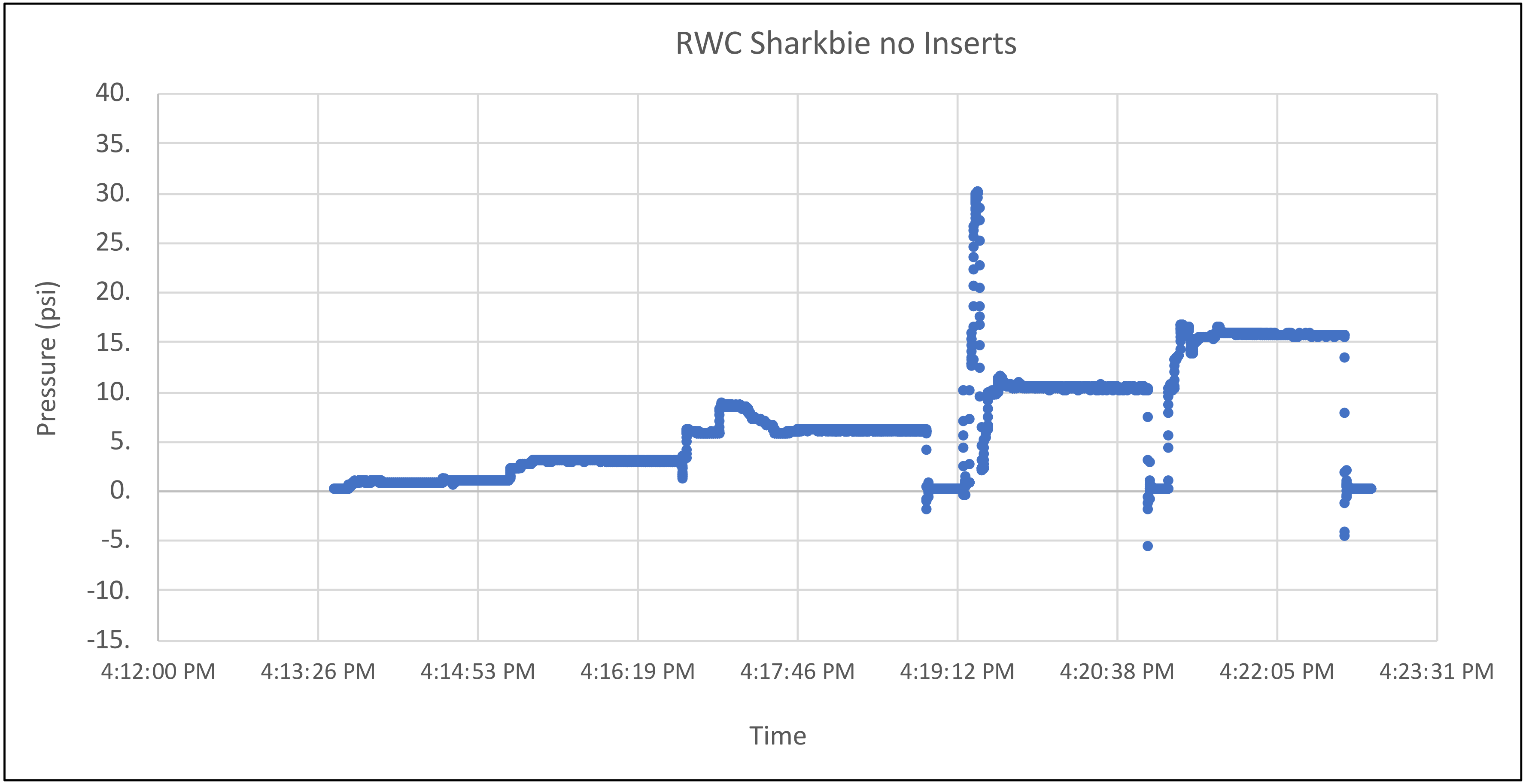
2 fps 4 fps 6 fps 8 fps

Pressure Drop (PSI) (0.5 inch Sharkbite w/inserts)



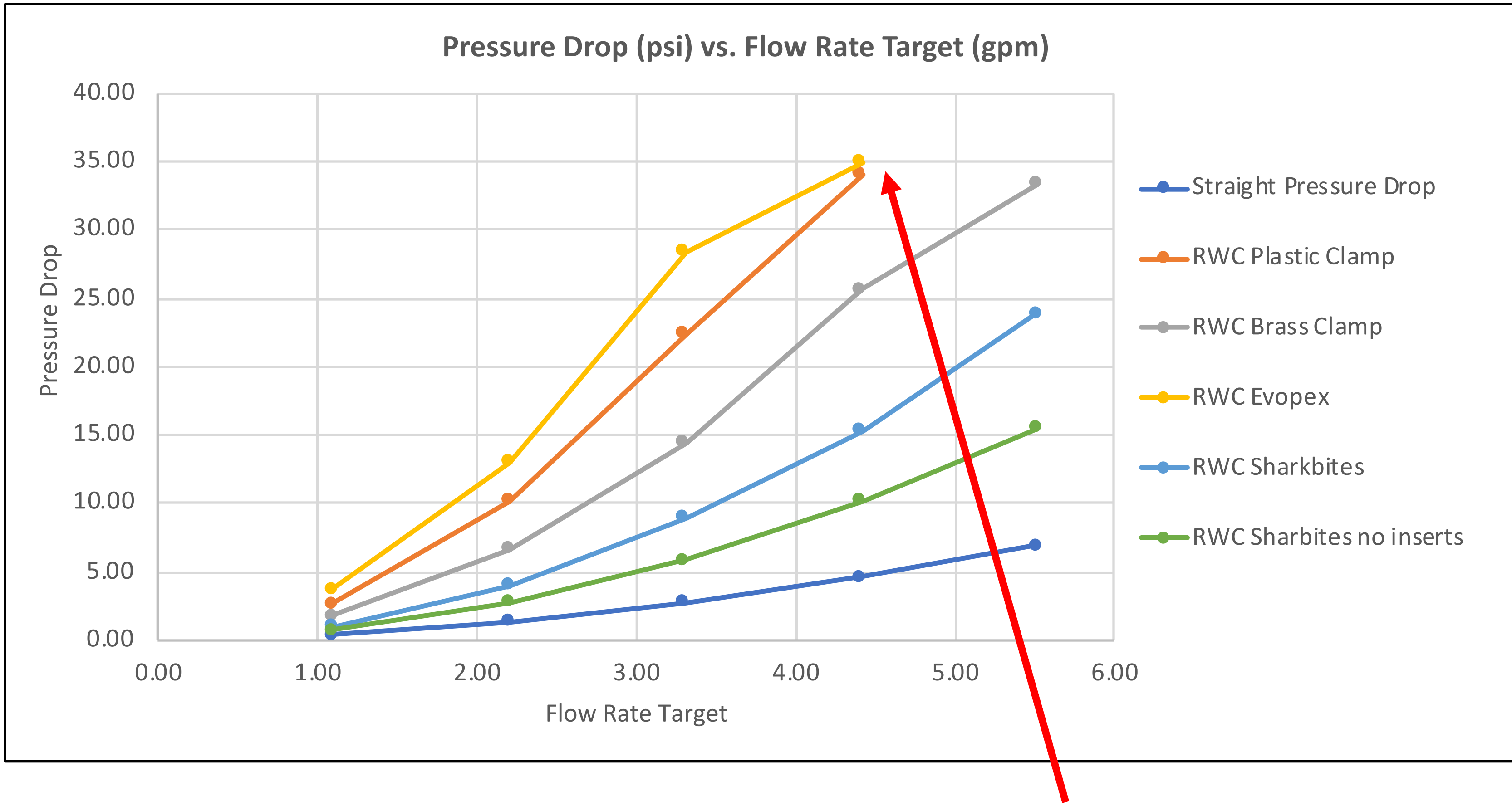
2 fps 4 fps 6 fps 8 fps 10 fps

Pressure Drop (PSI) (0.5 inch Sharkbite w/o inserts)



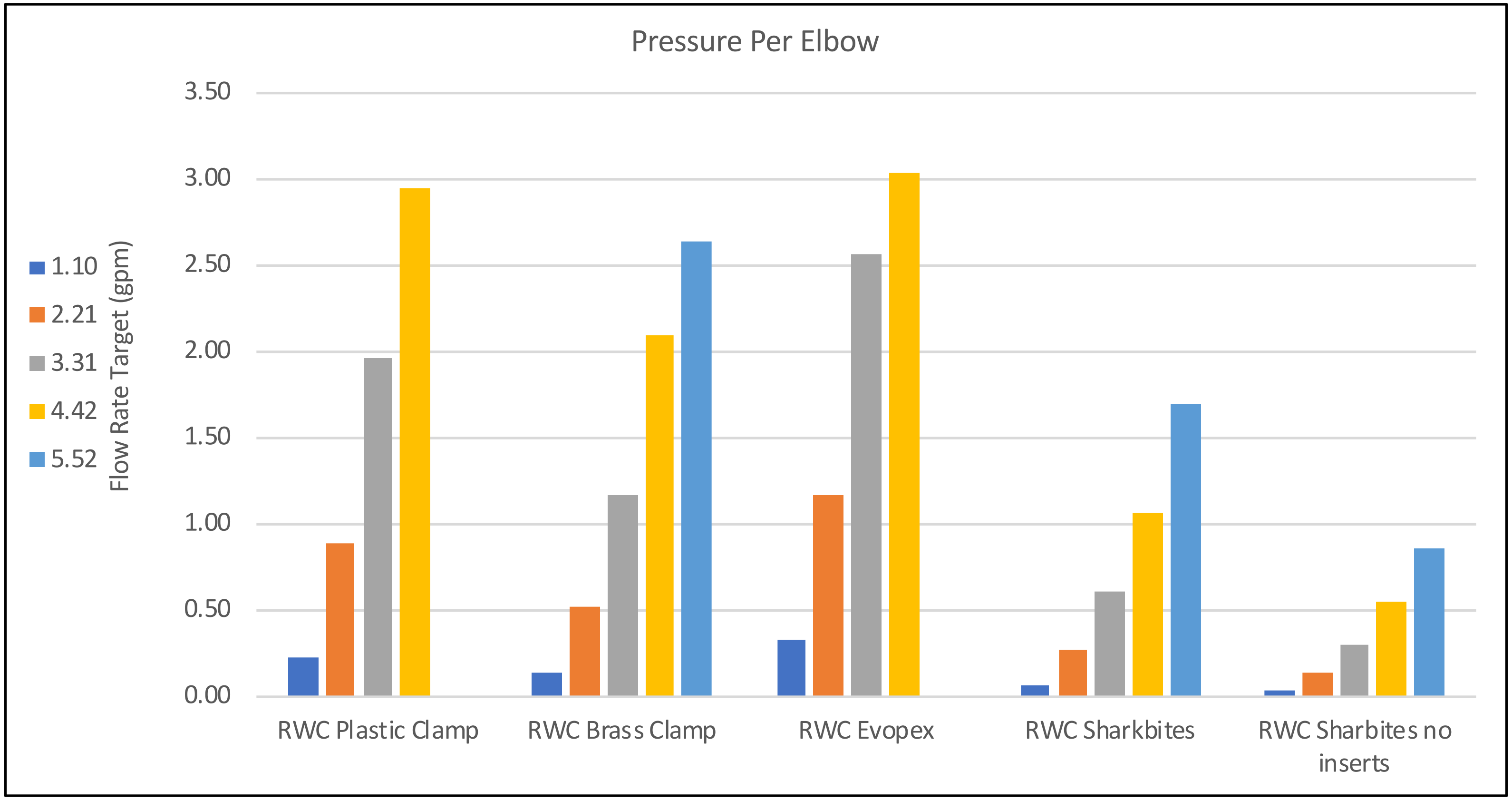
2 fps4 fps 6 fps 8 fps 10 fps

Pressure Drop Summary

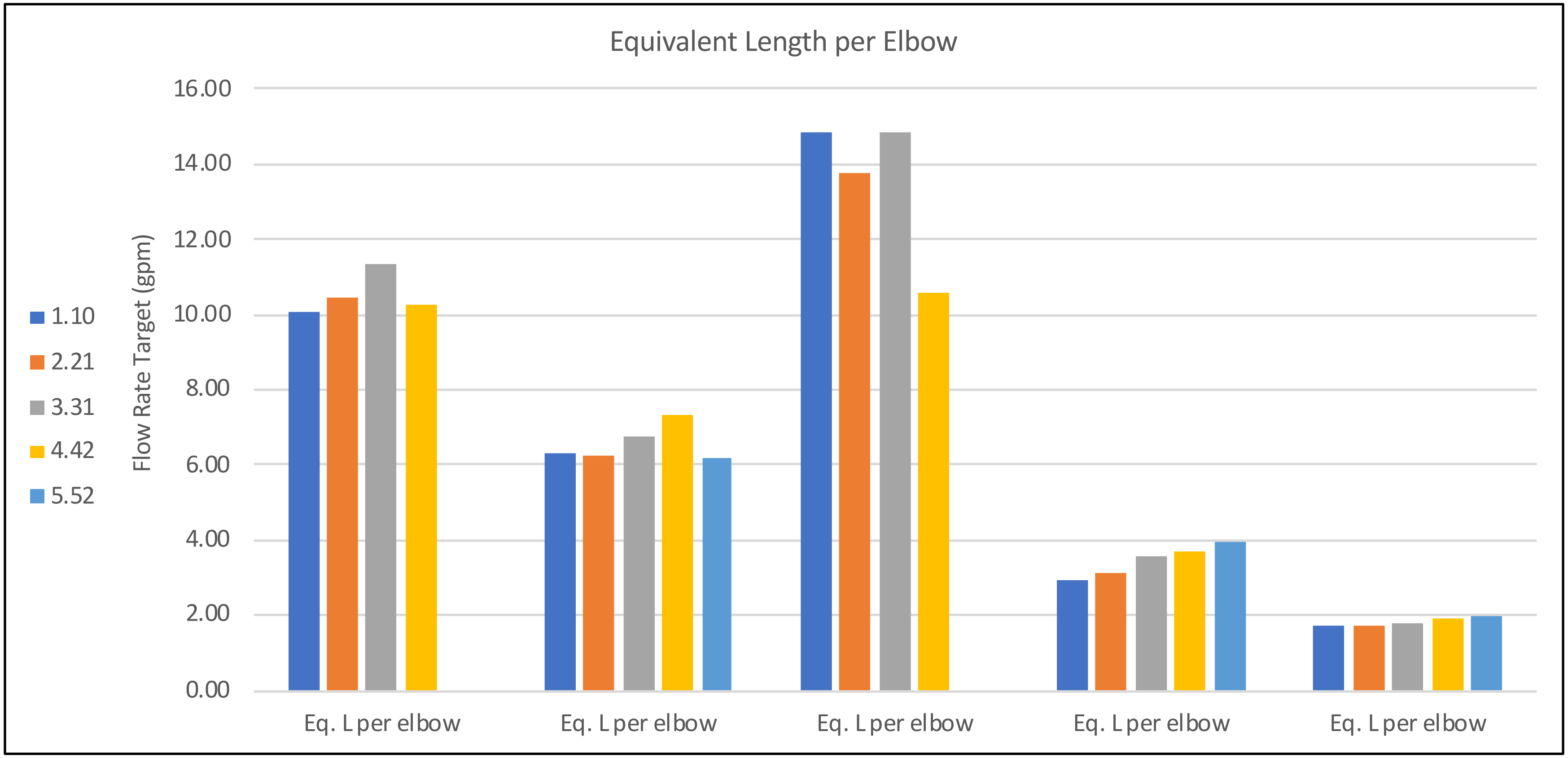


Didn't have enough available pressure to run 10 fps test

Pressure Drop per Elbow (PSI)



Equivalent Feet per Elbow (feet)



Pressure Drop - 2

- Is there a minimum radius of curvature through which there is no additional pressure drop other than that due to the length of the bend?
- Wouldn’t that be the most water, pressure, energy and time efficient bend?
- Ask me about the Swoop®

6. Viscosity of Hot and Cold Water

- What is the viscosity of hot water compared to cold water?
  - Is the difference small or large?
  - Cold water is 1.7-2.8 times more viscous than hot water for a wide range of temperatures typically found in buildings!
- It is almost as though there are 2 different fluids moving through the same pipe.
  - Slippery hot water and sluggish cold water.
  - This helps explain much of the extra volume and time to get hot water from the source to the use.

Ratio of the viscosity of water at a range of typical temperatures

Cold:Hot	50:120	50:140	70:120	70:140
Ratio	**2.31**	**2.76**	**1.73**	**2.06**

Legend	**Regime**	**Re** Range	**1-D Dispersive Transport**
	turbulent	20,000<**Re**	low (probably not important)
	transition	4,000<**Re**<20,000	low to moderate (might be important)
	critical	2,000<**Re**<4,000	moderate to high (likely to be important)
	laminar	0<**Re**<2,000	high (important)

Calculating the Reynolds Number

Re = 0.03404Q/vD	**Temp (F)**	**Viscosity (ft^2/s)**
Flow, Q (gpm)	50	0.000014063
Viscosity, v (ft^2/s)	60	0.000012075
Diameter, D (in)	70	0.000010503
	80	0.00000925
	90	0.000008234
	100	0.000007392
	110	0.000006682
	120	0.000006075
	130	0.000005551
	140	0.000005102

Reynolds Number: 70F

Temp = 70 F / 21 C	Flow (gpm)									
Diameter (in)	0.25	0.50	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.250	3241	6482	12964	19446	25928	32410	38892	45374	51856	64820
0.375	2161	4321	8643	12964	17285	21607	25928	30249	34570	43213
0.500	1620	3241	6482	9723	12964	16205	19446	22687	25928	32410
0.625	1296	2593	5186	7778	10371	12964	15557	18149	20742	25928
0.750	1080	2161	4321	6482	8643	10803	12964	15125	17285	21607
1.00	810	1620	3241	4861	6482	8102	9723	11343	12964	16205
1.25	648	1296	2593	3889	5186	6482	7778	9075	10371	12964
1.5	540	1080	2161	3241	4321	5402	6482	7562	8643	10803
2.0	405	810	1620	2431	3241	4051	4861	5672	6482	8102
2.5	324	648	1296	1945	2593	3241	3889	4537	5186	6482
3.0	270	540	1080	1620	2161	2701	3241	3781	4321	5402
3.5	231	463	926	1389	1852	2315	2778	3241	3704	4630
4.0	203	405	810	1215	1620	2026	2431	2836	3241	4051
5.0	162	324	648	972	1296	1620	1945	2269	2593	3241
6.0	135	270	540	810	1080	1350	1620	1891	2161	2701
8.0	101	203	405	608	810	1013	1215	1418	1620	2026

Reynolds Number: 140F

Temp = 140 F / 60 C	Flow (gpm)									
Diameter (in)	0.25	0.50	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.250	6672	13344	26688	40031	53375	66719	80063	93407	106750	133438
0.375	4448	8896	17792	26688	35583	44479	53375	62271	71167	88959
0.500	3336	6672	13344	20016	26688	33359	40031	46703	53375	66719
0.625	2669	5338	10675	16013	21350	26688	32025	37363	42700	53375
0.750	2224	4448	8896	13344	17792	22240	26688	31136	35583	44479
1.00	1668	3336	6672	10008	13344	16680	20016	23352	26688	33359
1.25	1334	2669	5338	8006	10675	13344	16013	18681	21350	26688
1.5	1112	2224	4448	6672	8896	11120	13344	15568	17792	22240
2.0	834	1668	3336	5004	6672	8340	10008	11676	13344	16680
2.5	667	1334	2669	4003	5338	6672	8006	9341	10675	13344
3.0	556	1112	2224	3336	4448	5560	6672	7784	8896	11120
3.5	477	953	1906	2859	3813	4766	5719	6672	7625	9531
4.0	417	834	1668	2502	3336	4170	5004	5838	6672	8340
5.0	334	667	1334	2002	2669	3336	4003	4670	5338	6672
6.0	278	556	1112	1668	2224	2780	3336	3892	4448	5560
8.0	208	417	834	1251	1668	2085	2502	2919	3336	4170

7. Converting Volume to Height

Most of us are between 5’– 7’ tall. This means we are roughly equal to:

- 1/8” pipe: 1 shot of liquor (1 ounce)
- 1/4” pipe: A “double” of liquor (2 ounces)
- 3/8” pipe: 1 glass of wine (4-6 ounces)
- 1/2” pipe: 1 cup of water (8 ounces)
- 3/4” pipe: 1 pint of beer (16 ounces)
- 1” pipe: 1 bottle of wine (750 ml)

Length of Pipe that Holds 8 oz of Water

	3/8" CTS	1/2" CTS	3/4" CTS	1" CTS
	ft/cup	ft/cup	ft/cup	ft/cup
"K" copper	9.48	5.52	2.76	1.55
"L" copper	7.92	5.16	2.49	1.46
"M" copper	7.57	4.73	2.33	1.38
CPVC	N/A	6.41	3.00	1.81
PEX	12.09	6.62	3.34	2.02

Questions?

Given human nature,
it is our job
to provide the infrastructure
that supports efficient behaviors.