The Unintended Consequences of Lowering Residential Lavatory Faucet Flow Rates:

An Analysis Informed by Measurement

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Purpose of the Study

The purpose of these tests was to compare the time it takes the temperature of water at ambient temperature to reach 110F as it passes through typical configurations of plumbing and the corresponding volume that is wasted waiting for the hot water to arrive.

Conclusions[1]

- The IOU-NRDC Case study and comments addressed the issue of waiting for hot water to arrive and concluded that the impact would be minimal. At least two of the other parties also briefly addressed the issue. The Energy Commission's staff analysis considered the issue in their recommendation not to adopt the CASE proposal. **However, none of the parties calculated the actual water and energy that would be wasted**. Given our understanding of the requirements of Title 20 decisions, the waste of water and energy needs to be calculated from the current base of nominal 2.2 gpm aerators down to either 1.5 gpm or 1.0 gpm, or whatever final flow rate is settled upon. If the nominal flow rate is reduced from 2.2 to 1.0 gpm:
  - **The waste of water while waiting ranges from 0.68-0.80 gallons per day.**
  - **The embedded energy in this wasted water ranges from 34.4 to 40.5 GWh per year (0.68-0.80 gallons/household per day x 13.8 million households[2] x 365 days per year x 10,045 kWh/million gallons).**
  - **The waste of energy ranges from 28.3-32.9 million therms per year.**
  - **However, the energy wasted at current flow rates is almost 3 times larger than the IOU's estimated savings when the stock turns over and this base-case waste appears to have been ignored.**
- Water that is wasted while waiting for hot water to arrive is 10-11% more when the nominal flow rate is reduced from 2.2 to 1.0 gpm. When comparing a nominal flow rate of 1.5 to 1.0 gpm the amount of water that is wasted while waiting for hot water to arrive is 3-4% more. This is 0.05 to 0.07 gallons per event. Assuming four such events a day results in additional waste of 0.20 to 0.28 gallons per day. In aggregate, this additional waste is 1 to 1.4 billion gallons per year (0.20-0.28 gallons/household per day x 13.8 million households[2] x 365 days per year). The embedded energy for this wasted water is about 10 to 14 GWh per year.
- Reducing the flow rate from 2.2 to 1.0 gpm increases the time it takes for the hot water to arrive from 55 to 140 seconds (155%) at high pressure and from 90-215 (139%) seconds at low pressure. Reducing the flow rate from 1.5 to 1.0 gpm increases the time it takes for the hot water to arrive by 43-56%.
- According to Table 5.4 in the IOU-NRDC CASE Report, the average lavatory faucet event was 37 seconds. **Just waiting for hot water to arrive at the daily events where hot water is needed at the faucet takes 1.5 to 5.8 times longer than the average faucet event; the event itself is longer still. It is highly likely that people will notice this significant increase in time and are not likely to be pleased.**

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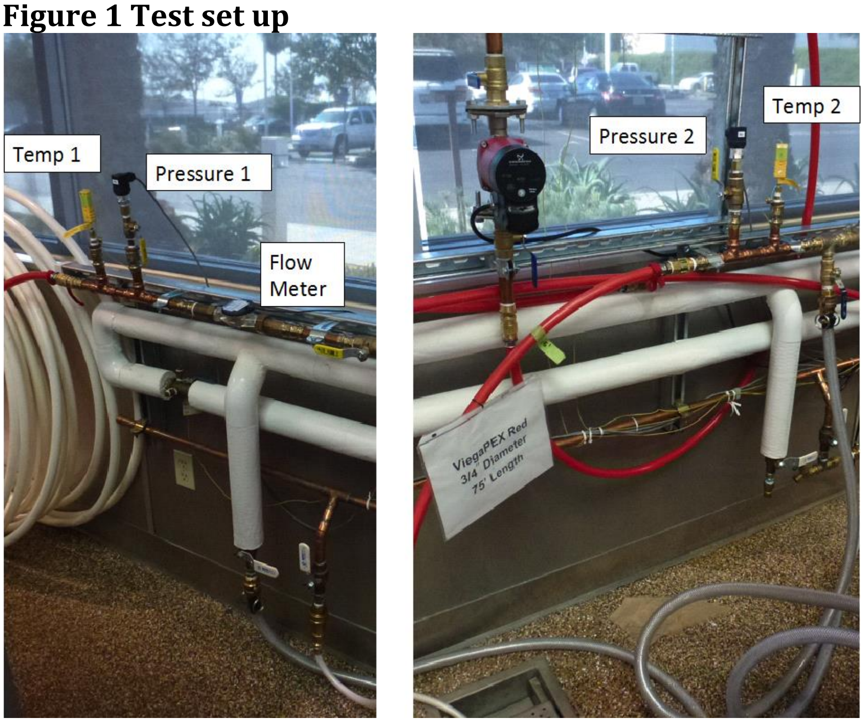
[1] This analysis uses information provided by the IOUs and NRDC. The IOU-NRDC CASE Report of August 2013 (Analysis of Standards Proposal for Residential Faucets & Faucet Accessories; CASE Report) indicates that there are at least two lavatory faucets in each home and 13.8 lavatory faucet events per house per day.

[2] Source: U.S. Census Bureau: http://quickfacts.census.gov/qfd/states/06000.html

Test Conditions

- Data was gathered to compare the performance of different faucet aerators operating in a range of pressures typical of that found throughout California.
- The length of pipe used in the test, 75 feet, is a reasonable approximation of the distance from the water heater to the furthest fixture in a 1,200 square foot single-story home. The volume, 1.5 gallons, based on the use of PEX, is also a reasonable estimate. A 2,400 square foot, two-story home would have a similar length and volume. The length and volume are representative of both new and existing homes.
- Faucet aerators that were tested are rated to flow at 2.2 gpm, 1.5 gpm and 1.0 gpm at 60 psi in accordance with the standard test procedure. Tests were conducted with system pressures close to this rated pressure and at a low pressure, approximately 20 psi. As pressure decreases below the rated pressure the flow rate through fixed orifice aerators decreases proportionally. When the pressure is 30 psi, the flow is roughly half of that when rated; when the pressure is zero, there is no flow.
- The water heater temperature ranged from 140-145F during the testing. This is higher than many water heaters are set; generally in the range of 120-125F.
- The ambient water temperature ranged from 75-80F. When compared to many climate zones in the state these are relatively high ambient water temperatures.
- Both the higher water heater temperature and the warmer ambient temperature tend to make the results conservative.
- Temperature sensors measured the temperature as the water entered the length of piping and as it exited. Pressure sensors measured the difference in pressure as the water flowed through the piping. An in-line flow meter measured the flow rate. Figure 1 shows the temperature and pressure sensors and the flow meter in the test setup.

Figure 1 Test set up



Test Results

Flow Rate

Table 1 compares the nominal to the actual flow rates at both high and low systems pressures. The upper half of the table presents the results for the high pressure tests; the lower half for the low pressure tests.

Table 1 Measured Flow Rates

High Pressure Tests (55-62 psi)							
Flow Rates (GPM)		Difference Compared to Rated Flow Rate		Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
Nominal	Actual	GPM	Percent	GPM	Percent	GPM	Percent
2.2	1.95	0.25	11%	0	0%	NA	NA
1.5	1.27	0.23	15%	0.68	35%	0	0%
1.0	0.84	0.16	16%	1.11	57%	0.43	34%
Low Pressure Tests (19-22 psi)							
Flow Rates (GPM)		Difference		Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
Nominal	Actual	GPM	Percent	GPM	Percent	GPM	Percent
2.2	1.18	1.02	46%	0	0%	NA	NA
1.5	0.76	0.74	49%	0.42	36%	0	0%
1.0	0.55	0.45	45%	0.63	53%	0.21	28%

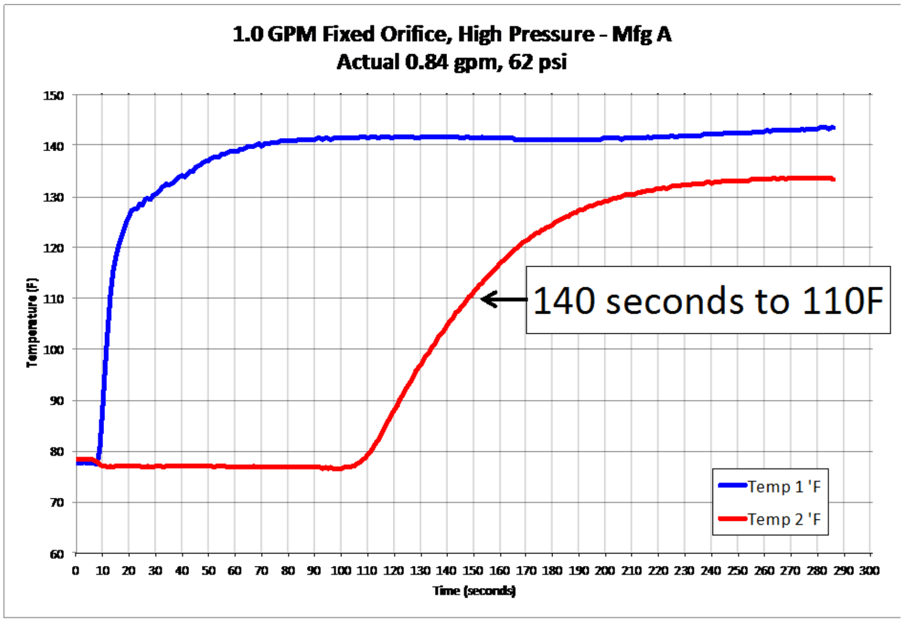
- The actual flow rates were always less than the rated flow rates[1]. The difference was 11-16% less at high pressures and 45-49% less at low pressures.
- The disparity is also significant when comparing the actual flow rates to the 2.2 gpm rated flow that consumers think they are getting now. In these cases the reduction was 53-57% less flow when the comparison is between nominal 2.2 and 1.0 gpm aerators. Even when the comparison is between nominal 1.5 and 1.0 gpm aerators, the reduction in flow ranges from 28-34%.
- The actual flow rate is important because when customers purchase a particular aerator they are never given any indication that it will actually operate at less than the flow rate marked on the package. When their local pressures are relatively close to the pressure used when rating the aerators (60 psi), the difference is relatively small and may not be perceived as significant. However, many communities in California supply water at pressures that range from 30-45 psi and there are occasions that actual pressures are closer to 20 psi. When making this comparison, the actual flow rate of a nominal 1.0 gpm aerator operating at low pressure is 72% less than the actual flow rate of a nominal 2.2 gpm aerator operating at high pressure.

[1] In accordance with ASME A118.1/CSA B125.1 (Section 5.4), aerators are to be rated based on the maximum flow rate.

Time to Tap

Figure 2 shows the temperature plot for one of the aerators tested. Temperature is on the vertical axis and time on the horizontal. The patterns shown here are typical of what happened in the other tests and what happens in real buildings.

Figure 2 Time-to-Tap for a Nominal 1.0 gpm Fixed Orifice Aerator



- The temperature of the water rises very quickly at Temp 1. The temperature of the water does not begin to rise at Temp 2 until much later. Both the slope of the temperature increase and the maximum temperature are less than that obtained at Temp 1.
- The 75 feet of piping used in the testing contained 1.38 gallons of water. If the flow rate was 1.5 gpm, the math would suggest that hot water would arrive in 55 seconds. In this test with the flow rate at 0.84 gpm, the math would suggest that hot water would arrive in 99 seconds. However, it took significantly longer than that, with the hot water arriving after 140 seconds had passed.
- The simplest reason for the increase in time is that the water has to heat the pipe. This additional energy occurs at all flow rates and increases as the flow rate is decreased.

Table 2 presents the time it took for the water to pass through the pipe and reach 110F. The upper half of the table presents the results for the high pressure tests; the lower half for the low pressure tests.

Table 2 Measured Time for Water to Reach 110F

High Pressure Tests (55-62 psi)						
Nominal Flow Rate	Time-to-Hot		Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
GPM	Sec	Min	Seconds	Percent	Seconds	Percent
2.2	55	0.9	0	0%	NA	NA
1.5	90	1.5	35	64%	0	0%
1.0	140	2.3	85	155%	50	56%
Low Pressure Tests (19-22 psi)						
Nominal Flow Rate	Time-to-Hot		Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
GPM	Sec	Min	Seconds	Percent	Seconds	Percent
2.2	90	1.5	0	0%	NA	NA
1.5	150	2.5	60	67%	0	0%
1.0	215	3.6	125	139%	65	43%

- At high pressure it took almost 1 minute for hot water to arrive when the nominal flow rate was 2.2 gpm. It took 90 seconds at 1.5 gpm and 140 seconds at 1.0 gpm. According to Table 5.4 in the IOU-NRDC CASE Report, the average lavatory faucet event was 37 seconds. Just waiting for hot water to arrive at the daily events where hot water is needed at the faucet takes 1.5 to 3.8 times longer than the average faucet event (55/37=1.48; 140/37=3.8); the event itself is longer still.
- At high pressure, the time increased by 64% and 155% when the nominal flow rates were reduced to 1.5 and 1.0 gpm respectively. Similar percent reductions occur at low pressures. However, the actual time increased to almost 4 minutes when a 1.0 gpm aerator was operating at low pressures. At low pressures, waiting for hot water to arrive takes up to 5.8 times longer than the average faucet event,
- Even when the comparison is between 1.5 and 1.0 gpm aerators, the time for hot water to arrive increased by 50 to 65 seconds depending on whether the aerator was operating at high or low pressure, respectively.
- As with flow rate, it is important to compare the actual times with what consumers would expect based on the rated flow rate. Since none of the aerators provided actual flow rates of 2.2 gpm, we do not have the time it would take at that flow rate as a baseline against which to compare the other numbers.
- For this analysis, we will use the actual flow rates of the nominal 2.2 gpm aerators, as the baseline, which provides a conservative comparison. Under these conditions it takes more than 2.5 times the time for hot water to arrive at nominal 1.0 gpm

compared to nominal 2.2 gpm when the system pressures are relatively high. It takes almost 4 times as long when the systems pressures are low.

Wasted Water at the Household

Table 3 presents the calculations of the volume of water that was wasted while water ran down the drain until water passed through the piping and reached 110F. The upper half of the table presents the results for the high pressure tests; the lower half for the low pressure tests.

Table 3 Calculated Volume Wasted While Waiting

High Pressure Tests (55-62 psi)					
Nominal Flow Rate	Water Wasted Waiting for Hot	Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
GPM	Gal	Gallons	Percent	Gallons	Percent
2.2	1.79	0	0%	NA	NA
1.5	1.91	0.12	7%	0	0%
1.0	1.96	0.17	10%	0.05	3%
Low Pressure Tests (19-22 psi)					
Nominal Flow Rate	Water Wasted Waiting for Hot	Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
GPM	Gal	Gallons	Percent	Gallons	Percent
2.2	1.77	0	0%	NA	NA
1.5	1.90	0.13	7%	0	0%
1.0	1.97	0.20	11%	0.07	4%

- At high pressures, compared to the actual flow rate of a nominal 2.2 gpm aerator, the additional wasted water ranged from 7-10% at 1.5 and 1.0 nominal flow rates, respectively. At low pressures the range was from 7-11%.
- When compared to the actual flow rate of a nominal 1.5 gpm aerator, the additional wasted water using a 1.0 gpm aerator ranged from 3-4%.
- While the additional volume of wasted water may seem to be small, in all cases, as the flow rate goes down, the waste increases.
- Table 5.2 in the IOU-NRDC CASE Report estimates that there are 2.01 lavatory faucets per household. It is reasonable to assume that there are two demands for hot water per day at each faucet that require hot water and that at the start of each of these events, the water in the pipes is not hot. Total is 4 “cold start” events or their equivalent, each day.
- At high pressures, when reducing the nominal flow rate from 1.5 to 1.0 gpm, the additional volume wasted is 0.05 gallons per event or 0.20 gallons per day.

- At low pressures, when reducing the nominal flow rate from 1.5 to 1.0 gpm, the additional volume wasted is roughly 0.07 gallons per event or an additional 0.28 gallons per day.
- In aggregate, based on high pressures, the additional waste is 1 billion gallons per year (0.20 gallons/household per day x 13.8 million households x 365 days per year). For low pressures, the additional waste is 1.4 billion gallons per year (0.28 gallons/household per day x 13.8 million households x 365 days per year).
- The indirect energy costs for these events are the embedded energy associated with indoor water. Using the number for the embedded energy in indoor cold water on page 5 of the IOU-NRDC CASE Report of 10,045 kWh/million gallons, the embedded energy for this wasted 1 to 1.4 billion gallons is about 10 to 14 GWh per year.
- **The waste of water and energy needs to be based on reducing the flow rate from the current nominal flow rate of 2.2 gpm down to either 1.5 or 1.0 gpm. At high pressures, the waste going from 2.2-1.0 gpm is 0.17 gallons per event or an additional 0.68 gallons per day. At low pressures, the waste is 0.2 gallons per event or 0.8 gallons per day.**

Wasted Energy at the Household

Table 4 shows the calculation for the energy wasted for each lavatory faucet event where hot water is needed. The patterns are the same as those in Table 3. The IOU-NRDC CASE Report (Table 5.3) assumed a 59F temperature rise to heat water, a specific gravity of 0.998, the mass of water as 8.29 pounds per gallon and an Energy Factor of 0.6 for gas water heaters. These factors were used to generate the numbers in Table 4.

Table 4 Calculated Energy Wasted per Event While Waiting

High Pressure Tests (55-62 psi)					
Nominal Flow Rate	Energy Wasted Waiting for Hot	Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
GPM	BTU	BTU	Percent	BTU	Percent
2.2	1455	0	0%	NA	NA
1.5	1551	96	7%	0	0%
1.0	1595	140	10%	45	3%
Low Pressure Tests (19-22 psi)					
Nominal Flow Rate	Energy Wasted Waiting for Hot	Difference Compared to Nominal 2.2		Difference Compared to Nominal 1.5	
GPM	BTU	BTU	Percent	BTU	Percent
2.2	1441	0	0%	NA	NA
1.5	1547	106	7%	0	0%
1.0	1604	163	11%	58	4%

- Reducing the flow rate from a nominal 1.5 to 1.0 gpm increases energy consumption by 45 to 58 BTU per lavatory faucet event that needs hot water.
  Assuming 4 "cold start" events per day, or their equivalent, the additional energy per household per day ranges from 180 to 232 BTU. This translates to 65,700 to 84,680 BTU per year per household or 0.66 to 0.85 therms per year.

Table 5 shows the calculations for the daily energy wasted waiting for hot water to arrive for each household and for all households in California.

Table 5 Calculated Energy Wasted While Waiting

High Pressure Tests (55-62 psi)				
Nominal Flow Rate	Energy Wasted Waiting for Each Cold Start Event	Energy Wasted Waiting Per Day	Energy Wasted Waiting Per Year	Energy Wasted Waiting Per Year for CA Households
GPM	BTU	BTU	Therms	Therms
2.2	1455	5820	21.2	293,158,437
1.5	1551	6203	22.6	312,428,992
1.0	1595	6382	23.3	321,449,251
Low Pressure Tests (19-22 psi)				
Nominal Flow Rate	**Energy Wasted Waiting for Each Cold Start Event**	**Energy Wasted Waiting Per Day**	**Energy Wasted Waiting Per Year**	**Energy Wasted Waiting Per Year for CA Households**
GPM	**BTU**	**BTU**	**Therms**	**Therms**
2.2	1441	5763	21.0	290,288,354
1.5	1547	6186	22.6	311,608,968
1.0	1604	6417	23.4	323,225,969

- At high pressures, reducing the flow rate from a nominal 2.2 gpm to 1.5 gpm takes 1.4 therms per year. Reducing the flow rate from 2.2 to 1.0 gpm takes 2.1 therms per year. Reducing the flow rate from 1.5 to 1.0 gpm takes 0.7 therms per year.
- At low pressures, reducing the flow rate from a nominal 2.2 gpm to 1.5 gpm takes 1.6 therms per year. Reducing the flow rate from 2.2 to 1.0 gpm takes 2.4 therms per year. Reducing the flow rate from 1.5 to 1.0 gpm takes 0.8 therms per year.
- The additional energy needed when reducing the nominal flow rate from 1.5 to 1.0 gpm ranges from 9 to 11.6 million therms per year.
- **If the nominal flow rate is reduced from 2.2 to 1.0 gpm and assuming all water heating is with natural gas, the waste of energy ranges from 28.3-32.9 million therms per year.**