

Energy-related Water Fixture Measurements: Securing the Baseline for Northwest Single Family Homes

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Reducing hot water consumption in single family homes is a mutual goal of Seattle City Light and partnering water utilities. In order to better quantify this savings potential, the City of Seattle sponsored updated research on hot water use by bathroom water fixtures in single-family homes. The research goal was to enable program planners to update parameters from several water and energy metering studies of the mid-1990s, in order to better estimate the hot water savings potential from high efficiency showerheads and faucets. The study investigated the water and energy-related flows in a representative sample of 71 homes having 151 bathrooms. The sample was selected from a broad range of homes based on property assessment characteristics such as year built and geographic location, so that results from the study could be extrapolated to the utility service area. This paper presents *in situ* flow rate measurements before and after installation of new efficient products, as well as observation of other water system and appliance characteristics such as water pressure, hot water temperature, and hot water wait times. The paper details step-by-step protocols for taking measurements. Based on the data collected, the paper adds an estimation of energy and water savings that would likely occur from installation of more efficient showerheads and aerators in the utility service area.

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Reducing hot water consumption in single family homes is a mutual goal of Seattle City Light and partnering water utilities. In order to better quantify this savings potential, the City of Seattle sponsored updated research on hot water use by bathroom water fixtures in single-family homes. The research goal was to enable program planners to update parameters from several water and energy metering studies of the mid-1990s, in order to better estimate the hot water savings potential from high efficiency showerheads and faucets. The study investigated the water and energy-related flows in a representative sample of 71 homes having 151 bathrooms. The sample was selected from a broad range of homes based on property assessment characteristics such as year built and geographic location, so that results from the study could be extrapolated to the utility service area. This paper presents *in situ* flow rate measurements before and after installation of new efficient products, as well as observation of other water system and appliance characteristics such as water pressure, hot water temperature, and hot water wait times. The paper details step-by-step protocols for taking measurements. Based on the data collected, the paper adds an estimation of energy and water savings that would likely occur from installation of more efficient showerheads and aerators in the utility service area.

Introduction

This study arose out of the need to re-assess the state of showerhead and faucet aerator flow efficiencies in the Puget Sound area. Fifteen years had passed since a major market intervention and subsequent revisions to plumbing codes and standards. The current baseline was unknown; meanwhile area utilities were planning to mount new programs to improve and secure efficiencies in bathroom water and energy use, and needed updated information.

Prior detailed metering and survey research in the early 1990s (see References) clearly established known factors for calculating programmatic energy savings, including the persons per household, number of daily showers per person, average shower length, proportion of shower water from the hot tap, and the water temperature rise (water heater outlet minus inlet).

However, over time since the mass showerhead distribution programs of 1992-1994, uncertainty had been building about various unknown factors. These include the median measure lifetime of 1992 showerheads (originally estimated at 15 years), subsequent replacement by changing market products, the impact of the 2.5 gpm plumbing code (1994), and the current baseline average flow rates for bathroom fixtures.

Therefore in 2006, Seattle City Light, a Pacific Northwest municipal electric utility, managed a study of bathroom water fixtures in single-family homes. The study was designed and conducted jointly with Seattle Public Utilities, the municipal water and sewer provider, to update parameters from the dated water and energy metering studies (PSE & BPA 1994; BPA & SCL 1994; Warwick & Bailey 1993; Warwick 1995). Critical new data were acquired to replace

baseline parameters first measured fifteen years ago, prior to the 1992 citywide mass distribution of efficient-flow faucet aerators and showerheads.

In 1992, existing baseline showerheads flowed at 3.0 gpm (SD=1.3) at full throttle and 2.5 gpm (SD=0.9) at user settings. Pressure-compensating program showerheads that had a maximum rated flow of 2.5 gpm were found by metering research to actually flow at 1.8 gpm (SD=0.3), at both full throttle and user settings *in situ* (PSE & BPA 1994; BPA & SCL 1994). During the intervening years, state plumbing codes and federal standards have brought most retail market showerheads down to rated 2.5 gpm or less.

Seattle City Light undertook this study to prepare for and justify a distribution in 2007 of new pressure-compensating showerheads rated 2.0 gpm, in partnership with long-time utility collaborators in the Puget Sound area: Puget Sound Energy (electric/gas), Seattle Public Utilities and the Saving Water Partnership (water/sewer). The new program was planned to secure a continued advantage over baseline conditions, and extend the life of efficient-flow showerheads for another fifteen years.

This paper describes methods employed and empirical findings from an observational and measurement-based study. Based on the field measurement data, the paper ends with a planning projection of water and energy savings that would likely occur from installation of more efficient showerheads and aerators in the utility service area.

Measurement Study Objectives

The purpose of this study were to investigate the energy-related flows of sink and shower fixtures in a representative sample of 75 single-family residences in the City of Seattle, and to acquire other data on characteristics of water appliances in the sampled homes that might be useful in future water and electric utility program planning. The study would help planners determine potential water and energy savings from replacing existing fixtures with energy efficient ones in typical homes. The study would also set the foundation for identifying, in the future, the average replacement (retirement) rate of plumbing fixtures and water-and-energy using appliances. At the same time, the study would help planners examine the trend toward installation of multiple showerheads in configurations that subvert utility efficiency goals and plumbing codes. The study investigators had the following four specific objectives:

1. **Showerhead Measurements.** Measure the full throttle flow rates (and corresponding static pressures) for existing and efficient showerheads in a sample homes in the City of Seattle.
2. **Bathroom Faucet Aerator Measurements.** Measure the full throttle flow rates for existing and efficient faucet aerators in a sample homes in the City of Seattle.
3. **Other Water Measurements.** Measure the flowing water pressure and hot water temperature for each showerhead in the sampled homes. Note the time taken for the hot water showerhead flow to reach a comfort temperature and the maximum (constant) temperature. Also measure the flushing volume of each toilet tank.
4. **Water Appliance Characteristics.** Take a digital photo of each existing showerhead. To the extent possible, also observe and use digital photography to record other important characteristics for each sampled home, including hot water fuel type, brand name of the existing showerhead, age of existing showerhead, presence of multiple-head or spa-like showers, age of toilet, age and type of clothes washer and dishwasher.

Methodology

A unique aspect of the study methodology was the attempt to overcome traditional barriers to in-home data collection and privacy by piloting a collaboration with real estate agents, taking measurements during scheduled realtor open houses. Due to the difficulty of cost-effectively recruiting homes that were in the desired geographic areas and age categories, in the end the study was limited to a sample of 71 homes. The study began with the development of a work plan, data collection forms and carefully designed procedures. It provided a detailed description of the data elements, which reflected the results from discussions among the consultant team, managing evaluator, and program staff from Seattle City Light and Seattle Public Utilities (SCL 2007).

Sample Targets

Data collection was performed on single-family homes representative of the population of homes in the Seattle City Light and Seattle Public Utilities service areas. In an effort to select representative homes, investigators compiled and analyzed real estate records in the Metroskan® database (licensed from First American Real Estate Solutions), which mirrors to a great extent records also accessible on the Internet from the King County Property Tax Assessor's office. The purpose was to determine the distribution of homes with respect to the following important parameters: general location (in one of five major geographical areas of Seattle); period built (five major construction periods); square footage; assessed property value, and number of bathrooms. Table 1 summarizes four of these parameters.

Table 1. Distribution of Seattle Single Family Detached Homes

Period Built		Square Footage		Property Value		Bathrooms	
1900-1919	22.8%	Under 1600	21.9%	\$100,000-249,999	20.3%	1	46.2%
1920-1939	24.0%	1600-1999	19.2%	\$250,000-299,999	17.0%	1.25-1.75	24.7%
1940-1959	35.4%	2000-2399	21.5%	\$300,000-349,999	17.2%	2	9.0%
1960-1979	8.3%	2400-2799	16.9%	\$350,000-449,999	21.4%	2.25-2.75	13.8%
1980-2006	9.5%	2800 & More	20.5%	\$450,000 & More	24.1%	3 or More	6.3%

With this information, the investigators created a series of bins, across which the sample was distributed, to achieve a representative baseline of important water system characteristics and performance measurements. With an intended sample size of only 75 homes, it was not reasonable to vary more than two parameters to create a total of 25 bins. Based on a review of the single-family home real estate data for the jurisdiction of Seattle, the investigators agreed that the two most appropriate parameters would be General Location and Period Built. A sample of homes that included a range within each of these parameters would provide a representative cross-section of water fixtures and conditions (e.g., degree of corrosion, water pressures, and plumbing system age) that would be expected city-wide. Geography is particularly important as Seattle is a hilly city with open water reservoirs and a wide range of residential water pressures.

The managing evaluator distributed the planned sample of 75 homes across the 25 bins according to the proportions found in the single-family home population. The target distribution is summarized in Table 2. The counts in each bin were viewed as targets to achieve during sample selection, to the extent that they can be supported by the candidate sites available to the study.

Throughout sample selection, an attempt was made to achieve the targeted distribution of homes. The ability to achieve the counts in each targeted bin was limited by the availability of candidates from the four sources of sample homes described below. The actual count of homes within each of the bins is also summarized in Table 2. It shows that some homes were treated in 21 of the 25 bins. The targets were reached exactly in 11 bins. Due to the limitations of candidates from the sample sources, the remaining 14 bins were slightly over- or under-sampled.

Table 2. Target and Actual Sample Cases

Period Built by Location	1900-1919	1920-1939	1940-1959	1960-1979	1980-2006	Area Total
TARGET BINS						
N / NE	2	5	8	2	2	19
W / NW	4	5	5	1	1	16
E / Central	6	4	1	1	1	13
S / SE	3	2	4	2	2	13
SW	3	3	6	1	1	14
Total	18	19	24	7	7	75
ACTUAL SAMPLE						
N / NE	2	3	8	2	1	16
W / NW	3	4	5	0	1	13
E / Central	4	5	1	0	1	11
S / SE	5	5	4	0	0	14
SW	3	3	7	1	3	17
Total	17	20	25	3	6	71

Sample Selection

Candidates for selection into the sample came from one of four sources described below. The initial intent was to obtain the entire sample from the first source. After it was determined that this source was not sufficient, three additional data sources were added. In the end, the last data source, which included acquaintances of the study team staff, proved to be the most fruitful.

Real estate open houses. Seattle Public Utilities and Windermere Real Estate established a cooperative arrangement whereby lists were provided to Seattle Public Utilities of homes for sale in the City of Seattle that were offering an open house to real estate agents. Homes on the list were pre-screened by Windermere so that they were available for use in this study without further recruitment. Windermere provided written permission from the homeowner for the measurement work to be done in the homes. This was initially expected to be the primary source of candidate homes. However, getting a sufficient count of candidate sites from this source proved to be more difficult than expected. Fifteen homes came from this data source.

Seattle City Light Neighborhood Power Program “Green Audit” service. Homes enrolled in the Green Audit service, offered by Seattle City Light, were used a secondary source. The Green Audit service was being offered in West Seattle only, so homes from this program were only used to meet the target requirements in the that geographic area. Seventeen homes came from this source.

Senior Services Program audit service. The Senior Services Program offers energy home audits and minor home repairs to eligible senior homeowners. Homes that received an audit under this program were used as a secondary source for this study. Data collection was limited

by the availability of eligible homes within the project schedule. Only two homes came from this source.

Acquaintances of the study team. Half of sampled homes (37 of the 71 sampled) came from lists of acquaintances compiled by the investigators. Selected homes did not have unusual levels of water conservation attitudes, actions, or water consumption. Residents in these homes were not employed by the utilities, consultants, or conservation organizations. Investigators were not aware of any participant characteristics that would bias results; a statistical bias analysis was not performed. In compiling the list, special attention was placed on selecting homes that addressed bins not filled by the other data sources.

As a thank-you for participating, efficient showerheads and aerators were installed at no charge as part of the study, and two compact fluorescent light bulbs were left with each homeowner.

Data Collection and Analysis

Investigating field staff visited the sampled homes and implemented the procedures documented in the detailed work-plan. Staff collected the required data and recorded observations on the field data collection forms. Field staff began data collection at each site by finding the identified site contact and making an appropriate introduction. In many cases the site contact was not the homeowner, particularly if the home was identified through the Windermere Real Estate Open House list. Field staff enlisted the help of the site contact to the extent appropriate to determine the information required.

The field data from collection forms were transferred to a spreadsheet, which computed the flow rates from the collected volume and time measurements. The data were subjected to quality control procedures to ensure that the information was accurate and reasonable. Summary statistics for each measured parameter included minimum, maximum, mean, median and standard deviation, along with frequency distributions for important characteristics variables. The digital photographs, identified for each bathroom and home, were electronically linked to the spreadsheet as well.

Measurement error. An analysis of measurement error was not performed in this study. However, instruments are calibrated periodically before being used in the field. According to the manufacturer, measurement errors are $\pm 1\%$ for the Ashcroft pressure gauge and Ashcroft thermometer ($\pm 1^\circ\text{F}$ at 100°F).

Hot water system. Field staff first located the hot-water tank or tanks and the bathrooms in the home. For each tank the *fuel type* (gas or electric) and the *system type* (tank, demand, heat pump, or unusual features) were documented along with the bathrooms they serve. Unusual features of the hot-water system, such as a circulating system, were recorded.

Showerheads. If the home had more than one shower, field staff determined which shower was situated farthest from the hot-water tank. A photograph of the existing showerhead was taken. The photo was matched with the bathroom number and home ID or address, for future reference linkage in the database. Hot water flow and delay time, the first measurements made, were taken

only at the shower farthest from the tank. With that exception, the following steps were repeated for each showerhead in the home.

1. In the bathroom farthest from the hot-water tank, the showerhead was turned on to *full flow* using *only hot* water (no cold water during this test). The amount of time that elapsed until the temperature reached 105 °F was recorded. Observation of the time continued until *maximum temperature* was reached, when the temperature became more or less stable (10 seconds pass with no additional temperature rise). The *time to 105 °F*, *time to maximum*, and the *maximum temperature* reached were recorded. As a caveat, time from previous draw (before or during investigator time on site) was not recorded, so average occupant wait times may be longer.
2. For all showerhead removals and attachments, care was taken to hold the shower arm tightly with a non-marking wrench to avoid any twisting behind the wall. The showerhead was not removed if it did not come off easily or there appeared to be a problem in terms of removal or potential for damage. Showerheads with old-style cast ball joint assemblies were not threaded to accept new showerheads, so only the *existing flow rate* was measured and no attempt was made to remove them.
3. The pressure gauge assembly was installed. The existing showerhead was then reinstalled.
4. Both *hot and cold temperature* water flow controls on the shower were opened to the maximum setting and the *static* water pressure with *no flow* was measured from the existing showerhead. The *dynamic* pressure with *full flow* from the existing showerhead was also measured.
5. With both *hot and cold water* flow controls on the shower at the maximum setting, the existing showerhead flow rate was measured using the graduated bucket capture method. The time needed to fill a measured volume of water was recorded.
6. If there was any leakage through the tub diverter valve when the shower was on, the leakage was measured and recorded on the data sheet.
7. The existing showerhead was removed from pressure gauge assembly. The new efficient 2.0 gpm flow showerhead (supplied by Seattle Public Utilities) was installed.
8. Step 4 was repeated for the new efficient showerhead
9. Step 5 was repeated for the new efficient showerhead
10. The new efficient showerhead and pressure gauge assembly were removed. The existing showerhead was reinstalled, if the customer did not want the efficient showerhead. The shower was turned on and the existing showerhead was tested for leaks, using Teflon tape to correct any joint leaks found.
11. The *manufacturer or brand name* of the existing showerhead was determined (if possible) and recorded. The *rated flow rate* was also recorded, if labeled on the showerhead.

12. The *manufacturing date* of the existing showerhead was estimated, using judgment based on bathroom having original equipment or suspicion of bathroom remodel, date of home construction, age of toilet, etc.
13. Notation was made if the shower had multiple heads or body sprays that could be turned on at the same time, or was a luxury spa-like shower. An attempt was made to measure *combined flow* or *total individual flows* from multiple heads and sprays. The designation, Showerhead '112' (bath 1, showerhead 1 of 2), '122' (bath 1, showerhead 2 of 2), and so forth was used to identify multiple showerheads or sprays in the same shower stall.

Faucet aerators. The required flow rate information for each bathroom faucet aerator was collected, using the procedures described below.

1. The mixed water temperature flow-rate from the existing faucet aerator was measured at full throttle. A plastic bag or other small collection device was used to capture and measure water. In a situation with very high flow-rates, it was necessary to measure flow for a shorter amount of time.
2. If possible, the existing aerator was replaced with a new efficient (1.0 gpm) aerator and the flow-rate measurement was repeated. The existing aerator was re-installed, if the customer did not want the efficient aerator.

Toilets. The required information for each toilet was collected using these procedures.

1. The lid of the toilet tank was removed.
2. The 'Full' level of water in the tank was marked with a small pencil line inside the tank.
3. A record was made of cases where water was observed to flow over the top of the overflow tube; of noises that indicated that the fill valve was slowly running; and if the toilet tank fill valve was most likely the original or an upgraded unit.
4. The incoming water to the tank was disabled by preventing the float from dropping during the flush.
5. The toilet was flushed by depressing the lever or button for three seconds.
6. The tank was refilled with water from a graduated bucket and notation was made of the amount of water needed to refill the toilet tank to the original level.
7. The year of manufacture of the toilet was noted. In many cases the date of manufacture was stamped on the inside of the porcelain tank or lid. Otherwise, the manufacture date was estimated from the age of the home, or estimated from the remodel year. If the date is not found stamped on the toilet, an E was added to the date (for example, '1963E') to indicate the date was estimated.
8. Any other observations regarding toilet leakage were recorded.
9. Before leaving each bathroom, absorbent towels were used to dry any dripped or standing water on fixtures, counters, or floors near the shower, sink, and toilet.

Other water appliance characteristics data. The required information was collected using the procedures described below.

1. The type of clothes washer (vertical or horizontal) and manufacturer were observed and recorded.
2. The dishwasher manufacturer was observed and recorded.
3. For both clothes washers and dishwashers, notation was made if the appliance was labeled Energy Star. The appliance door was opened and nameplate information was observed near the hinge area. If available, model number, serial number, and year of manufacture were also noted.

Findings

Across the 71 homes, data were collected from a total of 151 bathrooms. The homes averaged 2.1 bathrooms each, slightly more than the city average of 1.6 recorded in the property assessment files. Nearly all bathrooms had one or more faucets, one toilet, and one shower (or tub/shower combination), but in a few cases consisted of just one faucet, or one shower, or one toilet. Two circulating pumps were found but one was disengaged. The majority (54%) of the homes used electricity to heat hot water, while the remaining 46% used natural gas. The age of homes was representative of home ages in the city as a whole, with an average of 70 years. The average floor area was 1,857 square feet, about 400 square feet smaller than the city average (there were fewer “high-end” homes than exist in the city as a whole).

Table 3. Summary Statistics of Measured Parameters

Measurement	Fig.1	Units	N	Min	Median	Max	Mean	Std Dev
EXISTING FIXTURES								
Static Pressure	ExStatPsi	psi	133	36.0	69.0	128.0	73.1	17.4
Dynamic Pressure	ExDynPsi	psi	133	10.0	53.0	112.0	52.2	21.2
Mixed Shower Flow	ExShFlow	gpm	139	1.0	2.2	9.0	2.5	1.2
Aerator Flow	ExAerFlow	gpm	154	0.4	2.0	8.8	2.2	1.1
Tub Diverter Leak	—	gpm	94	0.0	0.0	1.3	0.1	0.3
Max Hot Water Temp	WaterHiTemp	°F	71	105.0	123.0	159.0	125.2	10.7
Time to Max °F	MintHiTemp	minutes	70	0.4	1.8	7.0	1.9	1.0
Time to 105 °F	Mint 105F	minutes	67	0.1	0.7	4.5	0.7	0.5
Hot Gallons to 105 °F	Gal 105F	gal	67	0.2	1.4	8.5	1.6	1.1
Toilet Volume	ToiletVol	gal	145	1.3	2.0	4.5	2.2	0.7
EFFICIENT REPLACEMENTS								
Dynamic Pressure	ReStatPsi	psi	132	22.0	61.0	111.0	61.2	18.1
Mixed Shower Flow	ReShFlow	gpm	132	1.2	1.8	2.4	1.8	0.2
Aerator Flow	ReAerFlow	gpm	116	0.8	1.0	1.2	1.0	0.1
Tub Diverter Leak	—	gpm	93	0.0	0.0	1.3	0.1	0.3

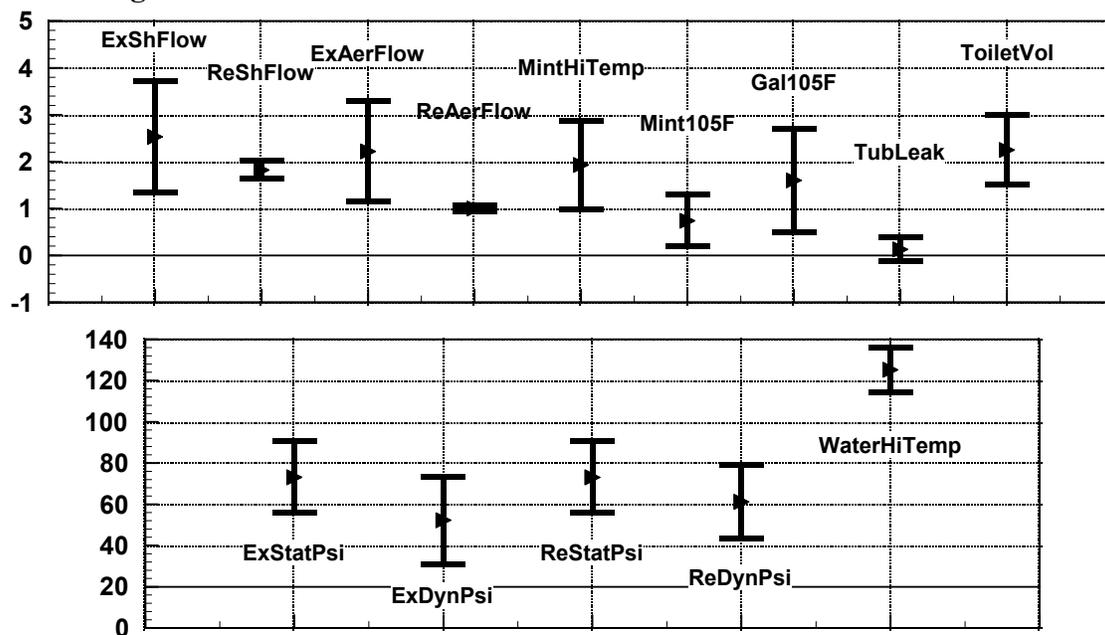
Table 3 provides summary statistics for the measured parameters. Figure 1, using acronyms found in Table 3, displays the statistics for these parameters. The existing values reflect the measured baseline equipment that currently exists in the home. The efficient replacement values reflect the measured performance after the installation of a Rated-2.0 gpm showerhead and a Rated-1.0 gpm aerator on the bathroom sink. The difference between the existing and efficient values reflects the performance of the efficiency improvements. Following are some observations made regarding the measured parameters.

Showerhead Measurements

Marked rating. Of the 144 showerheads, the vast majority (78%) were standard showerheads, while 22% were hand-held types. No luxury showerheads were observed. Across the 87 showerheads where the existing flow rating was marked and could be identified, the largest portion of the showerheads (95%) was marked 2.5 gpm. Only one showerhead was rated lower than 2.5 gpm and only three were rated above 2.5 gpm

Existing flow rate. The study measured the pre-retrofit full throttle flow rate for a total of 139 showerheads in 71 homes. The flow rate measurement could not be made at five shower arms because the water to the showerhead was shut off. The full throttle flow rate across the 139 showerheads where measurements could be made ranged from 1.0 to 9.0 gpm. *The mean flow rate was measured to be 2.5 gpm—slightly greater than the median flow rate of 2.2 gpm.*

Figure 1. Means and Standard Deviations of Measured Parameters



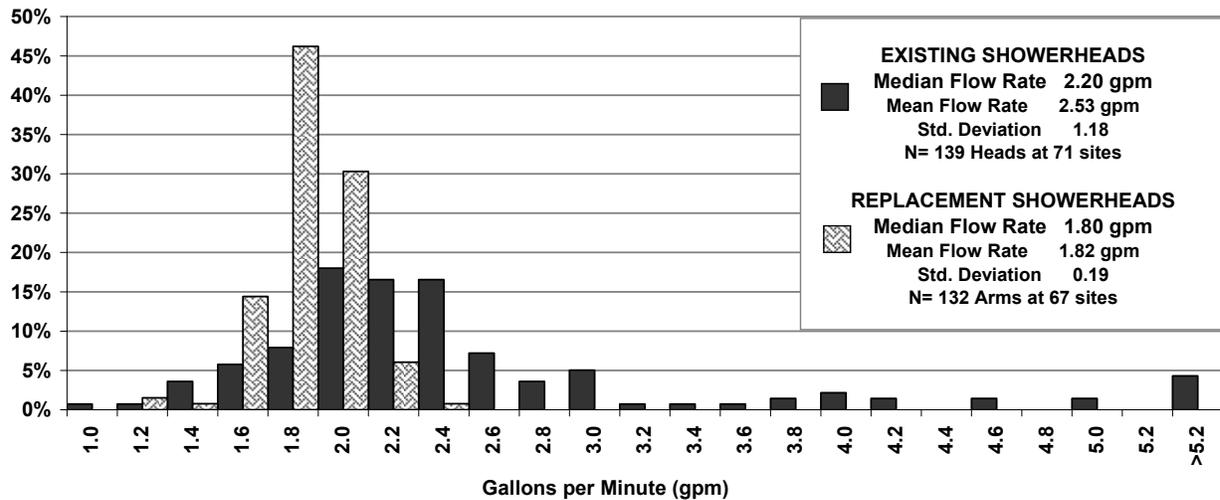
Replacement flow rate. The study measured the *in situ* post-retrofit full throttle flow rate for a total of 132 showerheads. Fewer measurements were made for the post-retrofit case because seven of the showerheads had ball joints that could not be retrofit. The full throttle flow rate for the efficient showerheads (rated 2.0 gpm) ranged from 1.2 to 2.4 gpm. The largest portion (46%) was between 1.6 and 1.8 gpm, while another 30% were between 1.8 and 2.0 gpm. *The mean flow rate was measured to be 1.8 gpm—the same as the median flow rate. This observed value is lower than the marked rating for this showerhead (2.0 gpm).*

Flow change. The efficient showerhead reduced the flow rate in all but a few cases where it replaced an existing clogged showerhead or a showerhead with the same rating. *On average the flow rate was reduced from a mean of 2.5 gpm to 1.8 gpm, resulting in water savings of 0.7 gpm.*

Distribution of Showerhead Flow Rates: Existing versus Replacement

Figure 2 shows the distribution of the measured pre-retrofit flow rates across the 139 existing showerheads where measurements were made. The figure shows that the largest portion of the measured flow rates was between 2.0 and 2.5 gpm. The second most common flow rate range was between 1.5 and 2.0 gpm. A total of 67% of the flow rate measurements were between 1.5 and 2.5 gpm. The mean flow rate was 2.53 gpm, while the median was 2.20 gpm. Among the 132 shower arms where post-retrofit measurements were made using the replacement showerhead, the mean flow rate was 1.82 gpm with a very narrow standard deviation.

Figure 2. Existing and Replacement Showerhead Measured Flow Rates



Aerator Measurements

Existing flow rate. The study measured the pre-retrofit full throttle flow rate for a total of 154 faucets in 71 homes. The full throttle flow rate ranged from 0.4 to 8.8 gpm. *The mean flow rate was measured to be 2.2 gpm—slightly greater than the median flow rate of 2.0 gpm.*

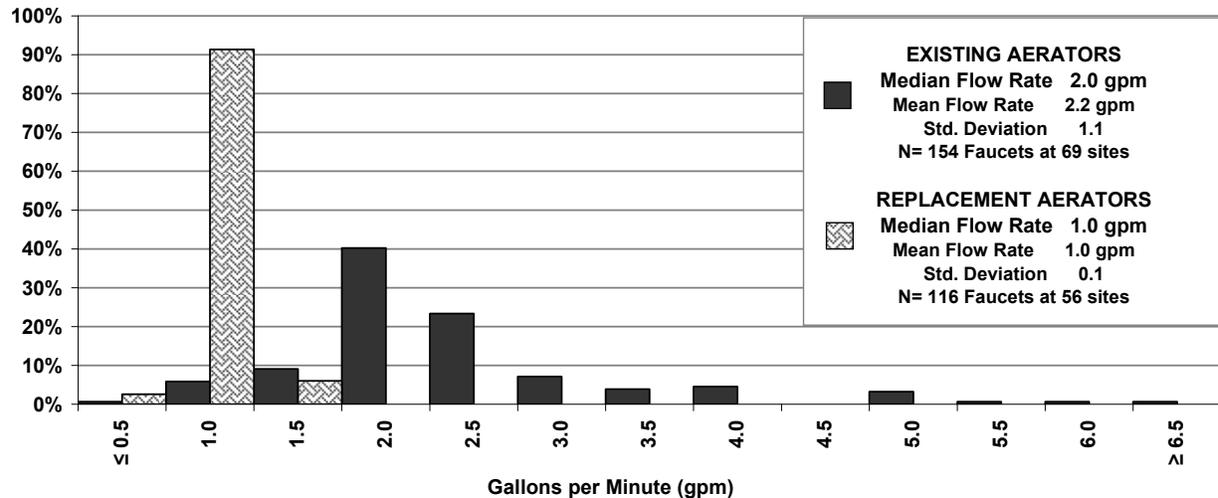
Replacement flow rate. The study measured the post-retrofit full throttle flow rate for a total of 116 faucets. Fewer measurements were made for the post-retrofit case because the efficient aerators would not fit on the faucets in 38 cases (25%). The flow rate of the efficient aerators (rated 1.0 gpm) ranged from 0.8 to 1.2 gpm. Of the 116 efficient aerators where measurements were made, the largest portion (91%) was between 0.8 and 1.0 gpm. *The mean flow rate was measured to be 1.0 gpm—the same as the median flow rate. This value accords with the marked flow rate for this aerator.*

Flow change. The efficient aerator reduced the flow rate in all but a few cases where it replaced an existing clogged aerator. *On average the full throttle flow rate was reduced from a mean of 2.2 gpm to 1.0 gpm, resulting in water savings of 1.2 gpm.*

Distribution of Aerator Flow Rates: Existing versus Replacement

Figure 3 shows the distribution of the measured pre-retrofit flow rates across the 154 existing bathroom faucets where measurements were made. The figure shows that the largest portion of the measured flow rates (40%) was between 1.5 and 2.0 gpm. The second most common flow rate range was between 2.0 and 2.5 gpm. A total of 64% of the flow rate measurements were between 1.5 and 2.5 gpm. The replacement faucet aerator is designed to flow at 1.0 gpm, which was confirmed by the *in situ* measurements.

Figure 3. Existing Faucet Aerator Measured Flow Rates



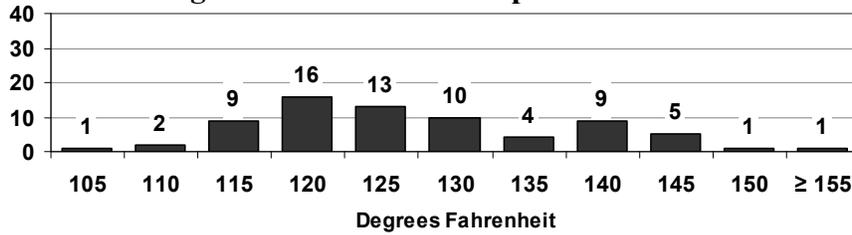
Water Temperature, Pressure, and Other Measurements

Static pressure. A measurement of static pressure was made before and after the installation of the efficient showerheads. *The static pressure did not change with the installation of the efficient showerheads.* The average static pressure was measured to be 73 psi. This was slightly greater than the median value of 69 psi. The static pressure ranged across the sampled homes from a high of 128 psi to a low of 36 psi.

Dynamic pressure. A measurement of dynamic pressure was made for each showerhead before and after the installation of the efficient showerheads. *The average dynamic pressure increased slightly, from 52 psi to 61 psi, with the installation of the efficient showerhead. A similar change is noted for the median pressure.* The existing system dynamic pressure ranged from a low of 10 psi to a high of 112 psi. A similar range of 22 psi to 111 psi is noted for the replacement case.

Maximum temperature. The maximum hot water temperature was measured at all 71 homes in the sample. The maximum hot water temperature ranged from 105°F to 159°F. *The average maximum temperature across the 71 cases was 125°F. The average was only slightly greater than the median temperature of 123°F.*

Figure 4. Maximum Temperature of Hot Water

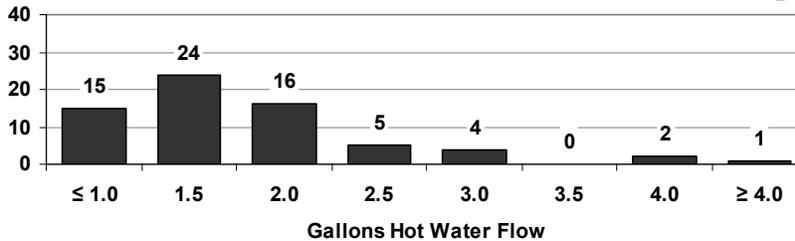


Comfort delay. The comfortable shower temperature was assumed to be 105°F, based on prior research (PSE & BPA 1994; BPA & SCL 1994). In all cases it was necessary to run some hot-tap water through the first test showerhead to reach this temperature. This is true even in the two homes that had circulating pumps; their wait times were close to the median value. The amount of time required to reach the comfort temperature ranged from 0.1 to 4.5 minutes. *On average it took 0.7 minutes to reach a temperature of 105°F. This value was the same as the median time.*

Maximum delay. In all cases it was necessary to run some water through the first test showerhead to reach the maximum temperature. The amount of time required to reach the maximum temperature ranged from 0.4 minutes to 7.0 minutes. *On average it took 1.9 minutes to reach the maximum temperature. This value was slightly greater than the median time of 1.8 minutes.*

Comfort volume. The amount of water that was used to reach the comfort temperature varied from 0.2 to 8.5 gallons. *On average 1.6 gallons of hot-tap water were used before the comfort temperature was reached. This value was slightly greater than the median volume of 1.4 gallons.*

Figure 5. Volume of Water Flow to Reach 105°F Comfort Temperature



Tub diverter. A total of 94 tub diverters were observed across the 71 homes. A range of 0 gpm (no leaks) to 1.25 gpm was measured across these cases. *On average the measured tub diverter leak rate was 0.1 gpm. The median leak rate was 0.006 gpm.* The leak rate did not change with the installation of the efficient showerheads.

Measurement Study Conclusions

The sample for this measurement study was small, but care was taken to ensure that it was fairly representative of the City of Seattle, based on geography and age of homes (and pipes). The high cost of in-home measurements generally limited sample size and dictated how extensive this research study could be. Investigators attempted a new technique to access homes

through realtor open houses, which they conclude only partially mitigated this limitation. The up-to-date baseline data from this study are critical for projecting savings for future programs, especially since past programs and code changes have altered the mix of measures in homes.

The investigators also concluded that collecting robust baseline data is not simple—it must be done carefully. This paper detailed some of the procedures implemented to ensure the quality and usefulness of data gathered, not only for planning the upcoming showerhead and aerator distribution program, but also to inform future program designs for the local partnership of water and electric utilities.

Projected Energy Savings from Showerhead and Aerator Replacements

Subsequent program plans have drawn upon this in-home measurement study to generate projections for a 2007 program to replace existing showerheads and aerators with the studied products. Table 4 summarizes energy savings expected in Seattle area single-family homes. The new baseline study updated two key parameters, *in situ* full-throttle flow rates with the existing and replacement showerheads, while prior research provided parameters that were not expected to change significantly over time.

The algorithm for estimating energy savings from showerhead replacements multiplies showerhead flow rate reduction (gallons/minute, adjusted from full-throttle to user-setting) by shower duration (minutes), shower water from hot tap (%), hot water temperature rise (°F), persons/household, showers/person/day, annual occupancy (days), conversion factor for electric heat (8.29 Btu/°F/gallon/3413), heat element loss factor, and delivered products installed (%).

Key parameters carried over from prior research (PSE & BPA 1994; Warwick 1995; Geist 2001; Mayer et al. 2000) include the following: ratio of user-setting to full-throttle flow rate (0.83 existing, 0.95 replacement), 7.84 minutes average shower length, 68% of shower water derived from the hot tap, 75°F water temperature rise (tank outlet minus inlet °F), 2.51 persons per household, 350 days annualized occupancy, and a 98% adjustment for heat lost from the element through the tank connection. Prior research has shown that the daily average number of showers per person is 0.55 in primary showerhead locations, 0.28 in secondary locations, and 0.64 regardless of shower location in the home (Brattesani & Okumo 1993; Brattesani & Tachibana 1994). Program planning projections are that 90% of showerheads delivered by the program will be installed. This is based on a pilot study survey with 704 respondents, which found that 93% installed delivered showerheads (Hampton 2006). The new program plan also estimates that 67% of households will request a single showerhead, while 33% will request a second showerhead as well. Post-implementation survey research in 2008 will test that assumption and provide correcting factors for the last two parameters.

Table 4. Projected Energy Savings from Average Electric Water Heat Customer in Seattle City Light Service Area

Expected Showerhead Savings per Household	Average Household	Showerhead 1 Primary	Showerhead 2 Secondary
Annual kWh Electricity Savings	201	172	88
Annual Gallon Water Savings	1593	1364	694
Daily Gallon Water Savings	4.55	3.90	1.98

As a result of calculations based on the new measurement study, the average energy savings expected from households requesting one program showerhead will be 172 kWh per

year, and a second showerhead (in the subset of homes that have two showers) will add 88 kWh. The citywide annual average per participating household is thus expected to be 201 kWh. Bathroom faucet aerators, saving 1.2 gpm, will provide an additional 50 kWh per installation.

Based on this hot water energy savings potential, Seattle City Light, in partnership with area water utilities, completed design of a cost-effective single family bathroom fixture retrofit program. The low cost per kWh of obtaining these savings, along with the leveraged financial partnership with water utilities, could make plumbing fixture retrofits one of the more cost-effective measures in the Seattle City Light energy conservation portfolio.

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