FINAL REPORT
STUDY ON BENEFITS OF REMOVAL OF WATER HARDNESS (CALCIUM AND MAGNESIUM IONS) FROM A WATER SUPPLY

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Acronyms

Btu	British Thermal Units
cf	cubic foot
Eq	equation
F	Fahrenheit
g	grams
gal	gallon
gm/yr	grams per year
gpm	gallons per minute
gpg	grains per gallon
lb/yr	pounds per year
kg	kilogram
kWh	kilowatt-hours
MJ	Megajoule
ppm	parts per million
scf	standard cubic foot
SMCL	Secondary Maximum Contaminant Level
WQA	Water Quality Association
y or yr	year or years

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Executive Summary

This study tested devices fed with softened and unsoftened water under controlled laboratory conditions designed to accelerate the water side scaling in the device and quantify the performance efficiency. The project specifically focused on efficiency improvements in household water heaters from use of softened water, and the subsequent effect on performance of fixtures, such as low flow showerheads and faucets, and appliances, such as laundry washers and dishwashers. For this study, Battelle tested 30 water heaters supplied by WQA over a 90-day period using a Battelle-developed and WQA approved test protocol. Battelle simultaneously studied the effect of water hardness on performance of faucets, low-flow showerheads, dishwashers, and laundry washers. Using the empirical data generated from the water heater testing and the effect on performance of fixtures and appliances, Battelle developed a differential carbon footprint assessment for homes using unsoftened water vs. softened water.

Water Heater Results

Battelle set up and tested ten storage type gas water heaters, ten storage type electric water heaters, and ten instantaneous gas water heaters with the following specifications using an accelerated scaling methodology developed at Battelle.

- Gas Water Heaters (10), 40 gal, 38,000 Btu/h burners
- Electric Water Heaters (10), 40 gal, 4500 W heating elements
- Tankless Gas Water Heaters (10), 199,000 Btu/h burners

Five of each type of device were tested without any preconditioning of the water supply, and the other five were tested using a water softener to remove hardness constituents from the water supply. Five units were chosen for each of the groupings in order to be able to calculate 95 percent confidence intervals for the results.

At the start of the test and at approximately one week intervals, the thermal efficiency of each water heater was measured to determine the change in efficiency as water side scale built up in each water heater. Each water heater was instrumented to measure the inlet and outlet water temperature at 15-second intervals, the amount of hot water generated, and the amount of energy (gas or electric) used to produce the hot water. These data were used to calculate the average thermal efficiency of the water heater.

In summary, the electric and gas storage water heaters and the instantaneous gas water heaters on soft water performed well throughout the entire testing period. Although the pressure regulators and needle valves were tweaked throughout the testing to maintain constant testing conditions, all of the water heaters on soft water required minimal attention because the conditions were very stable. This is reflected in the efficiency data for these units that show the efficiency remained essentially constant over the duration of the testing with the variations being within the experimental error of the instrumentation and testing protocol. Overall, the softened water did a good job of minimizing scale buildup in the water heaters.

In contrast, none of the electric or gas storage water heaters or the instantaneous gas water heaters on unsoftened water made it through the entire testing period because the outlet piping system consisting of one-half inch copper pipe, a needle valve, and a solenoid valve became clogged with scale buildup. Although the pressure regulators and needle valves were tweaked throughout the testing to try to maintain constant testing conditions, all of the water heaters on unsoftened water were removed from the testing at some point due to the inability to maintain sufficient flow.

Table ES-1. Summary of Results for Water Heaters

Water Heater Type	Water Supply	Average Thermal Efficiency, (%)		Equivalent Field Service (Years)	Average Annual Scale Accumulation[1] (grams/year)	Carbon Footprint[2] (kg CO_2/gal hot water)
		Test Start	Test End			
Instantaneous Gas	Unsoftened	80	72[3]	1.6	NA	0.052
	Softened	80	80	1.6	NA	0.050
Gas Storage	Unsoftened	70.4	67.4	2.0	528	0.066
	Softened	70.4	70.4	2.25	7	0.056
Electric Storage	Unsoftened	99.5	99.5	1.25	907	Not Determined
	Softened	99.3	99.3	1.25	14	Not Determined

Notes: [1] The submerged heating element in an electric water heater operates at very high temperatures which results in a high rate of scale buildup in electric water heater when compared to a gas water heater.
[2] Average over 15 years Equivalent Life.
[3] Deliming or Cleaning was performed at this point.

A summary of the results, discussed in the following paragraphs, is provided in Table ES-1. The instantaneous water heaters on unsoftened water had to be delimed at 1.6 years of equivalent field service, and the average efficiency of these units dropped from 80 percent at the start of the test to 72 percent when they were delimed. After deliming, the average efficiency of these units increased to about 77 percent, but was still below the 80 percent starting efficiency. The cost implications of these findings are addressed in this report.

The average efficiency of the gas storage water heaters on unsoftened water dropped from 70.4 percent at the start of the test to 67.4 percent at two years equivalent field service. These data were used to derive equations to predict the efficiency of gas storage water heaters as a function of water hardness and daily household hot water usage. The average rate of scale buildup in the gas storage water heaters on unsoftened water was about 528 gm/yr (1.16 lb/yr). The average rate of scale buildup in the gas storage water heaters on soft water was about 7 gm/yr (0.01 lb/yr), which is almost negligible.

The electric storage water heaters on both softened and unsoftened water were able to maintain a constant efficiency throughout the entire test period because the heating elements were completely submerged in the water. However, the life of the heating element in unsoftened water is expected to be shortened due to scale buildup increasing the operating temperature of the element. The average rate of scale buildup in the electric storage water heaters on unsoftened water was about 907 g/yr (2.00 lb/yr). The average rate of scale buildup in the electric storage water heaters on soft water was about 14 g/yr (0.03 lb/yr), which is almost negligible.

Fixtures and Appliances

Ten low flow showerheads were installed on the hot water supply coming from the instantaneous gas water heaters; five were tested on unsoftened water and five were tested using softened water. The low flow showerheads on unsoftened water were removed from testing as they clogged up to the point of not allowing adjustment to a 1.25 gpm flow rate at any time during the test. All of the low flow showerheads on softened water made it through the testing without any problems. However, the low flow showerheads on unsoftened water clogged after an average of 3,203 gallons of water flow through them. At the end of testing, the low flow showerheads were disassembled and the amount of scale buildup was documented with photographs of the components.

Ten low flow faucets were also installed on the hot water supply coming from the instantaneous gas water heaters; five were tested on unsoftened water and five were tested using softened water. The low flow faucets on unsoftened water were also removed from testing as they clogged up to the point of not allowing adjustment to a 1.25 gpm flow rate at any time during the test. All of the low flow faucets on softened water made it through the testing without any problems. However, the low flow faucets on unsoftened water clogged after the equivalent of 19 days of water flow through the faucets assuming an average household uses about 50 gallons of hot water per day. The collection of scale on the faucets using unsoftened water appears to be the result of scale breaking loose from upstream portions of the plumbing and being trapped in the strainers.

Six dishwashers (Kitchenaid) and laundry washers (General Electric) were purchased to test the effect of unsoftened water on the performance of the appliances. The electronic controls for this equipment were integrated into the automated data acquisition and control system designed for the testing. The wash and dry cycles of the dishwashers and the wash cycles of the laundry washers were controlled automatically with the units going through eight cycles every 24 hours. The clothes washers were loaded with 7 lbs of restaurant hand towels. The dishwashers were loaded with eight place settings of dishes and flatware. At the end of the 30 days of testing, the dishwashers and clothes washers were examined before a teardown analysis was initiated. The units using softened water were almost completely free of any water scale buildup. In contrast, the units using unsoftened water (26 grains per gallon) had noticeable water scale buildup on all of the interior surfaces after only 30 days of testing. Although both of the dishwashers and clothes washers completed the same number of wash cycles (240), the appearance of the inside of the units using unsoftened water shows that it needs to be delimed and cleaned due to the buildup of scale and deposits. On the other hand, the units using soft water look like they could be cleaned up to look like new with just a quick wipe down.

Carbon Footprint

Battelle assessed that carbon footprint of the water heaters by evaluating the energy consumption within the Home and the resulting greenhouse gas emissions. The results parallel those for the energy consumption, in that where there are energy efficiency differences there are also carbon footprint differences. For the storage type gas water heaters, there was a reduction in carbon footprint of 14.8% over a fifteen year water heater service life with softened water compared to 26 gpg hard water, when considering both the natural gas used for water heating and the electricity used for water softening. For the instantaneous water heaters, there was a reduction in carbon footprint of 4.4% over a fifteen year water heater service life, when considering both the natural gas used for water heating and the electricity used for water softening.

Conclusions

For gas storage and instantaneous water heaters, the use of a water softener to eliminate or minimize the scale forming compounds in water will result in the efficiency of the water heater remaining constant over the life of the unit. In contrast, gas storage and instantaneous water heaters using unsoftened water had a noticeable decrease in efficiency over the testing period resulting in higher natural gas use. This natural gas savings associated with the use of softened water will lead to direct energy and economic savings, as seen in the summary results in Table ES-2. In addition, because of the need to have the instantaneous water heater delimed or cleaned periodically, the economic savings can lead to recovery of the cost of a water softener and operating supplies in a period as short as a year, if the inlet water is sufficiently hard. Further, there are environmental benefits to the use of a water softener: the lower use of natural gas leads to reductions in the carbon footprint which are related to the decrease in total energy consumption. The increase in total energy consumption (as a result of a reduction in heat transfer efficiency) is related to the hardness: higher water hardness will lead to greater energy consumption without the use of water softener, and consequently greater energy costs.

Table ES-2. Estimated Savings for Gas-fired Water Heaters using Softened Water Over 15 years Life

Cost Elements	Water Hardness, grains per gallon						
	0	5	10	15	20	25	30
Instantaneous Gas Water Heaters							
Percent Life Cycle Energy Cost Savings,%[1]	NA	5.4	5.4	5.4	5.4	5.4	5.4
Percent Total Life Cycle Cost Savings, %[1]	NA	14.0	22.5	31.2	39.6	48.4	57.0
Estimated Usage before Deliming Required, years[2]	NA	8.4	4.1	2.7	2.0	1.6	1.4
Gas Storage Water Heaters							
Life Cycle Operating Efficiency Reduction From Baseline, %[3]	0.0	4.3	8.5	12.8	17.0	21.3	25.5
Percent Life Cycle Energy Cost Savings, %[4]	NA	3.1	6.6	10.3	14.5	19.0	24.2

Notes: [1] Derived from Table 5-2
[2] Derived from Table 5-1
[3] Derived from Table 5-3
[4] Derived from Table 5-4

Electric storage water heaters did not record any difference in the electricity consumption between units receiving softened or unsoftened water. However, the life of the heating element on the electric water heater receiving unsoftened water would be expected to have a shorter life.

Low flow showerheads and faucets using unsoftened water clogged in less than seven days of accelerated life testing, whereas those units using softened water made it through the test without any problems.

The dishwashers and clothes washers on either soft or unsoftened water made it through 30 days of accelerated scale testing, but the units on unsoftened water had noticeable scale buildup on all surfaces that had contact with unsoftened water.

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1.0 Introduction

The Water Quality Association (WQA) is an international trade organization representing members of all facets of the water treatment industry. One of their focus areas is water softening and its beneficial effects on equipment, clothing, and public perception of water quality. However, as with many other industries, the members recognize that consumers are increasingly focused not just on the direct benefits associated with a product, softened water in this case, but are concerned with the effect of a product on the environment.

To that end, the members decided they needed to quantify other benefits, in addition to cost benefits, of softened water such as:

- The effect on longevity of the appliances such as water heaters, laundry washers, dishwashers, beverage machines, shower heads, faucets, fixtures, and other household units from unsoftened water versus softened water.

The WQA perceives that many of the differentiators between using softened and unsoftened water may have significant "green" or sustainable environmental benefits. The ability to substantiate these benefits — or better — to quantify these benefits, would help WQA communicate the benefits that consumers and society may reap from softened water.

In addition, residential point-of-entry water purification systems, specifically water softeners, have come under increasing scrutiny and criticism from local environmental groups and wastewater agencies over the high levels of total dissolved solids and concentrated brine in the discharges. Given these developments, Water Quality Research Foundation, the research arm of WQA, feels that research should be conducted across the water softener life cycle to better understand the potential cost and energy benefits of softened water to a single family home or a household. WQA believes communicating these benefits to the general public would be helpful in addressing the scrutiny and criticism and potentially improve the product sustainability.

2.0 Goals and Objectives

The study on benefits of removal of water hardness (Calcium and Magnesium ions) from a water supply tested household appliances fed with softened and unsoftened water under controlled laboratory conditions. Study test protocol included accelerated testing of appliances to get 95 percent confidence intervals around the results.

3.0 Technical Approach

For the WQA, Battelle studied the beneficial effects of a water softener to a U.S. household. In addition to the traditional cost benefits of the softened water, this project will foster a better understanding of the effects of softeners on longevity and energy use of water-using appliances like water heaters, laundry washers, dishwashers, and the longevity of other household items, such as low flow shower heads, faucets, and clothing.

The project specifically focuses on efficiency improvements in household water heaters from use of softened water and the subsequent effect on longevity of fixtures, such as low flow showerheads and faucets, and appliances, such as laundry washers and dishwashers. For this study, Battelle tested 30 water heaters supplied by WQA over a 90-day period using a Battelle-developed and WQA approved test protocol that mimics typical U.S. household use of these appliances. Battelle simultaneously studied the effect on longevity of fixtures and appliances on sets of faucets, low-flow showerheads, dishwashers, and laundry washers over a 30-day period or until they failed — whichever was earlier.

The water heaters and all appliances for this study were provided directly by WQA or were purchased by Battelle upon WQA's approval. The WQA also provided service support for the water heaters during the 90-day test period. Culligan International provided two softeners (Model WS-210) for this study and provided weekly analytical support for water quality analysis.

Using the empirical data generated from the water heater testing and the effect on longevity of fixtures and appliances, Battelle developed a differential carbon footprint assessment for homes using unsoftened water vs. softened water.

Battelle also assessed the impact of unsoftened and softened water on the longevity of laundry washers, dishwashers and kitchen faucets. Laundry washers and dishwashers were operated on an accelerated schedule for 30 days, with three of each being tested with unsoftened water and an additional three of each with softened water. These were dismantled at the end of testing to assess the effect of unsoftened water on the expected appliance lifetime.

3.1 Water Heaters

Under the test protocol, Battelle performed accelerated water-side scale tests on storage type water heaters, instantaneous water heaters, and low flow showerheads to determine the amount of scale buildup in the equipment due to unsoftened water conditions and the impact of this scale on the efficiency or performance of these devices. Battelle set up and tested ten storage type gas water heaters, ten storage type electric water heaters, ten instantaneous gas water heaters with the following specifications using an accelerated scaling methodology developed at Battelle.

- Gas Water Heaters (10), 40 gal, 38,000 Btu/h burners
- Electric Water Heaters (10), 40 gal, 4500 W heating elements
- Tankless Gas Water Heaters (10), ~199,000 Btu/h burners

Five of each type of water heaters were tested without any preconditioning of the water supply, and the other five were tested using a water softener to remove hardness constituents from the water supply. Five units were chosen for each of the groupings in order to be able to calculate 95 percent confidence intervals for the results.

The accelerated test protocol was based on the following assumptions.

- The amount of scale buildup in the water heaters is proportional to the amount of hot water put through the device.

- The water heaters use a periodic water draw of approximately 1.25 gpm for 4 minutes, which is a total draw of 5 gallons of hot water through the device.
- To allow the water heaters to reheat sufficiently before the next draw, the time between water draws was 15 minutes for the gas storage type water heaters, 30 minutes for the electric storage type water heaters, and 12 minutes for the instantaneous gas water heaters.
- A control system was setup to automatically withdraw water from each tank at the set intervals for 24 hours a day. This yielded a total of 240, 480, and 600 gallons per day of hot water generated by the electric storage water heater, gas storage water heater, and gas instantaneous water heater, respectively.
- An average family in the U.S. uses about 50 gallons of hot water per day
- The acceleration factor for the water usage is 4.8, 9.6, and 12 for the electric storage water heater, gas storage water heater, and gas instantaneous water heater, respectively.
- The amount of scale buildup in the water heaters is directly proportional to the water hardness. With a water source with a hardness of approximately 26 grains per gallon, the scale buildup in the water heater to be approximately 2.6 times the amount than if Battelle were using a water source with 10 grains per gallon hardness. In this case, the acceleration factor for the water hardness is 2.6 (= 26/10).

In addition, a rough rule of thumb is that for every 20°F increase in setpoint temperature of the unit, the amount of water scale buildup is doubled. Electric storage type water heaters are shipped from the factory with their thermostats preset at 120°F. Battelle operated the test units at a setpoint temperature of 140°F for instantaneous water heaters, 160°F for gas storage water heaters, and 150°F for electric storage water heaters. Compared to the same unit operating at 120°F, the instantaneous water heaters, gas storage water heaters, and electric storage water heaters are expected to generate 2, 4, and 2.8 times as much scale, respectively, due to the higher operating temperature.

Using the above correlations, the overall acceleration factor for the cases described above is 35, 100, and 62 per day of testing for electric storage, gas storage, and gas instantaneous. Table 3-1 summarizes the individual factors and the composite. Each water heater was tested for 90 days at the above conditions.

Table 3-1. Summary of Acceleration Factor Calculations

Water Heater Type	Acceleration Factors			
	Water Volume	Hardness	Temperature Increase	Composite, Estimated Days Real Life to Actual Days Tested
Electric Storage	4.8	2.6	2.8	35
Gas Storage	9.6	2.6	4	100
Gas Instantaneous	12	2.6	2	62

At the start of the test and at approximately one week intervals, the thermal efficiency of each water heater was measured to determine the change in efficiency as water side scale builds up in each water heater. Each water heater was instrumented to measure the inlet and outlet water temperature at 15 second intervals, the amount of hot water generated, and the amount of energy (gas or electric) used to produce the hot water. This data was used to calculate the average thermal efficiency of the water heater.

At the end of the 90 days of testing, each water heater was carefully cut in half and the water side scale removed from the inside surfaces and weighed. A statistical analysis of the data was completed to determine the average performance improvements of the group of water heaters using softened water when compared to the baseline group of water heaters using unsoftened water. Ninety-five percent confidence intervals were calculated based on five water heaters being tested in each group.

3.2 Fixtures and Appliances

Ten low flow showerheads were installed on the hot water supply coming from the ten instantaneous gas water heaters. Five low flow showerheads were tested on unsoftened water, and the other five on softened water. Upon completion of the low flow showerheads testing, ten faucets were installed on the hot water supply coming from the ten instantaneous gas water heaters in the same configuration to study the impact of use on unsoftened and softened water.

The low flow showerheads or faucets were removed from testing as they clogged up to the point of not allowing adjustment to a 1.25 gpm flow rate at any time during the test. At the end of testing, the low flow showerheads were disassembled and the amount of scale buildup documented with photographs of the components.

To study the effect of softened water on longevity of the dish washers and laundry washers, Battelle installed six dishwashers and laundry washers, three of each on the hot water supply from the water heaters using unsoftened water and three of each on the softened water. The wash and dry cycles of the dish washers and the wash cycles of the laundry washers are controlled automatically with the units going through eight cycles every 24 hours.

As with the water heaters, Battelle assumed that the amount of scale buildup in the devices is proportional to the amount of hot water throughput. The acceleration factor applied to these tests was computed as follows:

1. The amount of scale buildup in the devices is proportional to the water hardness. Since Battelle used a source of water with a hardness of approximately 26 grains per gallon, the expected scale buildup in the appliances is approximately 2.6 times the amount than if a water source with 10 grains per gallon hardness had been used.
2. The estimated usage for each of these appliances is approximately one cycle per day, versus the eight cycles per day in the current testing.

There are other factors that will affect the longevity of appliances that were outside the scope of the current testing. One major factor is changes in habits for cleaning of laundry or dishes that may result from using softened water. Since softened water, in conjunction with detergents or other cleaning products, may clean more effectively than unsoftened water, users might find it acceptable to decrease the cycle time and yet achieve an acceptable level of cleanliness.

Remember that consumers are buying cleanliness of clothes and dishes, not soft water directly. This decrease in cycle time will lower the water consumption, the potential scale formation in the appliance and the water heater, the energy consumption, and the carbon footprint.

3.3 Differential Carbon Footprint

The energy to heat the water and the energy used by the appliances are the primary drivers to test carbon footprint of the test devices. The energy consumption during the 90-day water heater test and the 30-day appliances tests was monitored to understand both the change as a function of time, and the characteristic value for the energy consumption: long term average, final average, or multiple intermediate values. The energy consumption of the water softening equipment was provided by Culligan International based on data they had acquired during laboratory testing of residential water softeners under typical use conditions. Changes in the daily cumulative energy consumption of the appliances were correlated with observations on water consumption, water heater performance, and appliance operations to help in interpreting the data.

4.0 Test Protocol

4.1 Water Heaters

Five of each type of water heater were tested with raw water and the other five were tested using softened water. Water analysis and thermal efficiency tests were performed every week. Five gallons of water were drawn from each of the 30 units periodically at the rate of 1.25 gallons per minute over a 4-minute draw period. The following table, Table 4-1, presents the water draw cycles during the test period and the corresponding acceleration factor for the equipment.

The time interval between draws varies because the heat input rate is different for each water heater type, and sufficient time is needed for each type of water heater to heat the incoming water up to the thermostat setpoint temperature before the next water draw.

Table 4-1. Summary of Water Heater Operating Conditions

Water Heater Type	Time Intervals Between Draws	Total Flow per unit	Acceleration Factor (Based on 50 gal/day use)
Gas Storage	15 minutes	480 gal per day	9.6
Electric Storage	30 minutes	240 gal per day	4.8
Gas Instantaneous	12 minutes	600 gal per day	12.0

The test determined the scale build up and the impact on performance and efficiencies of the water heaters, low flow showerheads, and faucets. The test protocol used five units for each of the groupings in order to be able to calculate 95 percent confidence intervals for the results.

4.2 Fixtures and Appliances

Six laundry washers and dishwashers were tested, three of each on unsoftened and three of each on softened water with their wash cycles automatically controlled at 3-hour intervals to get 8 cycles per unit per 24-hour period, see Table 4-2. Detergents were added automatically to each system at a rate specified by the manufacturer in the Users' Manuals for either softened or unsoftened water.

Table 4-2. Summary of Appliance Operating Conditions

Test Parameters / Variable	Appliances		Notes
	Dishwashers	Laundry Washers	
Cycle Time	3 hrs/cycle	3 hrs/cycle	Dishwasher cycle includes extended drying option
Water Temp	140°F	140°F	
Test Load	8 place settings of dishes and flatware	7 lbs of test cloth	Similar to DOE test protocols for these appliances
Energy Monitoring	Monitored Daily, Calculated Per Cycle Average	Monitored Daily, Calculated Per Cycle Average	Watts Up Pro meters monitoring cumulative kWh
Make and Model	Kitchenaid KUDL03IVWH	General Electric WJRE5550H	Purchased from Lowes

4.3 Differential Carbon Footprint Assessment

To guide the data collection and analysis efforts Battelle developed the system boundaries for each test scenario and case (softened versus unsoftened water use) for this task. These diagrams show the primary energy consuming activities that occur within the home: natural gas and electricity consumption. They also illustrate which activities have been included in the analysis.

Battelle also assumed for each scenario that there are no differences in user behavior between cases that influence energy consumption, and therefore carbon footprint. For example, softened water might clean more efficiently leading to a change in the amount of detergent used or reduction in stain removers used for laundry. These actions could lead to a lower carbon footprint, but are ignored in this modeling.

System boundaries for the water heater and dishwasher test cases are shown below in Figures 4-1 and 4-2. Since the shower heads and faucets consume no energy themselves, their system boundary is indistinguishable from the water heater case. For this reason a system boundary diagram is not given for these cases. Similarly, the laundry washer system boundary can be derived from the dishwasher system boundary by a simple substitution of laundry washers for dishwashers in the following diagram; hence an explicit system boundary is not shown.

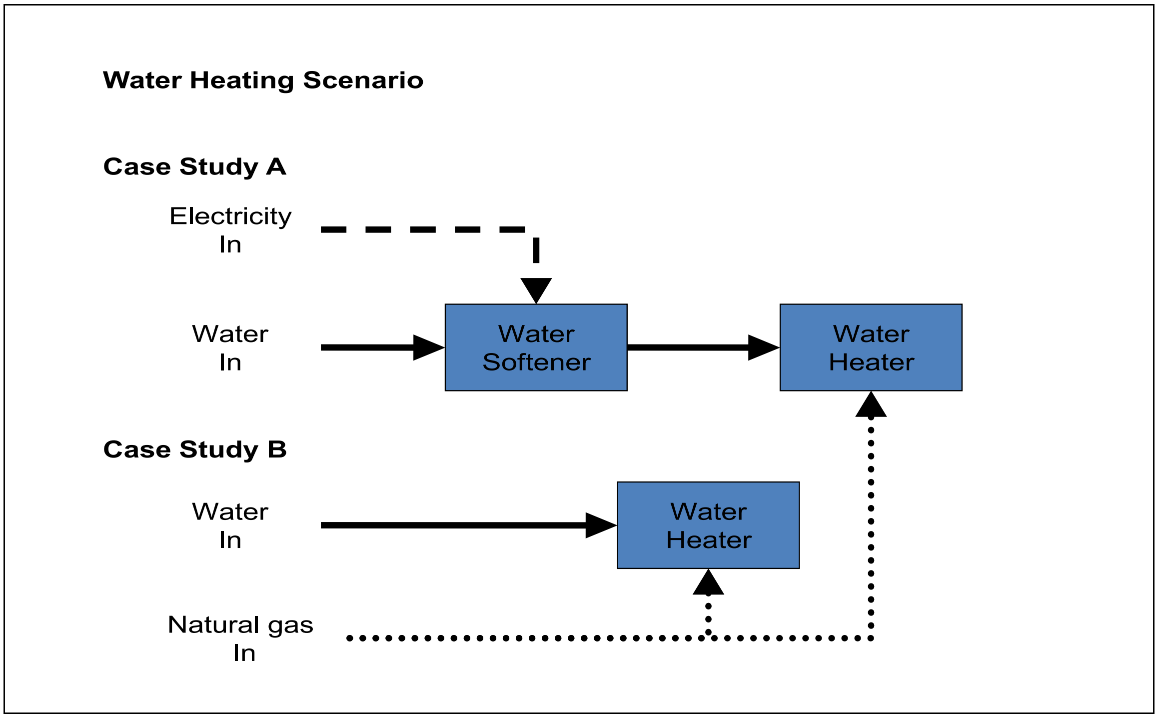


Figure 4-1. System Boundary for Water Heating Carbon Footprint

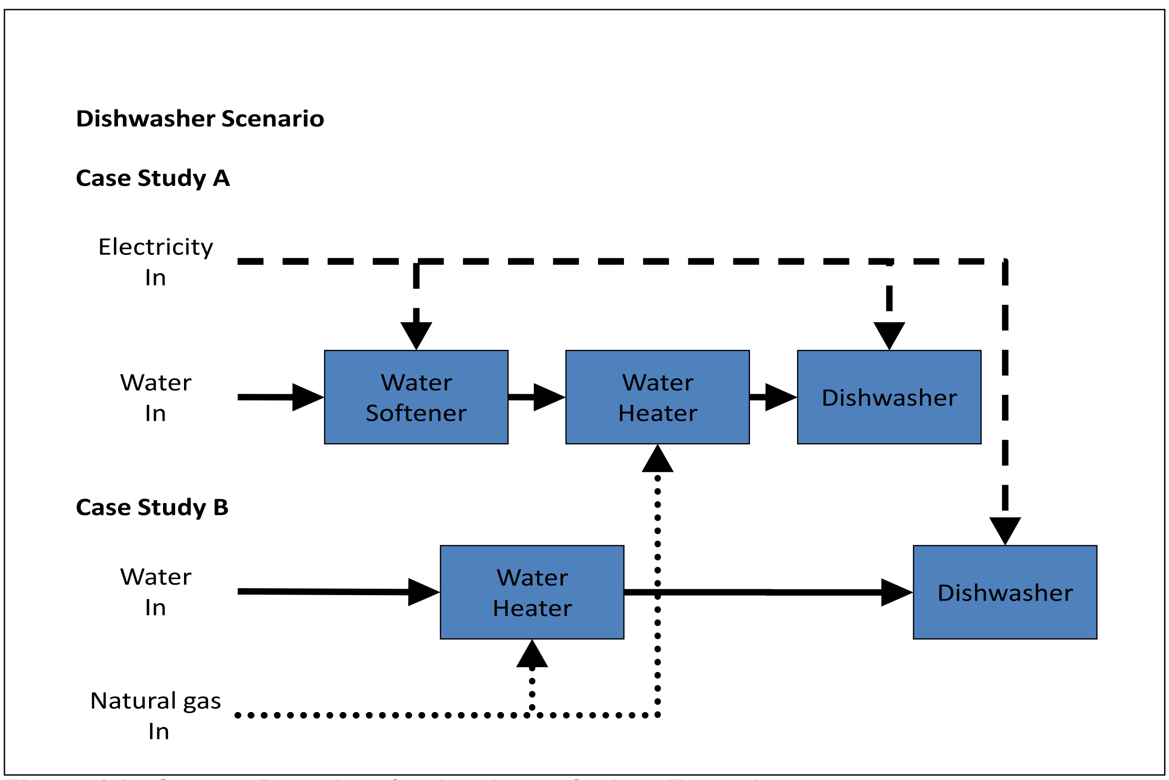


Figure 4-2. System Boundary for Appliance Carbon Footprint

From these systems diagrams Battelle developed a data collection scheme and quantitative models for each comparative test case to estimate the potential carbon footprint differences between using softened and unsoftened water, as seen below in Table 4-3.

To capture the electricity consumption of the appliances, one or more Watts Up? PRO energy monitoring meters was added to each circuit feeding electricity to the appliances. Three laundry washers are capable of being monitored by one meter, but the dishwashers had to be split between two meters (two dishwashers on one meter and one dishwasher on a meter alone) because of current demand.

Each weekday the cumulative energy consumption for each of the four sets of appliances: laundry washer with softened or unsoftened water, and dishwashers with softened or unsoftened water, was tabulated in a spreadsheet, along with the date and time of the observation. Knowing that a typical cycle was three hours, or eight cycles per 24 hours per appliance, the average per cycle energy consumption was calculated for each case (energy consumption between observations divided by number of cycles between observations). These values were plotted to look for trends, and notes on water heater and appliance operations added. The raw data is presented in Appendix A. The calculated results are presented in the next section, with the complete calculations presented in Appendix B.

Table 4-3. Carbon Footprint Calculation Data

	Unit Carbon Footprint	Units	Sources
Natural gas	0.0544	kg/SCF	US EPA AP-42, Section 1.4
Electricity	0.2083	kg/MJ	GaBi 4.3, US Power Grid Mix, TRACI GW Emissions

4.4 Lab Setup

Battelle filtered the well water source through a two-stage cartridge filtration system to remove large particulates, and reduce the oil and grease concentrations. Each stage was a spiral wound filter. The first stage was 50 micron filter, followed by a 20 micron filter. The outlet pressure from the filters was monitored daily, and filters were changed when the pressure dropped to near or below 30 psi on the water heater inlet side.

4.4.1 Water Heaters

The water heater test lab at Battelle was set up in three rooms, which are assigned by water heater type. The 10 storage type electric water heaters were set up in Room 1 and the 20 gas water heaters were assigned to Rooms 2 and 3, which are connected. The lab set up is pictured below in Figures 4-3 and 4-4.

Figure 4-3. Electric Water Heaters

Figure 4-4. Gas Water Heaters

4.4.2 Appliances

The appliance testing was set up along the walls of the rooms, as seen in Figure 4-5, used for the water heater tests. Three laundry washers and three dish washers were installed on the hot softened water line and the second set of appliance in the same configuration is installed on the unsoftened water line. The plastic tanks contained detergents that were dispensed into the appliances in the correct amount using peristaltic pumps. The clothes washers used Tide detergent and the dishwashers used Cascade detergent.

Figure 4-5. Appliance Testing

5.0 Results

The well water Battelle used for this testing contains an elevated concentration of iron which imparted red staining to the scale, the appliances, and the fixtures as is evident throughout the test results presented in this section. The unsoftened well water contained 26.2 grains per gallon of water hardness and 0.99 parts per million (ppm) or milligrams per liter (mg/liter) of iron. The softened well water contained less than 0.55 grain per gallon of water hardness and 0.27 ppm of iron. Samples of the scale were dissolved in solution and a quantitative analysis performed of the solutions to determine the percentage of calcium carbonate, magnesium, iron, and other species in the scale deposits. (See the results presented in Appendix Q). The analyses show the concentrations of calcium, magnesium, iron, copper, and manganese to be 2079 ppm, 96 ppm, 164 ppm, 28 ppm, and 21 ppm, respectively. This shows that calcium carbonate is the most significant constituent of the scale.

However; as is evident in the photographs presented further in this section, iron in the water has given the hard water deposits a red/brown tone. Iron causes unsightly red and/or brown staining in not only the scale but also on fixtures, faucets, porcelain, and clothing that contact the water. Iron is a rather common water problem in addition to and often accompanying hard water scaling. Iron is the fourth most abundant element on earth. It enters water naturally as it is dissolved from the earth's crust or as iron or steel pipes corrode. As iron reacts with oxygen it is converted from a water soluble and ionic ferrous iron into a precipitated red water ferric iron, which causes staining.

Like water hardness, iron does not cause health related problems in water supplies. Iron and water hardness rather create aesthetic and economic problems. The US Environmental Protection Agency advises a secondary maximum contaminant level (SMCL) for iron of 0.3 ppm to avoid aesthetically displeasing iron staining. Cation exchange water softeners replace hardness causing ions of calcium and magnesium as well as dissolved ions of other metallic elements, including iron and manganese, for those of sodium or potassium. Water softening is generally considered effective for treating levels of iron up to 5 ppm, although many field installations have performed very satisfactorily removing up to 15 ppm of dissolved Fe^{+2} iron with cation exchange water softeners. Many homeowners purchase water softeners to remove iron from their water supply in addition to calcium and magnesium. As is evident in the photographs, the appliances using unsoftened water were prone to heavy iron staining on all internal surfaces, whereas those appliances on softened water did not show this effect.

5.1 Water Heaters

Water heater efficiencies were calculated for the groups of instantaneous gas water heaters, gas storage water heaters, and electric storage water heaters. Five water heaters in each group were operated using unsoftened well water (26.2 grains per gallon, 0.99 ppm iron); and five water heaters were operated using softened well water (0.55 grains per gallon, and 0.27 ppm iron).

The efficiencies were calculated using the following energy balance. The energy output delivered from the hot water withdrawn from the tank is:

$$Q_{out} = mc(T_{out} - T_{in})$$

where m = the measured amount of water withdrawn from the tank,
c = the heat capacity of water,
T_{out} = the measure outlet water temperature, and
T_{in} = the measured inlet water temperature.

The energy input into the tank was determined for electric water heaters by directly measuring the kilowatt-hours used with a watt-hour meter. For gas water heaters, the energy input was determined using:

$$Q_{in} = V \times H$$

where V = the measured volume of natural gas used, and
H = the measured Btu content of the natural gas using a gas chromatograph.

The efficiency was then calculated using:

$$E = Q_{out} / Q_{in}$$

where E = the efficiency of the water heater.

5.2 Instantaneous Gas Water Heaters

The instantaneous gas water heaters chosen for these tests were residential models that had a maximum set point temperature of 140°F. However, the average outlet water temperature for each instantaneous gas water heater was measured every minute during the testing. The five instantaneous gas water heaters operating with soft water had an average outlet water temperature of 139.4°F, and the five instantaneous gas water heaters operating with unsoftened water had an average outlet temperature of 136.6°F. Since scale buildup generally increases with increasing temperature, it is important to operate both groups of water heaters with nearly identical hot water delivery temperatures. These temperatures meet this criterion.

5.2.1 Instantaneous Gas Water Heaters on Soft Water

Water heater efficiency measurements were taken periodically over the course of testing the instantaneous gas water heaters. For reference purposes, the equivalent field service time was determined by taking the total amount of water throughput and assuming the average U.S. household uses 50 gallons of hot water per day. Later the results will be generalized so that predictions can be made assuming either higher or lower household usage rates.

All of the efficiency data shown on these plots is included in Appendix C (on a CD) for the individual water heaters. Also included in the appendix are the statistical averages, standard deviations, and 95 percent confidence intervals for each set of data.

Figure 5-1 shows the measured efficiencies of the instantaneous gas water heaters did not change significantly over time, and averaged a constant value of 79.1 percent. Also shown on this graph, are the number of water heaters used to determine the average water heater efficiency at each point in time. At the start of the test there were five water heaters setup under identical conditions. In this case all five water heaters survived during the entire test.

Figure 5-2 shows the 95 percent confidence interval on each of the data points using the number of water heaters, the calculated standard deviation; and a Student's t-distribution. This shows that the efficiencies of the water heaters on soft water did not change significantly over the course of the testing, and a constant efficiency of 79.1 percent is a reasonable approximation. These instantaneous gas water heaters logged over three years of equivalent field service assuming a household uses 50 gallons of hot water per day.

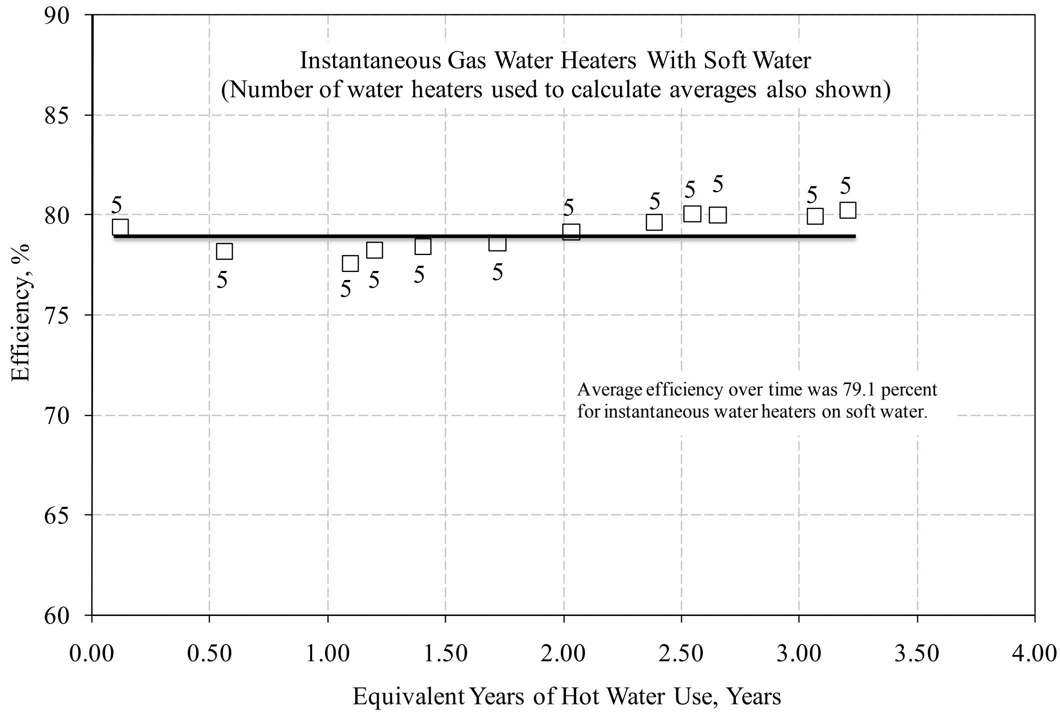


Figure 5-1. Efficiency of the instantaneous gas water heaters on soft water over time.

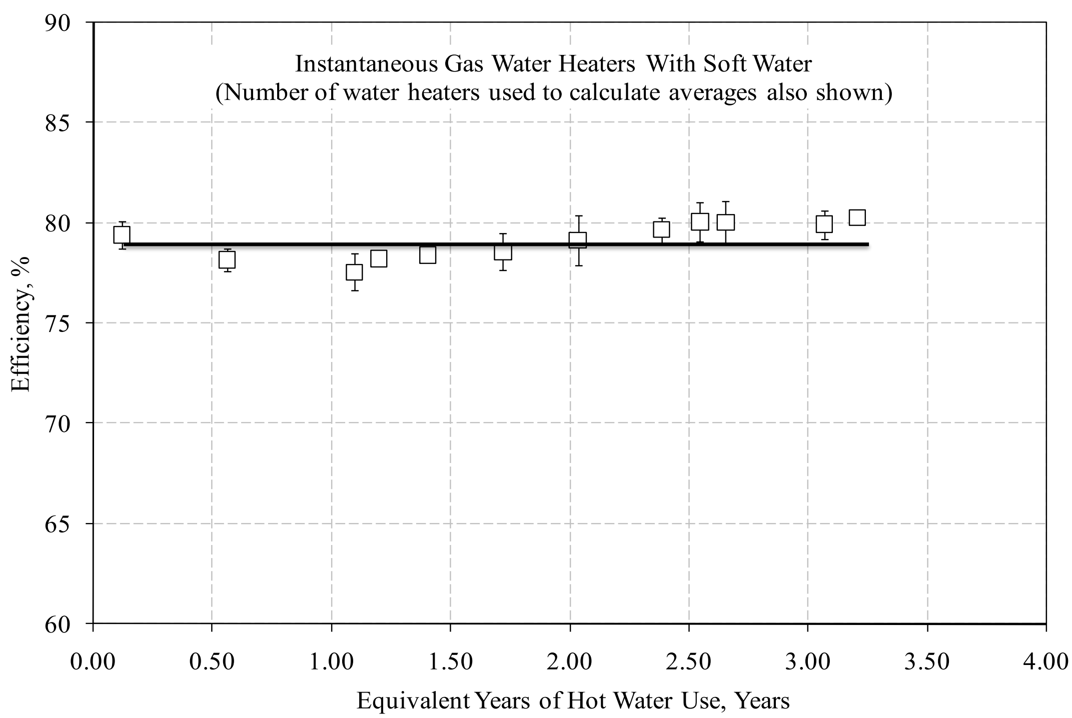


Figure 5-2. 95 percent confidence intervals for the efficiency measurements of the instantaneous gas water heaters on soft water.

In summary, the instantaneous gas water heaters on soft water performed well throughout the entire testing period. Although the pressure regulators and needle valves were tweaked throughout the testing to maintain constant testing conditions, the instantaneous gas water heaters on soft water required minimal attention because the conditions were very stable. This is reflected in the efficiency data for these units which show that the efficiency remained essentially constant over the duration of the testing with the variations being within the experimental error of the instrumentation and testing protocol. Overall, the softened water appears to have done a good job of preventing scale buildup in the instantaneous gas water heaters.

5.2.2 Instantaneous Gas Water Heaters on Unsoftened Water

Water heater efficiency measurements were also taken for an identical set of five instantaneous gas water heaters operating on unsoftened water. These results are also presented using an equivalent field service time determined by taking the total amount of water throughput and assuming the average U.S. household uses 50 gallons of hot water per day (Paul, *et al.*, 1994). Later the results will be generalized so that predictions can be made assuming either higher or lower household usage rates.

All of the efficiency data shown on these plots is included in Appendix C for the individual water heaters. Also included in the appendix are the statistical averages, standard deviations, and 95 percent confidence intervals for each set of data.

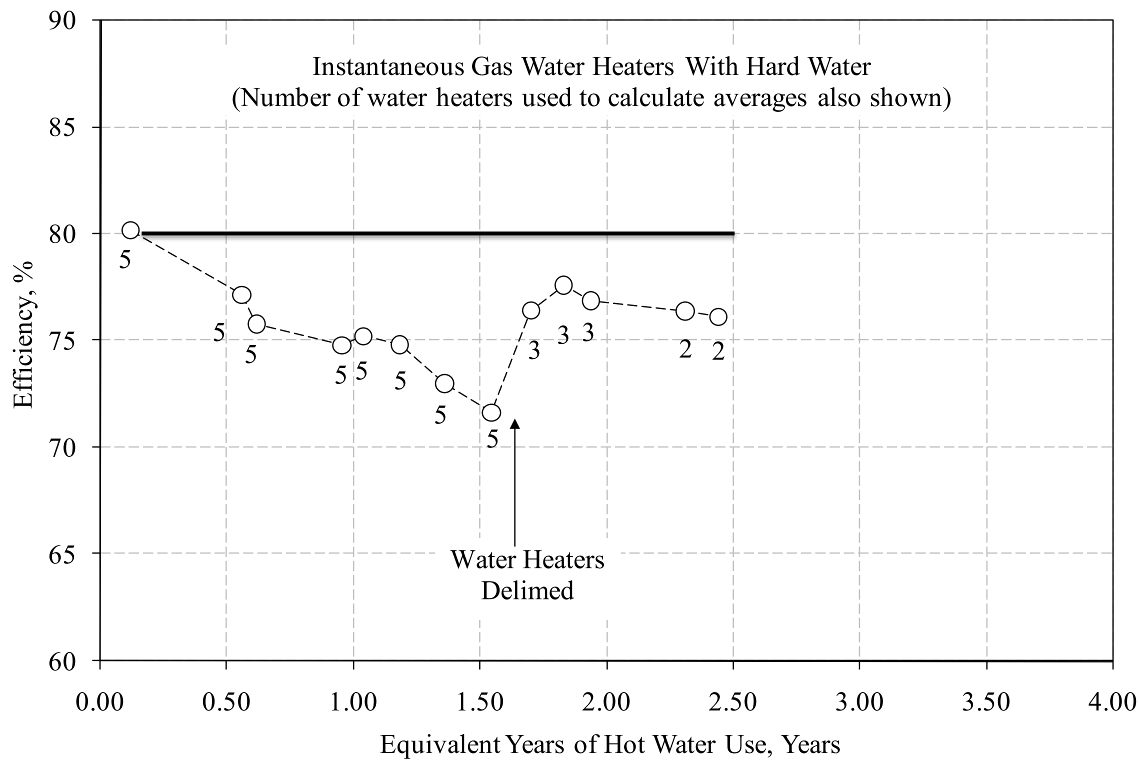


Figure 5-3. Efficiencies of the instantaneous gas water heaters using unsoftened water.

Figure 5-3 shows the measured efficiencies of the instantaneous gas water heaters that were operated using unsoftened water. In this case, the efficiency of the water heaters changes significantly with time because the internal surfaces of the heat exchanger begin to collect scale from the unsoftened water. The scale coating introduces an extra layer of resistance to heat transfer, and reduces the effectiveness of the heat exchanger. For reference, the initially measured water heater efficiency is shown as a constant value line over the testing period. Also shown on this graph are the number of water heaters used to determine the average water heater efficiency at each point in time.

At the start of the test there were five water heaters setup under identical conditions. All five water heaters were operating until about 1.6 years of equivalent hot water use. At this time the flow rate in two of the instantaneous water heaters on unsoftened water reduced to a trickle even though the control valves and pressure regulators were completely opened. One of the instantaneous water heaters was exhibiting an audible alarm and fault code indicating that the unit needed to be delimed. (Deliming is required when the efficiency falls below a value of approximately 72%.) A service technician from Best Plumbing (New Albany, OH) was called in to examine the units, and he delimed the instantaneous water heaters on unsoftened water using the set of deliming valves on the water heater. The deliming valves on these water heaters are a pair of three way valves that allow a service technician to isolate the instantaneous water heater from the rest of the inlet and outlet piping system, and to circulate a deliming solution through the water. The service technician circulated the deliming solution for 30 minutes through each of the units.

The efficiency of the three remaining water heaters on unsoftened water improved after the deliming procedure, but the flow through the two units that were down before the deliming procedure was still inadequate. A decision was made to cut open the one-half inch copper pipe immediately downstream of the water heater, but before the pressure regulator and needle valve. The Battelle technician used a hack saw to cut out the two 90 degree elbows shown in Figure 5-4

Examination of the outlet piping revealed that the copper piping was nearly completely plugged with scale at one of the elbows. However, the cutting of the pipe with the hack saw loosened scale on the vertical pipe walls after the elbows, and the scale collected in the lower elbow.

Figure 5-4 also shows the loose scale that was found inside of the elbow after it was dumped out onto a piece of paper. Pieces of the loose scale had a curvature that indicated that the scale was stuck to the one-half inch, vertical pipe walls prior to falling into the elbow. The thickness of several large pieces of scale were carefully measured and found to be about 0.05 inches thick. This scale was sent to Culligan International for analysis. Culligan dissolved the scale in solution and then performed a quantitative analysis of the solution to determine the percentage of calcium carbonate, magnesium, iron, and other species in the scale sample. The results are presented in Appendix O show the results for calcium, magnesium, iron, copper, and manganese to be 2079 ppm, 96 ppm , 164 ppm, 28 ppm, and 21 ppm, respectively. This shows that the overwhelming majority of the scale is calcium carbonate.

Figure 5-4. Loose scale inside the elbow from the instantaneous water heater on unsoftened water.

The pressure regulators downstream of all of the water heaters were disassembled and found to be clogged with scale as shown in Figure 5-5. Even after the pressure regulators were cleaned and reassembled, the two water heaters with inadequate flow rates before still had marginal flow rates. The instantaneous water heaters would not consistently fire with each water draw. It was subsequently learned that these instantaneous water heaters must have a minimum flow rate of water before they will fire. Based on testing, it was found that if the flow rate of water was greater than 0.5 gallons per minute, the instantaneous water heaters would fire consistently. At flow rates below 0.5 gallons per minute, the water heaters became very inconsistent in firing; sometimes they would fire and other times they would not fire during a water draw. Based on these observations, it was concluded that the downstream piping and fittings (needle valve and solenoid valve) were clogged with scale on these two units. The entire downstream piping and fittings would have to be replaced for these tests to continue, so the testing of these two units was discontinued.

At a time of about 2.3 equivalent years, one of the three remaining instantaneous water heaters on unsoftened water could not maintain insufficient flow to fire consistently, and testing was discontinued. At about 2.5 equivalent years, the piping systems on the remaining two instantaneous water heaters also clogged up to the point of causing the water heaters to fire inconsistently, so the testing of these units was discontinued. The downstream piping system on all of the instantaneous water heaters on unsoftened water would have to be either delimed or replaced for additional testing to continue with these units. In contrast to the unsoftened water tests, all of the instantaneous water heaters on soft water operated without difficulty to the scheduled end of the tests at about 3.2 equivalent years

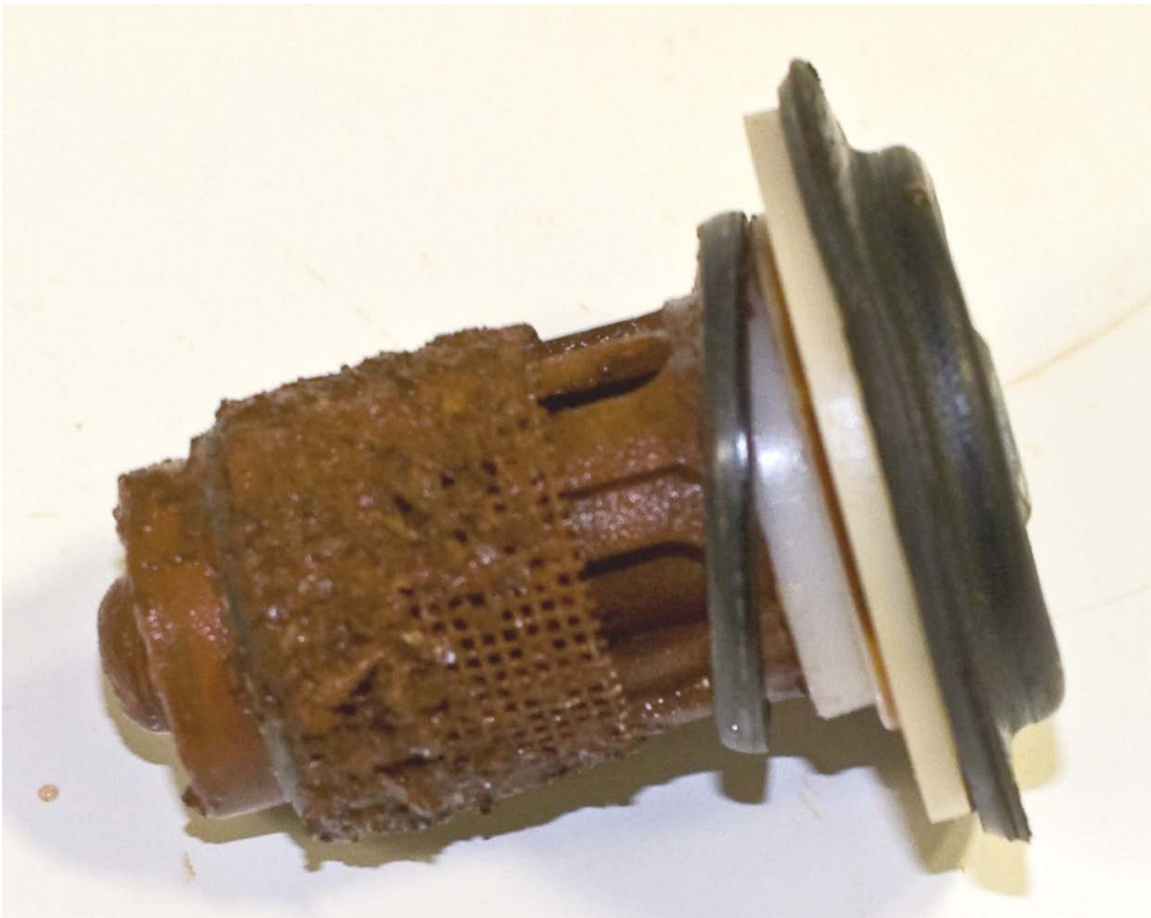


Figure 5-5. Clogging of the strainers from the disassembled pressure regulators of the instantaneous water heaters on unsoftened water.

With this explanation for the removal of some of the instantaneous water heaters using unsoftened water an examination of the efficiency data can begin. Figure 5-6 shows the 95 percent confidence interval on each of the data points using the number of water heaters, the calculated standard deviation; and a Student's t-distribution. At about 1.3 equivalent years into the testing, the 95 percent confidence intervals began to increase dramatically due to the unsoftened water scale buildup inside the water heaters and on the downstream piping system and control valves. After the water heaters were delimed, the efficiency of the remaining units improved to 77 percent, but did not recover to the measured initial efficiency of 80 percent.

Figure 5-7 looks at only the efficiency data of the instantaneous water heaters on unsoftened water prior to being delimed at about 1.6 equivalent years. A linear regression analyses of the efficiency data for the instantaneous water heaters on unsoftened water reveals the efficiency decreased on average about 5.33 efficiency points per year prior to the water heaters being delimed at about 1.6 equivalent years. The linear regression analsis yields a least squares fit to this data that reveals an equation for how the efficiency of the units changes with time as:

$E = E_o - 5.14t$ (Instantaneous Water Heaters Only) Equation 1

where E = the efficiency at time t,
E_o = the initial efficiency of the water heater at t = 0, in this case 80 %,
t = the time in equivalent years defined as usage in gallons divided by 18250 gallons per year.

This equation can be generalized to predict the efficiency of instantaneous water heaters at other water hardness levels, and for other daily hot water usage amount by putting it into the form below:

$E = E_o - bt$ Equation 2

where $b = (0.003924)HG$ (Instantaneous Water Heaters Only) Equation 3
H = the water hardness in grains per gallon,
G = the daily household hot water usage in gallons per day.

For the instantaneous water heaters on unsoftened water, the water hardness was 26.2 grains per gallon, and a daily hot water usage of 50 gallons per day was assumed. When these values are plugged into Eq. 3, the value for b is 5.14 which is identical to the coefficient used in Eq. 1. The expression for b assumes that if you double the usage rate, the amount of scale buildup inside the water heater also doubles.

For instantaneous water heaters on soft water with a water hardness level of 0.0 grains per gallon, Eq. 2 reduces to a constant value E_o for the efficiency for all times, which is consistent with Battelle's research findings discussed in Section 5.2.

The time required before deliming an instantaneous water heater can be predicted from Eq. 2 as a function of the water hardness and average household hot water usage. For this testing, the instantaneous water heaters on unsoftened water started out with an efficiency of 80 percent and were delimed when the efficiency dropped to about 72 percent, the level at which the alarm is activated. Using these efficiency limits, Table 5-1 was generated using Eq. 1, and shows how the efficiency of instantaneous water heater changes with time for various water hardness levels and for households that use either 50 or 100 gallons per day of hot water. When the water heater efficiency dropped to less than 72 percent in Table 5-1, a table entry of "Delime" was inserted to indicate that it was time to delime the instantaneous water heater. For instance, assuming a water hardness level of 10 grains per gallon, the time until deliming would be 4.4 years for a household using an average of 50 gallons of hot water per day, and 2.2 years for the same household using an average of 100 gallons of hot water per day. Besides the nuisance factor associated with having maintenance done on your water heater, the cost to delime the water heater is about $120 per visit.

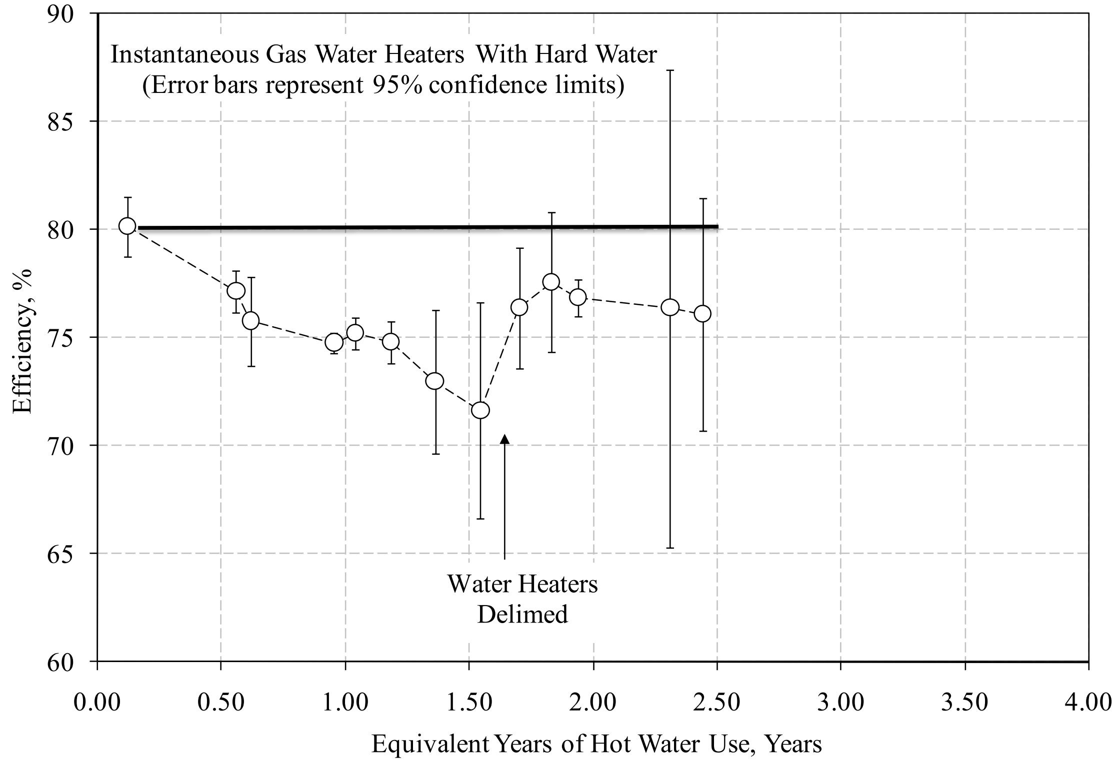


Figure 5-6. 95 percent confidence intervals for the efficiency measurements of the instantaneous gas water heaters on unsoftened water.

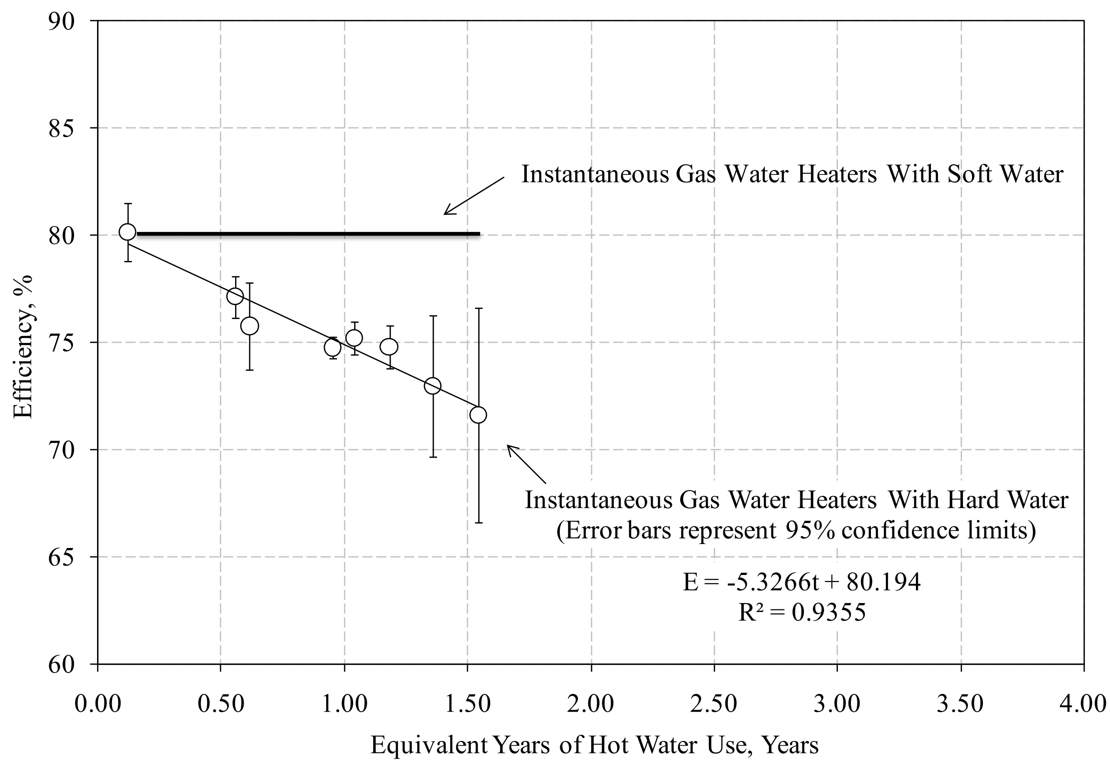


Figure 5-7. Linear regression of the efficiency data for the instantaneous water heaters on unsoftened water.

Table 5-1. Predicted efficiencies of instantaneous water heaters as a function of water hardness and hot water usage.

	50 Gallons Per Day of Hot Water Usage							100 Gallons Per Day of Hot Water Usage						
Time	Water Hardness in Grains Per Gallon							Water Hardness in Grains Per Gallon						
(Years)	0	5	10	15	20	25	30	0	5	10	15	20	25	30
0.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
0.2	80.0	79.8	79.6	79.4	79.2	79.0	78.8	80.0	79.6	79.2	78.8	78.4	78.0	77.6
0.4	80.0	79.6	79.2	78.8	78.4	78.0	77.6	80.0	79.2	78.4	77.6	76.9	76.1	75.3
0.6	80.0	79.4	78.8	78.2	77.6	77.1	76.5	80.0	78.8	77.6	76.5	75.3	74.1	72.9
0.8	80.0	79.2	78.4	77.6	76.9	76.1	75.3	80.0	78.4	76.9	75.3	73.7	72.2	Delime
1.0	80.0	79.0	78.0	77.1	76.1	75.1	74.1	80.0	78.0	76.1	74.1	72.2	Delime	
1.2	80.0	78.8	77.6	76.5	75.3	74.1	72.9	80.0	77.6	75.3	72.9	Delime		
1.4	80.0	78.6	77.3	75.9	74.5	73.1	Delime	80.0	77.3	74.5	Delime			
1.6	80.0	78.4	76.9	75.3	73.7	72.2		80.0	76.9	73.7				
1.8	80.0	78.2	76.5	74.7	72.9	Delime		80.0	76.5	72.9				
2.0	80.0	78.0	76.1	74.1	72.2			80.0	76.1	72.2				
2.2	80.0	77.8	75.7	73.5	Delime			80.0	75.7	Delime				
2.4	80.0	77.6	75.3	72.9				80.0	75.3					
2.6	80.0	77.4	74.9	72.3				80.0	74.9					
2.8	80.0	77.3	74.5	Delime				80.0	74.5					
3.0	80.0	77.1	74.1					80.0	74.1					
3.2	80.0	76.9	73.7					80.0	73.7					
3.4	80.0	76.7	73.3					80.0	73.3					
3.6	80.0	76.5	72.9					80.0	72.9					
3.8	80.0	76.3	72.5					80.0	72.5					
4.0	80.0	76.1	72.2					80.0	72.2					
4.2	80.0	75.9	71.8					80.0	Delime					
4.4	80.0	75.7	Delime					80.0						
4.6	80.0	75.5						80.0						
4.8	80.0	75.3						80.0						
5.0	80.0	75.1						80.0						
5.2	80.0	74.9						80.0						
5.4	80.0	74.7						80.0						
5.6	80.0	74.5						80.0						
5.8	80.0	74.3						80.0						
6.0	80.0	74.1						80.0						
6.2	80.0	73.9						80.0						
6.4	80.0	73.7						80.0						
6.6	80.0	73.5						80.0						
6.8	80.0	73.3						80.0						
7.0	80.0	73.1						80.0						
7.2	80.0	72.9						80.0						
7.4	80.0	72.7						80.0						
7.6	80.0	72.5						80.0						
7.8	80.0	72.3						80.0						
8.0	80.0	72.2						80.0						
8.2	80.0	72.0						80.0						
8.4	80.0	Delime						80.0						

In comparison, if the instantaneous water heater is using a water softener that is capable of removing all of the water hardness, the unit should never have to be delimed. In addition, there is a considerable cost savings associated with having an instantaneous water heater operating at a constant 80 percent efficiency as opposed to slowly degrading over time to about 72 percent efficiency before being delimed. Table 5-2 shows the energy costs associated with operating an instantaneous water heater as a function of water hardness. A 15-year life of the water heater was assumed. The instantaneous water heater using 30 grains per gallon unsoftened water costs $1,461 more to operate over its useful life than one using softened water (0 grains per gallon). Most of this cost is associated with the deliming process. However, using an inlet water with a lower hardness, the energy savings become more significant over the life of the water heater. (See the results for 5 gpg hardness in Table 5-2, where the energy cost savings is 39%, versus only 9% for the 30 gpg hardness case.)

Table 5-2. Energy costs as a function of water hardness for instantaneous water heaters.

Cost of Natural Gas Over The Life of an Instantaneous Gas Water Heater							
Water Hardness, grains/gallon	**0**	**5**	**10**	**15**	**20**	**25**	**30**
Water Inlet Temperature, F	46.6	46.6	46.6	46.6	46.6	46.6	46.6
Set Point Temperature, F	136.6	136.6	136.6	136.6	136.6	136.6	136.6
Life of Water Heater, Years	15	15	15	15	15	15	15
Efficiency at Beginning	80.0	80.0	80.0	80.0	80.0	80.0	80.0
Efficiency at Delimining	NA[1]	72.0	72.0	72.0	72.0	72.0	72.0
Natural Gas Used, mmBtu	256.5	270.3[2]	270.4	270.3	270.4	270.3	270.3
Natural Gas Price, $/mmBtu	$10	$10	$10	$10	$10	$10	$10
Cost of Natural Gas, $	$2,565	$2,703	$2,704	$2,703	$2,704	$2,703	$2,703
Added Cost Without Softener	$0	$138	$138	$138	$138	$137	$138
Deliming Cost $120	$0	$220	$439	$662	$878	$1,104	$1,324
Additional Operating Costs	$0	$358	$577	$799	$1,016	$1,242	$1,461

[1] With 0 grains per gallon hardness, the instantaneous water will not need to be delimed over the life of the unit and the efficiency remains constant at 80 %.

[2] Instantaneous water heaters using hard water operate at an average efficiency between 80 and 72 percent depending on how many times they need to be delimed over the life of the unit, and for this reason use slightly more gas than units on 0 gpg water (80 % efficient).

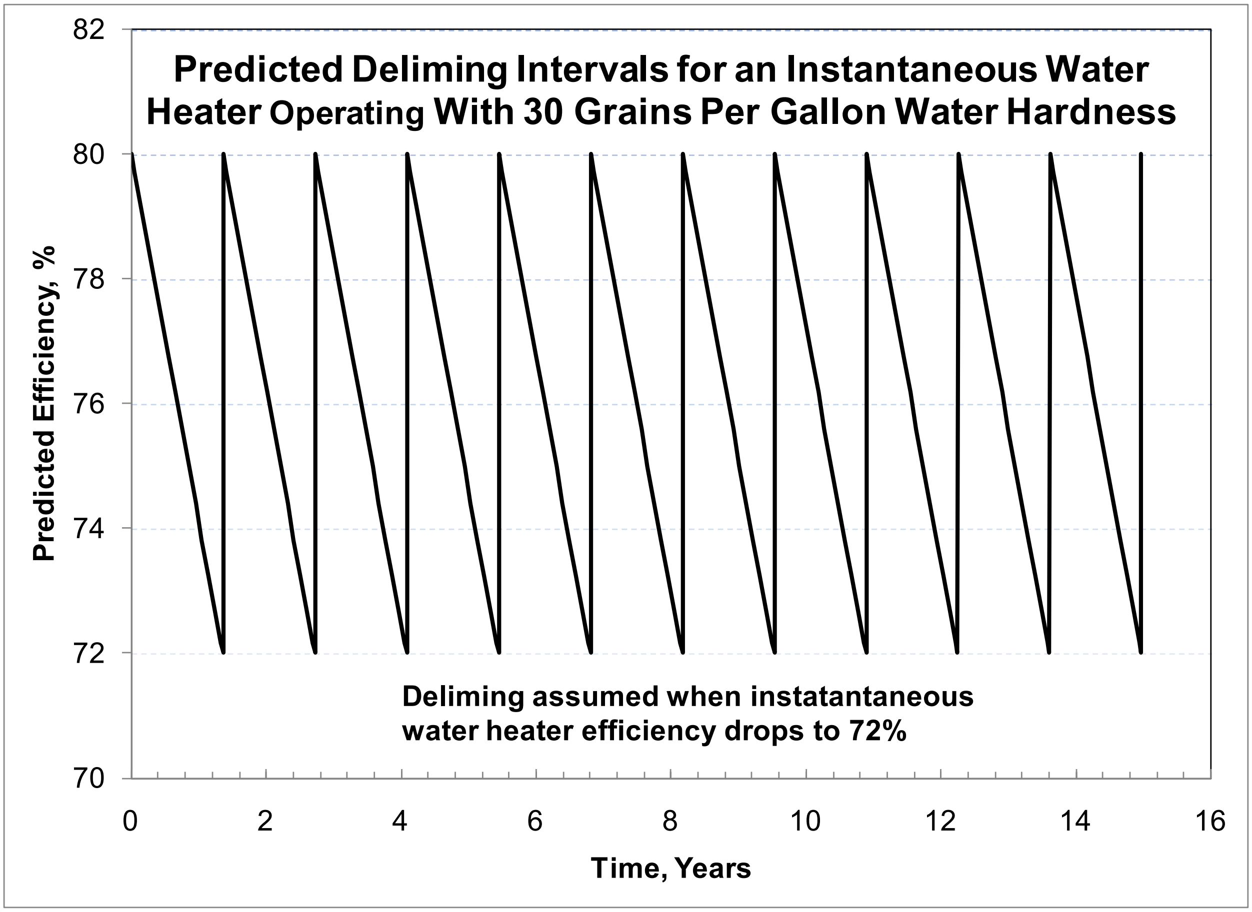


Figure 5-7A. The predicted deliming intervals for an instantaneous water heater operating with extremely hard water at 30 grains per gallon hardness.

At the end of the testing the instantaneous water heaters were disassembled and the heat exchangers cut in half in order to examine the scaling conditions inside the tubes. Appendices I and J contain the photos of the heat exchangers for instantaneous water heaters on softened and unsoftened water, respectively. The heat exchangers using unsoftened water had more scale inside the tubes than the ones on softened water. However, the heat exchangers on unsoftened water were delimed about 30 days before the end of the test, and therefore, do not have as much scale as might be expected if the water heaters had not been delimed. In addition, at the end of testing, the outlet piping on each water heater was carefully cut into short lengths (ends taped to keep loose scale inside), and shipped to one of the Water Quality Association members for additional analysis.

In summary, none of the instantaneous gas water heaters on unsoftened water made it through the entire testing period because the outlet piping system consisting of one-half inch copper pipe, a pressure regulator, a needle valve, and a solenoid valve became clogged with scale buildup. Although the pressure regulators and needle valves were tweaked throughout the testing to try to maintain constant testing conditions, the instantaneous gas water heaters on unsoftened water all dropped out of the testing before 2.5 years of equivalent field service. In contrast, the instantaneous water heaters on soft water all completed testing without difficulty when the tests were stopped at 3.2 years of equivalent field service. In addition, the instantaneous water heaters on unsoftened water had to be delimed at 1.6 years of equivalent field service, and the average efficiency of these units dropped from 80 percent at the start of the test to 72 percent when they were delimed. After deliming, the average efficiency of these units increased to about 77 percent, but was still below the 80.1 percent starting efficiency. The cost implications of these findings are addressed in the section of the report on life cycle costs.

5.3 Gas Storage Water Heaters

The gas storage water heaters chosen for these tests were residential models that had a maximum set point temperature of "Very Hot," which corresponds to a maximum water temperature of about 160°F. The average outlet water temperature for each gas storage water heater was measured every minute during the testing. The five gas storage water heaters operating with unsoftened water had an average outlet water temperature of 161.8°F, and the five gas storage water heaters operating with soft water had an average outlet temperature of 160.4°F. Since scale buildup generally increases with increasing temperature, it was important to operate both groups of water heaters with nearly identical hot water delivery temperatures. These temperatures meet this criterion.

5.3.1 Gas Storage Water Heaters on Soft Water

Water heater efficiency measurements were taken periodically over the course of testing the gas storage water heaters. For reference purposes, the equivalent field service time was determined by taking the total amount of water throughput and assuming the average U.S. household uses 50 gallons of hot water per day (Paul, *et al.*, 1994). Later the results will be generalized so that predictions can be made assuming either higher or lower household usage rates.

All of the efficiency data shown on these plots is included in Appendix E for the individual water heaters. Also included in the appendix are the statistical averages, standard deviations, and 95 percent confidence intervals for each set of data.

Figure 5-8 shows the measured efficiencies of the gas storage water heaters did not change significantly over time, and averaged a constant value of 69.0 percent. Also shown on this graph, are the number of water heaters used to determine the average water heater efficiency at each point in time. At the start of the test there were five water heaters setup under identical conditions. In this case, all five water heaters survived during the entire test, but one of the water meters failed part way through the test dropping the number of available units to four, and one of the thermocouples on another unit failed later in the test dropping the number of available units to three. Even though this reduced the number of units available for calculating average efficiencies, sufficient data was recorded to yield reasonable results.

Figure 5-9 shows the 95 percent confidence interval on each of the data points using the number of water heaters, the calculated standard deviation; and a Student's t-distribution. This shows that the efficiencies of the water heaters on soft water did not change significantly over the course of the testing, and a constant efficiency of 69.0 percent is a reasonable approximation. These water heaters logged over 2.25 years of equivalent field service assuming a household uses 50 gallons of hot water per day.

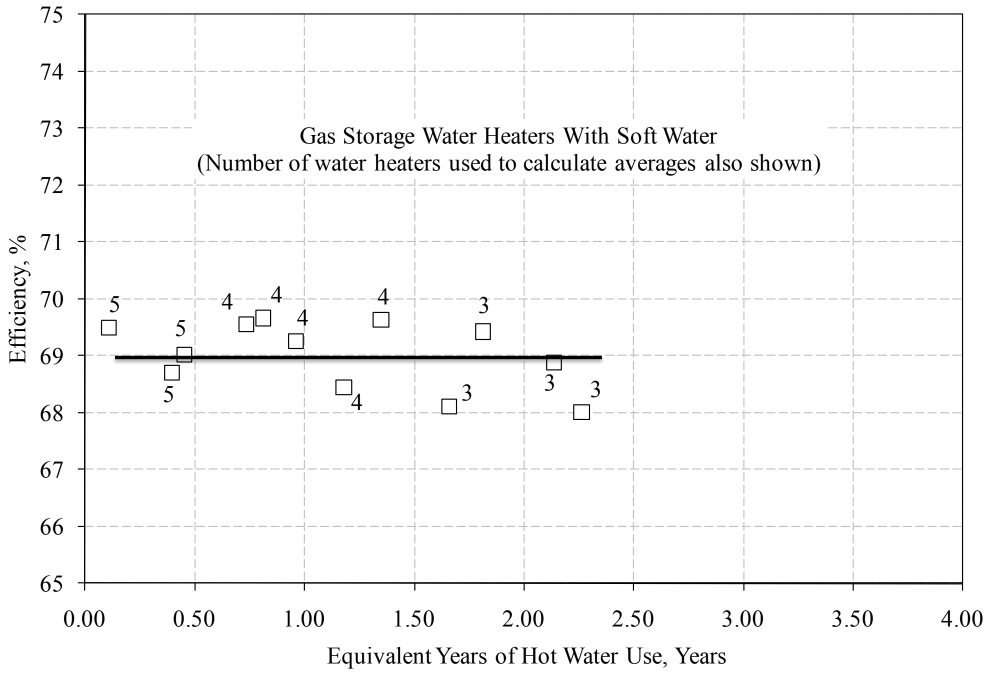


Figure 5-8. Efficiency of the gas storage water heaters on soft water.

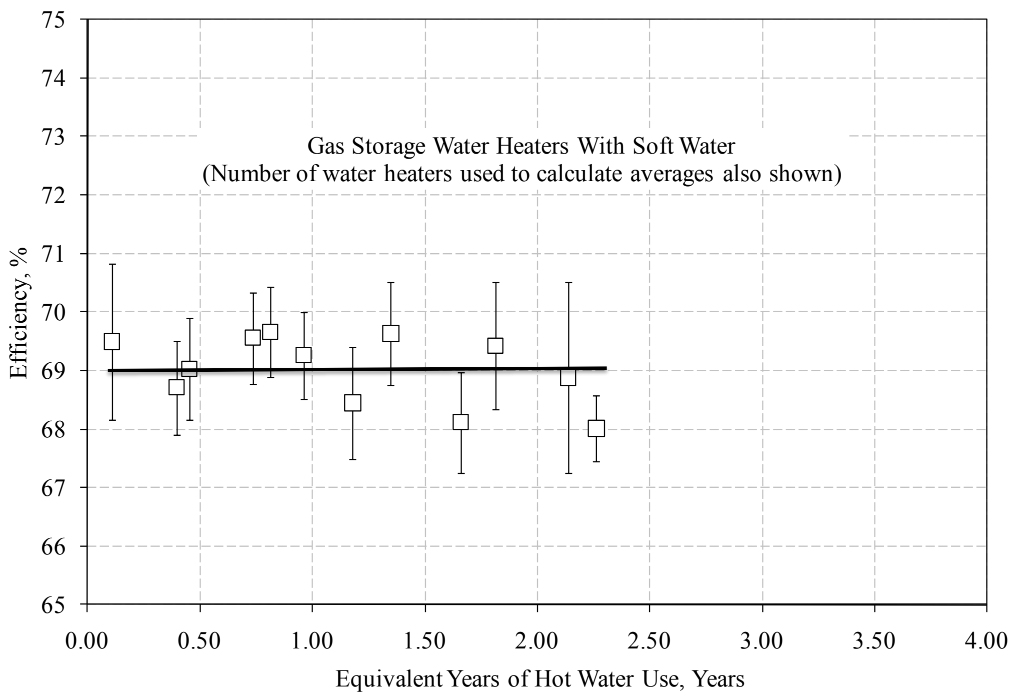


Figure 5-9. 95 percent confidence intervals for the efficiency measurements of the gas storage water heaters on soft water.

In summary, the gas storage water heaters on soft water performed well throughout the entire testing period. Although the pressure regulators and needle valves were tweaked throughout the testing to maintain constant testing conditions, the gas storage water heaters on soft water required minimal attention because the conditions were very stable. This is reflected in the efficiency data for these units which show that the efficiency remained essentially constant over the duration of the testing with the variations being within the experimental error of the instrumentation and testing protocol. Overall, the softened water appears to have done a good job of preventing scale buildup in the gas storage water heaters and piping system.

5.3.2 Gas Storage Water Heaters on Unsoftened Water

Water heater efficiency measurements were also taken for an identical set of five gas storage water heaters operating on unsoftened water. These results are also presented using an equivalent field service time determined by taking the total amount of water throughput and assuming the average U.S. household uses 50 gallons of hot water per day Paul, *et al.*, 1994). Later the results will be generalized so that predictions can be made assuming either higher or lower household usage rates.

All of the efficiency data shown on these plots is included in Appendix F for the individual water heaters. Also included in the appendix are the statistical averages, standard deviations, and 95 percent confidence intervals for each set of data.

Figure 5-10 shows the measured efficiencies of the gas storage water heaters that were operated using unsoftened water. In this case, the efficiency of the water heaters changes significantly with time because the internal surfaces of the heat exchanger begin to collect scale from the unsoftened water. The scale coating introduces an extra layer of resistance to heat transfer, and reduces the effectiveness of the heat exchanger. For reference, the initially measured water heater efficiency is a constant value of 69% over the testing period as seen in Figure 5-10. Also shown on this graph are the number of water heaters used to determine the average water heater efficiency at each point in time.

At the start of the test there were five water heaters setup under identical conditions. All five water heaters were operating until about 1.3 years of equivalent hot water use. It was at this point in time that it was noticed that the flow rate in one of the gas storage water heaters on unsoftened water had been reduced to a trickle even though the control valves and pressure regulators were completely opened. These water heaters were experiencing the same problems of scale buildup in the outlet piping system that the instantaneous water heaters experienced as explained in Section 5.2 of this report. However, since the gas storage water heaters were operating at a higher temperature (161.8°F) than the instantaneous water heaters (136.6°F), the clogging of the outlet piping started to occur at an earlier equivalent time. By the time the testing reached an equivalent time of 2.0 years only one water heater piping system was operating, and this one clogged up shortly thereafter. At the end of testing, the outlet piping on each water heater was carefully cut into short lengths (ends taped to keep loose scale inside), and shipped to one of the Water Quality Association members for additional analysis.

With this explanation for the removal of some of the gas storage water heaters using unsoftened water from the test at various points in time an examination of the efficiency data can begin. Figure 5-11 shows the 95 percent confidence interval on each of the data points using the number of water heaters, the calculated standard deviation; and a Student's t-distribution. At about 0.8

equivalent years into the testing, the 95 percent confidence intervals began to increase dramatically due to the unsoftened water scale buildup inside the water heaters and on the downstream piping system and control valves.

A least squares fit to this data reveals an equation for how the efficiency of the units changes with time as:

$E = E_o - 1.485t$ (Gas Storage Water Heaters Only) Equation 4

where E = the efficiency at time t,
E_o = the initial efficiency of the water heater at t =0, in this case 70.4 %,
t = the time in equivalent years defined as usage in gallons divided by 18250 gallons per year.

This equation can be generalized to predict the efficiency of gas storage water heaters at other water hardness levels, and for other daily hot water usage amount by putting it into the form below:

$E = E_o - bt$ Equation 5

where $b = (0.001133)HG$, (Gas Storage Water Heaters Only) Equation 6
H = the water hardness in grains per gallon, and
G = the daily household hot water usage in gallons per day.

For the gas storage water heaters on unsoftened water, the water hardness was 26.2 grains per gallon, and a daily hot water usage of 50 gallons per day was assumed. When these values are plugged into Eq. 3, the value for b is 1.485 which is identical to the coefficient used in Eq. 4. The expression for b assumes that if you double the usage rate, the amount of scale buildup inside the water heater also doubles.

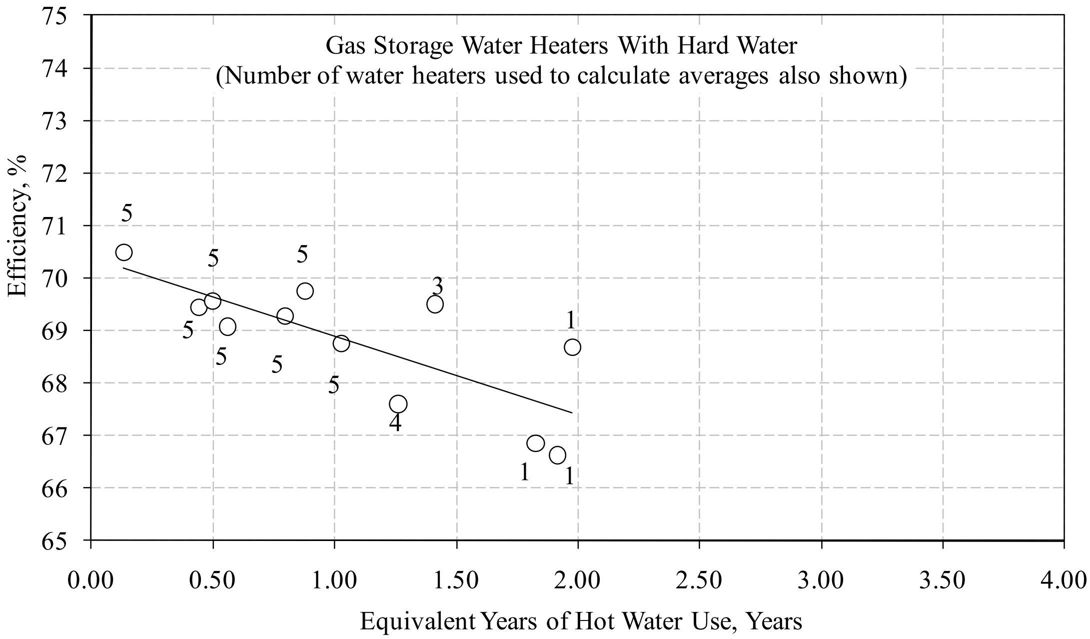


Figure 5-10. Efficiencies of the gas storage water heaters using unsoftened water.

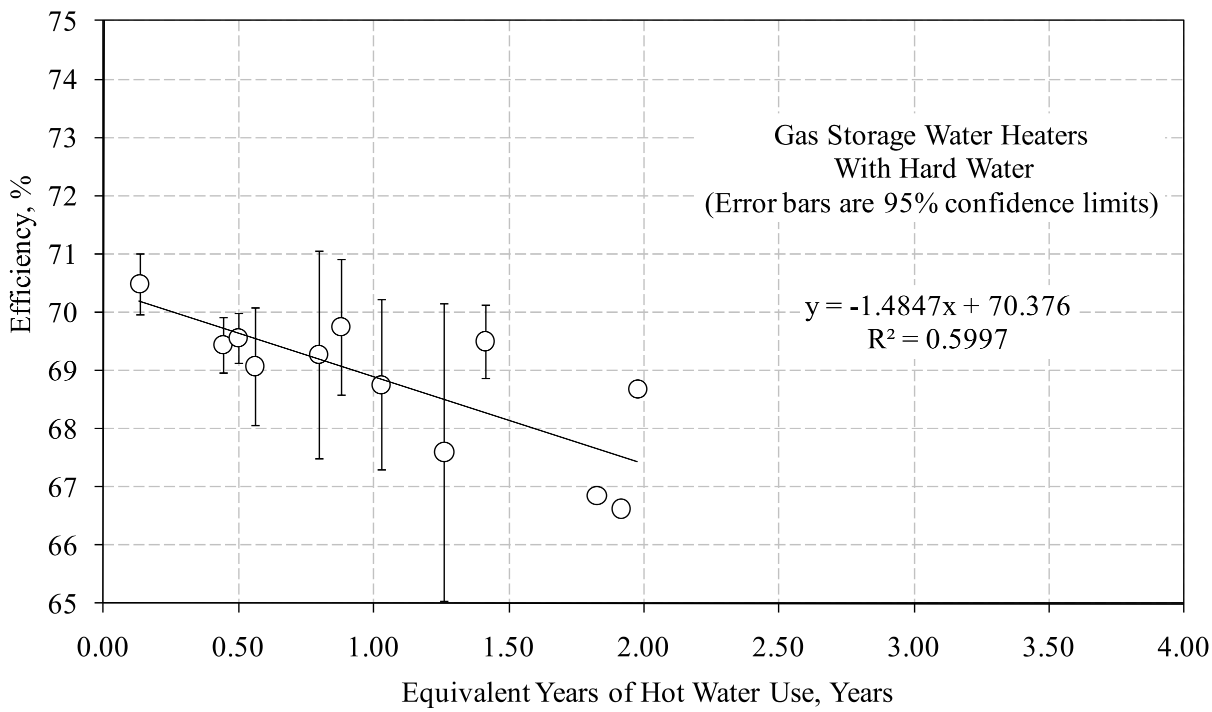


Figure 5-11. 95 percent confidence intervals for the efficiency measurements of the gas storage water heaters using unsoftened water.

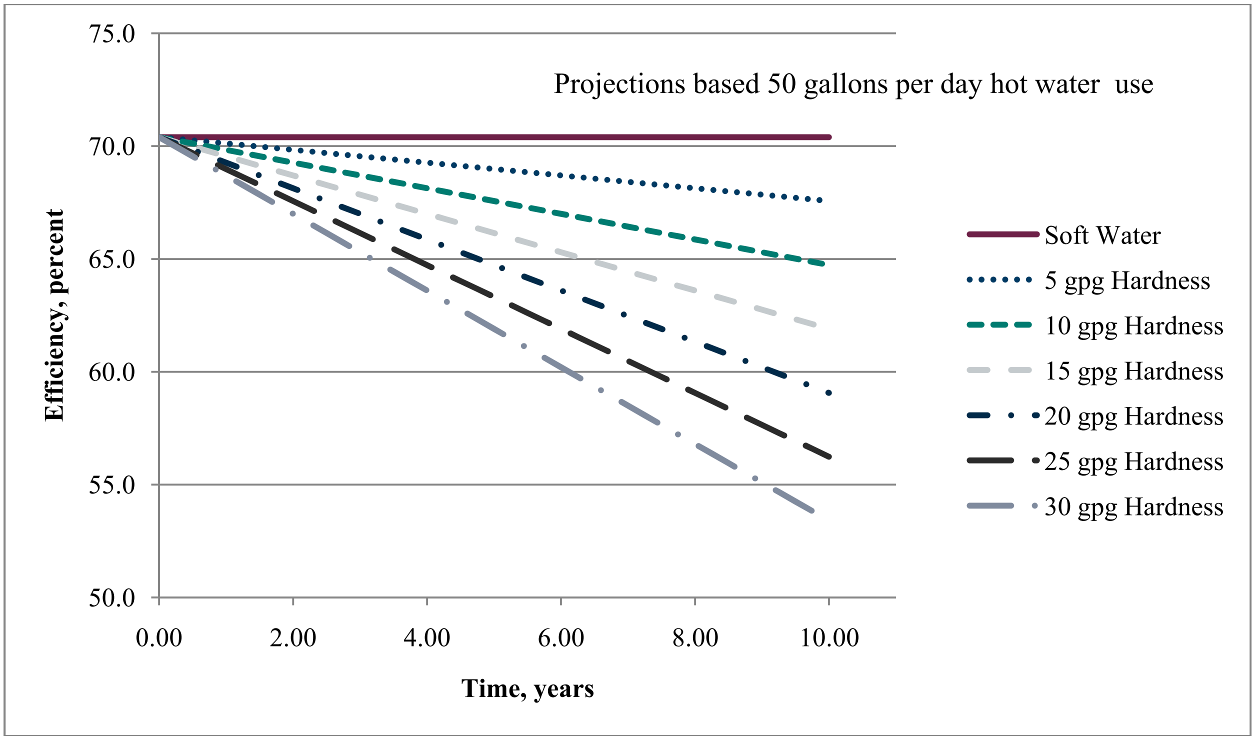


Figure 5-12. Predicted efficiency of a gas storage water heaters operating on soft water (0 grains per gallon) versus one operating on unsoftened water with a hardness of 30 grains per gallon.

Table 5-3. Predicted efficiencies of gas storage water heaters as a function of water hardness level and daily household hot water usage.

	50 Gallons Per Day of Hot Water Usage							100 Gallons Per Day of Hot Water Usage						
Time	Water Hardness in Grains Per Gallon							Water Hardness in Grains Per Gallon						
(Years)	0	5	10	15	20	25	30	0	5	10	15	20	25	30
0.00	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4	70.4
0.25	70.4	70.3	70.3	70.2	70.1	70.0	70.0	70.4	70.3	70.1	70.0	69.8	69.7	69.5
0.50	70.4	70.3	70.1	70.0	69.8	69.7	69.5	70.4	70.1	69.8	69.5	69.3	69.0	68.7
0.75	70.4	70.2	70.0	69.8	69.5	69.3	69.1	70.4	70.0	69.5	69.1	68.7	68.3	67.8
1.00	70.4	70.1	69.8	69.5	69.3	69.0	68.7	70.4	69.8	69.3	68.7	68.1	67.6	67.0
1.25	70.4	70.0	69.7	69.3	69.0	68.6	68.3	70.4	69.7	69.0	68.3	67.6	66.9	66.1
1.50	70.4	70.0	69.5	69.1	68.7	68.3	67.8	70.4	69.5	68.7	67.8	67.0	66.1	65.3
1.75	70.4	69.9	69.4	68.9	68.4	67.9	67.4	70.4	69.4	68.4	67.4	66.4	65.4	64.4
2.00	70.4	69.8	69.3	68.7	68.1	67.6	67.0	70.4	69.3	68.1	67.0	65.9	64.7	63.6
2.25	70.4	69.8	69.1	68.5	67.8	67.2	66.6	70.4	69.1	67.8	66.6	65.3	64.0	62.7
2.50	70.4	69.7	69.0	68.3	67.6	66.9	66.1	70.4	69.0	67.6	66.1	64.7	63.3	61.9
2.75	70.4	69.6	68.8	68.1	67.3	66.5	65.7	70.4	68.8	67.3	65.7	64.2	62.6	61.0
3.00	70.4	69.5	68.7	67.8	67.0	66.1	65.3	70.4	68.7	67.0	65.3	63.6	61.9	60.2
3.25	70.4	69.5	68.6	67.6	66.7	65.8	64.9	70.4	68.6	66.7	64.9	63.0	61.2	59.3
3.50	70.4	69.4	68.4	67.4	66.4	65.4	64.4	70.4	68.4	66.4	64.4	62.5	60.5	58.5
3.75	70.4	69.3	68.3	67.2	66.1	65.1	64.0	70.4	68.3	66.1	64.0	61.9	59.8	57.6
4.00	70.4	69.3	68.1	67.0	65.9	64.7	63.6	70.4	68.1	65.9	63.6	61.3	59.1	56.8
4.25	70.4	69.2	68.0	66.8	65.6	64.4	63.2	70.4	68.0	65.6	63.2	60.8	58.4	55.9
4.50	70.4	69.1	67.8	66.6	65.3	64.0	62.7	70.4	67.8	65.3	62.7	60.2	57.6	55.1
4.75	70.4	69.1	67.7	66.4	65.0	63.7	62.3	70.4	67.7	65.0	62.3	59.6	56.9	54.2
5.00	70.4	69.0	67.6	66.1	64.7	63.3	61.9	70.4	67.6	64.7	61.9	59.1	56.2	53.4
5.25	70.4	68.9	67.4	65.9	64.4	63.0	61.5	70.4	67.4	64.4	61.5	58.5	55.5	52.5
5.50	70.4	68.8	67.3	65.7	64.2	62.6	61.0	70.4	67.3	64.2	61.0	57.9	54.8	51.7
5.75	70.4	68.8	67.1	65.5	63.9	62.3	60.6	70.4	67.1	63.9	60.6	57.4	54.1	50.8
6.00	70.4	68.7	67.0	65.3	63.6	61.9	60.2	70.4	67.0	63.6	60.2	56.8	53.4	50.0
6.25	70.4	68.6	66.9	65.1	63.3	61.5	59.8	70.4	66.9	63.3	59.8	56.2	52.7	49.1
6.50	70.4	68.6	66.7	64.9	63.0	61.2	59.3	70.4	66.7	63.0	59.3	55.7	52.0	48.3
6.75	70.4	68.5	66.6	64.7	62.7	60.8	58.9	70.4	66.6	62.7	58.9	55.1	51.3	47.4
7.00	70.4	68.4	66.4	64.4	62.5	60.5	58.5	70.4	66.4	62.5	58.5	54.5	50.6	46.6
7.25	70.4	68.3	66.3	64.2	62.2	60.1	58.1	70.4	66.3	62.2	58.1	54.0	49.9	45.7
7.50	70.4	68.3	66.1	64.0	61.9	59.8	57.6	70.4	66.1	61.9	57.6	53.4	49.1	44.9
7.75	70.4	68.2	66.0	63.8	61.6	59.4	57.2	70.4	66.0	61.6	57.2	52.8	48.4	44.0
8.00	70.4	68.1	65.9	63.6	61.3	59.1	56.8	70.4	65.9	61.3	56.8	52.3	47.7	43.2
8.25	70.4	68.1	65.7	63.4	61.0	58.7	56.4	70.4	65.7	61.0	56.4	51.7	47.0	42.3
8.50	70.4	68.0	65.6	63.2	60.8	58.4	55.9	70.4	65.6	60.8	55.9	51.1	46.3	41.5
8.75	70.4	67.9	65.4	63.0	60.5	58.0	55.5	70.4	65.4	60.5	55.5	50.6	45.6	40.6
9.00	70.4	67.8	65.3	62.7	60.2	57.6	55.1	70.4	65.3	60.2	55.1	50.0	44.9	39.8
9.25	70.4	67.8	65.2	62.5	59.9	57.3	54.7	70.4	65.2	59.9	54.7	49.4	44.2	38.9
9.50	70.4	67.7	65.0	62.3	59.6	56.9	54.2	70.4	65.0	59.6	54.2	48.9	43.5	38.1
9.75	70.4	67.6	64.9	62.1	59.3	56.6	53.8	70.4	64.9	59.3	53.8	48.3	42.8	37.2
10.00	70.4	67.6	64.7	61.9	59.1	56.2	53.4	70.4	64.7	59.1	53.4	47.7	42.1	36.4

For gas storage water heaters on soft water with a water hardness level of 0.0 grains per gallon, Eq. 2 reduces to a constant value E_o for the efficiency for all times, which is consistent with Battelle's research findings discussed in Section 5.3.1.

Table 5-3 shows the predicted gas storage water heater efficiency as a function of the water hardness level and daily household hot water usage. This table was generated using Eq. 5 with Eq. 6 used to predict the value of b.

Figure 5-12 shows the efficiencies of gas storage water heaters operating on soft water is constant with time, whereas those units operating on unsoftened water experience significant degradation in efficiency over time.

In summary, none of the gas storage water heaters on unsoftened water made it through the entire testing period because the outlet piping system consisting of one-half inch copper pipe, a needle valve, and a solenoid valve became clogged with scale buildup. Although the system controls were tweaked throughout the testing to try to maintain constant testing conditions, the gas storage water heaters on unsoftened water all dropped out of the testing before 2.0 years of equivalent field service. In contrast, the gas storage water heaters on soft water all completed testing without difficulty when the tests were stopped at 2.3 years of equivalent field service. In addition, the average efficiency of these units dropped from 70.4 percent at the start of the test to 67.4percent at two years equivalent field service. Equations 5 and 6 can be used to predict the efficiency of gas storage water heaters as a function of water hardness and daily household hot water usage.

Table 5-4 shows the energy costs associated with operating a gas storage water heater as a function of water hardness. A fifteen year life of the water heater was assumed. The gas storage water heater using 30 grains per gallon unsoftened water costs $705 more to operate over its useful life than one using softened water.

Table 5-4. Energy costs for operating a gas storage water heater as a function of water hardness.

Cost of Natural Gas Over The Life of A Gas Storage Water Heater							
Water Hardness, grains/gallon	**0**	**5**	**10**	**15**	**20**	25	30
Water Inlet Temperature, F	71.8	71.8	71.8	71.8	71.8	71.8	71.8
Set Point Temperature, F	161.8	161.8	161.8	161.8	161.8	161.8	161.8
Life of Water Heater, Years	15	15	15	15	15	15	15
Efficiency at Beginning	70.4	70.4	70.4	70.4	70.4	70.4	70.4
Efficiency at End	70.4	66.3	62.2	58.1	54.0	49.8	45.7
Natural Gas Used, mmBtu	291.5	300.7	310.7	321.6	333.7	347.0	362.0
Natural Gas Price, $/mmBtu	$10	$10	$10	$10	$10	$10	$10
Cost of Natural Gas, $	$2,915	$3,007	$3,107	$3,216	$3,337	$3,470	$3,620
Added Cost Without Softener	$0	$92	$192	$301	$422	$555	$705

At the end of the testing the gas storage water heaters were disassembled and the scale was scraped from the inside surfaces, collected, and weighed. Table 5-5 shows the total amount of scale collected from each unit and the rate of scale buildup assuming an average family uses 50 gallons of hot water per day. The average rate of scale buildup in the gas storage water heaters on unsoftened water was about 528 gm/yr (1.16 lb/yr). The average rate of scale buildup in the gas storage water heaters on soft water was about 7 gm/yr (0.01 lb/yr), which is almost negligible. Appendices K and L contain the photos of the insides of the gas storage water heaters on softened and unsoftened water, respectively. The gas storage water heaters using unsoftened water had hard scale coating all of the hot surfaces, and it is easy to understand why the efficiency of the water heater would be impacted. However, the water heaters on soft water were almost completely free of scale buildup on the interior surfaces. This also explains why the efficiency of the water heaters on soft water did not change during the course of the testing.

Table 5-5. Hard water scale collected from the gas storage water heaters on unsoftened or softened water.

Gas Storage Water Heaters Using Unsoftened Water at 26.2 grains/gallon			
Water Heater	Inside Scale (gm)	Equiva-lent Field Service (yrs)	Scale Buildup Rate (gm/yr)
Unit 6	980	1.98	495
Unit 7	615	1.39	442
Unit 8	820	1.39	590
Unit 9	745	1.27	587

Gas Storage Water Heaters Using Softened Water at 1.2 grains/gallon			
Water Heater	Inside Scale (gm)	Equiva-lent Field Service (yrs)	Scale Buildup Rate (gm/yr)
Unit 16	15	2.32	6
Unit 17	15	2.21	7

5.4 Electric Storage Water Heaters

The electric storage water heaters chosen for these tests were residential models that had a maximum set point temperature of "Very Hot", which corresponds to a maximum water temperature of about 150°F. The average outlet water temperature for each electric storage water heater was measured every minute during the testing. The five electric storage water heaters operating with unsoftened water had an average outlet water temperature of 149.6°F, and the five electric storage water heaters operating with soft water had an average outlet temperature of 149.4°F. Since scale buildup generally increases with increasing temperature, it is important to operate both groups of water heaters with nearly identical hot water delivery temperatures. These temperatures meet this criterion.

5.4.1 Electric Storage Water Heaters on Soft Water

Water heater efficiency measurements were taken periodically over the course of testing the electric storage water heaters. For reference purposes, the equivalent field service time was determined by taking the total amount of water throughput and assuming the average U.S. household uses 50 gallons of hot water per day Paul, *et al.*, 1994). Later the results will be generalized so that predictions can be made assuming either higher or lower household usage rates.

All of the efficiency data shown on these plots is included in Appendix G for the individual water heaters. Also included in the appendix are the statistical averages, standard deviations, and 95 percent confidence intervals for each set of data.

Figure 5-13 shows the measured efficiencies of the electric storage water heaters did not change significantly over time, and averaged a constant value of 99.3 percent. Also shown on this graph, are the number of water heaters used to determine the average water heater efficiency at each point in time. At the start of the test there were five water heaters setup under identical conditions. In this case, all five water heaters survived during the entire test without any problems.

Figure 5-14 shows the 95 percent confidence interval on each of the data points using the number of water heaters, the calculated standard deviation; and a Student's t-distribution. This shows that the efficiencies of the water heaters on soft water did not change significantly over the course of the testing, and a constant efficiency of 99.3 percent is a reasonable approximation. These water heaters logged over 1.25 years of equivalent field service assuming a household uses 50 gallons of hot water per day.

In summary, the electric storage water heaters on soft water performed well throughout the entire testing period. Although the pressure regulators and needle valves were tweaked throughout the testing to maintain constant flow rates through the water heaters, the electric storage water heaters on soft water required minimal attention because the conditions were very stable. This is reflected in the efficiency data for these units which show that the efficiency remained essentially constant over the duration of the testing with the variations being within the experimental error of the instrumentation and testing protocol. Overall, the softened water appears to have done a good job of preventing scale buildup in the electric storage water heaters and piping system.

5.4.2 Electric Storage Water Heaters on Unsoftened Water

Water heater efficiency measurements were also taken for an identical set of five electric storage water heaters operating on unsoftened water. These results are also presented using an equivalent field service time determined by taking the total amount of water throughput and assuming the average U.S. household uses 50 gallons of hot water per day. Later the results will be generalized so that predictions can be made assuming either higher or lower household usage rates.

All of the efficiency data shown on these plots is included in Appendix H for the individual water heaters. Also included in the appendix are the statistical averages, standard deviations, and 95 percent confidence intervals for each set of data.

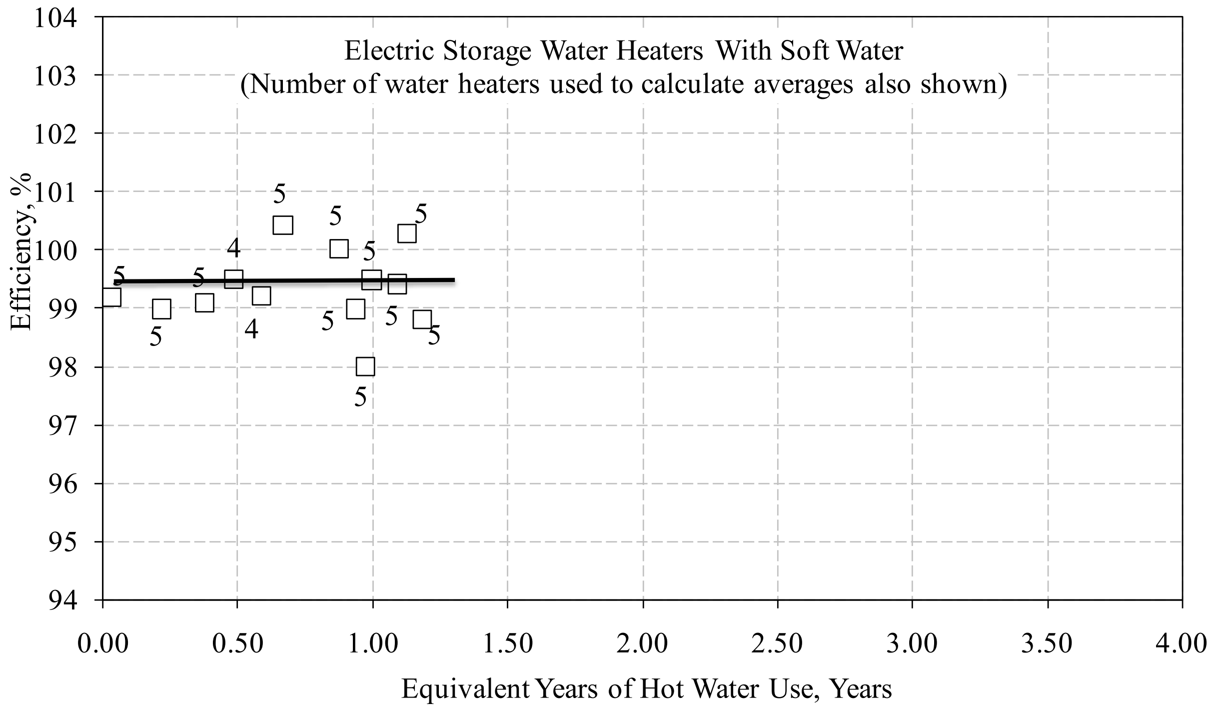


Figure 5-13. Efficiency of the electric storage water heaters using soft water.

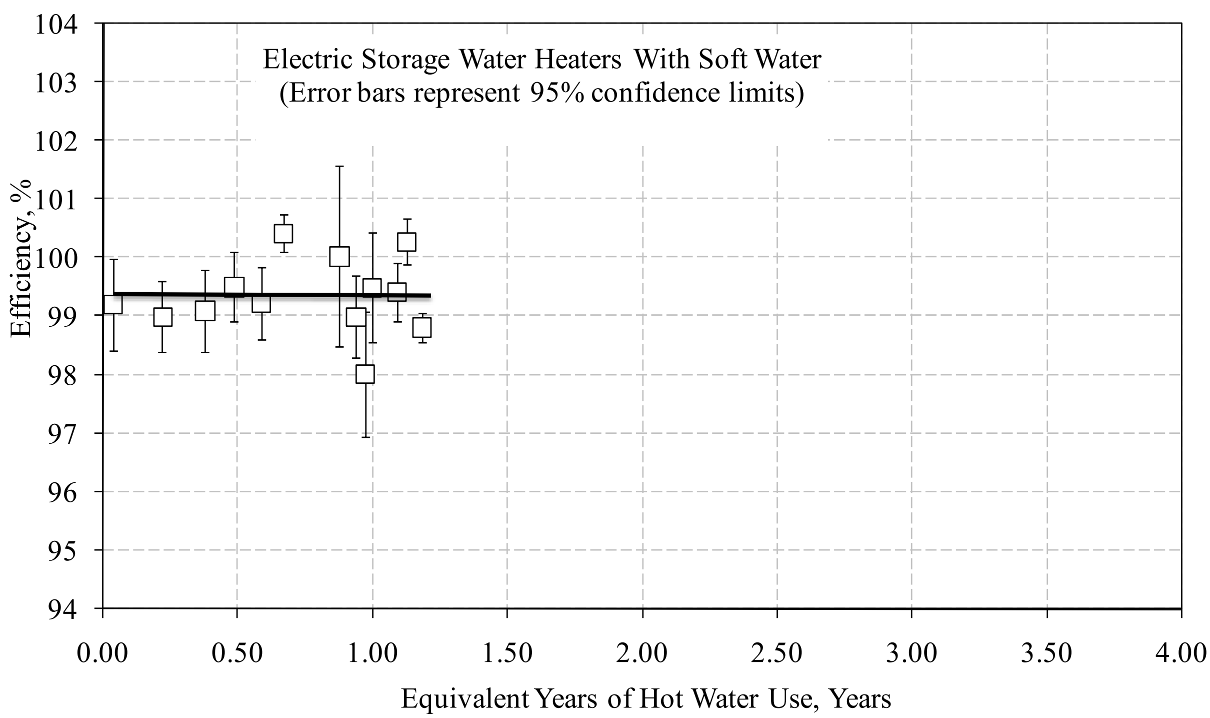


Figure 5-14. 95 percent confidence intervals for the efficiency measurements of the electric storage water heaters on soft water.

Figure 5-15 shows the measured efficiencies of the electric storage water heaters that were operated using unsoftened water. In this case, the efficiency of the water heaters did not change significantly with time because the heating element is completely submersed in the tank of water and the heat generated must enter the water. The efficiency of the electric water heaters on unsoftened water averaged 99.5 percent. The internal surfaces of the heating element will collect scale from the unsoftened water. The scale coating introduces an extra layer of resistance to heat transfer, and increases the operating temperature of the heating element, which is expected to reduce the life of the heating element. The 95% confidence intervals are shown in Figure 5-16.

At the start of the test there were five water heaters setup under identical conditions. All five water heaters were operating until about 0.4 years of equivalent hot water use. It was at this point in time that it was noticed that the flow rate in one of the electric storage water heaters on unsoftened water had been reduced to a trickle even though the control valves were completely opened. These water heaters were experiencing the same problems of scale buildup in the outlet piping system that the instantaneous water heaters experienced as explained in Section 5.2.2 of this report. By the time the testing reached an equivalent time of 0.8 years only one water heater piping system was operating, and this one clogged up shortly thereafter.

In summary, the electric storage water heaters on both softened and unsoftened water were able to maintain a constant efficiency throughout the entire test period because the heating elements were completely submerged in the water. However, the life of the heating element in unsoftened water is expected to be shorted due to scale buildup increasing the operating temperature of the element.

Table 5-6 shows the energy costs associated with operating an electric storage water heater as a function of water hardness. A fifteen year life of the water heater was assumed. The electric storage water heater using 26 grains per gallon unsoftenedwater costs same to operate over its useful life as the one using softened water because the efficiency of the submerged heating elements does not change over the life of the unit.

At the end of the testing the electric storage water heaters were disassembled and the scale was scraped from the inside surfaces, collected, and weighed. Table 5-7 shows the total amount of scale collected from each unit and the rate of scale buildup assuming an average family uses 50 gallons of hot water per day. The average rate of scale buildup in the electric storage water heaters on unsoftened water was about 907 g/yr (2.00 lb/yr). The average rate of scale buildup in the electric storage water heaters on soft water was about 14 g/yr (0.03 lb/yr), which is almost negligible. Appendices M and N contain the photos of the insides of the electric storage water heaters on softened and unsoftened water, respectively. The electric storage water heaters on unsoftened water had large amounts of loose scale in the bottom of the tank that had fallen off the heating element. However, the water heaters on soft water were almost completely free of scale buildup on the interior surfaces. In addition, at the end of testing, the outlet piping on each water heater was carefully cut into short lengths (ends taped to keep loose scale inside), and shipped to one of the Water Quality Association members for additional analysis.

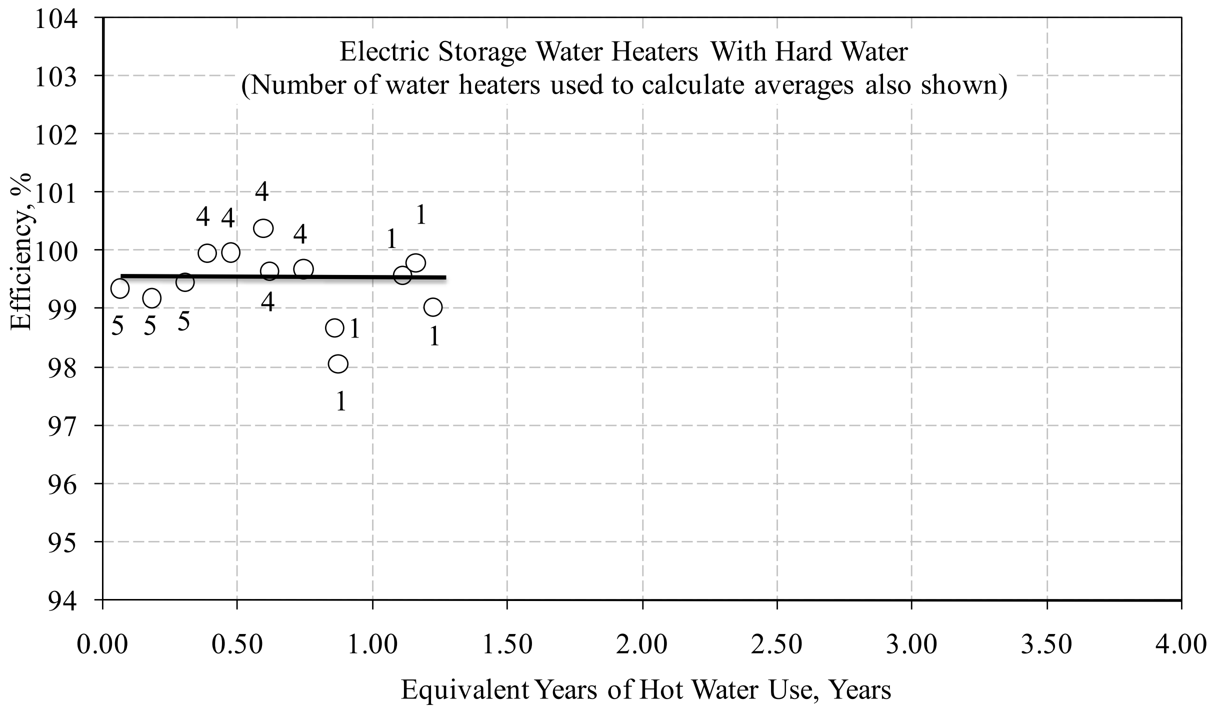


Figure 5-15. Efficiencies of the electric storage water heaters using unsoftened water.

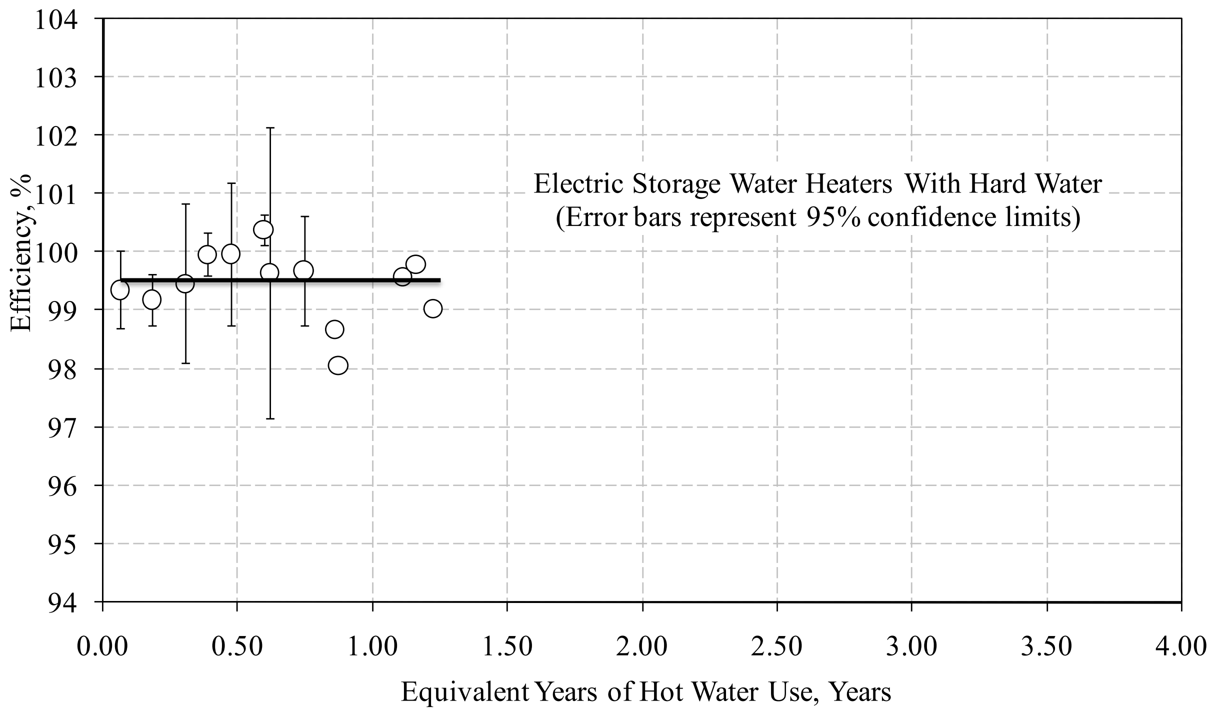


Figure 5-16. 95 percent confidence intervals for the efficiency measurements of the electric storage water heaters on unsoftened water.

Table 5-6. Energy costs for operating an electric storage water heater as a function of water hardness.

Cost of Electricity Over The Life of an Electric Storage Water Heater						
Water Hardness, grains/gallon	0	5	10	15	20	0
Water Inlet Temperature, F	60	60	60	60	60	60
Set Point Temperature, F	150	150	150	150	150	150
Life of Water Heater, Years	15	15	15	15	15	15
Efficiency at Beginning	99.4	99.4	99.4	99.4	99.4	99.4
Efficiency at End	99.4	99.4	99.4	99.4	99.4	99.4
Electricity Used, kWh	60513	60513	60513	60513	60513	60513
Electricity Price, $/kWh	$0.10	$0.10	$0.10	$0.10	$0.10	$0.10
Cost of Electricity, $	$6,051	$6,051	$6,051	$6,051	$6,051	$6,051
Added Cost Without Softener	$0	$0	$0	$0	$0	$0

Table 5-7. Hard water scale collected from each of the electric storage water heaters using either unsoftened or softened water.

Electric Storage Water Heaters Using Unsoftened Water at 26.2 grains/gallon				Electric Storage Water Heaters Using Softened Water at 1.2 grains/gallon			
Water Heater	Inside Scale (g)	Equiva-lent Field Service (yrs)	Scale Buildup Rate (g/yr)	Water Heater	Inside Scale (g)	Equiva-lent Field Service (yrs)	Scale Buildup Rate (g/yr)
Unit 21	740	1.22	607	Unit 26	15	1.23	12
Unit 22	715	0.72	993	Unit 27	20	1.16	17
Unit 23	720	0.72	1000	Unit 28	15	1.18	13
Unit 24	720	0.7	1029				

5.5 Fixtures and Appliance Test Results

5.5.1 Low Flow Showerheads

Ten low flow showerheads were installed on the hot water supply coming from the ten instantaneous gas water heaters; five were tested on unsoftened water and five were tested using softened water. These showerheads were tested for a total of seven days. At the end of the test, the showerheads using softened well water were performing nearly as well as the day they were installed. However, the showerheads using unsoftened well water had over three-fourths of their nozzles clogged at the end of the test.

The low flow showerheads on soft water each had an average of 3,663 gallons of water flow through them. Figure 5-17 shows a typical spray pattern from one of the showerheads using soft water at the end of the test.

At the end of testing, the low flow showerheads on unsoftened water each had an average of 3,203 gallons of water flow through them. Figure 5-18 shows a typical spray pattern from one of the showerheads using unsoftened water at the end of the test.

Assuming an average U.S. household size of 2.56 (2007 Census) and each person takes one shower a day using 10 gallons per shower, the number of days represented by the testing is 125 days for unsoftened water showerheads and 143 days for soft water showerheads. However, since these showerheads were operated at 140°F rather than 100°F, there is an acceleration factor of 4 associated with this temperature difference. Therefore, the showerheads operating on unsoftened water had an equivalent field service of 1.37 years, and the showerheads on soft water had an equivalent field service of 1.57 years. The unsoftened water was at approximately 26 grains per gallon, and the soft water was at approximately 0.55 grain per gallon.

Appendix R contains pictures that document the condition of the showerheads while they were being tested, at the end of the test, and after the teardown analysis.

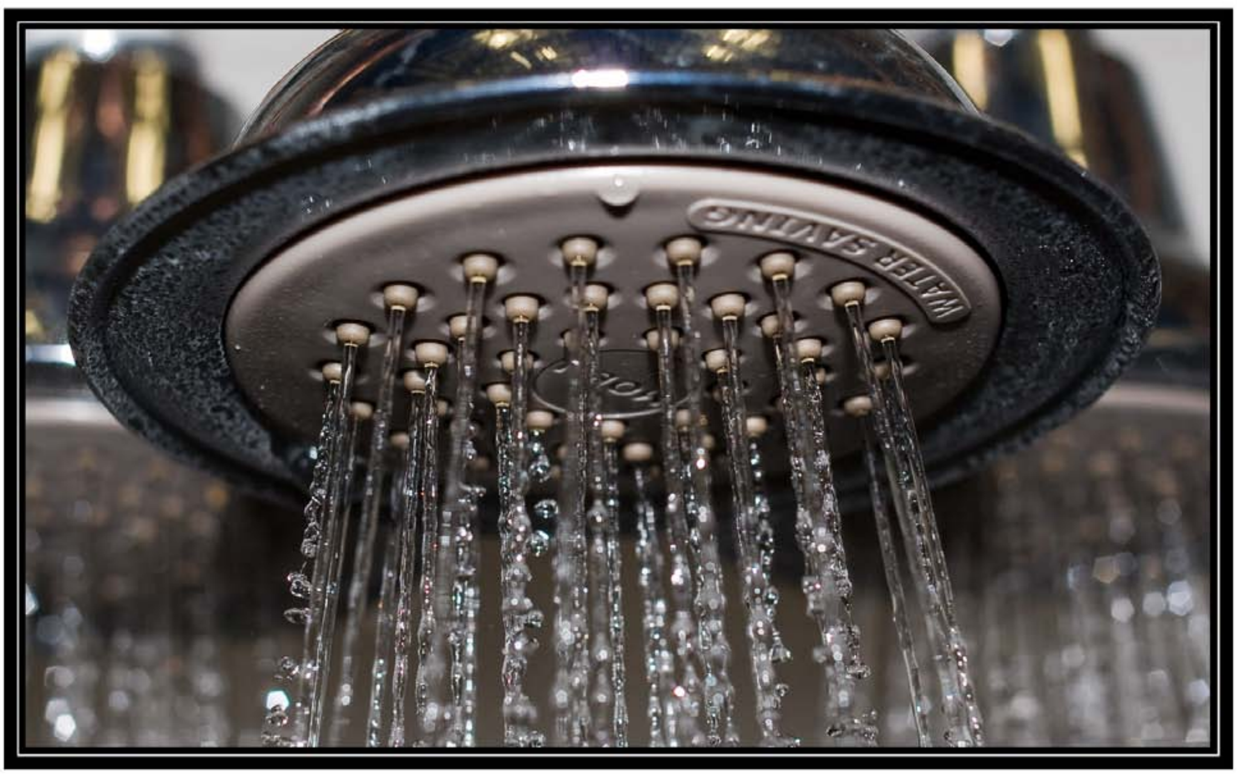


Figure 5-17. Typical spray pattern from one of the showerheads using soft water at the end of the test.

Figure 5-18. Typical spray pattern from one of the showerheads using unsoftened water at the end of the test.

5.5.2 Low Flow Faucets

After the tests with the showerheads were complete, ten low flow faucets were installed on the hot water supply coming from the ten instantaneous gas water heaters. Five low flow faucets were tested using unsoftened well water (26 grains per gallon), and five low flow faucets were tested using softened well water (0.55 grains per gallon). Figures 5-19 through 5-23 show the condition of the low flow faucet strainers after the equivalent of 19 days of water flow through the faucets assuming an average household uses about 50 gallons of hot water per day. The photos show that the low flow faucets on softened well water are relatively clean and continued to operate without problems over the period of the test. The low flow faucets on unsoftened well water showed large amounts of scale collection on the strainers, and were stopped after 19 equivalent days of testing because the specified flow rate of 1.25 gallons per minute could no longer be maintained.

At the end of the test, the faucets using softened well water were performing nearly as well as the day they were installed. However, the strainers on the faucets using unsoftened well water were almost completely clogged.

The collection of scale on the faucets using unsoftened water appears to be the result of scale breaking loose from upstream portions of the plumbing and being trapped in the strainers. Prior to installing the faucets, the instantaneous water heaters on unsoftened water had logged the equivalent of 1.6 years of hot water flow and the piping system appears to be coated with scale buildup. The instantaneous water heaters on softened well water had logged the equivalent of

2.0 years of hot water flow and yet the faucets on these heaters showed almost no scale collection on the strainers.

Figure 5-19. Photo showing the Set 1 faucet strainers at the end of the test.

Figure 5-20. Photo showing the Set 2 faucet strainers at the end of the test.

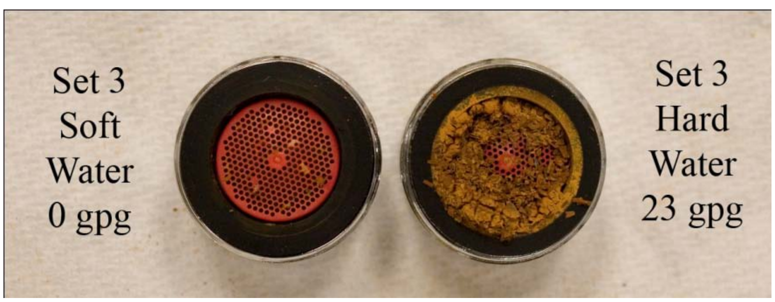


Figure 5-21. Photo showing the Set 3 faucet strainers at the end of the test.

Figure 5-22. Photo showing the Set 4 faucet strainers at the end of the test.

Figure 5-23. Photo showing the Set 5 faucet strainers at the end of the test.

5.6 Dishwashers and Clothes Washers Tested Using Unsoftened and Softened Water

Six dishwashers (Kitchenaid) and laundry washers (General Electric) were purchased to test the effect on longevity of the appliances. The electronic controls for this equipment were integrated into the automated data acquisition and control system designed for the testing. The laboratory set up of the appliances was completed with three each connected to hot unsoftened water and softened water from two gas heaters. Battelle's original intent was to use hot water generated from the ongoing water heater tests to run the dish washer and laundry washers test. However, the manufacturer's specifications on the dish washers required incoming water to be at 20 psig which was not available through the gravity feed planned earlier. With this variation, Battelle installed two 40-gal gas water heaters to supply either softened or unsoftened hot water to these appliances. This arrangement of dedicated water heaters for the appliance tests guarantees continuous availability of hot water for appliance tests and also allows a better control over the inlet temperature to the appliances. The wash and dry cycles of the dish washers and the wash cycles are controlled automatically with the units going through eight cycles every 24 hours.

The appliances are set up on a 3-hour operation cycle with automated dispensing of detergents. The clothes washers use Tide laundry detergent dispensed in amount indicated on the Tide package. The dishwashers are using Cascade laundry detergent dispensed in the amount indicated on the Cascade package.

The clothes washers are loaded with 7 lbs of restaurant hand towels. The dishwashers are loaded with eight place settings of dishes and flatware. These loadings are similar to those specified in the Department of Energy test protocols for clothes washers and dishwashers.

At the end of the 30 days of testing, the dishwashers were examined before a teardown analysis was initiated. Figure 5-24 shows the condition inside one of the dishwashers using softened water (0.55 grain per gallon) at the end of the test. The unit was almost completely free of any water scale buildup. In contrast, Figure 5-25 shows the condition inside one of the dishwashers using unsoftened water (26 grains per gallon) at the end of the test. The unit had noticeable water scale buildup on all of the interior surfaces after only 30 days of testing. Although both of the dishwashers completed the same number of wash cycles (240), the appearance of the inside of the dishwasher using unsoftened water shows that it needs to be delimed and cleaned due to the buildup of scale and deposits. On the other hand, the dishwasher using soft water looks like it could be cleaned up to look like new with just a quick wipe down.

Figure 5-24. Photos showing condition of dishwasher at the end of 30 days using soft water.

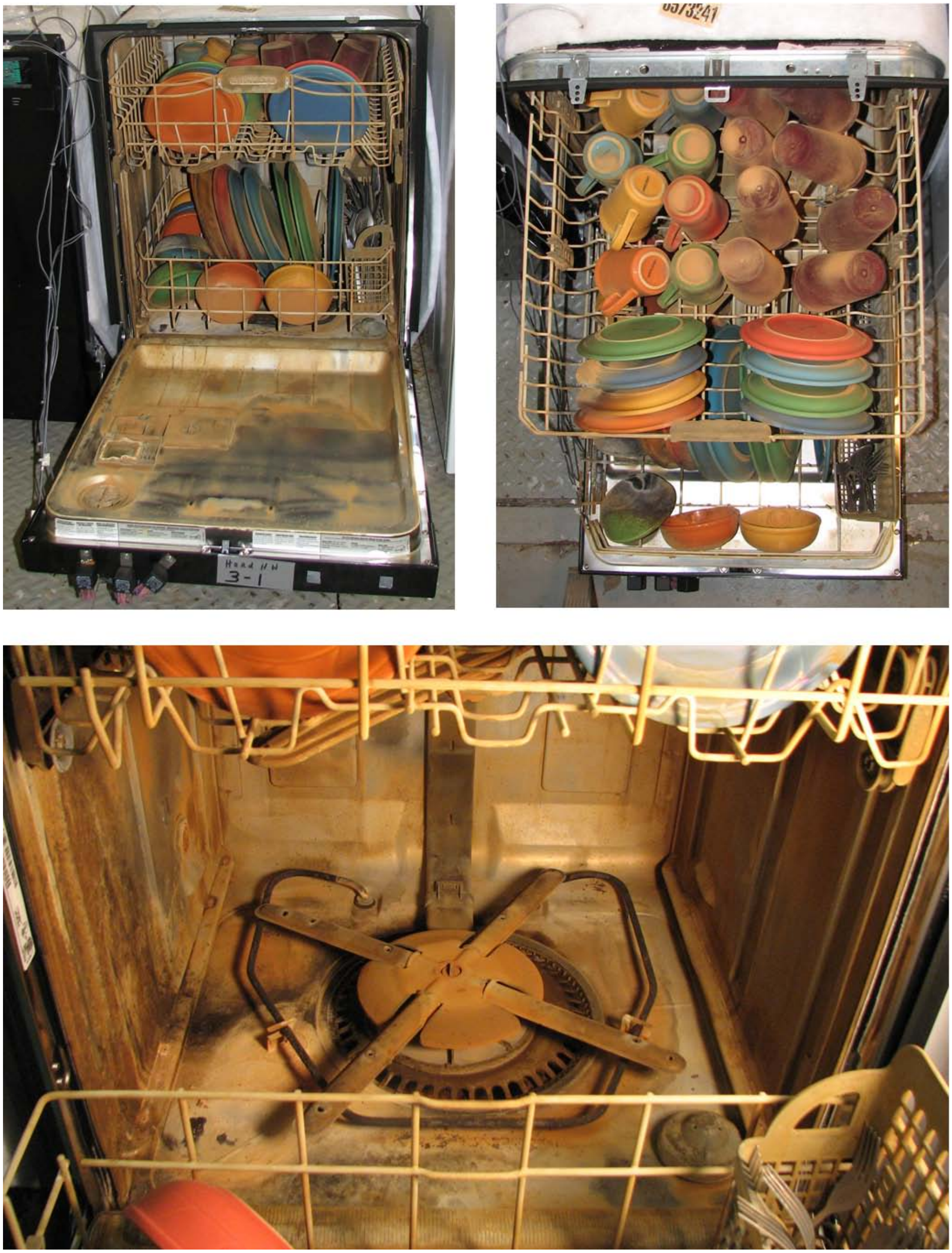


Figure 5-25. Photos showing condition of dishwasher at the end of 30 days using unsoftened water.

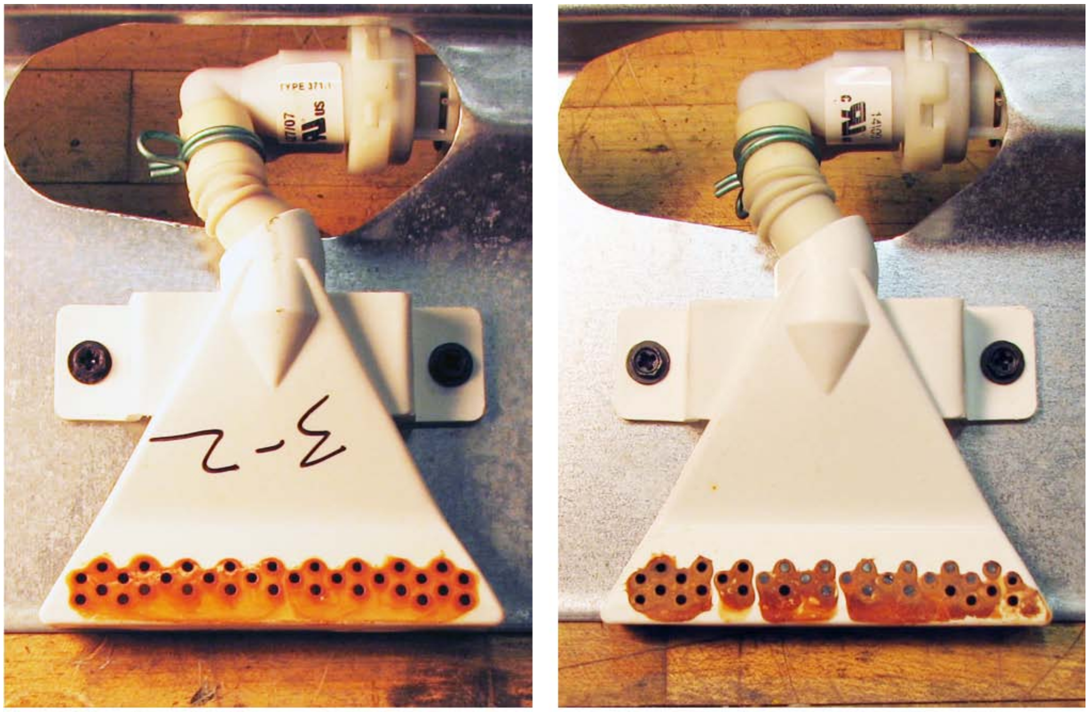
Results similar to the dishwashers were also obtained for the clothes washers. At the end of the 30 days of testing, the clothes washers were examined. Figure 5-26 shows that the clothes washers using soft water had almost no buildup of scale or deposits in the drum. In contrast, Figure 5-27 shows that clothes washers using unsoftened water had significant buildup of scale and deposits on the interior of the drum.

Figure 5-26. Drum of the laundry washer using softened water was almost completely free from water scale buildup.

Figure 5-27. Drum of the laundry washer using unsoftened water had significant water scale buildup on all of the interior surfaces.

Both of the clothes washers completed the same number of wash cycles (240), but the appearance of the inside of the clothes washer using unsoftened water shows that it needs to be delimed and cleaned due to the buildup of scale and deposits. On the other hand, the clothes washer using soft water looks like it could be cleaned up to look like new with just a quick wipe down.

A teardown analysis of the internal components of the clothes washers revealed that the spray nozzles on the clothes washers using softened water were completely open; however, the spray nozzles on the clothes washers using unsoftened water were partially clogged. Both are shown in Figure 5-28. On the clogged unit shown in the photograph, 15 of the 32 spray nozzles for the water supply to the drum were completely plugged. The plugged holes on the spray nozzles would be very difficult to clean because they are located inside the unit and cannot be seen without sticking your head inside of the drum.



Nozzles on Softened Water Nozzles on Hard Water

Figure 5-28. Laundry washer spray nozzles after 30 days of testing.

5.7 Summary of Findings on Fixtures and Appliances

The low flow showerheads, faucets, dishwashers, and clothes washers using softened water (0.55 grains per gallon) had almost no water scale buildup at the end of testing. In contrast, the identical fixtures and appliances tested using unsoftened water (26 grains per gallon) showed significant scale buildup on all interior surfaces. Furthermore, the showerheads and faucets on unsoftened water eventually became clogged to the points where the testing could no longer continue because of the reduced flow rates in these devices.

5.8 Differential Carbon Footprint

This section presents the results of the electricity consumption for the appliances testing per the protocol discussed in Section 4.3.

Figures 5-29 and 5-30, for laundry washers and dishwashers respectively, present the calculated energy consumption results. These are the per cycle energy consumption results, corrected for test and equipment disruptions, as noted in the raw data in Appendix A. This data is for the electricity consumed by the machines alone. It was combined with the energy consumption for water heating and water softening to compute the carbon footprint. (Note Battelle began by testing the Watts Up? PRO meter on only the laundry washers using unsoftened water to evaluate the Watts Up? PRO device. After a period of approximately two weeks, when the device was shown to operate as advertised and expected, testing began for the rest of the appliances. For this reason there is energy consumption data for the laundry washers using unsoftened water for the period from 7/12/2009 through 7/24/2009, but not for the other appliances.)

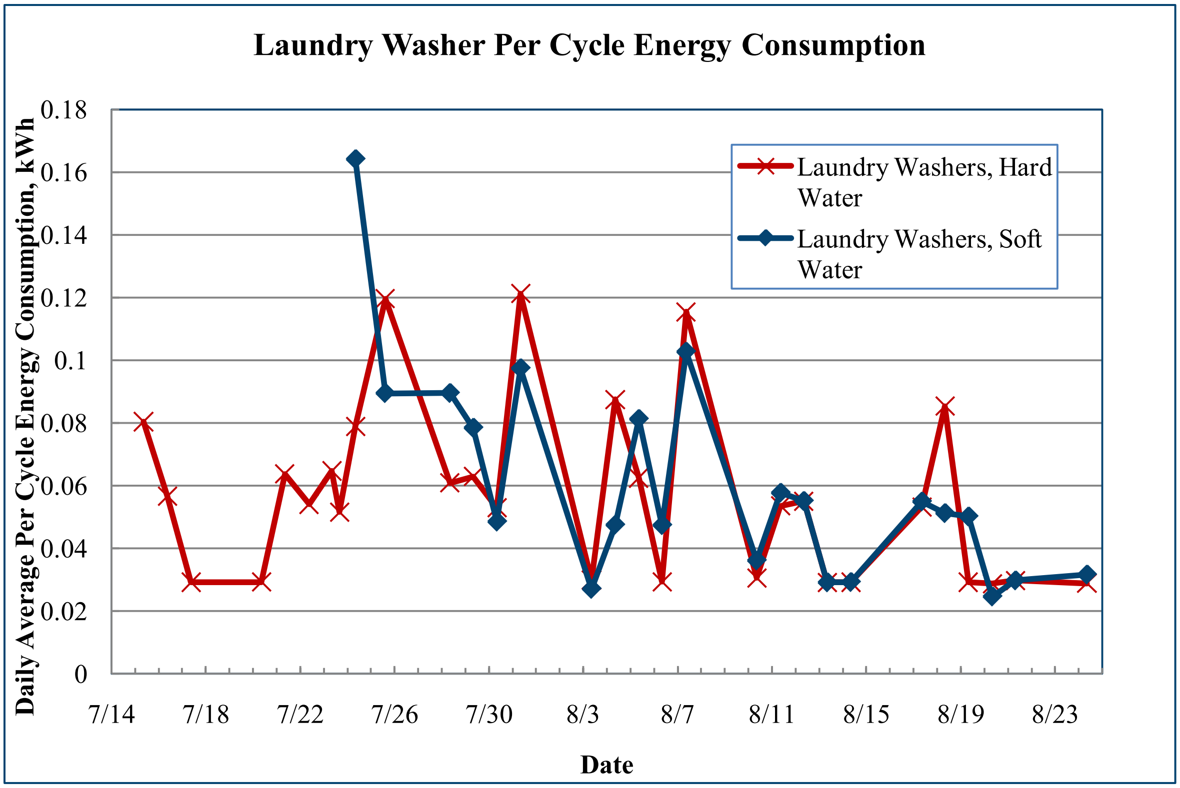


Figure 5-29. Summary of Laundry Washers Daily Average Per Cycle Energy Consumption.

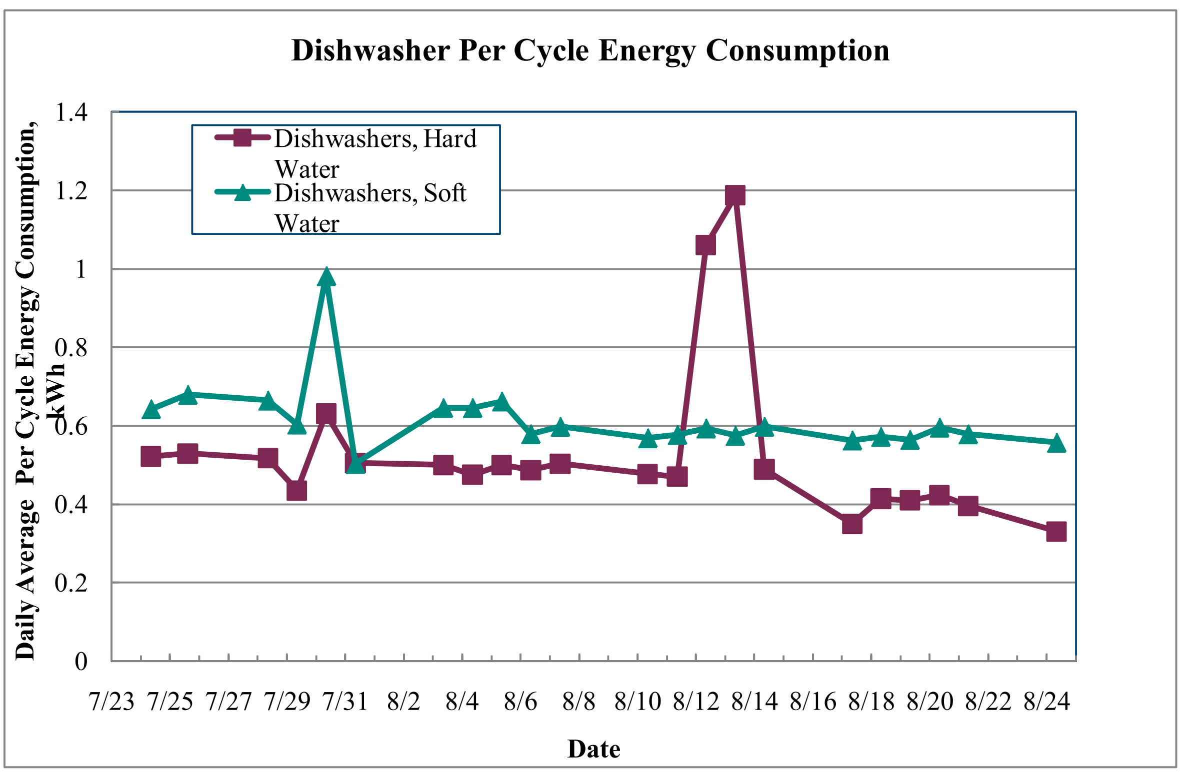


Figure 5-30. Summary of Dishwashers Daily Average Per Cycle Energy Consumption.

The peak in energy consumption between 8/12 and 8/14 was due to a water heater malfunction – the pilot light extinguished. The resulting spike in energy consumption is a result of the internal heater in the dishwasher bringing the water from ambient to operating temperature.

The electricity consumption data for the laundry washers is from the motor attached to the drum and agitator. For the dishwashers, the electricity consumption is for the motor and pump for the water dispensing system and the water heating and drying systems, which is why the electricity consumption is much higher. The inlet water temperature to each set of appliances was set to the same value.

As seen in the graphs in Figures 5-29 and 5-30, especially for the laundry washers, the electricity consumption is erratic. Despite considerable effort expended, Battelle was not able to locate a reason why the laundry washing machine energy consumption varied so greatly from day-to-day. The only useful observation that could be made is that the sets of units, unsoftened water or softened water, tended to vary in the same direction, which Battelle interpreted to mean there was some variable within the system which the test protocol had not been designed to control.

Battelle performed extensive testing of the dishwasher systems and were able to produce the graph shown in Figure 5-31. As seen, despite efforts to control system parameters, the dishwashers receiving unsoftened water and softened water performed differently. The dish-washers receiving softened water consistently showed a lag between the start of the cycle and the

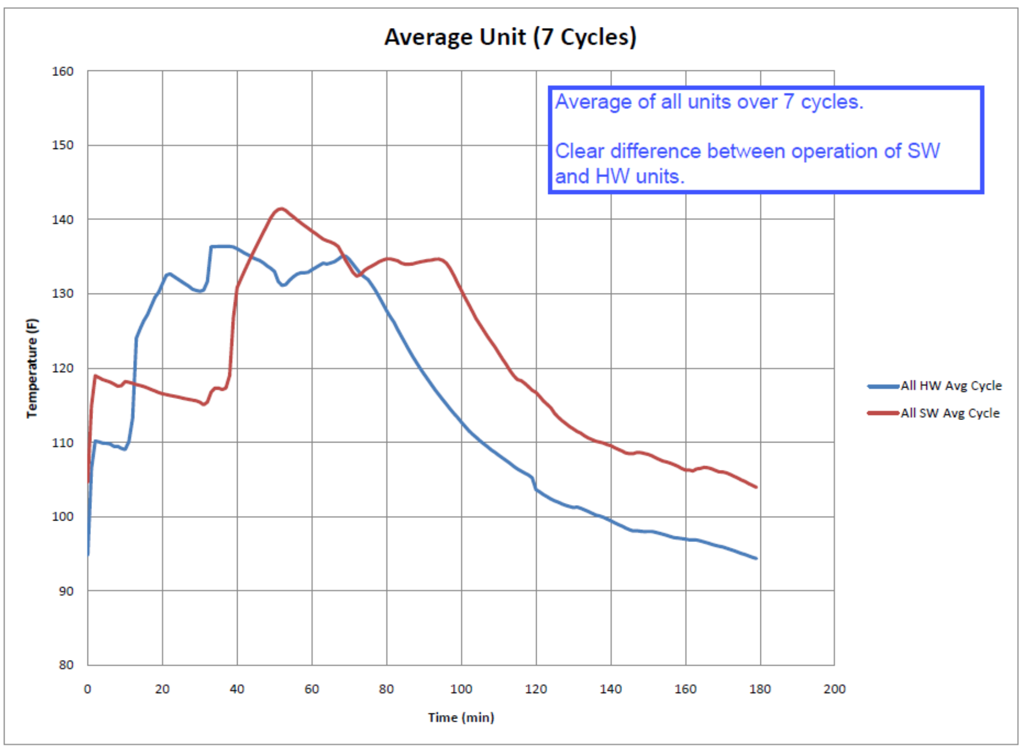


Figure 5-31. Example Dishwasher Operating Curves

initiation of the energy intensive portion of the wash cycle. Battelle believes one or more internal sensors were reacting adversely to the softened water.

After reviewing the test data and protocol, Battelle contacted both GE and KitchenAid to ask for clarifications on the appliance design characteristics, performance or environmental factors that might lead to the results seen. Battelle was unable to reach any conclusion with KitchenAid, but discussions with a GE Product Engineer (Jerrod Keppler, telephone conversation with David P. Evers, September 28, 2009) focused on the probability the line pressure was too low. The laundry washers from GE are designed to check the inlet line pressure, and when the pressure is too low they will not complete the cycle as programmed. Because the testing was automated, with each operating cycle initiated by the data logging and system control software at a specified time, the laundry machines were not allowed to wait for the line pressure to recover prior to finishing a cycle. In a home setting the machine would wait for a period for line pressure to recover and then initiate the cycle as programmed. In discussions with GE, the low electricity demand values Battelle measured correspond to the power consumption of the electronic controls (about 2 W per machine, or 0.006 kWh per cycle), while the highest values Battelle measured correspond with the values GE submitted for EnergyStar rating.

The water delivery system was designed to maintain a line pressure of 30 psig on the water heater inlet side. (The in line filters were changed when the line pressure dropped to approximately 30 pisg.) The test protocol for appliance cycles, with 30 minute offsets between the initiation of the cycle for each machine, was designed to eliminate water supply and line pressure issues.

Based on these results for water heater testing, one sample calculation of the carbon footprint savings that might be expected for natural gas water heating is presented in Table 5-8. The remaining calculations will proceed in a similar manner, and are presented in Appendix B, with the results summarized in Table 5-9.

Table 5-8. Example Carbon Footprint Calculations

	Energy Consumption	Units	Unit Carbon Footprint	Units	Carbon Footprint, kg per gallon	Purpose	Sources
Scenario:	**Water Heating - Natural gas Heating, per gallon hot water, 15 year average savings**						
Case: Unsoftened Water, 26.2 grains per gallon hardness							
Natural gas	1280	Btu/gal	0.0544	kg/SCF	0.066	Heating water	US EPA AP-42, Section 1.4
Electricity	0	MJ/gal	0.2083	kg/MJ	0		GaBi 4.3, US Power Grid Mix, TRACI GW Emissions
Total					**0.066**		
Case: Softened Water							
Natural gas	1065	Btu/gal	0.0544	kg/SCF	0.055	Heating water	
Electricity	0.006	MJ/gal	0.2083	kg/MJ	0.001	Operating softener	Softener energy use derived from Culligan data
Total					**0.056**		

The carbon footprint is dependent upon the energy consumption. Where the differences in energy consumption are large, such as with the gas storage water heater, the carbon footprint difference is also large. As can be seen in Table 5-8, most of the carbon footprint is a result of the combustion of natural gas for water heating, and not for operation of the water softening system. For the instantaneous water heater, where the system in frequently cleaned of scale, delimed, the natural gas consumption differential between the systems using softened and unsoftened water was much less, and the carbon footprint is also much less.

Table 5-9. Summary of Carbon Footprint Results

Scenario	Carbon Footprint, kg per gallon hot water		
	Case		Reduction
	Unsoftened Water	Softened Water	
Water Heating – Natural gas, Storage Type	0.066	0.056	14.8%
Water Heating – Natural gas, Instantaneous Type	0.052	0.050	4.4%

6.0 Conclusions

6.1 Instantaneous Gas Water Heaters

Reviewing the results in Table 5-2, for natural gas consumption, Battelle concludes that use of a water softener to reduce the scale forming compounds in water will result in natural gas savings. This natural gas savings will lead to direct economic savings. Because of the need to have the instantaneous water heater delimed or cleaned periodically, the economic savings can lead to recovery of the cost of a water softener and operating supplies in a period as short as months, if the inlet water is sufficiently hard. Further, the lower use of natural gas leads to reductions in the carbon footprint, see Table 5-9, in proportion to the decrease in total energy consumption. Total energy consumption accounts for both natural gas to fire the water heater and electricity to operate the softener.

6.2 Gas Storage Water Heaters

Similar to the conclusions for the instantaneous gas water heater, reviewing the results in Table 5-4, for natural gas consumption, Battelle concludes that use of a water softener to reduce the scale forming compounds in water will result in natural gas savings. Because of the much lower energy intensity of a gas storage water heater, Btu input rate per unit time and volume of water, the natural gas savings for a storage water heater are much lower than those for the instantaneous water heater, being approximately one-half the savings that might be found when using an instantaneous water heater. This energy savings will lead to direct economic savings in proportion to the reduced natural gas consumption. Further, the lower use of energy leads to reductions in the carbon footprint, see Table 5-9, in proportion to the decrease in total energy consumption. Total energy consumption accounts for both natural gas to fire the water heater and electricity to operate the softener.

6.3 Electric Water Heaters

Because of plugging of piping on the water heater outlet Battelle was unable to conduct a sufficient number of days of testing to demonstrate any changes in electricity consumption or potential cost savings for the electric storage water heaters. As discussed in Section 5.4.2, no difference in the electricity consumption between two electric storage water heaters, one receiving softened and the other unsoftened water, is expected. Given this lack of a difference in electricity consumption for water heating, the additional electricity required to operate a water softener would mean the softened water case would use more electricity than the unsoftened water case, thus the carbon footprint would be higher. However, because the electric water heater receiving softened water would be expected to have a longer life, there is expected to be cost savings supporting the use of softened water.

6.4 Fixtures and Appliances

Low flow showerheads and faucets using unsoftened water clogged in less than seven days of accelerated life testing, whereas those units using softened water made it through the test without any problems. Under the testing conditions at Battelle with high hardness of the inlet water, a water softener will significantly increase the life of faucets and fixtures.

7.0 References

New Mexico State Water Heater Efficiency Study

Paul, D. D., B.E. Ide, and P.A. Hartford, *Residential Hot Water Usage: A Review of Published Metered Studies*, GRI-94/0442, December 1994.

Appendix A
Appliance Energy Consumption Test Data

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Table A-1 Washer and Dishwasher Testing Results

Number of Cycles per Day: 8	Calculation Exception
Number of Machines Tested: 3	

Date	Time (24 hour clock)	Approximate Number of Cycles	Meter Readings, kWh				Date	Average Energy Consumption per Cycle, kWh				Notes
			Washing Machines, Hard Water	Washing Machines, Soft Water	Dishwashers, Hard Water (Sum of Two Meters)	Dishwashers, Soft Water (Sum of Two Meters)		Laundry Washers, Hard Water	Laundry Washers, Soft Water	Dishwashers, Hard Water	Dishwashers, Soft Water	
7/14/10	9:25		7.79									
7/15/10	8:40	7.75	9.66				7/15/10	0.080				
7/16/10	9:00	8.11	11.04				7/16/10	0.057				
7/17/10	8:55	7.97	11.74				7/17/10	0.029				WM-HW: Value seems low. Checking on operation
7/20/10	8:30	23.86	13.84				7/20/10	0.029				WM-HW: Value seems low. Checking on operation
7/21/10	8:20	7.94	15.36				7/21/10	0.064				
7/22/10	9:05	8.25	16.70				7/22/10	0.054				
7/23/10	8:15	7.72	18.20				7/23/10	0.065				
7/23/10	16:00	2.58	18.60	0.0001	0.0001	0.0015	7/23/10	0.052				Installation of remaining power meters (Watt Meter Pro)
7/24/10	8:20	5.44	19.89	2.68	8.52	10.5	7/24/10	0.079	0.16	0.52	0.64	

Table A-1 Washer and Dishwasher Testing Results												
Number of Cycles per Day: 8							**Calculation Exception**					
Number of Machines Tested: 3												
			Meter Readings, kWh					Average Energy Consumption per Cycle, kWh				
Date	Time (24 hour clock)	Approximate Number of Cycles	Washing Machines, Hard Water	Washing Machines, Soft Water	Dishwashers, Hard Water (Sum of Two Meters)	Dishwashers, Soft Water (Sum of Two Meters)	Date	Laundry Washers, Hard Water	Laundry Washers, Soft Water	Dishwashers, Hard Water	Dishwashers, Soft Water	Notes
7/25/10	14:30	10.06	23.5	5.38	24.49	30.99	7/25/10	0.12	0.090	0.53	0.68	System shut-down (unin-tended) Sat. 7/25 at 2:30 PM; WM HW: Values seems high.
7/28/10	8:20	7.11	24.8	7.29	32.94	45.17	7/28/10	0.061	0.090	0.52	0.66	DW HW: Value seems low. Cal-culations revised to account for system restart after delay. DW HW 3 failed to run 5 cycles after restart.
7/29/10	8:10	7.94	26.3	9.16	43.31	59.56	7/29/10	0.063	0.078	0.44	0.60	
7/30/10	8:20	8.06	27.5	10.26	55.72	78.87	7/30/10	0.053	0.049	0.63	0.98	All DW failed to cycle once at 11 P 7/29. Labview shutdown 7/29 1:45 p to 3:15 P.
7/31/10	8:15	7.97	30.4	12.59	67.8	90.9	7/31/10	0.12	0.097	0.51	0.50	DW SW: Value seems low.
8/3/10	8:25	24.06	32.5	14.49	102.9	136.2	8/3/10	0.030	0.027	0.50	0.65	WM: Values seem low.
8/4/10	8:25	8	34.6	15.63	114.3	151.7	8/4/10	0.088	0.048	0.48	0.65	
8/5/10	8:25	8	36.1	17.58	126.3	167.6	8/5/10	0.063	0.081	0.50	0.66	
8/6/10	8:15	7.94	36.8	18.71	137.9	181.4	8/6/10	0.029	0.047	0.49	0.58	SW WH Temp. Set Point adjust-ed +5F @ 11 A 8/5.

Washer and Dishwasher Testing

Calc Exception

Number of Cycles per Day 8

Number of Machines Tested 3

Date	Time (24 hour clock)	Approximate Number of Cycles	Meter Readings, kWh: Washing Machines, Hard Water	Washing Machines, Soft Water	Dishwashers, Hard Water (Sum of Two Meters)	Dishwashers, Soft Water (Sum of Two Meters)	Date	Average Energy Consumption per Cycle, kWh: Laundry Washers, Hard Water	Laundry Washers, Soft Water	Dishwashers, Hard Water	Dishwashers, Soft Water	Notes
8/7/10	8:30	8.08	39.6	21.2	150.1	195.9	8/7/10	0.12	0.10	0.50	0.60	First full day with higher SW WH Set Point.
8/10/10	8:25	23.97	41.8	23.8	184.4	236.8	8/10/10	0.031	0.036	0.48	0.57	
8/11/10	8:40	8.08	43.1	25.2	195.8	250.8	8/11/10	0.054	0.058	0.47	0.58	
8/12/10	8:15	7.86	44.4	26.5	220.8	264.8	8/12/10	0.055	0.055	1.06	0.59	HW Water Heater Pilot Out
8/13/10	8:15	8.00	45.1	27.2	249.3	278.6	8/13/10	0.029	0.029	1.19	0.58	HW Water Heater Pilot Out
8/14/10	8:10	7.97	45.8	27.9	261	292.9	8/14/10	0.029	0.029	0.49	0.60	
8/17/10	8:25	24.08	48.9	31.1	281.4	325.7	8/17/10	0.053	0.055	0.35	0.56	Labview crash from 9/15 9:30 PM through 9/16 11 AM, no cycling. DW HW value seems low.
8/18/10	7:50	7.81	50.9	32.3	291.1	339.1	8/18/10	0.085	0.051	0.41	0.57	
8/19/10	7:45	7.97	51.6	33.5	300.9	352.6	8/19/10	0.029	0.050	0.41	0.56	
8/20/10	8:05	8.11	52.3	34.1	311.2	367.1	8/20/10	0.029	0.025	0.42	0.60	
8/21/10	7:35	7.83	53.0	34.8	320.5	380.7	8/21/10	0.030	0.030	0.40	0.58	
8/24/10	8:15	24.22	55.10	37.10	344.5	137.2	8/24/10	0.029	0.032	0.33	0.56	DW SW: Meter appears to have reset between Friday morning and this morning. The value this morning was 27.4 kWh, about 1/10th the expected value.

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Appendix B
Carbon Footprint Calculations

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Table B-1 Water Heating Carbon Footprint Calculations

	Energy Consumption	Units	Unit Carboon Footprint	Units	Carbon Footprint, kg/gal	Purpose	Sources
Scenario:	Water Heating - Natural gas Heating, Storage Type, per gallon hot water, 15 year average savings						
Case:	Unsoftened Water, 26.2 grains per gallon Hardness						
Natural gas	1280	Btu/gal	0.054	kg/SCF	0.066	Heating water	US EPA AP-42, Section 1.4
Electricity	0		0.208	kg/MJ	0		GaBi 4.3, US Power Grid Mix, TRACI GW Emissions
Total					**0.066**		
Case:	Softened Water, 0 grains per gallon Hardness						
Natural gas	1065	Btu/gal	0.054	kg/SCF	0.055	Heating water	US EPA AP-42, Section 1.4
Electricity	0.006	MJ/gal	0.208	kg/MJ	0.001	Operating softener	Culligan Test Data, assuming three days between regeneration and 50 gal per day hot water demand
Total					**0.056**		
Savings, kg					0.010	kg CO2 equiv. per gallon hot water	
Savings, %					14.8		
Scenario:	Water Heating - Natural gas Heating, Instantaneous Type, per gallon hot water, 15 year average savings						
Case:	Unsoftened Water, 26.2 grains per gallon Hardness						
Natural gas	1007	Btu/gal	0.054	kg/SCF	0.052	Heating water	US EPA AP-42, Section 1.4
Electricity	0		0.208	kg/MJ	0		GaBi 4.3, US Power Grid Mix, TRACI GW Emissions
Total					**0.052**		
Case:	Softened Water, 0 grains per gallon Hardness						

	Energy Consumption	Units	Unit Carboon Footprint	Units	Carbon Footprint, kg/gal	Purpose	Sources
Natural gas	937	Btu/gal	0.054	kg/SCF	0.048	Heating water	US EPA AP-42, Section 1.4
Electricity	0.006	MJ/gal	0.208	kg/MJ	0.001	Operating softener	Culligan Test Data, assuming three days between regeneration and 50 gal per day hot water demand
Total					**0.050**		
Savings, kg					0.002	kg CO2 equiv. per gallon hot water	
Savings, %					4.4		

Appendix C
Energy Efficiency Data For
Instantaneous Gas Water Heaters Using Softened Water

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Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	2250	0.12	1087.9	79.4	878	719334	906017	79.4
2	2484	0.14	998.2	79.5	800	660727	825528	80.0
3	2171	0.12	924.7	78.7	741	606217	764645	79.3
4	1918	0.11	974.0	79.0	786	640805	811081	79.0
5	2173	0.12	1041.1	79.1	846	686083	872996	78.6
		0.12				Average		79.3
						Standard Deviation		0.53
						95% Confidence Level		0.66

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.0726	3261.2	0.0007	2.4
Nbutane	0.103	3270.7	0.0010	3.4
IsoPentane	0.0331	4010.7	0.0003	1.3
Npentane	0.0263	4019.7	0.0003	1.1
CO2	0.9834	0.0	0.0098	0.0
Ethane	2.884	1773.4	0.0288	51.1
Hexane	0.0671	4768.3	0.0007	3.2
Propane	0.5578	2523.8	0.0056	14.1
N2	0.8956	0.0	0.0089	0.0
Methane	94.5404	1012.3	0.9439	955.5
Nat Gas	100.1633		1.0000	1031.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	10349	0.57	640.7	79.4	524	423992	548020	77.4
2	10992	0.60	685.8	79.9	559	456694	584625	78.1
3	10511	0.58	744.0	79.2	597	490582	624367	78.6
4	9619	0.53	646.9	79.5	527	428468	551158	77.7
5	9603	0.53	629.5	79.9	515	418877	538608	77.8
		0.56				Average		77.9
						Standard Deviation		0.45
						95% Confidence Level		0.56

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4454	3261.2	0.0045	14.5
Nbutane	0.1256	3270.7	0.0013	4.1
IsoPentane	0.0209	4010.7	0.0002	0.8
Npentane	0.0156	4019.7	0.0002	0.6
CO2	1.0824	0.0	0.0108	0.0
Ethane	3.7162	1773.4	0.0371	65.9
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5057	2523.8	0.0051	12.8
N2	0.9752	0.0	0.0097	0.0
Methane	93.0708	1012.3	0.9300	941.4
Nat Gas	100.0776		1.0000	1045.8

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	20219	1.11	754.9	81.4	623	512032	646219	79.2
2	19844	1.09	684.1	81.6	575	465019	596430	78.0
3	20510	1.12	628.6	80.5	524	421556	543529	77.6
4	19484	1.07	561.1	80.8	469	377675	486479	77.6
5	19784	1.08	693.4	81.2	585	469270	606802	77.3
		1.09				Average		77.9
						Standard Deviation		0.76
						95% Confidence Level		0.94

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4484	3261.2	0.0046	14.9
Nbutane	0.1005	3270.7	0.0010	3.3
IsoPentane	0.0178	4010.7	0.0002	0.7
Npentane	0.0123	4019.7	0.0001	0.5
CO2	0.8692	0.0	0.0088	0.0
Ethane	3.279	1773.4	0.0333	59.1
Hexane	0.1058	4768.3	0.0011	5.1
Propane	0.4631	2523.8	0.0047	11.9
N2	1.5643	0.0	0.0159	0.0
Methane	91.5494	1012.3	0.9303	941.7
Nat Gas	98.4098		1.0000	1037.3

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	22354	1.22	2135.0	81.2	1763	1444118	1841683	78.4
2	21795	1.19	1950.4	81.4	1619	1322642	1691256	78.2
3	22303	1.22	1793.4	80.4	1477	1201272	1542919	77.9
4	21088	1.16	1604.7	80.8	1324	1079634	1383090	78.1
5	21764	1.19	1980.4	81.4	1651	1342083	1724684	77.8
		1.20				Average		78.1
						Standard Deviation		0.25
						95% Confidence Level		0.31

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3275	3261.2	0.0033	10.8
Nbutane	0.1116	3270.7	0.0011	3.7
IsoPentane	0.0354	4010.7	0.0004	1.4
Npentane	0.0268	4019.7	0.0003	1.1
CO2	0.7372	0.0	0.0074	0.0
Ethane	3.6925	1773.4	0.0373	66.1
Hexane	0.1274	4768.3	0.0013	6.1
Propane	0.5419	2523.8	0.0055	13.8
N2	1.3181	0.0	0.0133	0.0
Methane	92.2024	1012.3	0.9302	941.7
Nat Gas	99.1208		1.0000	1044.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	26580	1.46	2018.3	80.9	1657	1359502	1723197	78.9
2	25642	1.41	1833.9	81.1	1512	1238443	1572404	78.8
3	25842	1.42	1682.2	80.1	1375	1122315	1429931	78.5
4	24240	1.33	1499.2	80.5	1230	1005862	1279138	78.6
5	25673	1.41	1861.8	80.9	1544	1254775	1605682	78.1
		1.40				Average		78.6
						Standard Deviation		0.29
						95% Confidence Level		0.36

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3272	3261.2	0.0033	10.9
Nbutane	0.1386	3270.7	0.0014	4.6
IsoPentane	0.0362	4010.7	0.0004	1.5
Npentane	0.0274	4019.7	0.0003	1.1
CO2	0.6522	0.0	0.0066	0.0
Ethane	3.2888	1773.4	0.0335	59.4
Hexane	0.0423	4768.3	0.0004	2.1
Propane	0.6432	2523.8	0.0065	16.5
N2	1.4818	0.0	0.0151	0.0
Methane	91.5778	1012.3	0.9324	943.9
Nat Gas	98.2155		1.0000	1039.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	32715	1.79	1136.8	81.0	941	766686	982773	78.0
2	31821	1.74	1642.8	81.5	1339	1115128	1398441	79.7
3	30959	1.70	948.2	80.2	774	633241	808360	78.3
4	29871	1.64	1907.0	81.1	1579	1288703	1649095	78.1
5	31326	1.72	1044.2	80.8	864	703120	902355	77.9
		1.72				Average		78.4
						Standard Deviation		0.75
						95% Confidence Level		0.93

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3357	3261.2	0.0034	10.9
Nbutane	0.1173	3270.7	0.0012	3.8
IsoPentane	0.0274	4010.7	0.0003	1.1
Npentane	0.0228	4019.7	0.0002	0.9
CO2	0.7228	0.0	0.0072	0.0
Ethane	4.1233	1773.4	0.0412	73.1
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5975	2523.8	0.0060	15.1
N2	1.7025	0.0	0.0170	0.0
Methane	92.2152	1012.3	0.9223	933.7
Nat Gas	99.9843		1.0000	1044.4

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	37511	2.06	1283.1	80.5	1062	860647	1103664	78.0
2	39035	2.14	1932.9	81.6	1572	1313529	1633672	80.4
3	36031	1.97	1614.9	80.2	1297	1079131	1347884	80.1
4	37024	2.03	1639.2	80.9	1332	1104422	1384257	79.8
5	35722	1.96	1174.5	80.7	966	789468	1003898	78.6
		2.03				Average		79.4
						Standard Deviation		1.02
						95% Confidence Level		1.27

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3313	3261.2	0.0033	10.9
Nbutane	0.1103	3270.7	0.0011	3.6
IsoPentane	0.0337	4010.7	0.0003	1.4
Npentane	0.0246	4019.7	0.0002	1.0
CO2	0.7128	0.0	0.0072	0.0
Ethane	3.6145	1773.4	0.0365	64.7
Hexane	0.038	4768.3	0.0004	1.8
Propane	0.6151	2523.8	0.0062	15.7
N2	1.5846	0.0	0.0160	0.0
Methane	92.0332	1012.3	0.9287	940.1
Nat Gas	99.0981		1.0000	1039.2

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	44319	2.43	1925.6	79.0	1540	1267640	1641457	77.2
2	45317	2.48	1896.7	79.2	1494	1251551	1592427	78.6
3	42564	2.33	1807.7	78.3	1418	1178309	1511420	78.0
4	43666	2.39	1907.3	78.6	1506	1248830	1605217	77.8
5	41547	2.28	1744.3	79.0	1383	1148523	1474114	77.9
		2.38				Average		77.9
						Standard Deviation		0.49
						95% Confidence Level		0.60

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4523	3261.2	0.0045	14.8
Nbutane	0.1209	3270.7	0.0012	4.0
IsoPentane	0.0323	4010.7	0.0003	1.3
Npentane	0.0249	4019.7	0.0003	1.0
CO2	0.6957	0.0	0.0070	0.0
Ethane	5.4171	1773.4	0.0544	96.5
Hexane	0.0894	4768.3	0.0009	4.3
Propane	0.6161	2523.8	0.0062	15.6
N2	0.8054	0.0	0.0081	0.0
Methane	91.3012	1012.3	0.9171	928.4
Nat Gas	99.5553		1.0000	1065.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	47144	2.58	2825.0	78.3	2246	1842763	2375728	77.6
2	48096	2.64	2778.6	78.5	2162	1816711	2287151	79.4
3	45893	2.51	3329.4	77.6	2562	2152053	2710131	79.4
4	46463	2.55	2796.4	78.0	2180	1816967	2306194	78.8
5	44524	2.44	2977.6	78.3	2319	1943166	2453054	79.2
		2.54				Average		78.9
						Standard Deviation		0.78
						95% Confidence Level		0.97

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3874	3261.2	0.0039	12.8
Nbutane	0.1226	3270.7	0.0012	4.1
IsoPentane	0.0279	4010.7	0.0003	1.1
Npentane	0.0208	4019.7	0.0002	0.8
CO2	0.6713	0.0	0.0068	0.0
Ethane	4.9807	1773.4	0.0506	89.8
Hexane	0.0304	4768.3	0.0003	1.5
Propane	0.5282	2523.8	0.0054	13.6
N2	0.8214	0.0	0.0084	0.0
Methane	90.775	1012.3	0.9228	934.2
Nat Gas	98.3657		1.0000	1057.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	49027	2.69	1883.3	78.1	1497	1225683	1559898	78.6
2	49948	2.74	1852.4	78.3	1441	1208894	1501738	80.5
3	48113	2.64	2219.6	77.7	1708	1435852	1779466	80.7
4	48327	2.65	1864.3	78.0	1453	1211584	1514242	80.0
5	46509	2.55	1985.1	78.3	1546	1295455	1610670	80.4
		2.65				Average		80.0
						Standard Deviation		0.86
						95% Confidence Level		1.06

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3796	3261.2	0.0039	12.7
Nbutane	0.117	3270.7	0.0012	3.9
IsoPentane	0.0321	4010.7	0.0003	1.3
Npentane	0.0226	4019.7	0.0002	0.9
CO2	0.6884	0.0	0.0071	0.0
Ethane	2.6241	1773.4	0.0270	47.9
Hexane	0.0749	4768.3	0.0008	3.7
Propane	0.5248	2523.8	0.0054	13.6
N2	0.766	0.0	0.0079	0.0
Methane	92.0118	1012.3	0.9462	957.9
Nat Gas	97.2413		1.0000	1042.0

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	56288	3.08	1611.3	77.3	1243	1037998	1325451	78.3
2	57106	3.13	1600.0	77.5	1236	1032479	1317987	78.3
3	56664	3.10	1891.9	76.8	1445	1210268	1540851	78.5
4	55521	3.04	1600.8	76.9	1247	1026036	1329717	77.2
5	54177	2.97	1712.3	77.6	1326	1107259	1413957	78.3
		3.07				Average		78.1
						Standard Deviation		0.55
						95% Confidence Level		0.69

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3744	3261.2	0.0038	12.4
Nbutane	0.104	3270.7	0.0011	3.4
IsoPentane	0.0251	4010.7	0.0003	1.0
Npentane	0.0195	4019.7	0.0002	0.8
CO2	0.7216	0.0	0.0073	0.0
Ethane	5.8744	1773.4	0.0595	105.5
Hexane	0.0846	4768.3	0.0009	4.1
Propane	0.5996	2523.8	0.0061	15.3
N2	0.8326	0.0	0.0084	0.0
Methane	90.0902	1012.3	0.9125	923.8
Nat Gas	98.726		1.0000	1066.3

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	58663	3.21	2375.2	77.2	1829	1526572	1943285	78.6
2	59486	3.26	2380.0	77.4	1831	1534265	1945410	78.9
3	59437	3.26	2773.0	77.0	2121	1777864	2253530	78.9
4	57900	3.17	2378.8	77.1	1830	1527021	1944347	78.5
5	56698	3.11	2520.6	77.6	1946	1628410	2067596	78.8
		3.20				Average		78.7
						Standard Deviation		0.17
						95% Confidence Level		0.21

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4151	3261.2	0.0041	13.3
Nbutane	0.1542	3270.7	0.0015	5.0
IsoPentane	0.0389	4010.7	0.0004	1.5
Npentane	0.0289	4019.7	0.0003	1.1
CO2	0.7896	0.0	0.0078	0.0
Ethane	4.8028	1773.4	0.0472	83.6
Hexane	0.1743	4768.3	0.0017	8.2
Propane	0.6478	2523.8	0.0064	16.1
N2	0.8554	0.0	0.0084	0.0
Methane	93.942	1012.3	0.9224	933.7
Nat Gas	101.849		1.0000	1062.5

Appendix D
Energy Efficiency Data For
Instantaneous Gas Water Heaters Using Unsoftened Water

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Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	2156	0.12	977.8	80.4	781	654779	805922	81.2
2	2177	0.12	860.5	80.9	694	579592	716146	80.9
3	2154	0.12	878.6	80.7	724	590274	747103	79.0
4	2167	0.12	873.5	80.0	716	582222	738848	78.8
5	2216	0.12	922.3	80.1	746	615244	769805	79.9
		0.12				Average		80.0
						Standard Deviation		1.10
						95% Confidence Level		1.37

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.0726	3261.2	0.0007	2.4
Nbutane	0.103	3270.7	0.0010	3.4
IsoPentane	0.0331	4010.7	0.0003	1.3
Npentane	0.0263	4019.7	0.0003	1.1
CO2	0.9834	0.0	0.0098	0.0
Ethane	2.884	1773.4	0.0288	51.1
Hexane	0.0671	4768.3	0.0007	3.2
Propane	0.5578	2523.8	0.0056	14.1
N2	0.8956	0.0	0.0089	0.0
Methane	94.5404	1012.3	0.9439	955.5
Nat Gas	100.1633		1.0000	1031.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	10753	0.59	707.9	79.8	583	470568	609725	77.2
2	9287	0.51	657.0	80.3	545	439395	569983	77.1
3	11052	0.61	290.2	80.7	247	195128	258323	75.5
4	8843	0.48	396.1	80.5	330	265597	345127	77.0
5	10837	0.59	450.7	80.2	371	301095	388007	77.6
		0.56				Average		76.9
						Standard Deviation		0.78
						95% Confidence Level		0.97

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4454	3261.2	0.0045	14.5
Nbutane	0.1256	3270.7	0.0013	4.1
IsoPentane	0.0209	4010.7	0.0002	0.8
Npentane	0.0156	4019.7	0.0002	0.6
CO2	1.0824	0.0	0.0108	0.0
Ethane	3.7162	1773.4	0.0371	65.9
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5057	2523.8	0.0051	12.8
N2	0.9752	0.0	0.0097	0.0
Methane	93.0708	1012.3	0.9300	941.4
Nat Gas	100.0776		1.0000	1045.8

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	12242	0.67	701.7	78.7	576	460067	599388	76.8
2	10713	0.59	672.5	79.0	553	442657	575454	76.9
3	11665	0.64	288.5	79.3	249	190570	259110	73.5
4	9658	0.53	369.6	78.6	311	242075	323628	74.8
5	11813	0.65	455.9	79.1	373	300511	388145	77.4
		0.61				Average		75.9
						Standard Deviation		1.65
						95% Confidence Level		2.04

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3964	3261.2	0.0040	13.1
Nbutane	0.1087	3270.7	0.0011	3.6
IsoPentane	0.0198	4010.7	0.0002	0.8
Npentane	0.0141	4019.7	0.0001	0.6
CO2	1.0316	0.0	0.0104	0.0
Ethane	3.4285	1773.4	0.0347	61.5
Hexane	0.1199	4768.3	0.0012	5.8
Propane	0.4487	2523.8	0.0045	11.5
N2	1.1216	0.0	0.0113	0.0
Methane	92.198	1012.3	0.9324	943.8
Nat Gas	98.8873		1.0000	1040.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	18516	1.01	539.1	81.5	467	365836	484405	75.5
2	17268	0.95	501.6	81.2	433	339206	449138	75.5
3	17436	0.96	645.4	80.9	562	435127	582945	74.6
4	17008	0.93	749.3	79.8	641	498047	664889	74.9
5	16666	0.91	426.7	81.7	373	290317	386901	75.0
		0.95				Average		75.1
						Standard Deviation		0.39
						95% Confidence Level		0.48

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4484	3261.2	0.0046	14.9
Nbutane	0.1005	3270.7	0.0010	3.3
IsoPentane	0.0178	4010.7	0.0002	0.7
Npentane	0.0123	4019.7	0.0001	0.5
CO2	0.8692	0.0	0.0088	0.0
Ethane	3.279	1773.4	0.0333	59.1
Hexane	0.1058	4768.3	0.0011	5.1
Propane	0.4631	2523.8	0.0047	11.9
N2	1.5643	0.0	0.0159	0.0
Methane	91.5494	1012.3	0.9303	941.7
Nat Gas	98.4098		1.0000	1037.3

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	19993	1.10	1477.0	81.2	1264	999151	1320412	75.7
2	18643	1.02	1375.2	81.3	1179	931449	1231619	75.6
3	19216	1.05	1780.1	81.1	1542	1202385	1610820	74.6
4	18999	1.04	1991.1	78.3	1673	1299096	1747666	74.3
5	17843	0.98	1177.3	81.4	1021	798496	1066567	74.9
		1.04				Average		75.0
						Standard Deviation		0.60
						95% Confidence Level		0.74

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3275	3261.2	0.0033	10.8
Nbutane	0.1116	3270.7	0.0011	3.7
IsoPentane	0.0354	4010.7	0.0004	1.4
Npentane	0.0268	4019.7	0.0003	1.1
CO2	0.7372	0.0	0.0074	0.0
Ethane	3.6925	1773.4	0.0373	66.1
Hexane	0.1274	4768.3	0.0013	6.1
Propane	0.5419	2523.8	0.0055	13.8
N2	1.3181	0.0	0.0133	0.0
Methane	92.2024	1012.3	0.9302	941.7
Nat Gas	99.1208		1.0000	1044.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	22397	1.23	1018.2	80.2	865	680584	899556	75.7
2	20900	1.15	951.1	80.3	809	636569	841319	75.7
3	22118	1.21	1269.6	80.4	1088	850329	1131465	75.2
4	22423	1.23	1528.4	77.3	1271	984725	1321776	74.5
5	19942	1.09	975.0	79.7	843	647235	876678	73.8
		1.18				Average		75.0
						Standard Deviation		0.79
						95% Confidence Level		0.98

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3272	3261.2	0.0033	10.9
Nbutane	0.1386	3270.7	0.0014	4.6
IsoPentane	0.0362	4010.7	0.0004	1.5
Npentane	0.0274	4019.7	0.0003	1.1
CO2	0.6522	0.0	0.0066	0.0
Ethane	3.2888	1773.4	0.0335	59.4
Hexane	0.0423	4768.3	0.0004	2.1
Propane	0.6432	2523.8	0.0065	16.5
N2	1.4818	0.0	0.0151	0.0
Methane	91.5778	1012.3	0.9324	943.9
Nat Gas	98.2155		1.0000	1039.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	25873	1.42	1029.8	78.4	859	672186	897133	74.9
2	23618	1.29	1169.4	78.3	976	762612	1019327	74.8
3	25406	1.39	1297.2	77.8	1096	840398	1144654	73.4
4	26939	1.48	1564.2	76.6	1316	997827	1374420	72.6
5	22127	1.21	637.1	68.3	507	362224	529507	68.4
		1.36				Average		72.8
						Standard Deviation		2.66
						95% Confidence Level		3.30

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3357	3261.2	0.0034	10.9
Nbutane	0.1173	3270.7	0.0012	3.8
IsoPentane	0.0274	4010.7	0.0003	1.1
Npentane	0.0228	4019.7	0.0002	0.9
CO2	0.7228	0.0	0.0072	0.0
Ethane	4.1233	1773.4	0.0412	73.1
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5975	2523.8	0.0060	15.1
N2	1.7025	0.0	0.0170	0.0
Methane	92.2152	1012.3	0.9223	933.7
Nat Gas	99.9843		1.0000	1044.4

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	30044	1.65	1035.8	79.0	870	681825	904132	75.4
2	28078	1.54	999.9	80.1	839	667104	871915	76.5
3	29602	1.62	536.3	56.4	363	252052	377241	66.8
4	29542	1.62	501.8	70.8	408	295881	424007	69.8
5	23496	1.29	495.3	44.0	247	181422	256690	70.7
		1.54				Average		71.8
						Standard Deviation		4.04
						95% Confidence Level		5.02

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3313	3261.2	0.0033	10.9
Nbutane	0.1103	3270.7	0.0011	3.6
IsoPentane	0.0337	4010.7	0.0003	1.4
Npentane	0.0246	4019.7	0.0002	1.0
CO2	0.7128	0.0	0.0072	0.0
Ethane	3.6145	1773.4	0.0365	64.7
Hexane	0.038	4768.3	0.0004	1.8
Propane	0.6151	2523.8	0.0062	15.7
N2	1.5846	0.0	0.0160	0.0
Methane	92.0332	1012.3	0.9287	940.1
Nat Gas	99.0981		1.0000	1039.2

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	31524	1.73	107.0	78.7	87.0	70170	92732	75.7
2	Misread							
3	30538	1.67	95.7	77.6	79.0	61890	84205	73.5
4	30894	1.69	116.4	72.5	88.0	70268	93798	74.9
5	Low flow							
		1.70				Average		74.7
						Standard Deviation		1.10
						95% Confidence Level		2.74

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4523	3261.2	0.0045	14.8
Nbutane	0.1209	3270.7	0.0012	4.0
IsoPentane	0.0323	4010.7	0.0003	1.3
Npentane	0.0249	4019.7	0.0003	1.0
CO2	0.6957	0.0	0.0070	0.0
Ethane	5.4171	1773.4	0.0544	96.5
Hexane	0.0894	4768.3	0.0009	4.3
Propane	0.6161	2523.8	0.0062	15.6
N2	0.8054	0.0	0.0081	0.0
Methane	91.3012	1012.3	0.9171	928.4
Nat Gas	99.5553		1.0000	1065.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	34228	1.88	2703.8	78.1	2155	1759047	2280226	77.1
2	32902	1.80	3514.7	79.5	2848	2326428	3013372	77.2
3	32990	1.81	2451.7	77.2	1988	1576226	2103071	74.9
4	Low flow							
5	Low flow							
		1.83				Average		76.4
						Standard Deviation		1.28
						95% Confidence Level		3.19

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3874	3261.2	0.0039	12.8
Nbutane	0.1226	3270.7	0.0012	4.1
IsoPentane	0.0279	4010.7	0.0003	1.1
Npentane	0.0208	4019.7	0.0002	0.8
CO2	0.6713	0.0	0.0068	0.0
Ethane	4.9807	1773.4	0.0506	89.8
Hexane	0.0304	4768.3	0.0003	1.5
Propane	0.5282	2523.8	0.0054	13.6
N2	0.8214	0.0	0.0084	0.0
Methane	90.775	1012.3	0.9228	934.2
Nat Gas	98.3657		1.0000	1057.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	36024	1.97	1796.2	77.8	1448	1163339	1508369	77.1
2	35286	1.93	2384.2	79.3	1962	1574540	2043933	77.0
3	34639	1.90	1649.7	76.8	1325	1055947	1380682	76.5
4	Low flow							
5	Low flow							
		1.94				Average		76.9
						Standard Deviation		0.35
						95% Confidence Level		0.87

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3796	3261.2	0.0039	12.7
Nbutane	0.117	3270.7	0.0012	3.9
IsoPentane	0.0321	4010.7	0.0003	1.3
Npentane	0.0226	4019.7	0.0002	0.9
CO2	0.6884	0.0	0.0071	0.0
Ethane	2.6241	1773.4	0.0270	47.9
Hexane	0.0749	4768.3	0.0008	3.7
Propane	0.5248	2523.8	0.0054	13.6
N2	0.766	0.0	0.0079	0.0
Methane	92.0118	1012.3	0.9462	957.9
Nat Gas	97.2413		1.0000	1042.0

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	43160	2.36	1721.6	75.5	1344	1082101	1433151	75.5
2	Low flow							
3	41061	2.25	1532.8	75.8	1230	968016	1311589	73.8
4	Low flow							
5	Low flow							
		2.31				Average		74.7
						Standard Deviation		1.20
						95% Confidence Level		10.80

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.3744	3261.2	0.0038	12.4
Nbutane	0.104	3270.7	0.0011	3.4
IsoPentane	0.0251	4010.7	0.0003	1.0
Npentane	0.0195	4019.7	0.0002	0.8
CO2	0.7216	0.0	0.0073	0.0
Ethane	5.8744	1773.4	0.0595	105.5
Hexane	0.0846	4768.3	0.0009	4.1
Propane	0.5996	2523.8	0.0061	15.3
N2	0.8326	0.0	0.0084	0.0
Methane	90.0902	1012.3	0.9125	923.8
Nat Gas	98.726		1.0000	1066.3

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	45748	2.51	2588.8	73.6	1991.00	1588002	2115407	75.1
2	Low flow							
3	43226	2.37	2165.7	75.2	1720.00	1356630	1827474	74.2
4	Low flow							
5	Low flow							
		2.44				Average		74.7
						Standard Deviation		0.59
						95% Confidence Level		5.29

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.4151	3261.2	0.0041	13.3
Nbutane	0.1542	3270.7	0.0015	5.0
IsoPentane	0.0389	4010.7	0.0004	1.5
Npentane	0.0289	4019.7	0.0003	1.1
CO2	0.7896	0.0	0.0078	0.0
Ethane	4.8028	1773.4	0.0472	83.6
Hexane	0.1743	4768.3	0.0017	8.2
Propane	0.6478	2523.8	0.0064	16.1
N2	0.8554	0.0	0.0084	0.0
Methane	93.942	1012.3	0.9224	933.7
Nat Gas	101.849		1.0000	1062.5

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Appendix E
Energy Efficiency Data For
Gas Storage Water Heaters Using Softened Water

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Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	1894	0.10	781.9	102.7	928	668628	957613	69.8
2	2066	0.11	881.2	100.6	1023	738785	1055644	70.0
3	1892	0.10	862.3	95.2	974	683978	1005081	68.1
4	2037	0.11	842.3	98.2	961	689010	991666	69.5
5	2034	0.11	959.2	96.4	1065	770573	1098984	70.1
		0.11				Average		69.5
						Standard Deviation		0.84
						95% Confidence Level		1.33

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
Isobutene	0.0726	3261.2	0.0007	2.4
Nbutane	0.103	3270.7	0.0010	3.4
IsoPentane	0.0331	4010.7	0.0003	1.3
Npentane	0.0263	4019.7	0.0003	1.1
CO2	0.9834	0.0	0.0098	0.0
Ethane	2.884	1773.4	0.0288	51.1
Hexane	0.0671	4768.3	0.0007	3.2
Propane	0.5578	2523.8	0.0056	14.1
N2	0.8956	0.0	0.0089	0.0
Methane	94.5404	1012.3	0.9439	955.5
Nat Gas	100.1633		1.0000	1031.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	6687	0.37	428.8	102.3	505.00	365344	528149	69.2
2	7461	0.41	459.6	100.7	533.00	385386	557433	69.1
3	7409	0.41	495.2	94.7	552.00	390443	577304	67.6
4	7084	0.39	451.8	98.3	516.00	370048	539654	68.6
5	7577	0.42	456.6	98.9	521.00	376071	544883	69.0
		0.40				Average		68.7
						Standard Deviation		0.65
						95% Confidence Level		0.80

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4454	3261.2	0.0045	14.5
Nbutane	0.1256	3270.7	0.0013	4.1
IsoPentane	0.0209	4010.7	0.0002	0.8
Npentane	0.0156	4019.7	0.0002	0.6
CO2	1.0824	0.0	0.0108	0.0
Ethane	3.7162	1773.4	0.0371	65.9
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5057	2523.8	0.0051	12.8
N2	0.9752	0.0	0.0097	0.0
Methane	93.0708	1012.3	0.9300	941.4
Nat Gas	100.0776		1.0000	1045.8

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	7625	0.42	453.3	100.0	521	377669	542155	69.7
2	8475	0.46	489.4	98.7	557	402177	579617	69.4
3	8501	0.47	526.7	92.8	576	406985	599388	67.9
4	8079	0.44	480.3	96.6	540	386662	561926	68.8
5	8584	0.47	486.2	97.3	546	394095	568170	69.4
		0.45				Average		69.0
						Standard Deviation		0.70
						95% Confidence Level		0.87

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3964	3261.2	0.0040	13.1
Nbutane	0.1087	3270.7	0.0011	3.6
IsoPentane	0.0198	4010.7	0.0002	0.8
Npentane	0.0141	4019.7	0.0001	0.6
CO2	1.0316	0.0	0.0104	0.0
Ethane	3.4285	1773.4	0.0347	61.5
Hexane	0.1199	4768.3	0.0012	5.8
Propane	0.4487	2523.8	0.0045	11.5
N2	1.1216	0.0	0.0113	0.0
Methane	92.198	1012.3	0.9324	943.8
Nat Gas	98.8873		1.0000	1040.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	13329	0.73	569.6	102.1	665	484636	689784	70.3
2	13424	0.74	456.6	104.6	552	397965	572573	69.5
3	Meter Out							
4	13349	0.73	506.0	100.9	593	425329	615101	69.1
5	13441	0.74	447.4	102.8	533	383233	552864	69.3
		0.73				Average		69.6
						Standard Deviation		0.49
						95% Confidence Level		0.78

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4484	3261.2	0.0046	14.9
Nbutane	0.1005	3270.7	0.0010	3.3
IsoPentane	0.0178	4010.7	0.0002	0.7
Npentane	0.0123	4019.7	0.0001	0.5
CO2	0.8692	0.0	0.0088	0.0
Ethane	3.279	1773.4	0.0333	59.1
Hexane	0.1058	4768.3	0.0011	5.1
Propane	0.4631	2523.8	0.0047	11.9
N2	1.5643	0.0	0.0159	0.0
Methane	91.5494	1012.3	0.9303	941.7
Nat Gas	98.4098		1.0000	1037.3

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	14951	0.82	1622.2	103.5	1903	1398434	1987931	70.3
2	14724	0.81	1299.9	105.3	1568	1139751	1637980	69.6
3	Meter Out							
4	14790	0.81	1440.7	101.3	1681	1215681	1756023	69.2
5	14715	0.81	1274.0	103.1	1507	1094010	1574258	69.5
		0.81				Average		69.7
						Standard Deviation		0.48
						95% Confidence Level		0.76

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3275	3261.2	0.0033	10.8
Nbutane	0.1116	3270.7	0.0011	3.7
IsoPentane	0.0354	4010.7	0.0004	1.4
Npentane	0.0268	4019.7	0.0003	1.1
CO2	0.7372	0.0	0.0074	0.0
Ethane	3.6925	1773.4	0.0373	66.1
Hexane	0.1274	4768.3	0.0013	6.1
Propane	0.5419	2523.8	0.0055	13.8
N2	1.3181	0.0	0.0133	0.0
Methane	92.2024	1012.3	0.9302	941.7
Nat Gas	99.1208		1.0000	1044.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	18078	0.99	1458.8	103.8	1734.0	1261066	1803273	69.9
2	17272	0.95	1213.6	104.5	1468.0	1056404	1526646	69.2
3	Meter Out							
4	17623	0.97	1351.8	100.8	1583.0	1134870	1646240	68.9
5	17213	0.94	1188.0	102.9	1420.0	1018513	1476729	69.0
		0.96				Average		69.3
						Standard Deviation		0.46
						95% Confidence Level		0.74

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3272	3261.2	0.0033	10.9
Nbutane	0.1386	3270.7	0.0014	4.6
IsoPentane	0.0362	4010.7	0.0004	1.5
Npentane	0.0274	4019.7	0.0003	1.1
CO2	0.6522	0.0	0.0066	0.0
Ethane	3.2888	1773.4	0.0335	59.4
Hexane	0.0423	4768.3	0.0004	2.1
Propane	0.6432	2523.8	0.0065	16.5
N2	1.4818	0.0	0.0151	0.0
Methane	91.5778	1012.3	0.9324	943.9
Nat Gas	98.2155		1.0000	1039.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	22491	1.23	780.2	107.9	969	700989	1012016	69.3
2	20981	1.15	657.2	106.7	817	584260	853268	68.5
3	Meter Out		638.1	98.2	751			
4	21663	1.19	660.8	105.2	817	579012	853268	67.9
5	20844	1.14	651.5	105.1	801	570420	836558	68.2
		1.18				Average		68.4
						Standard Deviation		0.60
						95% Confidence Level		0.96

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3357	3261.2	0.0034	10.9
Nbutane	0.1173	3270.7	0.0012	3.8
IsoPentane	0.0274	4010.7	0.0003	1.1
Npentane	0.0228	4019.7	0.0002	0.9
CO2	0.7228	0.0	0.0072	0.0
Ethane	4.1233	1773.4	0.0412	73.1
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5975	2523.8	0.0060	15.1
N2	1.7025	0.0	0.0170	0.0
Methane	92.2152	1012.3	0.9223	933.7
Nat Gas	99.9843		1.0000	1044.4

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	26031	1.43	989.2	105.7	1190.00	870852	1236686	70.4
2	23979	1.31	837.9	106.9	1032.00	746242	1072487	69.6
3	Meter Out							
4	24657	1.35	845.6	105.1	1030.00	740008	1070409	69.1
5	23692	1.30	795.0	104.1	956.00	689465	993506	69.4
		1.35				Average		69.6
						Standard Deviation		0.56
						95% Confidence Level		0.88

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3313	3261.2	0.0033	10.9
Nbutane	0.1103	3270.7	0.0011	3.6
IsoPentane	0.0337	4010.7	0.0003	1.4
Npentane	0.0246	4019.7	0.0002	1.0
CO2	0.7128	0.0	0.0072	0.0
Ethane	3.6145	1773.4	0.0365	64.7
Hexane	0.038	4768.3	0.0004	1.8
Propane	0.6151	2523.8	0.0062	15.7
N2	1.5846	0.0	0.0160	0.0
Methane	92.0332	1012.3	0.9287	940.1
Nat Gas	99.0981		1.0000	1039.2

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	31549	1.73	3230.3	100.0	3722	2690458	3967210	67.8
2	29258	1.60	3171.9	99.7	3607	2633455	3844633	68.5
3	Meter Out							
4	30007	1.64	3208.1	97.4	3590	2603098	3826513	68.0
5	TC Out							
		1.66				Average		68.1
						Standard Deviation		0.35
						95% Confidence Level		0.86

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4523	3261.2	0.0045	14.8
Nbutane	0.1209	3270.7	0.0012	4.0
IsoPentane	0.0323	4010.7	0.0003	1.3
Npentane	0.0249	4019.7	0.0003	1.0
CO2	0.6957	0.0	0.0070	0.0
Ethane	5.4171	1773.4	0.0544	96.5
Hexane	0.0894	4768.3	0.0009	4.3
Propane	0.6161	2523.8	0.0062	15.6
N2	0.8054	0.0	0.0081	0.0
Methane	91.3012	1012.3	0.9171	928.4
Nat Gas	99.5553		1.0000	1065.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	34340	1.88	1225.0	98.8	1378	1008093	1435811	70.2
2	32098	1.76	1257.8	98.1	1431	1027919	1491035	68.9
3	Meter Out							
4	32874	1.80	1205.5	98.5	1373	988946	1430601	69.1
5	TC Out							
		1.81				Average		69.4
						Standard Deviation		0.69
						95% Confidence Level		1.09

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3796	3261.2	0.0039	12.7
Nbutane	0.117	3270.7	0.0012	3.9
IsoPentane	0.0321	4010.7	0.0003	1.3
Npentane	0.0226	4019.7	0.0002	0.9
CO2	0.6884	0.0	0.0071	0.0
Ethane	2.6241	1773.4	0.0270	47.9
Hexane	0.0749	4768.3	0.0008	3.7
Propane	0.5248	2523.8	0.0054	13.6
N2	0.766	0.0	0.0079	0.0
Methane	92.0118	1012.3	0.9462	957.9
Nat Gas	97.2413		1.0000	1042.0

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	40209	2.20	1505.1	98.2	1667	1231305	1771162	69.5
2	38121	2.09	1569.3	97.3	1724	1271583	1831724	69.4
3	Meter Out							
4	38574	2.11	1610.3	90.8	1694	1218495	1799849	67.7
5	TC Out							
		2.14				Average		68.9
						Standard Deviation		1.02
						95% Confidence Level		1.63

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4151	3261.2	0.0041	13.3
Nbutane	0.1542	3270.7	0.0015	5.0
IsoPentane	0.0389	4010.7	0.0004	1.5
Npentane	0.0289	4019.7	0.0003	1.1
CO2	0.7896	0.0	0.0078	0.0
Ethane	4.8028	1773.4	0.0472	83.6
Hexane	0.1743	4768.3	0.0017	8.2
Propane	0.6478	2523.8	0.0064	16.1
N2	0.8554	0.0	0.0084	0.0
Methane	93.942	1012.3	0.9224	933.7
Nat Gas	101.849		1.0000	1062.5

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	42346	2.32	413.5	93.1	435	320710	470095	68.2
2	40289	2.21	415.4	93.7	440	324350	475498	68.2
3	Meter Out							
4	41183	2.26	422.6	91.3	440	321420	475498	67.6
5	TC Out							
		2.26				Average		68.0
						Standard Deviation		0.36
						95% Confidence Level		0.57

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4239	3261.2	0.0042	13.6
Nbutane	0.1432	3270.7	0.0014	4.6
IsoPentane	0.0332	4010.7	0.0003	1.3
Npentane	0.0259	4019.7	0.0003	1.0
CO2	0.7291	0.0	0.0072	0.0
Ethane	6.1802	1773.4	0.0610	108.2
Hexane	0.1682	4768.3	0.0017	7.9
Propane	0.5769	2523.8	0.0057	14.4
N2	0	0.0	0.0000	0.0
Methane	93.004	1012.3	0.9182	929.6
Nat Gas	101.2846		1.0000	1080.7

Appendix F
Energy Efficiency Data For
Gas Storage Water Heaters Using Unsoftened Water

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Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	2398	0.13	964.0	94.6	1044.00	759854	1077314	70.5
2	2201	0.12	940.7	99.3	1069.00	777897	1103112	70.5
3								
4	2630	0.14	862.9	101.3	1007.00	728054	1039134	70.1
5	2498	0.14	846.8	103.6	999.00	730469	1030878	70.9
		0.13				Average		70.5
						Standard Deviation		0.33
						95% Confidence Level		0.52

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.0726	3261.2	0.0007	2.4
Nbutane	0.1030	3270.7	0.0010	3.4
IsoPentane	0.0331	4010.7	0.0003	1.3
Npentane	0.0263	4019.7	0.0003	1.1
CO2	0.9834	0.0	0.0098	0.0
Ethane	2.8840	1773.4	0.0288	51.1
Hexane	0.0671	4768.3	0.0007	3.2
Propane	0.5578	2523.8	0.0056	14.1
N2	0.8956	0.0	0.0089	0.0
Methane	94.5404	1012.3	0.9439	955.5
Nat Gas	100.1633		1.0000	1031.9

Efficiency Data For Gas Storage Waters Heater Using unsoftened Water

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	8280	0.45	500.0	106.1	608	441928	635871	69.5
2	8048	0.44	491.8	100.8	570	412982	596129	69.3
3	8409	0.46	505.1	104.6	604	439930	631688	69.6
4	7804	0.43	424.2	105.0	515	371091	538608	68.9
5	7700	0.42	450.5	106.0	544	397645	568937	69.9
		0.44				Average		69.4
						Standard Deviation		0.38
						95% Confidence Level		0.47

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4454	3261.2	0.0045	14.5
Nbutane	0.1256	3270.7	0.0013	4.1
IsoPentane	0.0209	4010.7	0.0002	0.8
Npentane	0.0156	4019.7	0.0002	0.6
CO2	1.0824	0.0	0.0108	0.0
Ethane	3.7162	1773.4	0.0371	65.9
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5057	2523.8	0.0051	12.8
N2	0.9752	0.0	0.0097	0.0
Methane	93.0708	1012.3	0.9300	941.4
Nat Gas	100.0776		1.0000	1045.8

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	9357	0.51	512.0	104.9	619	447321	644134	69.4
2	9097	0.50	498.4	99.6	573	413569	596266	69.4
3	9497	0.52	517.4	103.5	616	446183	641012	69.6
4	8720	0.48	435.7	103.7	522	376291	543195	69.3
5	8688	0.48	472.5	104.0	561	409374	583779	70.1
		0.50				Average		69.6
						Standard Deviation		0.34
						95% Confidence Level		0.42

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3964	3261.2	0.0040	13.1
Nbutane	0.1087	3270.7	0.0011	3.6
IsoPentane	0.0198	4010.7	0.0002	0.8
Npentane	0.0141	4019.7	0.0001	0.6
CO2	1.0316	0.0	0.0104	0.0
Ethane	3.4285	1773.4	0.0347	61.5
Hexane	0.1199	4768.3	0.0012	5.8
Propane	0.4487	2523.8	0.0045	11.5
N2	1.1216	0.0	0.0113	0.0
Methane	92.198	1012.3	0.9324	943.8
Nat Gas	98.8873		1.0000	1040.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	10470	0.57	556.6	104.9	685	486287	713841	68.1
2	10322	0.57	612.2	99.6	699	507958	727909	69.8
3	10621	0.58	562.1	103.5	681	484687	709151	68.3
4	9791	0.54	535.6	103.7	641	462526	667988	69.2
5	9815	0.54	563.6	104.0	671	488303	698730	69.9
		0.56				Average		69.1
						Standard Deviation		0.81
						95% Confidence Level		1.00

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.424	3261.2	0.0043	14.0
Nbutane	0.1126	3270.7	0.0011	3.7
IsoPentane	0.0207	4010.7	0.0002	0.8
Npentane	0.0153	4019.7	0.0002	0.6
CO2	1.0589	0.0	0.0108	0.0
Ethane	3.5194	1773.4	0.0357	63.4
Hexane	0.1135	4768.3	0.0012	5.5
Propane	0.4559	2523.8	0.0046	11.7
N2	1.0918	0.0	0.0111	0.0
Methane	91.6561	1012.3	0.9308	942.3
Nat Gas	98.4682		1.0000	1042.1

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	14330	0.79	456.4	108.5	581	412508	602653	68.4
2	14705	0.81	517.1	102.6	618	441796	641032	68.9
3	14176	0.78	480.2	104.0	594	416106	616138	67.5
4	14536	0.80	576.3	99.9	654	479511	678374	70.7
5	14943	0.82	620.0	100.4	706	518674	732312	70.8
		0.80				Average		69.3
						Standard Deviation		1.43
						95% Confidence Level		1.78

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4484	3261.2	0.0046	14.9
Nbutane	0.1005	3270.7	0.0010	3.3
IsoPentane	0.0178	4010.7	0.0002	0.7
Npentane	0.0123	4019.7	0.0001	0.5
CO2	0.8692	0.0	0.0088	0.0
Ethane	3.279	1773.4	0.0333	59.1
Hexane	0.1058	4768.3	0.0011	5.1
Propane	0.4631	2523.8	0.0047	11.9
N2	1.5643	0.0	0.0159	0.0
Methane	91.5494	1012.3	0.9303	941.7
Nat Gas	98.4098		1.0000	1037.3

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	15573	0.85	1242.3	110.6	1580	1144525	1650516	69.3
2	16143	0.88	1437.7	104.4	1726	1250034	1803032	69.3
3	15516	0.85	1339.6	108.7	1687	1213024	1762291	68.8
4	16085	0.88	1548.6	102.8	1812	1325837	1892870	70.0
5	16669	0.91	1725.5	102.3	1975	1469750	2063144	71.2
		0.88				Average		69.8
						Standard Deviation		0.93
						95% Confidence Level		1.16

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3275	3261.2	0.0033	10.8
Nbutane	0.1116	3270.7	0.0011	3.7
IsoPentane	0.0354	4010.7	0.0004	1.4
Npentane	0.0268	4019.7	0.0003	1.1
CO2	0.7372	0.0	0.0074	0.0
Ethane	3.6925	1773.4	0.0373	66.1
Hexane	0.1274	4768.3	0.0013	6.1
Propane	0.5419	2523.8	0.0055	13.8
N2	1.3181	0.0	0.0133	0.0
Methane	92.2024	1012.3	0.9302	941.7
Nat Gas	99.1208		1.0000	1044.6

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	17844	0.98	1095.3	111.5	1435	1016996	1492328	68.1
2	18797	1.03	1227.4	104.3	1500	1066841	1559925	68.4
3	17799	0.98	1060.1	109.2	1374	963935	1428891	67.5
4	19056	1.04	1421.0	103.1	1694	1220368	1761675	69.3
5	20087	1.10	1642.4	101.3	1890	1385934	1965505	70.5
		1.03				Average		68.8
						Standard Deviation		1.18
						95% Confidence Level		1.46

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3272	3261.2	0.0033	10.9
Nbutane	0.1386	3270.7	0.0014	4.6
IsoPentane	0.0362	4010.7	0.0004	1.5
Npentane	0.0274	4019.7	0.0003	1.1
CO2	0.6522	0.0	0.0066	0.0
Ethane	3.2888	1773.4	0.0335	59.4
Hexane	0.0423	4768.3	0.0004	2.1
Propane	0.6432	2523.8	0.0065	16.5
N2	1.4818	0.0	0.0151	0.0
Methane	91.5778	1012.3	0.9324	943.9
Nat Gas	98.2155		1.0000	1039.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1								
2	22009	1.21	583.2	101.2	714.00	491722	745696	65.9
3	21694	1.19	727.1	106.1	923.00	642610	963974	66.7
4	23203	1.27	770.7	104.3	938.00	669429	979640	68.3
5	25065	1.37	889.7	105.3	1075.00	780079	1122722	69.5
		1.26				Average		67.6
						Standard Deviation		1.60
						95% Confidence Level		2.55

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3357	3261.2	0.0034	10.9
Nbutane	0.1173	3270.7	0.0012	3.8
IsoPentane	0.0274	4010.7	0.0003	1.1
Npentane	0.0228	4019.7	0.0002	0.9
CO2	0.7228	0.0	0.0072	0.0
Ethane	4.1233	1773.4	0.0412	73.1
Hexane	0.1198	4768.3	0.0012	5.7
Propane	0.5975	2523.8	0.0060	15.1
N2	1.7025	0.0	0.0170	0.0
Methane	92.2152	1012.3	0.9223	933.7
Nat Gas	99.9843		1.0000	1044.4

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	26567	1.46	1152.3	101.4	1343	973087	1395688	69.7
2	25373	1.39	1115.4	97.6	1261	907205	1310471	69.2
3	25359	1.39	1117.7	100.9	1300	939555	1351001	69.5
4								
5								
		1.41				Average		69.5
						Standard Deviation		0.25
						95% Confidence Level		0.62

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3313	3261.2	0.0033	10.9
Nbutane	0.1103	3270.7	0.0011	3.6
IsoPentane	0.0337	4010.7	0.0003	1.4
Npentane	0.0246	4019.7	0.0002	1.0
CO2	0.7128	0.0	0.0072	0.0
Ethane	3.6145	1773.4	0.0365	64.7
Hexane	0.038	4768.3	0.0004	1.8
Propane	0.6151	2523.8	0.0062	15.7
N2	1.5846	0.0	0.0160	0.0
Methane	92.0332	1012.3	0.9287	940.1
Nat Gas	99.0981		1.0000	1039.2

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	33312	1.83	1191.8	103.2	1438	1024564	1532737	66.8
2								
3								
4								
5								
		1.83				Average		66.8
						Standard Deviation		
						95% Confidence Level		NA

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.4523	3261.2	0.0045	14.8
Nbutane	0.1209	3270.7	0.0012	4.0
IsoPentane	0.0323	4010.7	0.0003	1.3
Npentane	0.0249	4019.7	0.0003	1.0
CO2	0.6957	0.0	0.0070	0.0
Ethane	5.4171	1773.4	0.0544	96.5
Hexane	0.0894	4768.3	0.0009	4.3
Propane	0.6161	2523.8	0.0062	15.6
N2	0.8054	0.0	0.0081	0.0
Methane	91.3012	1012.3	0.9171	928.4
Nat Gas	99.5553		1.0000	1065.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	34928	1.91	1615.9	103.21	1970.90	1389220	2085076	66.6
2								
3								
4								
5								
		1.91				Average		66.6
						Standard Deviation		
						95% Confidence Level		NA

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3874	3261.2	0.0039	12.8
Nbutane	0.1226	3270.7	0.0012	4.1
IsoPentane	0.0279	4010.7	0.0003	1.1
Npentane	0.0208	4019.7	0.0002	0.8
CO2	0.6713	0.0	0.0068	0.0
Ethane	4.9807	1773.4	0.0506	89.8
Hexane	0.0304	4768.3	0.0003	1.5
Propane	0.5282	2523.8	0.0054	13.6
N2	0.8214	0.0	0.0084	0.0
Methane	90.775	1012.3	0.9228	934.2
Nat Gas	98.3657		1.0000	1057.9

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Gas Used (cf)	Water Energy Output (Btu)	Gas Energy Input (Btu)	Efficiency
1	36071	1.98	1143.2	104.8	1395.10	998445	1453629	68.7
2								
3								
4								
5								
		1.98				Average		68.7
						Standard Deviation		
						95% Confidence Level		NA

Component	Concen-tration, %	Energy Content Btu/cf	Normalized	Energy Content Btu/cf
IsoButane	0.3796	3261.2	0.0039	12.7
Nbutane	0.117	3270.7	0.0012	3.9
IsoPentane	0.0321	4010.7	0.0003	1.3
Npentane	0.0226	4019.7	0.0002	0.9
CO2	0.6884	0.0	0.0071	0.0
Ethane	2.6241	1773.4	0.0270	47.9
Hexane	0.0749	4768.3	0.0008	3.7
Propane	0.5248	2523.8	0.0054	13.6
N2	0.766	0.0	0.0079	0.0
Methane	92.0118	1012.3	0.9462	957.9
Nat Gas	97.2413		1.0000	1042.0

Appendix G
Energy Efficiency Data For
Electric Storage Water Heaters Using Softened Water

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Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	680	0.04	337.40	92.82	77.20	260871	263417	99.0
2	655	0.04	325.30	92.74	73.60	251301	251134	100.1
3	603	0.03	336.10	90.25	75.30	252674	256934	98.3
4	619	0.03	365.10	91.16	81.70	277239	278772	99.5
5	588	0.03	307.70	91.41	69.20	234287	236120	99.2
		0.03				Average		99.2
						Standard Deviation		0.63
						95% Confidence Level		0.78

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	3735	0.20	269.4	90.7	60.0	203561	204729	99.4
2	3936	0.22	259.2	91.3	58.1	197039	198245	99.4
3	4044	0.22	262.9	89.1	58.1	195017	198245	98.4
4	4083	0.22	254.0	89.0	55.6	188342	189715	99.3
5	4016	0.22	259.9	90.2	58.0	195196	197904	98.6
		0.22				Average		99.0
						Standard Deviation		0.49
						95% Confidence Level		0.60

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	6816	0.37	821.3	92.0	184.9	629303	630905	99.7
2	6785	0.37	740.5	92.6	169.1	570959	576993	99.0
3	6933	0.38	755.8	90.5	168.7	569955	575628	99.0
4	6878	0.38	728.1	90.5	163.8	548907	558909	98.2
5	6903	0.38	755.0	92.1	170.9	579016	583135	99.3
		0.38				Average		99.0
						Standard Deviation		0.56
						95% Confidence Level		0.70

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	8896	0.49	652.60	91.6	145.8	497725	497490	100.0
2	Misread meter							
3	8838	0.48	601.20	89.5	132.4	448348	451768	99.2
4	8745	0.48	585.30	89.8	129.2	437638	440849	99.3
5	8816	0.48	584.40	90.8	130.2	442233	444261	99.5
		0.48				Average		99.5
						Standard Deviation		0.37
						95% Confidence Level		0.59

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	10913	0.60	368.1	91.3	82.50	279991	281502	99.5
2	10499	0.58	332.0	91.4	74.40	252871	253863	99.6
3	10696	0.59	338.4	89.4	74.80	251976	255228	98.7
4	Misread meter							
5	10620	0.58	328.9	90.6	73.30	248108	250110	99.2
		0.59				Average		99.2
						Standard Deviation		0.39
						95% Confidence Level		0.62

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	12542	0.69	449.8	91.8	100.0	343920	341214	100.8
2	11955	0.66	391.8	91.7	87.3	299432	297880	100.5
3	12197	0.67	415.4	90.1	91.1	311754	310846	100.3
4	12013	0.66	402.4	90.9	89.2	304715	304363	100.1
5	12070	0.66	401.0	91.0	88.6	303839	302316	100.5
		0.67				Average		100.4
						Standard Deviation		0.26
						95% Confidence Level		0.32

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	16683	0.91	220.2	97.9	52.0	179506	177431	101.2
2	15563	0.85	190.9	98.1	45.1	155937	153888	101.3
3	16009	0.88	202.8	96.0	48.3	162110	164806	98.4
4	15720	0.86	196.9	96.9	46.9	158994	160029	99.4
5	15755	0.86	195.9	97.1	46.4	158391	158323	100.0
		0.87				Average		100.1
						Standard Deviation		1.25
						95% Confidence Level		1.55

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	17867	0.98	552.3	88.2	119.6	405706	408092	99.4
2	16715	0.92	542.0	88.4	119.1	398895	406386	98.2
3	17124	0.94	528.9	86.0	111.6	378713	380795	99.5
4	16808	0.92	516.5	86.9	110.3	373971	376359	99.4
5	16883	0.93	536.4	87.5	116.1	391054	396150	98.7
		0.94				Average		99.0
						Standard Deviation		0.57
						95% Confidence Level		0.71

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	18525	1.02	658.6	87.7	143.1	481378	488184	98.6
2	17359	0.95	644.3	88.0	139.8	472056	477017	99.0
3	17750	0.97	626.0	85.6	134.2	446506	457940	97.5
4	17421	0.95	613.3	86.6	132.0	442643	450403	98.3
5	17520	0.96	636.7	87.2	140.0	462635	477669	96.9
		0.97				Average		98.0
						Standard Deviation		0.85
						95% Confidence Level		1.06

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	18955	1.04	429.6	88.5	94.1	316767	321176	98.6
2	17795	0.98	436.1	88.6	94.0	322014	320741	100.4
3	18180	1.00	429.7	86.6	91.3	309894	311498	99.5
4	17821	0.98	399.3	87.4	85.1	290768	290373	100.1
5	17937	0.98	417.0	88.0	90.5	305566	308830	98.9
		0.99				Average		99.5
						Standard Deviation		0.75
						95% Confidence Level		0.94

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	20741	1.14	459.8	86.65	98.0	331883	334390	99.3
2	19525	1.07	447.7	87.07	95.8	324715	326883	99.3
3	19858	1.09	438.1	84.93	91.8	309926	313235	98.9
4	19486	1.07	429.1	86.04	90.4	307528	308458	99.7
5	19663	1.08	445.4	86.61	94.2	321342	321424	100.0
		1.09				Average		99.4
						Standard Deviation		0.40
						95% Confidence Level		0.50

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	21454	1.18	713.0	87.1	150.9	517077	514892	100.4
2	20219	1.11	694.7	87.4	147.2	505639	502267	100.7
3	20538	1.13	680.0	85.2	141.7	482823	483501	99.9
4	20150	1.10	664.7	86.1	139.1	476839	474629	100.5
5	20357	1.12	694.0	86.6	146.5	500377	499879	100.1
		1.13				Average		100.3
						Standard Deviation		0.32
						95% Confidence Level		0.40

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	22475	1.23	224.3	85.0	47.2	158876	161053	98.6
2	21205	1.16	208.3	85.5	44.0	148406	150134	98.8
3	21515	1.18	214.6	83.5	44.3	149243	151158	98.7
4	21102	1.16	208.6	84.2	43.4	146274	148087	98.8
5	21352	1.17	217.5	84.4	45.2	152963	154229	99.2
		1.18				Average		98.8
						Standard Deviation		0.20
						95% Confidence Level		0.25

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Appendix H
Energy Efficiency Data For
Electric Storage Water Heaters Using Unsoftened Water

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Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	1157	0.06	485.3	90.5	107.3	365873	366123	99.9
2	1150	0.06	443.5	92.7	101.6	342482	346674	98.8
3	1057	0.06	515.6	93.2	117.6	400268	401268	99.8
4	1297	0.07	544.2	92.2	123.9	417895	422764	98.8
5	1110	0.06	427.3	91.7	96.0	326314	327566	99.6
		0.06				Average		99.4
						Standard Deviation		0.53
						95% Confidence Level		0.66

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Electric Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	3215	0.18	164.5	89.9	36.2	123141	123520	99.7
2	3367	0.18	187.9	91.4	42.4	143131	144675	98.9
3	3415	0.19	193.4	92.1	43.7	148321	149111	99.5
4	3250	0.18	174.7	90.9	39.1	132259	133415	99.1
5	3117	0.17	172.9	90.2	38.5	129863	131367	98.9
		0.18				Average		99.2
						Standard Deviation		0.36
						95% Confidence Level		0.44

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	5764	0.32	682.0	90.5	149.8	513853	511139	100.5
2	5416	0.30	450.0	92.0	102.1	344958	348380	99.0
3	5711	0.31	564.6	92.9	130.8	437067	446308	97.9
4	5047	0.28	411.5	91.4	92.9	313145	316988	98.8
5	5761	0.32	658.4	91.2	146.7	500032	500561	99.9
		0.30				Average		99.2
						Standard Deviation		1.01
						95% Confidence Level		1.25

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	7519	0.41	543.2	90.5	119.6	409329	408092	100.3
2	6750	0.37	508.2	91.7	114.0	388181	388984	99.8
3	7228	0.40	459.1	92.9	104.0	355093	354863	100.1
4	6663	0.37	596.7	91.1	133.0	453047	453815	99.8
5	Low flow							
		0.39				Average		100.0
						Standard Deviation		0.24
						95% Confidence Level		0.38

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	9375	0.51	425.8	90.4	93.0	320577	317329	101.0
2	8919	0.49	435.3	91.8	97.8	332784	333707	99.7
3	8886	0.49	437.8	92.9	99.2	338767	338484	100.1
4	7337	0.40	430.4	91.6	96.5	328346	329272	99.7
5	Low flow							
		0.47				Average		100.1
						Standard Deviation		0.61
						95% Confidence Level		0.98

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	11137	0.61	482.3	89.2	104.5	358284	356569	100.5
2	10854	0.59	537.7	90.4	118.5	405066	404339	100.2
3	10836	0.59	541.6	91.9	120.9	414754	412528	100.5
4	10507	0.58	531.3	90.8	117.2	401761	399903	100.5
5	Low flow							
		0.59				Average		100.4
						Standard Deviation		0.16
						95% Confidence Level		0.26

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	11514	0.63	224.2	95.1	52.7	177570	179820	98.7
2	11273	0.62	249.3	97.2	59.9	201920	204387	98.8
3	11257	0.62	251.2	98.2	59.0	205387	201316	102.0
4	10920	0.60	246.7	96.6	58.7	198597	200293	99.2
5	Low flow							
		0.62				Average		99.7
						Standard Deviation		1.57
						95% Confidence Level		2.50

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	15302	0.84	999.0	86.4	211.1	719325	720417	99.8
2	13061	0.72	1026.0	88.1	219.5	752612	748965	100.5
3	13071	0.72	1041.4	89.2	228.7	773462	780357	99.1
4	12743	0.70	1040.9	87.6	223.9	759688	763979	99.4
5	Low flow							
		0.74				Average		99.7
						Standard Deviation		0.59
						95% Confidence Level		0.94

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	15658	0.86	355.6	86.1	75.7	255012	258330	98.7
2	Low flow							
3	Low flow							
4	Low flow							
5	Low flow							
		0.86				Average		98.7
						Standard Deviation		NA
						95% Confidence Level		NA

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	15908	0.87	250.2	85.9	53.5	179045	182519	98.1
2	Low flow							
3	Low flow							
4	Low flow							
5	Low flow							
		0.87				Average		98.1
						Standard Deviation		NA
						95% Confidence Level		NA

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	20232	1.11	604.7	83.8	124.2	422180	423788	99.6
2	Low flow							
3	Low flow							
4	Low flow							
5	Low flow							
		1.11				Average		99.6
						Standard Deviation		NA
						95% Confidence Level		NA

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	21151	1.16	920.0	83.7	188.40	641773	642848	99.8
2	Low flow							
3	Low flow							
4	Low flow							
5	Low flow							
		1.16				Average		99.8
						Standard Deviation		NA
						95% Confidence Level		NA

Unit	Total Water Used (Gallons)	Equivalent Years Gal/(50*365) (Years)	Water Used (Gallons)	Water Temperature Difference (F)	Electricity Used kWh	Water Energy Output (Btu)	Electric Energy Input (Btu)	Efficiency
1	22309	1.22	214.3	83.1	43.9	148394	149793	99.1
2	Low flow							
3	Low flow							
4	Low flow							
5	Low flow							
		1.22				Average		99.1
						Standard Deviation		NA
						95% Confidence Level		NA

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Appendix I
Photos of Heat Exchangers of Instantaneous Water Heaters After 90 Days Using Softened Water

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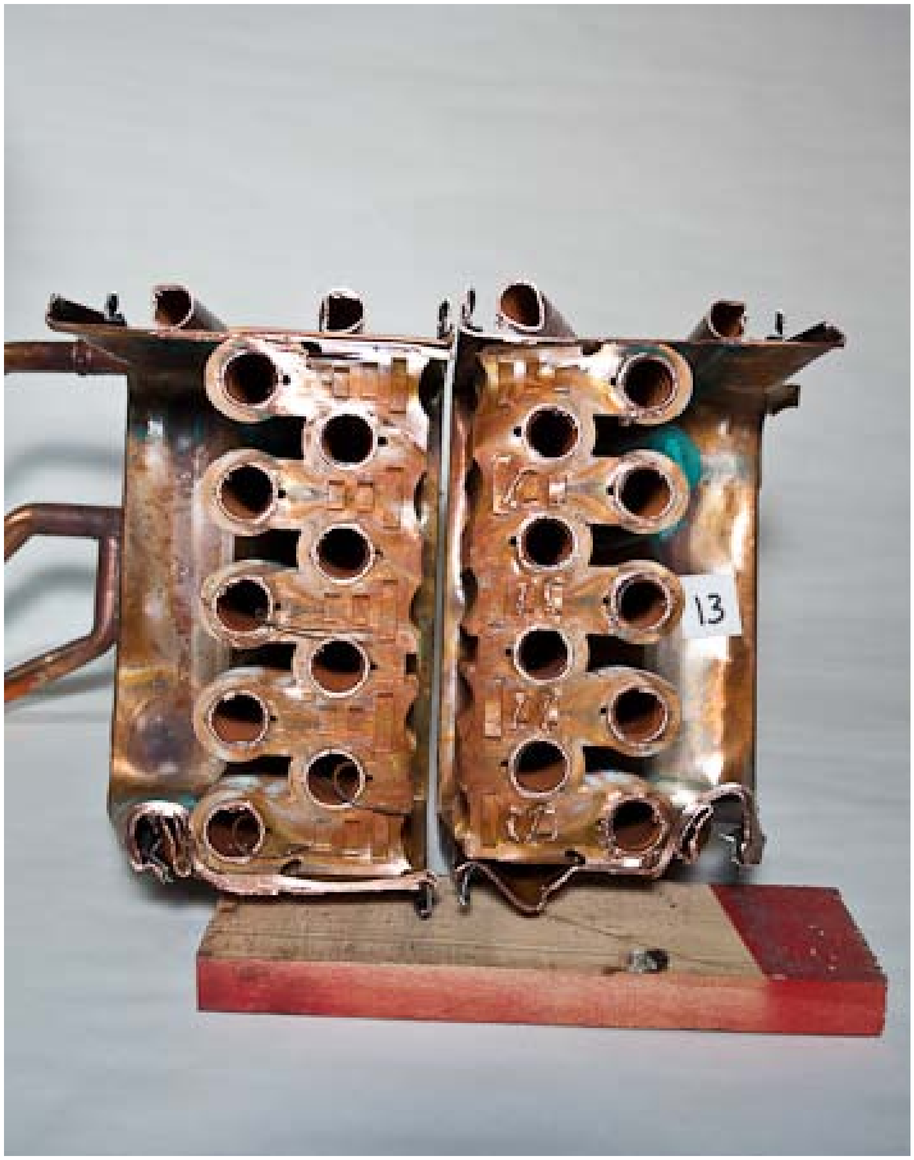
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Appendix J
Photos of Heat Exchangers of Instantaneous Water Heaters After 90 Days Using Unsoftened Water

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Appendix K
Photos of Gas Storage Water Heaters After 90 Days Using Softened Water

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Unit 17

Unit 18

Unit 19

Unit 20

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Appendix L
Photos of Gas Storage Water Heaters After 90 Days Using Unsoftened Water

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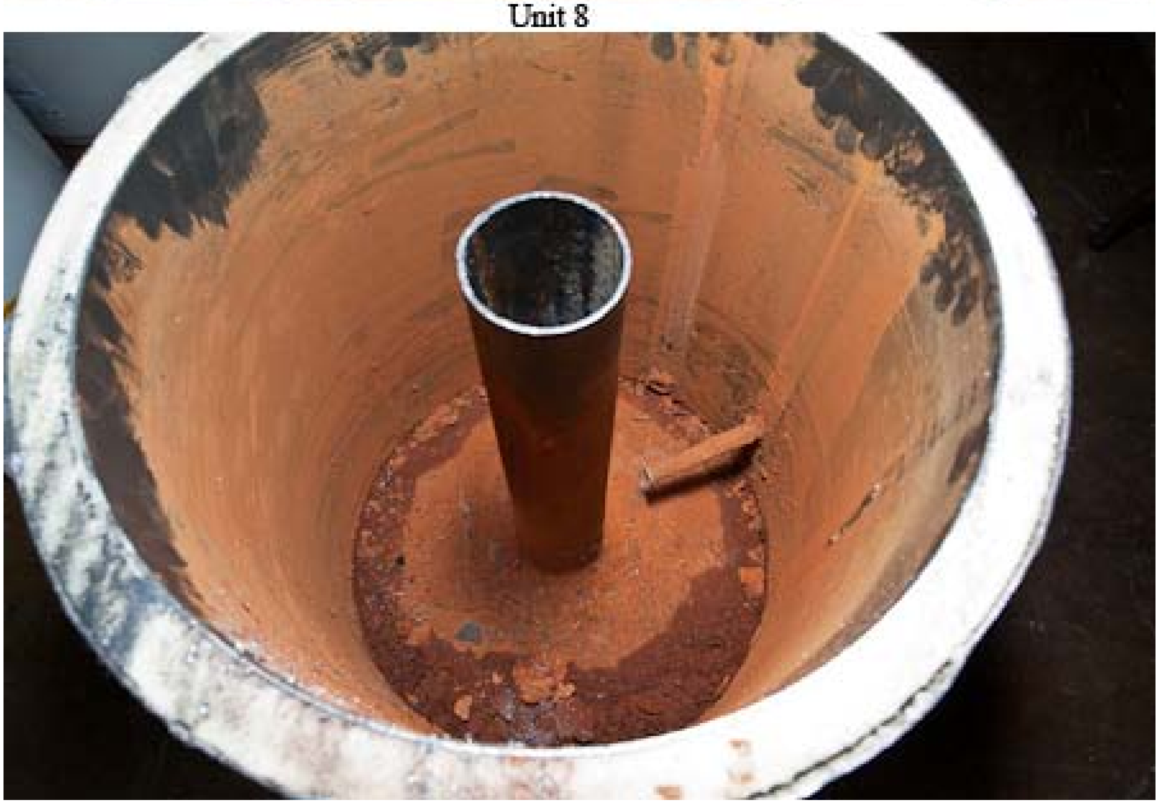
Unit 6

Unit 7

Unit 8



Unit 9

Unit 10

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Appendix M
Photos of Electric Storage Water Heaters After 90 Days Using Softened Water

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Appendix N
Photos of Electric Storage Water Heaters After 90 Days Using Unsoftened Water

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Unit 21

Unit 22

Unit 23

Unit 24

Unit 25

Appendix O
Culligan Analysis of Softened Well Water

Culligan

9399 W. Higgins Road Suite 1100
Rosemont, IL 60018

TELEPHONE 847/430-2800
FACSIMILE 847/430-2284

Report Date: 5/4/2009

CERTIFICATE OF ANALYSIS

ANALYSIS NUMBER: 0901862

Control Number: 20260

Culligan Research
9399 W. Higgins Rd. Suite
Rosemont, IL 60018

Account Number: 90005

Salesperson DARRELL PAUL

Customer: DARREL PAUL/STEVE REIF
505 KING AVE
COLUMBUS OH
Zip Code: 43201
Customer Account #:
cc: PAUL@BATTELLE.ORG

SAMPLE INFORMATION:

Analysis Type Requested Standard A Analysis

Sampled:	4/28/2009	Supply/Source:	PRIVATE WELL	Condition:	TREATED WATER
Received:	4/30/2009	Sampling Point:		Application:	Commercial

ANALYSIS INFORMATION:

Turbidity(Method 180.1 R 2.	0.6 NTU	Turbidity after filtration	N.M.
Conductivity(Method 120.1	1300.0 MMHOS/CM	Est. TDS by Conductivity	793.7
Color(Method 2120C)	7.6	Color after Acidification	5.2
pH(Method 150.1 R 1982)	7.4	Tannins	<2

Concentrations reported as mg/L (PPM) unless otherwise indicated

CATIONS (Method 200.7)	As Element	As CaCo3	ANIONS (Method 300.0)	As Element	As CaCo3
Calcium (Ca)	10.7	26.8	Chloride (Cl)	200	282.0
Magnesium (Mg)	4.4	18.1	Nitrate As N (NO3)	<0.5	<1.8
Sodium (Na)	315	686.7	Nitrite As N (NO2)	<0.1	<0.4
Potassium (K)	4	5.1	Sulfate (SO4)	97	100.9
Strontium (Sr)	0.11	0.1	Bicarbonate	415.9	340.9
Barium (Ba)	<0.01		Carbonate	N.M.	N.M.
Iron (Fe)	0.06		Fluoride (F)	0.4	1.00
Manganese (Mn)	0.02		Silica (SiO2)	13.7	
Copper (Cu)	<0.003				
Zinc (Zn)	<0.05				

	Mg/L	GPG		Mg/L	GPG		Mg/L	GPG
Cations (CaCO3)	736.7	43.08	Anions (CaCO3)	724.8	42.39	Hardness (CaCO3)	45	2.6

Additional Tests

Aluminum by ICP <50ug/L

*NA - Not Analyzed NM - Not Measured ND - Not Detected

This report can only be reproduced in its entirety. The results reported here are representative of the sample as received in the laboratory.

Certifications: CA-01133A; IL-000280; NY-11756; WI-399016200; TX-TX269-2003
IA-369

Richard Cook
Manager Analytical Laborator

Culligan

9399 W. Higgins Road Suite 1100
Rosemont, IL 60018

TELEPHONE 847/430-2800
FACSIMILE 847/430-2284

Report Date: 6/3/2009

CERTIFICATE OF ANALYSIS

ANALYSIS NUMBER: 0902302

Control Number: 20262

Columbus Water Cond., Inc.
5350 W Broad St
Columbus, OH 43228

Customer: DARRELL PAUL/STEVE REIF
505 KING AVENUE
COLUMBUS OH
Zip Code: 43201
Customer Account #:
cc: PAUL@BATTELLE.ORG

Account Number: 34181

Salesperson DARRELL PAUL

SAMPLE INFORMATION:

Analysis Type Requested: Standard A Analysis

Sampled:	5/28/2009	Supply/Source:	PRIVATE WELL	Condition:	TREATED WATER
Received:	5/29/2009	Sampling Point:	FAUCET	Application:	Commercial

ANALYSIS INFORMATION:

Turbidity(Method 180.1 R 2.	1.2 NTU	Turbidity after filtration	1.0
Conductivity(Method 120.1	1328.0 MMHOS/CM	Est. TDS by Conductivity	810.3
Color(Method 2120C)	10.9	Color after Acidification	2.7
pH(Method 150.1 R 1982)	7.4	Tannins	<2

Concentrations reported as mg/L (PPM) unless otherwise indicated

CATIONS (Method 200.7)	As Element	As CaCo3	ANIONS (Method 300.0)	As Element	As CaCo3
Calcium (Ca)	1.5	3.8	Chloride (Cl)	195	275.0
Magnesium (Mg)	0.2	0.8	Nitrate As N (NO3)	<0.5	<1.8
Sodium (Na)	316	688.9	Nitrite As N (NO2)	<0.1	<0.4
Potassium (K)	1.1	1.4	Sulfate (SO4)	82	85.3
Strontium (Sr)	<0.05	<0.1	Bicarbonate	398.2	326.4
Barium (Ba)	<0.01		Carbonate	N.M.	N.M.
Iron (Fe)	0.11		Fluoride (F)	0.4	1.00
Manganese (Mn)	<0.02		Silica (SiO2)	13.5	
Copper (Cu)	<0.003				
Zinc (Zn)	<0.05				

	Mg/L	GPG		Mg/L	GPG		Mg/L	GPG
Cations (CaCO3)	694.9	40.64	Anions (CaCO3)	687.7	40.22	Hardness (CaCO3)	5	0.3

Additional Tests

Aluminum by ICP <50ug/L

*NA = Not Analyzed NM = Not Measured ND = Not Detected

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Certifications: CA-01133A; IL-000280; NY-11756; WI-399016200; TX-TX269-2003A
IA-369

Richard Cook
Manager Analytical Laboratory

9399 W. Higgins Road Suite 1100
Rosemont, IL 60018

TELEPHONE 847/430-2800
FACSIMILE 847/430-2284

Report Date: 8/3/2009

CERTIFICATE OF ANALYSIS

ANALYSIS NUMBER: 0903708

Control Number: 20258

Culligan Research
9399 W. Higgins Rd. Suite
Rosemont, IL 60018

Account Number: 90005

Salesperson DARRELL PAUL

Customer: DARRELL PAUL/STEVE RIEF
505 KING AVENUE
COLUMBUS OH
Zip Code: 43201
Customer Account #:
cc: PAUL@BATTELLE.ORG

SAMPLE INFORMATION:

Analysis Type Requested Standard A Analysis

Sampled:	7/30/2009	Supply/Source:	PRIVATE WELL	Condition:	TREATED WATER
Received:	7/30/2009	Sampling Point:	EQUIPMENT	Application:	Commercial

ANALYSIS INFORMATION:

Turbidity(Method 180.1 R 2.	3.1 NTU	Turbidity after filtration	2.0
Conductivity(Method 120.1	1198.0 MMHOS/CM	Est. TDS by Conductivity	731.1
Color(Method 2120C)	14.0	Color after Acidification	3.8
pH(Method 150.1 R 1982)	7.4	Tannins	<2

Concentrations reported as mg/L (PPM) unless otherwise indicated

CATIONS (Method 200.7)	As Element	As CaCo3	ANIONS (Method 300.0)	As Element	As CaCo3
Calcium (Ca)	4	10.0	Chloride (Cl)	151	212.9
Magnesium (Mg)	0.9	3.7	Nitrate As N (NO3)	<0.5	<1.8
Sodium (Na)	252	549.4	Nitrite As N (NO2)	<0.1	<0.4
Potassium (K)	1.4	1.8	Sulfate (SO4)	74	77.0
Strontium (Sr)	0.05	0.1	Bicarbonate	351.5	288.1
Barium (Ba)	<0.01		Carbonate	N.M.	N.M.
Iron (Fe)	0.43		Fluoride (F)	0.4	1.00
Manganese (Mn)	<0.02		Silica (SiO2)	12.3	
Copper (Cu)	<0.003				
Zinc (Zn)	<0.05				

	Mg/L	GPG		Mg/L	GPG		Mg/L	GPG
Cations (CaCO3)	564.9	33.03	Anions (CaCO3)	579.0	33.86	Hardness (CaCO3)	14	0.8

Additional Tests

Aluminum by ICP <50ug/L

*NA - Not Analyzed NM - Not Measured ND - Not Detected

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Certifications: CA-01133A; IL-000280; NY-11756; WI-399016200; TX-TX269-2003
IA-369

Richard Cook
Manager Analytical Laborator

Appendix P
Culligan Analysis of Unsoftened Well Water

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Culligan

9399 W. Higgins Road Suite 1100
Rosemont, IL 60018

TELEPHONE 847/430-2800
FACSIMILE 847/430-2284

Report Date: 5/4/2009

CERTIFICATE OF ANALYSIS

ANALYSIS NUMBER: 0901861

Control Number: 20259

Culligan Research
9399 W. Higgins Rd. Suite
Rosemont, IL 60018

Customer: DARREL PAUL/STEVE REIF
505 KING AVE
COLUMBUS OH
Zip Code: 43201

Account Number: 90005

Customer Account #:

Salesperson DARRELL PAUL

cc: PAUL@BATTELLE.ORG

SAMPLE INFORMATION:

Analysis Type Requested Standard A Analysis

Sampled:	4/28/2009	Supply/Source:	PRIVATE WELL	Condition:	UNTREATED WATER
Received:	4/30/2009	Sampling Point:	EQUIPMENT	Application:	Commercial

ANALYSIS INFORMATION:

Turbidity(Method 180.1 R 2.	9.4 NTU	Turbidity after filtration	1.3
Conductivity(Method 120.1	1259.0 MMHOS/CM	Est. TDS by Conductivity	769.3
Color(Method 2120C)	5.9	Color after Acidification	3.8
pH(Method 150.1 R 1982)	7.4	Tannins	<2

Concentrations reported as mg/L (PPM) unless otherwise indicated

CATIONS (Method 200.7)	As Element	As CaCo3	ANIONS (Method 300.0)	As Element	As CaCo3
Calcium (Ca)	130	325.0	Chloride (Cl)	171	241.1
Magnesium (Mg)	37.2	153.3	Nitrate As N (NO3)	<0.5	<1.8
Sodium (Na)	95.9	209.1	Nitrite As N (NO2)	<0.1	<0.4
Potassium (K)	4.6	5.9	Sulfate (SO4)	84	87.4
Strontium (Sr)	1.95	2.5	Bicarbonate	415.4	340.5
Barium (Ba)	0.1453		Carbonate	N.M.	N.M.
Iron (Fe)	0.69		Fluoride (F)	0.3	0.75
Manganese (Mn)	0.22		Silica (SiO2)	13.9	
Copper (Cu)	<0.003				
Zinc (Zn)	<0.05				

	Mg/L	GPG		Mg/L	GPG		Mg/L	GPG
Cations (CaCO3)	693.2	40.54	Anions (CaCO3)	669.8	39.17	Hardness (CaCO3)	478	28.0

Additional Tests

Aluminum by ICP 66.71ug/L

*NA = Not Analyzed NM = Not Measured ND = Not Detected

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IA-369

Richard Cook
Manager Analytical Laborator

Culligan

9399 W. Higgins Road Suite 1100
Rosemont, IL 60018

TELEPHONE 847/430-2800
FACSIMILE 847/430-2284

Report Date: 6/3/2009

CERTIFICATE OF ANALYSIS

ANALYSIS NUMBER: 0902301

Control Number: 20256

Columbus Water Cond., Inc.
5350 W Broad St
Columbus, OH 43228

Customer: DARRELL PAUL/STEVE REIF
505 KING AVENUE
COLUMBUS OH
Zip Code: 43201
Customer Account #:
cc: PAUL@BATTELLE.ORG

Account Number: 34181

Salesperson DARRELL PAUL

SAMPLE INFORMATION:

Analysis Type Requested: Standard A Analysis

Sampled:	5/28/2009	Supply/Source:	PRIVATE WELL	Condition:	UNTREATED WATER
Received:	5/29/2009	Sampling Point:	WELL NO.3	Application:	Commercial

ANALYSIS INFORMATION:

Turbidity(Method 180.1 R 2.	16.4 NTU	Turbidity after filtration	2.9
Conductivity(Method 120.1	1330.0 MMHOS/CM	Est. TDS by Conductivity	811.8
Color(Method 2120C)	14.2	Color after Acidification	3.3
pH(Method 150.1 R 1982)	7.3	Tannins	<2

Concentrations reported as mg/L (PPM) unless otherwise indicated

CATIONS (Method 200.7)	As Element	As CaCo3	ANIONS (Method 300.0)	As Element	As CaCo3
Calcium (Ca)	128	320.0	Chloride (Cl)	195	275.0
Magnesium (Mg)	35.7	147.1	Nitrate As N (NO3)	<0.5	<1.8
Sodium (Na)	95.7	208.6	Nitrite As N (NO2)	<0.1	<0.4
Potassium (K)	4.7	6.0	Sulfate (SO4)	82	85.3
Strontium (Sr)	1.81	2.3	Bicarbonate	397.6	325.9
Barium (Ba)	0.1861		Carbonate	N.M.	N.M.
Iron (Fe)	1.28		Fluoride (F)	0.4	1.00
Manganese (Mn)	0.3		Silica (SiO2)	13.8	
Copper (Cu)	<0.003				
Zinc (Zn)	0.7				

	Mg/L	GPG		Mg/L	GPG		Mg/L	GPG
Cations (CaCO3)	681.7	39.87	Anions (CaCO3)	687.2	40.19	Hardness (CaCO3)	468	27.4

Additional Tests

Aluminum by ICP 73.26ug/L

*NA = Not Analyzed NM = Not Measured ND = Not Detected

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Certifications: CA-01133A; IL-000280; NY-11756; WI-399016200; TX-TX269-2003A
IA-369

Richard Cook
Manager Analytical Laboratory

Culligan

9399 W. Higgins Road Suite 1100
Rosemont, IL 60018

TELEPHONE 847/430-2800
FACSIMILE 847/430-2284

Report Date: 8/4/2009

CERTIFICATE OF ANALYSIS

ANALYSIS NUMBER: 0903707

Control Number: 20254

Culligan Research
9399 W. Higgins Rd. Suite
Rosemont, IL 60018

Customer: DARRELL PAUL/STEVE RIEF
505 KING AVENUE
COLUMBUS OH
Zip Code: 43201
Customer Account #:
cc: PAUL@BATTELLE.ORG

Account Number: 90005

Salesperson DARRELL PAUL

SAMPLE INFORMATION:

Analysis Type Requested Standard A Analysis

Sampled:	7/30/2009	Supply/Source:	PRIVATE WELL	Condition:	UNTREATED WATER
Received:	7/30/2009	Sampling Point:	EQUIPMENT	Application:	Commercial

ANALYSIS INFORMATION:

Turbidity(Method 180.1 R 2.	7.0 NTU	Turbidity after filtration	0.4
Conductivity(Method 120.1	1158.0 MMHOS/CM	Est. TDS by Conductivity	707.2
Color(Method 2120C)	6.7	Color after Acidification	4.6
pH(Method 150.1 R 1982)	7.3	Tannins	<2

Concentrations reported as mg/L (PPM) unless otherwise indicated

CATIONS (Method 200.7)	As Element	As CaCo3	ANIONS (Method 300.0)	As Element	As CaCo3
Calcium (Ca)	111	277.5	Chloride (Cl)	175	246.8
Magnesium (Mg)	29	119.5	Nitrate As N (NO3)	<0.5	<1.8
Sodium (Na)	88.3	192.5	Nitrite As N (NO2)	<0.1	<0.4
Potassium (K)	4.1	5.2	Sulfate (SO4)	85	88.4
Strontium (Sr)	1.4	1.8	Bicarbonate	352.0	288.5
Barium (Ba)	0.164		Carbonate	N.M.	N.M.
Iron (Fe)	0.99		Fluoride (F)	0.4	1.00
Manganese (Mn)	0.24		Silica (SiO2)	12.4	
Copper (Cu)	<0.003				
Zinc (Zn)	<0.05				

	Mg/L	GPG		Mg/L	GPG		Mg/L	GPG
Cations (CaCO3)	594.7	34.78	Anions (CaCO3)	624.7	36.53	Hardness (CaCO3)	398	23.3

Additional Tests

Aluminum by ICP 55.95ug/L

*NA = Not Analyzed NM = Not Measured ND = Not Detected

This report can only be reproduced in its entirety. The results reported here are representative of the sample as received in the laboratory.

Certifications: CA-01133A; IL-000280; NY-11756; WI-399016200; TX-TX269-2003
IA-369

Richard Cook
Manager Analytical Laborator

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Appendix Q
Culligan Analysis of Hard Water Scale
Taken From Piping at Outlet of Instantaneous Water Heater
Operating With Water of 26.2 Grains Per Gallon Hardness

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SCALE ANALYSIS

DATE:11/12/09

DEALER ADDRESS: Culligan International
9399 W. Higgins Rd.
Rosemont, IL 60018

ANALYSIS #:5693
DEALER FILE #:90005 Reif
CONTROL NO:
CONSUMER: Battelle

SAMPLE TAKEN: DATE RECEIVED:

CHARACTERISTICS:

MATRIX:Solid
COLOR:Red
SIZE: Small
DENSITY:Sinks in Water
TEXTURE: Grainy/Smooth

ANALYTICAL RESULTS:

The sample is a solid in water. The sample was dried overnight in an oven at 105 degrees C, then ground into a powder using a mortar and pestle. The sample is partly soluble in nitric acid, sulfuric acid and hydrochloric acid. Analysis of anions via wet chemistry techniques detected the presence of the following species; Carbonate
Analysis of cations via ICP detected the following elements in order of decreasing concentration; Calcium, Iron, Magnesium, Copper, Manganese

Table 1: Percent Compositions of Selected Cations.

Cation	ppm	% Composition
Ca	2079	37.1
Fe	163.6	2.9
Mg	95.6	1.7
Cu	27.7	0.5
Mn	21.4	0.4

Table 2: Wet Chemistry Analysis Results.

Species Tested For:	Test Results
CO_3^{2-}	+
OH^-	-
S^{2-}	-
Cl^-	-
SO_4^{2-}	-
Ortho-phosphate	-
Organics	-
Soluble Silicates	-
Insoluble Silicates	-

+ Test indicates presence of species.

- Test indicates absence of species.

SCALE ANALYSIS

DATE:11/12/09

DEALER ADDRESS: Culligan International
9399 W. Higgins Rd.
Rosemont, IL 60018

ANALYSIS #:5693
DEALER FILE #:90005 Reif
CONTROL NO:
CONSUMER: Battelle

SAMPLE TAKEN: DATE RECEIVED:

CHARACTERISTICS:

MATRIX:Solid
COLOR:Red
SIZE: Small
DENSITY:Sinks in Water
TEXTURE: Grainy/Smooth

ANALYTICAL RESULTS:

The sample is a solid in water. The sample was dried overnight in an oven at 105 degrees C, then ground into a powder using a mortar and pestle. The sample is partly soluble in nitric acid, sulfuric acid and hydrochloric acid. Analysis of anions via wet chemistry techniques detected the presence of the following species; Carbonate Analysis of cations via ICP detected the following elements in order of decreasing concentration; Calcium, Iron, Magnesium, Copper, Manganese

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Appendix R
Pictures of Low Flow Showerheads Using Unsoftened Well Water and Softened Well Water

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Figure 6-1A. Showerhead 1 on fourth day of testing with softened well water (<1 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

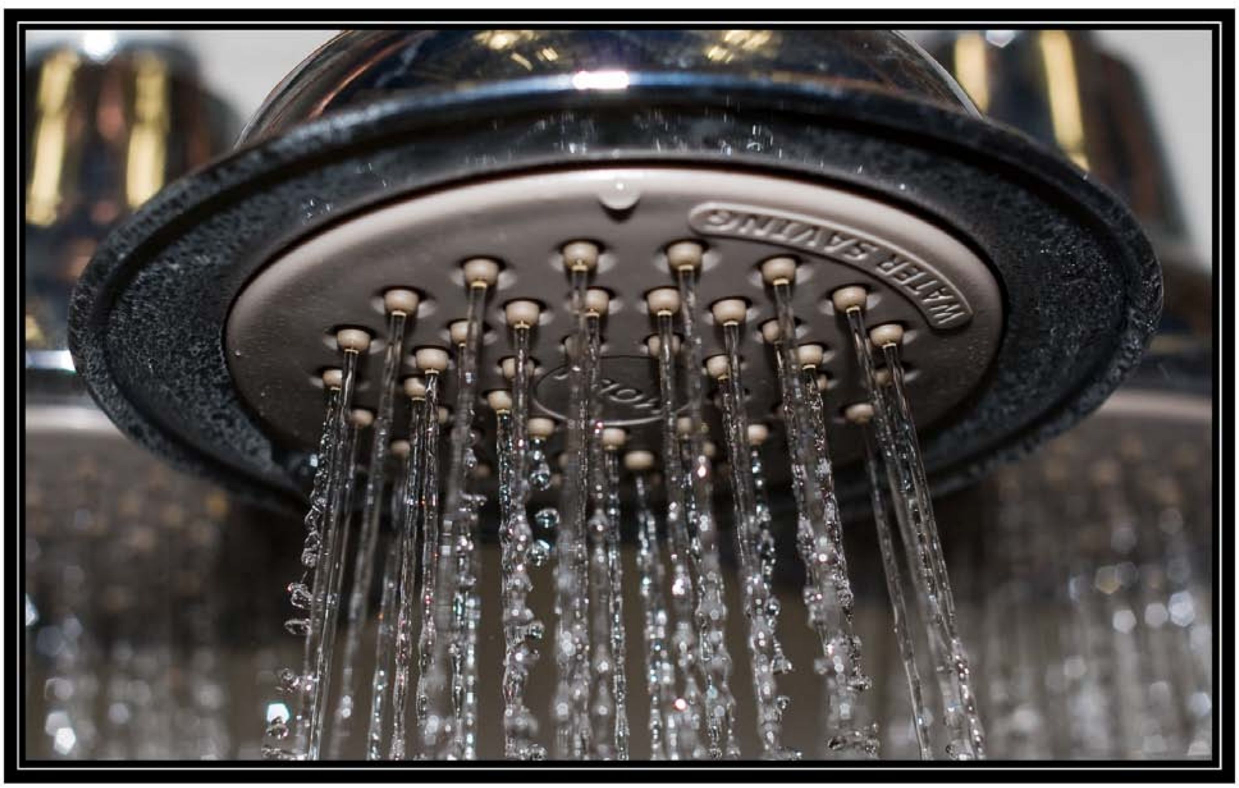


Figure 6-1B. Showerhead 1 on fourth day of testing with softened well water (<1 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-1C. Showerhead 1 on seventh day of testing with soft well water (<1 grain per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-1D. Showerhead 1 on seventh day of testing with soft well water (<1 grain per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 1
Front View

Showerhead 1
Back View

Figure 6-1E. Showhead No. 1 after seven days of testing with soft well water (<1 grain per gallon) showing 45 of 45 spray nozzles open.

Figure 6-2A. Showerhead 2 on fourth day of testing with softened well water (<1 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

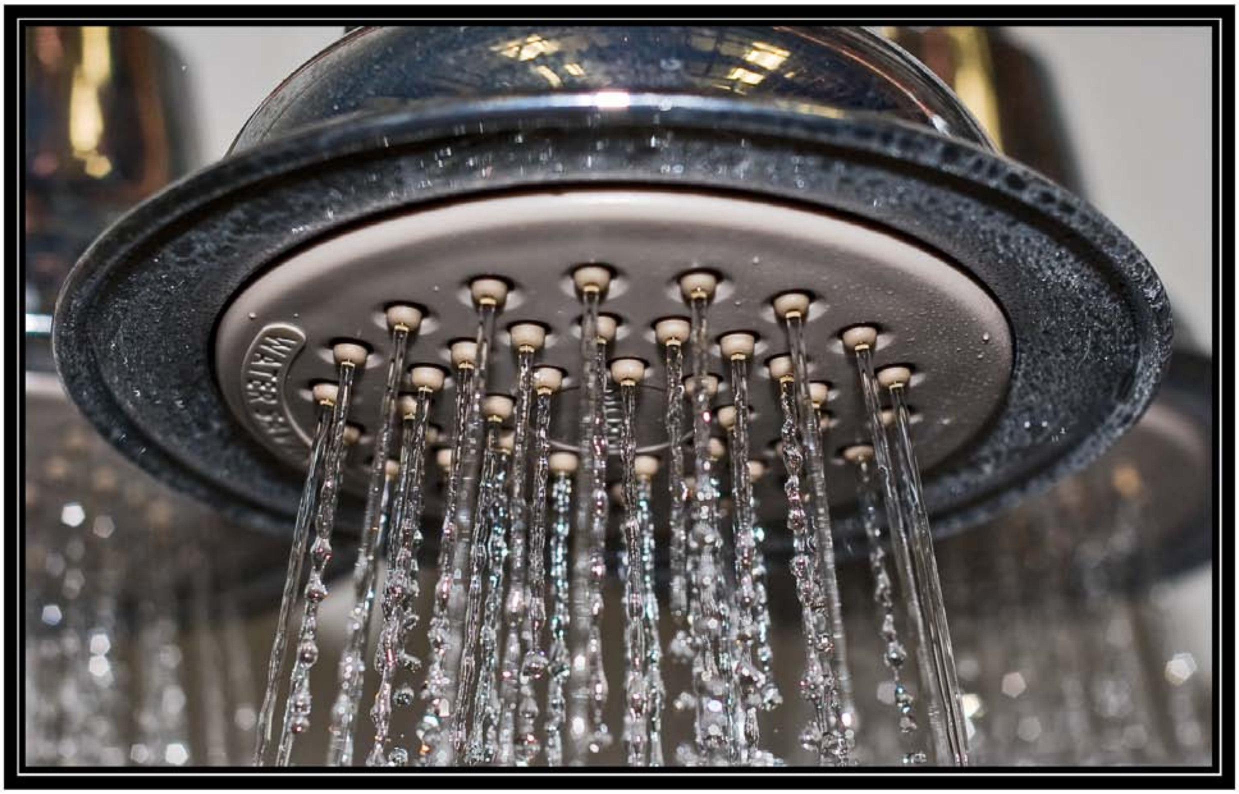
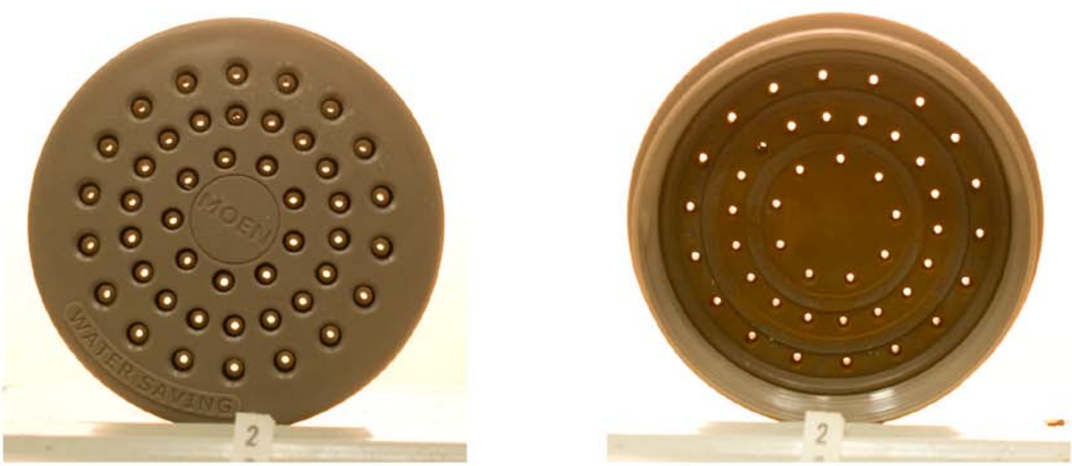


Figure 6-2B. Showerhead 2 on fourth day of testing with softened well water (<1 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-2C. Showerhead 2 on seventh day of testing with soft well water (<1 grain per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-2D. Showerhead 2 on seventh day of testing with soft well water (<1 grain per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009



Showerhead 2
Front View

Showerhead 2
Back View

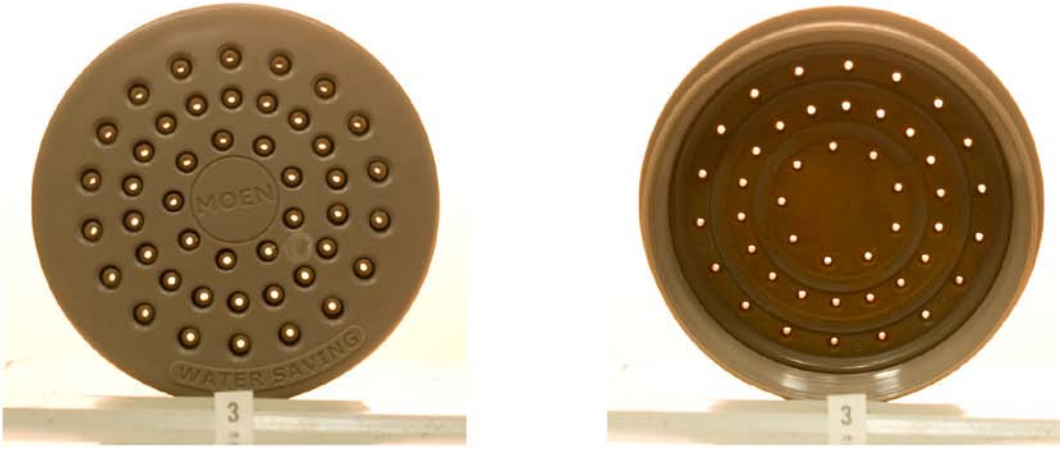
Figure 6-2E. Showhead No. 2 after seven days of testing with soft well water (1 grain per gallon) showing 45 of 45 spray nozzles open.

Figure 6-3A. Showerhead 3 on fourth day of testing with softened well water (<1 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-3B. Showerhead 3 on fourth day of testing with softened well water (<1 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-3C. Showerhead 3 on seventh day of testing with soft well water (<1 grain per gallon)

Figure 6-3D. Showerhead 3 on seventh day of testing with soft well water (<1 grain per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009



Showerhead 3
Front View

Showerhead 3
Back View

Figure 6-3E. Showhead No. 3 after seven days of testing with soft well water (<1 grain per gallon) showing 45 of 45 spray nozzles open.

Figure 6-4A. Showerhead 4 on fourth day of testing with softened well water (<1 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

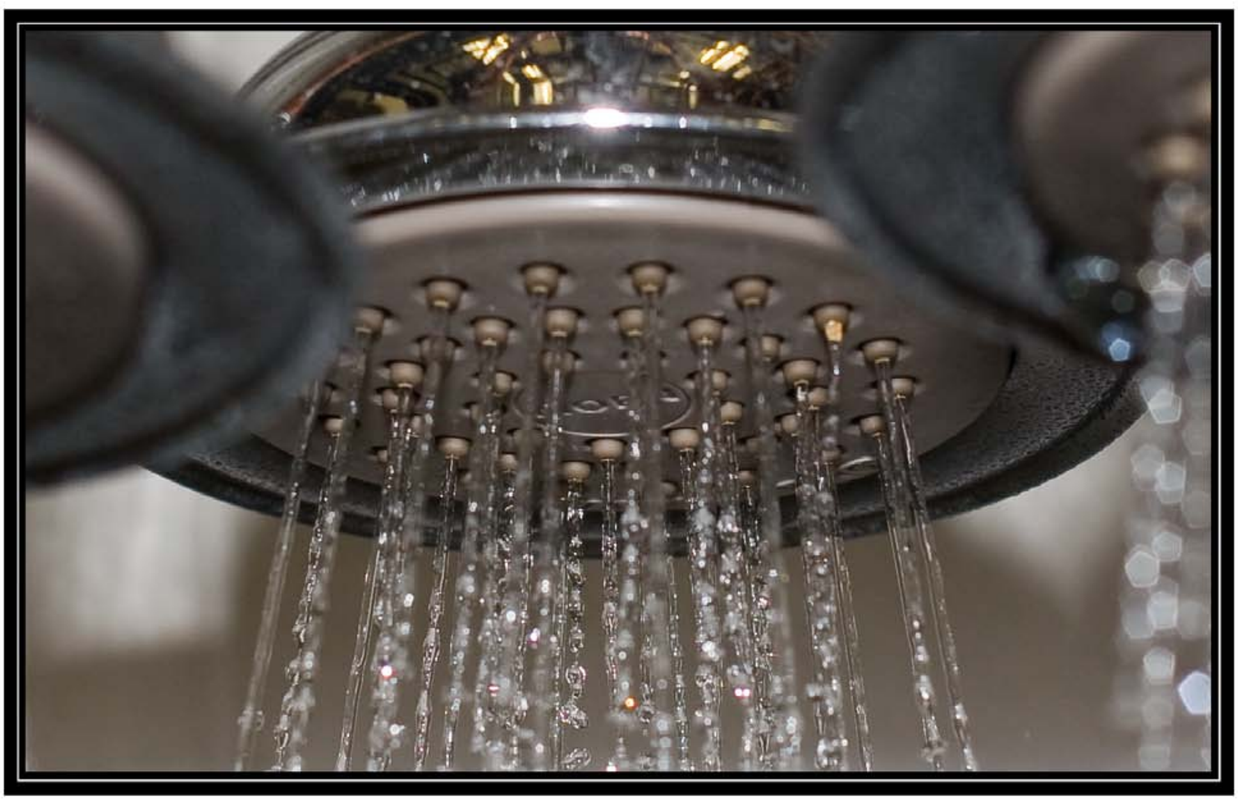


Figure 6-4B. Showerhead 4 on fourth day of testing with softened well water (<1 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-4C. Showerhead 4 on seventh day of testing with soft well water (<1 grain per gallon)

Figure 6-4D. Showerhead 4 on seventh day of testing with soft well water (<1 grain per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 4
Front View

Showerhead 4
Back View

Figure 6-4E. Showhead No. 4 after seven days of testing with soft well water (<1 grain per gallon) showing 45 of 45 spray nozzles open.

Figure 6-5A. Showerhead 5 on fourth day of testing with softened well water (<1 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-5B. Showerhead 5 on fourth day of testing with softened well water (<1 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-5C. Showerhead 5 on seventh day of testing with soft well water (<1 grain per gallon) showing conditon of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-5D. Showerhead 5 on seventh day of testing with soft well water (<1 grain per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 5
Front View

Showerhead 5
Back View

Figure 6-5E. Showhead No. 5 after seven days of testing with soft well water (<1 grain per gallon) showing 43 of 45 spray nozzles open.

Figure 6-6A. Showerhead 6 on fourth day of testing with hard well water (25 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-6B. Showerhead 6 on fourth day of testing with hard well water (25 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-6C. Showerhead 6 on seventh day of testing with Hard well water (28 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-6D. Showerhead 6 on seventh day of testing with hard well water (28 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 6
Front View

Showerhead 6
Back View

Figure 6-6E. Showhead No. 6 after seven days of testing with hard water (28 grains per gallon) showing only 6 of 45 spray nozzles open.

Figure 6-7A. Showerhead 7 on fourth day of testing with hard well water (25 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-7B. Showerhead 7 on fourth day of testing with hard well water (25 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-7C. Showerhead 7 on seventh day of testing with hard well water (28 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-7D. Showerhead 7 on seventh day of testing with soft well water (28 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 7
Front View

Showerhead 7
Back View

Figure 6-7E. Showhead No. 7 after seven days of testing with hard water (28 grains per gallon) showing only 6 of 45 spray nozzles open.

Figure 6-8A. Showerhead 8 on fourth day of testing with hard well water (25 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-8B. Showerhead 8 on fourth day of testing with hard well water (25 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-8C. Showerhead 8 on seventh day of testing with hard well water (28 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-8D. Showerhead 8 on seventh day of testing with hard well water (28 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 8
Front View

Showerhead 8
Back View

Figure 6-8E. Showhead No. 8 after seven days of testing with hard water (28 grains per gallon) showing only 6 of 45 spray nozzles open.

Figure 6-9A. Showerhead 9 on fourth day of testing with hard well water (25 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-9B. Showerhead 9 on fourth day of testing with hard well water (25 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-9C. Showerhead 9 on seventh day of testing with hard well water (28 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-9D. Showerhead 9 on seventh day of testing with hard well water (28 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 9
Front View

Showerhead 9
Back View

Figure 6-9E. Showhead No. 9 after seven days of testing with hard well water (28 grains per gallon) showing only 8 of 45 spray nozzles open.

Figure 6-10A. Showerhead 10 on fourth day of testing with hard well water (25 grains per gallon) showing condition of nozzles. Battelle testing for Water Quality Association. April 28, 2009

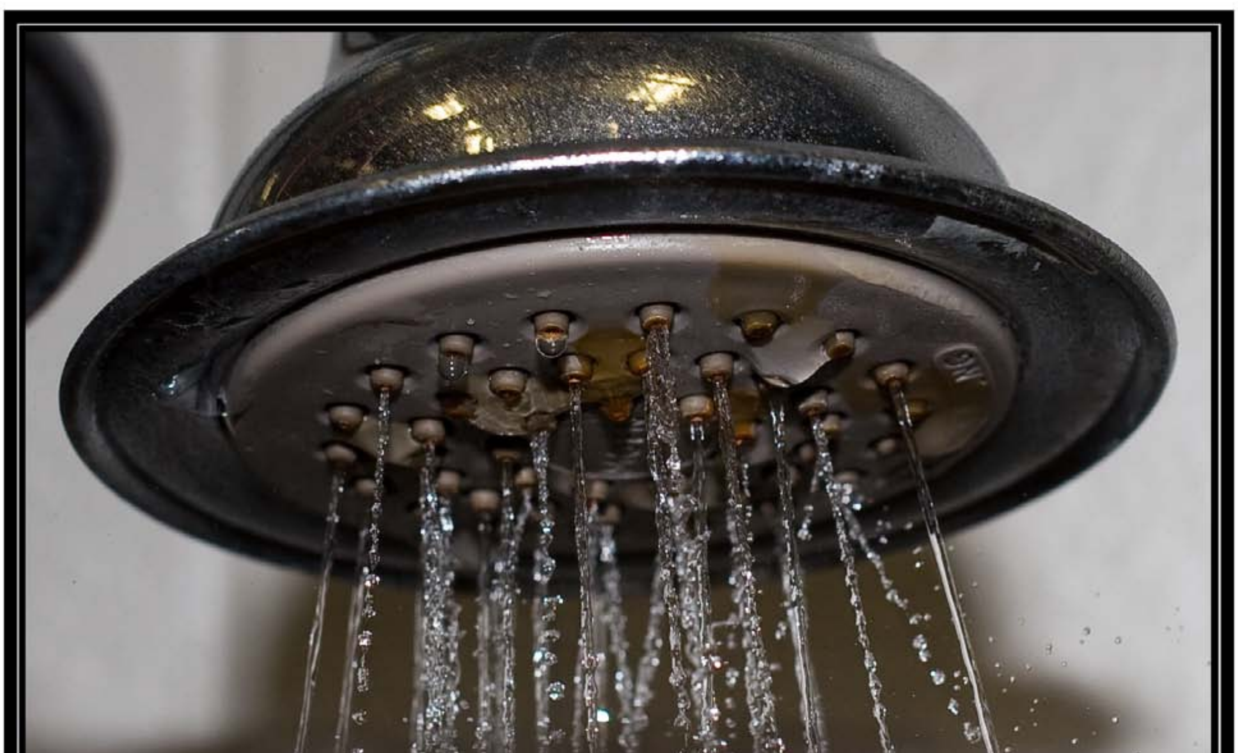


Figure 6-10B. Showerhead 10 on fourth day of testing with hard well water (25 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. April 28, 2009

Figure 6-10C. Showerhead 10 on seventh day of testing with hard well water (28 grain per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Figure 6-10D. Showerhead 10 on seventh day of testing with hard well water (28 grains per gallon) showing spray pattern. Battelle testing for Water Quality Association. May 1, 2009

Showerhead 10
Front View

Showerhead 10
Back View

Figure 6-10E. Showhead No. 10 after seven days of testing with hard well water (28 grains per gallon) showing only 11 of 45 spray nozzles open.

Showerhead 1
Soft Well Water

Showerhead 6
Hard Well Water

Figure 6-11A. Showerheads Nos. 1 and 6 after seven days of testing with soft (<1 grain per gallon) and hard (28 grains per gallon) well water, respectively, showing condition of scale on outside of spray nozzles. Nozzle 1 was cut open prior to this photo being taken. (May 1, 2009)

Showerhead 2
Soft Well Water

Showerhead 7
Hard Well Water

Figure 6-11B. Showerhead Nos. 2 and 7 after seven days of testing with soft (<1 grain per gallon) and hard (28 grains per gallon) well water, respectively, showing condition of scale on outside of spray nozzles.

Showerhead 3
Soft Well Water

Showerhead 8
Hard Well Water

Figure 6-11C. Showerhead Nos. 3 and 8 after seven days of testing with soft (<1 grain per gallon) and hard (28 grains per gallon) well water, respectively, showing condition of scale on outside of spray nozzles.

Showerhead 4
Soft Well Water

Showerhead 9
Hard Well Water

Figure 6-11D. Showerheads Nos. 4 and 9 after seven days of testing with soft (<1 grain per gallon) and hard (28 grains per gallon) well water, respectively, showing condition of scale on outside of spray nozzles.

Showerhead 5
Soft Well Water

Showerhead 10
Hard Well Water

Figure 6-11E. Showerheads Nos. 5 and 10 after seven days of testing with soft (<1 grain per gallon) and hard (28 grains per gallon) well water, respectively, showing condition of scale on outside of spray nozzles.