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Study Findings and Executive Summaries

Softened Water Benefits Study:

- **Energy Savings**
- **Detergent Savings**

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Softened Water Benefits Study

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The Energy Savings Study was conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation. The Detergent Savings Study was conducted in 2010 in conjunction with Scientific Services S/D, Inc. and funded by the Water Quality Research Foundation.

The Energy Savings Study (aka The Battelle Study)

Study on Benefits of Removal of Water Hardness (Calcium and Magnesium Ions) From a Water Supply

This study tested devices fed with softened and unsoftened water under controlled laboratory conditions designed to accelerate the waterside 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.

The Detergent Savings Study

Evaluation of Relative Effects of Hardness, Detergent Dose and Temperature to Evaluate Stain Removal Efficacy, and/or Use of Less Laundry Detergent at Lower Water Temperatures

The laundry study investigated stain removal with varying levels of hardness, detergent dose, and temperature. Detergent usage was 50, 75 and 100% of the manufacturers recommended level. Water hardness ranged from 0 to 513 ppm (30 grains/gallon). Wash temperature was 60, 80 and 100ºF. Statistical analysis was conducted to compare the ability of softening water to mitigate the adverse effects of lower detergent dosage and lower wash temperature in turn decreasing costs and energy usage.

Evaluation of the Effect of Water Hardness on Performance of Automatic Dishwasher Detergents and Savings Possible by Softening Water

Detergent savings was also evaluated for dishwashers. The detergent savings study included tests for removing difficult soils in addition to the spot and film evaluation. The relationship between detergent dose and hardness was investigated with three nonphosphate automatic dishwashing detergents with two consecutive wash-dry cycles for spot and film. One detergent was evaluated for five cycles to ensure that effects do not change with increased number of cycles.

The Energy Savings Study was conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation. The Detergent Savings Study was conducted in 2010 in conjunction with Scientific Services S/D, Inc. and funded by the Water Quality Research Foundation.

Softened Water Benefits Study

Energy Savings

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Study Findings

Gas Storage Tank Water Heaters:

- **With softened water –** Gas storage tank household water heaters operated on softened water maintained the original factory efficiency rating over a 15-year lifetime.
- **With hard water –** Hard water can lead to as much as a 24% loss of efficiency in water heaters.
  - Each 5 grains per gallon of water hardness causes a 4% loss in efficiency and 4% increase in cost for gas storage tank water heaters when using 50 gallons of hot water per day. (On 30 gpg hard water, that's 24% less efficient than with softened water.)

Tankless Heaters:

- **The economic savings of softened water with instantaneous tankless water heaters can lead to recovery of the cost of a water softener and operating supplies in a period as short as a year,** if the incoming water is sufficiently hard.
- **With softened water –** Indoor instantaneous gas water heaters (tankless heaters) operated on softened water maintained the original factory efficiency rating over a 15-year lifetime.
- **With hard water**
  - The study found that tankless water heaters completely failed to function because of scale plugging in the downstream plumbing after only 1.6 years of equivalent hot water use on 26 gpg hard water.
  - Softened water saves 40% of costs compared to operating on 20 gpg and saves 57% compared to operation on 30 gpg hard water.

Electric Water Heaters:

- **Up to 30 pounds calcium carbonate rocklike** scale deposits can accumulate in electric water heaters.
- **Each 5 gpg of water hardness caused 0.4 pounds of scale** accumulation each year in electric storage tank household water heaters.
- ***"the life of the heating element can be expected to shorten due to scale buildup increasing the operating temperature of the element"*** in the electric storage water heaters operating on unsoftened water, says Battelle Memorial Institute.

Carbon Footprint:

- **The carbon footprint increases 18%** for gas storage tank water heaters when operated on 26 gpg hard water for 15 years as compared to the same operation on 0 gpg softened water.
- **For instantaneous-type natural gas water heaters, this same carbon footprint increases 4%** when operated on 26 gpg hard water versus 0 gpg softened water over 15 years.

Showerheads and Fixtures:

- **With softened water –** Showerheads on soft water maintained a brilliant luster and full flow. Faucets on softened water performed well throughout the study; nearly as well as the day they were installed.
- **With hard water –** Showerheads on hard water lost 75% of the flow rate in less than 18 months.
  - Faucets on hard water could not maintain the specified 1.25 gallons per minute flow rate because of scale collection of the strainers. The strainers on the faucets using unsoftened water were almost completely plugged after 19 equivalent days of testing.

Benefits of Removal of Water Hardness From a Water Supply research study conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation.

Executive Summary

This study tested devices fed with softened and unsoftened water under controlled laboratory conditions designed to accelerate the waterside 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 waterside 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.

Benefits of Removal of Water Hardness From a Water Supply research study conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation.

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	Test Start	Test End	Equivalent Field Service (Years)	Average Annual Scale Accumulation[1] (grams/year)	Carbon Footprint[2] (kg CO_2/gal hot water)
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 pounds 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.

Benefits of Removal of Water Hardness From a Water Supply research study conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation.

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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 a water softener, and consequently greater energy costs.

Table ES-2 – Estimated Savings for Gas-fired Water Heaters Using Softened Water Over 15 Years Life

	Water Hardness (grains per gallon)						
Cost Elements	**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

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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.

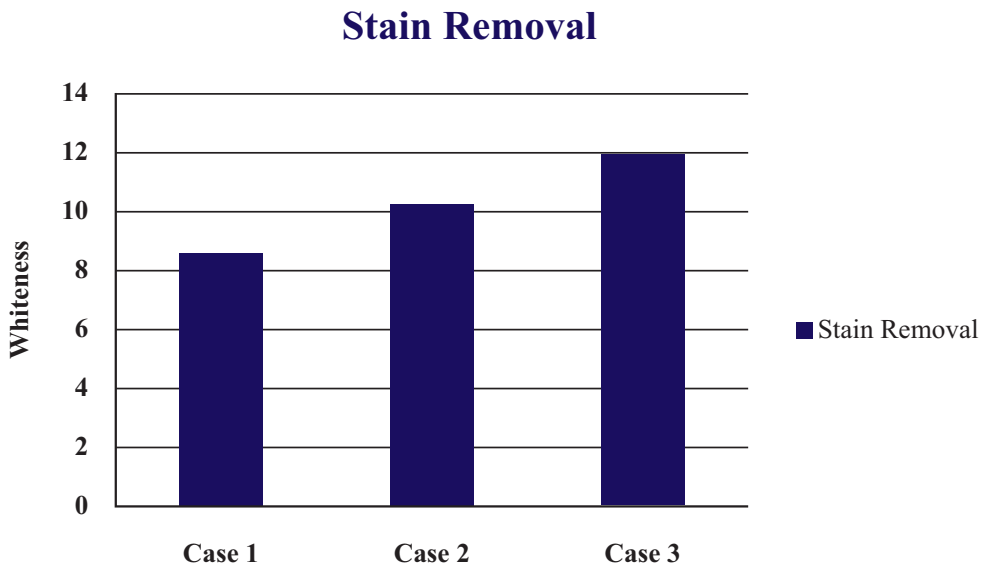
Low flow showerheads and faucets using unsoftened water clogged in less than seven days of accelerated life testing, whereas those units using softened water made it through the test without any problems.

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.

Benefits of Removal of Water Hardness From a Water Supply research study conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation.

Laundry Study Findings

The savings in detergent use and the energy required to heat the water is very high for each of the stains tested. Even when 50% of the detergent is used at a lower temperature of 60ºF instead of 100ºF, the washing yielded improved results when the softened water was used as compared to when hard water was used. The graph below shows that one can use cold water and half the detergents for washing clothes stained with any or all of these stains and still achieve the soil removal desired, if the very hard water is softened prior to such use. This is the most significant conclusion of this study.



Pattern	Hardness, ppm	Dose, %	Temperature, F
Case 1	513	100	100
Case 2	256.5	75	80
Case 3	0	50	60

- Stain removal performance increases dramatically when hardness is removed even when dose and temperature are also lowered. Depending on the stain, hardness reduction was up to 100 times more effective at stain removal than increasing temperature or increasing detergent dose.
- Softening water will allow use of less detergent and save energy by lowering water temperatures while still maintaining or improving performance.
- When water of any hardness is softened prior to its use in washing, the detergent use can be reduced by 50% and the washing can be carried out in 60ºF cold water instead of 100ºF hot water and achieve the same or better stain removal yielding whiter clothes.
- This was true for all stains and all detergents tested.
- This was verified for top-loaded and high-efficiency front-loaded washers.

The Detergent Savings Study was conducted in 2010 in conjunction with Scientific Services S/D, Inc. and funded by the Water Quality Research Foundation.

Softened Water Benefits Study

Detergent Savings – Laundry Study

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Executive Summary

A series of designed experiments were carried out to compare the effects of detergent dose, water hardness, and wash temperature on the stain removal performance of five household laundry detergents by Scientific Services Laboratories located near Middletown, NY.

- **Detergent usage was 50, 75 and 100% of the manufacturers recommended level.**
- **Water hardness levels of 0 and 513 ppm (30 gpg) plus a center point level of 257 ppm (15 gpg) were employed in these experiments.**
- **Wash temperatures tested were 60, 80 and 100ºF.**

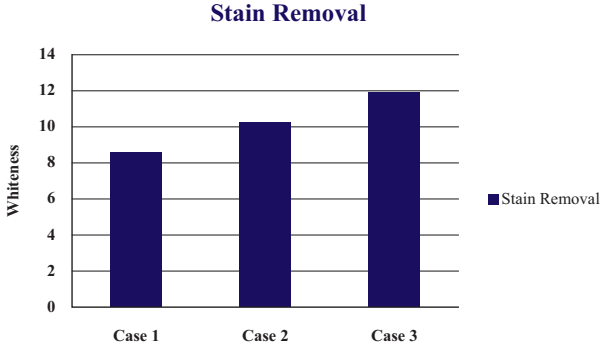
Stain removal effect of the following nine stains were studied:

- **Blood, coffee, dust sebum, grass, red wine, chocolate pudding, chocolate ice cream, barbecue sauce, ground in clay**

Six (6) liquid and three powder detergents were used in this study with five of them being used more completely in these experiments.

The guidelines of ASTM D 4265 were followed for the tests. Standard soiled and stained cotton swatches were used. The reflectance readings before and after the wash were measured and used for the analysis. JMP statistical software program was used to interpret the implications of the results obtained in this study.

The savings in detergent use and the energy required to heat the water is very high for each of the stains tested. Even when 50% of the detergent is used at a lower temperature of 60ºF instead of 100ºF, the washing yielded improved results when the softened water was used as compared to when hard water was used. The graph below shows that one can use cold water and half the detergents for washing clothes stained with any or all of these stains and still achieve the soil removal desired, if the very hard water is softened prior to such use. This is the most significant conclusion of this study.



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The Detergent Savings Study was conducted in 2010 in conjunction with Scientific Services S/D, Inc. and funded by the Water Quality Research Foundation.

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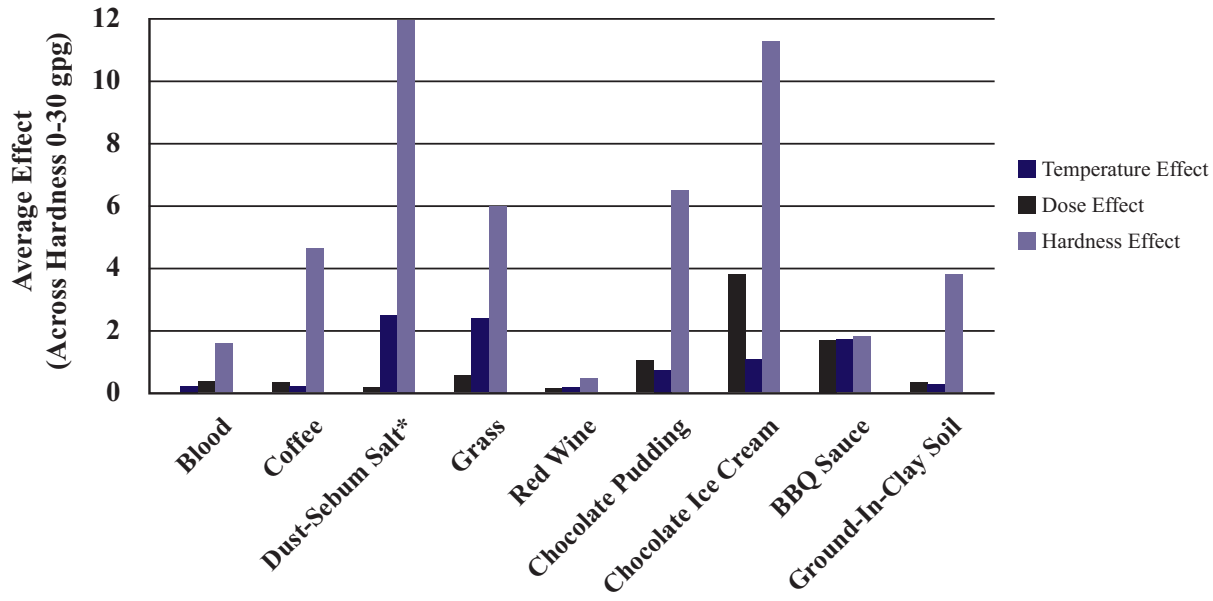
Reduction of hardness is significantly more effective on stain removal than either increase in temperature or detergent dose. This is demonstrated in the graph below for top loading washers, but it was also confirmed for side loading washers.

Top-Loaded Washers
Comparison of Temperature, Dose, and Hardness Effects on Stain Removal



*Note that the hardness effect of dust-sebum actually continues to 62.6 and is the most significant effect.

The results also showed the following conclusions:

- **Stain removal performance increases dramatically when hardness is removed even when dose and temperature are also lowered. Depending on the stain, hardness reduction was up to 100 times more effective at stain removal than increasing temperature or increasing detergent dose.**
- **Softening water will allow use of less detergent and save energy by lowering water temperatures while still maintaining or improving performance.**
- **When water of any hardness is softened prior to its use in washing, the detergent use can be reduced by 50% and the washing can be carried out in 60ºF cold water instead of 100ºF hot water and achieve the same or better stain removal yielding whiter clothes.**
- **This was true for all stains and all detergents tested.**
- **This was verified for top-loaded and high-efficiency front-loaded washers.**

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Softened Water Benefits Study

Detergent Savings – Dishwasher Study

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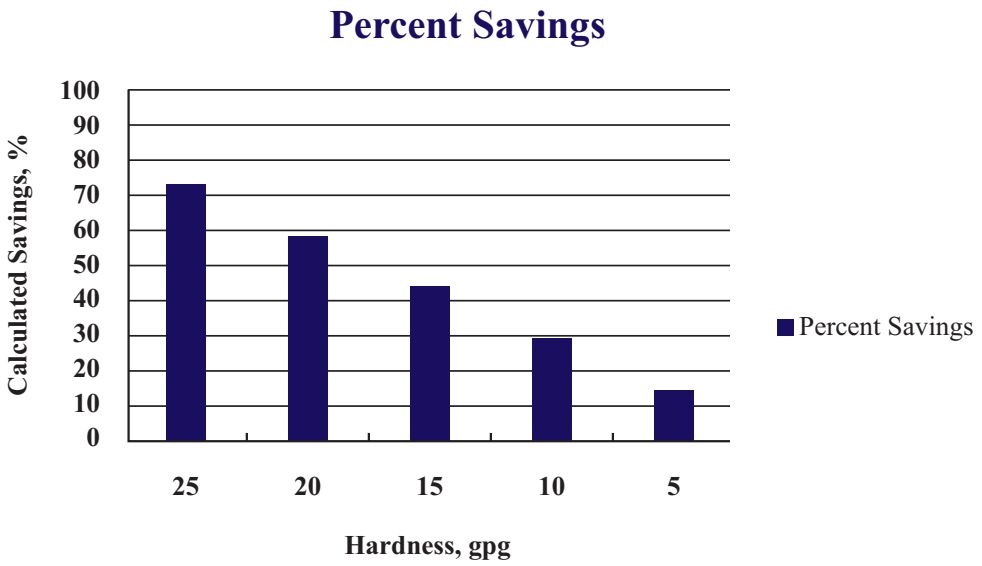
Dishwasher Study Findings

Statistically significant improvements by softening water with hardness were observed in spotting and filming performance as well as in better soil removal in automatic dishwashing. A graph showing the savings in detergent possible has been generated.



- Detergent savings up to 70% was observed for dishwashing when softened water was used compared to hard water. Depending on the soil, hardness reduction was found to be up to 12 times more effective at soil removal than increasing detergent dose.
- Hardness reduction was ~6 times more effective at reducing spotting and twice as effective at reducing filming as increasing detergent usage.
- One detergent was run for an additional three cycles to show that the hardness/dose performance relationship would persist.
- Air drying as a way to save electrical energy was evaluated and is promising to provide better results when softened water is used rather than hard water.
- With both tablet detergents, the beneficial effect of softening the wash water is much greater than the use of two tablets rather than one.

The Detergent Savings Study was conducted in 2010 in conjunction with Scientific Services S/D, Inc. and funded by the Water Quality Research Foundation.

Executive Summary

A study was conducted to investigate the interaction of detergent dose and water hardness levels on the performance of automatic dishwashers. Removal of difficult soils, as well as the resultant appearance in terms of spotting and filming, was measured by Scientific Services S/D, Inc. located in Sparrow Bush near Middletown, NY.

Two dishwashers with the specified load, as shown below, were used in all of these tests. The load consisted of:

- **Dinner plates, silverware, glasses**
- **Standard soils for filming and spotting including oatmeal, dry milk, and grease**
- **Hard-to-remove-soils such as egg yolk, pizza sauce, spinach, brownie mix, fish, bread crumbs & olive oil**

The guidelines of ASTM D 3556 were followed for the tests. Evaluations of the glasses and saucers were performed at the end of each of the two cycles after cooling and aging. At least three trained evaluators were used.

Six commercially available detergents (4 liquid and 2 tablets) were used in this study with three being used in the main part of the study in a comprehensive way.

Detergent levels and hardness levels used in these tests are shown below:

- **Detergent dosages used in these tests were the amounts that can be contained in small cup, large cup, and in both cups, which corresponds to 30 g, 55 g, 85 g.**
- **Water hardness levels of 0 and 513 ppm (30 gpg) plus a center point level of 257 ppm (15 gpg) were employed in these experiments.**
- **Results were then arranged for statistical analysis by JMP Statistical Software.**

Statistically significant improvements by softening water with hardness were observed in spotting and filming performance as well as in better soil removal in automatic dishwashing. A graph showing the possible savings in detergent has been generated as shown on the following page:

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Softened Water Benefits Study

Detergent Savings – Dishwasher Study

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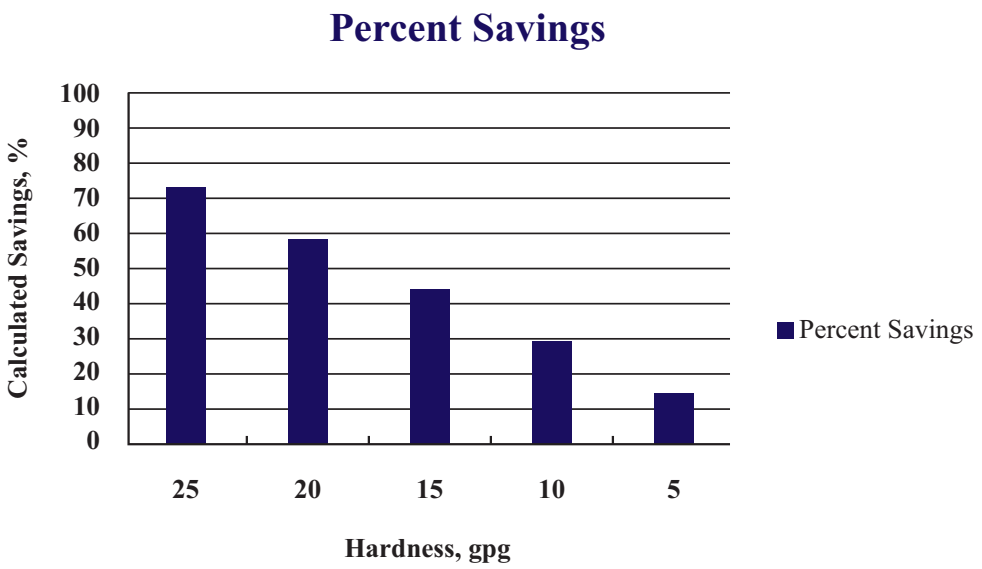

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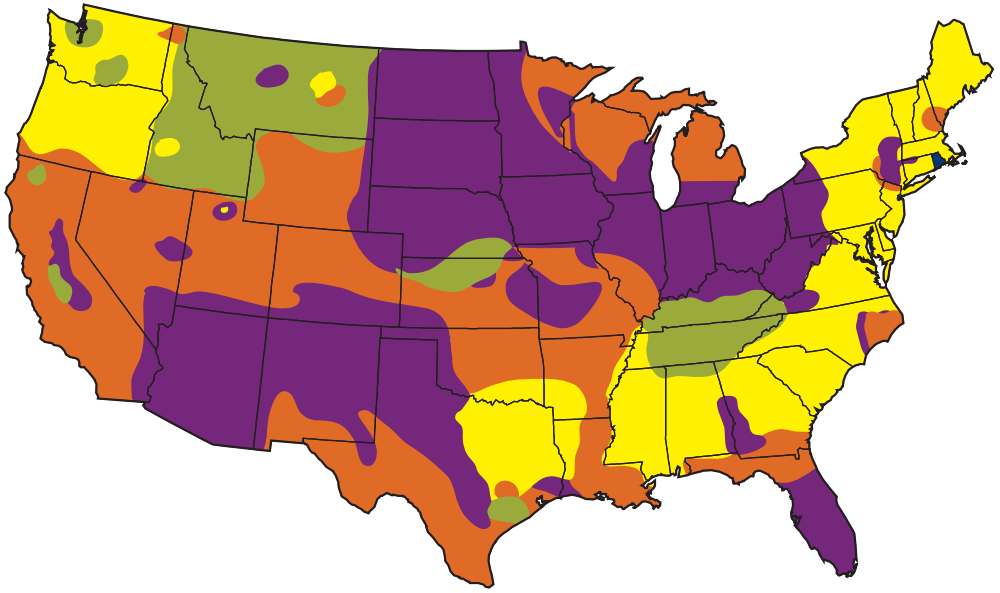
CONCENTRATION OF WATER HARDNESS ACROSS THE UNITED STATES

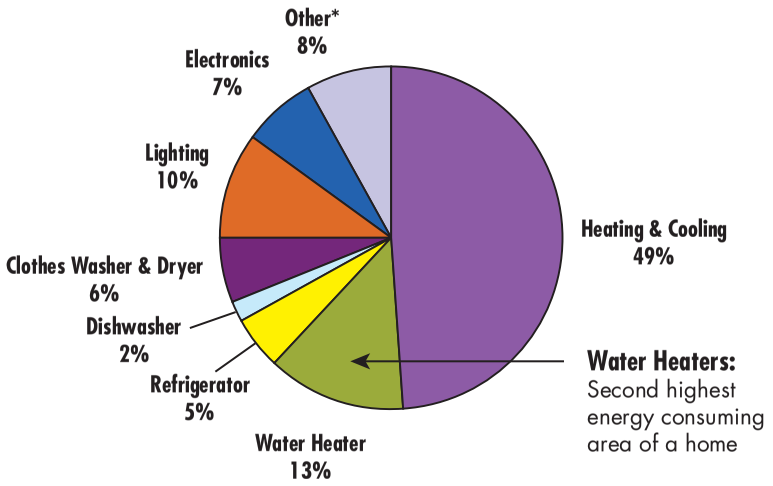


- Very Hard (10+ gpg)
- Hard (7-10.5 gpg)
- Moderately Hard (3.5-7 gpg)
- Slightly Hard (1-3.5 gpg)

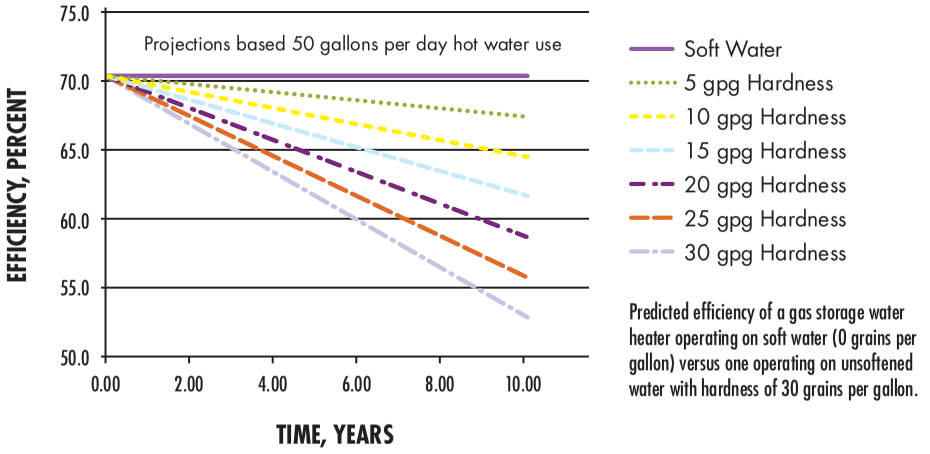
gpg = grains per gallon

Source: Water Quality Association

US HOUSEHOLD ENERGY USAGE



PREDICTED EFFICIENCY



Predicted efficiency of a gas storage water heater operating on soft water (0 grains per gallon) versus one operating on unsoftened water with hardness of 30 grains per gallon.

Benefits of Removal of Water Hardness From a Water Supply research study conducted in 2009 in conjunction with the Battelle Memorial Institute and funded by the Water Quality Research Foundation.

Water Quality Association

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