SWEEP

(Save Water & Energy Education Program)

Frigidaire

caroma AUSTRALIA

City of WILSONVILLE in OREGON

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

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The Save Water and Energy Education Program: SWEEP

Water and Energy Savings Evaluation

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Executive Summary

In 1999 and 2000, in response to a significant water shortage, two of Oregon's fastest growing cities, Lafayette and Wilsonville, volunteered to be "test communities" for an innovative approach to saving water and energy. The Save Water and Energy Education Program (SWEEP) was designed to maximize water and energy savings in these communities and to serve as a model for other communities seeking an integrated approach to resource efficiency.

The cities of Lafayette (pop. 2,586) and Wilsonville (pop. 13,991) joined with a number of companies and government agencies to implement a program that seeks to educate citizens, involve students from local schools, demonstrate the effectiveness of high-efficiency appliances, and save money for citizens and the cities. In addition to the cities, program partners included the U.S. Department of Energy, Electrolux Home Products (donor of 50 sets of Frigidaire high-performance clothes washer/dryer pairs and dishwashers), Caroma USA, Inc. (donor of over 100 high-performance dual-flush toilets), the Pacific Northwest National Laboratory (PNNL), Portland General Electric (the serving electric utility and donor of faucet aerators and low-flow showerheads), Energy Technology Laboratories (also a donor of showerheads), the Oregon Office of Energy, CTSI Corporation, the Northwest Energy Efficiency Alliance, the League of Oregon Cities, and the Mid-Willamette Valley Council of Governments.

Participating appliance and fixture manufacturers donated the water and energy-efficient devices for installation in the 50 test homes, 25 in each community. The equipment included clothes washers, clothes dryers, dishwashers, toilets, showerheads, and faucet aerators. All homes received the new appliances and toilets; only a subset of homes received the new showerheads and aerators because most of the homes had already participated in a successful showerhead/aerator program sponsored by Portland General Electric.

PNNL evaluated the water and energy savings achieved in these homes. This was done with a unique approach to estimating end-use water savings using data collected at the whole-house water meter. These data were then disaggregated into individual household water uses, using a special software package. This method allows appliance-by-appliance water savings estimates without having to individually meter those appliances. More limited end-use metering was done to verify results and to collect energy use data. Data were collected over a two-month *baseline* period (before SWEEP was implemented) and then again over a two-month *retrofit* period (after the new equipment was installed).

The evaluation results presented below are from the end-use metering of the 50 test homes. These homes were chosen for their water savings potential—the test homes were built before

passage of the Energy Policy Act of 1992 (EPAct),[1] when the use of some types of water- and energy-efficient equipment became mandatory. In addition, the homes were chosen to be representative of those in the communities—that is, they were chosen to ensure the program had a representative distribution of both home size and occupancy.

Figure S.1 presents the 25-home aggregation of all annual indoor water use for the *baseline* (before SWEEP was implemented), for the *retrofit* (after SWEEP was implemented), and for the resulting *savings*. The results are presented for both cities and then for the combined study mean. The units shown in the graph are in thousands of gallons (kgal).

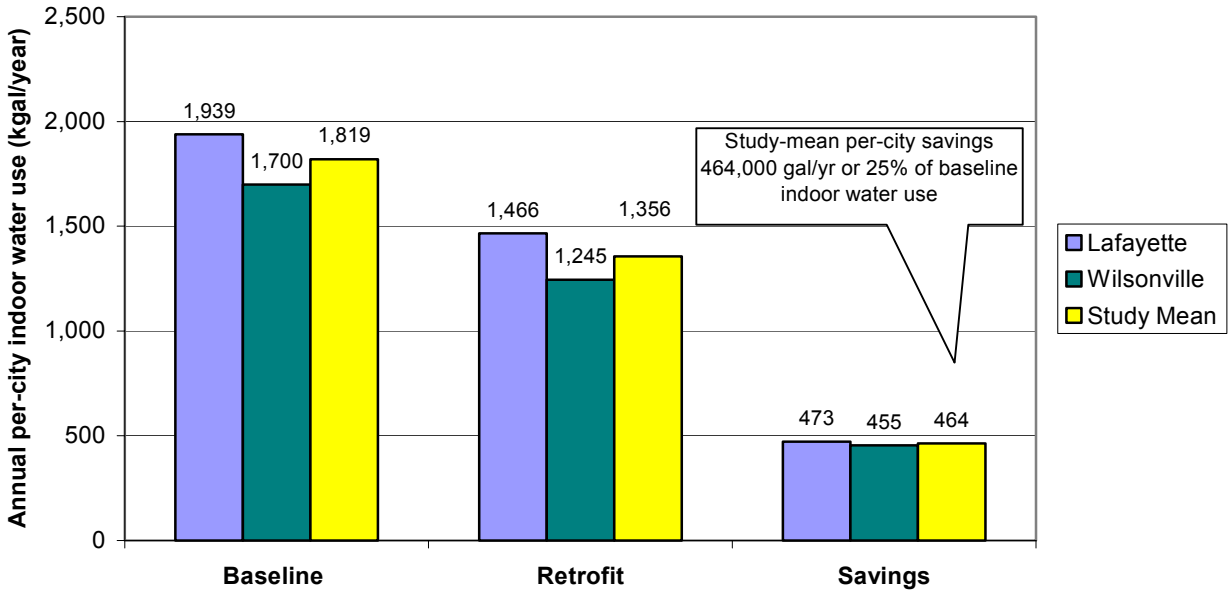

Figure S.1. Annual Per-City Indoor Water Use and Savings (kgal/yr) for the 25 SWEEP Homes in Each City: Aggregated Program Equipment (clothes washer, dishwasher, and toilet) Findings

While the sample of homes in SWEEP is not representative of the entire population of homes in these cities, we do feel it is representative of homes built before the passage of EPAct. The water savings potential for a SWEEP program implemented in 100, pre-EPAct homes would be more than 1.8 million gallons/yr; if implemented in 1,000 homes the SWEEP savings potential would be over 18.5 million gallons/yr.

[1] The Energy Policy Act of 1992 (EPAct) was signed into law by President George Bush and was designed to, among other things, help reduce the amount of energy and water used by various consumer and industrial products.

Couching these savings in a slightly different way, if one were to place one-gallon plastic milk jugs, side-by-side, and fill them with the annual water savings from 100 SWEEP homes, the line of jugs would stretch about 175 miles—or from Portland to Roseburg along Interstate 5.

Presented in Figure S.2 are the aggregated per-home findings for both cities and the study mean. The aggregated per-home data indicate a mean annual savings of about 18,600 gallons. These savings represent a 25% reduction in mean per-home indoor water use over the baseline. Put in different terms, these savings represent the water used by over 700 clothes washing cycles—that's about two-years' worth of clothes washing for the typical family.

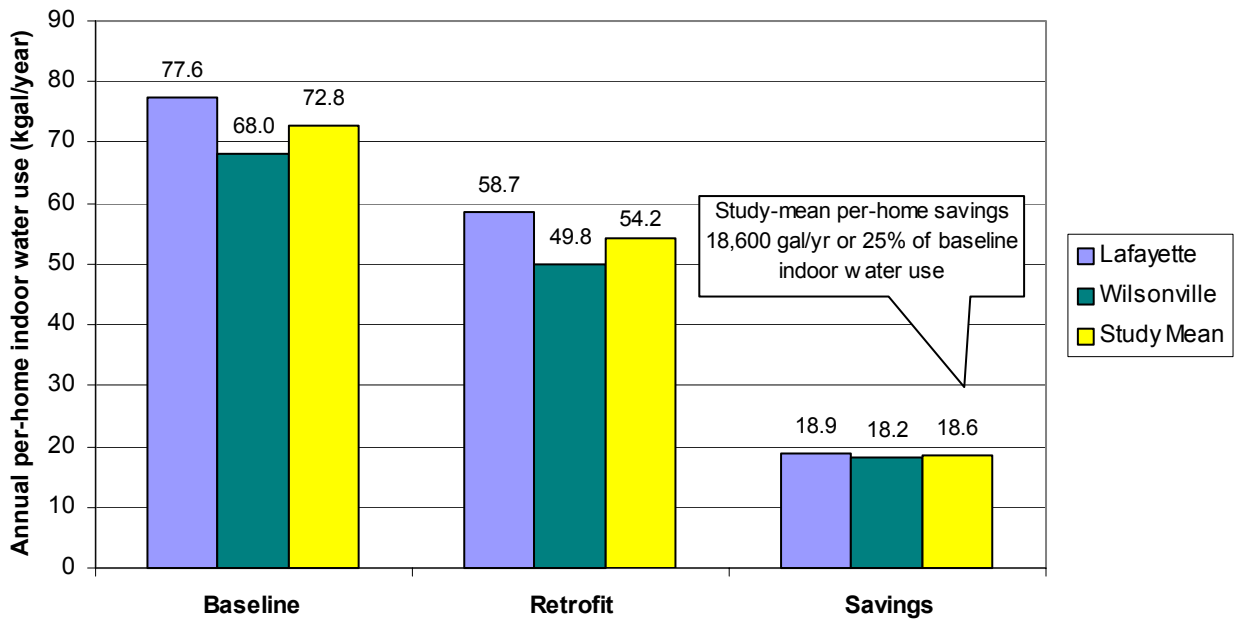

Figure S.2. Annual Per-Home Indoor Water Use and Savings (kgal/yr): Aggregated Program Equipment (clothes washer, dishwasher, toilet) Findings

Clothes Washer Results

Figure S.3 presents the mean per-cycle clothes washer total water use and savings resulting from the SWEEP program. The mean water savings was 15.2 gallons/cycle, for a 38% reduction in use over the baseline. Aggregated over the year, the new clothes washer results in mean savings of over 6,300 gallons per home. These annual savings represent the water used by more than 250 clothes washings in the new washer.

Figure S.4 presents the mean per-cycle clothes washer total energy use and savings from the program. The mean electricity savings from the new washer was 0.9 kWh/cycle, for a 68% reduction in use over the baseline (data presented here assume electric water heater—gas water heating is discussed in the body of this report). Aggregated over the year, the clothes washer

results in a mean electricity savings of 440 kWh per home—that's about the amount of electricity used in a new energy-efficient refrigerator for one year.

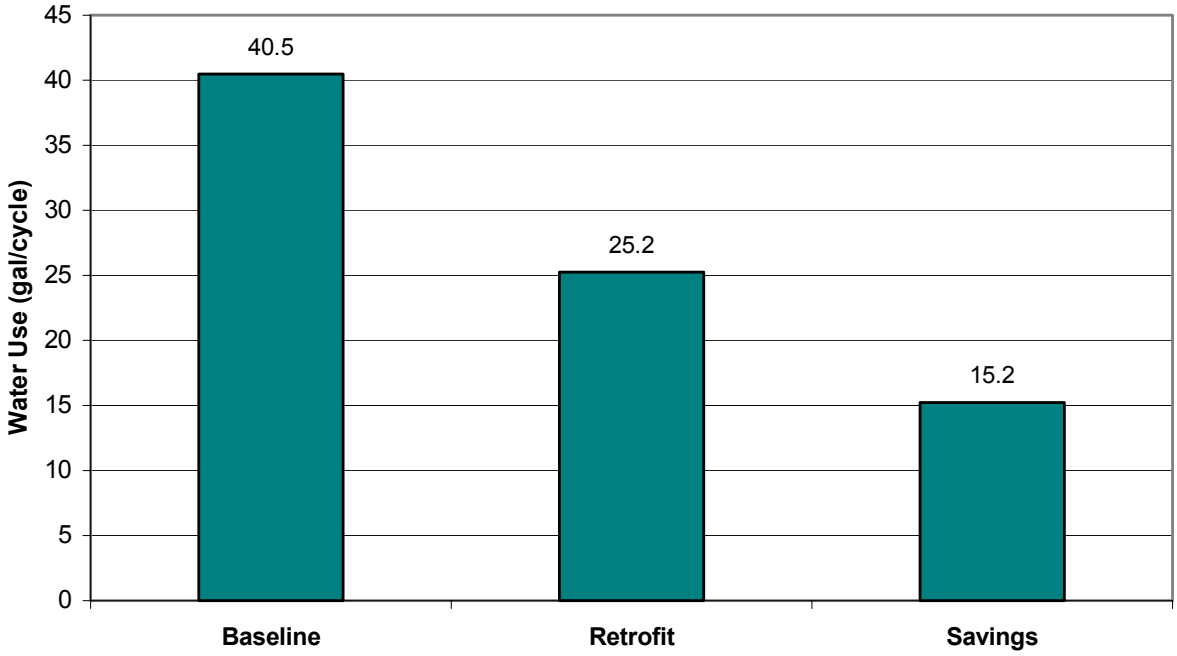

Figure S.3. Clothes Washer Findings: Mean Per-Cycle Water Use and Savings (gal/cycle)

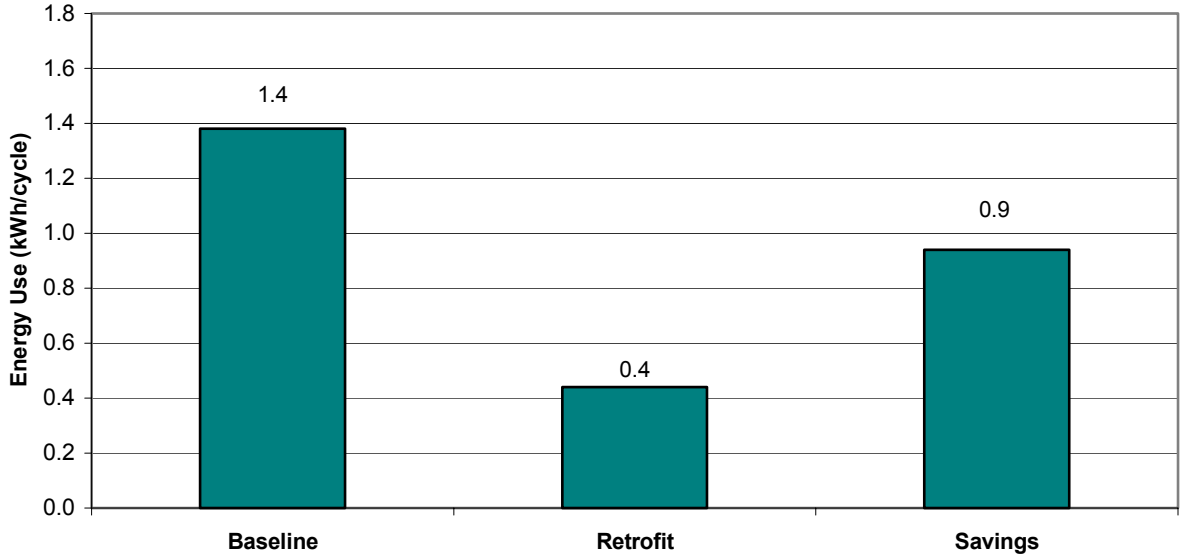

Figure S.4. Clothes Washer Findings: Mean Per-Cycle Electricity Use and Savings (kWh/cycle)

Clothes Dryer Results

Figure S.5 presents the mean per-cycle clothes dryer total energy use and savings from the program. The mean electricity savings from the new dryer was 0.8 kWh/cycle, for a 25% reduction in use over the baseline. Aggregated over the year, the clothes dryer results in a mean electricity savings of 290 kWh per home.

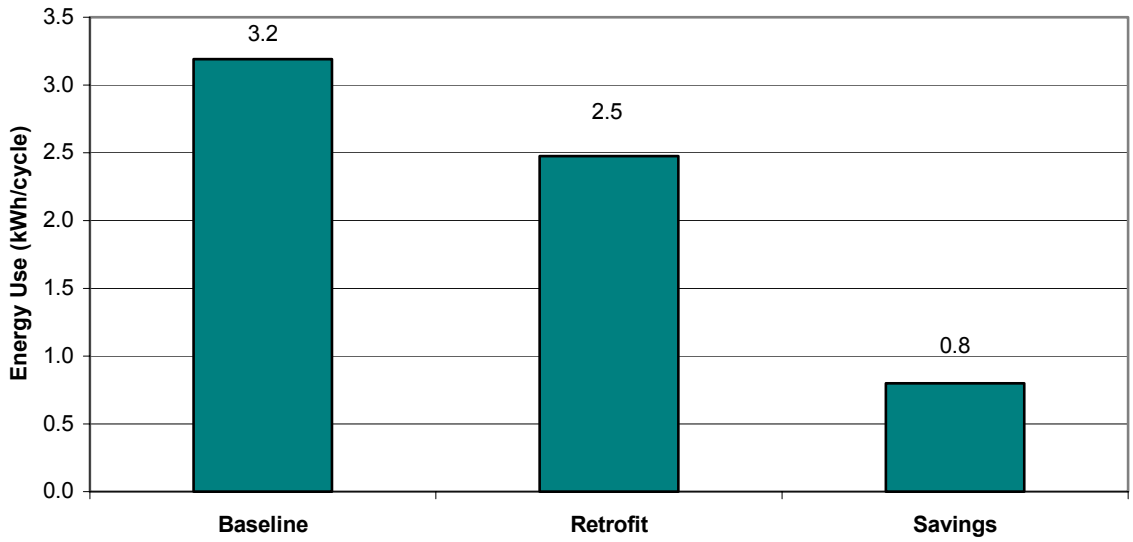

Figure S.5. Clothes Dryer Findings: Mean Per-Cycle Electricity Use and Savings (kWh/cycle)

Dishwasher Results

Figure S.6 presents the mean per-cycle dishwasher total water use and savings from the program. The mean water savings from the new washer was 3.7 gallons/cycle, for a 39% reduction in use over the baseline. Aggregated over the year, the dishwasher results in mean savings of 690 gallons per home in water savings. These annual savings represent the water used by more than 120 dishwashings in the new dishwasher.

Figure S.7 presents the mean per-cycle dishwasher energy use and savings from the program. The mean electricity savings from the new dishwasher was 0.6 kWh/cycle, for a 39% reduction in use over the baseline. Aggregated over the year, the dishwasher results in a mean electricity savings of 110 kWh per home.

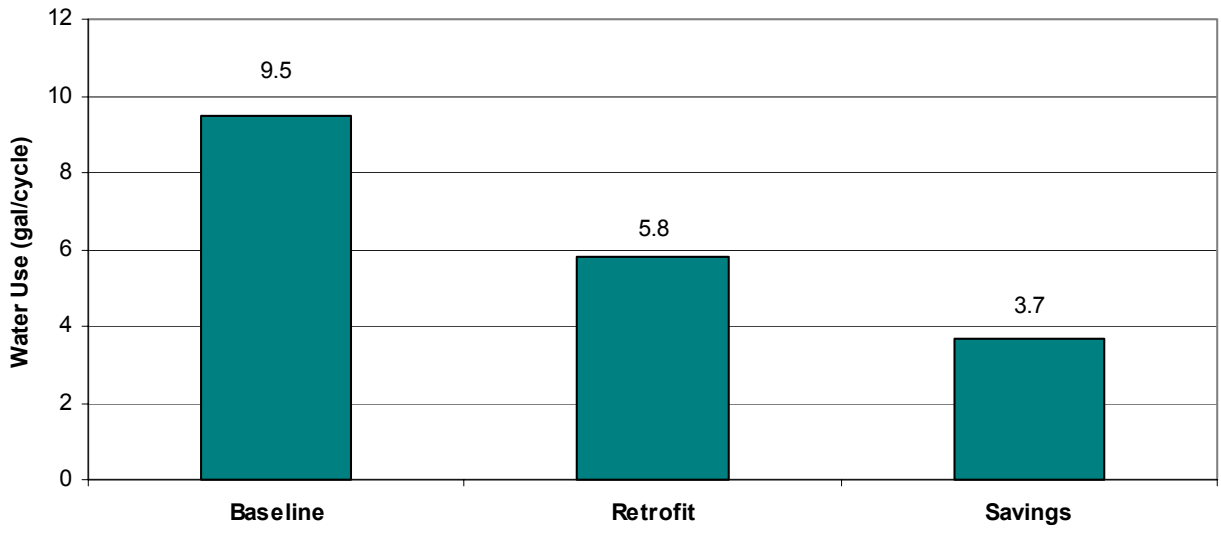

Figure S.6. Dishwasher Findings: Mean Per-Cycle Water Use and Savings (gal/cycle)

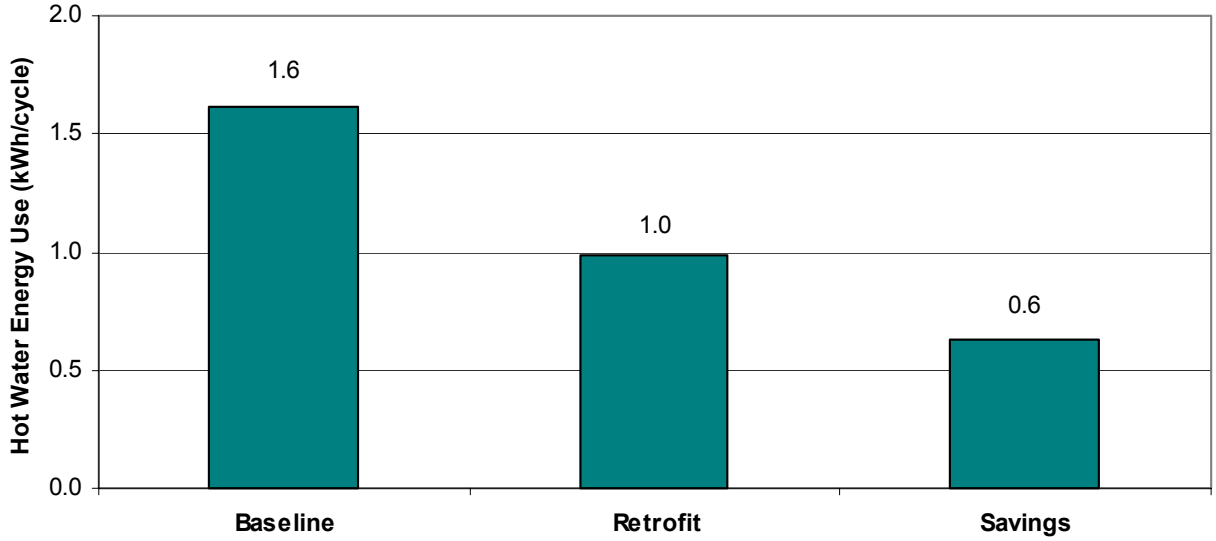

Figure S.7. Dishwasher Findings: Mean Per-Cycle Energy Use and Savings (kWh/cycle)

Toilet Results

Figure S.8 presents the mean per-cycle toilet water use and savings from the program. The mean water savings from the new toilet was 2.6 gallons/cycle, for a 67% reduction in use over the baseline. Aggregated over the year, the new toilets result in mean savings of over 11,550 gallons per home in water savings. These annual savings represent the water used by more than 8,800 flushes of the new toilet.

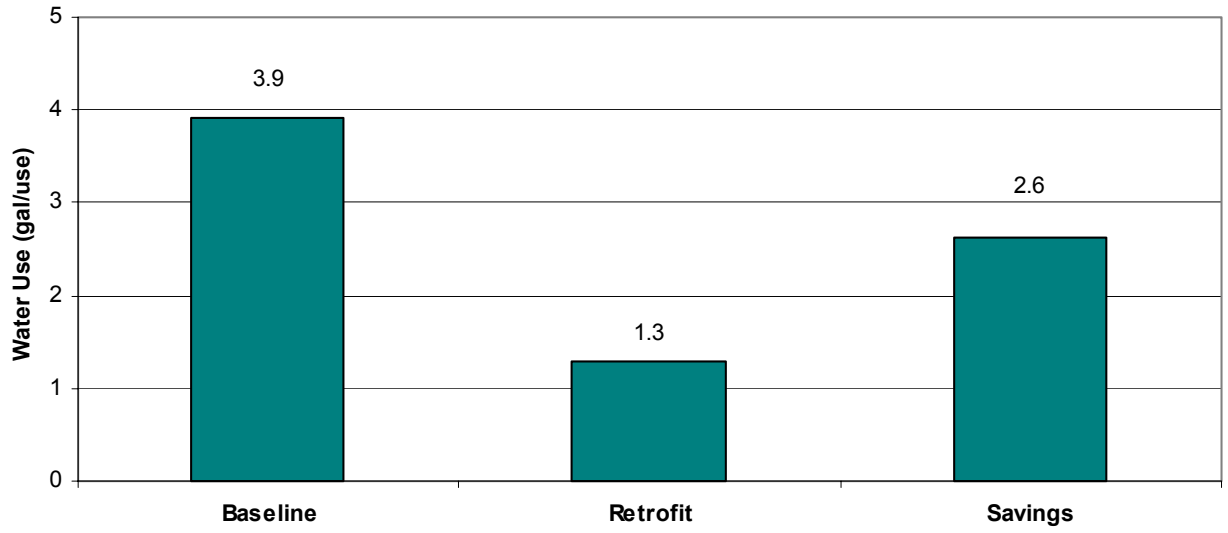

Figure S.8. Toilet Results: Mean Per-Cycle Water Use and Savings (gal/use)

Annual Savings

Figure S.9 presents the mean annual per-home water savings by equipment type from the program. It's interesting to note that while on a per-cycle or per-use basis the clothes washer is the dominant savings device in the program (15.2 gallons/cycle savings for the clothes washer to 3.7 gallons/cycle for the dishwasher to 2.6 gallons/use for the toilet), it's the toilet that overwhelmingly drives the total program savings over time. These savings, of course, result from the relative high usage a toilet sees in comparison to the other equipment in a typical home.

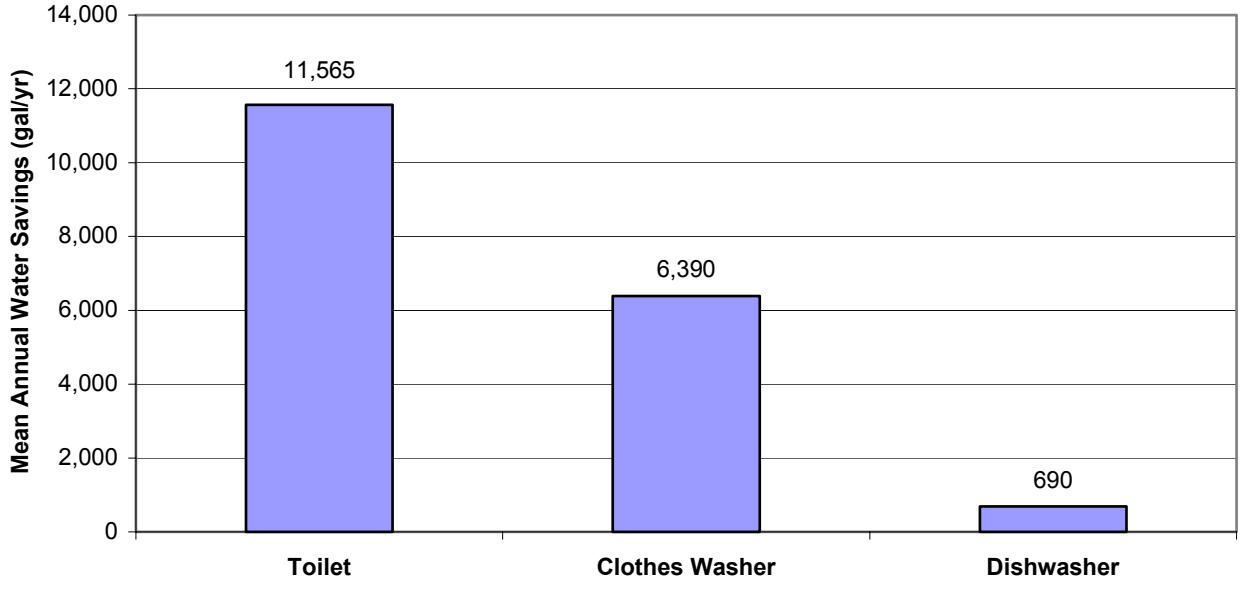

Figure S.9. Mean Annual Per-Home Water Savings (gal/year)

The annual energy savings estimated from the program equipment is included in Figure S.10. These saving are predominately related to the savings in hot water in both clothes washers and dishwashers; clothes dryer savings may be due to a reduction in the remaining moisture content (i.e., due to the high spin speeds typically achieved in front-loading clothes washers, there may be less moisture remaining in the clothes after washing, a so-called lower *remaining moisture content*) and to other unknown technical effects from substituting *retrofit* clothes dryers for *baseline* clothes dryers. Also shown in Figure S.10 are the savings that accrue at the central points of water distribution and wastewater treatment. These savings, labeled Water System Impact, result from less water needing to be pumped and treated at the water supply and wastewater treatment points, and therefore less electricity is used.

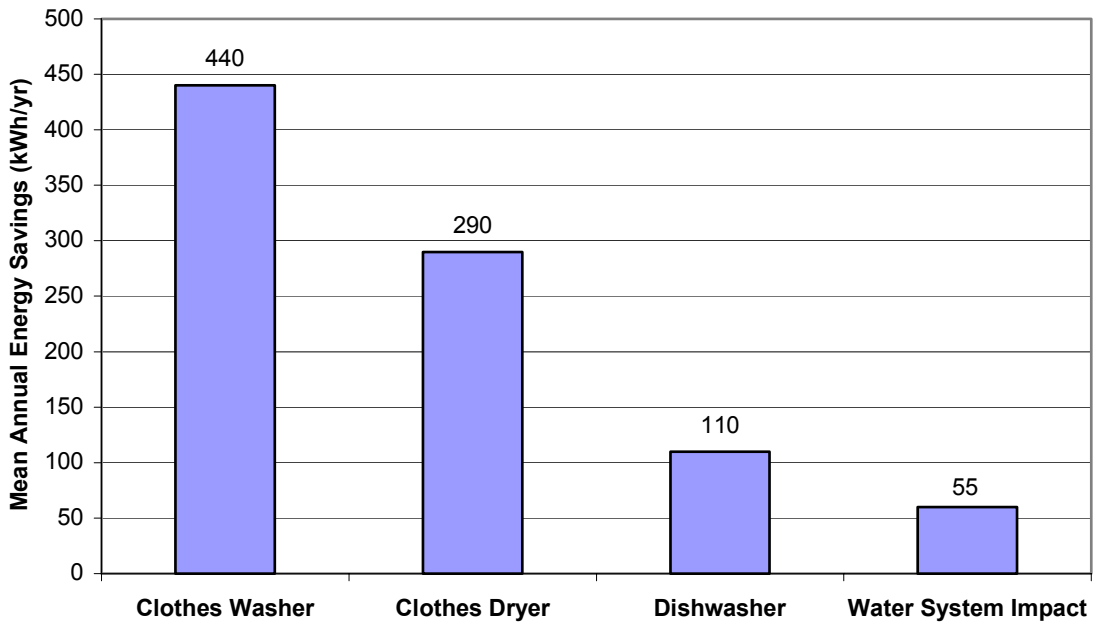

Figure S.10. Mean Annual Per-Home Energy Savings (kWh/year)

When compared with the *baseline* equipment, every year the aggregated savings from the new washer, dryer, and dishwasher (840 kWh/yr and 7,080 gallons/yr) results in enough energy and water to provide the average SWEEP home with 250 free clothes washings, 110 free dishwashings, and enough electricity savings left over to run an energy-efficient refrigerator all year.

Additional energy savings were evaluated for two other program devices, the low-flow showerheads and hot water heaters. However, these data were not reported due to statistical significance issues—in the case of the showerheads, only 6 of the 50 homes had all high-flow baseline showerheads replaced with low-flow showerheads (the other 44 homes already had replaced some or all of their showerheads with low-flow models). In the case of hot water heaters, the relatively short duration of metering precludes the ability to draw statistically significant results from the data.

The values of the resource savings in the SWEEP study homes are significant and will be reflected in lower energy and water bills. Figure S.11 presents the mean annual impact per home, by appliance and by resource savings. These calculations use a combined marginal rate for water/wastewater of $6.50 per 1,000 gallons saved, and a marginal electricity rate of $0.058 per kilowatt-hour saved; these rates are what the average resident pays in both cities. To estimate the savings for homes with natural gas water heaters, the electricity portion of the savings should be multiplied by 0.65.[2]

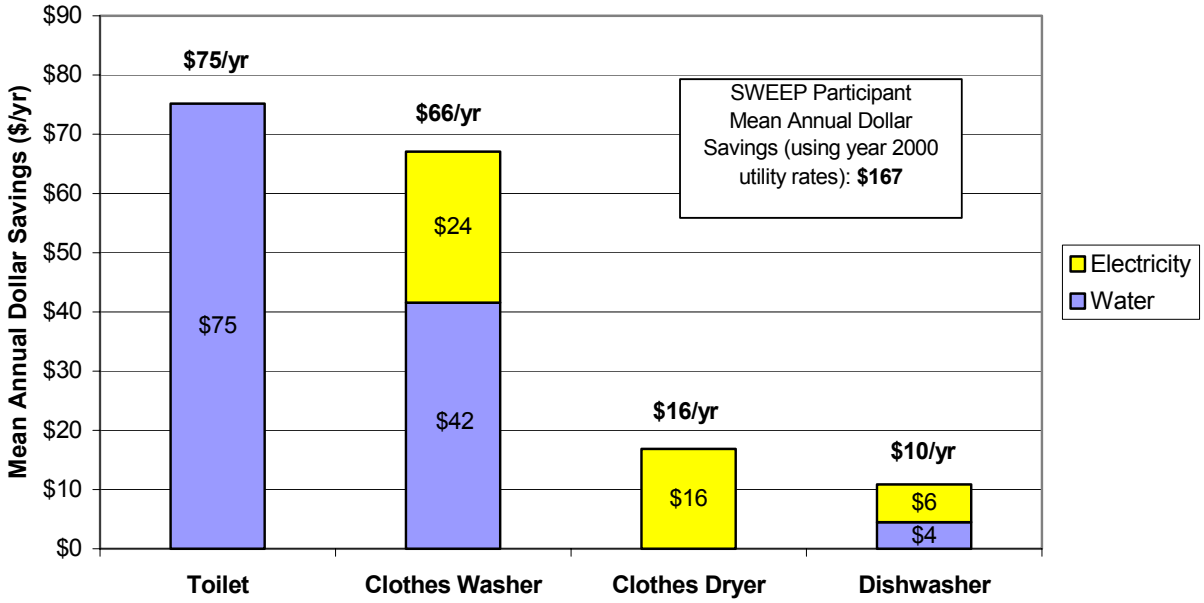

Figure S.11. Mean Annual Per-Home Dollar Savings ($/year): SWEEP Program Equipment Findings (using year 2000 utility cost of $6.50/kgal and $0.058/kWh)

In summary, the SWEEP equipment used in the test homes in Lafayette and Wilsonville, Oregon, produced significant savings in water and energy when compared with the *baseline* equipment. The SWEEP study demonstrated that a properly chosen suite of appliances and equipment can make a significant impact on indoor water use—the study mean savings were 25% of indoor water use, for a mean per-home savings of 18,600 gallons/yr. These water savings were present with the new clothes washer (with a 38% reduction over the mean baseline use), the new dishwasher (with a 39% reduction over the baseline use), and the new toilets (with a 67% reduction over the baseline use). The resulting per-home mean annual energy savings from the program totaled 840 kWh and reduced clothes washer energy use (mechanical and hot water) by 68%, dishwasher energy use (hot water use only) by 39%, and clothes dryer energy use by 25%. The energy savings from reduced water distribution and water/wastewater treatment

[2] This factor adjusts the results to account for the difference in gas and electricity cost as well as their difference in typical efficiencies.

were calculated to be 55 kWh per home per year. These savings are realized by the community through reduced electricity use by supply pumps and other water/wastewater treatment equipment.

From a regional perspective, if SWEEP were implemented in 1,000 pre-EPAct homes, the expected resource savings would include over 18.5 million gallons of water per year and over 890,000 kWh/yr.

Finally, it should be noted that the water/wastewater rate in both communities will be increased over the next year, with the final target of $8.00 per 1,000 gallons. Likewise, given the current electricity-supply situation, electricity rate increases are probable. Both of these actions would serve to increase the cost savings, making this equipment even more economically attractive. Figure S.12 presents the annual dollar savings of this equipment using the anticipated water/wastewater rate of $8.00/kgal, and assuming a 50% increase in electricity rates from $0.058/kWh to $0.087/kWh.

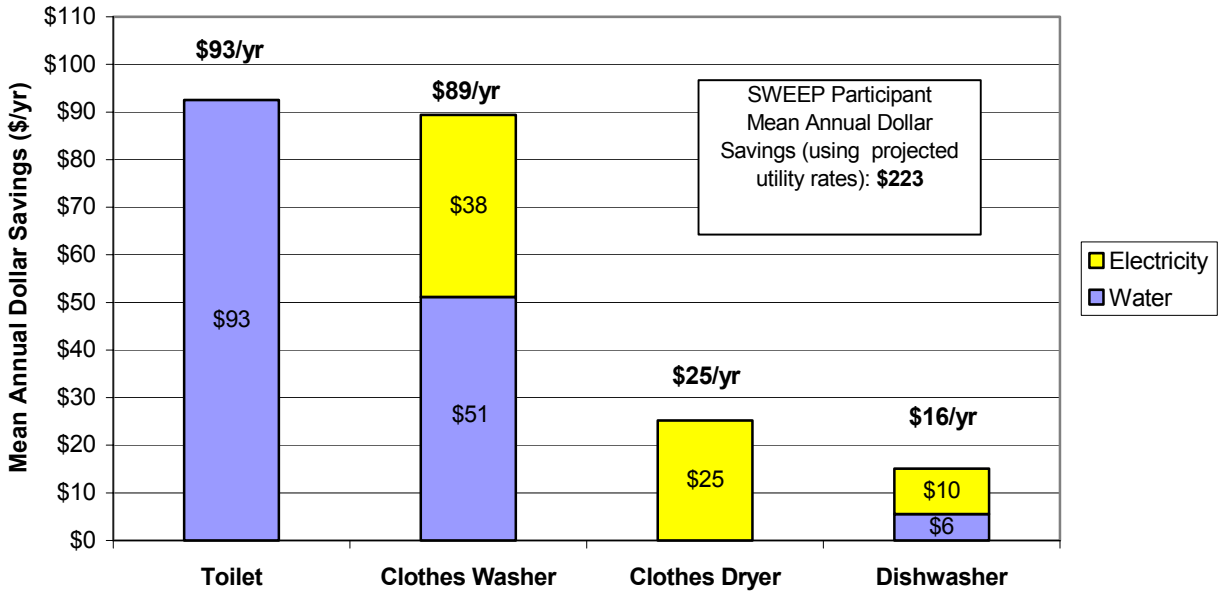

Figure S.12. Mean Annual Per-Home Dollar Savings ($/year): SWEEP Program Equipment Findings (assumes future utility cost of $8.00/kgal and $0.087/kWh)

Acknowledgments

The authors of this report would like to thank all the participants of SWEEP, including Louis and Terry Nelson, Sally J. Razo, Don and Kathy Jones, Tia Wagener, Bob and Shanon Cullen, H. Alan Ross, Flora Lane, Terry L. Yarbrough, Erica Morgan, Eileen Ray, Ann Helm, Jackie Constans, Laura and Terry Archer, Theresa Syphers, Jeff and Louis Winter, Doug Wasson, Valerie Katzler, Frank and Evelyn Palmer, Nancy Larson, Cecil and Jean Mead, Kirk and Mari Morgan, Rick and Gina Regalado, Mike and Barb Lewis, Don and Stephanie Beehner, Kathy Chytka, Mark T. Laughman, Troy Roberts, Gerri Krummel, Neal Stixrud, Charles O. Reeves, Alan and Wendy Johnson, John Helser, Albert Levit and Patricia Rehberg, Lori Anderson, James Gillies, Lynn and Tim Woodley, Adele Lehan, Bernard Bruenderman, Heather and Dan Duff, Terry Baxter, John and Lynn Ries, Thomas and Rosanne Case, Mary Joyce VanWechel, Randal Wortman, Bryan Loun, Michael and Lisa Leman, Ken Cooper, Heath and Elizabeth Foott, Jeffrey D. Stokes, and Tom and Michelle Ripple for their participation in the SWEEP study. Without their commitment and allowing the necessary access to their homes, this study would not have been possible.

The authors would also like to thank Electrolux Home Products and Tony Evans, Caroma USA, Inc. and Darrell Rasell, and Portland General Electric and John McLain for their generous donations of appliances and equipment to this program. In addition, we'd like to thank CTSI Corporation and Jim Craft for his assistance in planning SWEEP and conducting water audits, Ray Engle of Energy Technology Laboratories for his donation of showerheads, and Krohn's Appliance for their expertise in equipment installation.

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Introduction and Background

Who would have thought that Oregon's notoriously soggy Willamette Valley could have a water shortage? The residents of two of its fastest growing communities—that's who! It's true. The residents of Lafayette and Wilsonville, Oregon, are in the midst of a water shortage. These two cities, located about 20 miles south/southwest of Portland, are two of Oregon's fastest growing communities. Lafayette, with a population of 2,586, has experienced 100% growth since 1990. Wilsonville, with a population of 13,991, has experienced similar growth during this period. This rapid growth has strained the water supply and wastewater treatment systems in both communities.

Due to these constraints, both communities volunteered to participate in a research project targeting maximum indoor water savings via a community-wide water conservation program. This program, titled the Save Water and Energy Education Program (SWEEP), was the result of a coalition of organizations including officials from both communities, the U.S. Department of Energy, Electrolux Home Products (donor of 50 sets of Frigidaire high-performance clothes washer/dryer pairs and dishwashers), Caroma USA, Inc. (donor of over 100 high-performance dual-flush toilets), the Pacific Northwest National Laboratory (PNNL), Portland General Electric (the serving electric utility and donor of faucet aerators and low-flow showerheads), the Oregon Office of Energy, CTSI Corporation, Energy Technology Laboratories (also a donor of showerheads), the Northwest Energy Efficiency Alliance, the League of Oregon Cities, and the Mid-Willamette Valley Council of Governments.

The SWEEP concept as applied to Lafayette and Wilsonville included the installation and field evaluation of high-performance water- and energy-efficient equipment. Moreover, the program included the promotion of this type of equipment through schools and community education, as well as energy and water audits, technical assistance, and financial incentives packages taking advantage of tax credits, low-interest loans, and manufacturer rebates.

Through a series of planning meetings, the concept of SWEEP was developed and implemented. Lafayette began SWEEP in September of 1999 with the selection of 25 homes chosen for their water-savings potential and representation of community residences. These homes were then instrumented with a variety of end-use metering equipment to capture water and energy use data. Data were collected both before and after the installation of the water- and energy-efficient equipment. The new equipment included efficient clothes washers and dryers, dishwashers, toilets, and low-flow showerheads. The metering of this new equipment was completed in March of 2000, at which time a comprehensive education program targeting both the school system and the community was initiated. This education program focused on hands-on learning about water and energy efficiency in the school system as well as a community-wide water and energy efficiency campaign.

Figure 1. SWEEP Planning Meeting

Once the evaluation of Lafayette was completed, the metering equipment was moved to Wilsonville where the program was begun in March of 2000. As with Lafayette, 25 homes were chosen, followed by metering both before and after the new equipment was installed. All metering equipment was removed from Wilsonville by September of 2000.

Currently, the Oregon office of Energy is carrying on the SWEEP program in five communities: Wilsonville, Lafayette, Salem, Bend, and Redmond.

The balance of this document addresses the SWEEP process with a focus on the evaluation of the water- and energy-efficient equipment.

This report is organized as follows:

- The second section provides an overview of the program evaluation objectives.
- The third section describes how SWEEP was developed.
- The fourth section provides the metering plan used in the program.

- The fifth section presents the evaluation findings.
- The sixth section presents the study conclusions.
- The seventh section lists the references used in this report.
- The appendices provide specific information on additional analysis results, as well as additional information on the program appliances and equipment, the metering equipment, and a variety of other program resource documents.

Overview and Evaluation Objectives

The objective of this study was to evaluate the water- and energy-savings potential from a suite of indoor water- and energy-efficient equipment in a set of homes built before passage of the Energy Policy Act of 1992 (EPAct).[3] Pre-EPAct homes were targeted because they typically contain less water-efficient equipment than new homes, and thus present a larger opportunity for water savings. Lafayette and Wilsonville, Oregon, two water-constrained cities, were chosen as the study sites.

As a secondary objective, the data from this and related studies will be used in the development of a water conservation model being developed by George Mason University. This model is designed to give small- to medium-size communities a tool useful in estimating the effects of changes in end-use water consumption from a variety of conservation opportunities. This model will examine the effects that end-use water savings have on the system's capital investment needs as well as quantify water and resulting energy savings to the system.

Finally, this study was conducted to help decision-makers and consumers alike evaluate the real-world performance of this equipment. The authors and program partners hope to bring about an increased awareness of the benefits of the water- and energy-efficient equipment included in this program as well as that available through other manufacturers.

[3] The Energy Policy Act of 1992 (EPAct) was signed into law by President George Bush and was designed to, among other things, help reduce the amount of energy and water used by various consumer and industrial products.

How SWEEP Was Developed

The SWEEP concept and development was made possible through a series of informal agreements between program partners. Integral to these agreements was a partnership between the two cities, the U.S. Department of Energy (DOE), the Pacific Northwest National Laboratory (PNNL), Portland General Electric (PGE) and their subcontractor CTSI Corporation, the Oregon Office of Energy (OOE), Frigidaire Home Products Corporation, Caroma USA, Inc., the Northwest Energy Efficiency Alliance (NEEA) the League of Oregon Cities, and the Mid-Willamette Valley Council of Governments. The key activities that were part of SWEEP are presented in the flow chart in Figure 2.

Study Site Selection

Following a successful demonstration of high-performance clothes washers in Bern, Kansas (ORNL 1998), DOE was interested in continuing the promotion and demonstration of water- and energy-efficient equipment. To this end, DOE asked NEEA if there was interest in the Pacific Northwest to conduct a demonstration. For their part, NEEA solicited local Oregon communities asking for interest in participation. Among others, Lafayette and Wilsonville responded to this solicitation. Some very general guidelines were used in final selection of these communities. These guidelines included:

- *Recurring water/wastewater capacity issues*—a documented need was a key requisite.

- *Presence of municipal water/wastewater utilities*—it was felt that a private utility would have other economic interests to consider, potentially complicating the process.

- *Community size*—a small enough community to make possible a project with substantial community-wide impact.

- *Community interest*—city official, city personnel, and community resident commitment to the program would be necessary for its success.

Of these guidelines, the first, a documented need for assistance, was the most important. As one of the key objectives, this study targeted communities that have a significant need for water conservation. In both communities, fast-paced growth exacerbating already capacity-constrained water supply and treatment systems made them ideal candidates.

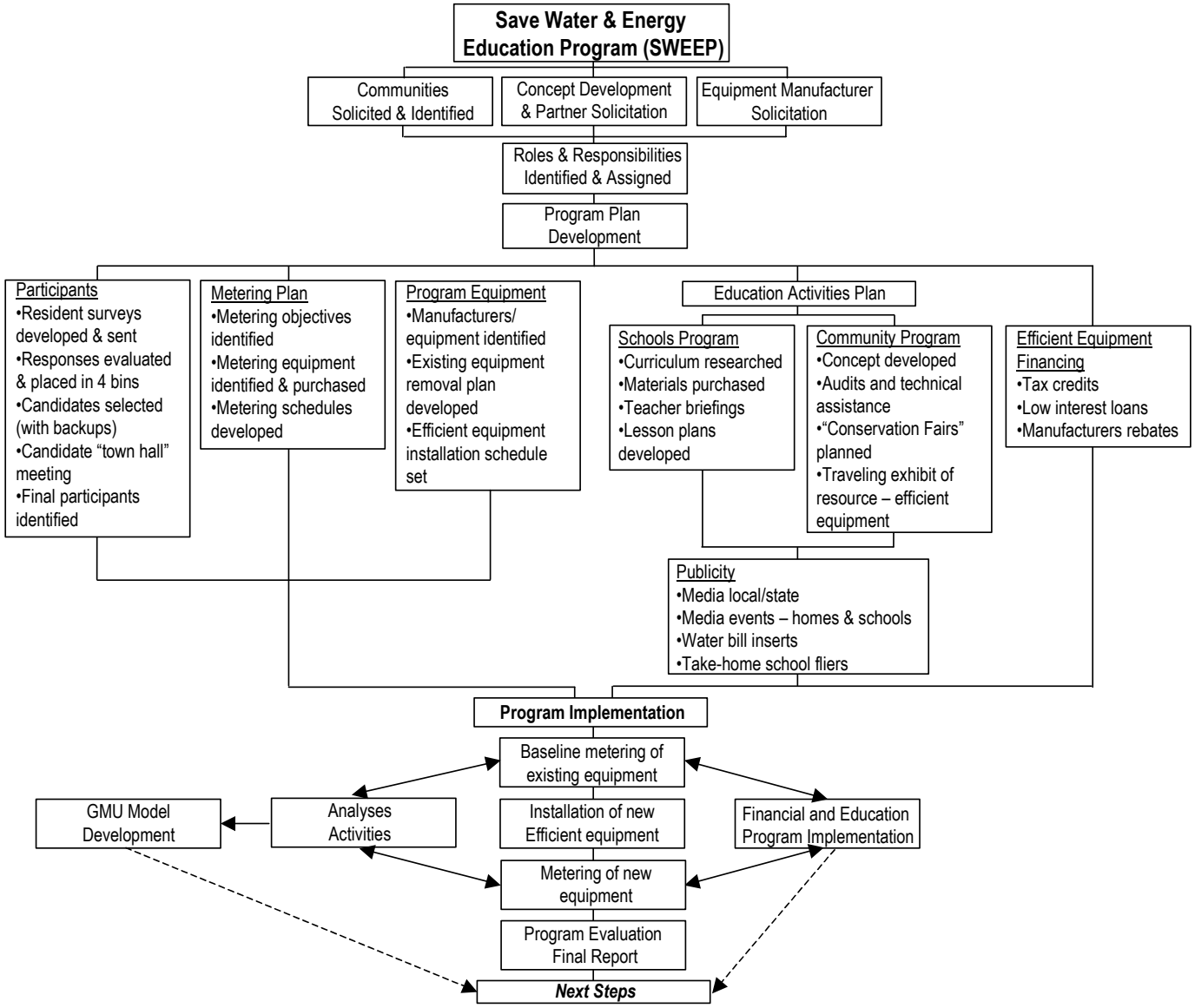

Figure 2. Key Activities of SWEEP

Study Sites

Lafayette, Oregon. Located about 20 miles southwest of Portland along historic Highway 99 and in the heart of Willamette Valley wine country, Lafayette bills itself as Oregon's third oldest city having been incorporated in 1847. As in many greater metropolitan areas, once rural farming communities are giving way to residential development and are serving as bedroom communities to these expanding metropolitan areas. Lafayette is no different in its relation to Portland. Lafayette's location, accessibility via Highway 99, and scenic surroundings have led to 100% growth in population since 1990; the current population is 2,586. This growth has outstripped the community's ability to upgrade an antiquated infrastructure—most notable are the water supply and wastewater treatment systems.

Figure 3. Lafayette City Hall

Lafayette currently supplies water from wells and a reservoir located on city-owned watershed property. In periods of high demand, mostly in the summer months, the reservoir supply must be supplemented with water from backup wells. During these periods, water quality has been questioned; in addition, issues have been raised as to the sufficiency of supply to both provide for residential water uses and have a buffer for other city activities such as fire-fighting.

The treatment of wastewater takes place at a treatment facility located on the banks of the Yamhill River. While effective, this facility is dated and suffers from capacity issues, particularly in winter months when rain water infiltrates the wastewater return system. Plans have been drawn to replace this treatment facility.

Faced with continued growth, Lafayette has begun negotiations with neighboring communities and landowners to identify new sources of ground water. Additionally, the city is scheduled to begin construction of a new wastewater treatment facility in the fall of 2001.

In 1999, Lafayette generated and used approximately 80 million gallons of water. The marginal combined water/wastewater cost for Lafayette residents varies with use. However, on average, most residents pay between $6.00 and $7.00 per 1,000 gallons (kgal). The marginal electricity rate in Lafayette is approximately $0.058 per kilowatt-hour (kWh). Both of these rates are expected to increase in the near future.

Figure 4. SWEEP Study Sites of Lafayette and Wilsonville, Oregon

Wilsonville, Oregon. Also located about 20 miles, in this case directly south, of Portland, Wilsonville is both a residential community and an employment center along the rim of the Portland metro area's urban growth boundary. Conveniently located on Interstate 5, Wilsonville affords quick and easy access to Portland while still maintaining a rural sense of space and environment. Wilsonville, too, has experienced significant population growth over the past 10 years, with growth of 97% over that time; the current population is 13,991.

Water supply is a major constraint on further development in Wilsonville. Wilsonville currently supplies water to its residents from wells and, as with Lafayette, during the summer season these supplies have been getting dangerously low and jeopardizing the city's ability to carry out all of its necessary activities. In fact, measurements taken at city wells indicate the water table is dropping about four feet per year. To mitigate this problem, Wilsonville has instituted strict summer outdoor water use restrictions in four of the past six years. In addition, Wilsonville had put a temporary moratorium on new residential construction in 1999 and 2000.

Faced with the continued shortages and increasing growth pressures, Wilsonville recently approved the construction of a new water treatment facility on the banks of the Willamette River. While this facility is expected to ease the water shortages in Wilsonville, it comes at the expense of higher water rates—water rates are expected to double in a two-year period—and continued shortages are expected during the two-year construction schedule. The new treatment facility is expected to be on-line in April of 2002.

In 1999, Wilsonville generated and used about 925 million gallons of water with roughly 30% of that allocated to single-family residential connections. The marginal combined

water/wastewater cost for Wilsonville residents also varies with use. However, on average most residents pay about $6.50/kgal. The marginal electricity rate in Wilsonville is approximately $0.058/kWh. Both of these rates are also expected to increase in the near future.

Participant Selection

Working with both cities, PNNL staff developed an informational letter and questionnaire that was mailed to each single-family residence served by the municipal water systems. The letter was designed to provide information about the program, its duration, participant responsibilities, and equipment included. The questionnaire was designed to give the program partners information about their potential participant. Both the letter and the questionnaire are included in this report as Appendix A. As stated previously, participants were not selected in a random fashion; rather they were selected to fulfill an important objective of this study, i.e., choosing a representative sample of participants living in pre-EPAct homes. Figure 5 shows a typical SWEEP home.

Figure 5. Typical SWEEP Home

The selection process made use of a number of participant screens developed to target a representative sample of community residents while still fulfilling the program objectives. These screens included:

- *Owner occupied residences*. Program partners wanted to make sure that those using the water and energy were also those paying for the water and energy. Furthermore, the installation of the new equipment could not legally be done in a home not owned by the occupant.

- *Pre-EPAct home construction*. As a primary objective, program partners wanted to target homes with the greatest conservation potential. Pre-EPAct homes typically did not have low-flush toilets and fixtures as original equipment.

- *Home size*. Two different home size groupings or bins were developed to segment the participants selected. The first bin has homes with less-than 1,800 ft^2 and the second has homes with 1,800 ft^2 or more.

- *Home occupancy*. As with home size, two home occupancy bins were developed to further segment the participants selected. The first bin was three and fewer occupants and the second was greater than three occupants.

In all, 25 homes in each community were selected and chosen to participate in this program. Table 1 presents the distribution of homes by city into the four bins.

Baseline Equipment

Given our participant selection criteria, most of the toilets and dishwashers found in the homes were of pre-1992 vintage. In a few cases, homes had been retrofit with post-1992 equipment. In the case of toilets, these retrofit installations were noted. In the case of showerheads and faucet aerators, a very successful program implemented by PGE had already retrofit many of the participant homes with energy- and water-efficient low-flow showerheads and faucet aerators. The baseline penetration of these efficient devices in participant homes was approaching 70%.

Table 1. SWEEP Number of Participants and Participant Distribution

City	Bin 1: ≤3 occupants <1,800 ft^2	Bin 2: ≤3 occupants ≥1,800 ft^2	Bin 3: >3 occupants <1,800 ft^2	Bin 4: >3 occupants ≥1,800 ft^2
Lafayette	7	5	6	7
Wilsonville	6	6	6	7

As expected, the existing program appliances and equipment showed a large variance in age. Ages ranged from only 1-2 years to greater than 20 years old. Table 2 presents the mean age of the existing appliances. In the case of toilets, the home age was usually a good surrogate for the toilet age when the age data were not available. Figure 6 pictures SWEEP baseline toilets on their way to disposal.

Table 2. Mean Age Data in Years for Program Appliances

Appliance/City	Clothes Washer Mean Age (years)	Clothes Dryer Mean Age (years)	Dishwasher Mean Age (years)	Home/Toilet Mean Age (years)
Lafayette	8.8	9.4	8.2	38.8
Wilsonville	10.4	11.0	8.3	17.4

Figure 6. SWEEP *Baseline* Toilets Headed for Disposal

Efficient Equipment

The efficient equipment installed in all 50 homes was identical. It included a new ENERGY STAR®[4] front-loading clothes washer and matching dryer, an energy- and water-efficient ENERGY STAR dishwasher, an innovative two-button toilet imported from Australia, and low-flow showerheads/faucet aerators. A brief description of each piece of efficient equipment is provided below. Pictures and other technical documentation can be found in Appendix B.

Clothes Washer/Dryer. The clothes washer/dryer models included in SWEEP were the Frigidaire Gallery model FWTR647GHS washer and Gallery model FDE546RES dryer. The washer model, being an ENERGY STAR horizontal-axis (H-axis) model, uses less water and energy than standard top-loading, vertical-axis (V-axis) washers. Indeed, other studies (ORNL 1998; EPRI 1997) have quantified the benefits of a variety of H-axis washers over V-axis washers. The measure of efficiency of a clothes washer is the so-called clothes washer energy factor. The energy factor is the normalized (to tub volume) measure of energy consumption (mechanical/motor and water heating) per standard wash cycle and given in units of cubic feet of tub volume per kilowatt-hour per cycle (ft^3/kWh/cycle); it is important to note that the *higher* the energy factor the more efficient the washer. The current minimum energy factor allowed for residential clothes washers is 1.18 ft^3/kWh/cycle. A typical clothes washer may have an energy factor (depending on age) of 1.18 to 1.40, while to qualify as ENERGY STAR the clothes washer must have an energy factor of 2.50 or more. The Frigidaire clothes washer included in this program has an energy factor of 4.01.

Dishwasher. The dishwasher model included in SWEEP was the Frigidaire Gallery model GLDB656JS. Through proprietary wash technology, this model is promoted as energy and water efficient and also carries the ENERGY STAR label. The measure of efficiency of a dishwasher is the so-called dishwasher energy factor. This energy factor is the inverse of the energy consumption for one full cycle and given in units cycles per kilowatt-hour (cycle/kWh). As with the clothes washer energy factor, it is important to note that the *higher* the dishwasher energy factor the more efficient the dishwasher. The current minimum energy factor allowed for residential dishwashers is 0.46 cycle/kWh. A typical dishwasher may have an energy factor (depending on its age) of 0.46 to 0.50, while to qualify as ENERGY STAR the dishwasher must have an energy factor of 0.52 or more. The Frigidaire dishwasher included in this program has an energy factor of 0.64.

[4] The ENERGY STAR program is a voluntary partnership among the U.S. Department of Energy, the U.S. Environmental Protection Agency, product manufacturers, local utilities, and retailers. Partners help promote efficient products by labeling with the ENERGY STAR logo and educating consumers about the benefits of energy efficiency. ENERGY STAR-labeled products promote low utility bills and environmental benefits. A list of qualifying ENERGY STAR products and their efficiency levels can be found on the ENERGY STAR web site at www.energystar.gov

Toilets. The toilets included in SWEEP are manufactured and imported from Australia by Caroma USA, Inc. This design, the Caroma Caravelle 305, makes use of an innovative two-button flushing mechanism; one button is designated for liquid waste and the other button is designated for solid waste. The liquid-flush is advertised to use 0.8 gallons while the solid-flush uses the current standard of 1.6 gallons. The measure of efficiency of a toilet is the amount of water used per standard flush. The current maximum allowed water use per flush is 1.6 gallons. A typical toilet manufactured before 1992 uses about 3.5 gallons per flush, while toilets manufactured before 1985 have been found to use as much as 5 to 6 gallons per flush.

Showerheads. The showerheads included in SWEEP were a well-tested and accepted low-flow model. This same model was used in a very successful showerhead retrofit program that resulted in the high baseline penetration of these showerheads in both communities prior to the start of SWEEP. The measure of efficiency of a showerhead is the flow rate, given in gallons per minute (gpm). The showerhead included in this program was rated at 2.5 gpm. Older and/or high-flow showerheads have been found to use as much as 8 to 10 gpm.

The appliances and equipment described above define the SWEEP "program equipment." The following analysis focuses on this equipment, evaluating its water and energy savings potential as installed in the participant's homes. While all homes received the new appliances and toilets, only a subset of homes received the new showerheads and aerators. This is because most of the homes had already participated in a successful showerhead/aerator program sponsored by Portland General Electric.

Schools and Community Programs

Integral to the success of SWEEP was an educational program targeting both the school system and the communities. The focus of the school education program was hands-on learning about energy and water efficiency in the local elementary and middle schools. The community programs targeted awareness campaigns and offered creative financing options for the purchase of energy and water efficient appliances.

Schools Program

In both communities, elementary and middle-school students participated in a water-and energy-efficiency curriculum titled Learning to Be Water Wise and Energy Efficient™. In Lafayette, the curriculum was incorporated as part of a science module in the elementary school. In Wilsonville, the curriculum was a centerpiece of a week-long "Outdoor School" completed by 200 6th grade students. This curriculum was specifically designed for hands-on learning and was purchased by the communities. Information on the curriculum used can be found in Appendix A.

In addition to the middle-school curriculum, Wilsonville SWEEP organizers developed a writing contest open to all middle-school students. Participating students were asked to write a poem or short essay explaining to a fictional (or real) neighbor why it is important to save water and energy. The contest resulted in 96 entries that were judged by a local senior citizens group. All participants received free movie passes and the four finalists each received $50 gift certificates. The grand-prize winner received a new efficient Frigidaire washer/dryer set. The entries of the four semifinalists were included in the following month's water bill and sent to 4,000 residential accounts. The four winning entries are included in Appendix A.

Community Program

Both communities organized water and energy conservation fairs and other awareness activities as part of various community events. Appendix A presents some of the promotional material used for these events.

In addition to awareness, both communities participated in a low-interest loan program developed by the OOE and administered by PGE via the monthly electric bill. This program complimented the OOE's existing Efficient Appliance Tax Credit program already in place. Sample documents for both programs can be found in Appendix A.

Figure 7 shows some of the people and equipment so important to SWEEP.

Figure 7. New Appliances, Happy Participants, and SWEEP Program Partners: Ready for Installation

Metering Plan

The SWEEP water and energy evaluation completed three levels of water-use metering intervention. The first level (Level I) focused on end-use metering of the clothes washer, dryer, and hot water heater. The second level (Level II) used the existing whole house water meters in combination with an innovative data logger and software package to meter end-use water consumption. The third level (Level III) focused on the metering at the water and wastewater system treatment points and the development of a model to estimate the system-wide benefits of the program. Each level was designed to fold into the level above, with the third level serving as an aggregated total of the previous two.

Objectives

The SWEEP evaluation was designed to determine the impacts of a targeted water and energy conservation program in the cities of Lafayette and Wilsonville, Oregon. The objectives were as follows:

- Evaluate the per-cycle water and energy savings of new high-performance front-loading clothes washers compared with existing standard top-loading clothes washers.

- Evaluate the per-cycle water and energy savings of new high-efficiency dishwashers compared with existing pre-EPAct dishwashers.

- Evaluate the per-use water and energy savings of new high-efficiency low-flow showerheads compared with existing showerheads.

- Evaluate the per-use water savings of new high-efficiency dual-flush toilets compared with existing pre-EPAct toilets.

- Estimate annual water-use savings resulting from the installation of the "program equipment" in the 50 homes.

- Collect clothes dryer energy use data for subsequent evaluation by DOE.

- Collect water heater energy use data for subsequent evaluation by DOE.

- Collect additional information on the laundering habits of participants with the use of "laundry journals" detailing load size, cycle selections, and additives for subsequent evaluation by Frigidaire.

- Develop a model to estimate system-wide water supply and wastewater return impacts resulting from the retrofit equipment and the comprehensive community and schools water- and energy-use education program.

Metering Plan

As discussed, this evaluation proposes three levels of water-use metering. Where possible each level was aggregated up to the level above with the third level serving as the aggregated total of the previous two levels. Discrepancies at each level were explored for data inconsistencies and/or indications of system anomalies (i.e., leakage, infiltration, etc.). Because of the desire to project these evaluation results onto other communities, a representative demographic sample of Lafayette and Wilsonville was needed. Due to budget constraints this evaluation focused on a total sample size of 25 homes in each community; 10 homes in each community were proposed for Level I metering, and all 25 homes in each community for Level II metering. All 50 homes selected were pre-EPAct homes and were divided between the four demographic groups, or bins, discussed in the Participant Selection subsection on page 9.

Level I Metering

The primary objectives of Level I metering was to evaluate high-performance clothes washer resource savings (energy and water), to collect clothes dryer energy-use data, and to collect hot water heater energy-use data. A secondary objective of Level I metering was to generate clothes washer water-use data that could be compared with similar data collected by Level II metering equipment.

Level I metering relied on end-use metering equipment (data logger and water and electricity metering equipment) as well as occupant intervention. The occupant was asked to keep a "laundry journal" detailing dates and times of clothes washings, wash cycle selection, detergent types and amounts, etc. A copy of the laundry journal form is included in Appendix A. A description of each Level I metered parameter is included below. A diagram showing metering connections is provided in Figure 8.

Clothes Washer Water Temperature: Water temperature, both hot and cold, was recorded at the time of metering equipment installation and at subsequent visits to the home. These measurements were used to calculate the energy content of the hot water used.

Clothes Washer Water Use: Water use was metered by water flow meters installed on the hot and cold supply line to the washers. The meters provided per-cycle water use data to the data logger where it was stored in a time-series format at 5-minute intervals.

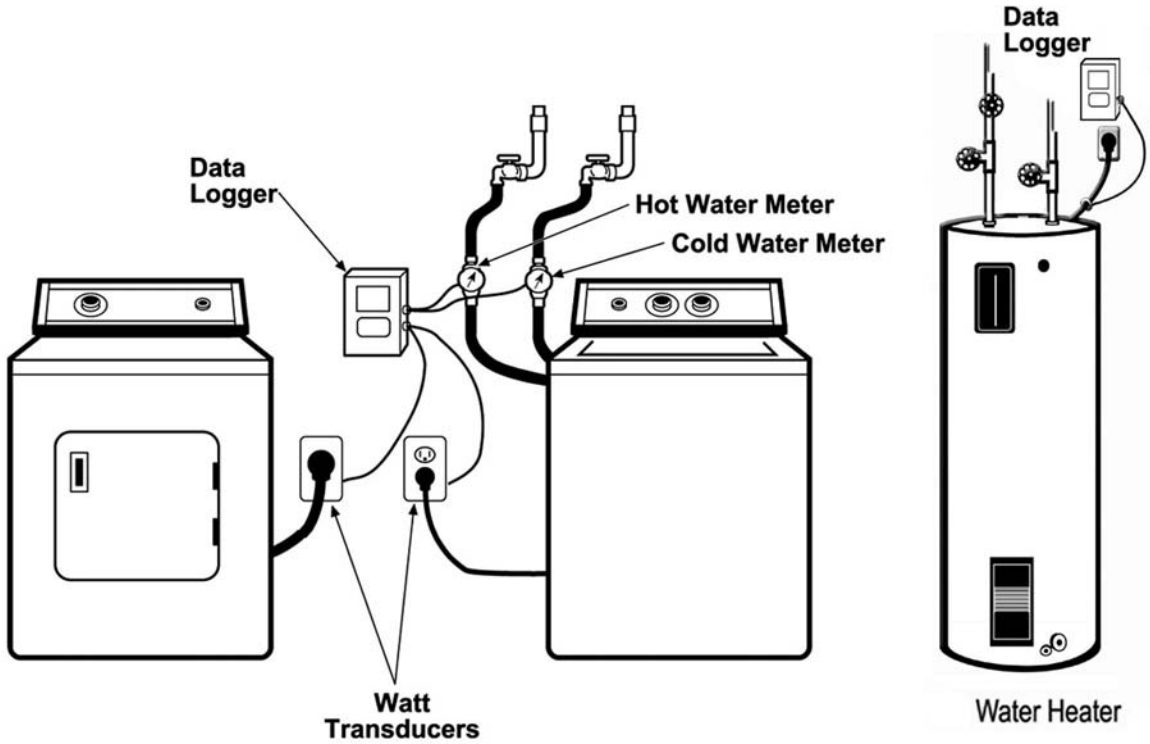

Figure 8. Level I Metering Equipment and Connections

Clothes Washer Energy Use: Clothes washer electrical energy use was metered by watt transducers installed on the power connections to the washer. The transducers provided per-cycle electricity-use data to the data logger, where it was stored in a time-series format. The clothes washer hot water energy use was calculated using the volume of hot water used (as recorded by the hot-water meter) and the temperature difference of the water coming in-to and out-of the water heater.

Clothes Dryer Energy Use: Clothes dryer energy use was monitored by watt transducers installed on the power connections to the dryer. The transducers provided per-cycle electricity use data to the data logger where it was stored in a time-series format.

Hot Water Heater Energy Use: Hot water heater energy use was monitored by current transformers (CTs) installed on the power connections to the water heater. The CTs provided electricity-use data to the data logger where it was stored in a time-series format at 5-minute intervals.

The data loggers used to record and store data held approximately 90 days worth of data. At monthly intervals these data loggers were downloaded in the field by analysts. The specifications and additional pictures of the metering equipment used in Level I are included in Appendix C.

Figure 9. End Use Metering (Level I) Equipment as Installed in Participant's Home

Level II Metering

The objective of Level II metering was to measure water use at the participant's city water-metering point (the city water meter is usually located in a metering "pit" at the participant's home). This metering was done to estimate end-use water consumption before and after the installation of the efficient equipment. The metering technique for Level II metering used an innovative data logger, the Meter-Master, developed by F.S. Brainard of Burlington, NJ. The Meter-Master is a data logger and a magnetic sensor that is attached to the city water meter; the logger and sensor were installed inside the metering pit and left there for the duration of the metering period. Figure 10 shows installed Meter-Master logger in a metering pit.

As water is used it flows through the city water meter, spinning magnets inside the meter. This magnetic movement is picked up by the sensor and registered by the logger. The Meter-Master logs data every 10 seconds and writes a record to memory. Once collected, these magnetic pulses were downloaded and processed through a software program called Trace Wizard©.

Figure 10. Meter-Master Metering (Level II) Equipment Installed in Metering Pit

The software program, Trace Wizard, developed by Aquacraft, Inc. of Boulder, Colorado, was designed to recognize specific flow signatures of water-using devices and appliances. The basic premise behind its development is that most residential water-using devices use water at relatively constant flow rates and volumes. Toilets, for instance, will typically flush with the same flow rate and volume. The same is largely true for clothes washers, dishwashers, showers, etc. The key to the successful use of the software is in the user's ability to recognize a specific water-using event and categorize it as such. Once categorized, the software uses this signature to identify similar events throughout the period. As the different events are identified, the software stores this information as it builds a water-use database. Once complete, this database becomes a disaggregation of the specific end uses of the total water use as seen by the city water meter. The specifications and additional pictures of the metering equipment used in Level II are included in Appendix C.

Figure 11 presents a typical Trace Wizard screen used by analysts in processing the Meter-Master data. Visible in this trace are a number of water-use events that have been color coded for recognition. Along the left border of the figure are small boxes that are used by the analyst in identifying the various end uses, the event properties, and other identifying characteristics. On the graph window, the X-axis represents a two-hour time window, the Y-axis gives the flow rate of the event in gallons per minute (gpm); therefore, the area under any specific colored region represents the actual water use, in gallons, for that event. Along the right portion of the screen is a legend identifying different water using events. Shown on this particular trace are a number of

faucet uses (yellow events), a shower (red/orange event), two toilet flushes (green events), and a dishwasher event (starts with one turquoise labeled Dishwasher@ in the legend area, followed by four pink events). For water uses that have multiple discrete events making up a complete cycle (e.g., a clothes washer or dishwasher), the first event in the series is identified with the event name plus the '@' symbol.

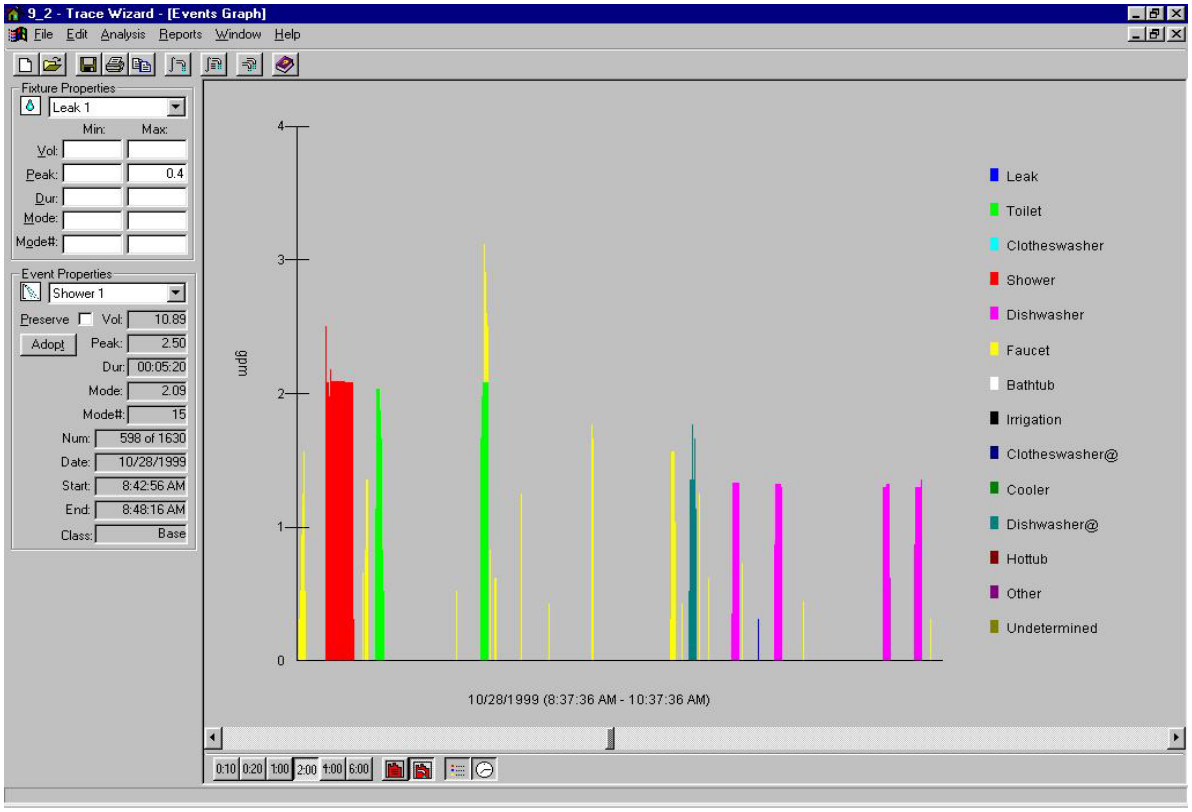

Figure 11. Typical Trace Wizard Output Screen Used in Meter-Master Data Processing

It is interesting to note that the shower event shown on the screen in Figure 11 begins with a small spike and then settles down to a flow of about 2 gpm. This shower was taken in a bathtub that also has a shower fixture. The initial spike represents the water being turned on at the bathtub faucet and let run before the bathtub shut-off was activated sending the water to the lower-flow-rate showerhead.

A diagram showing the Meter-Master metering connections and a depiction of Trace Wizard's function is provided in Figure 12.

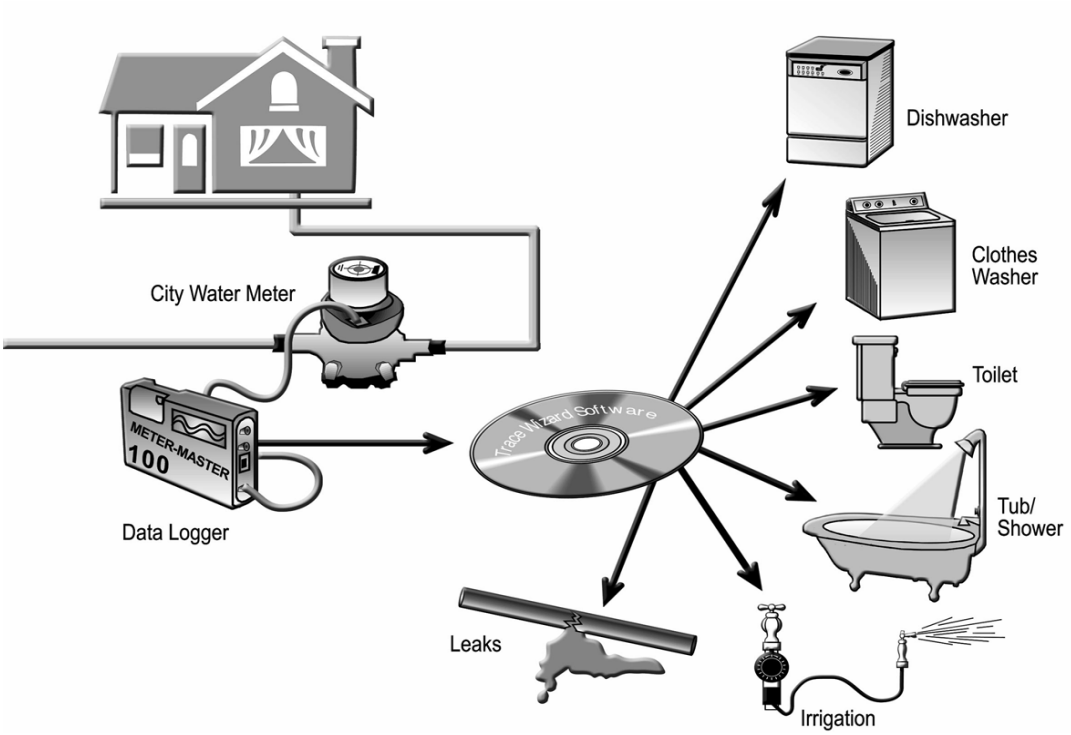

Figure 12. Level II Metering Equipment Connections and Trace Wizard Interface

While the Meter-Master/Trace Wizard system has the potential of accurately quantifying significant water using appliances and equipment, this evaluation was not successful at accurately quantifying lower-flow water uses such small faucet uses and leaks. Because of this inadequacy, this analysis focused on the larger uses consistent with the program objectives and made no attempt to quantify leaks and other low-flow water using events.

These results of Level II metering provided detailed water savings values for the major water end-use equipment included in the study. Level II metering affected all 25 homes in each community. Included in these homes were the 10 Level I homes, allowing for an accuracy check of the Meter-Master/Aquacraft system, through comparison with the end-use metering equipment installed on the clothes washers.

Level III Metering

Level III metering was designed to track system-wide impacts of the overall program. This metering took place using the existing city water supply and wastewater return metering and is used in conjunction with a model being developed at George Mason University to estimate system-wide benefits to this program. Level III metering connections are shown in Figure 13.

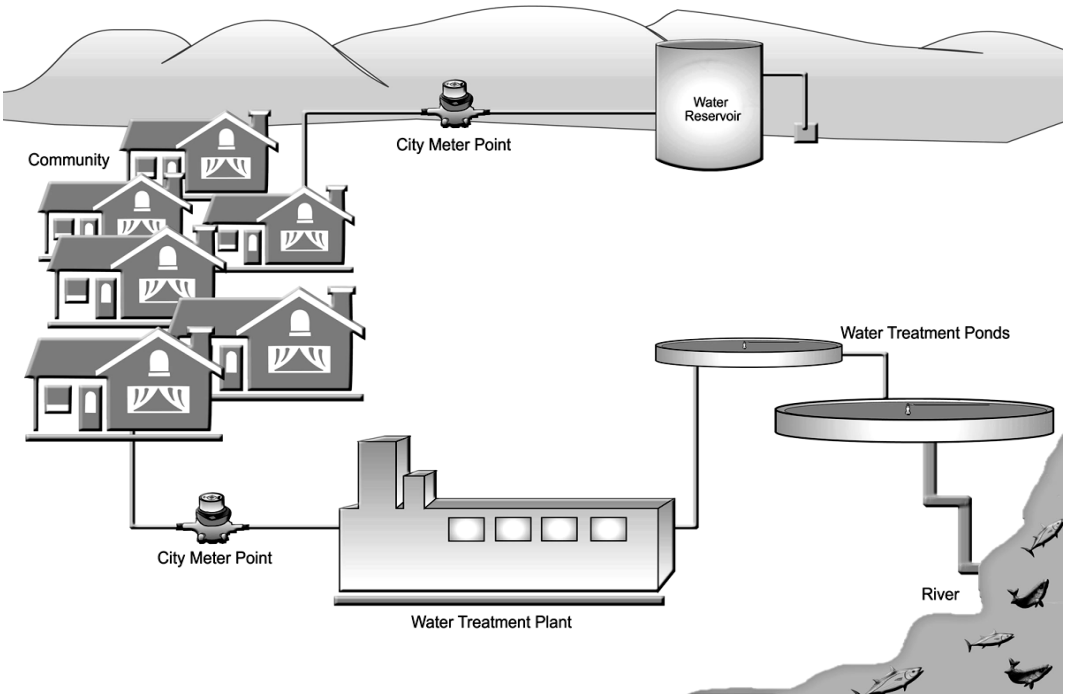

Figure 13. Level III Metering Connections

Evaluation Findings

The data collected from the 50 SWEEP homes represented an enormous analysis effort. Consider that 50 homes (25 at a time) were monitored for end-use water flow at each city water meter; this metering was recording data every 10 seconds. Additionally, in about half of the homes, dedicated end-use metering was installed at the clothes washer, clothes dryer, and hot water heater, and this metering was recording data every 5 minutes. Simple calculations show that the metering equipment used on this project recorded more than 220,000 data points per day.

The findings below are presented starting at the highest level of aggregation—the aggregated city-wide savings results, and progressing to the lowest level—the equipment end-use results. These results are followed by the aggregated annual end-use results. The results presented in this section are for the "program equipment," including the clothes washer and dryer, the dishwasher, and the toilet. The showerheads are not presented here because of the small sample size of homes receiving the retrofit low-flow showerhead. A very successful showerhead retrofit campaign by PGE over the previous two years resulted in a high penetration of low-flow showerheads; only three homes in each community went from a situation of having all standard-flow showerheads to having all low-flow showerheads. Due to the small sample size, the savings proved to be statistically insignificant; these data are included in Appendix D.

Aggregated Data

The data presented below represent the aggregated totals of water use in each of the 50 homes. These data were generated using a combination of data collected with the Meter-Master metering system and data collected over the past 2 years by the cities at the city water meter. For consistency in calculating the aggregated savings, the Meter-Master clothes washer data were used instead of the end use data collected at the clothes washer.

Aggregated Per-City Data

Figure 14 presents the 25-home aggregation of all annual indoor water use for the *baseline* (before SWEEP was implemented), for the *retrofit* (after SWEEP was implemented), and for the resulting *savings*. The results are presented for both cities and then for the combined study mean. The units on the graph are thousands of gallons (kgal).

The mean annual baseline indoor water use was calculated using the city's water meter readings for each home. To calculate these values, two-years of consumption data were examined. These data were then reduced to include only the months of November, December, January, and February—in the Pacific Northwest, residential water use during these months is likely to be strictly indoor use. Calculating the total mean indoor water use by this method allowed for a

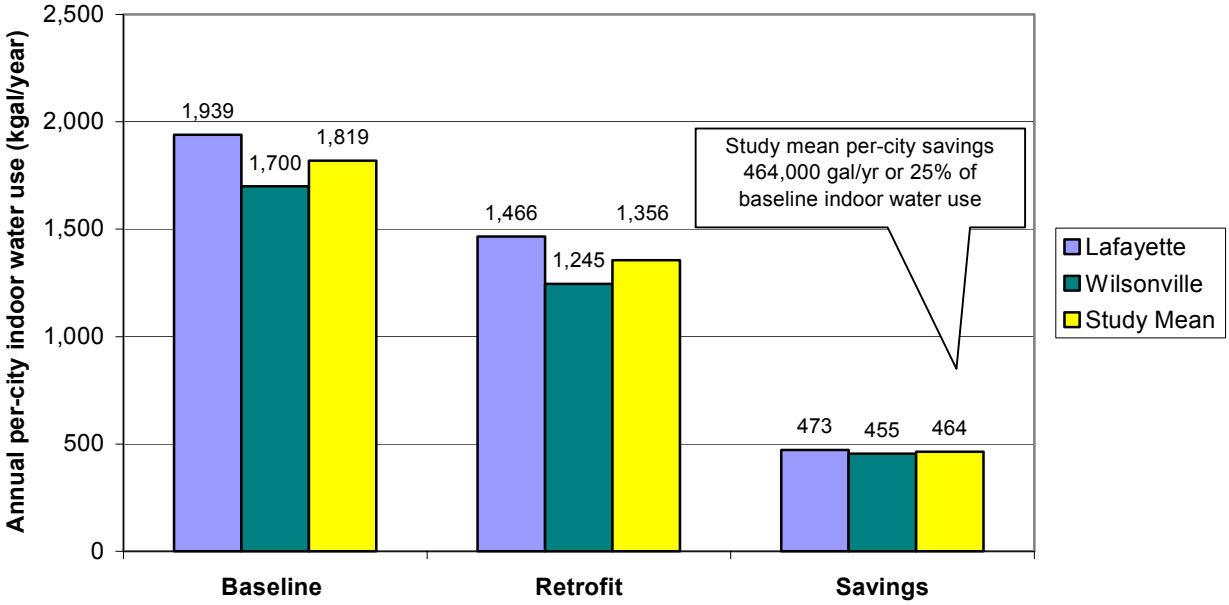

Figure 14. Annual Indoor Water Use and Savings (kgal/yr) for the 25 SWEEP Homes in Each City: Aggregated Program Equipment (clothes washer, dishwasher, toilet) Findings

more representative mean total indoor water use than using the Meter-Master data for only the periods metered. The results of this calculation produced a mean indoor water use for each participant with an overall mean of 72,750 gallons/home/year. This value compares well with data collected as part of an American Water Works Association (AWWA) 1,000 home water use study. This study (AWWA 1999) reported a mean annual indoor water use range of 61,300 to 90,600 gallons/home/year.

The mean annual indoor *retrofit* water use was the difference between average annual *baseline* indoor water use and the end-use savings calculated by Meter-Master at each home. In other words, retrofit water use was calculated by subtracting the estimated water savings from the estimated baseline water use. This approach was chosen because the authors believed they could more accurately estimate water savings from the Meter-Master data than they could from the total indoor water use.

As shown in Figure 14, the aggregated 25-home data indicate that each community will save in excess of 450,000 gallons/yr resulting from the installation of the SWEEP equipment in the 25 homes. For the 25 homes in each community, these savings represent roughly a 25% reduction in all indoor water uses. The community-specific savings are 473,000 gallons/yr in Lafayette, for a 24% savings of indoor water use in the study homes, and 455,000 gallons/yr in Wilsonville, for a 27% savings of indoor water use in the study homes. In addition to the community water savings, savings in pumping and water/wastewater treatment costs should be realized as well.

Aggregated Per-Home Findings

Presented in Figure 15 are the aggregated per-home findings for both cities and the study mean. The aggregated per-home *baseline* data were calculated again using two-years of city billing data. The *retrofit* data represent the mean indoor water use with all "program equipment" implemented (clothes washer, dishwasher, and toilet) and were calculated using the Meter-Master data collected at each home. The units in Figure 15 are in thousands of gallons (kgal).

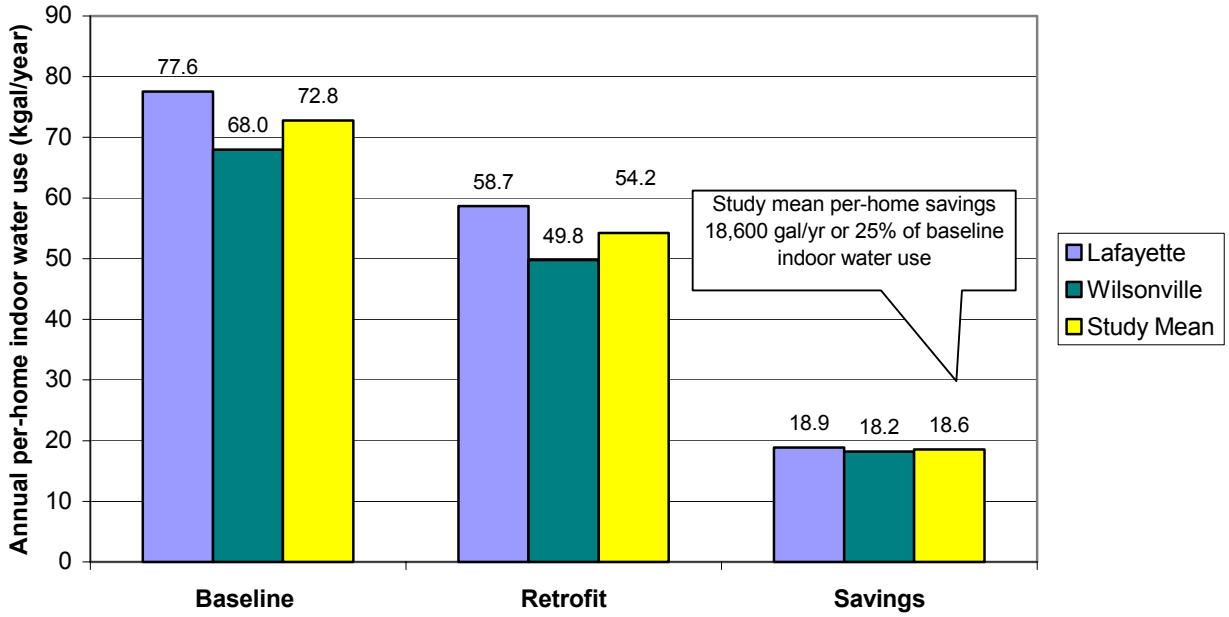

Figure 15. Annual Per-Home Indoor Water Use and Savings (kgal/yr): Aggregated Program Equipment (clothes washer, dishwasher, toilet) Findings

The aggregated per-home data indicate a mean annual savings of about 18,600 gallons. This mean included a low of 5,800 gallons/yr (single-occupant household) to a high of 55,400 gallons/yr (seven-occupant household). These savings represent a 25% reduction in mean per-home indoor water use over the baseline. The community-specific mean savings are 18,900 gallons/home/year in Lafayette, for an average of 24% savings in indoor water use, and 18,200 gallons/home/year in Wilsonville, for a mean savings of 27% in indoor water use.

End Use Data

The findings presented below represent data from two different metering systems, the Meter-Master metering and end-use metering equipment (see the Metering Plan section). One of the analysis goals of this study was to validate the Meter-Master metering equipment with the end-use metering installed on the clothes washers in 20 of the 50 homes. In addition to being

redundant, the value of the end-use metering was that it allowed for detailed metering of the total clothes washer water use, hot and cold water use, and the machine energy (motor and controls), as well the dryer energy use.

For the statistical analysis in this study, 95% confidence intervals were computed for the mean difference in energy consumption within households after the *retrofit* equipment was installed. If the lower limit of the resulting confidence interval is greater than zero, one can conclude the amount of energy savings is statistically significant. This procedure assumes that observed energy consumptions are independent and constitute random samples from the respective underlying populations. While the participating households were not actually randomly selected, this is not expected to significantly impact the conclusions on energy savings.

This analysis assumes that the observed energy consumptions in the *baseline* and *retrofit* samples are representative of the expected energy consumptions on any given day with the same appliances. Sources of variability in the data include differences in appliance usage both within and between households. Of particular influence are the differences in different appliance usages due to factors such as temperature selection or load size. None-the-less, any water and energy savings found statistically significant are deemed so above and beyond this inherent type of variability in the consumption data.

The confidence intervals are computed in the following manner. The average savings is computed for each of the 50 households by subtracting the average *retrofit* appliance energy consumption from the *baseline* average appliance energy consumption. The mean and standard deviation of these 50 resulting household average savings are then represented respectively by D-bar and S_d. The resulting 95% confidence interval is then

$$\text{D-bar} \pm 1.96\, S_d \,/\, \text{sqrt}(50).$$

The 1.96 value is the corresponding percentile of the normal distribution that is appropriate due to the Central Limit Theorem given the relatively large sample size. The quantity S_d/sqrt(50) is the estimated standard error of the mean. Note that 95% of the time such intervals are computed, the true underlying water or energy savings for the particular appliance would be captured within the interval. Thus when the lower limit of a resulting interval exceeds zero, we are at least 95% confident that the true associated savings are indeed greater than zero.

Clothes Washer Findings

Figure 16 presents the Meter-Master mean per-cycle clothes washer total water use. These data are presented by community for the *baseline*, the *retrofit*, and for the resulting *savings*. The study's mean Meter-Master clothes washer data indicate a per-cycle savings of about 15.2 gallons. This included a mean savings low of 4.5 gallons/cycle (baseline machine was likely relatively new and/or used on low-water setting) to a mean savings high of 25.0 gallons/cycle (baseline machine was likely an older high water using model and/or used on

full-load setting). The standard deviation of these savings is 6.7 gallons/cycle. The corresponding 95% confidence interval for the true mean savings, as described in above, is therefore 15.2 ± 1.96 x 6.7/sqrt(50). This gives the interval 15.2 ± 1.86, or (13.3, 17.1). We can thus conclude with 95% confidence that the true mean savings is not only greater than zero, but also actually greater than (or equal to) 13.3 gallons/cycle.

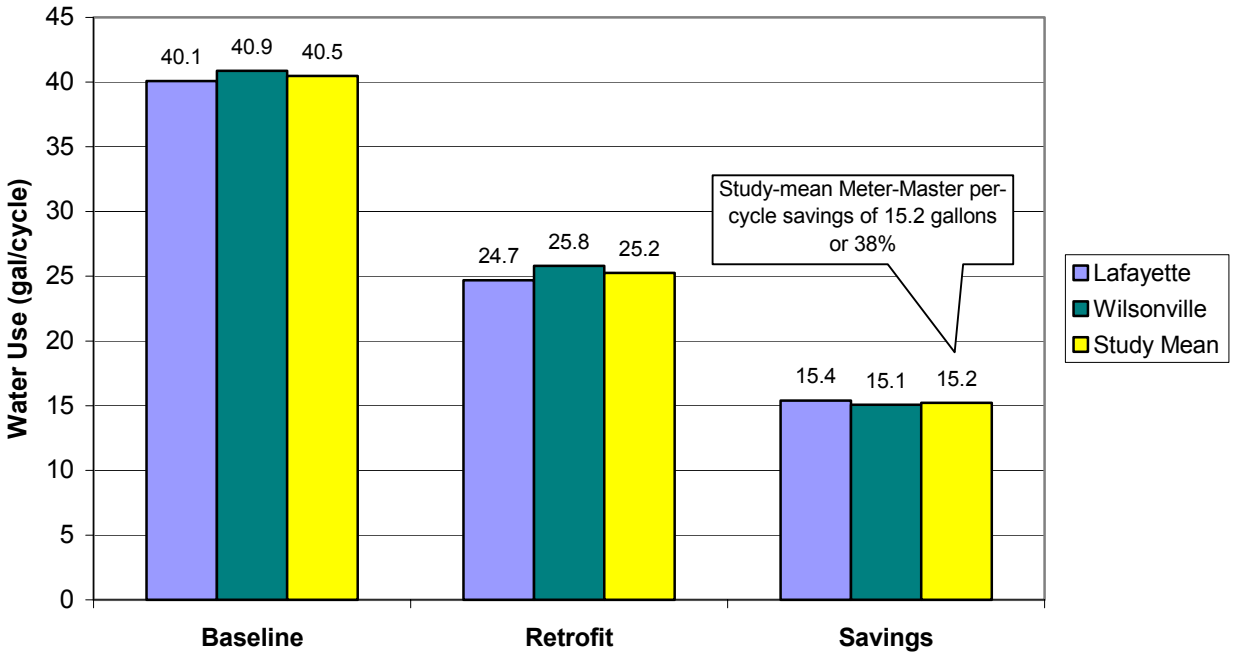

Figure 16. Clothes Washer Water Findings: Meter-Master Mean Per-Cycle Water Use and Savings (gal/cycle)

These savings represent a 38% reduction in the mean per-cycle clothes washer water use over the baseline. The community-specific savings are 15.4 gallons/cycle in Lafayette, for a mean savings of 38%, and 15.1 gallons/cycle in Wilsonville, for a mean savings of 37%.

Figure 17 also presents the mean clothes washer total water use results; however, these data were collected by the dedicated *end-use* metering equipment installed at the clothes washer. It is interesting to note the consistency of findings between the two metering systems. In most cases, these mean data differ by less than 1-2 gallons when comparing the results from the two metering systems. This end-use validation of the Meter-Master equipment gave us additional confidence in the metering systems.

The mean end-use clothes washer data indicate a per-cycle savings of 14.1 gallons. This included a mean savings low of 5.5 gallons/cycle, to a mean savings high of 23.0 gallons/cycle. The standard deviation of this savings is 4.6 gallons/cycle. Due to the smaller sample size (recall the end use metered data were collected on only 20 of the homes), the resulting confidence intervals are larger. The corresponding 95% confidence interval for the true mean savings is

14.1 ± 2.29, or (11.8, 16.4). We can thus conclude with 95% confidence that the true mean savings is greater than (or equal to) 11.8 gallons/cycle.

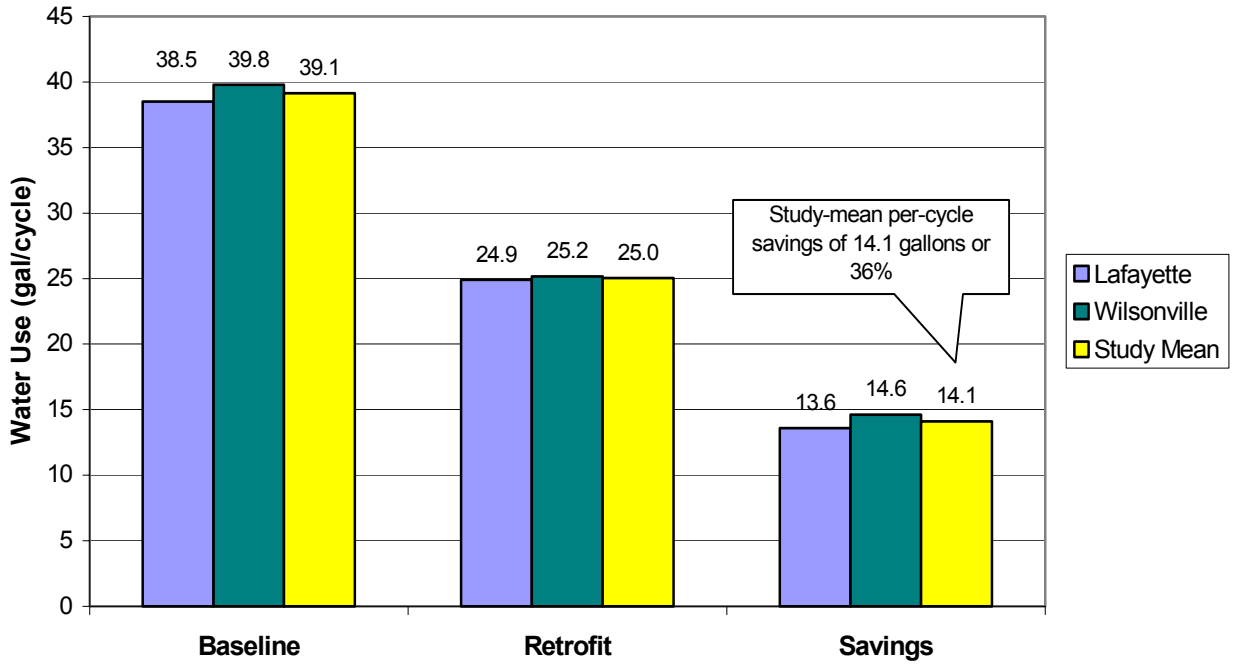

Figure 17. Clothes Washer Water Findings: End-Use Metered Mean Per-Cycle Water Use and Savings (gal/cycle)

These savings represent a 36% reduction in mean per-cycle clothes washer water use over the *baseline*. The community-specific savings are 13.6 gallons/cycle in Lafayette, for a mean savings of 35%, and 14.6 gallons/cycle in Wilsonville, for a mean savings of 37%.

The energy used by the clothes washers takes place by two different mechanisms. First, the energy needed by the electric motor and washer controls, and second the energy embodied in the hot water used by the washers. The energy used by the motor and controls is monitored directly; however, the energy embodied in the hot water must be calculated. To calculate this energy, the volume of the hot water used and both the hot and cold water temperatures are needed. As shown in Figure 8, the volume of hot water is measured by a dedicated hot water meter. The water temperature of both the hot and cold supply was measured during metering installation and equipment removal visits to the homes. Using these values, the energy content of the hot water is calculated. It should be noted that in homes using a natural gas water heater (20 of the 50 homes), this calculation accurately estimates the energy savings; however, it underestimates the actual amount of energy purchased by the participant for the use of heating hot water. For the purposes of consistency and simplicity, all savings are reported in kilowatt-hours (kWh).

In the case of a home with a gas water heater, to accurately account for the amount purchased, the natural gas water heater conversion efficiency should be used. The actual energy savings amount would be greater due to the inefficiency of energy conversion in a gas water heater compared with an electric water heater. However, the dollar value of these savings would be less due to the difference in energy cost between gas and electricity. Based on an average gas water heater conversion efficiency (estimated at 75%) and current electricity and natural gas prices ($0.058/kWh and $0.83/therm), the energy use and savings specific to the gas water heater case would increase by a factor of 1.33,[5] while the cost savings would decrease by a factor of 0.65.[6] Therefore, to calculate the energy savings in the gas water heater case, one would multiply the electric savings by 1.33 and convert these to the proper units, either therm or Btu. To calculate the relative dollar savings, one would multiply the electric water heater dollar savings by 0.65.

Figure 18 presents the mean clothes washer energy use and savings results. It is interesting to note the difference in *baseline* energy use comparing the Lafayette mean (1.1 kWh/cycle) to the Wilsonville mean (1.7 kWh/cycle). This difference is likely a function of the differences in *baseline* washer types, age, and usage (i.e., cycles selected) in the two communities. It is also interesting to note that in the *retrofit* case the difference is much less, perhaps indicating the variance in the *baseline* was more a function of the *baseline* equipment characteristics and less a function of usage.

The mean per-cycle clothes washer energy use data indicate a savings of 0.9 kWh/cycle. This included a mean savings low of 0.03 kWh/cycle and a mean savings high of 0.18 kWh/cycle. The standard deviation of this savings is 0.7 kWh/cycle. The corresponding 95% confidence interval for the true mean savings is 0.9 ± 0.35, or (0.6, 1.3). We can thus conclude with 95% confidence that the true mean savings is greater than (or equal to) 0.6 kWh/cycle.

These savings represent a 64% reduction in mean per-cycle clothes washer energy use over the *baseline*. The community-specific savings are 0.7 kWh/cycle in Lafayette, for a mean savings of 63%, and 1.2 kWh/cycle in Wilsonville, for a mean savings of 71%.

Clothes Dryer Findings

Figure 19 presents the mean clothes dryer energy use and savings results. It is again interesting to note the difference in *baseline* energy use comparing the Lafayette mean (3.7 kWh/cycle) to the Wilsonville mean (2.6 kWh/cycle). This difference is also likely a function of the differences in *baseline* dryer types, age, and usage in the two communities. However, unlike the clothes washer finding of less difference in the *retrofit* case, the clothes

[5] Factor calculated as 1 divided by the efficiency, or 1/0.75.

[6] Factor calculated as follows: [($0.83/therm x 1 therm/100,000 Btu x 3,412 Btu/kWh x 1/0.75)/ ($0.058/kWh)].

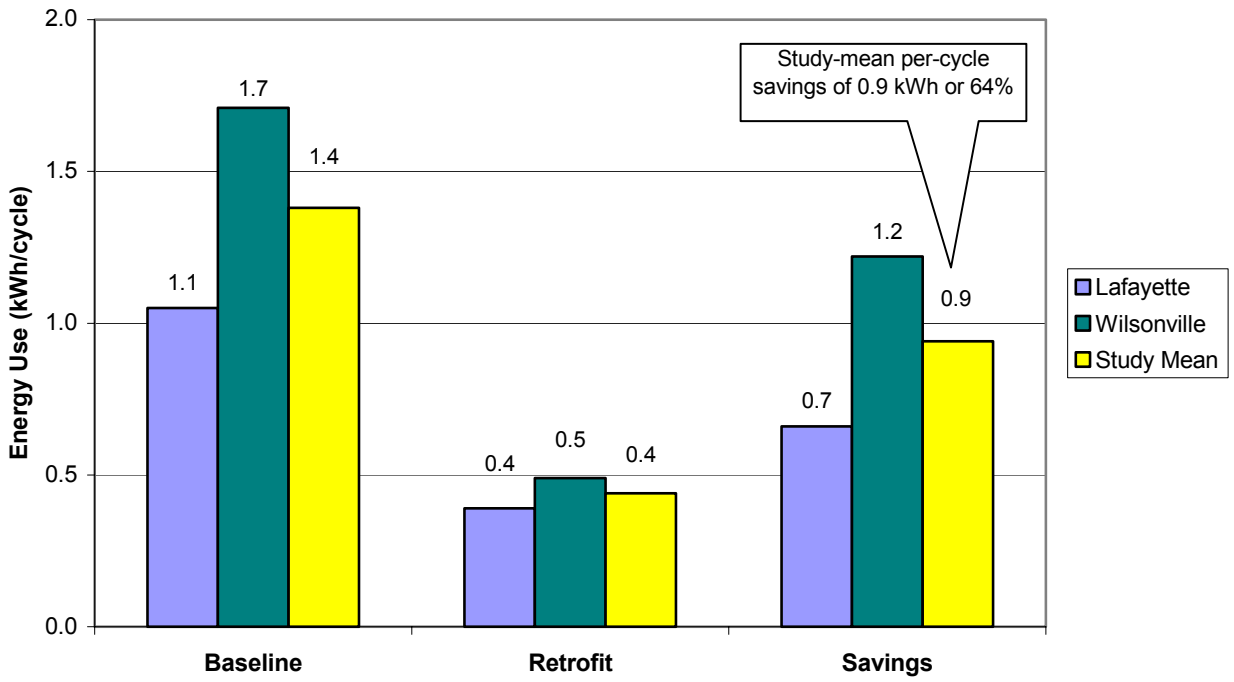

Figure 18. Clothes Washer Energy Findings: End-Use Metered Mean Per-Cycle Energy Use and Savings (kWh/cycle)

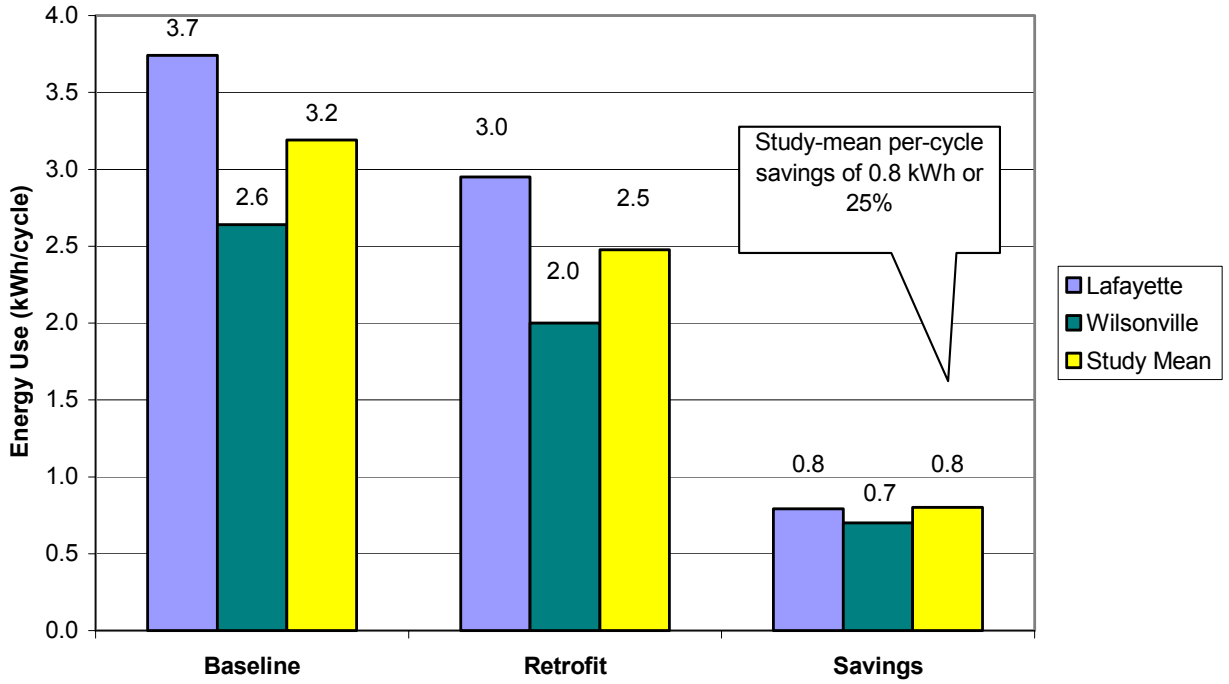

Figure 19. Clothes Dryer Energy Findings: End-Use Metered Mean Per-Cycle Energy Use and Savings (kWh/cycle)

dryers continue to show significant variance between cities in the *retrofit* case. Here, the consistent difference may suggest that the variance is more a function of how the equipment is used and less a function of equipment characteristics.

Taking a closer look at the dryer savings, it is important to note that, unlike clothes washers where energy savings are linked mostly to the hot water savings, the source of the clothes dryer energy savings is not as clear. The clothes dryer savings may be a result of one or more of the following mechanisms.

First, due to the high spin speeds typically achieved in front-loading clothes washers, at the end of the clothes washing cycle there may be less moisture remaining in the clothes, a so-called lower *remaining moisture content*. If this is the case, and if the dryer has the necessary controls to turn itself off when it senses the clothes are dry, the *retrofit* dryer should use less energy than the *baseline* case.

Second, by virtue of its design and age, the way a dryer is used can have a potentially large impact on its energy use. For instance, while all new dryers have automatic termination control (i.e., the dryer shuts off automatically when the clothes are dry) they also have the "timed dry" option. Thus, the termination control option selected can have a large impact on dryer energy use. In this evaluation, the option selected was not tracked; therefore, the savings (or in two participant's cases, the *increased use*) over the *baseline* are influenced by any changes in how dryers were used. Furthermore, prior to 1994, clothes dryers were not required to have termination control; therefore, many dryers functioned on a timed-dry mode only. The lack of termination control (or the lack of use, if it were present) can result in additional energy use due to improperly timed settings.

Finally, some dryer savings could be related to technology improvements of the new dryer in relation to an old, or poorly maintained, *baseline* dryer. Even in comparison to old dryers having termination control, some savings may be expected from the new dryer because of improvements in heat delivery, termination control accuracy, and perhaps the installation of the vent connection.

To better allocate the source(s) of the dryer savings, a more detailed study of clothes dryer savings potential should be completed. This study should include determining the remaining moisture content, along with an accurate accounting of clothes washed and then dried, while capturing all settings selected and energy used both at the washer and dryer.

The mean per-cycle clothes dryer energy-use data indicate a savings of 0.8 kWh/cycle. This included a mean savings low of -0.29 kWh/cycle and a mean savings high of 1.52 kWh/cycle. The standard deviation of this savings is 0.78 kWh/cycle. The magnitude of this standard deviation reflects the occurrence of negative savings (increased energy use in the *retrofit* case). While these negative saving occurrences (2 of 20) could be considered "outliers," there was not enough information to make a defendable judgment; therefore, these data were included. The

corresponding 95% confidence interval for the true mean savings is 0.8 ± 0.39, or (0.4, 1.2). We can thus conclude with 95% confidence that the true mean savings is greater than (or equal to) 0.4 kWh/cycle.

Dishwasher Findings

Figure 20 presents the mean per-cycle dishwasher total water use and savings results. These data are presented by community for the *baseline*, the *retrofit*, and the resulting *savings*. The dishwasher data indicate a mean per-cycle savings of about 3.7 gallons. This included a mean savings low of -1.4 gallons/cycle (*baseline* machine was relatively new and used on low-water cycle) to a mean savings high of 8.6 gallons/cycle (*baseline* machine was an older high-water-using model). The standard deviation of these savings is 2.0 gallons/cycle. As with the clothes washer data, there is some difference in savings by community. This variance is likely a function of the differences in *baseline* dishwasher types, age, and usage (i.e., cycles selected) in the two communities. The corresponding 95% confidence interval for the true mean savings is 3.7 ± 0.55, or (3.2, 4.3). We can thus conclude with 95% confidence that the true mean savings is greater than (or equal to) 3.2 gallons/cycle.

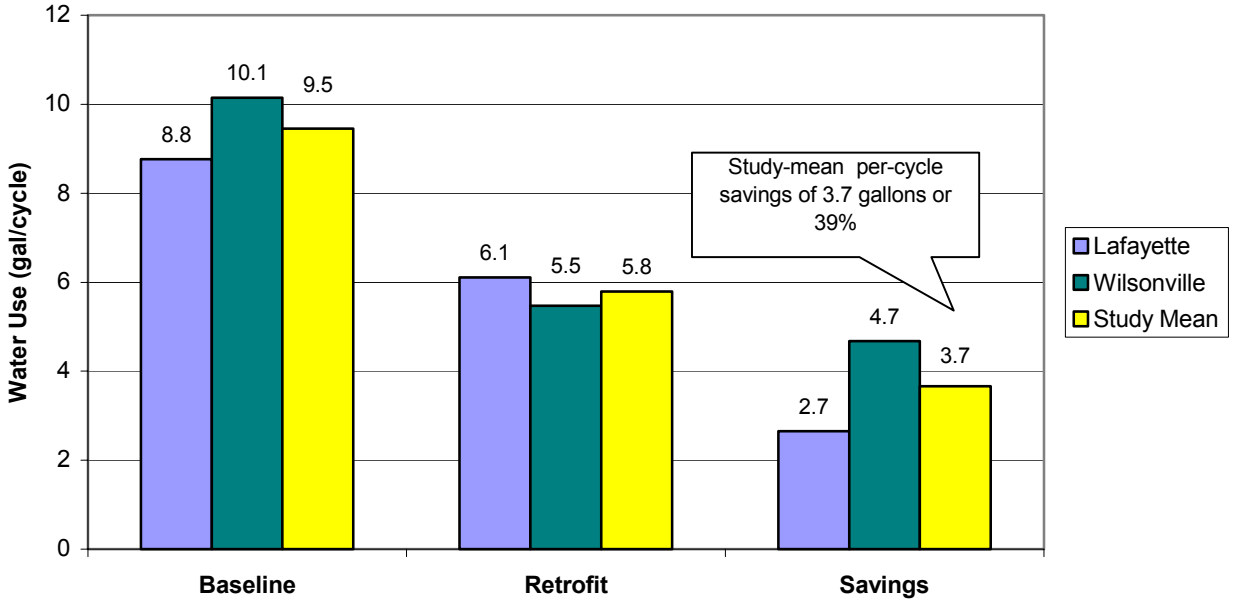

Figure 20. Dishwasher Water Findings: Meter-Master Mean Per-Cycle Water Use and Savings (gal/cycle)

These savings represent a 39% reduction in mean per-cycle dishwasher water use over the baseline. The community-specific savings are 2.7 gallons/cycle in Lafayette, for an average of 30% savings, and 4.7 gallons/cycle in Wilsonville, for an average of 46% savings.

Figure 21 presents the mean dishwasher hot water energy use and savings results. It is important to note that the savings presented here are only in hot water; the pumping, internal water heating, and controls energy were not metered for the dishwashers. While these unmetered parameters represent a portion of the total dishwasher energy use, this analysis assumes a similarity in function of these parameters from the *baseline* to the *retrofit* as well as similarity in use by the resident (e.g., if a resident used the "heated drying" mode in the *baseline* case it was also used in the *retrofit* case).

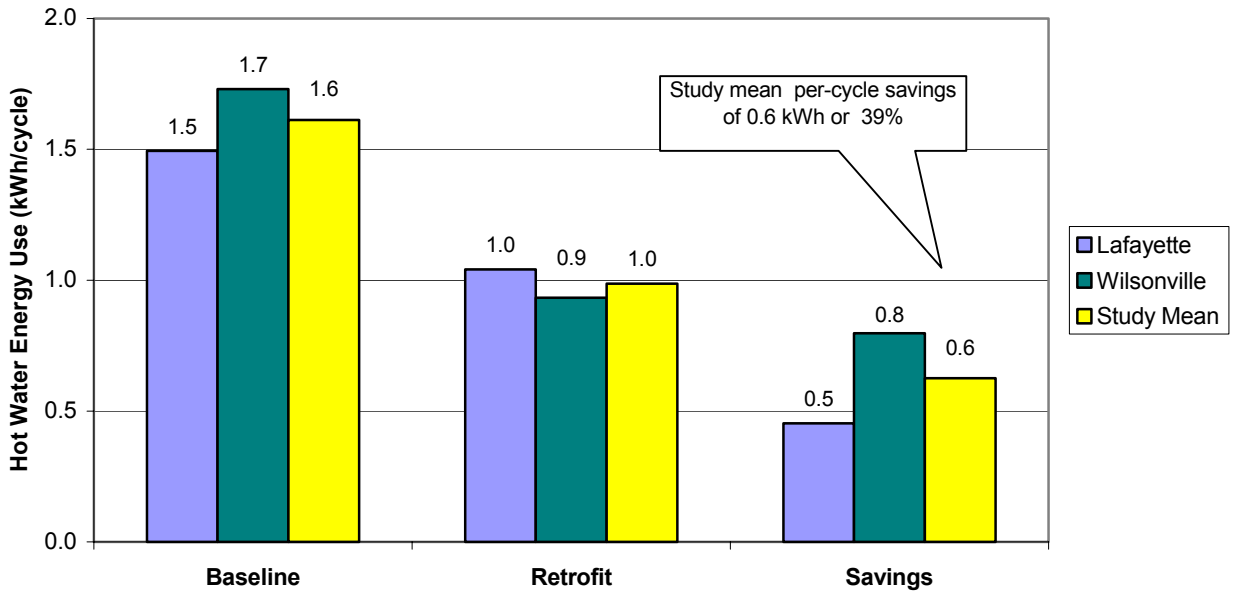

Figure 21. Dishwasher Energy Findings: Meter-Master Mean Per-Cycle Hot Water Energy Use and Savings (kWh/cycle)

The dishwasher hot water energy use and savings were calculated based on the volume of water use (as recorded be the Meter-Master) and the temperature difference of the water coming into and out of the water heater. These savings are considered conservative in that once water is inside a dishwasher it typically is further heated by the dishwasher's booster heater. Typically, this water is heated to between 140 and 160°F. This analysis captures the reduction in hot water being delivered to the dishwasher; however, it does not capture the reduction in the energy that the booster heater uses to elevate the water to the higher temperature.

The mean per-cycle dishwasher hot water energy use data indicate a savings of 0.6 kWh/cycle. These savings represent a 39% reduction in mean per-cycle dishwasher hot water energy use over the *baseline*. The community-specific savings are 0.5 kWh/cycle in Lafayette, for a mean savings of 30%, and 0.8 kWh/cycle in Wilsonville, for a mean savings of 46%.

Toilet Results

Figure 22 presents the mean per-use toilet total water use and savings results. These data are presented by community for the *baseline*, the *retrofit*, and the resulting *savings*. As discussed in the Efficient Equipment subsection on page 14, the retrofit toilets are a unique design employing an innovative two-button flushing mechanism; one button is designed for liquid waste and the other is designed for solid waste. The data showed that the toilets performed as expected, with the liquid flush using about 0.9 gallons and the solid flush using about 1.6 gallons. The differential between the two flushing modes, 0.7 gallons per flush, could be expected to be saved by using this technology over a standard low-flush (i.e., 1.6 gallon per flush) toilet in the liquid flushing mode. Furthermore, the data showed that on average the liquid flush mode was used about 65% of the time. Therefore, based on the study-wide use, this toilet design offers an additional 2,000 to 2,500 gallons savings per home per year over the standard 1.6 gallon per flush toilet.

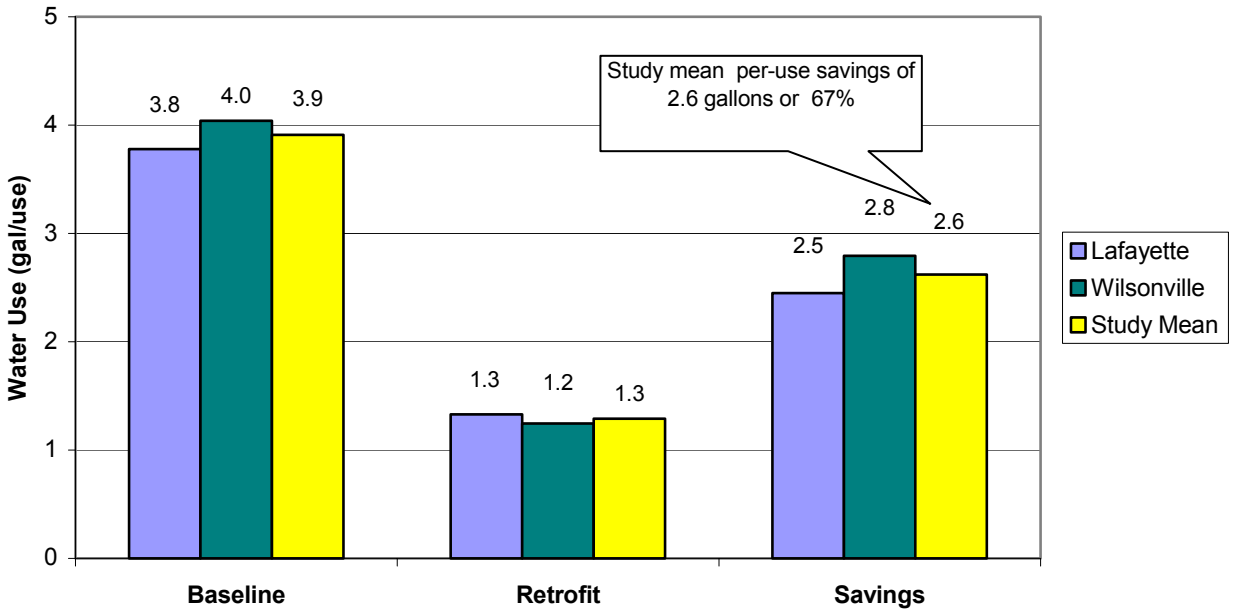

Figure 22. Toilet Results: Meter-Master Mean Per-Use Water Use and Savings (gal/use)

The toilet data indicate a mean per-use savings of about 2.6 gallons. This included a mean savings low of 1.6 gallons/use (most likely a pre-EPAct toilet modified to operate in a low-consumption mode) and a mean savings high of 4.5 gallons/use. The standard deviation of these savings is 0.87 gallons/use. The corresponding 95% confidence interval for the true mean savings is 2.6 ± 0.24, or (2.4, 2.8). We can thus conclude with 95% confidence that the true mean savings is not only greater than zero, but also actually greater than (or equal to) 2.4 gallons/use.

It is interesting to note the difference in *baseline* water use comparing the Lafayette *baseline* mean of 3.8 gallons/use to the Wilsonville *baseline* mean of 4.0 gallons/use. This difference is likely a function of the differences in *baseline* toilet types and age in the two communities. It is also interesting to note that in the *retrofit* case, the same relative difference exists (about 12%); however, the higher usage has changed cities from Wilsonville in the *baseline* case to Lafayette in the *retrofit* case. The variance in the retrofit case would have to be explained by toilet usage and the ability of the user to select one of two toilet-flushing flush modes (see the Efficient Equipment subsection for equipment description and Appendix B for toilet specifications).

End-Use Annual Savings Data

The data collected were analyzed on a per-cycle/per-use basis as well as on a per day basis. Capturing data on a per-day basis affords the ability to estimate the annual impacts of the water and energy saving. While these extrapolations can be subject to a variety of external variations (e.g., seasonal differences in how people use their clothes washer or other equipment), the authors of this evaluation feel comfortable that in most cases those variations would not significantly affect the outcome.

Annual Water Savings

Figure 23 presents the mean annual per-home water savings by equipment type. It is interesting to note that while on a per-cycle or per-use basis the clothes washer is the dominant savings device in the program (15.2 gallons/cycle savings for the clothes washer to 3.7 gallons/cycle for the dishwasher to 2.6 gallons/use for the toilet), it is the toilet that overwhelmingly drives the total program savings over time because it is used more often. Moreover, these savings indicate the importance of prioritization when making decisions on equipment selections for inclusion in a water conservation program.

On a per-home basis, the mean annual water savings is about 18,600 gallons. From a regional perspective, if SWEEP were implemented in 1,000 pre-EPAct homes the expected water savings would be over 18.5 million gallons/yr.

Annual Energy Savings

The annual energy savings estimated from the program equipment is included in Figure 24. As mentioned, these saving are predominately due to the savings in the hot water in both the clothes washers and dishwashers; the clothes dryer savings may due to a reduction in remaining moisture content in addition to other technical advantages of the *retrofit* clothes dryer over the *baseline* dryer.

Figure 23. Mean Annual Per-Home Water Savings (gal/year)

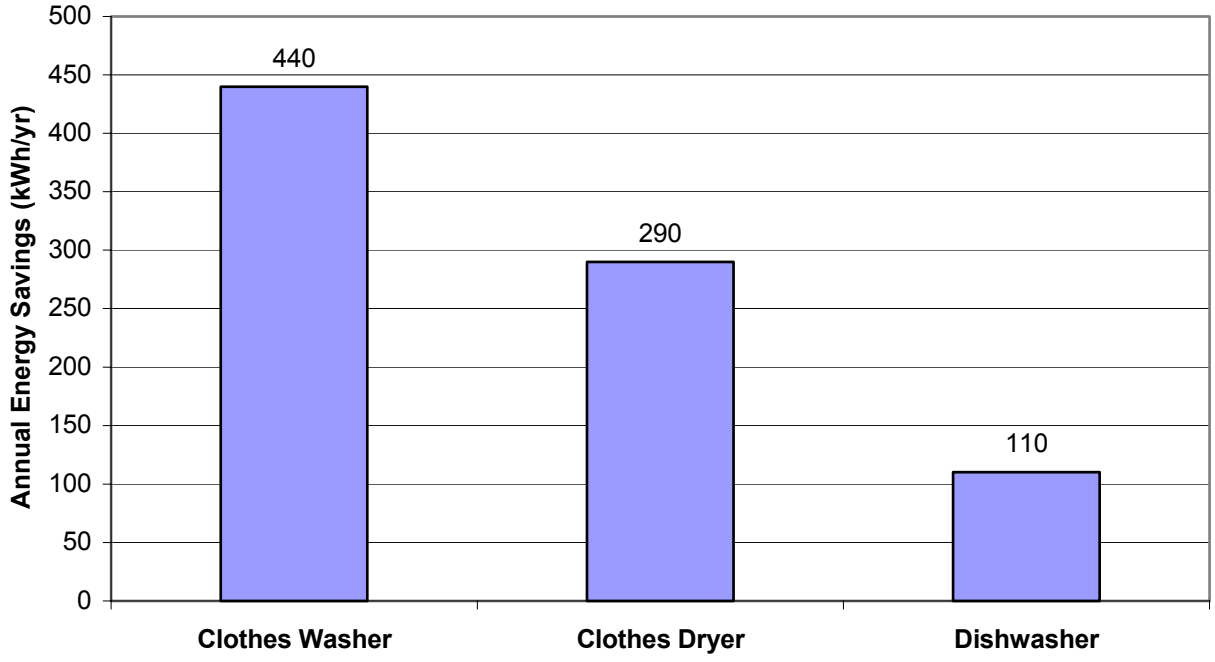

Figure 24. Mean Annual Per-Home Energy Savings (kWh/year)

Additional energy savings were evaluated for two other program appliances, low-flow showerheads and hot water heaters. These data are not reported in the body of this report due to statistical significance issues—in the case of the showerheads, only 6 of the 50 homes had all high-flow baseline showerheads replaced with low-flow showerheads. In the case of the hot water heaters, the relatively short duration of metering precludes the ability to draw statistically

significant results from the data. While not statistically significant, the data are presented, in Appendix D. While the accuracy of the data collected for the showerheads and hot water heaters is not suspect, the potential for misuse of the findings has led the authors to consider these data interesting, but not valid for decision-making purposes. Furthermore, the authors of this evaluation request that these data not be used for any evaluation, decision-making, or program development purposes. These data are provided because the corresponding equipment was metered and program partners indicated an interest in their results.

In addition to the reduced water and energy use at each home, there are, depending on the types of water/wastewater treatment systems, corresponding reductions in energy use at the distribution and treatment systems. These reductions usually include reduced energy use for pumps and mixing/aerating equipment, as well as reductions in treatment chemicals. Preliminary data from Wilsonville indicate an average energy intensity of 3.0 kWh/kgal. This value is the sum of the water supply/treatment energy intensity of 2.5 kWh/kgal and the wastewater treatment intensity of 0.5 kWh/kgal. While this is lower than the California statewide average of 4.1 kWh/kgal (CEC 1999), it is in the range of the expected energy intensities of 1.9 kWh/kgal to 9.0 kWh/kgal (QEI 1992). Based on the mean per-home water savings of 18,600 gallons/yr, the resulting energy impact at the community water distribution, water/wastewater treatment systems is about 55 kWh per home per year.

On a per-home basis, the mean annual electricity savings (assuming electric water heating) is 840 kWh. From a regional perspective, and including the electrical savings at the points of water distribution and treatment, if SWEEP were implemented in 1,000 pre-EPAct homes, the expected electricity savings would be over 890,000 kWh.

Conclusions

The major objective of this study was to evaluate a suite of water- and energy-efficient appliances installed in 50 homes. The quantification of the savings took place on a per-appliance, per-cycle basis and were aggregated-up by home and finally across all homes in the study. All savings were calculated in relation to the existing baseline equipment present in the homes at the start of the study.

The results of this study showed that the mean per-city savings, from the appliances and equipment installed, was more than 450,000 gallons/yr for the 25 homes in each community. The per-home savings were reported at a mean of 18,600 gallons/yr and about 840 kWh/yr. The mean per-home dollar savings, using mid-2000 water/wastewater and electricity rates, is estimated to be greater than $160 per year.

The benefits to the two cities from this program are in the potential for reducing demand both at the water supply and waste treatment points. These demand reductions, while not having a significant impact from only 25 homes, could hold great potential as the program grows. One very positive effect the demand reductions can have is providing needed relief to water system capacity shortages occurring on the "peak day." Additional impacts can take the form of justifying delays in planned capital upgrades to the system. These delays can have a net positive dollar impact to the communities through the deferment of capital expense. These potential system impacts from SWEEP-type programs are the focus of the computer model being developed by George Mason University and due to be released in spring 2001.

The results of the individual program appliances showed that on a per-cycle basis the clothes washer reported the greatest amount of water savings at about 15.0 gallons/cycle. These were followed by the dishwasher savings at 3.7 gallons/cycle and then the toilet at 2.6 gallons/use.

Examining the per-home results on an annual basis showed that clothes washers still showed significant savings, a mean of 6,390 gallons/yr; however, these savings were roughly half of the mean annual savings reported from the toilets, 11,565 gallons/yr. Of course, this is because toilets are used far more often than clothes washers; therefore, the annual savings are much higher.

The value of the resource savings in the SWEEP study is significant and will be reflected in lower energy and water bills for the homeowner. Figure 25 presents the mean annual impact per home, by appliance and by resource savings. These calculations use a current Lafayette and Wilsonville combined marginal rate of water/wastewater of $6.50 per 1,000 gallons saved and a

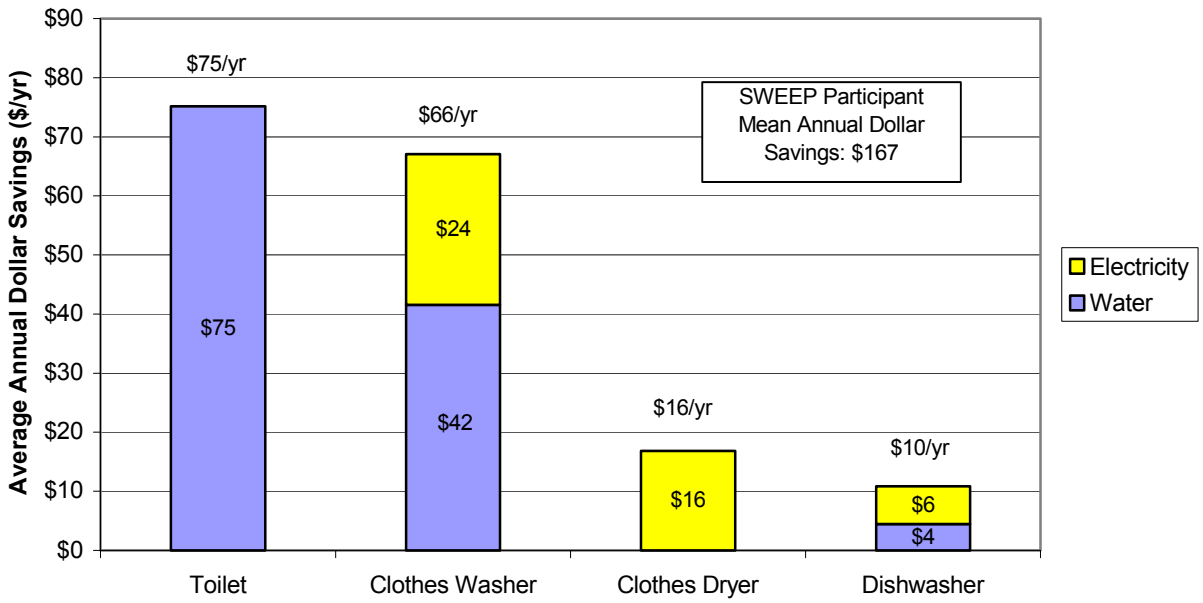

Figure 25. Mean Annual Per-Home Dollar Savings ($/year): SWEEP Program Equipment Findings

current marginal electricity rate of $0.058 per kilowatt-hour saved. To calculate the dollar savings for homes using natural gas water heaters, the electricity portion of the savings should be multiplied by 0.65.[7]

It should again be noted that the water/wastewater rate in both communities will be increased over the next year with the final target approaching $8.00 per 1,000 gallons. Likewise, the electricity and natural gas rate increases are expected. In addition to saving dollars today, these appliances and fixtures afford the ability to hedge against future water, electricity, and natural gas rate increases.

In summary, the SWEEP program, as implemented in the communities of Lafayette and Wilsonville, Oregon, produced significant savings in water and energy when compared with the *baseline* equipment. The study demonstrated that a properly chosen suite of appliances and equipment can make a significant impact on indoor water use—the study mean savings were 25% of indoor water use, for an average per-home savings of 18,600 gallons/yr. These water savings were present at the clothes washer with a 38% reduction over the mean baseline use, the dishwasher with a 39% reduction over the baseline use, and the toilets with a 67% reduction over the baseline use. The resulting per-home mean annual energy savings totaled 840 kWh and reduced clothes washer energy use (mechanical and hot water) by 68%, dishwasher energy use (hot water use only) by 39%, and clothes dryer energy use by 25%.

[7] This factor adjusts the results to account for the difference in gas and electricity costs, as well as their difference in assumed water heater efficiencies, see the Clothes Washer Findings subsection on page 28.

Finally, from a regional perspective, if SWEEP were implemented in 1,000 pre-EPAct homes, the expected resource savings would include over 18.5 million gallons of water and over 890,000 kWh of electricity per year.

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