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Energy Savings from Energy-Efficient Showerheads: REMP Case Study Results, Proposed Evaluation Algorithm, and Program Design Implications

W. M. Warwick

September 1993

Prepared for
the Bonneville Power Administration
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Pacific Northwest Laboratory
Richland, Washington 99352

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Foreword

This report presents results from a field study of energy-efficient showerheads conducted for the Bonneville Power Administration (Bonneville) by the Pacific Northwest Laboratory (PNL). The results and other findings presented in this report are the products of PNL research and do not constitute Bonneville policy.

Summary

The Bonneville Power Administration (Bonneville) has initiated two field studies of water-saving devices, the Regional End-Use Metering Program (REMP) study conducted by the Pacific Northwest Laboratory (PNL) and the Bonneville/Puget Sound Power and Light (Puget Power) water flow study just being implemented. These studies address the same subject using somewhat different approaches. The objectives of these studies is to provide statistically valid estimates of energy savings from energy-efficient showerheads under known field conditions. These results will be used to infer energy savings from Bonneville's appliance efficiency program as part of a program impact evaluation.

This report has three purposes. The first is to summarize the results of the REMP field study. The second is to introduce and explain the "energy savings algorithm" proposed for the Bonneville program impact evaluation. This algorithm will use data from both the REMP and Puget Power studies, as well as appropriate field data offered by participating utilities. The third purpose is to present information that may be useful in reviewing the current Bonneville program design and estimating savings from program design alternatives.

Overview

In 1991, Bonneville initiated research to determine the energy saving potential of energy-efficient showerheads installed at participating REMP sites. The research was implemented in two phases by PNL. The first phase was a field study designed to identify field conditions associated with the installation of energy-efficient showerheads. PNL collected energy use data from field

study participants concurrently. The second phase of the study analyzed energy savings. This report summarizes the findings of both phases of this field study.

A total of 150 single-family REMP sites were eligible for participation in this study (out of 154 single-family homes in REMP). The sites are located in Oregon, Washington, Idaho, and Western Montana. REMP homes are equipped with data loggers that record energy use individually for all major household circuits, including space and water heating. Although REMP sites are probably not statistically representative of the region, they include a cross section of residences and occupants. To recruit field-study participants, residents were offered a \$40 cash incentive, free showerheads, free professional installation, and a return of their old showerheads upon request.

Savings from energy-efficient showerheads depend on several program factors, including participation in a retrofit program, replacement of high-flow showerheads with energy-efficient showerheads, and use of the retrofit showerheads for bathing. Savings are also dependent on field conditions, such as existing water flow rates, water pressure, and water supply source. A summary of field study results on these topics is provided below.

Program and Measure Results and Savings Estimates

The savings from retrofit programs depend on participation in the program and installation and performance of measures. Many homes have more than one shower. Consequently, results need to distinguish between the number of homes or participants in the program, and the number of showerheads, or measures.

Program Findings

Program participation is the number of participants or households who agreed to install showerheads. Of the 150 sites eligible to participate in the REMP study, 111 elected to participate. However seven withdrew, for a total of 105 who participated in the initial site visit. Six homes dropped out during the site visits, resulting in a 65% program participation rate.

Program penetration is defined as the fraction of participants who actually had showerheads installed. Ninety-eight of the initial 111 house-holds who volunteered to participate were retrofit with energy-efficient showerheads, for an 88% program penetration rate.

Program persistence is based on the fraction of the households that installed showerheads where at least one showerhead remained in service. After 15 months, 92 of the 98 homes that were retrofitted retained at least one showerhead for a 94% program persistence rate.

Measure Findings

Measure participation is based on the actual number of showerheads distributed compared to the total number that could be installed. In this study it is estimated that the original 150 potential participants had 240 showerheads. Of the 240, 158 were replaced for an approximate measure participation of 66%.

Measure penetration is based on the number of efficient showerheads installed in homes penetrated by the program compared to the number that could have been installed. The 98 homes that received showerheads contained 161 showers; 158 showerheads were replaced for a measure penetration of 98% for the 98 homes, and 66% for the 150 original eligible homes.

Measure persistence is based on the fraction of measures that remain in service compared to the number installed. Of the 158 showerheads that were

installed in the 98 homes, 149 remained in service after 15 months for a 94% measure persistence rate.

Field Measurements

Energy savings from retrofit showerheads result from reduced hot water use. This field study measured actual water flow rates to assess energy savings potential as well as energy use changes pre- and post-retrofit. Energy-efficient showerheads rated at 2.5 gpm (brand name Ondine) and 2.0 gpm (brand name ETL) were retrofit in this study. Participants were not given a choice of showerheads. Showerhead selection was based solely on research requirements. Pre-existing showerhead flow rates at REMP sites were unknown prior to this study. Initial field measurements revealed flow rates below 4 gallons per minute (gpm) which was lower than expected. A 2-gpm rated showerhead was substituted in the study to obtain maximum savings. This showerhead brand actually performed at 1.7-gpm, or better than its rating.

The energy-efficient showerheads effectively reduced water flows. Average flows prior to retrofit were 3.2 gpm; after retrofit they were 1.4 gpm at the 98 retrofit sites. However, the average 44% flow rate reduction masked a wide variation that included flow increases at 15% of the ETL sites and 23% of the Ondine sites. Low water pressure was associated with these sites.

Twenty percent of the participants had wells. The average water pressure for well-supplied homes was 37.9 pounds per square inch (psi), as compared to 66.1 psi for city-supplied homes.

Savings Estimates

Energy savings were estimated using end-use metered data for water heaters at participating sites. Data from 85 sites was used for this analysis. Some sites were excluded because they had a second water heater that was gas-fired or had missing or unreasonable data. Savings were estimated using water heating energy use measurements for one year

prior to, and one year after, energy-efficient showerheads were retrofit at each site.

Net savings of 363 kWh per household were estimated for the first year after showerhead retrofit. Analysis of savings results indicate that the key factors affecting savings are pre-existing showerhead flows, the flow rate of the retrofit showerhead, and the fraction of showerheads replaced in each home. Significantly lower savings were identified among sites with low water pressure (below 45 psi).

Program Implications

Savings from retrofit programs will vary from first-year savings due to the normal replacement of measures. Bonneville staff provided PNL with an estimated measure life of 12 years. In other words, Bonneville expects the stock of showerheads to be replaced once, on average, over a 12-year period. If this replacement rate is used to project savings

over the 12-year life of a showerhead, it reduces annual savings each year as retrofit showerheads are removed. Projecting first-year savings from REMP sites for the 12-year measure life results in estimated lifetime savings of 2,667 kWh for these sites, or average annual savings of 222 kWh.

Savings vary directly with changes in flow rates. Flow rate changes are a function of the flow rate of the retrofit showerhead brand. REMP savings were obtained primarily from a 2-gpm rated showerhead that performed at 1.7-gpm. If 2.5-gpm showerheads were used at REMP sites instead, first-year savings are estimated to be 181 kWh and lifetime savings would be 1,334 kWh. After 1994, national standards mandate 2.5-gpm showerheads. As a result, expected savings will be reduced as the existing stock of showerheads are replaced and pre-flow rates trend toward 2.5 gpm. This "free rider" effect significantly affects savings projections for participants in programs after 1994.

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1.0 Introduction

The Bonneville Power Administration (Bonneville) has initiated two field studies of hot water-saving devices (energy-efficient showerheads and faucet aerators). In 1991 Bonneville commissioned PNL to perform a field study of energy-efficient showerheads for Bonneville utilizing an existing sample of end-use metered residential customer sites from Bonneville's Regional End-Use Metering Program (REMP). The REMP showerhead field study is now complete. The second field study is a water flow field study that Bonneville is currently implementing in conjunction with Puget Sound Power and Light (Puget), which will include the retrofit of both energy-efficient showerheads and faucet aerators. This report describes PNL's findings based on the results of the REMP field study.

1.1 Background

The field study was conducted among participants in REMP to decrease the expense and time associated with energy-use data collection. The REMP sites had also participated in earlier Bonneville residential energy-use research. In 1983, Bonneville conducted a regional residential survey of over 4,000 residences in the Northwest called the Pacific Northwest Residential Energy Consumption Survey (PNWRES). A sample of these residences was recruited for inclusion in the End-Use Load and Conservation Assessment Project (ELCAP), a multi-year study Bonneville initiated in 1985. Under ELCAP, energy-use monitoring equipment was installed to individually meter a variety of electrical circuits in over 400 selected buildings. ELCAP's successor is REMP, which continues data collection from a sub-set of the original ELCAP sites. A total of 154 single-family homes are still participating in

the REMP metering study. Of these 154 sites, 150 were eligible for the showerhead installation field study described in this report. (Some were ineligible because they had gas water heaters.) Although the field study sites are not directly representative of the region, they were drawn from PNWRES in a way that permits extrapolations to the region.

Bonneville initiated the Energy-Efficient Showerhead Field Data Collection Project in August 1991. The goal of the project was to collect site-specific field data regarding the installation of energy-efficient showerheads. The field data collection effort was implemented by PNL to collect information about site and occupant characteristics that may affect participation in energy-efficient showerhead programs and performance of energy-efficient showerheads in use. In the course of the field study, data was collected on the following:

- installation of showerheads
- site and occupant characteristics
- post-installation retention and satisfaction.

The procedures used to recruit sites and install energy-efficient showerheads mirrored those encountered in a showerhead retrofit program: customers were solicited to participate, arrangements were made to install showerheads, and payments were made after installation. As a result, observations were made that permitted identification of program implementation barriers, installation problems, and measure penetration rates.

Each REMP site is equipped with a data logger that records energy use, individually, for all major

appliance circuits, including space and water heating. Data is recorded hourly, and archived on a monthly basis. Several years of data are available for each site. The availability of electric water heater energy use data for the pre-retrofit period meant that retrofit savings data could be collected as soon as showerheads were installed, reducing research time.

1.2 Organization of the Report

The results presented in this report are drawn from analysis of the REMP field study results together with results from earlier studies conducted by Bonneville and/or PNL, and noted in this

introduction. REMP field study results are provided in Section 2. These results include estimated savings from showerhead retrofits at REMP sites during the study period. These savings estimates are based on post-hoc analyses of energy use data. As such, they represent savings at a previous point in time. They are not projections of future savings, but may be used to project savings, under specified assumptions and conditions. A method for extrapolating these estimates to the region for evaluation purposes is presented in Section 3. Study conclusions are contained in Section 4. Section 5 uses study results to project savings into the future as a means of illustrating implications of study results on program designs.

2.0 Summary of REMP Field Study Results

Field study results including participation, penetration, and persistence; energy savings; and load shapes are presented in this section.

2.1 Participation, Penetration, and Persistence

The focus of the showerhead field study was single-family homes with at least one electric water heater. The REMP sample included 150 eligible single-family homes. Attempts were made to recruit each of these homes to participate in the field study by promising free, professional replacement of current showerheads, return of original showerheads upon request, repair of minor plumbing problems, and a \$40 cash payment. Participating homes were subjected to a field inspection and multiple surveys.

This approach is similar to a program designed for professional installers, it included an aggressive installation feature (10% of the showers required minor but special installation procedures) a significant cash payment, and return of showerheads. The disposition of the original REMP sample is shown in Table 2.1.

It is unrealistic to assume that all showerheads in a retrofit program will be replaced, based on the REMP study. Despite using professional installers, generous incentives, and the promise of return of original showerheads if requested, 10% of the showerheads could not be replaced due to occupant objections or physical installation barriers. Another 10% of the showerheads were installed due to the use of professional installers who were able to overcome plumbing barriers that may prevent homeowners from installing new showerheads on their own.

2.1.1 Site Results

The savings from retrofit programs depend on participation in the program and installation and performance of measures. The success of a program is usually based on the number of sites that are involved at various stages of a program.

Program participation is the number of households who initially agreed to have showerheads installed. Recruitment letters and follow-up phone calls were made to 150 REMP sites, and 111 elected to participate, for a 74% participation rate.

Program penetration is the fraction of households that had showerheads installed compared to the number who could have participated. Ninety-eight of the 150 REMP homes had at least one showerhead replaced, for a 65% penetration rate among all households. Alternatively, 98 of the 111 participants installed one or more showerheads for a 88% penetration rate among interested households.

Program persistence is the fraction of initial participants who had showerheads installed who still have at least one in place. Persistence was measured two ways. First, a survey was administered after showerheads had been in place about 8 months. Thirty out of 36 responses indicated no showerheads had been replaced, for a persistence rate of 83%. If the six sites who claim to have removed showerheads are the only sites who did so, persistence in the entire sample increases to 93% at 8 months. Persistence was also calculated based on the actual rate of return of original showerheads by PNL staff, because survey responses are not always reliable. At the end of the REMP study, 15 months after retrofit, 92 of the 98 homes had not asked

Table 2.1. Field Study Participation History

REMP Showerhead Study Original Sample	150	4 of the 154 REMP sites were not eligible for program participation because they were manufactured homes or were known to have a gas water heater ^(a)
REMP showerhead sites recruited	111	111 of the 150 agreed initially to participate
	- 6	6 of the 111 homes were dropped from the study before the site visits--either the owner changed mind or we learned the home had a gas water heater
REMP initial retrofit participants (homes visited)	105	105 sites were visited
	- 7	At 7 homes the owners changed their minds about participating or we decided not to install a new showerhead because we found nonstandard plumbing or a gas water heater ^(a)
REMP final participants	98 ^(b)	New showerheads were actually installed in 98 sites
	- 7	3 had missing data and 4 had gas water heaters ^(a)
REMP potential-savings sites	91 ^(c)	91 sites had complete sets of useable data
REMP energy-savings sites	85 ^(d)	85 sites had energy use data that was complete after appropriate outlier sites were removed
<p>(a) The original ELCAP study included a case study of homes with gas space and water heating. These were excluded from the showerhead field study. However, some of the eligible sites had multiple water heaters, including both gas and electric models. In addition, some of the electric water heaters in the original sample may have been converted to gas.</p> <p>(b) Participation, penetration and persistence calculations are based on the 98 site sample.</p> <p>(c) All flow rate calculations are based on the sample size of 91.</p> <p>(d) All energy savings calculations are based on an 85 site sample, unless noted.</p>		

PNL for their showerheads back, for a 94% program persistence rate.

2.1.2 Measure Results

Homes can have multiple showers. As a result, participation, penetration, and persistence need to be

reported based on the number of showers or measures, as well as the number of homes or participants.

A total of 173 showers were identified at the 105 homes PNL visited. Although attempts were made to retrofit all showerheads in each home, this

was not possible in all cases. The distribution of showers per home and the number of showerheads retrofit are summarized in Table 2.2.

Achievement of **conservation potential** is based on the number of measures that are installed at various stages of a program.

Measure participation is based on the actual number of showerheads distributed compared to the total number that could be installed. The original 150 potential REMP participants had an estimated 240 showerheads. Of the 240, 158 were replaced for an approximate measure participation rate of 66%.

Measure penetration is based on the number of efficient showerheads installed in homes compared to the number that could have been installed. The 98 homes that received showerheads contained 161 showers; 158 showerheads were replaced for a measure penetration of 98% for the 98 participating homes, and 66% for the 150 original eligible homes.

Measure persistence is based on the fraction of measures that remain in service compared to the number installed. Survey responses did not identify the number of showerheads that were replaced, so the only source of data on measure persistence is requested returns. Of the 158 showerheads that

were installed in the 98 homes, 149 remained in service after 15 months for a 94% measure persistence rate.

Of the 105 sites, only 91 will be used for energy savings analyses due to non-electric water heaters and critical missing data. Of these 91 sites, 139 showerheads were replaced.

2.1.3 Flow Measurement Results

Savings from showerheads are directly related to how much water flow is reduced. Prior to this field study, there was little information about the flow rates of existing showerheads. This field study measured actual water flow rates before and after retrofit to assess energy savings potential.

Although several showerhead brands are included in Bonneville's overall showerhead program, the initial REMP field study design specified a single brand and model of showerhead to minimize the differences in performance from one brand to another. However, two brands of showerheads were ultimately used as replacements.

The first choice was an Ondine brand showerhead (Ondine). The Ondine model selected had a 2.5-gallon per minute (gpm) design flow rate. However, after completing flow rate measurements and installations in 13 homes (22 showerheads),

Table 2.2. Installations (105 sites)

Number of Showers	Number of Sites	Number of Sites with This Number of Showerheads Replaced				Total Number of Showerheads Replaced
		1	2	3	0	
1	47	44	NA	NA	3	44
2	48	3	43	NA	2	89
3	10	1	0	8	1	25
Total:	105 sites					158

field personnel noted that before-replacement flow rates were lower than expected. "Before" flow rates averaged 3.9 gpm instead of the 4 to 5 gpm flow rate they had expected. A 50% flow reduction was desired to measure total water heating energy use change pre- and post-retrofit.

A second retrofit showerhead, the ETL Spa 2001 brand (ETL), (rated at 2.0 gpm) was purchased as a substitute. Field observations indicate the ETL showerheads performed at 1.7 gpm, or better than their rating. Pre- and post-flow rate measurements and flow rate changes, or savings potential, are summarized in Table 2.3.

The average post-retrofit flow rate was 1.8 gpm. The average flow reduction was 1.4 gpm. The flow rate reduction and energy savings is specific to the brand of showerhead used in the program. Accordingly, the energy savings of 363 kWh observed is specific to this sample and these showerheads. Extrapolation of these results to other sites will require appropriate adjustments to reflect the post-retrofit flow rates of each showerhead brand used to provide relevant savings estimates. (See Section 5 for an illustration.)

2.1.4 Savings Potential

The basis for water and energy savings from energy-efficient showerheads is in the change of flow rates pre- and post-retrofit. This change is a function of pre-existing flow rates and the performance of the brand of energy-efficient showerhead. The pre-existing flow rates observed in the REMP study ranged from less than 1 gpm to over 5 gpm. Although 27% of the pre-retrofit flows exceeded 4 gpm, 29% were below 2.5 gpm (Figure 2.1). In order to achieve a maximum amount of savings, or to reduce flow rates at the maximum number of sites, retrofit showerhead flow rates need to be very low. Table 2.4 indicates how the choice of retrofit showerhead flow rate affects retrofit program market and savings potential.

2.2 Energy Savings

Energy savings are described in terms of total participant or gross savings, non-participant effects, and net savings.

Table 2.3. Average Water Flow Results (in gpm)

	Number of Showerheads ^(a)	Rating	Pre-Flow	Post-Flow	Change	%
ETL Sites	136	2.0	3.09	1.67	1.42	-46
Ondine Sites	22	2.5	3.89	2.55	1.34	-34
Overall	158	NA	3.21	NA	1.41	-44
^(a) for 98 sites where showerheads were retrofit.

Cumulative Frequency of Showerheads									
170	166	153	121	93	81	59	46	27	16

Figure 2.1. Distribution of Measured Pre-Flow Rates

Table 2.4. Potential for Savings at Various Retrofit Flow Rates

Design Flow Rate of Retrofit Showerhead (gpm)	Number of REMP Showerheads with Savings (base 170)	Fraction of REMP Showerheads with Savings (170=100%)
3.0	81	48%
2.5	93	55
2.0	121	71
1.5	153	90
1.0	166	98

2.2.1 Participant (Gross) Savings

A total of 85 participant sites were used for analysis of pre- and post-retrofit potential energy use and savings. The focus of this analysis was energy savings rather than energy use. Accordingly, the results for savings are more reliable than estimates

of energy use. Estimated savings from participants are 515 kWh per home per year for program sites. This estimate of energy savings for showerheads is a "gross" savings estimate. In other words, it attributes all changes in water heating energy use to the showerhead retrofits. The field study was conducted during a prolonged region-wide drought which

peaked during the post-retrofit period. This was accompanied by water rationing, a variety of public appeals to conserve, and heightened awareness of water-saving measures like energy-efficient showerheads. It is reasonable to assume that some of the savings observed in this study resulted from this charged atmosphere.

2.2.2 Participant/Control Group Results

Control groups are normally used to "control for" or adjust results from programs to reduce the effect of normal or expected variations. The original plan for the REMP field study did not include the use of a control group to estimate savings. However, a large number of eligible REMP sites did not participate in the retrofit study, creating a convenient pool of homes for a control group. A total of 56 REMP non-participants were used as a control group.

The non-participant control group showed a decrease in consumption of 153 kWh per home per year in the year following retrofit. The Pacific Northwest was experiencing a drought at that time and it was assumed that non-participants changed their hot water energy use in the post-retrofit period in response to drought-related appeals and other factors. Program participants would also be expected to change their hot water energy use in response to drought appeals and these changes should not be attributed to participation in the showerhead retrofit study.

2.2.3 REMP Net Showerhead Savings

The net savings estimated from the field study are derived from the results from the participant sample adjusted for control group load changes. The net savings for the REMP sites was 363 kWh per home per year.

2.2.4 Other Energy Use Analyses

As noted in Section 2.2, these REMP field study data were analyzed several ways. The results presented in Sections 2.2.1 through 2.2.3 are the most appropriate to estimate the average energy savings from the REMP field study. However, these other analyses provide insights into the role that selected other factors may have in energy savings. Because of small sample sizes and likely biases, these results are not particularly robust and should be used with caution. Nevertheless, they point to issues that should be investigated further, using both this data and larger samples.

2.2.4.1 Billing Data Results

End-use metering among the REMP sites permits reconstruction of energy use to resemble data from billing meters. To remove any weather effects, the space heating end-use data were omitted, creating a data set that resembles billing data for customers with electric water heating, but not electric space heat. The results of this analysis are shown in Table 2.5.

Table 2.5. Savings Estimates from REMP "Billing" Data

	Mean Savings (kWh)	Sample
Participants	620	85
Controls	387	56
Net Savings	233	NA

The "billing data" estimate of savings is not a reliable substitute for the end-use metered estimate. This is due to the fact that the billing data estimate has much greater variance than its end-use counterpart. This has a significant impact on statements relating to confidence ranges. For example, the 95% confidence range for savings is 83 to 643 kWh when using the end use estimate. For the same level of confidence, the billing data estimate creates a range of -337 to 793 kWh per year. Thus, we are confident the "true result" is contained within the billing data standard error (e.g., 363 is between 83 and 643), but we are equally confident the mean differences in the billing data are not the "true result" (e.g., 363 is not equal to 233). In simple terms, analyses of results from end-use and metered data indicate that savings estimates based on billing data comparisons are not accurate.

2.2.4.2 Saving Estimates by Showerhead Brand

Two brands of showerheads were used in the REMP study: the Ondine rated at 2.5 gpm, and the ETL rated at 2.0 gpm. The difference in rated flow should provide different savings. However, differences in the pre-retrofit flow rates tend to mask this effect. Table 2.6 compares the results on the basis of showerhead brand.

The sites with Ondine brand showerheads saved slightly more energy, both absolutely and on an average per-gallon-flow reduction basis. This could indicate that the design of the showerhead, or the flow rate, affects savings in ways that are not clear. For example, the lower flows associated with the ETL brand showerhead may be offset by slightly longer showers. However, the sample of "Ondine" sites is so small, the differences between the two brands are not statistically significant.

2.2.4.3 Effect of Other Conservation Actions

Water heaters generally last 10 to 12 years before they fail. During the study period several water heaters were replaced. This could affect energy savings if more energy-efficient water heaters were installed during the post-retrofit period. Participants were asked if they replaced their water heater in the post-retrofit period. According to survey responses, 1 of the 56 control sites and 10 of the 85 participant sites replaced their water heater. These responses are difficult to verify, so their reliability is unknown. Nevertheless, if these sites are dropped from the analysis this potential source of error would be eliminated, see Table 2.7.

Table 2.6. Comparison of Savings by Showerhead Brand

Brand	Number of Showerheads	Pre-Flow (gpm)	Post-Flow (gpm)	Flow Change (gpm)	No. of Sites	Gross kWh Savings	Net ^(a) kWh Savings
ETL	136	3.09	1.67	1.42	73	511	358
Ondine	22	3.89	2.55	1.34	12	542	389
Overall	158	3.21		1.41	85	515	363
^(a) Estimated control group savings = 153 kWh							

Table 2.7. Savings for Sites Where Water Heaters Were Not Replaced

	Mean Savings (kWh)	Sample
Participants	491	75
Controls	150	55
Net Savings	341	NA

The differences in savings that result from this analysis are also not statistically different from those in the full sample. However, if the observed differences are attributed to the water heater replacement, savings of 165 kWh can be inferred at the one control site and savings averaging 240 kWh can be inferred at the 10 participant sites.

2.2.4.4 Effect of Low Water Pressure

Water pressures in the field study varied widely. Nevertheless, retrofit showerhead performance was comparable across the range except when water pressures were low (i.e., less than 45 psi). The principal determinant of low water pressure was a domestic well as a household water supply. The low flow rates, both pre- and post-retrofit, associated with these sites reduced the average savings among all field study sites, and is reflected in the 363-kWh savings estimate. Savings at normal and low water pressures are shown in Table 2.8. Twenty percent of the field study sites were served

by domestic wells. This is similar to the fraction of homes served by wells in the region as a whole (as found in the PNWRES 1983, ELCAP, and REMP surveys).

Again, the low pressure sample is too small to draw robust conclusions.

2.3 Load Shapes

The typical water heater uses a constant amount of power when it is on, typically about 4,500 watts, and no power when it is off. Accordingly, a minute-by-minute picture of energy use for a single water heater would look like a series of spikes or lines separated by periods of no load. When these loads are aggregated over longer time intervals, such as hourly, the loads are averaged to include the zero load, or no-load periods. This has the effect of reducing the apparent load. When loads are averaged across multiple sites, a similar effect

Table 2.8. Comparison of Savings at Low Water Sites

	Gross Savings (kWh)	Sample
"Normal" Pressure	545	71
Low Pressure	309	10
Difference	236	NA

results. Averaging across sites is called "diversification" and the resulting picture of loads is called a "diversified load shape." PNL represented the diversified loads in composite load shapes that reflect average loads for the year across the sample. Load shapes were prepared to reflect the pre- and post-retrofit loads and the post-retrofit loads were subtracted from the pre-retrofit loads to derive a load shape for the "gross" energy savings. The load shapes of the hot water loads for the "test" or participant sample are presented in Figure 2.2. The load shapes for the control sample are presented in Figure 2.3. The shape of the gross savings from the test and control groups is presented in Figure 2.4. The "net" load shape, derived by subtracting the savings load shapes in Figure 2.4, is presented in Figure 2.5.

Figure 2.2. Pre/Post Hot Water Profile for Test Sample

Figure 2.3. Pre/Post Hot Water Profile for Control Sample

Figure 2.4. Annual Hot Water Savings Profile--Test and Control

Figure 2.5. Net Hot Water Savings Profile

3.0 Impact Evaluation Algorithm

Over 100 utilities have signed-up for Bonneville's Appliance Efficiency Program, making it one of the most popular of Bonneville's conservation acquisition programs. The utilities used a variety of distribution methods and brands of measures with different performance characteristics. This variety complicates program impact evaluation because the distribution methods and showerhead brands vary in effectiveness and hence impact. Consequently, the various measures will have to be accounted for on a utility-by-utility basis, rather than the more efficient sampling basis, to ensure reliable evaluation results. At this point, PNL is proposing to begin collecting this information from Bonneville's area office records. If necessary, utilities may be approached to complete the data collection and to collect information for a proposed process evaluation. The impact records required are relatively limited, consisting of types of distribution methods used, number of showerheads distributed, number of customers participating, and brands of showerheads distributed.

3.1 Energy Savings Algorithm

The impact evaluation of this program is expected to be based on an energy savings algorithm developed by PNL during the REMP field study. This algorithm is shown below:

$$\text{Savings} = ((\text{REMP Net Showerhead Savings}) (\text{Adjustments from the Bonneville/Puget Water Flow Study})) (\text{Retrofit Rate Ratio}) (\text{Retrofit Showerhead Flow Rate Ratio}) (\text{Ratio of wells (Persistence)}) + ((\text{Net Savings from Faucet Aerators}) (\text{Aerator Retrofit Rate}) (\text{Persistence}))$$

Each of these factors is explained below. Some factors in the proposed Energy Savings Algorithm will be based on results from the Bonneville/Puget Power water flow study, as indicated by the variables in *italics* type.

REMP Net Showerhead Savings. Savings estimates will be benchmarked on the observed savings from the REMP study, namely 363 kWh per year.

Adjustments from the Bonneville/Puget Water Flow Study. The Bonneville/Puget Power water flow study may provide insights that result in adjustments to the REMP savings estimates.

Retrofit Rate Ratio. The REMP savings are based on a retrofit rate of 90% per home. Retrofit rates are expected to differ from this value depending on the type of distribution method used. The actual rate observed will be calculated using utility data whenever such data is available. In the absence of local data, an installation rate based on similar programs will be assumed.

Retrofit Showerhead Flow Rate Ratio. The REMP results are based on a pre-flow rate of 3.2 gpm, a post-flow rate of 1.8 gpm, and a net change in flow rate of 1.4 gpm. Differences in the flow rates of retrofit showerheads (from the 1.8 observed in REMP) will affect savings; so too will differences in pre-existing shower flows (from 3.2 gpm). The actual rate observed will be calculated using utility data whenever such data is available. In the absence of local data, the specified flow rate of the retrofit showerhead will be substituted for the REMP post-flow rate of 1.8 gpm and the REMP pre-flow rate assumed to calculate the change in

flow rate. This rate will be used to calculate a flow rate change ratio using the REMP results and this ratio will be used to scale energy savings.

Ratio of wells. The REMP sample had an average of 20% wells. The actual rate will be calculated using utility data whenever such data is available. In the absence of local data, the REMP rate will be assumed.

Net Savings from Faucet Aerators. Estimated energy savings from faucet aerators will be derived from the Bonneville/Puget Power water flow study.

Aerator Retrofit Rate. Estimated installation rates for faucet aerators will also be derived from the Bonneville/Puget Power water flow study.

Persistence and Measure Life. The REMP study revealed a replacement rate of 6% after 15 months, for a persistence rate of 94%. Although the replacement rate was declining after 15 months, some participants were still asking for their old showerheads back. Other studies of showerheads have produced persistence rates of about 90% after 2 years. Accordingly, a persistence rate of 90% after 2 years will be used in the evaluation. An effective measure life of 12 years has been proposed by Bonneville for showerheads (see Section 3.2.2). This value will be used to estimate the effective life and replacement rate for measures that remain after the first 2 years.

3.2 Other Factors

There are other factors that are assumed to affect program savings, most notably demographics, measure life, and free ridership. Each of these is discussed briefly below.

3.2.1 Demographic Factors

In previous analyses of ELCAP data (a larger sample) PNL observed correlations between the number of household occupants (and other household demographics) and water heating energy use. The REMP data did not reveal similar correlations between water heating energy savings and these same demographic characteristics. Consequently, no demographic factors are proposed for the energy savings algorithm.

3.2.2 Measure Life

The term measure life is used in several ways. In supply curves it is used to indicate the maximum useful life of a measure, or the so-called "test measure life." In a program or evaluation context, it is used to indicate the "average" age of a measure when it is retired from use. This is called "effective measure life." Program managers use measure life to indicate the age at which one-half of the measures have been replaced, a sort of "measure half-life." Bonneville staff proposed a maximum "measure life" of 12 years at the outset of this program. This is consistent with data from other regions which indicates they are normally then removed coincident with other changes (new occupants, bathroom remodeling, etc.). After about 7 years, one-half of the showerheads have been replaced. It is assumed that the remaining measures will continue to be replaced such that all are gone by year 12. This affect will be captured in the "persistence" term included in the algorithm.

3.2.3 Free Riders

Free riders are program participants that would have installed conservation measures even without the program. Typically, these are individuals who

would be installing program-mandated measures primarily for reasons other than utility energy savings, such as being required by building codes, other standards, or personal economics. The current Bonneville program was initiated prior to the adoption of codes affecting water flow. However, Oregon adopted water conservation codes that took effect in October 1992 and Washington adopted

water conservation codes effective July 1993. In addition, national standards will go into affect in January 1994. These effects will not significantly affect this evaluation because most of the measures being evaluated were installed before these codes became effective. Nevertheless, this affect will need to be reflected in future program evaluations.

4.0 Conclusions and Recommendations

The REMP field study provides the most comprehensive data to date on factors affecting the retrofit of hot water conservation measures and associated energy and water savings. Of these, four stand out: pre-existing flow rates, installation rates in homes, estimated net savings in the face of adoption of water conservation codes, and retrofit showerhead brand (post-retrofit flow rates).

4.1 Pre-Existing Flow Rates

The biggest influence on achieving energy savings from energy-efficient showerheads is the change in water flow from pre- to post-installation. Most current energy-efficient showerheads are rated at between 2.0 to 2.5 gpm. As a result, the change in flow rate is primarily dependent on the flow rate of the pre-existing showerhead. Prior to the REMP study, it was assumed that "normal" showerhead flow rates were in the 4- to 5-gpm range. Pre-installation flows measured in the REMP study averaged 3.2 gpm, including some sites with very low pre-existing flows. Only 27% of the

showerheads measured in the REMP study had pre-flows over 4 gpm. In fact, slightly more (29%) had flows of 2 gpm or less (Figure 2.1).

This finding implies that if showerheads are distributed randomly, roughly one-quarter of them will produce no savings (and some may actually increase water flow). If savings from the 80 REMP sites retrofit with the same 2-gpm showerhead (ETL Spa 2001) are compared on the basis of "low" versus "normal" water pressure the impact of low water pressure on savings potential is obvious (Table 4.1). Pre-flow rate is a critical variable in savings potential. The pre-flow rates among low-pressure sites average 1 gpm less than those of the other sites (2.3 gpm versus 3.3 gpm). The pre-flow rate for the low pressure sites is near the "target" post-flow rate. In fact, it is below the 2.5-gpm rating for showerheads distributed in Bonneville's current program. Eliminating these sites does not significantly change the pre-flow rate for the full sample (3.09 gpm for all 80 sites versus 3.3 gpm for the 62 normal pressure sites).

Table 4.1. Affect of Pressure on Flow Rates and Savings (80 ETL sites only)

	Low Pressure Sites	"Normal" Sites	All ETL Sites
Number of Sites	18	62	80
Mean Pressure (psi)	36.6	67.7	60.7
Mean Pre-Flow (gpm)	2.3	3.3	3.09
Mean Post-Flow (2.0 gpm ETL showerhead) (gpm)	1.4	1.75	1.67
Difference (gpm savings)	.92	1.56	1.42

However, eliminating these sites would significantly reduce the number of sites that need to be retrofit to achieve most of the available savings (Only 80% of the sites would need to be retrofit).

The association between wells and low water pressure may provide a reasonable basis for screening participants without actually conducting site-specific flow measurements (See Section 2.4.3). Similarly, water pressure could be measured using an outside water faucet without entering the home. This may be a low-cost, non-intrusive way to avoid low savings sites. Finally, some city water bureaus have records of water pressure rates that could be used to identify areas of a town with chronically low water pressure that could be avoided.

Alternatively, flow rate changes were observed from low pressure sites. These average savings, 0.92 gpm, are 66% of the flow rate changes for the entire sample, and 53% of the "normal" pressure sites. The ability of a showerhead to deliver a "satisfactory" shower at low pressure remains an open question. If the showerhead is not designed to perform well at low pressure, participants will remove it. Among the 10 sites with the lowest water pressure in this study, savings of 309 kWh were estimated (Table 2.8). This is 57% of the savings estimated for 71 "normal" pressure sites, which implies that the showerhead performed adequately and achieved comparable energy savings. However, the small size of low pressure sample may make these results statically insignificant.

To screen or not to screen, that is the question. The primary impact of either option is on program cost-effectiveness. Screening sites for water pressure prior to retrofit will increase program costs. Similarly, installing showerheads in sites that only yield half the savings will also increase program costs. The trade-off between these two choices depends on the cost of screening and program

delivery. If screening is used, it will likely require a site visit, adding to program delivery costs. It may also engender ill-will if customers who expect a showerhead are later denied.

4.2 Delivery Mechanisms and Installation Rates

The REMP study used a very aggressive strategy to recruit participants and replace showerheads including personal phone calls to recruit participants and professional installation of free measures with a \$40 customer incentive payment. Nevertheless, only two-thirds of those contacted actually participated in the study. The study used professional installers to replace showerheads, and they did replace showerheads in 98 homes. (Eight percent of the sites recruited were technically ineligible for retrofit because they had non-electric water heaters). About 10% of the showerheads that were replaced required additional plumbing changes to accommodate the new showerhead effectively. The REMP study provides a useful ceiling for participation of about 66% of the contacted customers and 90% of their showerheads. Programs that do not rely on personal recruitment or professional installation will likely have lower participation and installation rates. Other studies by PNL and utilities indicate that both program participation and the percentage of showerheads retrofit in a home vary depending on the program design and delivery mechanisms. Programs that depend on customer installation, for example, have been observed to achieve installation rates of only 50% among recruited customers.

These results have several implications:

- First, the more "personal" the program design, in terms of participant recruitment, the higher the participation rate.

- Second, the closer the program design is to professional installation, the greater the fraction of showerheads replaced in each home.
- Third, customer installation programs will likely face plumbing barriers that limit retrofit rates to about 80-88% per home, assuming each home is provided with sufficient replacement showerheads.
- Fourth, programs that limit the number of showerheads distributed arbitrarily prevent the complete replacement of showerheads in all homes. Less than 45% of the REMP homes had only one shower. A program design limited to one showerhead per customer would have missed 40% of the showerheads. This could include programs that rely on over-the-counter and door hanger distribution methods. On the other hand, distribution methods that provide participants with unlimited showerheads are also inefficient. This could include over-the-counter and response card designs that do not track participants explicitly and may provide participants with more showerheads than they need.
- Finally, distribution of showerheads to homes without electric water heaters or with dual fuel water heaters remains a program design issue.

4.3 Water Conservation Codes and Free Ridership

A 12-year effective measure life assumption means that showerheads being replaced today would be replaced over the next 12 years without the program. Savings attributable to the program accrue because the program showerheads are energy

efficient and the "non-program" replacements are assumed to be non-energy efficient. However, both Washington and Oregon have adopted standards for water-using fixtures that mandate reduced flows since the Bonneville program began. Similar national standards will take effect next year. The standard for showerheads is a 2.5-gpm maximum flow rate. The presence of these standards means that over the next 12 years the flow rate from existing showerheads will be reduced to 2.5 gpm without this program. Consequently, a 0.7 gpm flow reduction per showerhead will be achieved independent of the program (based on REMP data). These savings are "free riders" and should not be credited to the program. (An exception could be justified if the program sponsor was instrumental in adopting the new code. This is unlikely in the case of national codes as the influence of a single utility is rarely sufficient to change Federal law.)

The effect of a "free rider" adjustment is presented in Table 4.2. The age of current showerheads is unknown. Assuming all of them are new (which they would be if replaced in a program), Table 4.2 projects a uniform (straight-line) replacement rate for the current stock of showerheads over a 12-year period. As indicated, program impacts are significantly reduced as a result of the showerhead standards. Much of the expected savings (0.7 gpm) will be lost by the twelfth year of the program. This implies that a showerhead retrofit program based on 2.5-gpm showerheads would lose its effectiveness several years after the new water conservation standards are in place.

One way to boost program savings in the face of water conservation codes would be to install showerheads that performed better than 2.5 gpm. Further savings over and above those achieved with 2.5-gpm showerheads would be "firm" savings, unaffected by free rider effects.

Table 4.2. Free Riders Resulting from Water Efficiency Codes

Year	Pre-Use without Code (gpm)	Code Impact on Pre-Retrofit Flows (gpm)	Free Ridership (gpm)
1993	3.2	0.0	0.0
1994	3.2	3.14	0.06
1995	3.2	3.08	0.12
1996	3.2	3.03	0.18
1997	3.2	2.97	0.23
1998	3.2	2.91	0.29
1999	3.2	2.85	0.35
2000	3.2	2.79	0.41
2001	3.2	2.73	0.47
2002	3.2	2.68	0.53
2003	3.2	2.62	0.58
2004	3.2	2.56	0.64
2005	3.2	2.50	0.70

4.4 Retrofit Showerhead Brand

Energy savings potential from showerhead and aerator measures is a function of the effectiveness of the brand of measure installed. Showerhead flow rates are measured using a standard water pressure. However, the showerheads may perform differently at different pressures, especially at low pressure. Showerheads are available in many flow rate categories. Some of these perform better than they are rated. For example, the ETL brand of showerheads used in the REMP study is rated at 2 gpm, but actually performs at 1.7 gpm. The most popular retrofit showerhead brands are rated at 2.5 gpm. Given the "better than rated" performance of the ETL showerhead, the performance of each showerhead brand used in a program should be verified using calibrated tests at various water pressures.

4.5 Implications for Program Design

This report contains results that can be used to reliably design programs that range from low cost, low total savings to high cost, high total savings. The per unit cost of savings depends on the interaction of several program design elements and their incremental cost. The primary program design choices are between professional installation during a site visit and self-installation by the participant.

The risks from self-installation are non-installation, incomplete installations (not all showerheads replaced), more measures given out than installed, and showerheads installed in "low savings" sites (low flow, low pressure, or non-electric water heat). These risks can be offset by lower administrative overhead, higher participation, and

better customer relations. Benchmark data on the number of showers per home can be derived from U.S. Census Bureau data or local surveys. The number of showerheads returned can be derived by the number of program participants to develop an estimate of the "measure penetration" or the fraction of showerheads replaced, on average, in each home. "Low savings" sites can be treated one of two ways. The first is to select showerhead brands that perform well at low water pressure and provide high savings (i.e., 2-gpm rated showerheads). The second is to determine the fraction of domestic wells from U.S. Census Bureau or other data and assume that showerheads distributed to this fraction of sites will produce no, or limited savings. This latter procedure should also be used to discount for measures distributed to sites with non-electric water heating unless those sites have already been removed from participation by checking against utility records or otherwise screening for eligibility.

Professional installation is relatively risk free as long as the installers are trustworthy. Since professional installation requires a site visit, the installer can note water heating fuel type, number of showers, and water supply source and pressure. The installer should be encouraged to try for 100% showerhead replacement at each site and should also turn in the old showerhead as evidence of retrofit.

"Low savings" sites can be screened out or "high performance" showerheads can be installed at those sites.

Program success using these two approaches can be measured two ways. The first is in terms of the total amount of savings acquired. The second is the cost per unit of savings. Professional installations will acquire more savings per site, and probably in total, due to the high rate of showerhead replacement at each home. Self-installations are likely to be cheaper per unit since installation is essentially "free."

REMP savings from 1.8-gpm showerheads with a 90% installation rate are 363 kWh the first year per home and projected to be 2,667 kWh per home over the 12-year life of the showerhead, including normal replacement rates. If professional installation costs \$25 and measures cost is \$9 per site, the unlevelized program costs are 12.7 mills per kWh over the life of the measure. Assuming a 53% self-installation rate, first-year savings from REMP sites would have been 221 kWh and lifetime savings would be 1,630 kWh. If the program costs \$17 per site, program savings would cost 10.4 mills per kWh. Using these assumptions, the self-installation program has an advantage in per unit costs, but achieves only 61% of the potential savings.

5.0 Projected Program Impacts

The REMP study was not designed to provide direct estimates of program savings or impacts. Instead it was designed to provide a foundation for developing these estimates using alternative assumptions. Estimated program savings using the REMP study results vary depending on assumptions made about measure persistence and measure life, measure installation rates, and retrofit measure performance.

These impacts can be viewed several ways: as first-year savings, as savings over the projected life of the measures, and as average annual savings over the life of the measure (total lifetime savings divided by measure life). Projected program savings are provided in Tables 5.1, 5.2, and 5.3 below, based on the assumptions described in the following sections.

Table 5.1. Estimated Program Savings with Professional Installation (pre-code)

Flow Rate	1st-Year Savings (kWh)	12-Year Lifetime Savings (kWh)	Ave. Annual Savings (kWh)
2.5 gpm ^(a)	181	1,334	111
2.25 gpm	246	1,810	151
2.0 gpm	310	2,286	191
REMP 1.8 gpm	363	2,667	222
1.7 gpm ^(b)	388	2,858	238
^(a) The Ondine showerhead was rated and performed at 2.5 gpm.			
^(b) The ETL showerhead was rated at 2.0 gpm and performed at 1.7 gpm.			

Table 5.2. Estimated Program Savings with Self-Installation (pre-code)

Flow Rate	1st-Year Savings (kWh)	12-Year Lifetime Savings (kWh)	Ave. Annual Savings (kWh)
2.5 gpm	111	815	68
2.25 gpm ^(a)	150	1106	92
2.0 gpm	190	1397	116
REMP 1.8 gpm	221	1,630	135
1.7 gpm ^(b)	237	1,746	146
^(a) The Ondine showerhead was rated and performed at 2.5 gpm.			
^(b) The ETL showerhead was rated at 2.0 gpm and performed at 1.7 gpm.			

Table 5.3. Estimated Showerhead Program Lifetime Savings (in kWh) by Year of Participation

	Professional Installation				REMP	Self-Installation				REMP
	Flow Rate					Flow Rate				
Year	2.5	2.25	2.0	1.8		2.5	2.25	2.0	1.8	
Pre-code ^(a)	1334	1810	2286	2667		815	1106	1397	1630	
1994	1222	1699	2175	2556		747	1038	1329	1562	
1995	1111	1588	2064	2445		679	970	1261	1494	
1996	1000	1476	1953	2334		611	902	1193	1426	
1997	889	1365	1842	2223		543	834	1125	1358	
1998	778	1254	1730	2111		475	766	1057	1290	
1999	667	1143	1619	2000		407	699	990	1222	
2000	556	1032	1508	1889		340	631	922	1154	
2001	444	921	1397	1778		272	563	854	1087	
2002	333	810	1286	1667		204	495	786	1019	
2003	222	699	1175	1556		136	427	718	951	
2004	111	587	1064	1445		68	359	650	883	
2005	0	476	953	1334		0	291	582	815	
(a) "Pre-code" indicates savings without the effects of 2.5-gpm national flow rate standards.										

5.1 Measure Persistence and Measure Life Impact

Measure life has been defined in a variety of ways. For resource assessment, it has been defined to mean maximum technical life, or "test measure life," which represents the age at which the measure fails. An alternative definition is "effective measure life" which reflects the age at which the bulk of the measures are retired from use, for whatever reason, including changes in style, functionality, bathroom remodels, and so on. For planning purposes,

Bonneville uses a value of 12 years that approximates an "effective measure life."

Some program participants are dissatisfied with the performance of the conservation measures after they are installed; consequently, they replace them. Measure persistence is a term used to characterize the retention of program measures by participants. Information on measure persistence and normal replacement rates over the life of water-saving measures is scarce. A review of studies of showerhead replacement rates reported by Ken Keating of

Bonneville indicates a peak in replacements around 7 to 8 years after installation.

The estimates provided in Tables 5.1, 5.2, and 5.3 are based on an assumed measure life of 12 years with a measure replacement rate for the first 2 years of 5% per year (from REMP persistence results) and replacements peaking around year 8 then trending to zero by year 12 (Table 5.4). Savings from measures will be eroded due to their replacement. Over the 12-year life of the measure the replacements implied in Table 5.4 equal 42% of potential savings. In other words, about one-half of potential savings are captured over the life of a program-installed measure.

Table 5.4. Measure Persistence and Replacement

Year after Installation	Remaining Measures
1	95%
2	90%
3	90%
4	90%
5	80%
6	70%
7	60%
8	50%
9	38%
10	25%
11	13%
12	0%

5.2 Retrofit Installation Rate Impact

There are two primary installation mechanisms, professional and occupant installation. The REMP study used professional installers and managed to replace an average of 90% of all showerheads at each site. This rate was achieved both due to the ability of the installers to overcome selected plumbing barriers and their willingness to convert all showerheads in the home. Programs that rely on installation by occupants are expected to achieve a lower installation rate due to occupant unwillingness to tackle difficult installations and to change all showerheads in the home. This is based, in part, on results from other utility studies of self-installation programs. A key factor in achieving high levels of retrofits is removal of the current showerheads from the home. Based on available data, and assuming current showerheads are removed from the home (instead of retained by the participant), the installation rate assumed in the projections shown in Tables 5.1, 5.2 and 5.3 is 90% for professional installations (from REMP) and 55% for self-installation.

5.3 Free Rider Impact

Free riders are program participants who normally would have installed program measures on their own. In other words, as their showerheads required replacement, they would have replaced them with energy-efficient showerheads. In most energy-efficiency programs, the number of free riders is not significant. However, a 2.5-gpm Federal standard for showerheads will go into effect in January 1994. This has the effect of gradually reducing the pre-retrofit flow rates and potential savings available every year after the new standard takes effect (see Table 4.2). This effect is included in the projected total lifetime savings for each year of participation in Table 5.3.

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