Evaluation of HET Retrofit Water Savings

Program Description

The Southern California Edison Low Income Direct Install High Efficiency Toilet Pilot Program was implemented by a partnership between Metropolitan Water District (MWD) and Irvine Ranch Water District to deliver and install High Efficiency Toilets (HET) for multi-family households in low-income areas within mutual MWD and SCE service territories. As part of its Low-income Direct Install HET Program, Southern California Edison in partnership with MWD has retrofit a total of 276 toilets in 176 low-income multi family homes. These homes were retrofit with dual flush toilets using two different flush volumes, 1.28 gpf intended for solid waste and 0.8 gpf for liquid waste [1]. Past field studies have shown that single-family homes retrofit with dual flush toilets result in an average household flush volume of 1.29gpf [2]. The purpose of this report is to document the observed changes in water use in low-income multi family homes located in SCE service area, after being retrofit with HET.

The target market for this Pilot is families that qualify as low-income households. The California Public Utilities Commission uses criteria for defining low income status as is defined in the Health and Human Services poverty guidelines for the lower 48 states (HHS, 2008). Two criteria determine this characterization: the number of persons per household and whole-household income level, as shown below:

> Poverty Level = number of persons per household * $3600 + $6800
> Low-income Threshold = 200% of Poverty Level

Table 1 shows some other baseline information about the study sample. This information was obtained from a combination of sources, including billing data, flow trace data, and information provided by the installers during the retrofits. For comparison purposes data from a September, 2008 study of individually metered multi family units has been inserted[3]. The IRWD data consisted of the entire population of individually metered multi-family apartments in the Irvine Ranch service area taken from their billing data. These were apartments, with virtually no outdoor water use. A mail survey was conducted which provided the data for the number of persons and bathrooms. The water use of the SCE low income group, while smaller in number is quite similar to that of the larger group.

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[1] The toilets installed were Caroma Sydney, model 305, which are designed to flush at 1.28 gpf for full flushes and 0.8 gpf for half flushes.

[2] 1.29gpf with a standard deviation of 0.41 is based on field studies where single family residences in East Bay Municipal Utility District and Seattle Public Utilities were completely retrofit with dual flush toilets with 0.8 gpf and 1.6 gpf options. Funk, A., Mayer, P. & Luettgen, M., 2010. Dual Flush Savings - An Analysis of Field Data. *Water Efficiency Journal for Water Resource Management*, 1:5:44.

[3] DeOreo, W. B., and Hayden, M. (2008). "Analysis of Water Use Patterns in Multi-Family Residences." Prepared by Aquacraft Inc. for Irvine Ranch Water District, Irvine, CA. (See Table 5, pg 15 for water use data, Table 12, pg 31 for population and toilet data)

Table 1: Characteristics of sample group

Parameter	SCE	IRWD (2008)
Number of multi family homes sampled	41	4657
Average number of people per home	2.7	2.6
Average number of toilets per home	1.8	2.0
Average number of toilets retrofit per home	1.6	na
Average baseline indoor water use (gphd)	138	147.4
Average Annual Use (kgal/ccf)	50.4 kgal 67.5 ccf	53.8 kgal 71.9 ccf
Average per capita use (gpcd)	51.1	56.7
Income Status	Low	Mixed

Evaluation and Data Collection Methods

Flow Trace Methodology

The water impacts for SCE's HET program were estimated using the flow trace methodology developed by Aquacraft, Inc. The purpose of flow trace analysis is to obtain precise information about water use patterns: Where, when, and how much water is used by a variety of devices including toilets, showers, baths, faucets, clothes washers, dishwashers, hand-held and automatic irrigation systems, evaporative coolers, home water treatment systems, leaks, and more. The collected data are precise enough that individual water use events such as a toilet flush or a clothes washer cycle or miscellaneous tap use can be isolated, quantified and then identified. This technique makes it possible to disaggregate most of the water use in a residential home and to quantify the effect of many conservation measures, from toilet and faucet retrofit programs to behavior modification efforts. It is also possible to disaggregate water use into more coarse categories. For example, the changes in water use from much larger end user categories with large meters serving their water demands (i.e. industrial facilities) can be measured by demand profile changes in domestic/indoor, process and other category water uses.

The flow trace methodology is based on the fact that there is consistency in the flow trace patterns of most water uses. For example, a specific toilet will generally flush with the same volume and flow rate day in and day out. A specific dishwasher exhibits the same series of flow patterns every time it is run. The same is true for clothes washers, showers, irrigation systems, etc. By recording flow data at 10-second intervals, a rate determined by Aquacraft to optimize accuracy and logger memory, the resulting flow trace provides accurate data for quantifying and categorizing almost all individual water uses in each study home.

Trace Wizard is a software package developed by Aquacraft Inc., specifically for the purpose of analyzing flow trace data. Trace Wizard provides the analyst with powerful signal processing tools and a library of flow trace patterns for recognizing a variety of residential fixtures. Any consistent flow pattern can be isolated, quantified, and categorized using Trace Wizard including leaks, evaporative coolers, humidifiers, and swimming pools. Once all the water use events have been isolated and quantified and statistics generated, Trace Wizard implements a user defined set of parameters developed for each individual study residence to categorize the water use events and assign a specific fixture designation to each event. Additional detail on the flow trace method and the Trace Wizard software is included in Appendix A of this report.

M&V Meter Sample

This study group of homes was sampled based on local demographic low-income qualifiers, which enabled income thresholds to be identified. Once the list of individually metered low-income multi family qualifying homes was prepared, a systematic random sampling methodology, (developed by this study's Internal Team) using interval sampling, provided the data logging sample.

Of the 176 low-income multi family homes retrofit, a sample of 41 was successfully data logged[4]. The retrofit homes were from two apartment complexes in SCE service area. The homes in these complexes are individually metered, meaning each apartment unit has a single water meter serving its domestic indoor uses that is not connected to outdoor usage. Data loggers were fixed to these water meters and their water use was monitored for 14 days before and 14 days after the retrofit so that the changes in water use could be measured, and the impact of the HET's evaluated. The pre-retrofit data were collected between June 29th and July 13th, 2009, and the post-retrofit data set was collected between September 29th and October 14th, 2009.

Water Impact Estimation Methods

Using the flow trace method and metered data discussed above, the water savings resulting from HET retrofits were estimated using the paired, pre and post-retrofit data from 41 homes, for the following parameters, which were obtained from analysis of the flow trace data.

1) Average gallons per day of total domestic use per unit
2) Average gallons per day for toilet flushing per unit
3) Average number of flushes per unit per day
4) Average leakage rates per unit per day

These values were tabulated and paired t-tests were run to determine if there were statistically significant changes in the means at both a 90% and 95% confidence intervals. The differences between the two levels were not great enough to change any of the conclusions of the study. In addition to the statistical analysis of means the data were analyzed using regression techniques to determine whether models based on either the number of toilets replaced, the number of persons per home, or a combination of both gave improved estimates compared to simple averages.

All of the replacement toilets were identical, which simplified the analysis. The hourly water use data for the sample were tabulated and a comparison was made between pre and post water use. Both total water use and toilet use were analyzed.

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[4] The original research plan estimated a sample of 50 homes would be successfully data logged. Prior to the HET retrofit 56 homes were successfully data logged. The design of the HET Pilot only allowed for HET retrofits in homes after installers inspected the existing toilets to determine whether the home had candidate high flush volume toilets. After inspection, 15 more of the pre-retrofit data logged group were removed from the post-retrofit data logging group due to the fact that they were already equipped with 1.6gpf ULFT. Having a smaller sample reduced the accuracy of the predictions, but a larger sample was not available. While a larger sample might have given more definitive answers, the results form this sample are indicative.

Because of the relatively short interval of 11 weeks between the pre and post data collection periods it was assumed that occupancy rates were stable. The other assumption made is that the units included in this sample are typical of the low-income multi-family units in this pilot program's general population. While this seems like a reasonable assumption, sufficient data on the general population was not available to verify it. Savings estimates were normalized on the basis of the numbers of toilets replaced and numbers of persons per unit, which will allow the results to be generalized to other similar properties but with different populations and numbers of toilets.

Analysis

Total Indoor Use

The average baseline (pre-retrofit) water use for the study group was 138.3 gallons per household per day (gphd). This averages 51.2 gallons per capita per day (gpcd), but there is a very weak relationship between the persons per home and the household water use. As shown in Figure 1, the household water use in these units is almost independent of the number of residents reported by the residents. The regression line shows that for one occupant the daily water use is expected to be 75.77 gphd, but that water use rises with the number of occupants raised to the .35 power. This may be due to the fact that the residents were not reporting accurate data, or that the number of persons actually living in the units varied from day to day. In any case, as discussed below, it helps explain why models of water savings were not responsive to the number of occupants. (Note that in Figure 1 one outlier, with over 600 gphd was excluded from the data.)

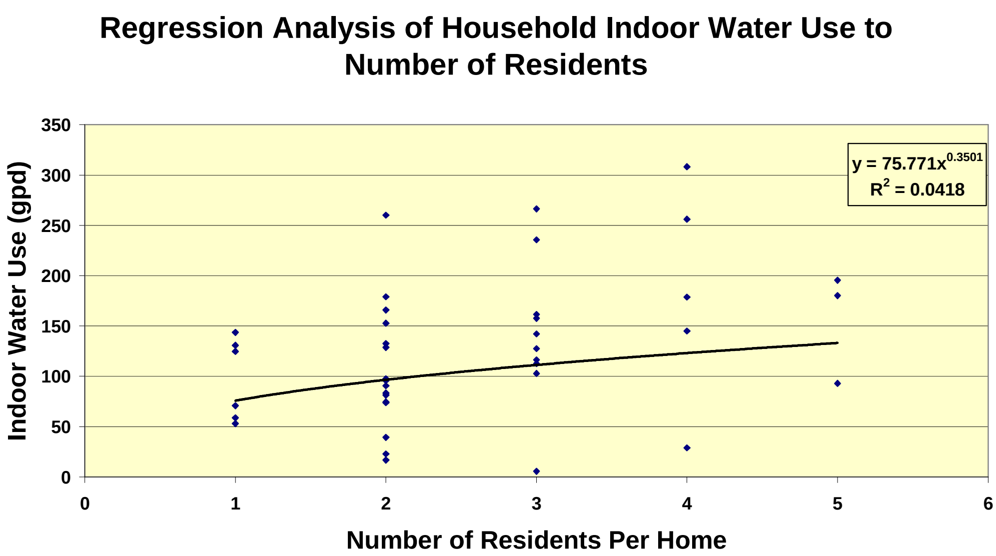


Figure 1: Household indoor water use vs number of occupants (pre-retrofit)

Figure 2 shows that prior to the retrofits the average indoor water use for the units was 138.3 gphd. After the retrofits the average indoor water use dropped by 20 gallons per household per day (gphd) to 118.0 gphd. However, as shown in Table 2, there was such a high amount of variability in the daily use of the 41 households that this change in indoor water use was not statistically significant at either the 95% or 90% confidence levels. The change in overall indoor water use ranged from an increase of 328 gphd to a decrease of 204 gphd. The data do, however, suggest a programmatic reduction in indoor use by approximately 20 gpd. Examination of the end use data help clarify the situation since they focus in on individual uses for which there is less variability.

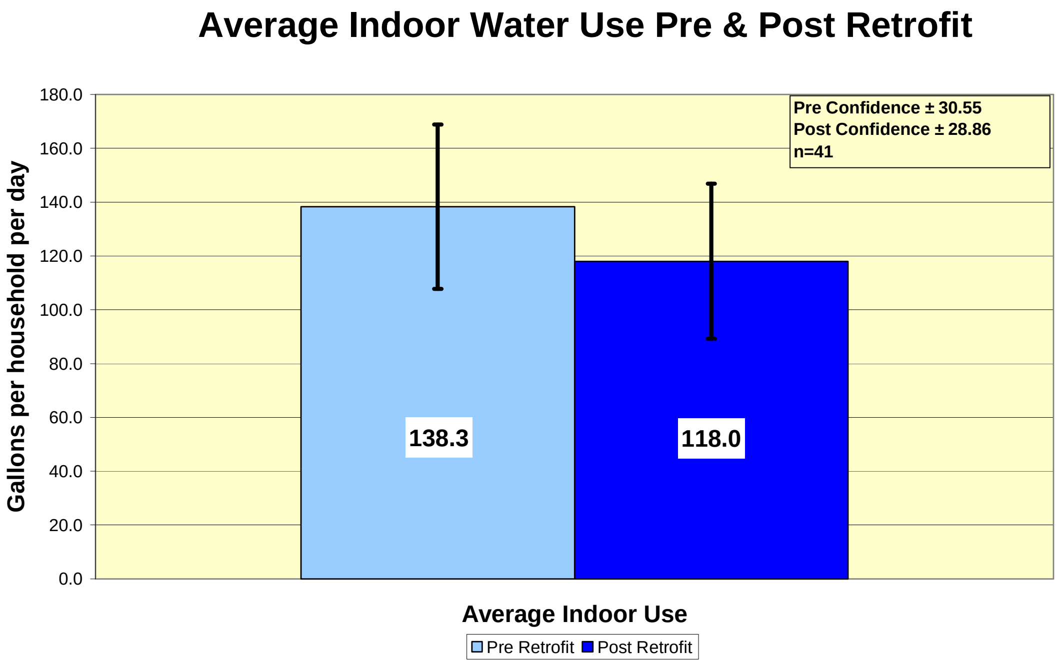


Figure 2: Comparison of pre/post average indoor water use

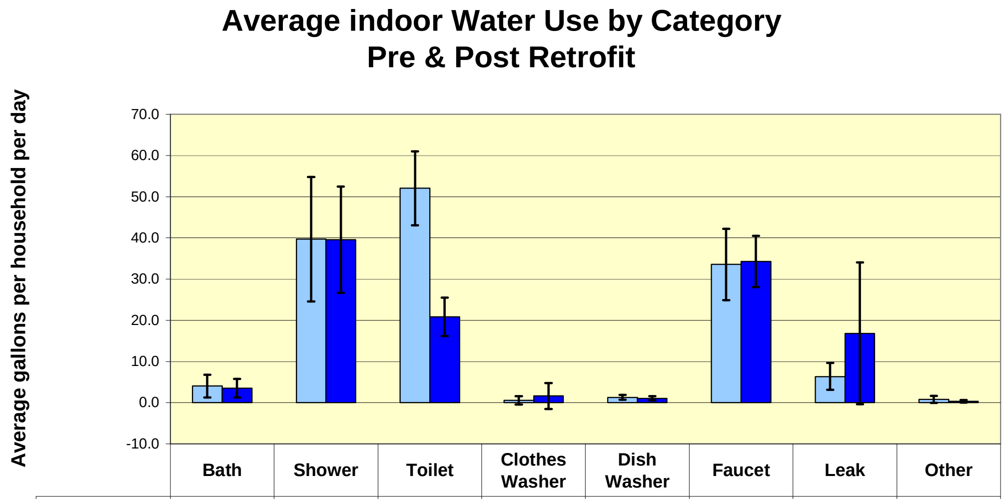
Table 2: Changes in total indoor use by unit

Keycode	Pre-retrofit Indoor (GPD)	Post-retrofit Indoor (GPD)	Change in Indoor Use (GPD)
09M201	579	404	-175
09M202	162	235	73
09M204	256	199	-57
09M205	266	82	-185
09M207	142	108	-34
09M208	166	143	-23
09M210	179	79	-100
09M214	144	126	-17
09M215	53	35	-18
09M216	17	32	15
09M217	125	49	-76
09M219	128	91	-37
09M220	116	88	-28
09M221	153	106	-47
09M222	236	31	-204
09M223	91	44	-46
09M224	260	244	-16
09M225	75	70	-5
09M226	308	162	-146
09M227	96	157	62
09M228	71	65	-5
09M229	131	228	97
09M232	29	73	44
09M233	132	461	328
09M234	145	87	-58
09M237	195	125	-71
09M238	158	82	-76
09M239	179	89	-90
09M240	74	48	-26
09M241	113	101	-12
09M242	39	55	16
09M243	129	120	-8
09M245	83	53	-31
09M251	103	0	-103
09M250	59	47	-12
09M252	180	176	-4
09M253	93	135	42
09M254	23	45	22
09M255	81	65	-16
09M256	6	224	219
09M257	98	73	-25
Average	138.28	118	-20.3
Std Dev	99.81	94.30	94.05
Count	41	41	41
95%CI	30.55	28.87	28.79
90% CI	25.64	24.23	24.16

Comparison of End Use Data

The water use situation becomes clearer when individual end use data are compared, as is done in Figure 3. When individual end uses are compared the data show slight increases in faucet and shower use, a large increase in leaks, and a still larger decrease in toilet use. Of these changes, however, only the toilet use change is statistically significant at either the 95% or 90% confidence levels. Average daily toilet use dropped from 52.1 gphd to 20.8 gphd as a result of the retrofit. This represented a decrease of 31.3 gphd attributable to the toilet replacement.

When changes in the other end uses are considered it becomes clear that the increases in the faucet, leaks and shower use are masking the decrease in the toilet use. It is interesting to note that if one had only water meter data, from which daily readings were obtained it would not be possible with a sample of this size to identify any change in water use associated with the retrofit. When the end use data are available, however, the changes in toilet use can clearly be quantified. It is also interesting to note that if only toilet water data were obtained, for example by use of sub meters attached to the toilets it would have been impossible to quantify the change in leakage. If the leaks were occurring in the toilets the sub-meters would have registered them as toilet use (when they may be toilet leaks), and would have under estimated the savings from the retrofits. If they have occurred elsewhere in the plumbing system the sub-meters would have missed them, and over-estimated the savings.



	Bath	Shower	Toilet	Clothes Washer	Dish Washer	Faucet	Leak	Other
Pre Retrofit	4.0	39.7	52.1	0.5	1.3	33.6	6.3	0.8
Post Retrofit	3.5	39.6	20.8	1.6	1.1	34.3	16.8	0.3

Figure 3: Comparison of pre/post retrofit household water use by end use category

The data from the 41 homes that were retrofit with HET toilets, and for which valid data were obtained indicate that the retrofit resulted in an average toilet water savings of 31.2 ± 8.2 gphd during the data logging period, or 11,388 gallons per home per year. This represents a 60% reduction in average household toilet water use in these study homes.

The histogram in Figure 4 shows the average daily toilet water use in homes before and after HET installs, and Figure 5 shows a histogram of average household flush volumes pre and post retrofit. These figures show a clear shift in both average toilet water use and flush volumes per unit. The average flush volumes dropped from 3.84 gpf prior to the retrofit to 1.62 gpf after the retrofit. The graph shows that prior to the retrofit the bulk of the flushes were between 3 and 4.5 gpf, and the after the retrofit the bulk of the flushes were between 0.75 and 1.75 gpf, which is where they would be expected to be based on the types of toilets used for the retrofit.

One unexpected result that Figure 5 shows, however, is that after the retrofits there were still 22% of the homes that inexplicably had average flush volumes greater than 2.0 gpf and up to 5 gpf. It is not known whether these were old toilets that could not be replaced or HET toilets that were malfunctioning. The fact that not all of the post retrofit toilets were flushing at 1.6 gpf or less measurably reduced the effectiveness of the program. An estimate of the potential additional savings if all of the candidate toilets had been replaced with properly functioning HET is provided below in Table 7.

It is possible that the reduction in toilet use was due to a change in the number of times per day the toilets were flushed after the retrofit. The data, however, indicate that the pre retrofit flush rate was 13.42 flushes per day, and the post retrofit flush rate was 13.52 flushes per day, which is statistically identical. So, it is clear that while there may have been variations among the units, overall, the reduction in toilet use was not affected by a change in how frequently the residents flushed the toilets. This is also a good indication that the average number of residents remained constant between the two periods.

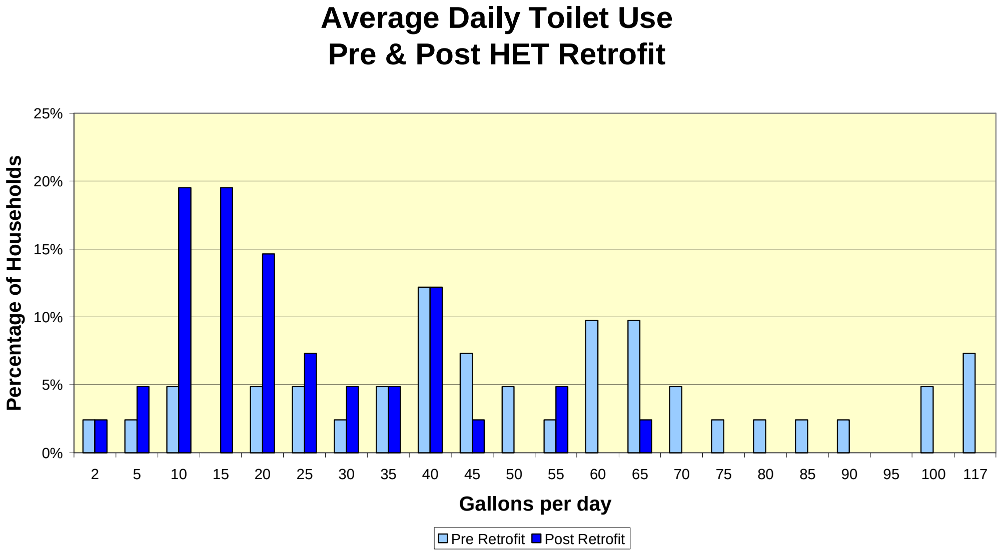


Figure 4 Average daily toilet water demands pre post retrofit

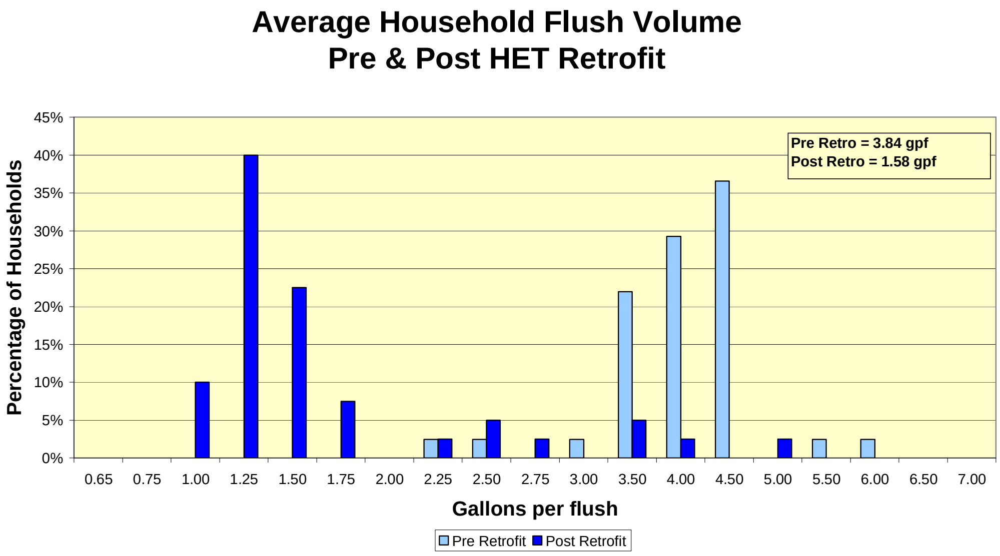


Figure 5 Average pre post flush volume

The savings data can be expressed on the basis of average savings per occupant, or average savings per toilet replaced. The average number of toilets replaced per unit was 1.6 and the average number of persons per unit was 2.7. Table 3 shows the toilet use data on a gross level and normalized on the basis of per capita and per toilet replaced data.

Table 3: Average toilet use data

Period	Per Household (gpd)	Per Toilet (gpd) (ave = 1.6)	Per Capita (gpd) (ave=2.7)
Pre-Retrofit	52.1	na	19.3
Post-Retrofit	20.8	na	7.7
Change	31.2	19.5	11.6

As mentioned above the post retrofit leakage increased by 10.5 gpd from the pre-retofit level, and this increase caused the net savings in the program to drop from 31 gphd to 20 gphd. Given the fact that the only change that was made to the apartments in this study was that their toilets were replaced, it is difficult to avoid the conclusion that the increase in leakage is related to the toilet replacement. Consequently, it is important to understand the pattern of the post-retrofit leakage.

Table 4 summarizes the leakage data for the pre and post retrofit periods. It is noteworthy that while the average leakage rate increased the median rate stayed constant. This indicates that whatever change in leakage occurred did so on a small number of homes. If the leakage rate had changed on a larger number of homes the median value would have increased.

Table 4: Pre-post leakage data

Period	Average Leakage (GPD)	Median Leakage (GPD)
Pre-Retrofit	6.3	2.7
Post-Retrofit	16.8	2.7
Change	10.5	0

In Figure 6 the data show that after the retrofits only 10 percent of the units had leakage rates greater than 18 gpd, but in Figure 7 the data show that these homes contribute 75% of the total leakage volume. This information is important since it shows that the leakage is not a general problem with the toilet replacements, but that there is a potential for a small number of installations to generate a large amount of leakage, which if left un-addressed can neutralize a significant proportion of the hoped for savings from the retrofit program.

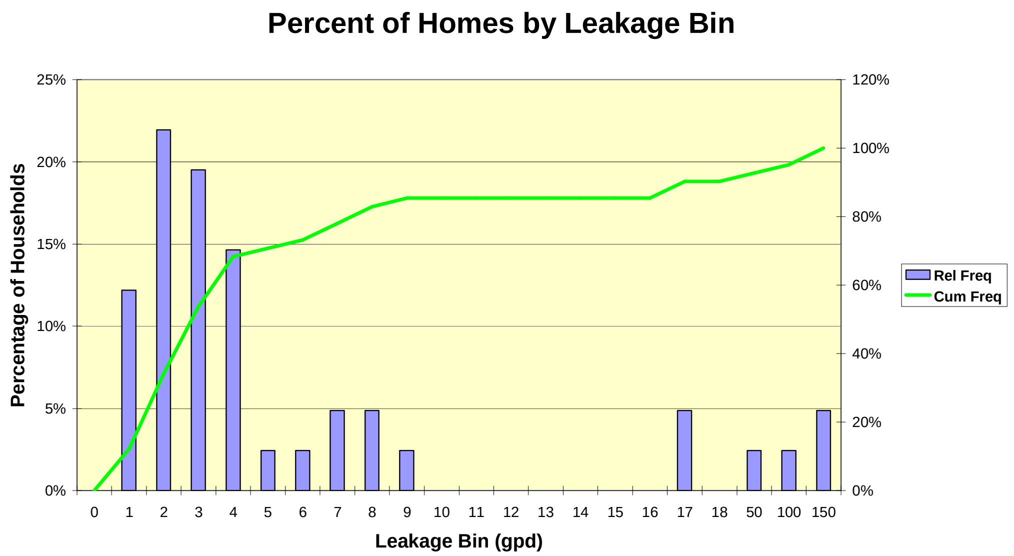


Figure 6: Percent of customers falling into leakage bins

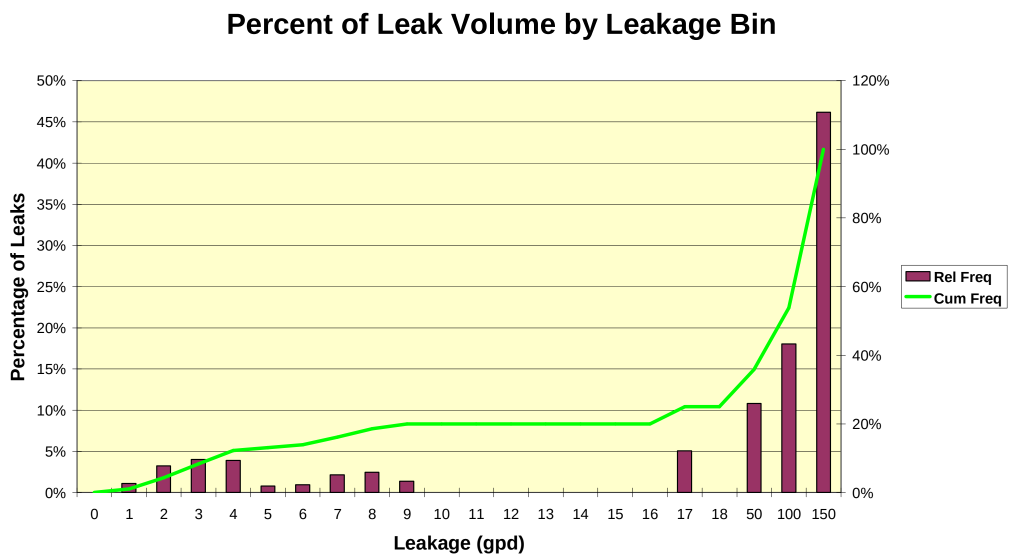


Figure 7: Percent of leakage volume attributable to leakage bins

The data show that the average savings in household toilet use was 31.2 gphd. In order to determine whether better estimates of water savings can be derived by relating water savings to the number of toilets replaced or the number of persons per dwelling statistical analyses were undertaken. Models of changes in toilet water use versus both the number of toilets and the number of people were prepared. These models were marginally better predictors of savings than the average. Two linear regression models, shown in Figure 8 and Figure 9 of the change in toilet water use verses the number of toilets replaced and the number of residents per home are shown. A multiple regression using both parameters was also performed. The results for all three models are summarized in Table 5.

While none of the three models provided are decisively better than use of the averages. They are all slightly better, and of the three, the best is the multiple regression, Model 3. This model predicts the change in toilet water use as a function of the average number of toilets replaced and the average number of residents in the homes. If one inserts the averages for the number of toilets replaced and residents per home from Table 1 the model predicts a savings of 31.56, compared to the observe change of 31.2.

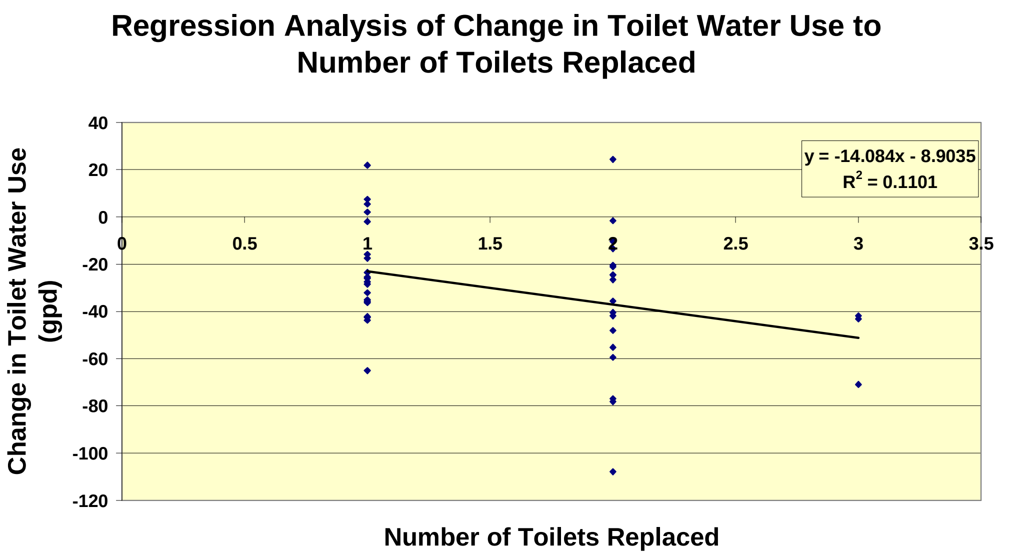


Figure 8: Regression analysis of change in toilet water use verses reported number of toilets replaced per unit

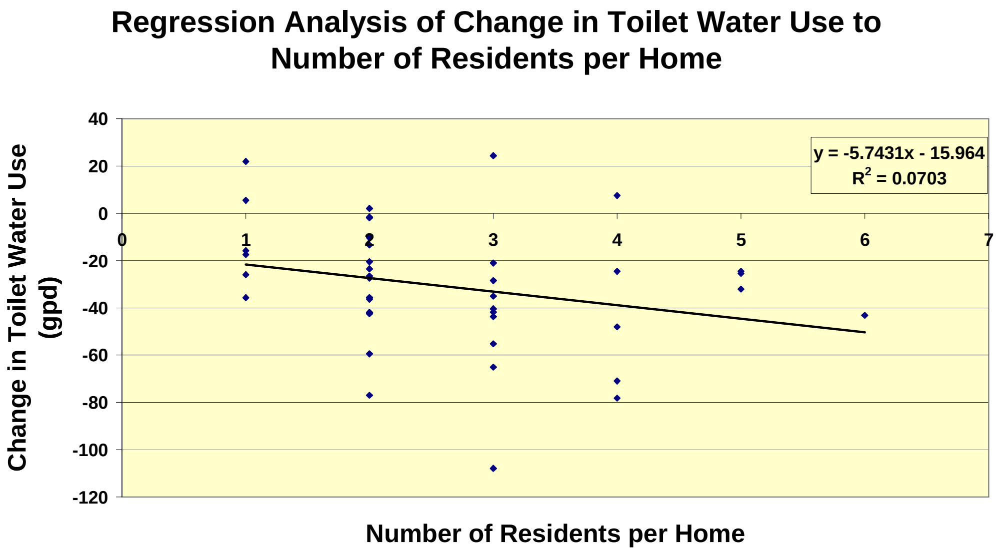


Figure 9 Regression analysis of change in toilet water use verses reported number of persons per unit

Table 5: Model parameters

Model	Description	Formula	R^2
1	Change v toilets replaced	Y= -14.1T - 8.9	**0.11**
2	Change v no. residents	Y= -5.74R - 15.96	**0.07**
3	**Change v toilets + residents**	**Y= -3.89 - 11.46T -3.46R**	**0.13**

Discussion and Summary

There were three important findings in this evaluation:

1. There was a definite reduction in toilet water use associated with the retrofit, which can be described as a function of the number of persons per dwelling units and the number of toilets replaced from Table 5.
2. Leakage increased by a substantial amount in four of the units, which increased the average leakage for the group as a whole by 11 gphd.
3. For reasons unknown there were a few units that still appeared to have high volume toilets.

As shown in Table 6, the reduction in indoor use in the residences equals the reduction in toilet use plus the increase in leakage. Of the three parameters shown in the table the toilet use was the one that was clearly significant from a statistical perspective. The other two categories had too much scatter in their data to prove statistically significant with this sample size.

Table 6: Summary in changes in household use after retrofit

Household water use category	Average change in use after retrofit
Total indoor use	-20.3 ± 29 gphd
Toilet flushing use	-31.3 ± 8 gphd
Leakage	11 ± 17 gphd
Toilet flushes per day	-0.08 ± 2.35 fphd

As discussed above, it is hard to avoid the conclusion that the increase in leakage was related to the toilet replacement: either due to malfunctioning toilets or problems with the installation. While the measured increase in leakage is an important observation, it does not change the fact there was a clear reduction in toilet water use from the retrofits. The flow trace methodology used in this study accurately quantified the water savings associated with HET retrofits in multi family homes by disaggregating individual water uses, including leaks.

The data from the individual homes shows that the increase in leakage was due to large increases in just four units. These types of leaks are large enough that they are likely to be found and repaired, so they are by nature transient. The research team does not believe that the fact that leaks developed during the retrofit should outweigh the savings from the toilet retrofits, but the leakage should not be ignored either. In essence, both the leakage and the toilet savings should be considered independently. Any future program quality control should include consideration of how post retrofit leaks will be monitored and repaired in order to insure that the full savings from the retrofits are realized.

The second issue with the results was the residual high flush volumes found in some units. As mentioned above, 9 out of the 41 study homes maintained at least some high volume flushes (>2.0 gpf) after the retrofit. The objective of the retrofit portion was to replace all pre-1994 toilets with a flush volume greater than that of a standard ULFT at 1.6 gpf. This finding suggests one of two possibilities: either the HET toilets were malfunctioning or for some reason it was not possible to replace them. All that the flow trace data reveal is the volume of the flushes, so without going back to the homes to inspect them, it is not possible to say precisely why the volumes are as high as they were observed. This conclusion, as well as the leakage conclusion, has important implications for future retrofit programs since it points out that savings from retrofits are conditional on proper installations and avoiding creation of leaks.

To further underscore the importance of proper installation, the water savings discussed above were adjusted to show the maximum achievable savings from HET retrofits assuming that all the HET toilets in this program were properly adjusted and functioning at HET volumes. If after the retrofits all of the toilets had achieved an average flush volume of 1.29 gpf, the water savings from HET retrofits would have been 34.4 gallons per home per day, or 12,556 gallons per home per year[5]. Table 7 shows the values for the observed and maximum achievable savings from this program's replacement of pre-ULFT toilets with HET toilets.

Table 7 Toilet water savings with original and alternative gpf data

	Observed Savings	Max Achievable Savings
Water Savings per home per day (gal)	31.2	34.4

Based on the flow trace data collected during the HET evaluation and interpretation of the results under the alternative toilet gpf analysis, the evaluation team recommends that the estimated water savings from this HET replacement program be reported at 31.2 gallons per household per day actual savings, with two caveats: that the maximum achievable savings would be 34.4 gphd

[5] This average flush volume of 1.29gpf agrees well with the 1.24gpf average flush volume measured in: Funk, A., Mayer, P. & Luettgen, M., 2010. Dual Flush Savings - An Analysis of Field Data. *Water Efficiency Journal for Water Resource Management*, 1:5:44.

had 100% of the flushes been held the HET design volumes, and that provisions need to be taken to check for and repair any leaks that develop as a result of the retrofits.

In order to generalize the results of this study to other low income populations the equation from Model 3 in Table 5 can be used. Even though this model has a low regression coefficient, it is better than the use of simple averages, and it relates both key parameters of toilets replaced and population to the anticipated water savings.

Discussion of Uncertainty, Threats to Validity, Potential Free Ridership

It is important when evaluating potential projects to identify and discuss where issues remain. Where an HET retrofit project is concerned, there is always the possibility that some fixtures might not function properly. If pre-post analysis were limited to water billing data, the results of retrofitting homes with HET would contain an increased level of uncertainty. In this study where flow trace data were collected at each household water meter, it is possible to determine the volume of the flush, but it is not possible to say precisely what actual make and model of toilet was in use. For example, it is known from the flow trace data that there were a certain number of flushes at more than 2.0 gpf in the post retrofit data set. It is not known, however, if this is due to the HET toilets being out of adjustment when installed, tampered with by the residents, or perhaps for unknown reasons some of the toilets could not be replaced.

It is also possible for the flow trace analysis to mis-identify water events as toilets that are actually something else in the home that has the appearance of a toilet flush. For example, toilet flushes are normally identified by their peak flow rates, which are usually 3-6 gpm, their flush volumes, which for HET models should be around 1.3 gallons, and their durations, which are around 30 seconds. Kitchen and bathroom sinks normally flow at less than the 3 gpm, but someone could open up a bathtub and run it for 30 seconds then immediately shut it off in a way, and that would appear to be a toilet flush on the flow trace. The chances of someone doing this even once are small, but the chances of someone doing this multiple times in precisely the same patterns (as a toilet would do) are extremely low. So, misidentification of this type would be an occasional random error.

The issue of leakage is one that needs to be considered. In this pilot study a gross reduction in water use from toilet replacements of 31 gphd was observed. At the same time, however, there was an increase of 11 gphd due to leaks. This is an area that requires additional study and can only be resolved with a larger sample or by following up on the actual toilets installed and the actual leaks observed. The data do, however, show that leakage control must be considered as part of the program design.

Biases in the data were addressed as part of the sampling plan. The households sampled in this study are representative of the homes in the developments from which they were chosen. The one area where uncertainty remains is in how representative these results are for all low-income multi-family developments. Given the fact that this study measured a fairly predictable mechanical device found in all housing units, there is a good chance that the observed results are applicable to other similar projects where non-ULF toilets are replaced with HET devices. The data for the study project were compared to a larger sample of individually metered multi-family units from Irvine Ranch, and were found to be quite similar to this larger population in terms of household and per-capita use.

For planning purposes the use of the average value of 31.2 gphd is recommended. In order to generalize to other properties with different populations and number of toilets, model 3 from Table 5 is recommended. Ultimately, a larger sample of similar projects or more intensive site work would help add addition certainty to the program results by demonstrating their repeatability.

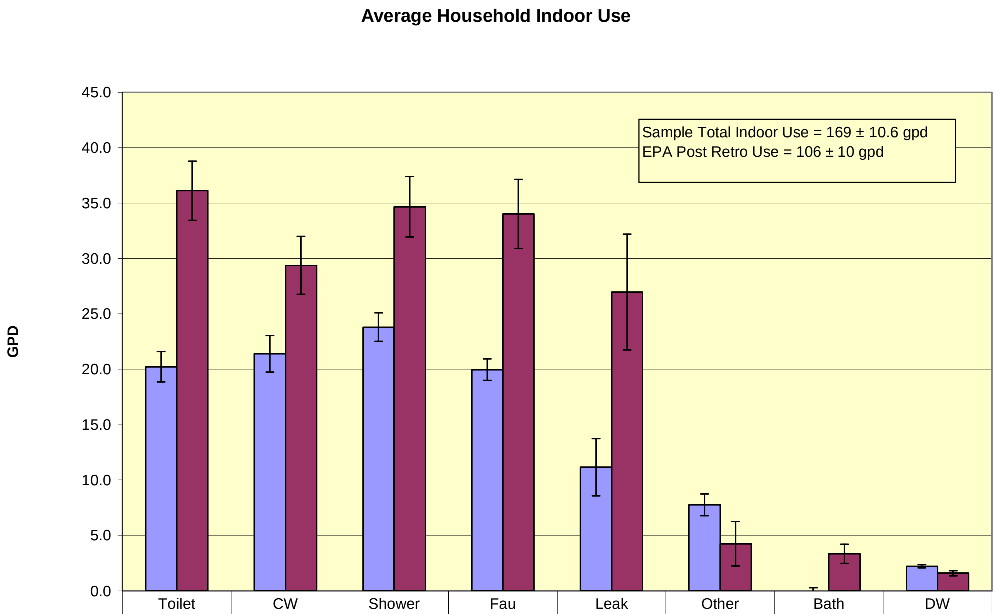
Appendix A: Flow Trace Analysis Methodology

The purpose of flow trace analysis is to obtain precise information about water use patterns: Where, when, and how much water is used by a variety of devices including toilets, showers, baths, faucets, clothes washers, dishwashers, hand-held and automatic irrigation systems, evaporative coolers, home water treatment systems, leaks, and more. The collected data are precise enough that individual water use events such as a toilet flush or a clothes washer cycle or miscellaneous tap use can be isolated, quantified and then identified. This technique makes it possible to disaggregate most of the water use in a residential home and to quantify the effect of many conservation measures, from toilet and faucet retrofit programs to behavior modification efforts. It is also possible to disaggregate water use into more coarse categories. For example the changes in water use from much larger end user categories with large meters serving their water demands (ie. industrial facilities) can be to measured by demand profile changes in domestic/indoor, process and other category water uses.

The flow trace methodology is based on the fact that there is consistency in the flow trace patterns of most water uses. For example, a specific toilet will generally flush with the same volume and flow rate day in and day out. A specific dishwasher exhibits the same series of flow patterns every time it is run. The same is true for clothes washers, showers, irrigation systems, etc. By recording flow data at 10-second intervals, a rate determined by Aquacraft to optimize accuracy and logger memory, the resulting flow trace is accurate enough to quantify and categorize almost all individual water uses in each study home.

Trace Wizard is a software package developed by Aquacraft Inc., specifically for the purpose of analyzing flow trace data. Trace Wizard provides the analyst with powerful signal processing tools and a library of flow trace patterns for recognizing a variety of residential fixtures. Any consistent flow pattern can be isolated, quantified, and categorized using Trace Wizard including leaks, evaporative coolers, humidifiers, and swimming pools. Once all the water use events have been isolated and quantified and statistics generated, Trace Wizard implements a user defined set of parameters developed for each individual study residence to categorize the water use events and assign a specific fixture designation to each event.

Figure 10 shows a typical analysis that can be performed on household flow traces with Trace Wizard software. In this example of a sample of single-family homes, the average baseline water demand profile for each of the domestic categories is shown. These baseline data results are compared against a test group of homes in which the fixtures and appliances (minus the dish washers) were retrofit to best available technology (circa 2000). This provides a clear comparison of the performance of the sample water demand profile against a known benchmark group.



	Toilet	CW	Shower	Fau	Leak	Other	Bath	DW
Post Retro	20.2	21.4	23.8	20.0	11.2	7.8	0.0	2.2
Sample	36.1	29.4	34.7	34.0	27.0	4.2	3.3	1.6

Figure 10 Example of water use analysis with flow trace data disaggregated by Trace Wizard

The hourly water demand profiles that are generated in this study for the six categories of end uses may reliably be used as benchmarks to predict how much, when and where water is being used.

The flow trace analysis technique and the Trace Wizard software have been used as the fundamental analytic tool in a number of residential, commercial, industrial and institutional water use studies both in the U.S. and worldwide including:

- Heatherwood Residential End-use and Retrofit Studies – 1995-96, Aquacraft
- Westminster Water Use Study – 1998, Aquacraft
- Perth Residential End Uses of Water Study – 1999, Australia
- Residential End Uses of Water – 1999, AWWA
- Commercial and Institutional End Uses of Water – 2000, AWWA
- Pinellas County Utilities Water Conservation Opportunities Study – 2002, Aquacraft
- Seattle Market Penetration Study – 2003, Aquacraft
- Yarra Valley Water District Residential End-use Study – 2003, Australia
- EPA Residential Retrofit Studies (Seattle, EBMUD, Tampa) – 2004, Aquacraft
- Water Efficiency Opportunities in California Supermarkets – 2004, Aquacraft
- Monterey Pre-Rinse Spray Valve Study – 2005, Quantec
- Regional Water Authority of Sacramento CII Studies – 2005, Aquacraft
- Santa Paula Residential End-use Study – 2006, RBF Consulting
- New Zealand Residential Demand Study – 2007, Branz
- Lathrop and American Canyon, CA End-use Studies – 2008, RBF Consulting
- California (CALFED) Residential End-use Baseline Study – 2009, Aquacraft
- Gold Coast Water Residential End-use Study – 2009, Australia

Validation studies have confirmed the repeatability and reliability of the flow trace methodology. Figure 11 shows the most recent validation study of the flow trace analysis methodology. The National Renewable Energy Lab (NREL) compared end-use disaggregation using flow trace analysis to measurements based in in-line meters installed on individual water supply lines inside specifically equipped test homes in Boulder, CO (Magnusson, L., 2009).

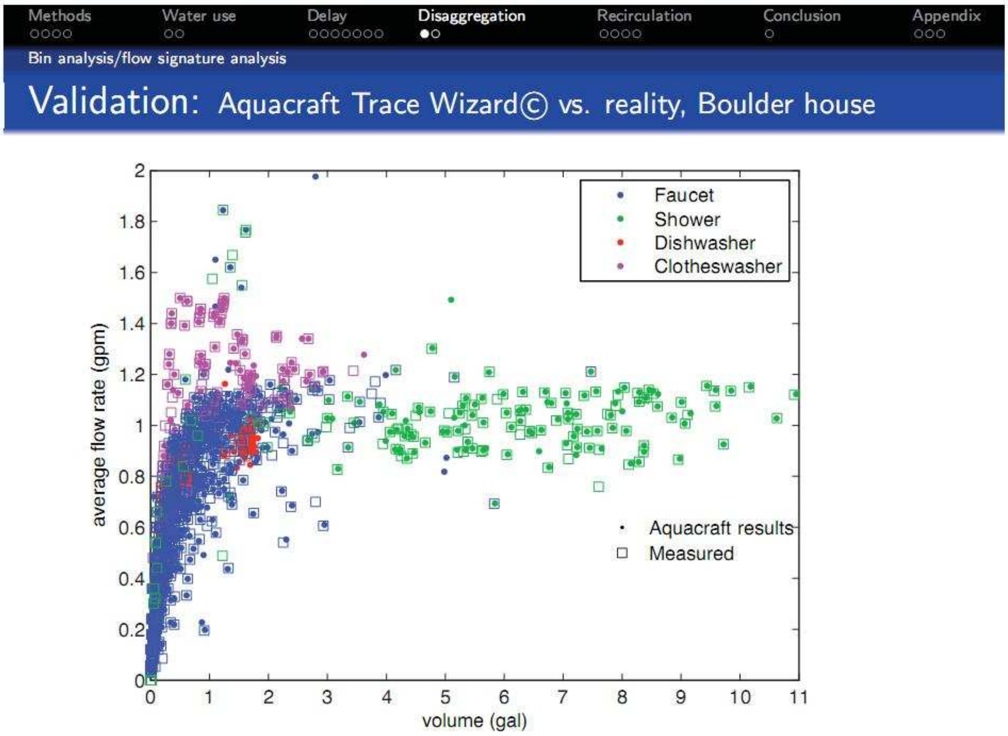


Figure 11 Comparison of flow trace analysis results to sub-meter measurements (Magnusson, L., 2009)

The Aquacraft Inc. results are based on flow trace analysis of a single meter supplying hot water to all of the fixtures in the homes. Individual faucet, shower, dishwasher and clothes washer events have been sorted by flow rate and volume for both sets of measurements. Where ever the two points coincide there is agreement. These appear as boxes with dots in them. As can be seen from Figure 3, there is excellent agreement between the flow trace and sub-meter measurements. When the measured water usage of faucet, shower, dishwasher, and clothes washer events are combined in the NREL study, Trace Wizard analysis and the in-line water meter data are 88% in agreement.

Appendix B: Regression Analysis Modeled Variables

Keycode	PreretroIndoorGPD	PostretroIndoorGPD	Indoor Change	PreretroToiletgpd	PostretroToiletgpd	ToiletChange	NumRetro	PersonsperHome
09M201	579	404	-175	97	54	-43	3	6
09M202	162	235	73	44	9	-35	1	3
09M204	256	199	-57	104	33	-71	3	4
09M205	266	82	-185	117	9	-108	2	3
09M207	142	108	-34	58	16	-42	3	3
09M208	166	143	-23	82	39	-43	1	2
09M210	179	79	-100	115	38	-77	2	2
09M214	144	126	-17	39	13	-26	1	1
09M215	53	35	-18	28	10	-18	1	1
09M216	17	32	15	4	6	2	1	2
09M217	125	49	-76	40	4	-36	1	1
09M219	128	91	-37	73	32	-40	2	3
09M220	116	88	-28	40	11	-28	1	3
09M221	153	106	-47	85	26	-60	2	2
09M222	236	31	-204	68	3	-65	1	3
09M223	91	44	-46	53	12	-42	2	2
09M224	260	244	-16	80	52	-27	1	2
09M225	75	70	-5	19	8	-10	2	2
09M226	308	162	-146	40	16	-25	2	4
09M227	96	157	62	34	7	-27	2	2
09M228	71	65	-5	31	36	5	1	1
09M229	131	228	97	40	62	22	1	1
09M232	29	73	44	7	15	7	1	4
09M233	132	461	328	63	43	-21	2	2
09M234	145	87	-58	64	16	-48	2	4
09M237	195	125	-71	69	37	-32	1	5
09M238	158	82	-76	61	17	-44	1	3
09M239	179	89	-90	96	18	-78	2	4
09M240	74	48	-26	20	6	-13	2	2
09M241	113	101	-12	38	17	-21	2	3
09M242	39	55	16	23	21	-2	1	2
09M243	129	120	-8	56	14	-42	1	2
09M245	83	53	-31	48	12	-36	1	2
09M251	103	0	-103	55	0	-55	2	3
09M250	59	47	-12	25	9	-16	1	1
09M252	180	176	-4	65	39	-26	1	5
09M253	93	135	42	48	23	-25	2	5
09M254	23	45	22	7	5	-2	2	2
09M255	81	65	-16	38	15	-23	1	2
09M256	6	224	219	2	26	24	2	3
09M257	98	73	-25	59	23	-36	2	2
Average	138.28	118	-20.3	52	21	-31	1.6	2.7
Std Dev	99.81	94.30	94.05	29.31	15.14	26.80	0.63	1.24
Count	41	41	41	41	41	41	41	41
95%CI	30.55	28.87	28.79	8.97	4.63	8.20	0.19	0.38
90% CI	25.64	24.23	24.16	7.53	3.89	6.88	0.16	0.32

Appendix C: Data Collection Sheets

The following four tables show the data sheets used for the pre and post retrofit installations of HET.

SCE Multi-family HET pilot program: EM&V Steps

Step	Responsible Party*	Task	Completion dates
1	IC	Generates list of ~500 low-income qualified multi-family units	
2	EcoNW	Randomly select sample of 60 multi-family units from IC list of low-income qualified units	
3	EcoNW	Send sample list to Installer and EM&V contractor	
4	Aquacraft	Acquire individual meter numbers from water agency	
5	Aquacraft	Pre-retrofit site visit to install data loggers onto individual water meters - loggers collect flow trace data for two weeks	
6	Aquacraft	Site visit to retrieve data loggers from individual water meters	
7	Aquacraft	Inform Installer when it is OK to proceed with HET retrofits	
8	BL	Retrofit sample units with HET	
9	BL	Inform Aquacraft of retrofit completion and provide field information collect by installers	
10	Aquacraft	Post-retrofit site visit to install data loggers onto individual water meters - loggers collect flow trace data for two weeks	
11	Aquacraft	Site visit to retrieve data loggers from individual water meters	
12	Aquacraft	Pre and Post-retrofit data analysis and computation of impacts	

Key to responsible parties

EM&V prime contractor	*EcoNW*	*EcoNorthwest*
EM&V contractor	*Aquacraft*	*Aquacraft Inc.*
EM&V field subcontractor	*IC*	*Irvine Company*
Installer	*BL*	*Bottom Line*

Aquacraft	IRWD & Irvine Company						Bottom Line			
Keycode	Meter Make	Meter Model	Meter Size	Register Number -OR- Meter Serial Number	Persons per Home	Toilets per Home	# of Toilets Retrofit	Make & Model of Old Toilet	Make & Model of New Toilet	Comments
09M201	Neptune	T10	5/8	46512156	6	3	3	Briggs	Caroma Sydney 305	
09M202	Neptune	T10	5/8	77959550	3	1	1	Briggs	Caroma Sydney 305	
09M203	Neptune	T10	5/8	77959593	1	2	2	Briggs	Caroma Sydney 305	
09M204	Neptune	T10	5/8	77959603	4	3	3	Briggs	Caroma Sydney 305	
09M205	Neptune	T10	5/8	78823976	3	2	2	Briggs	Caroma Sydney 305	
09M206	Neptune	T10	5/8	78823997	4	3	3	Briggs	Caroma Sydney 305	
09M207	Neptune	T10	5/8	78823998	3	3	3	Briggs	Caroma Sydney 305	
09M208	Neptune	T10	5/8	78824004	2	2	1	Briggs	Caroma Sydney 305	
09M209	Neptune	T10	5/8	78823968	1	1	0	Briggs	Caroma Sydney 305	
09M210	Neptune	T10	5/8	85375685	2	2	2	Briggs	Caroma Sydney 305	
09M211	Neptune	T10	5/8	78823964	3	1	0	Briggs	Caroma Sydney 305	
09M212	Neptune	T10	5/8	78823965	1	1	0	Briggs	Caroma Sydney 305	
09M213	Neptune	T10	5/8	78823949	1	1	0	Briggs	Caroma Sydney 305	
09M214	Neptune	T10	5/8	78823950	1	1	1	Briggs	Caroma Sydney 305	
09M215	Neptune	T10	5/8	78823921	1	1	1	Briggs	Caroma Sydney 305	
09M216	Neptune	T10	5/8	78824497	2	1	1	Briggs	Caroma Sydney 305	
09M217	Badger	?	5/8	16173142	1	1	1	Briggs	Caroma Sydney 305	
09M218	Neptune	T10	5/8	78823929	3	3	0	Briggs	Caroma Sydney 305	
09M219	Neptune	T10	5/8	78823930	3	3	2	Briggs	Caroma Sydney 305	
09M220	Neptune	T10	5/8	78823898	3	1	1	Briggs	Caroma Sydney 305	
09M221	Neptune	T10	5/8	78823905	2	2	2	Briggs	Caroma Sydney 305	
09M222	Neptune	T10	5/8	78823903	3	2	1	Briggs	Caroma Sydney 305	
09M223	Neptune	T10	5/8	78823877	2	2	2	Briggs	Caroma Sydney 305	
09M224	Rockwell	?	5/8	78823908	2	2	1	Briggs	Caroma Sydney 305	
09M225	Neptune	T10	5/8	78823894	2	2	2	Briggs	Caroma Sydney 305	
09M226	Neptune	T10	5/8	78823816	4	2	2	Briggs	Caroma Sydney 305	
09M227	Neptune	T10	5/8	78823819	2	2	2	Briggs	Caroma Sydney 305	
09M228	Neptune	T10	5/8	78823875	1	1	1	Briggs	Caroma Sydney 305	
09M229	Neptune	T10	5/8	78823833	1	2	1	Briggs	Caroma Sydney 305	
09M230	Neptune	T10	5/8	78823828	1	1	1	Briggs	Caroma Sydney 305	
09M231	Neptune	T10	5/8	78823835	3	1	0	Briggs	Caroma Sydney 305	
09M232	Neptune	T10	5/8	78823836	4	2	1	Briggs	Caroma Sydney 305	
09M233	Neptune	T10	5/8	79770530	2	3	2	Briggs	Caroma Sydney 305	
09M234	Neptune	T10	5/8	79770536	4	2	2	Briggs	Caroma Sydney 305	
09M235	Neptune	T10	5/8	79770521	3	2	0	Briggs	Caroma Sydney 305	
09M236	Neptune	T10	5/8	37739924	2	1	1	Briggs	Caroma Sydney 305	
09M237	Neptune	T10	5/8	79770503	5	3	1	Briggs	Caroma Sydney 305	
09M238	Neptune	T10	5/8	79770481	3	1	1	Briggs	Caroma Sydney 305	
09M239	Neptune	T10	5/8	79770543	4	2	2	Briggs	Caroma Sydney 305	
09M240	Neptune	T10	5/8	79770456	2	2	2	Briggs	Caroma Sydney 305	
09M241	Neptune	T10	5/8	79770432	3	2	2	Briggs	Caroma Sydney 305	
09M242	Neptune	T10	5/8	79771985	2	1	1	Briggs	Caroma Sydney 305	
09M243	Neptune	T10	5/8	79770443	2	1	1	Briggs	Caroma Sydney 305	
09M244	Neptune	T10	5/8	79770446	1	1	0	Briggs	Caroma Sydney 305	
09M245	Neptune	T10	5/8	79770407	2	1	1	Briggs	Caroma Sydney 305	
09M246	Neptune	T10	5/8	79770412	1	1	0	Briggs	Caroma Sydney 305	
09M247	Neptune	T10	5/8	79771988	4	2	0	Briggs	Caroma Sydney 305	
09M248	Neptune	T10	5/8	79771983	3	2	1	Briggs	Caroma Sydney 305	
09M249	Neptune	T10	5/8	79770421	1	1	1	Briggs	Caroma Sydney 305	
09M250	Neptune	T10	5/8	79770422	1	1	1	Briggs	Caroma Sydney 305	
09M251	Neptune	T10	5/8	77407926	3	2	2	Briggs	Caroma Sydney 305	
09M252	Neptune	T10	5/8	77408011	5	2	1	Briggs	Caroma Sydney 305	
09M253	Neptune	T10	5/8	77407981	5	2	2	Briggs	Caroma Sydney 305	
09M254	Neptune	T10	5/8	77407964	2	2	2	Briggs	Caroma Sydney 305	
09M255	Neptune	T10	5/8	77407995	2	1	1	Briggs	Caroma Sydney 305	
09M256	Neptune	T10	5/8	77408027	3	2	2	Briggs	Caroma Sydney 305	
09M257	Neptune	T10	5/8	84597679	2	2	2	Briggs	Caroma Sydney 305	
09M258	Neptune	T10	5/8	77408041	3	2	0	Briggs	Caroma Sydney 305	
09M259	Neptune	T10	5/8	77408080	3	2	0	Briggs	Caroma Sydney 305	
09M260	Neptune	T10	5/8	77407694	2	2	2	Briggs	Caroma Sydney 305	

[6]

[6] Homes with '0' toilets replaced were excluded from the impact analysis.

Aquacraft pre-retrofit data logging sheet												
Install									Pick-up			
Aquacraft Keycode #	Logger #	Register Number -OR- Meter Serial Number	Meter Size	Meter Make & Model	Meter Model	Aquacraft Field Technician	Install Date and Time	Meter Reading at Install (cf)	Aquacraft Field Technician	Pick-up Date and Time	Meter Reading at Pick-up
09M201	12608	46512156	5/8	Neptune	T10	MKD	6/29/2009 15:47	119934	MKD	7/13/09 18:50	121041
09M202	12598	77959550	5/8	Neptune	T10	MKD	6/29/2009 15:46	56797	MKD	7/13/09 18:50	57083
09M203	12613	77959593	5/8	Neptune	T10	MKD	6/29/2009 15:45	30175	MKD	7/13/09 18:50	30177
09M204	12590	77959603	5/8	Neptune	T10	MKD	6/29/2009 15:44	38686	MKD	7/13/09 18:50	39165
09M205	12580	78823976	5/8	Neptune	T10	MKD	6/29/2009 15:25	45631	MKD	7/13/09 18:45	46137
09M206	12607	78823997	5/8	Neptune	T10	MKD	6/29/2009 15:24	54141	MKD	7/13/09 18:30	54768
09M207	11370	78823998	5/8	Neptune	T10	MKD	6/29/2009 15:23	44086	MKD	7/13/09 18:30	44356
09M208	12586	78824004	5/8	Neptune	T10	MKD	6/29/2009 15:22	51364	MKD	7/13/09 18:30	51680
09M209	12617	78823968	5/8	Neptune	T10	MKD	6/29/2009 15:01	10404	MKD	7/13/09 18:30	10529
09M210	12566	85375685	5/8	Neptune	T10	MKD	6/29/2009 12:07	9156	MKD	7/13/09 18:00	9499
09M211	12587	78823964	5/8	Neptune	T10	MKD	6/29/2009 14:56	24287	MKD	7/13/09 18:15	24663
09M212	12592	78823965	5/8	Neptune	T10	MKD	6/29/2009 14:56	16177	MKD	7/13/09 18:15	16282
09M213	12566	78823949	5/8	Neptune	T10	MKD	6/29/2009 12:58	10803	MKD	7/13/09 17:20	10958
09M214	12611	78823950	5/8	Neptune	T10	MKD	6/29/2009 12:57	28930	MKD	7/13/09 17:20	29241
09M215	11321	78823921	5/8	Neptune	T10	MKD	6/29/2009 12:55	14917	MKD	7/13/09 17:20	15013
09M216	12606	78824497	5/8	Neptune	T10	MKD	6/29/2009 14:34	21801	MKD	7/13/09 18:15	21837
09M217	12577	16173142	5/8	Badger	?	MKD	6/29/2009 14:54	55755	MKD	7/13/09 18:00	56016
09M218	12619	78823929	5/8	Neptune	T10	MKD	6/29/09 12:55	29753	MKD	7/13/09 17:20	30049
09M219	12605	78823930	5/8	Neptune	T10	MKD	6/29/2009 12:53	29067	MKD	7/13/09 17:20	29311
09M220	12585	78823898	5/8	Neptune	T10	MKD	6/29/2009 14:53	28251	MKD	7/13/09 18:00	28471
09M221	12615	78823905	5/8	Neptune	T10	MKD	6/29/2009 12:52	34799	MKD	7/13/09 17:40	35078
09M222	12582	78823903	5/8	Neptune	T10	MKD	6/29/2009 14:53	38436	MKD	7/13/09 18:00	38875
09M223	11349	78823877	5/8	Neptune	T10	MKD	6/29/2009 14:52	39047	MKD	7/13/09 18:00	39215
09M224	12597	78823908	5/8	Rockwell	?	MKD	6/29/2009 12:50	27588	MKD	7/13/09 17:40	28068
09M225	11314	78823894	5/8	Neptune	T10	MKD	6/29/2009 11:40	31859	MKD	7/13/09 16:56	32000
09M226	12579	78823816	5/8	Neptune	T10	MKD	6/29/2009 11:32	62406	MKD	7/13/09 16:37	62996
09M227	11329	78823819	5/8	Neptune	T10	MKD	6/29/2009 11:31	32336	MKD	7/13/09 16:40	32700
09M228	11372	78823875	5/8	Neptune	T10	MKD	6/29/2009 11:56	26160	MKD	7/13/09 16:20	26291
09M229	11386	78823833	5/8	Neptune	T10	MKD	6/29/09 11:18	50375	MKD	7/13/09 16:45	50724
09M230	12612	78823828	5/8	Neptune	T10	MKD	6/29/09 11:55	15953	MKD	7/13/09 16:20	16098
09M231	12583	78823835	5/8	Neptune	T10	MKD	6/29/2009 11:07	29286	MKD	7/13/09 16:20	29467
09M232	11319	78823836	5/8	Neptune	T10	MKD	6/29/09 11:30	37856	MKD	7/13/09 16:45	37912
09M233	12565	79770530	5/8	Neptune	T10	MKD	6/29/09 11:00	35904	MKD	7/13/09 16:20	36157
09M234	11297	79770536	5/8	Neptune	T10	MKD	6/29/09 10:59	41348	MKD	7/13/09 16:20	41649
09M235	11364	79770521	5/8	Neptune	T10	MKD	6/29/09 10:58	26369	MKD	7/13/09 16:20	26542
09M236	12620	37739924	5/8	Neptune	T10	MKD	6/29/09 10:57	89293	MKD	7/13/09 16:20	89477
09M237	11377	79770503	5/8	Neptune	T10	MKD	6/29/09 9:55	39982	MKD	7/13/09 15:15	40350
09M238	11312	79770481	5/8	Neptune	T10	MKD	6/29/09 9:55	20068	MKD	7/13/09 15:15	20353
09M239	12564	79770543	5/8	Neptune	T10	MKD	6/29/09 10:18	37602	MKD	7/13/09 15:24	37941
09M240	11373	79770456	5/8	Neptune	T10	MKD	6/29/09 9:36	52552	MKD	7/13/09 15:15	52696
09M241	11375	79770432	5/8	Neptune	T10	MKD	6/29/09 9:30	33054	MKD	7/13/09 15:15	33273
09M242	11356	79771985	5/8	Neptune	T10	MKD	6/29/09 10:29	16012	MKD	7/13/09 15:40	16088
09M243	11398	79770443	5/8	Neptune	T10	MKD	6/29/2009 9:24	23960	MKD	7/13/09 15:15	24203
09M244	11302	79770446	5/8	Neptune	T10	MKD	6/29/2009 9:12	19193	MKD	7/13/09 13:50	19392
09M245	12574	79770407	5/8	Neptune	T10	MKD	6/29/2009 9:12	17235	MKD	7/13/09 13:50	17340
09M246	11393	79770412	5/8	Neptune	T10	MKD	6/29/2009 9:09	8491	MKD	7/13/09 13:50	8534
09M247	12568	79771988	5/8	Neptune	T10	MKD	6/29/2009 8:50	35675	MKD	7/13/09 12:51	35952
09M248	11376	79771983	5/8	Neptune	T10	MKD	6/29/2009 8:42	49977	MKD	7/13/09 11:33	50445
09M249	11303	79770421	5/8	Neptune	T10	MKD	6/29/2009 10:09	12255	MKD	7/13/09 14:36	12372
09M250	11383	79770422	5/8	Neptune	T10	MKD	6/29/2009 10:09	11518	MKD	7/13/09 14:53	11626
09M251	11294	77407926	5/8	Neptune	T10	MKD	6/29/09 16:06	40347	MKD	7/13/09 20:20	40513
09M252	11397	77408011	5/8	Neptune	T10	MKD	6/29/09 16:26	46102	MKD	7/13/09 20:15	46445
09M253	12563	77407981	5/8	Neptune	T10	MKD	6/29/09 16:33	56061	MKD	7/13/09 20:15	56242
09M254	11307	77407964	5/8	Neptune	T10	MKD	6/29/09 16:01	35852	MKD	7/13/09 20:10	35903
09M255	11401	77407995	5/8	Neptune	T10	MKD	6/29/09 16:38	28042	MKD	7/13/09 20:00	28195
09M256	11385	77408027	5/8	Neptune	T10	MKD	6/29/09 16:59	68470	MKD	7/13/09 19:45	68479
09M257	11309	84597679	5/8	Neptune	T10	MKD	6/29/09 17:01	5533	MKD	7/13/09 19:30	5719
09M258	12562	77408041	5/8	Neptune	T10	MKD	6/29/09 17:16	37861	MKD	7/13/09 19:30	38007
09M259	11390	77408080	5/8	Neptune	T10	MKD	6/29/09 16:58	24754	MKD	7/13/09 19:30	24878
09M260	11311	77407694	5/8	Neptune	T10	MKD	6/29/09 17:18	48040	MKD	7/13/09 19:30	48218

Aquacraft post-retrofit data logging sheet												
Install										Pick-up		
Aquacraft Keycode #	Logger #	Register Number -OR- Meter Serial Number	Meter Size	Meter Make & Model	Meter Model	Aquacraft Field Technician	Install Date and Time	Install Time	Meter Reading at Install (cf)	Aquacraft Field Technician	Pick-up Date	Meter Reading at Pick-up
09M201a2	12586	46512156	5/8	Neptune	T10	MKD	9/29/2009	11:08	125911	MH	10/13/2009	126673
09M202a2	11307	77959550	5/8	Neptune	T10	MKD	9/29/2009	11:18	58949	MH	10/13/2009	59383
09M203a2	11386	77959593	5/8	Neptune	T10	MKD	9/29/2009	11:12	30193	MH	10/13/2009	30195
09M204a2	11294	77959603	5/8	Neptune	T10	MKD	9/29/2009	11:16	41514	MH	10/13/2009	41865
09M205a2	12590	78823976	5/8	Neptune	T10	MKD	9/29/2009	11:56	52309	MH	10/13/2009	52455
09M206a2	12618	78823997	5/8	Neptune	T10	MKD	9/29/2009	11:39	57549	MH	10/13/2009	58082
09M207a2	11385	78823998	5/8	Neptune	T10	MKD	9/29/2009	11:44	45696	MH	10/13/2009	45892
09M208a2	11349	78824004	5/8	Neptune	T10	MKD	9/29/2009	11:37	52906	MH	10/13/2009	53171
09M209a2		78823968	5/8	Neptune	T10							
09M210a2	11309	85375685	5/8	Neptune	T10	MKD	9/29/2009	12:19	10774	MH	10/13/2009	10924
09M211a2		78823964	5/8	Neptune	T10							
09M212a2		78823965	5/8	Neptune	T10							
09M213a2		78823949	5/8	Neptune	T10							
09M214a2	12607	78823950	5/8	Neptune	T10	MKD	9/29/2009	12:34	31852	MH	10/13/2009	32100
09M215a2	12594	78823921	5/8	Neptune	T10	MKD	9/29/2009	12:44	15521	MH	10/13/2009	15585
09M216a2	11312	78824497	5/8	Neptune	T10	MKD	9/29/2009	14:18	22077	MH	10/13/2009	22135
09M217a2	12620	16173142	5/8	Badger	?	MKD	9/29/2009	14:27	57161	MH	10/13/2009	57257
09M218a2		78823929	5/8	Neptune	T10							
09M219a2	11298	78823930	5/8	Neptune	T10	MKD	9/29/2009	12:37	30804	MH	10/13/2009	30964
09M220a2	12579	78823898	5/8	Neptune	T10	MKD	9/29/2009	14:09	29435	MH	10/13/2009	29595
09M221a2	12564	78823905	5/8	Neptune	T10	MKD	9/29/2009	12:57	35825	MH	10/13/2009	36037
09M222a2	11306	78823903	5/8	Neptune	T10	MKD	9/29/2009	14:06	40682	MH	10/13/2009	40736
09M223a2	12598	78823877	5/8	Neptune	T10	MKD	9/29/2009	14:03	39945	MH	10/13/2009	40027
09M224a2	11311	78823908	5/8	Rockwell	?	MKD	9/29/2009	12:54	31121	MH	10/13/2009	31592
09M225a2	11397	78823894	5/8	Neptune	T10	MKD	9/29/2009	14:46	32807	MH	10/13/2009	32942
09M226a2	11329	78823816	5/8	Neptune	T10	MKD	9/29/2009	15:01	66191	MH	10/13/2009	66736
09M227a2	12616	78823819	5/8	Neptune	T10	MKD	9/29/2009	15:03	34751	MH	10/13/2009	35076
09M228a2	11314	78823875	5/8	Neptune	T10	MKD	9/29/2009	15:22	27041	MH	10/13/2009	27166
09M229a2	12587	78823833	5/8	Neptune	T10	MKD	9/29/2009	15:08	53454	MH	10/13/2009	53874
09M230a2	12566	78823828	5/8	Neptune	T10	MKD	9/29/2009	15:24	16748			
09M231a2		78823835	5/8	Neptune	T10							
09M232a2	11383	78823836	5/8	Neptune	T10	MKD	9/29/2009	15:13	37941	MH	10/13/2009	38076
09M233a2	12562	79770530	5/8	Neptune	T10	MKD	9/29/2009	16:06	37354	MH	10/13/2009	38191
09M234a2	12582	79770536	5/8	Neptune	T10	MKD	9/29/2009	16:02	42973	MH	10/13/2009	43137
09M235a2		79770521	5/8	Neptune	T10							
09M236a2	12585	37739924	5/8	Neptune	T10	MKD	9/29/2009	16:24	90244	MH	10/13/2009	90351
09M237a2	12603	79770503	5/8	Neptune	T10	MKD	9/29/2009	16:30	42111	MH	10/13/2009	42346
09M238a2	12615	79770481	5/8	Neptune	T10	MKD	9/29/2009	16:34	21263	MH	10/13/2009	21412
09M239a2	11376	79770543	5/8	Neptune	T10	MKD	9/29/2009	17:44	39206	MH	10/13/2009	39370
09M240a3	12617	79770456	5/8	Neptune	T10	MKD	9/29/2009	17:36	53543	MH	10/13/2009	53628
09M241a2	12577	79770432	5/8	Neptune	T10	MKD	9/29/2009	17:40	34490	MH	10/13/2009	34630
09M242a2	11393	79771985	5/8	Neptune	T10	MKD	9/29/2009	16:42	16924	MH	10/13/2009	17026
09M243a2	12597	79770443	5/8	Neptune	T10	MKD	9/29/2009	17:25	25374	MH	10/13/2009	25596
09M244a2		79770446	5/8	Neptune	T10							
09M245a2	12613	79770407	5/8	Neptune	T10	MKD	9/29/2009	17:20	18245	MH	10/13/2009	18350
09M246a2		79770412	5/8	Neptune	T10							
09M247a2		79771988	5/8	Neptune	T10							
09M248a2	12606	79771983	5/8	Neptune	T10	MKD	9/29/2009	18:01	52491	MH	10/13/2009	52908
09M249a2	11401	79770421	5/8	Neptune	T10	MKD	9/29/2009	17:02	12741	MH	10/13/2009	12748
09M250a2	11319	79770422	5/8	Neptune	T10	MKD	9/29/2009	17:00	12220	MH	10/13/2009	12267
09M251a2	11372	77407926	5/8	Neptune	T10	MKD	9/30/2009	9:08	40749	MH	10/13/2009	40749
09M252a2	11346	77408011	5/8	Neptune	T10	MKD	9/30/2009	9:26	48447	MH	10/13/2009	48756
09M253a2	12565	77407981	5/8	Neptune	T10	MKD	9/30/2009	9:32	57735	MH	10/13/2009	57977
09M254a2	12583	77407964	5/8	Neptune	T10	MKD	9/30/2009	10:12	36341	MH	10/13/2009	36415
09M255a2	12612	77407995	5/8	Neptune	T10	MKD	9/30/2009	10:05	28877	MH	10/13/2009	28992
09M256a2	11297	77408027	5/8	Neptune	T10	MKD	9/30/2009	9:45	70601	MH	10/13/2009	71005
09M257a2	12563	84597679	5/8	Neptune	T10	MKD	9/30/2009	9:59	6569	MH	10/13/2009	6700
09M258a2		77408041	5/8	Neptune	T10							
09M259a2		77408080	5/8	Neptune	T10							
09M260a2	11390	77407694	5/8	Neptune	T10	MKD	9/30/2009	9:53	48957			

Appendix D: Pre-Post Water Use Tables

The following tables show the key toilet data collected per home. The first table represents the Pre Retrofit data and the second table the Post Retrofit data.

Table 8 Pre retrofit data

Keycode	Total Volume (gal)	Trace (days)	Total GPD	Toilet Events	Toilet Total (gal)	Toilet (gpd)	Average Flush Volume (gal)	Leak Total (gal)
09M201	7522.04	13	578.62	373	1258.10	96.78	3.27	520.24
09M202	2100.26	13	161.56	166	578.21	44.48	3.48	285.78
09M204	3327.85	13	255.99	322	1348.02	103.69	4.16	37.42
09M205	3464.08	13	266.47	421	1520.41	116.95	3.61	35.13
09M207	1848.91	13	142.22	200	756.69	58.21	3.78	253.12
09M208	2157.18	13	165.94	316	1062.99	81.77	2.94	40.10
09M210	2328.22	13	179.09	362	1496.84	115.14	4.13	16.91
09M214	1868.25	13	143.71	25	509.45	39.19	3.18	671.13
09M215	689.29	13	53.02	82	363.87	27.99	4.44	34.98
09M216	167.61	10	16.76	10	35.89	3.59	3.59	15.57
09M217	1621.51	13	124.73	129	518.99	39.92	3.93	43.24
09M219	1658.13	13	127.55	163	947.49	72.88	5.81	35.07
09M220	1511.42	13	116.26	131	515.76	39.67	3.74	15.32
09M221	1986.18	13	152.78	266	1106.57	85.12	4.16	46.91
09M222	3064.33	13	235.72	245	884.19	68.01	3.54	240.36
09M223	1177.88	13	90.61	156	695.18	53.48	4.37	22.08
09M224	3382.64	13	260.20	241	1038.29	79.87	4.29	11.23
09M225	969.64	13	74.59	58	241.71	18.59	4.17	49.73
09M226	4006.69	13	308.21	138	521.28	40.10	3.78	9.68
09M227	1501.30	13	115.48	81	443.29	34.10	5.47	82.64
09M228	919.70	13	70.75	92	397.82	30.60	4.14	21.81
09M229	44981.58	13	3460.12	158	522.16	40.17	3.30	34.78
09M232	300.76	10	30.08	30	73.97	7.40	2.47	2.63
09M233	1721.57	13	132.43	205	821.29	63.18	3.89	20.77
09M234	1319.61	9	146.62	128	579.93	64.44	4.50	16.72
09M237	2541.27	13	195.48	281	898.03	69.08	3.18	53.03
09M238	2050.15	13	157.70	190	790.22	60.79	4.05	15.72
09M239	2323.32	13	178.72	315	1245.46	95.80	3.84	208.51
09M240	959.51	13	73.81	69	253.84	19.53	3.68	36.43
09M241	1464.97	13	112.69	142	499.24	38.40	3.35	142.17
09M242	511.48	13	39.34	94	298.82	22.99	3.18	8.56
09M243	1671.89	13	128.61	183	732.96	56.38	4.01	8.09
09M245	1084.61	13	83.43	144	628.56	48.35	4.37	14.39
09M250	763.67	13	58.74	81	323.57	24.89	3.99	22.73
09M251	1336.53	13	102.81	165	717.65	55.20	4.35	154.15
09M252	2342.08	13	180.16	388	838.65	64.51	2.14	28.47
09M253	1208.59	13	92.97	139	618.30	47.56	4.42	21.47
09M254	297.94	13	22.92	22	87.02	6.69	3.96	0.29
09M255	1057.05	13	81.31	120	496.06	38.16	4.13	55.44
09M256	72.98	13	5.61	8	27.35	2.10	3.42	4.29
09M257	1268.10	13	97.55	243	766.32	58.95	3.05	30.87

Table 9 Post retrofit data

Keycode	Total Volume (gal)	Trace (days)	Total GPD	Toilet Events	Toilet Total (gal)	Toilet (gpd)	Average Flush Volume (gal)	Leak Total (gal)
09M201A2	5245.58	13	403.51	299	696.58	53.58	2.33	1005.35
09M202A2	3057.45	13	235.19	117	122.33	9.41	1.05	1473.44
09M204A2	2581.42	13	198.57	310	425.88	32.76	1.37	212.38
09M205A2	1059.72	13	81.52	116	117.60	9.05	1.01	7.91
09M207A2	1406.66	13	108.20	238	213.00	16.38	0.89	279.69
09M208A2	1872.24	13	144.02	482	510.36	39.26	1.06	40.24
09M210A2	1031.78	13	79.37	351	496.62	38.20	1.41	20.62
09M214A2	1644.13	13	126.47	176	171.47	13.19	0.97	48.29
09M215A2	459.96	13	35.38	123	135.84	10.45	1.10	9.59
09M216A2	416.82	13	32.06	71	72.45	5.57	1.02	16.75
09M217A2	636.67	13	48.97	49	55.35	4.26	1.13	71.69
09M219A2	1179.01	13	90.69	136	421.29	32.41	3.10	82.36
09M220A2	1151.44	13	88.57	118	145.34	11.18	1.23	58.95
09M221A2	1393.33	13	107.18	251	332.95	25.61	1.33	42.95
09M222A2	405.90	13	31.22	23	37.84	2.91	1.65	93.58
09M223A2	577.23	13	44.40	131	149.96	11.54	1.14	34.99
09M224A2	3171.53	13	243.96	260	681.90	52.45	2.62	28.87
09M225A2	909.85	13	69.99	89	107.28	8.25	1.21	7.68
09M226A2	2168.22	13	166.79	66	201.91	15.53	3.06	24.78
09M227A2	2046.97	13	157.46	84	97.47	7.50	1.16	109.27
09M228A2	848.38	13	65.26	103	468.42	36.03	4.55	22.97
09M229A2	2968.93	13	228.38	203	806.67	62.05	3.90	209.59
09M232A2	942.62	13	72.51	161	192.97	14.84	1.20	21.13
09M233A2	5989.60	13	460.74	224	554.34	42.64	2.47	4463.16
09M234A2	1129.19	13	86.86	152	212.49	16.35	1.40	31.06
09M237A2	1632.90	13	125.61	230	480.62	36.97	2.09	30.62
09M238A2	1061.02	13	81.62	167	221.83	17.06	1.33	13.81
09M239A2	1152.96	13	88.69	205	228.80	17.60	1.12	11.08
09M240A3	618.70	13	47.59	59	78.84	6.06	1.34	9.36
09M241A2	1329.55	13	102.27	185	225.21	17.32	1.22	98.55
09M242A2	720.78	13	55.44	197	273.25	21.02	1.39	39.41
09M243A2	1562.15	13	120.17	141	184.18	14.17	1.31	79.30
09M245A2	587.78	11	53.43	136	131.65	11.97	0.97	12.29
09M250A2	282.69	6	47.11	64	54.42	9.07	0.85	20.89
09M251A2	8.07	8	1.01			0.00		8.07
09M252A2	2116.45	12	176.37	298	467.99	39.00	1.57	34.40
09M253A2	1619.42	12	134.95	238	272.34	22.70	1.14	28.50
09M254A2	552.13	12	46.01	37	60.83	5.07	1.64	17.86
09M255A2	778.05	12	64.84	134	175.95	14.66	1.31	27.55
09M256A2	2693.25	12	224.44	264	317.21	26.43	1.20	45.90
09M257A2	875.31	12	72.94	224	279.87	23.32	1.25	27.87

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