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Title: Estimating and Verifying United States Households' Potential to Conserve Water

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Abstract: Here behavior and technological impacts on residential indoor water use and conservation efforts in the U.S. are identified. Pre-existing detailed end-use data was collected before and after toilets, faucets, showerheads and clothes washers were retrofitted in 96 owner-occupied, single-family households in Oakland, California, Seattle, Washington, and Tampa, Florida between 2000 and 2003. Water volume, duration of use, and time of use were recorded and disaggregated by appliance for two weeks before and four weeks after appliances were retrofitted. For each appliance, observed differences in water use before and after retrofits are compared to water savings predicted by simple analytical, regression, and hybrid models. Comparisons identify prediction precision among models. Results show that observed and predicted distributions of water savings are skewed with a small number of households showing potential to save more water. Regression and hybrid model results also show the relative and significant influence on water saved of both technological (flow rates of appliances) and behavioral (length of use, frequency of use) factors. Additionally, regression results suggest the number of residents, performance, and the frequency of appliance use are key factors that distinguish households that save the most water from households that save less. Study results help improve engineering methods to estimate water savings from retrofits and allow water utilities to better target subcategories of households that have potential to save more water.

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Mr. Walski's work and interests are in the same line of the work presented here.

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Dr. Vogel is interested in water resources systems and optimization. He should provide effective feedback on this work.

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This work is based on EPA standards, thus it would be interesting to see their point of view.

Opposed Reviewers:

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4 1 Estimating and Verifying United States Households’ Potential to Conserve Water

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18 7 ABSTRACT

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20 8 Here behavior and technological impacts on residential indoor water use and
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22 9 conservation efforts in the U.S. are identified. Pre-existing detailed end-use data was collected
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25 10 before and after toilets, faucets, showerheads and clothes washers were retrofitted in 96
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30 12 Tampa, Florida between 2000 and 2003. Water volume, duration of use, and time of use were
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33 13 recorded and disaggregated by appliance for two weeks before and four weeks after appliances
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36 14 were retrofitted. For each appliance, observed differences in water use before and after
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39 15 retrofits are compared to water savings predicted by simple analytical, regression, and hybrid
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9 25 INTRODUCTION
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14 27 Urbanization and growing populations are placing increased demands on scarce, limited,
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17 28 municipal water supplies. Compared to expensive supply-side options to expand municipal or
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20 29 regional water infrastructure, residential water conservation can cost effectively help demands
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23 30 match available supplies. Conservation can include technological changes, such as replacing old
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25 31 toilets, faucets, showerheads, dishwashers, and laundry machines with newer and more
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28 32 efficient appliances mandated by the 1992 U.S. Energy Policy Act (EPA). However, to include
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30 33 water conservation in water supply/demand planning, it is important to correctly know and
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33 34 forecast current and future water demands and the volume of water potentially saved by
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35 35 conservation actions.
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38 36 Planners and water managers have forecasted water demand and estimated water
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41 37 savings for many conservation programs and measures (Berk et al., 1993; Buchberger and
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43 38 Wells, 1996; Kenney et al., 2008; Michelsen et al., 1999; Renwick and Archibald, 1998; Walski et
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46 39 al., 1985). For example, low flow showerheads and toilet dams were distributed among
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49 40 Hamilton Township residents in 1978; subsequently customers were surveyed to identify the
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51 41 number of devices actually installed, and coefficients obtained from this data were used in an
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53 42 algorithm to predict water savings (Walski et al., 1985). Data loggers have been installed on the
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56 43 supply line for single-family residences, recording the total instantaneous water demand of the
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59 44 household (Buchberger and Wells, 1996). Models to estimate household-level water demands
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4 45 have been developed as a function of price, weather, house and household characteristics, as
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7 46 well as other policy restrictions and interventions during the study periods (Kenney et al., 2008,
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10 47 Michelsen et al., 1999; Renwick and Archibald, 1998). Water conservation program planners
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12 48 have also probabilistically described the volume of water saved from conservation actions by
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15 49 enumerating uncertainties associated with costumer demographic, behavioral, and
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17 50 technological parameters that influence water savings (Rosenberg, 2007).
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20 51 Tracking only the flow or usage rates of more efficient appliances doesn't provide a
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22 52 direct way to estimate savings because human behaviors also play an important role—the
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25 53 duration and frequency of appliance use. Additionally, when people know they are using a
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28 54 water-conserving appliance, they may use the appliance longer or more frequently. This
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30 55 increased use may swamp expected water savings (Campbell et al., 2004).
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33 56 Still, the demand forecasting and conservation estimation methods discussed above can
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35 57 be improved in several ways. First, estimates of water saved by structural conservation actions
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38 58 need to be empirically verified. More carefully gathering and storing observations of water use
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41 59 and pairing observations to estimates can help with empirical verification (Walski et al., 1985).
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43 60 Second, household heterogeneity must be more explicitly considered (Whitcomb, 1990;
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46 61 Rosenberg, 2007). Studies typically include a wide variety of explanatory variables (such as
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49 62 income, household size, lot size, age of house, etc.) culled from secondary data sources to
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51 63 characterize household heterogeneity, but use only one aggregate and primary-sourced
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54 64 dependent variable--monthly billed water use (Kenney et al., 2008). Using disaggregated end
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56 65 use data for each water appliance can add more specificity. Third, technological and behavioral
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59 66 factors influencing water savings can be better described, disentangled, and considered as
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4 67 explanatory variables. For example, the duration and frequency each resident in a household
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7 68 uses an appliance may differ. At the same time, the flow, flush, or use rate of an existing
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10 69 appliance can depend on numerous factors including when the appliance was manufactured
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12 70 and whether it has been maintained. Similarly, the flow, flush, or use rate of a retrofitted
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15 71 appliance set by the manufacture may differ from the installed or actual rate. Thus, water use
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17 72 and savings depend on both technological and behavioral factors acting together.

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20 73 Until recently, it has been difficult to separately measure and differentiate technological
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22 74 and behavioral factors. However, this separation is now possible using data logging and
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25 75 disaggregation methods deployed for a national study of nearly 1,200 households (Mayer et. al,
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28 76 1999) and a water appliance retrofit study for 96 households in Oakland, CA, Seattle, WA, and
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30 77 Tampa, FL between 2000 to 2003 (USEPA, 2004). The latter retrofit study data include two
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33 78 weeks before and four weeks after each household was retrofitted with water efficient toilets,
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36 79 faucets, showers, dishwashers, and clothes washers. Prior work describes the disaggregation
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38 80 method (Mayer et. al, 1999), organized the retrofit data, reported summary statistics such as
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41 81 average water saved by each appliance retrofit, and developed regression models to estimate
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43 82 demands using number of residents and house size as independent variables (USEPA, 2004).

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45 83 This case study presents analytical, hybrid, and regression models to estimate the water
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48 84 saved when retrofitting indoor water appliances and describe the prediction precision and
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51 85 efficacy among models. Models are built from and verified against the previously collected,
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54 86 USEPA end-use retrofit study data (2004); model variables include pre-existing and retrofitted
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56 87 flush and flow rates of water appliances, such as toilets, showerheads, faucets and clothes
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59 88 washers. Also, the models use behavioral variables such as the duration and frequency of
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appliance use. In this way, the models identify separate and combined effects of technological and behavioral factors. We also show the distributions of water saved among households and regression models identify characteristics of households with the potential to save the most water from retrofits. Case study results highlight ways U.S. water utilities can target retrofits to households with potential to save the most water.

THE DATA SET

This work uses end-use data previously collected from 96 single-family houses in Seattle, WA, East Bay Municipal Utility District (EBMUD), and Tampa, FL., between 2000 and 2003 before and after each household was retrofitted with water efficient appliances (USEPA, 2004). Water use was recorded by placing data loggers on each participating household's water meter and recording water flow through the meter at 10 seconds intervals. Flow signals were then post processed to determine the duration, water volume, and frequency of household leaks, outdoor, and indoor water uses including toilets, showers, clothes washers, faucets (USEPA, 2004). For details on the methods used to monitor and disaggregate end uses, see Mayer et al. (1999).

The houses selected for the study used more than 227 liters (60 gallons) per capita per day and were representative of households in the three cities. Participating homes averaged 46 years in age. Old homes are less likely to have water-conserving appliances; however participating homes initially showed a wide range of appliance flow and flush rates indicating varied old to newer, water-conserving appliances. Also, additional socio-demographic data was

collected on each participating household, including adults per household, children per household, number of bedrooms, number of bathrooms, floor area, and price paid for water.

Water use data collected before the retrofit constituted the base line water use for each household. Next, water appliances were retrofitted with more efficient ones, i.e., existing toilets were replaced with low flush volume toilets. One month after the retrofit, water use was again recorded for two weeks. Finally, six months after the retrofit, water use was logged for two more weeks to identify behavioral changes and the persistence of water savings from the retrofits.

In general, households reduced the water use after they were retrofitted with the new appliances (Figure 1). The initial analysis found annual water savings averaged 79, 21, 6, and 5 cubic meters per year, respectively, for toilet, clothes washer, showerhead, and faucet retrofits (USEPA, 2004). Yet six homes didn't save any water after retrofits, while other households saved more than 750 cubic meters per year. Overall, 93% of the households saved water, showing that retrofits can be effective. Figure 1 also suggests that utility companies can improve conservation program effectiveness with reduced effort if they can target programs to households on the right tail of the distribution with the most potential to conserve water.

ANALYSIS METHODS

Analytical and regression methods are used to estimate water saved and estimates are compared to the actual water saved by households participating in the USEPA study. The methods used in this research have as an objective to predict the savings observed. Below, we

present methods to calculate actual savings and develop analytical, hybrid, and regression models. Hybrid models embed an analytical equation in the regression model.

Actual Savings

First, actual water savings were calculated by subtracting the volume of water used by each appliance during the pre-retrofit period from the volume used during the post-retrofit period. Household average daily use values are used and then extrapolated to a per year basis.

Analytical Models

Second, an analytical model was developed for each appliance retrofitted. Each analytical model calculates household water savings by simply multiplying the expected change in water volume per use associated with the appliance retrofit by the frequency of appliance use and by the number of people in the household. The expected change in water volume per use is calculated by subtracting the post-retrofit flow rate (liters per use) from the pre-retrofit flow rate. Each analytical model is dimensionally consistent and all parameters can be determined or easily calculated from the monitored and disaggregated appliance end use data. A separate analytical model was developed for each appliance. For example, the analytical model to estimate the water saved by retrofitting a showerhead was:

$$W_{analytical} = j[(g) - (h)]k * 365 \quad (1)$$

Where:

$W_{analytical}$ = water saved by the appliance (in this case by the showerhead) as estimated using the analytical model [liters/household/year].

j = Persons per Household. Permanent residents in the homes at the time the study was done [persons/hh]

g = Average flow rate of appliance pre-retrofit [liters/min]

h = Average flow rate of appliance post-retrofit [liters/min]

k = Average shower time per person per day [min/person/day]

Average flow rates were calculated by dividing the total shower water use logged during the pre- and post-retrofit periods by the total time the shower was used during each period. Average shower time is the total use time over the pre and post retrofits periods divided by the number of residents in the house and the number of days of the pre- or post-retrofit period. For toilets and clothes washers, the pre- and post-retrofit use frequencies were different; hence, the parameter corresponding to k in Eq. 1 could not be factored out of the parenthesis; in those models, use terms were combined with flow rates as part of the difference term. Since some appliances weren't used every day during the study period, the use per day is calculated only taking into account days that the appliance was actually used. Analytical estimates are computed individually for each household using household-specific model parameters.

Hybrid Models

Hybrid (log-log) models were developed for each appliance (Equation 2). These log-log regressions estimate savings using both technological and behavioral variables and are a hybrid between analytical and regression models (see below). They take the log of the analytical model (Eq. 1), then add coefficients to improve the fit between the observed and estimated water savings (Equation 2). In this way, they (i) embed dimensionally consistent and

measurable parameters included in the analytical model, (ii) allow coefficient estimation to improve model fit associated with regression models, and (iii) quantify the relative influence of technological and behavioral factors.

$$\ln(W_{actual}) = a_1 \ln(g - h) + a_2 \ln j + a_3 \ln k + y + z \quad (2)$$

Where:

$\ln(W_{actual})$ = Natural log of actual water saved by the appliance (in this case by the showerhead) [liters/household/year],

α_n = Regression coefficients,

g , h , j , and k are as defined previously,

y = Intercept [liters/hh/year], and

z = Random effects not explained by model variables [liters/hh/year]

The hybrid model excludes households whose water use *increased* after retrofits (negative savings). We dropped these households because it is not possible to take the log of a negative number. Also, use before and after retrofits was statistically different for toilets and clotheswashers, so variables representing both pre and post retrofits frequency of use were included in the hybrid models for these appliances. Despite these limitations, the hybrid model offers an intermediary comparison between fitted regression and not-fitted analytical models.

Regression Models

Third, we also used several regressions models to explain water savings as a function of different independent variables. Regression models use the same variables as the analytical

models, but include coefficients to improve the fit between actual and estimated savings. Coefficients have units that depend on the regression equation, cannot be measured from the end use data for an individual household (like for the analytical models), and can only be determined by regressing a large number of households. Independent variables include the number of persons per household, pre- and post-retrofit volumes per use, and the frequency of use of each appliance. After regressing, examining the coefficient values can help disentangle technological (volume per use), behavioral (frequency of use), demographic (# of people), and economic (water price) factors, and their relative influences on water use and water saved by retrofits.

For example, Equation 3 shows a semi-log regression model.

$$W_{actual} = a_1 \ln j + a_2 \ln g + a_3 \ln h + a_4 \ln k + y + z \quad (3)$$

Where:

W_{actual} = actual water saved by the appliance (in this case by the shower)

[liters/household/year]

a_n = Regression coefficients, and

$j, g, h, k, y,$ and z are as defined previously.

For the regression models developed for shower and other water appliances, the natural log of the independent variables was calculated, and then the regression coefficients were identified using linear least-squares regression.

Additional regressions also used independent variables related to socio-economic characteristics of the households. These socioeconomic characteristics included the price paid

per unit of water, number of full and $\frac{3}{4}$ bathrooms (i.e., bathrooms without a bathtub/shower), location (city), and household size. Initial analyses showed that household location was not significant; these results are not presented but are available upon request. Characteristics were taken from the written survey responses provided by households (USEPA, 2004). These regressions allow us to identify and distinguish high savers from low savers households.

RESULTS

We present model results by appliance. For each hybrid and regression model we developed, we report regression coefficient values and the R^2 showing the fraction of variation in the dependent variable (water saved) that is explained by the model variables. A Kolmogorov-Smirnov test (K-S test) was also used to compare resulting distributions of water saved among households by the analytical, hybrid, and regression models to the actual water saved. The K-S test indicates if the distributions of two datasets differ significantly, and makes no assumption about the distribution shapes or the sample size (Chakravarti et al., 1967). The K-S test gives a D value, D being the maximum difference between the two cumulative density functions tested. We reject the null hypothesis that the two distributions are the same when the associated probability P is less than 0.05.

Toilet Models

Analytical, hybrid, and regression models were tried, with the regression model and model variables explaining more of the variations in actual water saved than the hybrid model

(Table 1). In the hybrid and regression toilet models, both the technological and behavioral variables (i.e., flush volumes and frequencies of use) are significant, have the expected signs, and large influences as indicated by coefficient and elasticity values (Table 2, first 6 rows). On average, technological and behavioral factors have a greater effect on the water saved by retrofitting the toilet than does the demographic factor (number of residents). In Table 2, elasticity values indicate the percentage change in water use associated with a 1% change in the variable value, are unitless, and allow more ready comparisons of model variable effects among variables and across models. Elasticity and coefficient value results are the same for the Hybrid model because the model uses a log-log equation form.

Figure 2 is a normal probability plot and shows observed and modeled distributions of water savings among households when retrofitting toilets. It shows the distributions are not normally distributed, but that the analytical, hybrid, and regression models explain distributions of savings among households similar to observed savings. These observations are confirmed by K-S tests ($P \geq 0.05$ for all models; Table 3). The analytical and regression models have the smallest D values and their predicted distributions are statistically most similar to the observed distributions of savings. The regression and K-S test results show that the analytical and regression models can effectively estimate residential savings when retrofitting toilets.

Shower Models

Table 2 (rows 7 to 10) shows the results for the hybrid and regression models developed to estimate water saved by retrofitting showerheads. In these models, a single average shower

length per person per day was used rather than separate pre- and post- retrofit shower times, since these times were not significantly different ($t\text{-stat} = -0.59$, $P = 0.55$). Regression results show the appliance flow rates and number of permanent resident variables are significant.

Coefficient and elasticity values show what is expected: post retrofit showerhead flow rate variable reduces water use, and increases savings. Technological variables are significant at the 95% level for both regression models, while the behavioral component is only significant at the 95% level in the hybrid model. According to the elasticity values shown in Table 2, technological factors have larger effects on savings than demographic or behavioral factors. For the regression model, the behavioral shower length variable is only significant at the 52% level.

Regression model variables explain 27% of the variation in water saved by retrofitting showerheads (Table 1) and suggest there are many other (unobserved) variables which may also explain water savings. When the K-S test was applied to the regression model, a D value of 16% was obtained, but only significant at the 17% level. Results of the K-S test gave the analytical model a D value of 13% significant at the 40% level (Table 3). These results show that the distributions of savings estimated by the analytical and regression models are statistically similar to the observed distribution of savings (Figure 3). In contrast, the hybrid model has a larger D value and significance less than 5% which indicate this model is statistically different than the observed distribution of savings.

Clothes Washer Models

For the hybrid and regression models of water saved by retrofitting clothes washers, technological and behavioral variables are significant at the 95% level (Table 2). In both models all variables have the expected signs. The variables with the largest coefficient values are the Average Pre-Retrofit Load Volume and the Loads Pre-Retrofit [#/person/day]. Again, both technological and behavioral factors affect water savings.

K-S tests indicate the three modeled distributions of savings are statistically similar to the observed savings (Table 3; $P > 0.05$). The regression model distribution has the lowest D value and highest significance and is the most similar to the observed distribution of savings.

Regression and K-S test results show that the analytical and regression models fit well, while the hybrid model overestimates savings. Estimating water savings by clothes washers can be done in precise way using analytical and regression models, and provides an efficient way to estimate water savings by households based on technological and behavioral characteristics.

Faucet Models

The analytical model of faucet savings was similar to the one used for the analytical shower model. The faucet model also used average use time since there wasn't a significant difference between pre and post retrofit use time.

The hybrid and regression models have as independent variables the average flow rates pre- and post- retrofits, the number of residents, and the average length of use per person per day. Regression model variables can explain 70% of the variations in water savings (Table 1). Coefficients associated with each variable all have the expected sign and are significant. The

average pre and post retrofit flow rate have the largest coefficient values and most influence faucet water savings (Table 2). The hybrid model also has a similar R^2 , although this model only estimates positive savings due to the log-log formulation. These results suggest that technological and behavioral factors influence water savings, but that technological factors – the flow rates before and after faucet retrofits – are more important.

Three houses located on the right tail of the observed distribution of water saved by retrofits had a high faucet use time before the retrofit compared to the time after (a difference of more than 200 min/hh/day). This change suggests a significant behavioral change in those households. However, it is also possible that these households had uncommon uses prior to retrofits, or that malfunctioning faucets in these houses were logged as faucet use rather than leaks.

K-S test results show that the distributions of savings among households predicted by the hybrid and regression faucet models are similar (Table 3). However, the distribution predicted by the analytical model is likely different than the observed distribution. Water savings by faucet retrofits can be effectively estimated using hybrid and regression models.

TAIL ANALYSIS

One of the purposes of this study is to identify households with the potential to save more water. These houses are located in the right tails of the water savings distributions shown in Figures 1 through 3. Here we use survey and end-use data collected about and at the houses to identify characteristics of households that will likely save the most water from retrofits.

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4 325 To do this, we ranked households by water volume saved by retrofitting each appliance,
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7 326 then separated the largest savers (top 20 households) for each appliance from the rest. We
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10 327 chose this breakpoint to allow sufficient degrees of freedom to run regressions for each group.
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12 328 This segregation also means a certain household could be in the high savings group for one
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15 329 appliance, but not for other appliances. For each appliance, separate linear regressions were
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17 330 made for the groups of largest and smaller savers. For each group, water savings was regressed
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20 331 against the independent variables (water price, number of residents, number of full and three-
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22 332 quarter bathrooms, flow rate, and frequency of use).

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25 333 For each appliance, households that saved the most water by retrofitting the appliance
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28 334 had more residents than households that saved less water (Table 4). On average, large savers
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30 335 had approximately one more person per household than small savers. Similarly, households
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33 336 that saved the most water from retrofits had, prior to retrofits, appliances that delivered larger
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35 337 volumes per use and were less water efficient. This difference was significant for the toilet,
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38 338 shower, and faucet models ($P < 0.05$). Another factor that differentiated high savers from low
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41 339 savers across most appliances was behavior. High savers tended to use appliances more
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43 340 frequently than low savers with this difference significant for the toilet and faucet models.

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45 341 Interestingly, results also show that both high and lower savers used laundry machines
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48 342 with about the same frequency. Both groups also typically had the same number of bathrooms;
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51 343 as such, these two factors are not particularly helpful to differentiate users in the two groups.

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53 344 Although not statistically significant, the largest savers generally faced lower water
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56 345 prices than smaller savers. This finding runs counter to microeconomic theory that suggests
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59 346 higher water prices should encourage larger reductions in water use. However, in this study,

the participating cities paid for and installed all water efficient appliances for households. Thus, the counterintuitive result may occur because larger savers had a lower financial incentive prior to the study to invest in water conservation measures and possibly used more water then (price was also constant through the study period). Together, the tails analysis suggests that a large family size combined with a water efficient appliance and high frequency of use result in large water savings from retrofits.

DISCUSSION

We have developed analytical, regression, and hybrid models to estimate water savings by retrofitting toilets, showerheads, clothes washers, and faucets. K-S test results show the three types of models all reasonably predict distributions of water saved except for the hybrid model for shower retrofits and the analytical model for faucet retrofits. Regression results indicate regression and hybrid models for toilet and clothes washer retrofits explain more of the variations in water saved than models for shower and faucet retrofits. This result is expected because toilets and clothes washers have a fixed water volume per use whereas users can regulate shower and faucet flow rates during each use. Additionally, regression models for toilets and clothes washers explained more of the variations in water savings than the hybrid models. In these instances, behavior varied before and after retrofits and it was not possible to separate the behavior component in the hybrid models. For shower and faucet models where the behavioral variable was separated, hybrid models explained as much or more of the variation in water savings as regression models (Table 1). These comparisons emphasize the

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4 369 importance to include behavioral factors in models to estimate water savings by retrofits. They
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7 370 also suggest that a simple analytical approach to estimate savings may suffice when data is
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12 372 More elaborate regression and hybrid models are warranted when it is important to
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15 373 show the separate and combined effects of technological and behavioral factors on water use
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17 374 and water savings (Table 2). Elasticity values shown in Table 2 provide a way to normalize and
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20 375 compare the relative effects of technological and behavioral factors on water savings. In all
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22 376 models, technological and behavioral factors are important and significant (Table 2). In several
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25 377 models such as for showers and faucets, the technology component contributes more to overall
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27 378 water savings than the behavioral component as represented by larger elasticity values in the
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30 379 regression results. This effect is magnified for appliances where behavior didn't change pre and
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33 380 post retrofits. In a few cases, households increased their water use after the retrofits, as a
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35 381 consequence of behavioral changes that offset technological improvements. For appliances
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38 382 such as toilets and washing machines where household use behavior changed pre- and post-
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41 383 retrofit, it was not possible to differentiate in the hybrid models effects of technology and
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43 384 behavioral factors. Instead, an average change in water use variable was introduced that
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46 385 aggregated behavioral and technological factors prior to regression. Otherwise, both the
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48 386 regression and hybrid models use the same natural log of the independent variables and the
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51 387 main difference is that the hybrid model regresses against the natural log of the dependent
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53 388 variable (water saved) whereas the regression model regresses against the actual value.

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When comparing characteristics of households that saved the most water by retrofits to households that saved less water, in general, high-saving households had more residents than households that saved less water. Also, prior to retrofitting, these households had less efficient appliances and used appliances more frequently than households that saved less water by retrofits. Utility companies can use these findings to identify and target household with high potential to save water. To target, utilities should seek houses with the larger number of residents and with the least efficient appliances. Utilities can determine high occupancy from household surveys or census records. Utilities could also use property parcel or permitting records as an indicator of the age (and likely flow rates) of appliances inside a house. Study results also show that houses with a higher frequency of use save more water, but this household behavior may be difficult for a utility to identify and target in campaigns to motivate behavioral change. Utilities cannot install data loggers in the houses of all their customers. In efforts to identify households with potential to save the most water, water utilities can and sometimes do rely on large billed water use as a proxy for behavior; however, demographic and technologic factors such as household size and appliance flow rates can confound this practice. Our finding and current practices identify the need for further research to identify household behavioral indicators that utilities can readily measure and reliably act upon to target households with large potential to save water from retrofits.

It is important to point out that the models use as a variable the number of permanent residents and do not account for visitors during the study period. Unobserved visitors could alter the frequencies with which appliances are used. Also, the data collected by the loggers was aggregated by appliance type, which means technological and behavioral variable values

for each appliance type were results of averaging across all appliances of the same type in a house. Further, the analysis excluded the leakage volume saved by retrofitting leaky appliances since intermittent leaks from faucet drips, unsealed toilet flappers, and other sources prior to retrofit were disaggregated separately apart from appliance water use. In the disaggregation, these leaks are easily identified by their very low flow rates (too low to be faucets), association with other events that might initiate a leak, or duration different than faucet use (Mayer et. al, 1999). This exclusion means actual water savings from retrofits are larger than reported savings; it also identifies a further need for improved leak prediction and modeling capabilities. Finally, for hybrid models, we dropped some households from the analysis because it was not possible to calculate the log of water savings for households that *increased* use after retrofits and had negative savings. Thus, sample sizes were different among the analytical, hybrid, and regression models.

CONCLUSSIONS AND RECOMMENDATIONS

We developed analytical, hybrid, and regression models to estimate water savings using detailed, disaggregated water end-use data collected before and after retrofitting toilets, showers, faucets, and clothes washers in 100 households in Oakland, California Seattle, Washington, and Tampa, Florida. Water savings result from a combination of the technology installed in the households and the use of appliances. Our models use technological and behavioral variables and represent an improvement on prior models that rely on only demographic and household characteristics.

Results show analytical, hybrid, and regression models can all reasonably characterize distributions among households of water saved by retrofits. Use analytical models to estimate water savings in a simple, dimensionally consistent way when data already exists to describe the technological and behavioral factors that influence savings. Alternatively, use regression and hybrid models when there is a need to (i) estimate indoor residential water savings based on technological and behavioral components, and (ii) separate out the effects of each component. For all the appliances, technological and behavioral variables such as flow rates, durations, and use frequency are significant with technological variables having a larger effect on water saved for appliances such as showers and faucets where the user regulates the appliance flow rate during each use event.

Houses that saved more water from retrofits tended to have more residents than those who saved little or no water. They also had less efficient appliances prior to retrofits, used appliances more frequently, and experienced lower water prices than lower savers. U.S. water utilities can use these case study findings in conjunction with census data, customer surveys, and property parcel and permitting records to identify customers with high potential to conserve water indoors.

U.S. water utilities can use these case study results and findings to target customers with more residents, less efficient appliances, and high use frequency to replace old appliances for newer and more efficient ones to conserve water. With targeting, utility water conservation programs can save more water with less effort. The case study results also help improve engineering methods to estimate water savings from retrofits.

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Table 1. Models sample size and fit.

Appliance	Hybrid Model		Regression Model	
	N	R ²	N	R ²
Toilet	85	0.64	96	0.88
Shower	58	0.36	94	0.27
Clotheswasher	85	0.79	95	0.91
Faucet	83	0.73	96	0.70

Table 2. Summary of technological regression models for water saved when retrofitting toilets, showers, clotheswashers, and faucets.

Appliance	Variable	Hybrid			Regression		
		Coefficient	Elasticity	t-stat	Coefficient	Elasticity	t-stat
Toilet	a - Average Pre-Retrofit Flush Volume [l/flush]	-	-	-	18,826.49	2.00	21.25**
	b - Average Post-Retrofit Flush Volume [l/flush]	-	-	-	-8,180.29	-0.87	-4.96**
	c - Average Change in Water Use [l/person/day] ¹	1.78	1.78	11.41**	-	-	-
	d - Persons Per Household [# of permanent residents]	1.01	1.01	6.08**	7,263.36	0.77	8.18**
	e - Average Flushes-Pre-Retrofit [#person/day]	-	-	-	17,431.67	1.85	16.67**
	f - Average Flushes-Post-Retrofit [#person/day]	-	-	-	-8,370.90	-0.89	-7.68**
Shower	g - Average Pre-Retrofit Flow Rate [l/min]	-	-	-	7,119.39	4.17	4.47**
	h - Average Post-Retrofit Flow Rate [l/min]	-	-	-	-5,381.74	-3.15	-2.05**
	i - Average Change in Flow Rate [l/min] ²	1.88	1.88	4.19**	-	-	-
	j - Persons Per Household [# of permanent residents]	0.82	0.82	3.13**	3,435.85	2.01	3.17**
	k - Average Shower Length [minutes/person/day]	0.48	0.48	2.56**	530.44	0.31	0.70
Clotheswasher	l - Average Pre-Retrofit Load Volume [l/load]	-	-	-	25,646.17	2.41	23.92**
	m - Average Post-Retrofit Flush Volume [l/load]	-	-	-	19,462.56	-1.83	-10.44**
	n - Average Change in Water Use [l/person/day] ³	1.32	1.32	13.93**	-	-	-
	o - Persons Per Household	0.84	0.84	4.81**	10,600.49	1.00	7.84**
	p - Loads- Pre-Retrofit [#person/day]	-	-	-	29,912.17	2.81	23.85**
	q - Loads-Post-Retrofit [#person/day]	-	-	-	-19,385.20	-1.82	-13.12**
Faucet	r - Average Pre-Retrofit Flow Rate [l/min]	-	-	-	11,824.38	3.98	8.40**
	s - Average Post-Retrofit Flow Rate [l/min]	-	-	-	-9,084.77	-3.08	-7.40**
	t - Average Change in Flow Rate [l/min] ⁴	3.14	3.14	10.64**	-	-	-
	u - Persons Per Household [# of permanent residents]	0.76	0.76	4.56**	4,806.63	1.62	6.23**
	v - Average Use [minutes/person/day]	0.99	0.99	7.43**	5,461.62	1.84	8.87**

** Significant at the 95% level.
- Indicates variables not used in the model.
¹ c = (a * e - b * f)
² i = (g - h)
³ n = (l * p - m * q)
⁴ t = (r - s)

Table 3. K-S test results. K-S stat (D) and (significance [P]).

Appliance	Analytical	Hybrid	Regression
Toilet	0.167 (0.130)	0.186 (0.080)	0.167 (0.130)
Shower	0.128 (0.403)	0.472 (0.003)	0.160 (0.166)
Clotheswasher	0.105 (0.644)	0.190 (0.070)	0.084 (0.875)
Faucet	0.250 (0.004)	0.188 (0.077)	0.156 (0.175)

Table 4. Comparing average characteristics of households that save the most water to households that save less water.

Appliance	Largest Savers (n=20)					Smaller Savers (n=76)				
	Water Price [USD\$/m3]	Residents [persons/hh]	# Full Baths + 3/4 Baths	Volume per Use ^a	Frequency of Use ^b	Water Price [USD\$/kgal]	Residents [persons/hh]	# Full Baths + 3/4 Baths	Volume per Use ^a	Frequency of Use ^b
Toilet	1.93	3.4	2.0	22.3**	7.0**	1.88*	2.53**	1.9	13.2**	4.5**
Shower	1.62**	3.7**	2**	9.8**	6.9**	2.0	2.5	1.9	7.6**	4.8
ClothesWasher	1.73	3.2	1.8	166.8	1.9	1.9	2.6**	2.0	135.7	1.9**
Faucet	1.56	3.4	2.2	5.5**	34.4**	1.98*	2.5**	1.9	3.8**	8.6**

** Significant at the 95% level.

* Significant at the 90% level.

a. liters per flush, liters per minute, liters per wash, and liters per minute, respectively, for toilets, showers, laundry machines, and faucets.

b. flushes/person/day, minutes/person/day, washes/household/day, and minutes/person/day, respectively, for toilets, showers, laundry machines, and faucets.

Figure 1
[Click here to download Figure: Fig 1.pdf](#)

Figure 2
[Click here to download Figure: Fig 2.pdf](#)

Figure 3
[Click here to download Figure: Fig 3.pdf](#)

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Figure 1. Distribution among household of water saved by retrofitting toilets, showers, faucets, and clothes washers.

Figure 2. Cumulative distribution among households of water saved by retrofitting toilets.

Figure 3. Cumulative distribution among households of water saved by retrofitting showerheads.

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Manuscript/Chapter Title: Estimating and Verifying United States Household's Potential To Conserve Water

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B. Then count the number of text lines (include footnote & titles)

1-column table = up to 60 characters wide by: 17 lines (or less) = 158 word equiv. up to 34 lines = 315 word equiv. up to 51 lines = 473 word equiv. up to 68 text lines = 630 word equiv.	2-column table = 61 to 120 characters wide by: 17 lines (or less) = 315 word equiv. up to 34 lines = 630 word equiv. up to 51 lines = 945 word equiv. up to 68 text lines = 1260 word equiv.
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Figure type size can't be smaller than 6 point (2mm).

B. Use ruler and measure figure to fit 1 or 2 column wide format.

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1-column fig. = up to 3.5 in.(88.9mm) wide by: up to 2.5 in.(63.5mm) high = 158 word equiv. up to 5 in.(127mm) high = 315 word equiv. up to 7 in.(177.8mm) high = 473 word equiv. up to 9 in.(228.6mm) high = 630 word equiv.	2-column fig. = 3.5 to 7 in.(88.9 to 177.8 mm) wide by: up to 2.5 in.(63.5mm) high = 315 word equiv. up to 5 in.(127mm) high = 630 word equiv. up to 7 in.(177.8mm) high = 945 word equiv. up to 9 in.(228.6mm) high = 1260 word equiv.
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Total Tables/Figures:	1735
Total Words of Text:	6246

(word equivalents)

Total words and word equivalents:	7981
printed pages:	7

Estimating Length of Text			
Count # of words in 3 lines of text:		36	
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# of words per page		264.00	
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Title & Abstract		500	
Total # refs	13	315	
Length of Text is		5831	subtotal
		415	plus headings
		6246	TOTAL words
		5	printed pages

Estimating Length of Tables & Figures:			
Tables	Word Equivalents	Figures	Word Equivalents
Table 1	158	Figure 1	158
2	630	2	158
3	158	3	158
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June 21, 2011

SUBJECT: Re-submission of Manuscript #WRENG-575 to Journal of *Water Resources Planning and Management*

Emily Sirotta
Editorial Coordinator

JWRPM

Dear Ms. Sirotta:

Please find attached an electronic copy of manuscript #WRENG-575 titled “Estimating and Verifying United States Households’ Potential to Conserve Water” by Francisco J. Suero, Peter W. Mayer, and David E. Rosenberg. I am resubmitting the manuscript for publication as a Case Study in the *Journal Water Resources Planning and Management*.

A summary of changes with responses to the reviewers’ comments is attached to this letter. Should you need to contact me, please use the above e-mail address, or phone number.

Sincerely,

Francisco J. Suero (the corresponding author)

Attachments

- Summary of changes/Responses to Reviewers Comments
- Manuscript

Summary of Changes and Responses to Reviewers' Comments on WRENG-575

(Estimating and Verifying United States Households' Potential to Conserve Water)

Summary of Changes:

We appreciate the time the reviewers and associate editor have taken to provide a second round of extremely helpful feedback to improve the writing and the paper's contribution to estimate households' potential to conserve water. We have revised with the following principal changes made largely in response to the reviewer comments:

1. Changed all Imperial units to SI units,
2. Changed the cumulative probability plots to normal probability plots,
3. Edited tables and equations to make them consistent throughout the manuscript,
4. Clarified concepts of the statistical tests used,
5. Edited the manuscript to make it more clear and consistent.

Below, responses to individual comments further elaborate on the above general points. The original comment is presented in **black** and our response in **red**.

Reviewer #1

1. As to use of SI units versus imperial units: the ASCE guidelines state "All ASCE publications use SI units in text, figures, and tables. Customary (also known as English or imperial) units may be included in parentheses, if the author chooses."

We have changed all Imperial units to SI units.

2. the paper is based on the statistical analysis and comparison of the different methods. It is unsatisfactory that there are no qualitative statements on when an R^2 , K-S stat or t-stat are considered to be satisfactory (e.g. $R^2 > 0.7$, K-S Stat $< xx$, t-stat $< yy$). This means that one model may do better than the other, but if it does well (or good enough) is still unclear. In the text, statements like "likely similar" do not provide clarification. Also, statements like "very" or "much more" are not very scientifically.

We have removed words like satisfactory and instead base statistically similar on a P value < 0.05 (or > 0.95).

3. I find it confusing that the parameters as used in equation (1) have the same names (a, b, c, d) as parameters in Table 2, but have different meanings. It seems that a (Eq 1) equals j (Table 2), b=g, c=k, d= h. The same can be said for Eq (2)-(3).

Yes. The equations now all use consistent notation which is also consistent with the notation in Table 2.

4. In 242 "D value is large ..." what is large (see comment #2)? In Table 3 this is called K-S Stat (not D value).

We have edited to clarify that we reject the null hypothesis when the K-S statistic, D, is greater than 0.4 and the associated probability P is < 0.05 . In table 3, we now write: "K-S Stat (D)".

5. In 262 "... model can effectively estimate ..." Is this true? P-value > 0.05 .

Please see the first paragraph of the Results section. Since $P > 0.05$, we accepted the null hypothesis that the two distributions are similar.

6. In 272 and 273. change "significant" to "statistically significant".

Changed.

7. In 279-280. Values from the table were rounded in the text, but not correctly.

We have corrected the values reported in the text (now on lines 273-274).

8. with the shower models, the hybrid model was not discussed. With a statistical significance (small P) it can be concluded that it does not suffice (large K-S stat).

Thank you for pointing this fact out. We have added a sentence on lines 276-278 which discusses this result.

9. Mind that figure 3 is not discussed in the text.

Thank you for the observation. It is now discussed in the showerhead results section.

10. In 292 "likely the most similar" (see also comment #2), $P = 0.875$. Statistically very much not significant.

We have reworded this sentence to read "The regression model distribution has the lowest D value and highest significance and is the most similar to the observed distribution of savings." The sentence now appears on lines 287-288.

11. Ln 293 "fit very well". I would remove "very".

Thank you, done.

12. In 344. How can the reader conclude this from table 4? From table 4 I would conclude the same for the shower.

Yes, this observation is correct and is already noted twice in the text. The paragraph starts "Across appliances..." (line 339) meaning the results subsequently discussed apply to all the appliances including the shower. Later we note that the differences are statistically similar for

toilet, shower, and faucet retrofits. To clarify, we have revised the opening of the paragraph to read “For each appliance, ...”.

13. In 364 “explain much more” I would remove “much”

“Much” has been removed.

14. In 365 “the result is likely”. Do you mean “the result is as expected”?

Yes, and we have clarified this by writing “expected” instead of “likely”.

15. In 391 “the main difference” this suggests that you think that the models are very similar. This is not the case. The hybrid model is not a linear model; all the parameters are multiplied (see what happens if the left and right side of the equation are raised to the power of “e”).

Yes, the observation of non-linearity naturally follows from the hybrid model equation. However, raising both models to the power of “e” shows that both models are also non-linear (and thus similar).

Hybrid model:

$$\ln(W_{actual}) = \alpha_1 \ln(g - h) + \alpha_2 \ln j + \alpha_3 \ln k + y + z$$

$$e^{\ln(W_{actual})} = e^{\alpha_1 \ln(g-h) + \alpha_2 \ln j + \alpha_3 \ln k + y + z}$$

$$W_{actual} = c \cdot (g - h)^{\alpha_1} \cdot (j)^{\alpha_2} \cdot (k)^{\alpha_3}$$

Regression Model

$$W_{actual} = a_1 \ln j + a_2 \ln g + a_3 \ln h + a_4 \ln k + y + z$$

$$e^{W_{actual}} = e^{a_1 \ln j + a_2 \ln g + a_3 \ln h + a_4 \ln k + y + z}$$

$$e^{W_{actual}} = c \cdot (j)^{a_1} \cdot (g)^{a_2} \cdot (h)^{a_3} \cdot (k)^{a_4}$$

This similarity stems from a structural similarity we have already noted in the text—namely, that both models take the natural log of the independent variables. Therefore, we have left the text unchanged.

16. In 407. How can utilities know which households have high frequency of use, how can they target these households? Is there also a significant relation between total water use and saving potential? This would be easier for a water company to establish. This may include both large households and high frequency of use into one parameter.

Yes, utilities sometimes use overall water use as an indicator of behavior, but reliance solely on water use is confounded by demographic and behavioral factors. We have added a sentence in the discussion which notes this point. “Water utilities can and sometimes do rely on large billed water use as a proxy for behavior in efforts to identify households with potential to save the most water; however, demographic and technologic factors such as household size and appliance flow rates can confound this practice.” As shown in the figure below, yes, in some cases, high users also save the most water. However, we also see several high users that save little water. More generally and for each appliance, there is wide vertical spread (water saved) among households that use the same water volume pre-retrofit – which suggest other factors (apart from water use) affect water savings. Again, as we already noted in the text, we feel this limitation really motivates further research in this area.

17. In 446-447: which model do you recommend?

We thought our recommendation was clear in the proceeding sentences where we outlined the conditions under which it was appropriate to use each model. We have reworded these sentences in active voice to make our recommendation more clear (lines 422-427).

18. table 2, ln 11. Why are coefficient and elasticity for the hybrid model different?

Thank you for the observation. That was a typo, which is now fixed.

19. in tables 1-3 the hybrid model is mentioned before the regression model. In the text it is the other way around. Consistency prevents mistakes in reading the tables.

Thank you, we have corrected this in the text.

20. table 4. I would like to see more information on units in the table or the caption. The frequency of use for a shower may be in minutes (I don't think that a household of on average 3.7 people would take 6.9 showers per day). Toilet flushes 7 per day is most likely per person per day. Water price in \$ per m3? Please clarify.

We have added units and footnotes to Table 4 to clarify the units used for each appliance. Thanks.

21. fig 2 and 3. As stated before, please use a normal probability plot. With this I mean that the y-axis is not linear as it is now, but is set to the normal probability. This will most likely lead to less curved lines and will provide more insight in the differences at the tails.

We have changed the cumulative probability plots to normal probability plots. The traces are still curved and indicate the distributions are not normal. We have added this observation in the text.

Reviewer #3:

1) on line 280, the authors claim that the "results show that the distribution of savings estimated are statistically similar to the observed distribution" - I am not sure how they can make that argument, especially for the shower model.

Please keep in mind, a low D-value and high significance level indicate the distributions are statistically similar. The sentence referenced only the similarity between the analytical and regression models. Yes, the hybrid shower model is likely different. We have added a sentence to clarify. See also our response to Reviewer #2, comment #8.

2) The shower models shows terrible R2 values (i.e. 0.36 and 0.27) and yet the authors seem to ignore this issues and still continue to present results associated with these models as significant.

The overall fit may be poor (for a variety of reasons discussed later in the manuscript), but several of the variables in the model are significant (i.e., the coefficients differ from zero and thus explain part of the water savings). The low R2 just means there are other unobserved variables (not included in the model) that also explain water savings. We have added this note on lines 270-271.

3) Line 319 "distributed" should be distribution

Fixed. Thanks.

4) The authors acknowledge in line 314 that "The change....could be due to "malfunctioning faucets in these houses were loggest as faucet use rather than faucet leaks" I think the same arugment can likely be made with regard to the toilets. The authors provide no plots of actual time series or even discuss such an evaluation as a basis for excluding such a possibility. Without some measure of certainty with regard to the issues, the resulting models for these uses seem to be highly questionable, and thus it seems that the resulting models and conclusions that are drawn from such results are highly suspect. Yet the authors confidently conclude: "High savers tended to use appliances more frequently than low savers with this difference significant for the toilet and facuet models." I do not believe the authors have provided sufficient data from which to draw such a conclusion and thus I cannot justify approving a paper that may mislead the reader by providing what I consider to be highly suspect results. For example, the authors conclude that this "Study results also show that houses with a higher frequency of use save more water" - it is quite possible that if these houses were subject to leaky faucets and toilets, then what is being perceived by a high frequency is nothing more than evidence of leaks.

As noted in the Data Set section (line 101), leaks were recorded and disaggregated separately in the database (USEPA, 2004). The average leakage rate decreased from 33.6 gpd before retrofits to 11.2 gpd after retrofits, a reduction of 67%. The median leak rate also dropped to 4.6 gpd--which shows that the leakage rates are still heavily skewed to the right (USEPA, 2004). As the reviewer suggests, this reduction in leakage is likely because of the new and more efficient appliances; appliances tend to malfunction as they get older. Generally, the observed data and model estimates excluded these leaks since leaks were disaggregated separately and we did not use the leak data in the case study analysis.

This separation is possible because the Flow Trace Wizards can identify two kinds of leaks. The first type is intermittent leaks, such as toilet flappers or faucet drips and the second is continuous leaks due to broken valves or leaky pipes. Intermittent leaks are

identified by their very low flow rates (too low to be faucets), association with other events that might initiate a leak, or the fact that they simply do not appear to be faucet use, and because they occur too frequently to be explained by someone standing at a sink and operating a faucet for a long duration. Intermittent leaks are very common, and most traces contain a number of these types of leaks. The lower limit of “leak” detection is based on the ability of the water meter to register the flow. To the extent that the meters cannot register very low flows, leakage measurements would be under-estimated. Obviously, there can be a blurred line, for example, with faucets and toilets, between the use event (when the faucet is turned towards off or the toilet flush ends) and the leak begins (dripping faucet or leak through the toilet flapper). This is the uncertainty we meant in the original text to which the reviewer referred.

Constant leaks, on the other hand, are continuous events. In some cases these may not be leaks at all, but instead represent a device that has a constant water demand, such as a reverse osmosis system or a once-through cooler. The presumption, though, is that these are leaks. Use of survey information can be used in conjunction with the end use data to look for correlations between leakage and fixtures in the home to see if there might be a relationship that helps clarify the source of the “leak” and leak-like events. Generally, though, appliance retrofits, which are the focus of this case study, would not affect the continuous leakage; thus we observe that the post-retrofit leak rate is 11.2 gpd and still positive.

In the discussion section (lines 411-415), we now explain that our analysis excludes leak volumes saved by fixing leaky appliances. We also summarize how we are able to separate out these leaked volumes.

- 5) The authors did not examine the possible geographical impacts on the data. What statistical analysis is provided to insure that the demand patterns in Oakland or Seattle or Tampa are similar or dissimilar. It would seem that such an analysis would be required to eliminate this possible variables from impacting the analysis.

We found that the location (city) was not a significant explanatory variable of water savings. Please see last paragraph of the methods section for a sentence that clarifies this finding.

- 6) One of the stated objectives of the paper is to provide a basis for utilities to reduce cost, yet no general \$ amounts are hypothesized or projected. Just how much money could a utility be expected to save?

Actually, the objective as stated at the end of the introduction is to identify ways U.S. water utilities can target retrofits to households with potential to save the most water (lines 91-92). Cost is not mentioned until the second to last sentence of the conclusions. Cost savings for utilities are well documented in USEPA (2004) which we quote here below. To further avoid confusion, we have removed the words “and lower costs” from line 443 in the manuscript.

The Utility Perspective

The water that is saved as a result of residential retrofits has a value to the water utility in the form of the capital cost of developing new firm yield supply. This is a major amount of money and is frequently overlooked in conservation planning. The value needs to be based on firm yield (available in dry years) rather than the cost of water on the spot market when available. Water developed in this way can be used for supplying new growth, as a drought reserve, or for environmental enhancement.

In parts of the country with limited supplies, the capital cost to develop new firm yield

can easily exceed \$10,000/acre foot. A savings of 30 kgal per existing customer amounts to 0.092 af/customer, which, at \$10,000/af, would have a capital value of \$920/af. If the utility provided this money to the customers this would reduce the total gross cost of the retrofits to \$664 and the pay-back period down to 2.4 years. So homes in which the existing fixtures and appliances had a full economic life in front of them could be replaced with a payback period to the customer down at the incremental cost range. The capital value of the saved water would accrue to the utility as a one time amount in the year that the retrofit project was performed. So, a utility with an active retrofit program with savings and costs as described above would realize a capital value of \$920,000 per year in water supply.

7) In looking at the distribution of water saved for retrofitting showerheads, (Figure 3) it would seem that the observed distribution is likely normally distributed. It is likely there are existing probability function or transformation function (e.g. sigmoid function) that could provide a better fit to the data than the models examined by the authors. This slide also raises another interesting question that seems to be ignored by the authors - it appears that the net savings from showerheads (i.e. integration of the function), seems to be almost zero. It would seem that this is fairly significant and should be discussed.

*We believe the Normal probability plots requested by Reviewer #2 also address this comment. However, note that the distributions of water savings are *not* normally distributed. With regard to the second comment, the average observed savings from retrofitting appliances (which represents the integration the reviewer mentions) are already reported on line 119. On average, retrofitting showerheads saved 1,600 gallons/hh/year. This amount was smaller than toilets and clotheswashers, but larger than faucets and certainly greater than zero.*

8) Finally, I do not believe the authors have made their case and as a result the paper is fundamentally flawed:

1) the conclusions drawn from the data seem highly suspect

We believe revisions in response to the comments above now clarify how conclusions are drawn from the data and responses.

2) the authors continue to ignore several important observations

We believe revisions in response to the comments above now consider these observations.

3) without a detailed cost analysis it is really impossible to know whether the cost savings for a water utility warrant the cost of the extra upgrades

Again, please see our response to comment #6 above.

4) by the authors own admission, it is likely to be difficult for most utilities to actually take advantage of the results of the study and then implement them in a way that would provide a reasonable savings.

Here, a clarification is needed. We noted that utilities can make use of two of the three key findings – at present, they are not yet able to make use of the finding related to the

frequency of appliance use. Utilities can directly make use of our other findings regarding household size and appliance flow rates. The current inability of utilities to make use of appliance frequency of use highlights a need for further research in this area which we identify in both the Discussion and Conclusions.

As a result, I do not believe the paper in its current form provides any significant contribution to this area, and thus I would recommend that the paper not be accepted for publishing