WaterSense Program

Methodology for National Water Savings Analysis Model Indoor Residential Water Use

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1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) influences the market for plumbing fixtures and fittings by encouraging consumers to purchase products that carry the WaterSense label, which certifies those products as performing at low flow rates compared to unlabeled fixtures and fittings. As consumers decide to purchase water-efficient products, water consumption will decline nationwide. Decreased water consumption should prolong the operating life of water and wastewater treatment facilities.

This report describes the method used to calculate national water savings attributable to EPA's WaterSense program. A Microsoft Excel spreadsheet model, the National Water Savings (NWS) analysis model, accompanies this methodology report. Version 1.0 of the NWS model evaluates indoor residential water consumption. Two additional documents, a Users' Guide to the spreadsheet model and an Impacts Report, accompany the NWS model and this methodology document. Altogether, these four documents represent Phase One of this project. The Users' Guide leads policy makers through the spreadsheet options available for projecting the water savings that result from various policy scenarios. The Impacts Report shows national water savings that will result from differing degrees of market saturation of high-efficiency water-using products.

This detailed methodology report describes the NWS analysis model, which examines the effects of WaterSense by tracking the shipments of products that WaterSense has designated as water-efficient. The model estimates market penetration of products that carry the WaterSense label. Market penetration is calculated for both existing and new construction. The NWS model estimates savings based on an accounting analysis of water-using products and of building stock. Estimates of future national water savings will help policy makers further direct the focus of WaterSense and calculate stakeholder impacts from the program.

Calculating the total gallons of water the WaterSense program saves nationwide involves integrating two components, or modules, of the NWS model. Module 1 calculates the baseline national water consumption of typical fixtures, fittings, and appliances prior to the program (as described in Section 2.0 of this report). Module 2 develops trends in efficiency for water-using products both in the business-as-usual case and as a result of the program (Section 3.0). The NWS model combines the two modules to calculate total gallons saved by the WaterSense program (Section 4.0). Figure 1 illustrates the modules and the process involved in modeling for the NWS model analysis.

The output of the NWS model provides the base case for each end use, as well as a prediction of total residential indoor water consumption during the next two decades. Based on the calculations described in Section 4.0, we can project a timeline of water savings attributable to the WaterSense program. The savings increase each year as the program results in the installation of greater numbers of efficient products, which come to compose more and more of the product stock in households throughout the United States.

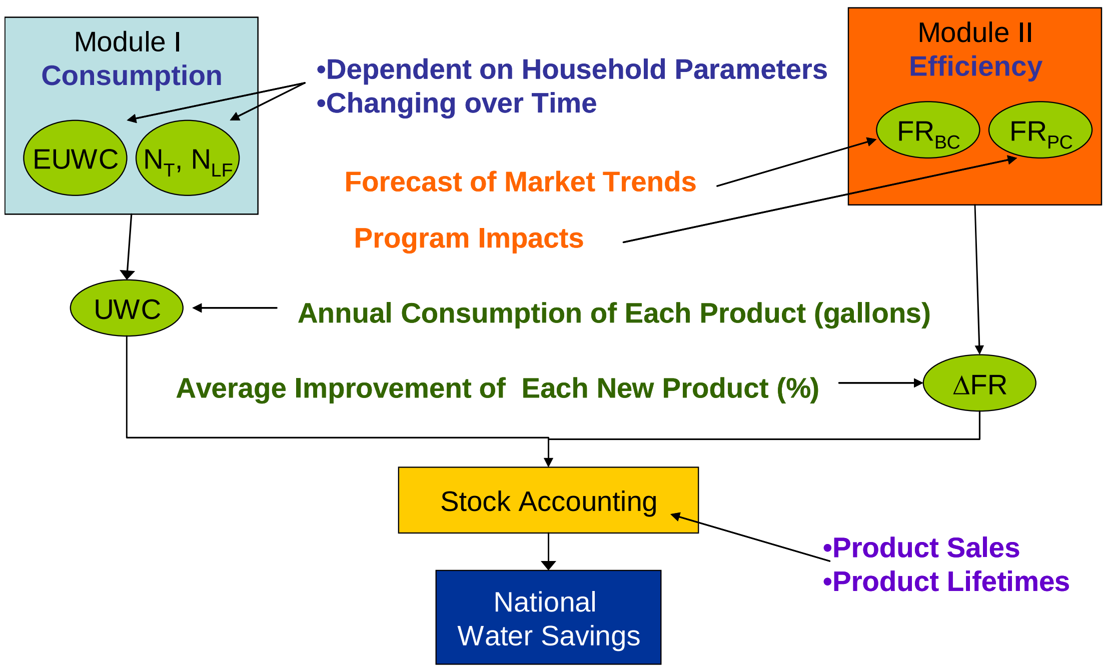

Figure 1 – Flow Chart Showing NWS Modules and Process. [EUWC = end-use water consumption; N_T = number of toilets; N_{LF} = number of lavatory faucets; UWC= unit water consumption; FR_{BC} = base-case flow rate; FR_{PC} = policy-case flow rate.]

1.1 Document Overview

Our model development begins as a bottom-up accounting of water consumed by the major end uses in single- and multi-family residences and in mobile homes. Section 2.0 describes development of Module 1 of the model—base-case consumption for each major residential end use for water, along with the number of each product per household. Both types of data are necessary to calculate savings. For instance, to assess the savings from high-efficiency toilets, we must know how much water typical residential toilets consume. This flow rate is correlated to continually demographic parameters such as the number of people in a household, house size, and income. This first module parameterizes those variables in order to forecast per-household end-use consumption over time. The second part of Section 2.0 describes the parameterization and forecast of average numbers of toilets, faucets, and showerheads per household. We also forecast the saturation rate of washing machines and dishwashers, which is the percentage of households in which each type of appliance is present.

Module 2 requires developing unit efficiency scenarios. As described in Section 3.0, an efficiency scenario is a timeline of the average market efficiency for each product in the base case or the policy case. By *market efficiency*, we mean the average efficiency of products for sale in a given year weighted by market share. For past years, the base case and policy case are identical, and we calculate average efficiency from historical data. For future years, the efficiency of products sold in the policy case is higher than in the base case. This increased market share of efficient products represents the impact of the WaterSense program at the unit level, reflecting the results of the program's informational and promotional efforts.

Once constructed, the modules described in Sections 2.0 and 3.0 are integrated in order to calculate national water savings attributable to national standards and the WaterSense program. As described in Section 4.0, this calculation uses the stock accounting method, which tracks efficient products installed in households nationwide and totals the water savings produced by each, given that each product installed in the policy case has a higher efficiency than an analogous product in the base case. The model estimates market penetration of high-efficiency water-using products in both existing and new construction. Finally, the accounting method keeps track of how long products remain in the stock before being replaced.

References are provided in Section 5.0. This report contains three appendixes: Appendix A, which defines some of the terms used in the report; Appendix B, which describes sources for the data used in developing the modules and model; and Appendix C, which describes how we model product replacement time.

1.2 Scope of the Model

The end uses addressed by the model comprise products that WaterSense has already included or is considering including in its labeling program or that are major residential water-using devices, such as:

- Toilets
- Showers/Bathtubs
- Faucets
- Washing Machines
- Dishwashers

The model establishes baseline residential consumption for only those plumbing products and appliances for which the WaterSense program has established efficiency and performance criteria (i.e., toilets, showerheads, and faucets) or those (washing machines and dishwashers) that were included in calculations for the Residential End-Use Water Study (REUWS) produced by the American Water Works Association Research Foundation (AwwaRF) in 1999. The model does not evaluate water use related to products such as shower tiles, water-using refrigerators, or specialty baths. Nor does this phase of the model address outdoor or commercial end-use consumption, which will be addressed in the second and third phases of the NWS model analysis.

2.0 MODULE 1: DETERMINING BASELINE WATER USE

Water-efficiency programs seek to reduce water consumption relative to "business as usual," or a base case. An important measure of a program's success is the percentage reduction in consumption it achieves. To estimate the effects of an efficiency program, therefore, one must assess baseline consumption. This bottom-up National Water Savings (NWS) analysis model estimates the unit water consumption from each end use. The numbers of plumbing fixtures and appliances per household also are modeled.

Two factors, which we model separately, are needed to determine the baseline consumption of each water-using product. These factors, shown in Figure 2, are: (1) the water consumed by each end use (end-use water consumption, or EUWC), and the number of products (N) representing each end use (see Figure 1). The first factor is the water consumed for a certain purpose (toilet, bathing, and so on); the second is the number of fixtures, fittings, or appliances in each household used for each given purpose (number of toilets, showerheads, and so on).

To understand the effects of historical changes in water consumption, to project effects of current policies, and to develop potential further program efforts, the model identifies general trends and examines the relationship between water consumption and various population segments. For example, household water consumption is correlated with the number of household members. If household size decreases, per-household consumption likely will decline. On the other hand, if consumption is found to correlate positively with income (because of less concern for utility costs), and real incomes grow, one might expect consumption to increase.

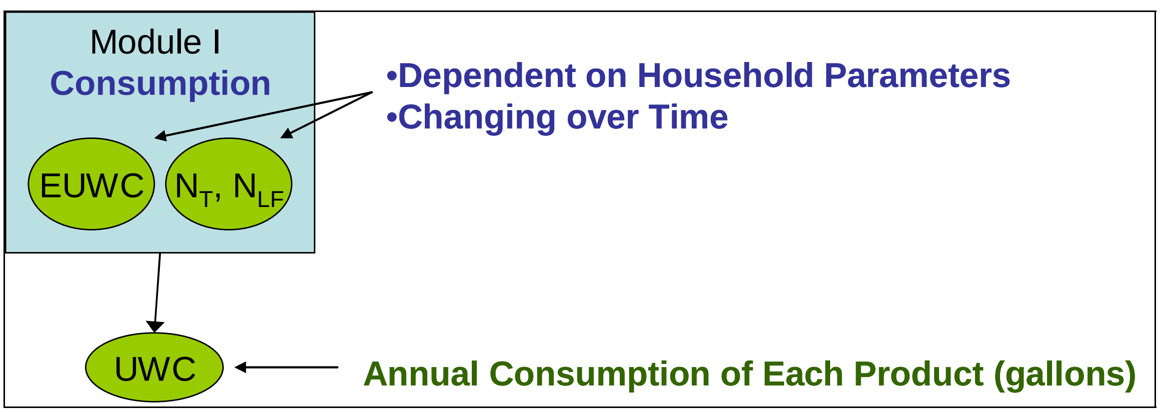

Figure 2 – Module 1 of the NWS Model. EUWC = end-use water consumption; N_T = number of toilets; N_{LF} = number of lavatory faucets; and UWC = unit water consumption.

2.1 End-Use Water Consumption

End-use water consumption (EUWC) is defined as the number of gallons consumed by a household in a day to satisfy one end use (toilet, shower, clothes washer, dishwasher, or faucet). We derive baseline consumption for each end use in a base year from a detailed study, Residential End Uses of Water (REUWS) (AwwaRF, 1999). The average end-use water consumption (in gallons per capita per day) that REUWS reports for the survey year 1998 serves as the foundation for our estimates of baseline water consumption. The average household consumption for each end use is shown in Table 1.

Table – 1 End-Use Indoor Water Consumption (gallons per capita per day) (AwwaRF, 1999)

Total Indoor	Toilet	Shower	Bath	Faucet	Clothes Washer	Dishwasher	Other Domestic	Leaks
71	18.5	11.6	1.2	10.9	15	1	1.6	9.5

We model total average household consumption as the sum of the average EUWCs plus estimated average leakage, as follows.

$$\textit{HH Consumption} = EUWC_T + EUWC_{S+B} + EUWC_F + EUWC_{WM} + EUWC_{DW} + EUWC_{OD} + Leak$$

where:

HH	=	household
$EUWC_T$	=	end-use water consumption for toilets
$EUWC_{S+B}$	=	end-use water consumption for showers and baths
$EUWC_F$	=	end-use water consumption for faucets
$EUWC_{WM}$	=	end-use water consumption for washing machines
$EUWC_{DW}$	=	end-use water consumption for dishwashers
$EUWC_{OD}$	=	end-use water consumption for other domestic activities
$Leak$	=	unaccounted-for water consumption

In addition to estimating the average water consumption for each end use, the REUWS report quantifies the dependence of end-use consumption on several key variables. This quantification enables us to adjust the quantities of water consumed for various end uses based on differences in the number of people in a household, the age of the house, and so on.

The REUWS study determined parameters for describing the dependence of consumption on each variable. The resulting model for each EUWC has the general form:

$$EUWC = \cdot X_1^{a_1} \cdot X_2^{a_2} \cdot X_3^{a_3} . X_4^{a_4} X_5^{a_5} \cdot e^{b_1 X_6 + b_2 X_7 + b_3 X_8} \qquad \text{(Eq.1)}$$

The following list gives the key variables.

X_1	=	marginal price of water (dollars per 1,000 gallons)
X_2	=	household size (number of persons)
X_3	=	household floor space (square feet)
X_4	=	household income (dollars per year)
X_5	=	marginal price of sewage (dollars per 1,000 gallons)
X_6	=	dwellings built before 1960 (percent)
X_7	=	dwellings built after 1990 (percent)
X_8	=	households that rent vs. own (percent)

In this equation, *EUWC* is the water consumption per capita for each end use. This consumption is determined by the value of each variable *X* defined above, combined with a parameter *a* or *b* for each combination of end-use variables. The parameters determined by the REUWS study are shown in Table 2.

Table – 2 REUWS Parameters that Determine End-Use Water Consumption

	a_1	a_2	a_3	a_4	a_5	b_1	b_2	b_3
Toilet	-0.225	0.509	0.117			-0.091	-0.164	
Shower & Bath	-0.514	0.885		0.171		0.349		
Faucet		0.498	0.077			-0.254		
Washing Machine		0.852		0.162				
Dishwasher	-0.5171	0.345		0.196				
Leaks	-0.485	0.392	0.217		-0.16			-0.264

The exception to the form given in Equation 1 is the category termed Other Domestic, which is modeled by the following equation.

$$EUWC_{OD} = 1.024 \times EUWC_{T}^{0.117} \times EUWC_{F}^{0.253} \times EUWC_{CW}^{-0.054} \times Leak^{0.083} \times EUWC_{OUT}^{0.086} \times X_2^{0.162} \times X_4^{-0.058} . e^{0.507(HOTTUB)+0.263(COOLER)} \quad \text{(Eq. 2)}$$

The Other Domestic category includes all miscellaneous indoor water use. It reflects consumption by other end uses, outdoor consumption ($EUWC_{OUT}$), and the presence of a hot tub and/or evaporative cooler, designated by the variables *HOTTUB* and *COOLER*, respectively.

We model each EUWC for each year based on the expected variation from consumption in the base year, 1998. The EUWC for each end use is calculated for each year according to a relation that has the following form.

$$EUWC(y) = EUWC(1998) \times \left(\frac{X_1(y)}{X_1(1998)}\right)^{a_1} \cdot \left(\frac{X_2(y)}{X_2(1998)}\right)^{a_2} \cdots \left(\frac{e^{b_1 X_3(y) + b_2 X_4(y) \cdots}}{e^{b_1 X_3(1998) + b_2 X_4(1998) \cdots}}\right) \quad \text{(Eq. 3)}$$

where $X_1(y)$ and $X_1(1998)$ are the values of the variable X_1 in year *y* and in the reference year 1998. The ellipses indicate additional variables not shown. Equation 3 makes explicit which variables are considered significant for identifying trends in end-use consumption and, thereafter, for estimating savings. We evaluate variables X_1 through X_8, because forecasts for those variables are an important part of the modeling. Variables for which no forecast is available, and which do not affect savings estimates, are neglected. Neglected variables include those that affect Other Domestic consumption: $EUWC_{OUT}$, *HOTTUB,* and *COOLER.*

The REUWS model considers showers and baths as a single end use, although the survey itself reports average consumption by each separately. Showers represent most of the combined use, representing 11.6 gallons per capita per day versus 1.2 gallons per capita per day for baths. We assume that installation of water-efficient showerheads affects showers, but not baths. To calculate the end-use consumption of showers only, we multiply the combined end-use consumption by the relative contribution from showers according to the REUWS survey. We assume that this contribution is constant over time.

$$EUWC_S = \frac{11.6}{(11.6 + 1.2)} \times EUWC_{S+B} = 0.906 \times EUWC_{S+B} \qquad \text{(Eq. 4)}$$

In addition to the variables described above, REUWS considers some parameters related to efficiency, such as the current market penetration of toilets. Rather than incorporating those parameters directly into the NWS model, we model efficiency in detail for each water-using product according to trends in fixture and appliance sales and in distributions of market efficiency. These factors are detailed in Section 3.0.

For appliances, we modified the REUWS model, which considers overall consumption as dependent on income, water prices, and household size. The average end-use consumption for washing machines and dishwashers, however, depends on both the ownership rate and use pattern for the appliance. To improve precision, we used on historical ownership data to model appliance ownership separately from fixture and fitting ownership (Section 2.2.2). We assume that income directly affects only the ownership rate, not the water consumption of each appliance.

The REUWS equations describe the dependence of end-use water consumption on income, water prices, and household size. By assuming that REUWS equations can be generalized to the entire country, this dependence can be used to forecast the per-household consumption for each end use. Our forecast uses average household square footage from the Annual Energy Outlook [Energy Information Administration (EIA), 2007] of the entire housing stock. Likewise, we model household income, population, and size based on trends from the U.S. Census for the entire country. The EIA's Residential Energy Consumption Survey (RECS) (EIA, 2001) provided household size variables, and AWWA-Raftelis data (Fisher, 2006) provided water prices.

As noted in Section 2.2.1, the numbers of fixtures and fittings in new houses is increasing more rapidly than is the building stock as a whole, reflecting the increasing number of bathrooms and half-bathrooms in new homes. Similarly, the surface area (square footage) of new homes has increased rapidly in the past few years, and projections are that floor space will continue to increase. It is important, therefore, to model water consumption separately for this market segment, as consumption is dependent explicitly on floor space according to Equation 1. For this reason, we divide the housing stock into two components, existing homes and new (future) construction, and model water use in each component separately.

We model the water consumption for newly constructed homes using the trend in floor space for new construction obtained from the Annual Energy Outlook for 2007 (EIA, 2007). As Table 2 shows, the end uses that depend on household square footage are water consumption by toilets and faucets, along with water loss to leaks. We assume that fixtures and fittings are used in the same way in new construction and existing housing stock. For example, the dependence of water use on income and household size is assumed to be consistent for both new and existing stock.

2.2 Numbers of Fixtures, Fittings, and Appliances

In addition to the total nationwide water consumption from all plumbing products and appliances associated with a certain end use, we model the number of fixtures and fittings and the installation rate of appliances.

2.2.1 Numbers of Toilets, Showerheads, and Faucets

In general, the number of fixtures per household is increasing while household size (number of occupants) is decreasing, meaning that each fixture serves fewer people. Thus consumption per fixture, and the savings associated with one fixture, is decreasing. The REUWS study does not provide variables for determining the number of fixtures and fittings per household, or the saturation rate[1] of appliances, and we found no such model in the literature. For the NWS model analysis, therefore, we used historical trends as the basis for modeling the number of fixtures per household and the saturation rate of appliances.

We assumed that the number of plumbing fixtures and fittings per household depends primarily on household income and housing type; that is, whether the household occupies a single-family home, a unit in a multi-family building, or a mobile home. Other variables, such as household size (occupancy) or floor space, may be added as they are found to be significant.

The number of plumbing fixtures is related directly to the number of bathrooms. We define the number of plumbing fixtures as follows.

Toilets: one in each full bathroom + half-bathroom
Shower or bathtub: one in each full bathroom
Faucets: one in each full bathroom + half-bathroom + 1 (kitchen)

Income determines the number of bathrooms; the number of fixtures and fittings follows directly from that information.[2] Showerheads were modeled as the number of full bathrooms only.[3] Faucets were not modeled separately: the number of faucets was assumed to be one greater than the number of toilets to account for a kitchen sink faucet.[4]

The data and derived fixture/fitting variables are shown in Table 3 for single-family homes and housing units in multi-family buildings. We assumed that each mobile home contains one toilet, one shower, and two faucets.

[1] The literature commonly refers to the rate of purchase, ownership, or installation as the “saturation” rate. We use the term “saturation rate” for the percentage of homes using a clothes washer and/or dishwasher.
[2] Data available at http://www.census.gov/const/www/charindex.html
[3] Households in the category of “1 to 1.5” bathrooms were divided into those having 1 bathrooms and those having 1.5 bathrooms according to ratios found in the EIA (2001) data set. Households in the category of 3 or more bathrooms were assumed to have 3.5 bathrooms.
[4] Many homes, especially newer homes, may have additional sinks, such as a utility sink or second kitchen sink. We assume that these do not significantly raise the average non-bathroom sink beyond one.

Table – 3 Household Income and Number of Fixtures/Fittings for New Single- and Multi-Family Homes

	Single-Family Households (HHDs)				HHDs in Multi-Family Buildings			
Year	*HHD Income*	*Toilet*	*Shower*	*Faucet*	*HHD Income*	*Toilet*	*Shower*	*Faucet*
1973	$54,343	1.88	1.60	2.88				
1974	$52,744	1.91	1.61	2.91				
1975	$51,232	1.88	1.59	2.88				
1976	$52,469	1.96	1.67	2.96				
1977	$53,179	1.99	1.69	2.99				
1978	$56,152	2.05	1.74	3.05	$32,980	1.42	1.20	2.42
1979	$56,597	2.06	1.74	3.06	$33,250	1.47	1.24	2.47
1980	$54,897	2.06	1.73	3.06	$32,252	1.57	1.30	2.57
1981	$54,261	2.01	1.70	3.01	$31,897	1.60	1.32	2.60
1982	$54,623	1.99	1.69	2.99	$32,131	1.63	1.36	2.63
1983	$55,235	2.08	1.76	3.08	$32,499	1.53	1.27	2.53
1984	$56,956	2.16	1.82	3.16	$33,517	1.61	1.35	2.61
1985	$58,309	2.18	1.84	3.18	$34,330	1.65	1.37	2.65
1986	$60,560	2.29	1.91	3.29	$35,681	1.63	1.36	2.63
1987	$61,705	2.37	1.95	3.37	$36,359	1.67	1.40	2.67
1988	$62,488	2.44	1.99	3.44	$36,822	1.71	1.41	2.71
1989	$64,313	2.49	2.02	3.49	$37,908	1.70	1.41	2.70
1990	$62,765	2.52	2.05	3.52	$36,982	1.74	1.44	2.74
1991	$61,396	2.50	2.03	3.50	$36,185	1.75	1.43	2.75
1992	$61,299	2.51	2.01	3.51	$36,158	1.72	1.42	2.72
1993	$63,685	2.53	2.02	3.53	$37,642	1.74	1.44	2.74
1994	$64,928	2.55	2.04	3.55	$38,385	1.73	1.43	2.73
1995	$66,100	2.55	2.04	3.55	$39,041	1.82	1.49	2.82
1996	$67,465	2.57	2.07	3.57	$39,871	1.85	1.51	2.85
1997	$69,625	2.59	2.08	3.59	$41,168	1.82	1.49	2.82
1998	$71,663	2.63	2.10	3.63	$42,361	1.82	1.50	2.82
1999	$74,080	2.65	2.12	3.65	$43,797	1.87	1.54	2.87
2000	$74,807	2.71	2.13	3.71	$44,242	1.88	1.55	2.88
2001	$74,099	2.74	2.15	3.74	$43,852	1.93	1.58	2.93
2002	$72,495	2.74	2.16	3.74	$42,897	1.88	1.55	2.88
2003	$72,328	2.76	2.17	3.76	$42,817	1.90	1.56	2.90
2004	$72,100	2.78	2.19	3.78	$42,687	1.91	1.57	2.91
2005	$73,077	2.83	2.22	3.83	$43,274	1.99	1.62	2.99
2006	$73,807	2.83	2.21	3.83	$43,707	1.99	1.62	2.99

Because the number of fixtures and fittings in new construction generally is increasing, we model installations in new housing separately from replacements in existing housing. For older homes, we model the number of toilets, showerheads, and faucets based on the number of bathrooms and half-bathrooms given in EIA (2001); see Table 4. The character of the stock is modeled in this way until the year 1989, after which we track the stock according to the characteristics of new construction as described above.

Table – 4 Estimated Number of Fixtures/Fittings per Household by Housing Type

	Single-Family Households				
Vintage	*Baths*	*Half-Baths*	*Toilets*	*Showers*	*Faucets*
Before 1940	1.33	0.32	1.65	1.33	2.65
1940-49	1.33	0.27	1.60	1.33	2.60
1950-59	1.37	0.29	1.66	1.37	2.66
1960-69	1.41	0.32	1.74	1.41	2.74
1970-79	1.49	0.34	1.83	1.49	2.83
1981-89	1.56	0.37	1.93	1.56	2.93
	Households in Multi-Family Buildings				
Vintage	*Baths*	*Half-Baths*	*Toilets*	*Showers*	*Faucets*
Before 1940	1.04	0.08	1.12	1.04	2.12
1940-49	1.04	0.07	1.11	1.04	2.11
1950-59	1.05	0.11	1.15	1.05	2.15
1960-69	1.08	0.11	1.19	1.08	2.19
1970-79	1.12	0.10	1.22	1.12	2.22
1981-89	1.16	0.12	1.28	1.16	2.28

Finally, we model the number of fixtures and fittings that will be installed in future homes according to a macroeconomic regression analysis. Generally, we assume that the number of fixtures and fittings increases as real incomes increase, converging to a maximum when income reaches a certain level. If we plot the number of fixtures against per-household income, the graph is expected to resemble an S-shaped curve. The logistic and Gompertz functions are most widely used to describe such a process.

To generate the S-curve we chose a logistic function that has the following generic form.

$$Logistic(Inc, \beta, \gamma) = \frac{1}{1 + \gamma \times e^{-\beta \times Inc}}, \qquad \text{(Eq. 5)}$$

where *Inc* is the independent variable (household income), and β and γ are parameters. The logistic function has a maximum value of one. The minimum is greater than zero, and the parameters β and γ determine the minimum value and the rapidity of increase. Households generally have more than one of each type of plumbing fixture or fitting. We therefore use scaling parameters to adjust the logistic function so that it covers the range of likely values of the dependent variable. For example, we find that most households have between one and four toilets (full plus half-bathrooms), depending on income category. In this case, the dependent variable is a number of toilets between one and four. The number of toilets, N_T, therefore is given by:

$$N_T = N_T^{Min} + \left(N_T^{Max} - N_T^{Min}\right) \times Logistic(Inc, \beta, \gamma) = N_T^{Min} + \frac{\left(N_T^{Max} - N_T^{Min}\right)}{1 + \gamma \times e^{-\beta \times Inc}}, \quad \text{(Eq. 6)}$$

where $N_T^{Min} = 1$ and $N_T^{Max} = 4$.

We fit the model to the data in Table 3.[5] The algebraic transformation of Equation 6 gives:

$$\ln\left(\frac{N_T^{Max} - N_T^{Min}}{N_T - N_T^{Min}} - 1\right) = \ln\gamma + \beta \times Inc \qquad \text{(Eq. 7)}$$

from which lnγ and β can be determined by linear regression. Table 5 shows the parameters determined through linear regression by housing type. The value of R^2 is high (greater than 0.9) for each regression, indicating that variations in the dependent variable (number of fixtures/fittings) are explained well by variations in the independent variable (income).

Table – 5 Model Parameters Determined through Linear Regression by Housing Type

Fixture/Fitting	Min.	Max.	lnγ	β	R^2
Single-Family Households					
Showerhead	1	2.5	4.06	-7.3E-05	0.924
Toilet	1	4	3.58	-5.4E-05	0.920
Faucet	2	5	3.58	-5.4E-05	0.920
Households in Multi-Family Buildings					
Showerhead	1	2.5	4.08	-8.3E-05	0.912
Toilet	1	4	3.42	-6.0E-05	0.959
Faucet	2	5	3.42	-6.0E-05	0.959

Once determined, the parameters are fed back into Equation 6 to forecast future values of *N*, which is calculated for each fixture/fitting for each year according to the average household income for each housing type, as projected by the Department of Energy's Annual Energy Outlook (EIA, 2007).

Figure 3 compares numbers of fixtures and fittings derived from U.S. Census data to the numbers calculated by the model.

[5] The linear regression function is an add-on for Microsoft Excel, provided as part of the Analysis ToolPak.

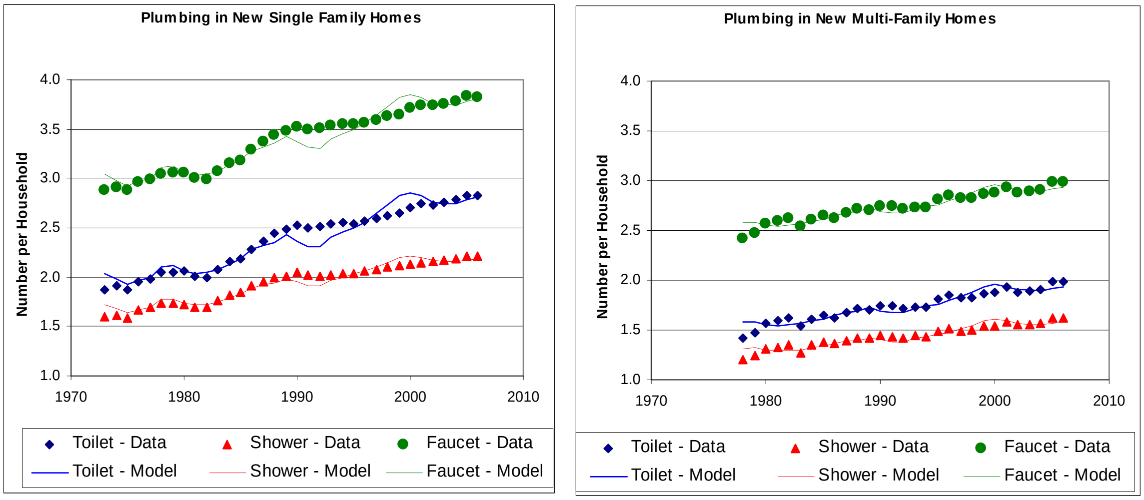

Figure 3 – Data and Model Results for New Single- and Multi-Family Homes

Figure 3 shows that the logistic function generally provides an adequate description of long-term trends in numbers of baths and half-baths in new single- and multi-family homes. Except for two periods in the 1990s, model results and data coincide well. In the early 1990s, real incomes dropped, but construction practices did not reverse themselves—the trend toward more bathrooms simply slowed for a few years. Later in the decade, trends in numbers of bathrooms fell behind income, which increased rapidly. These effects are expected, because construction trends do not react instantaneously to income trends. Over the long term, and with the assumption of smoothly growing incomes, we expect that the agreement between data and model results will be well within the margin of accuracy for our analysis.

2.2.2 Ownership of Clothes Washers and Dishwasher

As mentioned in Section 2.2.1, in addition to household size, saturation rate is a primary determinant of water consumption. This fact applies to washing machines and dishwashers as well as to fixtures and fittings. To model the ownership rate of these major water-using appliances, we constructed an income-based model for each housing type.

Appliance ownership is modeled using RECS data (EIA, 2001). The RECS data set reports appliance ownership based on assigning households to nine income categories. Data are shown in Table 6.

Table – 6 Dishwasher and Washing Machine Ownership by Income Category and Building Type (EIA, 2001)

Average Household Income in Category	Single-Family Household		Household in Multi-Family Building		Household in Mobile Home	
	Washing Machine	*Dishwasher*	*Washing Machine*	*Dishwasher*	*Washing Machine*	*Dishwasher*
$3,170	80%	19%	25%	20%	60%	12%
$9,508	87%	18%	22%	11%	69%	13%
$15,847	87%	25%	29%	18%	81%	16%
$22,186	92%	38%	28%	34%	79%	42%
$31,695	92%	44%	25%	38%	85%	33%
$44,373	93%	56%	33%	44%	96%	52%
$57,051	98%	60%	44%	52%	97%	48%
$79,238	98%	75%	42%	57%	92%	52%
$110,934	98%	80%	52%	52%	82%	66%

Note: We did not include the highest RECS income category (>$130,000) because of uncertainties in its average income.

Unlike plumbing fixtures, which depend on building characteristics and hence can be related to the building vintage and household income at the time of construction, appliances can be added or changed at any time and thus are assumed to be a function of present income only. The saturation rate for washing machines and dishwashers is modeled using the same functional form as used for plumbing fixtures and fittings (Equation 6), with a maximum ownership of one:

$$Sat = 1.0 \times Logistic(Inc, \beta, \gamma) = \frac{1}{1 + \gamma \times e^{-\beta \times Inc}} \qquad \text{(Eq. 8)}$$

This relation is transformed as before (Equation 7) to allow for linear regression analysis.

$$\ln(Sat - 1) = \ln\gamma + \beta \times Inc \qquad \text{(Eq. 9)}$$

Results of these regressions are given in Table 7. The values of R^2 for appliances are less than for plumbing fixtures.

Table – 7 Appliance Model Parameters Determined through Linear Regression by Housing Type

Appliance	**lnγ**	**β**	**R^2**
Single-Family Households			
Washing Machine	-2.21	-1.03E-05	0.57
Dishwasher	1.37	-2.84E-05	0.92
Households in Multi-Family Buildings			
Washing Machine	1.23	-1.22E-05	0.883
Dishwasher	1.47	-1.94E-05	0.673

Mobile Homes			
Washing Machine	-0.71	-4.36E-05	0.672
Dishwasher	1.64	-2.38E-05	0.749

We used the model parameters in Table 7 to forecast the saturation rate in each year for each housing type. We scaled the estimate from the REUWS (1998) survey based on the trend in the saturation rate for appliances:

$$EUWC_{WM,DW}(y) = EUWC_{WM,DW}(1998) \times \left(\frac{HS(y)}{HS(1998)} \right)^{a} \cdot \left(\frac{Sat(y)}{Sat(1998)} \right) \qquad \text{(Eq. 10)}$$

In Equation 10, *HS* is household size (number of occupants) in the year of interest, and *a* is the exponent parameter given by the REUWS analysis (0.85 for washing machines, 0.35 for dishwashers). *Sat* is the saturation (ownership) rate in each year.

2.3 Unit Water Consumption

We model the total number of toilets nationwide as equal to the number of full bathrooms plus half-bathrooms. Consumption per fixture is obtained by dividing the end-use consumption by the number of fixtures. The following equation, for example, applies to toilets.

$$UWC_T = \text{Consumption per Toilet} = EUWC_T / N_T = EUWC_T/(N_B + N_{HB}) \qquad \text{(Eq. 11)}$$

where:

$EUWC_T$ = water consumption for all toilets in the household
N_T = number of toilets
N_B and N_{HB} = numbers of bathrooms and half-bathrooms, respectively

3.0 MODULE 2: DEFINING EFFICIENCY TRENDS IN BASE-CASE AND POLICY SCENARIOS

This section describes the second module of the NWS model. In addition to the demographic and economic factors described in the preceding section, a major determinant of end-use water consumption is the efficiency of fixtures and appliances. Figure 4 shows the factors evaluated in Module 2. The market has changed over time as water-efficient plumbing fixtures and high-efficiency appliances have gained market share. Not only federal minimum standards (see Table 8), but also voluntary programs such as EPA's WaterSense, have increased the market share of high-efficiency products. The primary outputs of the NWS analysis model are estimates of the national effects of such programs.

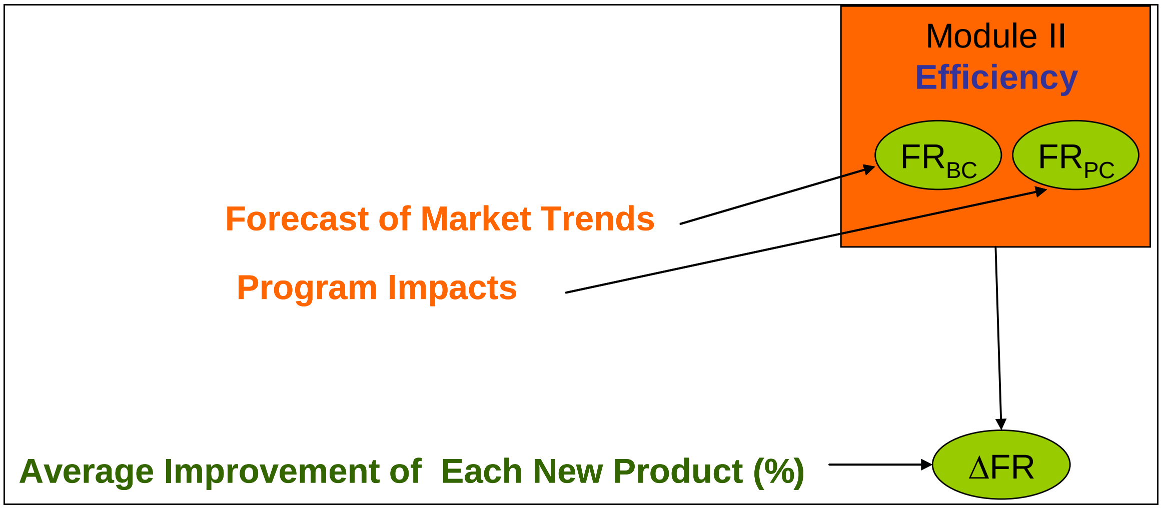

Figure 4 – Module 2 of the NWS Model. [FR_{BC} = base-case flow rate; FR_{PC} = policy-case flow rate].

3.1 Historical Data and Projections of Market Trends

The daily or annual amount of water used by a given product depends not only on its frequency of use, but also on its water consumption per use. The flow rate from a showerhead or faucet, for example, is called the device, or unit, water use efficiency. The water use efficiency of a fixture, fitting, or appliance reflects the period when it was manufactured, shipped, and installed. For ease of estimation, we assume that all fixtures, fittings, or appliances manufactured in a given year were also shipped and installed in that year. The vintages of water-using devices in established housing stock depend on whether the products were installed during construction or during replacement or remodeling. It is difficult to find publicly available data regarding sales or shipments of showerheads, faucets, toilets, washing machines, and dishwashers separated by flow rate. Nor is the information available directly from the manufacturers. A combination of publicly available data, purchased data reports, and engineering estimates underlie the shipment and efficiency inputs to the NWS model. This section describes the method we used to obtain shipment numbers and efficiency ratings for various types of products.

Table – 8 Federal Maximum Water Use Standards for Toilets, Showerheads, and Faucets (Vickers, 2001)

Product	Maximum Water Use	Effective Date of Standard
Toilets		
Gravity tank	1.6 gpf*	1/1/1994
Flushometer tank	1.6 gpf	1/1/1994
Showerheads		
All except safety showers	2.5 gpm† (at 80 psi‡) or 2.2 gpm (at 60 psi)	1/1/1994
Faucets and Replacement Aerators		
Lavatory faucets	2.5 gpm (at 80 psi) or 2.2 gpm (at 60 psi)	1/1/1994
Lavatory replacement aerators	2.5 gpm (at 80 psi) or 2.2 gpm (at 60 psi)	1/1/1994
Kitchen faucets	2.5 gpm (at 80 psi) or 2.2 gpm (at 60 psi)	1/1/1994
Kitchen replacement aerators	2.5 gpm (at 80 psi) or 2.2 gpm (at 60 psi)	1/1/1994

*gpf – gallons per flush
†gpm – Gallons per minute
‡psi – pounds per square inch

3.1.1 Toilets

We obtained quantities of toilets shipped from both publicly available and purchased data for the years 1987, 1992, 1997, and for 2002 through 2007 (Catalina Research, 2007; D&R International, 2005). The water use efficiency of toilets is defined by gallons per flush (gpf). Table 9 shows estimates of the percentages of toilet shipments by water use efficiencies for the years 1949 through 2006 and forecasted percentages for 2007 through 2030. Toilet efficiency has changed dramatically since 1949, when most toilets required 5 to 7 gpf. Although the 1970s began with a predominance of 5-gpf toilets, by the end of the decade most toilets required 3.5 gpf. In anticipation of the 1994 federal standard of 1.6 gpf, manufacturers began producing high-efficiency toilets beginning in the latter half of the 1980s. Toilets that use 1.6 gpf, which began to gain market share in the 1990s, now represent the majority of toilets sold. As of 2007, 1.28-gpf toilets are beginning to enter the market; by 2014 they are projected to represent 11 percent of the market for new toilets.

Table – 9 Market Shares for Toilet Efficiencies by Year (in percents)

Year	1.28 gpf*	1.6 gpf	3.5 gpf	5 gpf	7 gpf	10 gpf	Weighted Average Flow Rate per Flush
1950	0%	0%	0%	75%	23%	2%	5.6
1951	0%	0%	0%	75%	23%	2%	5.6
1952	0%	0%	0%	75%	23%	2%	5.6
1953	0%	0%	0%	75%	23%	2%	5.6
1954	0%	0%	0%	75%	23%	2%	5.6
1955	0%	0%	0%	76%	22%	2%	5.5

Year	1.28 gpf*	1.6 gpf	3.5 gpf	5 gpf	7 gpf	10 gpf	Weighted Average Flow Rate per Flush
1956	0%	0%	0%	78%	20%	2%	5.5
1957	0%	0%	0%	79%	19%	2%	5.5
1958	0%	0%	0%	81%	17%	2%	5.4
1959	0%	0%	0%	82%	16%	2%	5.4
1960	0%	0%	0%	84%	15%	1%	5.4
1961	0%	0%	0%	85%	14%	1%	5.3
1962	0%	0%	0%	86%	13%	1%	5.3
1963	0%	0%	0%	87%	13%	1%	5.4
1964	0%	0%	0%	88%	13%	1%	5.4
1965	0%	0%	0%	86%	13%	1%	5.3
1966	0%	0%	0%	87%	12%	1%	5.3
1967	0%	0%	0%	87%	12%	1%	5.3
1968	0%	0%	0%	88%	11%	1%	5.3
1969	0%	0%	0%	88%	11%	1%	5.3
1970	0%	0%	0%	89%	10%	1%	5.3
1971	0%	0%	0%	89%	10%	1%	5.3
1972	0%	0%	0%	90%	9%	1%	5.2
1973	0%	0%	0%	90%	9%	1%	5.2
1974	0%	0%	10%	81%	9%	0%	5.0
1975	0%	0%	25%	66%	9%	0%	4.8
1976	0%	0%	35%	58%	7%	0%	4.6
1977	0%	0%	77%	17%	6%	0%	4.0
1978	0%	0%	80%	15%	5%	0%	3.9
1979	0%	0%	86%	11%	3%	0%	3.8
1980	0%	0%	89%	9%	2%	0%	3.7
1981	0%	0%	91%	7%	2%	0%	3.7
1982	0%	0%	93%	5%	2%	0%	3.6
1983	0%	0%	93%	5%	2%	0%	3.6
1984	0%	0%	94%	4%	2%	0%	3.6
1985	0%	0%	94%	4%	2%	0%	3.6
1986	0%	1%	94%	3%	2%	0%	3.6
1987	0%	3%	95%	1%	1%	0%	3.5
1988	0%	6%	92%	1%	1%	0%	3.4
1989	0%	8%	90%	1%	1%	0%	3.4
1990	0%	10%	88%	1%	1%	0%	3.4
1991	0%	25%	74%	1%	1%	0%	3.1
1992	0%	40%	59%	1%	1%	0%	2.8
1993	**0%**	**54%**	**45%**	**1%**	**1%**	**0%**	2.5
1994	0%	82%	18%	0%	0%	0%	1.9
1995	0%	85%	15%	0%	0%	0%	1.9
1996	0%	86%	14%	0%	0%	0%	1.9
1997	0%	100%	0%	0%	0%	0%	1.6
1998	0%	100%	0%	0%	0%	0%	1.6
1999	0%	100%	0%	0%	0%	0%	1.6
2000	0%	100%	0%	0%	0%	0%	1.6
2001	1%	100%	0%	0%	0%	0%	1.6

Year	1.28 gpf*	1.6 gpf	3.5 gpf	5 gpf	7 gpf	10 gpf	Weighted Average Flow Rate per Flush
2002	1%	100%	0%	0%	0%	0%	1.6
2003	1%	99%	0%	0%	0%	0%	1.6
2004	2%	98%	0%	0%	0%	0%	1.6
2005	3%	97%	0%	0%	0%	0%	1.6
2006	3%	97%	0%	0%	0%	0%	1.6
2007	5%	95%	0%	0%	0%	0%	1.6
2008	5%	95%	0%	0%	0%	0%	1.6
2009	5%	95%	0%	0%	0%	0%	1.6
2010	5%	95%	0%	0%	0%	0%	1.6
2011	8%	93%	0%	0%	0%	0%	1.6
2012	9%	91%	0%	0%	0%	0%	1.6
2013	10%	90%	0%	0%	0%	0%	1.6
2014	11%	89%	0%	0%	0%	0%	1.6
2015	13%	87%	0%	0%	0%	0%	1.6
2016	15%	85%	0%	0%	0%	0%	1.6
2017	19%	81%	0%	0%	0%	0%	1.5
2018	21%	79%	0%	0%	0%	0%	1.5
2019	24%	76%	0%	0%	0%	0%	1.5
2020	28%	72%	0%	0%	0%	0%	1.5
2021	32%	68%	0%	0%	0%	0%	1.5
2022	36%	64%	0%	0%	0%	0%	1.5
2023	39%	61%	0%	0%	0%	0%	1.5
2024	43%	57%	0%	0%	0%	0%	1.5
2025	47%	53%	0%	0%	0%	0%	1.5
2026	51%	49%	0%	0%	0%	0%	1.4
2027	54%	46%	0%	0%	0%	0%	1.4
2028	58%	42%	0%	0%	0%	0%	1.4
2029	62%	38%	0%	0%	0%	0%	1.4
2030	66%	34%	0%	0%	0%	0%	1.4

* gpf – gallons per flush

The last column of Table 9 shows the shipment-weighted average (percent) of each flow rate. For each year, that percentage is multiplied by its corresponding flow rate. Then for all products the flow rates are summed to obtain an average flow rate for the mix of efficiencies on the market. The flow rate for any give year is given by:

$$FR_{BaseCase}(y) = \sum_{yo}^{y} (Shipment\% \times Flowrate) \qquad \text{(Eq. 12)}$$

Two variables represent the market-weighted average flow rate for the base case and the policy case: $flow_{BaseCase(y)}$ and $flow_{Policy(y)}$. The difference between those variables in the years following 2007 will represent the water savings attributable to the WaterSense program.

3.1.2 Showerheads and Faucets

We obtained unit efficiency values for showerheads and faucets from Internet Web sites (for example, Healthgoods and eFaucets). Dollar values of shipments came from purchased data for the years 1995, 2000, and 2005 [Freedonia Group Inc., 2006; Specialists in Business Information (SBI), 2007]. We divided the shipment values by the average unit prices found on the Internet to estimate numbers of showerheads and faucets purchased and installed.

3.1.3 Clothes Washers and Dishwashers

Estimates of efficiency levels for clothes washers and dishwashers are available from several sources. Shipments for the years 1990 through 2006 are published by the Association of Home Appliance Manufacturers (AHAM). For 2007 through 2009 we used forecast estimates from *Appliance Magazine*. Finally, for years after 2009, we forecast shipments based on the average annual growth rate between 2000 and 2009.

AHAM tracks the energy efficiency, but not the water flow rate, of clothes washers and dishwashers. Estimates of water flow rate are available from Lawrence Berkeley National Laboratory's analysis of energy-efficiency standards for those products. Because both appliances use hot water, their water consumption is related closely to energy efficiency. Their water consumption was evaluated as part of the studies supporting energy-efficiency standards [U.S. Department of Energy (DOE), 1990, 2000]. Energy-efficiency standards for both appliances took effect in 1994. Additional standards took effect for clothes washers in 2004 and 2007. We utilize estimates of pre-1994 flow rates that were made in support of the 1994 standard. Because the 1994 standard for clothes washers was not expected to affect water consumption significantly, we estimated that flow rates gradually increased at a rate of 0.2 percent per year starting in 1995. Per-cycle water use was reduced significantly as a result of the 2004 standard; further reductions are expected from the 2007 standards. For future projections we assumed that, lacking additional standards, there will be no further reduction in water consumption attributable to clothes washer.

Although water consumption by dishwashers declined somewhat as a result of the 1994 standard, we assume that it did not improve thereafter. Table 10 summarizes annual shipments and flow rates for clothes washers and dishwashers.

Table – 10 Shipments and Flow Rates for Clothes Washers and Dishwashers

	Clothes Washers		**Dishwashers**	
Year	*Shipments (millions)*	*Flow (gal/cycle)*	*Shipments (millions)*	*Flow (gal/cycle)*
1990	5.59	39.18	3.47	11.83
1991	5.42	39.18	3.34	11.83
1992	5.63	39.18	3.58	11.83
1993	5.92	39.18	3.85	11.83
1994	6.16	39.18	4.30	9.44

Year	Clothes Washers		Dishwashers	
	Shipments (millions)	*Flow (gal/cycle)*	*Shipments (millions)*	*Flow (gal/cycle)*
1995	6.08	39.18	4.30	9.44
1996	6.23	38.82	4.58	9.44
1997	6.33	38.45	4.65	9.44
1998	6.84	38.05	4.97	9.44
1999	7.31	37.96	5.54	9.44
2000	7.50	37.88	5.66	9.44
2001	7.34	37.79	5.48	9.44
2002	7.75	37.71	6.05	9.44
2003	8.15	37.63	6.28	9.44
2004	8.83	35.14	6.95	9.44
2005	9.23	35.14	7.29	9.44
2006	9.50	35.14	7.13	9.44
2007	9.55	21.03	7.74	9.44
2008	9.65	21.03	7.97	9.44
2009	9.75	21.03	8.13	9.44
2010-2030	2000-2009 Growth rate	No change	2000-2009 Growth rate	No change

4.0 CALCULATING NATIONAL WATER SAVINGS

Sections 2.1 and 2.2 of this report described a stock accounting model to forecast the residential water consumption for all end uses based on demographic trends. In addition, we model the number of fixtures or fittings in the stock and in new construction, so that we can more accurately estimate flows of each individual piece of equipment. In Section 3, we characterized quantities of new equipment entering the stock, along with market share by efficiency level. It is through market share and efficient technologies that government efforts such as the WaterSense program reduce water consumption. This section explains how those elements are brought together to calculate national water savings from EPA's WaterSense program. Figure 5 shows the final calculations performed in the National Water Savings (NWS) model in order to estimate national water savings.

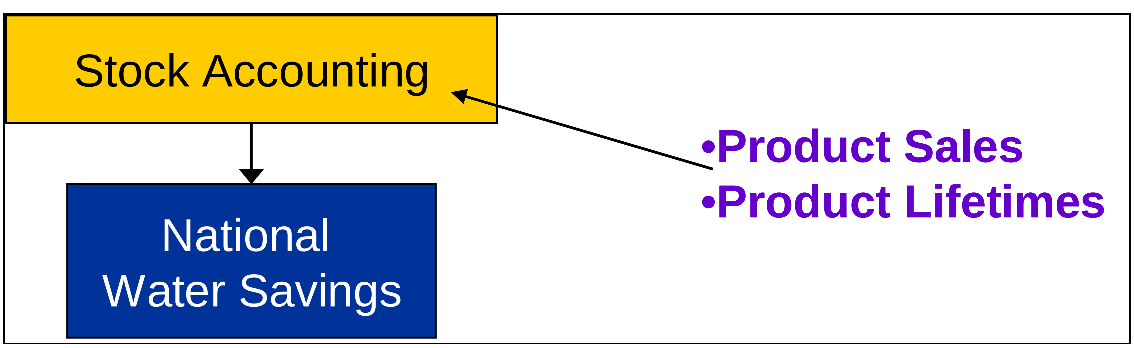

Figure 5 – Final Calculations in the NWS Model

In calculating national water savings attributable to the WaterSense program, we compare the following two scenarios.

- *Base Case* – The base case is determined by demographic trends and trends in equipment efficiency arising from market forces or pre-existing government programs. It includes no changes effected by new government policy.
- *Policy Case* – This scenario includes the likely effects of market transformations produced by the WaterSense program, which are in addition to market-based efficiency improvements.

National water savings attributable to WaterSense is represented by the difference between the *base case* and the *policy case*. In the absence of any changes in product efficiency, the EUWC in each year is given according to Equation 3, reproduced below.

$$EUWC(y) = EUWC(1998) \times \left(\frac{X_1(y)}{X_1(1998)} \right)^{a_1} \cdot \left(\frac{X_2(y)}{X_2(1998)} \right)^{a_2} \cdots \left(\frac{e^{b_1 X_3(y) + b_2 X_4(y) \cdots}}{e^{b_1 X_3(1998) + b_2 X_4(1998) \cdots}} \right)$$

This number, multiplied by total number of households, gives the national consumption by each end use assuming that no changes in product efficiency occur after the base year of 1998. Such changes have occurred, however, and are expected to continue even in the absence of a program such as WaterSense. To compare results of the two scenarios defined above, we must evaluate the effects of changes in product efficiency.

We evaluate those effects by estimating changes in unit water consumption (*UWC*) of products shipped over time. The UWC is calculated from EUWC according to Equation 11. For the base case, Equation 14 gives the value of UWC in terms of the flow rates provided in Tables 9 and 10. The base-case UWC for each product is given by:

$$UWC_{BaseCase}(y) = UWC(y) \times \frac{flow_{BaseCase}(y)}{flow_{BaseCase}(y_0)} \qquad \text{(Eq. 14)}$$

In Equation 14, *flow* is the market-weighted flow rate of the product under consideration.

Development of the policy case follows the same steps, with *flow* determined according to the projections of market share of high-efficiency toilets or lavatory faucets under the WaterSense program. Market share, given as percentages in Tables 11 and 12, is the fraction of total shipments that are labeled by WaterSense. The term y_0 is the reference year (1998). Indexes for each end use are omitted for simplicity. Thus $UWC_{PolicyCase}(y)$ is given by:

$$UWC_{PolicyCase}(y) = UWC \times \frac{flow_{PolicyCase}(y)}{flow_{BaseCase}(y_0)} \qquad \text{(Eq. 15)}$$

Table 11 – Market -Weighted Flow Rates for High-Efficiency Toilets

Year	Base Case	Low	Medium	High	Year	Base Case	Low	Medium	High
2007	5%	5%	5%	5%	2019	24%	33%	65%	98%
2008	5%	5%	6%	9%	2020	28%	38%	75%	99%
2009	5%	5%	8%	12%	2021	32%	43%	85%	99%
2010	5%	5%	10%	15%	2022	36%	48%	95%	99%
2011	8%	10%	20%	30%	2023	39%	53%	97%	99%
2012	9%	13%	25%	38%	2024	43%	58%	99%	99%
2013	10%	14%	27%	41%	2025	47%	63%	99%	99%
2014	11%	15%	30%	45%	2026	51%	68%	99%	99%
2015	13%	18%	35%	53%	2027	54%	73%	99%	99%
2016	15%	20%	40%	60%	2028	58%	78%	99%	99%
2017	19%	25%	50%	75%	2029	62%	83%	99%	99%
2018	21%	28%	55%	83%	2030	66%	88%	99%	99%

Table 12 – Market-Weighted Flow Rates for Lavatory Faucets

Year	Base Case	Low	Medium	High	Year	Base Case	Low	Medium	High
2007	0%	0%	0%	5%	2019	30%	40%	50%	55%
2008	1%	3%	4%	5%	2020	33%	44%	55%	65%
2009	2%	3%	5%	6%	2021	36%	48%	60%	75%
2010	3%	4%	7%	8%	2022	39%	52%	65%	85%
2011	6%	8%	10%	10%	2023	42%	56%	70%	95%
2012	9%	12%	15%	20%	2024	45%	60%	75%	97%
2013	12%	16%	20%	25%	2025	48%	64%	80%	99%
2014	15%	20%	25%	27%	2026	51%	68%	85%	99%
2015	18%	24%	30%	30%	2027	54%	72%	90%	99%
2016	21%	28%	35%	35%	2028	57%	76%	95%	99%
2017	24%	32%	40%	40%	2029	60%	80%	99%	99%
2018	27%	36%	45%	50%	2030	63%	84%	99%	99%

The unit water savings for the average product installed after policy implementation is:

$$UWS(y) = UWC_{BaseCase}(y) - UWC_{PolicyCase}(y) \qquad \text{(Eq. 16)}$$

From here, national water savings are calculated by summing up unit water savings (UWS*)* for each type of fixture, fitting, or appliance. After products are installed under a particular policy, they produce savings as long as they remain installed. If they are replaced, and the program is still in place, they generally will be replaced by products of the same efficiency. Thus we can estimate changes in market share due to the program. National water savings (NWS) is the sum of unit savings over all products. The model takes care not to double-count for replacements made after the program has started. The formula for obtaining national water savings is:

$$NWS(y) = \sum_{j=1}^{y-\bar{y}} UWS(y-j) \times S(y-j) \times Surv(j) \quad \text{(Eq. 17)}$$

where:

NWS(y)	=	national water savings in year *y*
UWS(y-j)	=	unit water savings for products shipped in year *y*
S(y-j)	=	number of products shipped in year y
Surv(j)	=	probability of survival in year *j*
$\bar{y}$	=	year the program was implemented

The elements and indices used in this equation require some comment. The sum of unit savings accounts for all products shipped during or after the year the program is implemented that are still operating in year *y*. The probability of survival is given by a function that determines where a product will still be installed after a certain number of years, *j*, after installation. Appendix C contains survival probabilities developed for various products**.** The sum of unit savings counts products that are *j* years old from the year the program was implemented. The first term of the series counts the per-unit savings for products shipped in the previous year, *UWS(y-1)*, times the number sold in that year, *S(y-1)*, times the fraction of those surviving for one year, *Surv(1)*. The subsequent terms account for each cohort of products back to the first year of the program.

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Appendix A: Terms

Below are definitions of some of the terms used in this document. The definitions reflect those used in the American Society of Mechanical Engineers (ASME) publications that present plumbing standards.[6]

Plumbing Fixture: receptor for water or waterborne wastes that discharges into a drainage system.

Plumbing Fixture Fitting: fitting, attached to or accessible from a fixture, that controls the volume and/or directional flow of water to, or from, that fixture.

Plumbing Fitting: device designed to control and/or guide the flow of water.

Faucet: terminal fitting.

Conservation: practices that reduce water use.

Consumption: use of water that allows its evaporation or makes it unfit for any subsequent use.

High-Efficiency: products or technologies that require less water to do the same amount of work as conventional products or technologies.

Stock: the quantity of an appliance that is installed in residences or the number of residential buildings in use.

Shipments: deliveries from manufacturers to retailers. Shipments are related closely to sales and installations.

[6] ASME Standards: Approved as American National Standards A112.19.2M Vitreous China Plumbing Fixtures, and A112.18.1M, Plumbing Fixture Fittings.

Appendix B: Sources of Data

The capability of the National Water Savings (NWS) analysis model to calculate water savings accurately depends on the detail and quality of the data used. We obtained data regarding shipments and rated efficiencies of plumbing fixtures and fittings and of appliances. This appendix describes sources of general data input to the NWS model.

Data specific to product shipments and efficiency were purchased from several sources: (1) the Freedonia Group report titled, *Plumbing Fixtures & Fittings*; (2) Catalina Research's *U.S. Toilet Market Profile*; and (3) *Kitchen and Bath Fixtures and Fittings in the U.S* from Specialists in Business Information (SBI). We obtained the Freedonia and Catalina reports from MarketResearch.com.

In addition, we used publicly available data from a report titled, *Plumbing Fixtures Market Overview: Water Savings Potential for Residential and Commercial Toilet and Urinals*, produced by D&R International; Koeller and Company; and Veritec Consulting, Ltd. (referred to as D&R Int'l.). The report summarizes the market and potential for water savings for residential and commercial toilets and urinals, plumbing fixtures that represent 26 percent of residential indoor water use (about 12 percent of total residential use) and 8.5 percent of total commercial water use.

In addition to the sources of data described above, this report refers to other sources as appropriate.

The first column of Table B.1 identifies equipment or building variables; the second and third columns identify the purpose of and source for the associated data; and the last three columns indicate whether the data were publicly available, purchased, or estimated using intermediate models or assumptions.

Table B.1 – Sources of Data Used in NWS Model

Variable	Purpose	Source	Publicly Available	Purchased	Estimated
Equipment					
Shipments - Toilets	Quantity in use: used to develop water consumption value	Marketing Research, PMI*		X	

Variable	Purpose	Source	Publicly Available	Purchased	Estimated
Shipments - Faucets	Quantity in use: used to develop water consumption value	Marketing Research, PMI*		X	
Shipments - Showerheads	Quantity in use: used to develop water consumption value	Marketing Research, PMI*		X	
Shipments - Clothes Washers	Quantity in use: used to develop water consumption value	AHAM, GAMA†	X		
Shipments - Dishwashers	Quantity in use: used to develop water consumption value	AHAM, GAMA†	X		
Lifetime - Toilets	Used to develop replacement rate	D&R Int'l.	X		
Lifetime - Faucets	Used to develop replacement rate	Consumer Reports	X		
Lifetime - Showerheads	Used to develop replacement rate	Consumer Reports	X		
Lifetime--Clothes Washers	Used to develop replacement rate	Consumer Reports	X		
Lifetime- Dishwashers	Used to develop replacement rate	Consumer Reports	X		
Rated Efficiency - Toilets	Used to develop water consumption value		X		X
Rated Efficiency - Faucets	Used to develop water consumption value		X		X
Rated Efficiency - Showerheads	Used to develop water consumption value		X		X
Rated Efficiency - Clothes Washers	Used to develop water consumption value				X
Rated Efficiency- Dishwashers	Used to develop water consumption value				X
Buildings					
Number of Single-Family Homes	Used to develop water consumption value	RECS (EIA)§	X		

Variable	Purpose	Source	Publicly Available	Purchased	Estimated
Number of Multi-Family Homes	Used to develop water consumption value	RECS (EIA)§	X		
Number of Mobile Homes	Used to develop water consumption value	RECS (EIA)§	X		
Vintage	Used to develop replacement rate	RECS (EIA)§	X		
Geographic Location	Used to develop replacement rate	RECS (EIA)§	X		
Number of Full Bathrooms#	Used to develop water consumption value	Marketing Research, RECS (EIA)§	X	X	
Number of Half-Bathrooms#	Used to develop water consumption value	Marketing Research, RECS (EIA)§	X	X	
Toilets#	Used to develop water consumption value	Standard (EPACT)**	X		
Showerheads#	Used to develop water consumption value	Standard (EPACT)**	X		
Faucets#	Used to develop water consumption value	Standard (EPACT)**	X		
Clothes Washers#	Used to develop water consumption value	Standard (EPACT)**	X		
Dishwashers#	Used to develop water consumption value	Standard (EPACT)**	X		
Toilets#	Used to develop water consumption value	Historical flush rate, D&R Int'l.	X		
Showerheads#	Used to develop water consumption value	Historical flow rate, CEC§	X		
Faucets#	Used to develop water consumption value	Historical flow rate, CEC§	X		
Clothes Washers#	Used to develop water consumption value	Historical flow rate, CEC§	X		
Dishwashers#	Used to develop water consumption value	Historical flow rate, CEC§	X		

* PMI (Plumbing Manufacturers Institute) has yet to determine whether their members will allow their data to be disseminated.
† AHAM -- Association of Household Appliance Manufacturers/GAMA – Gas Appliance Manufacturers' Association
‡ CEC – California Energy Commission
§ RECS (EIA) – Residential Energy Consumption Survey (Energy Information Administration)
# – Average number of devices per house
** EPACT – Energy Policy Act (1992)

Table B.2 summarizes the data obtained from the three purchased reports described above.

Table B.2 – Summary of Data from Purchased Reports

		Freedonia	**Catalina**	**SBI**
Numbers Shipped by Year		**Reported in Dollars**	**Dollars, quantity**	**Reported in Dollars**
.	Toilets	1995, 2000, 2005	1992-2012	2001-2005
	Showerheads	1995, 2000, 2005		2001-2005
	Faucets (kitchen)	1995, 2000, 2005		2001-2005
	Faucets (bathroom)	1995, 2000, 2005		2001-2005
	Bathtubs	1995, 2000, 2005		2001-2005
Building Construction Trends		X	X	
Remodeling and Replacement Trends		X	X	1980-2005
Housing Overview		X	X	X
Bathroom Trends		X	X	X
Regional Trends		X		
Imports			X	X

Appendix C: Product Survival Function

Information regarding the total stock and vintage of fixtures, fittings, and appliances in any given year is needed in order to calculate national water savings. The stock is calculated using a straightforward accounting method that takes each year's sales as input. For each year, a survival function identifies the fraction of the previously installed cohort that remains. For the purposes of this analysis, the survival function is a simple curve based on an average lifetime.

For each product type, we estimate an average, minimum, and maximum lifetime. The assumed lifetimes for each product are given in table C.1.

Table C.1 – Minimum, Average, and Maximum Lifetimes for Fixtures, Fittings, and Appliances

Lifetime (years)	Toilet	Shower	Faucet	Clothes Washer	Dishwasher
Minimum	10	5	5	5	5
Average	20	10	10	10	9
Maximum	30	15	15	15	14

We used the parameters in Table C.1 to generate a survival function by assuming a triangular retirement distribution. This distribution provides that no products are retired before the minimum or after the maximum lifetime. The maximum probability of retirement occurs at the average lifetime, and the probability is normalized (scaled) so that the area under the curve equals 100 percent. The function is converted into a survival probability according to:

$$Surv(j) = 1 - \sum_{i=0}^{j-1} R(i) \qquad \text{(Eq. C.1)}$$

In Equation C.1, *R* is the triangular retirement distribution.