MEASUREMENT OF WATER CONSERVATION SAVINGS: INDUSTRY STANDARDS VS. SCIENTIFIC METHODS

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Many state, regional and local water supply agencies have made commitments to pursue vigorous water conservation programs. These programs may range from adopting laws or ordinances that require water-efficient plumbing fixtures in new buildings to community-wide conservation campaigns involving intensive public information campaigns and/or campaigns aimed at retrofitting bathroom fixtures in existing buildings. The implementation of these programs requires often sizable public expenditures, thus making it necessary to compare the cost-effectiveness of conservation alternatives with the cost of obtaining new sources of supply. In order to make such a comparison it is necessary to determine water savings that can be attributed to water conservation measures. The uncertainty that surrounds the estimates of water conservation savings is often perceived as a major obstacle to using water conservation as one of the viable alternatives in water supply planning.

Unfortunately, methods of analysis that could improve the precision of conservation measurements are not a part of standard methods of analysis used by water industry planners. Recently, major urban water suppliers in California have recognized the need to apply valid scientific methods for estimating water savings and economic impacts of water conservation measures (Hoag, 1990). This paper provides a brief review of the most critical considerations in adopting the scientific approaches for measuring conservation savings by water industry.

Theoretical Framework

Effectiveness, or the expected volume of water savings that can be attributed to the implementation of a specific water conservation measure is a function of water use without conservation and two conservation parameters:

$$E_{i,s,d,t} = Q_{s,d,t} * R_{i,s,d} * C_{i,s,t} \qquad (1)$$

where $E_{i,s,d,t}$ = effectiveness (water savings) of measure i (e.g., plumbing code) in user sector (e.g., single-family residential) for the dimension of use d (e.g., indoor use) at time t (e.g.,year 2000), in gallons per day.

$Q_{s,d,t}$ = water use without conservation in sector s, dimension d at time t, in gallons per day, as affected by forces other than conservation (e.g., income, household size, weather and others).

$R_{i,s,d}$ = fraction reduction in the use of water by sector s in use dimension d expected as the result of implementing measure i.

$C_{i,s,t}$ = coverage of measure j in use sector at time t expressed as a fraction of total water use in that sector.

This formula is derived from a relationship first presented in Baumann et al. (1979). The most distinct features of this approach are the sectorial and seasonal disaggregation of water use and the dynamic character of water savings (i.e., effectiveness varies over time). The two conservation parameters, R and C are difficult to measure and are subject to some simplifying assumptions. For example, $R_{i,s,d}$ is assumed constant over time (e.g., it assumes a constant percent reduction in single-family indoor water use due to installation of bathroom fixtures that comply with the plumbing code). The coverage, $C_{i,s,t}$, is also difficult to measure. For example, if a new plumbing code will be implemented on January 1, 1992, then the coverage value for single-family residential sector in the future year (e.g., year 2000) is defined as a portion of total single-family use that would take place in homes built after January 1, 1992 if these homes were not complying with the plumbing code. This value can be approximated by the ratio of the new housing units (built after January 1, 1992) to the total projected number of units for the year 2000.

The effectiveness of several conservation measures implemented together is:

$$E^{L}_{s,d,t} = \sum_{i=1}^{L}(Q_{s,d,t} * R_{s,d,t} * C_{i,s,t} * I_{i,i+j,d}) \quad (2)$$

where $E^{L}_{s,d,t}$ = combined effectiveness (water savings) of L conservation measures.

$I_{i,i+j,d}$ =interaction factor for the combinations of individual pairs of measures, i and i+j, for dimension d, where j= 1,2,...,L.

The interaction factor I is probably the most critical parameter in evaluating the combined effects of water conservation measures. $I_{i,i+j,d}$ =1 if measures are independent (or nonoverlapping). However, many conservation programs include measures that are likely to interact with each other.

Current Practice

The assumptions about the effects of water conservation measures are often made despite some significant gaps in knowledge. about actual unit savings (or fraction reduction factors), market penetration (or coverage) and interaction effects. For many measures, the values of these parameters practically are nonexistent. For some measures the data are not reliable and have to be very carefully examined before they are used to formulate the assumptions. Currently, water agencies have to rely on "consensus" estimates of unit savings and coverage which were not derived from empirical data or if they are based on empirical measurements, these measurements were not obtained using scientific methods.

For example, with respect to unit savings, there is a tendency in the conservation planning practice to assume a savings rate for each measure on per capita basis (e.g., 15.2 gallons per capita per day for water-efficient plumbing fixtures) and use it as a constant for all communities and all time periods. This savings rate is taken to represent a difference in average water use between homes that comply with new plumbing code and older homes, regardless of the level of indoor water use in homes without the new plumbing fixtures. The use of the fractional reduction factor (see equation 1) which represents percent savings in indoor water use would mitigate, to some extent, the somewhat unrealistic assumption of constant savings but it does not account for all factors that can influence actual savings.

Coverage (or market penetration) is an unknown quantity for most measures. For example, fixture retrofit campaigns suffer from imprecise estimates of the actual installation rates of the retrofit devices by homes that received the devices. The self-reported adoption of these devices (i.e., obtained through telephone surveys) is not a reliable measure. Often residents simply do not know if they have a low-flow shower head or a 3.5 gallon toilet tank. Also the results of on-site surveys and water audits cannot easily be generalized to assess the community-wide adoption rates because of both nonscientific sampling and small sample size.

Also, double counting of water savings is a real problem when structural measures (e.g., retrofit) and nonstructural measures (e.g., education or pricing) are used together in a conservation program. The interaction between measures may be competitive, complementary, or synergistic. For example, if technological (or nonmarket) conservation measures are combined with price incentives, the combined effectiveness of conservation and price (E_{c+p}) can be:

1) Competitive, i.e., nonmarket conservation measures may preempt the impact of price increases and

$$E_{c+p} < E_c + E_p; \qquad I_{c,p} < 1 \tag{3}$$

2) Complementary, i.e., impacts of nonmarket conservation measures is virtually independent of the impact of price, and

$$E_{c+p} = E_c + E_p; \qquad I_{c,p} = 1 \tag{4}$$

3) Synergistic, i.e., nonmarket conservation measures enhance the impact of price changes.

$$E_{c+p} > E_c + E_p; \qquad I_{c,p} > 1 \tag{5}$$

The assumption about which of the three types of interaction applies will have a major effect on the estimate of aggregate savings. Very little empirical data exists to assess the degree to which conservation measures interact.

Finally, the important quantity in estimating water savings is the level of water use that would be observed in absence of conservation measures. The current practice is to determine future water requirements per person or housing unit as constant over time. If a constant per capita water use is assumed than there is a potential for underestimating future water use with conservation, if the demographic, economic and climatic characteristics of an urban area are expected to change in the direction that will increase per capita use.

In summary, the current industry, Standards for the evaluation of water conservation are inadequate or nonexistent. Subsequently, the use of water conservation as a viable alternative in water supply planning is severely constrained. There is a need to develop a set of standard procedures for measuring the effects of existing water conservation programs and extrapolation of these measurements to other geographical areas and future time periods. These procedures should be based on scientific principles of research. The following sections gives examples of a scientific approach to the evaluation of water conservation.

Scientific Methods

The scientific methods of evaluation comprise three analytical components: data, measurement and extrapolation. Equations 1 and 2 represent the extrapolation component. These models have to be conceptually correct ways of extrapolating the empirical measurements of fractional reduction in water use and coverage parameters to predict the effectiveness of water conservation for different time periods. Equation 1 implies that a disaggregate forecast (by season and sector) is required in order to obtain a precise estimate of conservation savings.

The estimates of fractional reduction in water use have to be derived from empirical data. In most cases the data will be obtained by taking samples of water users. These samples have to be obtained using scientific sampling (e.g., simple random sampling, stratified random sampling) in order to ensure the applicability of measurements to total population of users. Probability sampling will produce representative samples provided that the sample size is sufficiently large. The precision of measurement is a function of sample size and the variance in the measured population characteristic. Variance in water use of individual households is very large. Table 1 shows the mean and standard deviation in water use in several samples of single-family homes. If water conservation savings are to be measured as a difference in mean water use between homes with and without conservation devices then very large samples will be required. For example, the absolute measurement error of 15 gallons per day with standard deviation in water use reported by Dziegielewski and Opitz (1988) would require a sample of 2400 homes. This error merely would equal the expected savings in water use.

Significant cost savings can be achieved without sacrificing the accuracy of measurement by employing econometric modelling of water use which isolate part of the variation in water use by attributing it to systematic differences among households (such as income, household size, family composition and other characteristics). The precise measurement of conservation savings requires sophisticated modelling of water use using the standards of econometric analysis for model specification and estimation techniques. At this date only a handful of adequate statistical analyses of conservation savings have been performed. The results of studies that attempted to measure conservation savings of retrofit devices are summarized in Table 2. These results show significant differences in estimates of conservation savings and further improvement is needed to enhance replicability of these measurements.

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TABLE 1.
EXAMPLES OF VARIANCE IN SINGLE-FAMILY WATER USE

Source	Sample	Mean Water Use	Standard Deviation
1. Bruvold & Smith, 1988	August, 1982 use in 182 homes in San Francisco Bay Area	138.3 gpcd	112.2 gpcd
2. Boland, McPhail & Opitz	Winter season use in 955 homes in Southern California	99.1 ccf / 6-mo.	125.3 ccf / 6-mo.
	Summer season use in 903 homes in Southern California	159.6 ccf / 6-mo.	283.1 ccf / 6-mo.
3. Dziegielewski & Opitz, 1988	Monthly water use in 950 homes in Phoenix from April, 1984 to, December, 1986	497.7 gpd	374.2 gpd
	January, 1986 use in 644 homes	103.4 gpd	62.3 gpd
4. Griffin & Chang, 1990	Aggregate monthly use in 30 Texas communities during January, 1983 to December, 1985	165.7 gpcd	55.5 gpcd
5. Nieswiadomy & Molina, 1989	Summer month use in a sample of 101 customers from Denton, Texas (1976 - 1980)	14,060 gal / month	11,218 gal / month

TABLE 2.
A COMPARISON OF REPORTED WATER SAVINGS OF RESIDENTIAL RETROFITS

		Estimates converted to Per Household (and Per Capita) Savings		
Source	Reported Savings	Gal / Cap / Day	Gal / House / Day	Remarks
Morgan, 1980	Average saving of 780 cubic feet per year for each installer household.	6.4[b]	16.0	A sample of 473 households in California, of which 296 installed conservation kits (showerhead flow restrictors, toilet dams, leak detection tablets.
Maddaus, 1987	Per capita savings	11.2	30.6[a]	A national sample of 281 homes. Savings devices include 2.75 gpm showerhead and toilet dam.
Palmini and Shelton, 1982	Annual water savings of 7400 gallons per year in a household installing the kit.	(--)	20.3	A sample of 105 households in East Brunswick township, New Jersey. Savings in a household installing one or more of the devices.
Dziegielewski and Opitz, 1988	Average water savings in homes designated as "installers" using a binary variable in a structural water demand model.	5.1[c]	16.5	A sample of 1,388 single-family homes in Phoenix, Arizona. A 95 percent confidence interval for household savings is from 6.9 to 26.1 gal / day.

[a] Estimated from per capita using 2.73 persons per household.

[b] Estimated from total household savings using 2.5 persons per household.

[c] Estimated capita savings obtained using 3.22 persons per household (sample mean).