

**RESIDENTIAL WATER DEMAND MANAGEMENT PROGRAMS:
A SELECTED REVIEW OF THE LITERATURE**

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CONTENTS

Review

Introduction.....	1
Program Comparisons.....	1
<i>W. O. Maddaus</i>	2
<i>Renwick and Green</i>	3
<i>Campbell, Larson, Johnson, and Watts</i>	4
<i>L. A. Maddaus</i>	5
<i>White, Howe, and Fane</i>	7
<i>Miri</i>	9
<i>Keyes, Schmitt, and Hinckle</i>	11
Cost Effectiveness Methodology	11
<i>Discounting the Future</i>	11
<i>Full Cost Accounting</i>	12
<i>Probability of Success</i>	13
Bibliography	15

Appendixes

Guidebooks and Handbooks	17
Methods of Evaluating Conservation Programs	22
Integrated Resource Planning	26
Metering.....	28
Conservation Pricing: Residential Demand	30
Conservation Pricing: Industrial Demand.....	42
Plumbing.....	46
Water Efficient Landscaping	47
Reclaimed Water.....	48
Public Involvement and Education	49

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I. Introduction

This review consists of three parts. First, I review a handful of papers that compare the effectiveness of alternative demand management programs. Second, I examine methods used in the literature to evaluate alternative demand management programs. Finally, I include several appendixes that list references to major topics in the water demand management literature.

I do not review studies of the response of water demanded to changes in price because thorough reviews of this literature are available, at least for residential water demand. Appendix 5 provides an extensive list of references on residential water demand and pricing. Most of these are from USEPA (2004) and the literature reviews by Arbues *et. al.* (2003) and Epsy *et. al.* (1997). Far fewer studies of industrial demand for water have been published. The industrial demand references in Appendix 6 were compiled from de Gispert (2004) and Reynaud (2003).

II. Program Comparisons

The papers that I review here presented analytical comparisons of the effectiveness of alternative demand management programs. Comparison methods varied widely among these papers. Only four papers, W. O. Maddaus (1984), Renwick and Green (2000), Campbell *et. al.* (1999), and L. A. Maddaus (2001) measured outcomes after programs were implemented. Several planning studies compared expected costs to expected water savings. Among this group, papers by White and Howe (1998) and White and Fane (2002) compared expected costs per unit of water saved. A paper by Miri (*n.d.*) reported results from a survey of state conservation programs and Keyes *et. al.* (2004) identified organizational characteristics that led to successful water conservation programs.

W. O. Maddaus

Maddaus (1984), sponsored by the U. S. Department of Housing and Urban Development, is the granddaddy of published studies comparing water conservation programs and was probably the most influential. The study presented field results from several demonstration projects that examined effects of water-saving fixtures, water pressure, and water metering on household water use. As the author points out,

In the past, water engineers and planners had to rely on estimates based mostly upon laboratory tests of low-flow fixtures. These estimates, spanning a range of 300 percent, have caused confusion in the water field and a general lack of confidence in water conservation techniques. Now with the HUD projects completed, water planners have a better basis for calculating the benefits of water conservation programs with more confidence that predicted savings will be realized.

(Maddaus 1984, 1-1)

The principal quantitative results are summarized in the table on the next page. Retrofit programs, in particular, resulted in less water savings than might be expected because some homes that did not receive retrofit kits already had retrofits installed and, more importantly, many homes that received retrofit kits did not install them. For one program where retrofit kits were bulk mailed to households, installation rates were 27 percent for toilet tank bags (dropping to 19 percent several months later) and 21 percent for shower flow restrictors (dropping to 10 percent several months later). Higher installation rates were achieved in two programs that occurred during a drought and had different methods of distribution: 60 percent for toilet displacement bottles (dropping to 47 percent five years later) and 30 percent for shower flow restrictors (dropping to 26 percent five years later).

Summary of HUD Study Results

Water Conservation Practice	Observed Water Savings
Install water meters	20 percent
Reduce pressure 30 to 40 psi	3 to 6 percent
Fix toilet leaks	24 gallons per day per toilet
0.5 gallons per flush toilet	19.6 gallons per capita per day
0.5 gallons per minute shower head	13.8 gallons per capita per day
3.5 gallons per flush toilet	8.0 gallons per capita per day
3 gallons per minute shower head	7.2 gallons per capita per day
Retrofit Kits	4 to 7 gallons per capita per day
Water-efficient cloths washer	1.7 gallons per capita per day
Water-efficient dish washer	1.0 gallons per capita per day

(Maddaus 1984, 1-7)

Renwick and Green

The following list provides brief descriptions of California programs carefully examined by Renwick and Green (2000) as well as brief descriptions of the effects of each program on residential water consumption.

Restrictions

Prohibit certain water uses, such as washing down sidewalks or driveways, or banning landscape irrigation during peak evapotranspiration hours.

Reduced consumption 29 percent.

Rationing

Allocate a fixed quantity of water to each household and impose severe marginal price penalties for exceeding the allotment.

Reduced residential consumption 19 percent

Retrofit Kits

Distribute free retrofit kits including low-flow showerheads, tank displacement devices, and dye tablets for leak detection.

Reduced residential consumption 9 percent.

Public Information Campaign

Alert households to shortages, attempt to motivate more water-efficient behavior, and provide information on means to reduce usage.

Reduced residential consumption 8 percent.

Rebate

Provide rebates for installing ultra-low-flow toilets.

Had no significant effect on residential consumption.

Affidavit Requirement

Require all households to file an affidavit attesting that specific water-efficient devices were installed in the household.

Had no significant effect on residential consumption.

(Renwick and Green 2000)

Renwick and Green also estimated the price elasticity of residential demand for water to be -0.16, rising to -0.20 in summer months from June to August.

Campbell, Larson, Johnson, and Watts

The data sample utilized by Campbell *et. al.* (1999) combined census-tract information and climate data with monthly water bills for 1,200 households in Phoenix, Arizona, over a period from 1990 to 1996. Water prices changed during this period and several conservation programs were implemented. Most of the conservation programs involved installing new plumbing fixtures. Two programs, *Seniors Helping Seniors* and *Metrotech/Neighbors Helping Neighbors* used trained volunteers to distribute and help install low-flow plumbing devices. The *Low-Flow Fixtures and Devices Ordinance* required all new and replacement fixtures to meet low-flow requirements. Audit kits were mailed to households for the program called *Unsolicited Audit Kits*. Households that returned their audit cards received water-conserving devices and fixtures. The *Union Hills Drop-Off* was a blanket program that distributed hardware to virtually every doorstep in the program area and the *Depot Pick-Up* program was similar, except customers had to pick up hardware at a central depot.

Findings listed by Campbell, *et.al.* included:

"Water price can be an even more effective conservation method than the most effective non price method."

[They estimated the own-price elasticity of demand to be - 0.27.]

"A citywide ordinance mandating water-saving devices for all new and replacement fixtures overall saved the most water of any non-price conservation policy."

"Targeted retrofit programs are the next most promising category of policies and measures analyzed."

"Retrofit programs not based on some indication of need are not good bets."

(Campbell, *et. at.* 1999, 4)

The authors pointed out that, "distressingly, the *Union Hills* [drop-off] and *Depot* [pick-up] programs were actually estimated to cause additional water usage of the same order of magnitude as the savings of several of the best programs." (Campbell, *et. at.* 1999, 10)

L. A. Maddaus

Lisa A. Maddaus (2001) analyzed water use in Davis, California, before and after a switch from fixed monthly fees to fees with a variable component contingent upon water use. She records that installation of water meters, mostly financed with a loan from the state, cost approximately \$480 per meter and annual meter reading cost \$60,000. (Maddaus 2001,5)

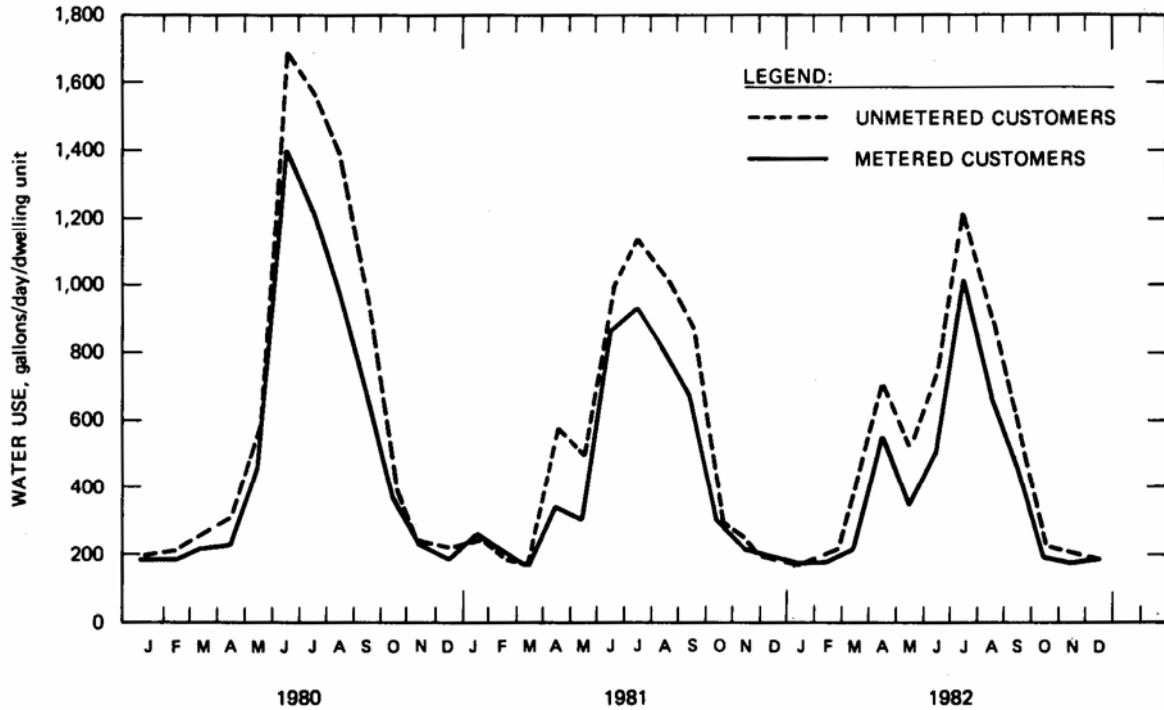
The fixed monthly bill originally was \$199 per year for a single family residence, after the rate change the fixed component became \$102 per year with a variable component of \$ 0.49 per hundred cubic feet. The water bill for a household with constant use of 225 hundred cubic feet per year, which Maddaus identified as median household use, increased \$13 per year as a consequence of the rate change. (Maddaus 2001, 7) She reported the following figures for average, single family residential use:

Year	Gallons per Account per Day
1966	540
1997	538
1998	490
1999	465

(Maddaus 2001, 16)

The new rates took effect in September, 1998. There was a significant decline in use for the year 1998 even though the new rates were in effect only during part of that year. Maddaus speculates that public awareness of the upcoming rate change began to affect consumption before the rate change took effect. Water consumption rose in 1999, but was still about 13 percent below what it was before the rate change.

Maddaus' review of the literature indicated that installation of water meters typically reduced consumption in the range of 10 to 30 percent and sometimes as much as 50 percent. Her list of references regarding the impact of metering is included here as Appendix 4.



Average Daily Water Use
(Maddaus 1984, 7-4)

By comparison, William O. Maddaus (1984) in the HUD study reviewed earlier found a 20 percent reduction in water use for metered, compared to un-metered, households. This study was unique because it compared use among nearly identical houses, in the same neighborhoods, with established water use patterns. The above graph, reproduced from this study, shows that water consumption was about the same for metered and un-metered households during winter months when most water use was indoors. The primary difference was greater outdoor water use by un-metered households during the summer months.

White, Howe, and Fane

The studies by W. O. Maddaus, Renwick and Green, Campbell *et. al.*, and L. A. Maddaus were *ex post* in the sense that they measured consequences of demand management policies after those policies were implemented. However, planning studies, by their nature, are

ex ante in the sense that they analyze expected consequences before policies are implemented. For example, White and Howe (1998) and White and Fane (2002) evaluated the potential cost-effectiveness of a range of demand management policies considered for implementation at two locations in Australia. They ranked projects with a unit-cost measure called "levelised cost" which appears to be an appropriate and effective measure for comparing incremental unit costs of projects with differing sizes and payback periods. Levelised cost will be discussed in greater detail in the next section of this report.

Levelised cost is found by dividing the present value of future costs by the "present value" of future water saved. The denominator is a physical quantity, not a monetary quantity, so the ratio measures discounted units of money per discounted unit of water. The table reproduced below shows the programs, expected reduction in consumption, and expected cost measured in levelised Australian cents per liter.

Levelised Cost of Reducing Consumption

	Liters per Capita per Day	Levelised Cost (A¢ per liter)
1. Shower head performance standard	8.6	0.0014
2. Price increase (10 A¢ per kL over 2 years)	1.9	0.0018
3. Clothes washer performance standard	3.5	0.041
4. Outdoor water use restrictions	1.8	1.063
5. Shower head rebate (A\$10)	0.7	0.14
6. Residential indoor audit & retrofitting	3.4	0.19
7. As for 6 (free for low-income)	1.5	0.25
8. Active leakage control	7.2	0.30
9. Industrial & commercial audits	2.9	0.42
10. Hotel audits	1.3	0.42
11. Outdoor water use promotion	0.2	0.49

(continued on next page)

**Levelised Cost of Reducing Consumption
(continued)**

	Liters per Capita per Day	Levelised Cost (A¢ per liter)
12. Industrial reuse project 1	2.3	0.53
13. Industrial reuse project 2	1.8	0.65
14. Outdoor irrigation systems audits	0.3	0.67
15. Washing machine rebate (A\$150)	0.4	0.70

(White and Fane 2001)

Miri

Miri (*n.d.*) reported results from a survey partially funded by the American Water Works Association that canvassed state demand management programs. The survey was sent to all 50 states and eventually 42 states responded, Georgia was one of the eight that did not respond. Half the states responding to the survey had statewide conservation management plans or strategies, 25 states required public water systems to prepare conservation plans, and 18 states had the power to accept or reject local conservation plans. (Miri *n.d.* 4) Enforcement of local plan requirements followed from state permitting and lending activities:

The most popular mechanism by which the system plans are required and reviewed is as a condition of receiving and/or retaining a water allocation or withdrawal permit. Eighteen of the 25 states requiring public water system conservation plans (72.0%) utilize this type of trigger. The next most popular mechanisms, with five states (20.0%) using each of them, are as a condition of receiving financial assistance from the state and as a part of the state's required review of public water supply facility plans.

(Miri *n.d.* 4)

The following table lists issues that states required local plans to address.

Number of States	Issues Required to be Addressed in Local Plans
20	public education and awareness
18	water use (demand projections, peak demands, etc.)
18	identification of conservation measures
16	conservation rates
13	system data (sources, interconnections, etc.)
12	water audits
11	lawn irrigation ordinances
11	amount of water to be saved

(Miri *n.d.* 5)

Some other survey results relating to state funding included:

Number of States	State Activities
30	conservation outreach and technical assistance
10	conservation research and demonstration programs
16	state funding of demand reduction programs
11	state funding of local outreach programs
9	state funding of system leak detection and repair
6	state funding of residential demand reduction
4	state funding of customer leak detection

(Miri, *n.d.* 5-7)

Keyes *et. at.* (2004) compared selected water districts to identify organizational attributes of effective demand management programs. Their principal conclusion was that successful demand management programs shared all seven of the following characteristics:

1. political leadership,
2. stakeholder involvement in planning and implementation,
3. a detailed policy outlining goals and conservation measures,
4. detailed water use data, demand forecasting, and monitoring,
5. stable funding sources for water conservation measures,
6. sufficient staff and technical assistance to implement the program, and
7. broad-based education and outreach.

(Keyes, *et. at.* 2004, 1)

III. Cost-Effectiveness Methodology

The phrase "integrated resource planning", that is now common in water planning papers, originated in the electricity planning literature and refers to the doctrine that evaluations of alternatives for capacity expansion to augment supply should be accompanied by evaluations of alternatives for demand management to attenuate consumption. Usually this boils down to cost-effectiveness comparisons of alternatives instead of full-blown cost-benefit comparisons.

Analytical problems discussed in the literature arise because the projects being compared often have radically different scales and lifetimes. This problem and two others are discussed here.

Discounting the Future

A typical demand management program entails an initial money outlay that will generate savings in water consumption spread out over the future. The usual procedure to account for the timing of income or spending is to discount money streams back to their present values.

However, unless one is careful, discounting can lead to erroneous results when comparing projects that are dramatically different in size or timing of future flows of money or water. As

mentioned earlier in this review, White and Howe (1998) and White and Fane (2002) ranked demand management projects with a ratio they called "levelised cost." This technique is explained in detail in Fane and White (2003) and it is especially useful for ranking unit costs among programs of different sizes and durations.

The numerator of the levelised cost ratio is the present value of all initial and future costs incurred by a program and the denominator is the discounted amount of all initial and future water reductions. The numerator is a dollar value, the denominator is a quantity of water; the ratio itself is a *discounted cost per discounted unit of water*:

$$Levelized\ Cost = \frac{\sum_{i=0}^N \frac{C_i}{(1+r)^i}}{\sum_{i=0}^N \frac{Q_i}{(1+r)^i}} .$$

This ratio scales money amounts according to the times when they occur, which is the case with usual present value procedures, but it also scales water quantities according to the times when *they* occur. This second feature of levelising cost is not incorporated in usual present value procedures and for that reason levelised cost is especially appropriate for comparing unit costs of projects with radically different sizes or durations.

Full Cost Accounting

Needless to say, reliable cost comparisons of demand management programs only occur when all costs are taken into account, including the costs of administering and implementing the programs. Administration and implementation costs are often *implicit* costs that do not entail actual money outlay but are, nevertheless, real claims on the use of valuable resources. If workers are paid to administer and implement a program, then the cost of their time is the amount they are paid. But sometimes workers are not paid explicitly, instead their time is

merely shifted away from other duties. Then the value of their time must be imputed according to their rate of pay and the amount of time shifted from other duties.

Implementation often involves expenditures of time by water customers, time used for self-installing plumbing fixtures is an example of this type of cost. The starting point for imputing self-installation cost is the cost of hiring a plumber to do the work. It might be argued that the time a handyman spends self-installing fixtures would be less valuable than time spent by a professional plumber. But one must remember that a plumber who does this kind of work on a regular basis will use less time than a handyman and, further, the value of a handyman's "leisure" time spent installing plumbing fixtures is greater than the handyman's pay at his normal job, otherwise the handyman would be working at his normal job instead of installing plumbing fixtures at home.

Probability of Success

The most prominent lesson from the demand management literature is that programs to encourage demand management activities do not guarantee that the desired activities will actually take place. For example, many studies show especially low expected cost of plumbing retrofits when the probability of installation is *assumed* to be one hundred percent. But *actual* demand management programs generally have low installation rates, sometimes very low. At least one program of distributing retrofit kits to customers' doorsteps had an installation rate of *zero*. (Campbell, *et. at.* 1999) When the probability that the encouraged behavior will actually occur is taken into account, the costs of many programs are much less favorable.

Clearly, probability of success is one of the most important considerations in cost-effectiveness comparisons of alternative water demand management programs. The appropriate calculation is to multiply the water quantity in the denominator of the levelised cost ratio by the program's probability of success or, equivalently, by the expected installation rate.

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