Residential Water Audit Program

Evaluation of Program Outcomes and Water Savings

A & N Technical Services, Inc.

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THE 1992 CITY OF SAN DIEGO RESIDENTIAL WATER AUDIT PROGRAM: EVALUATION OF PROGRAM OUTCOMES AND WATER SAVINGS

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PREFACE

The City of San Diego Water Utilities Department's Water Conservation Program implemented a residential survey ("audit") program for single family households from July until December of 1992. The City audited approximately 2,500 single family residences during this first phase of the program.

Urban water suppliers that are signatories to the Memorandum of Understanding (MOU) Regarding Urban Water Conservation in California are required to implement residential and commercial water audits in accordance with Best Management Practice 1 (BMP 1). Although the MOU makes some preliminary estimates of possible water savings from residential audits, the level and persistence of these savings have been questioned.

To assist water planners in reliably accounting for water savings achieved through residential water audits, this report details an impact evaluation that was conducted using data collected from the first phase participants and a control group of nonparticipants. These results should interest all signatories of the MOU as well as other utilities that count on demand-side management to yield a portion of their future water supply.

EXECUTIVE SUMMARY

In the summer of 1992, the City of San Diego implemented a residential audit program. Managed in-house, the program resulted in approximately 2,500 single family residential audits. Eligibility into the program was not based upon the level of water consumption. Any single family household could choose to participate.

The City of San Diego is not necessarily typical of other regions in Southern California. Being mostly coastal, its average pre-drought water consumption was about 360 gallons per household per day among single family households. Average consumption in hotter inland areas of California is estimated at over 500 gallons per household per day. In addition, water for single family households in San Diego has been priced according to a two-tier inclining block rate since 1983. Currently, single family households pay approximately $1.285 per hundred cubic feet (HCF) for the first 10 HCF per month. For consumption exceeding this threshold, the price rises to $1.420 per HCF. Sewer charges for single family households used to be a flat monthly fee until July 1993. This has now changed. Since July 1993, sewer charges are based upon household water consumption recorded for the most recent winter months.

All the above mentioned factors make San Diego different from other parts of the State. Although these factors can influence the effectiveness of residential audits, none of them enters into the water savings estimates stated for residential audits in the Memorandum of Understanding Regarding Urban Water Conservation in California (MOU).

Estimated Net Water Savings

Based on the MOU's estimates, single family residential audits in San Diego should have saved approximately 33 gallons per household per day. The detailed evaluation performed in this study compares participants to a control group of nonparticipants. It suggests savings of only slightly over 18 gallons per household per day. Many reasons can be put forth to explain this discrepancy.

First, over 60 percent of showerheads found in the audited residences already had flow rates under 3 gallons per minute. In part, this resulted from the City's plumbing retrofit program where retrofit kits containing low-flow showerheads, toilet displacement devices and dye tablets were distributed to more than 145,000 single family households during 1991 and 1992; and in part from low water pressure or mineral deposits in the showerheads due to aging. Replacement of such showerheads with new low-flow showerheads obviously did not save much water. If the MOU's estimates are refined to account for preexisting fixtures, the water savings estimate reduces from 33 to 27.5 gallons per household per day. This is still considerably higher than the savings estimated in this study.

Part of the discrepancy may be explained by an inclining block rate structure that possibly made San Diegans somewhat water efficient even prior to the audit. For example,

plumbing and toilet leaks were found in only 4 to 6 percent of participating residences. Although reliable statewide estimates of plumbing leakage are unavailable, many suspect that leakage rates in other parts of the state may be higher. Furthermore, the evaluation was performed during a time period when average water use was still depressed as a result of the drought. In the summer of 1993, water use was approximately 20 percent below the historical norm corrected for climate. Ongoing conservation could have reduced the effectiveness of the audit. If so, net savings resulting from the program should rise as water use creeps back to the historical norm.

What Would a Targeted Program Save?

Because the MOU recommends targeting only the highest 20 percent water users among single family residences, it is perhaps more relevant to address savings that should result from a targeted program. For this, net average savings must be subdivided into its indoor and outdoor components. We performed this subdivision by analyzing net savings among households that reported no turf area and households that reported complete turf related information, including irrigation system type. Net savings among participating households with no turf were estimated to be approximately 12.4 gallons per household per day. This estimate compares reasonably well with our refined mechanical estimate of indoor water conservation (13.6 gallons per household per day) although it is substantially lower than the MOU's estimate of indoor water savings, excluding leak detection, of 19.1 gallons per household per day. Among households with complete turf related information, net savings were estimated to be approximately 26.1 gallons per day. The data did not provide sufficient resolution to judge whether net savings among residences with complete turf related information depended on the type of irrigation system. However, preliminary indicators suggest that the audit was more effective among residences with automatic sprinklers than residences with either a manual sprinkler system or drip irrigation system. This is not surprising because residences with automatic sprinklers used the greatest amount of water before the drought and did not conserve as much during the drought. Thus, there was greater room for savings in residences with automatic sprinklers. The City also sent a followup postcard to participants with automatic sprinklers to remind them of the need to change controller settings according to season. This followup was probably also beneficial.

We also attempted to estimate directly the net savings among the highest 20 percent water users in our sample. The top 20 percent water users were identified according to average pre-drought water use. This 80 percent reduction in sample size substantially reduced the level of statistical precision in our savings estimates. As a result, the net savings estimate was not significantly different from the net estimate of 26 gallons per household per day for participants with complete turf related information. However, not all participants with complete turf related information fell in the top 20 percent water use

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bracket. Thus, we conservatively estimate that a targeted audit program in the City of San Diego will produce water savings of approximately 26 gallons per household per day, or somewhat higher. This estimate is again much lower than the MOU's estimate for a program that targets the highest 20 percent of water users—approximately 44.7 gallons per household per day. The difference between the two estimates may reduce somewhat as average water use creeps back up to its pre-drought levels.

Did Water Savings Diminish Over Time?

Many water planners argue that residential audits produce only temporary behavioral change. Accordingly, water savings diminish over time. Analysis of water use data one year after program implementation showed no decrease in net water savings among participants. Whether these savings will persist over longer periods is still an open question. On the one hand, it could be argued that only savings resulting from indoor retrofits will persist over time (i.e., approximately 12.4 gallons per household per day). On the other hand, if net estimates of savings are biased downwards because of ongoing conservation, the net impact may even increase in the future. Only additional followup evaluations can address this issue.

In any event, extrapolation of savings estimates from San Diego to other parts of the State must be done with full recognition that San Diego's climate and rate structure make it different from many other parts of California.

Cost-Effectiveness of Residential Audit Programs

Residential audits implemented in 1992 cost the City of San Diego approximately $46.30 per site. The actual cost of each audit including San Diego Gas and Electric's (SDG&E) portion was somewhat higher, approximately $52 per site. Because of ongoing conservation and the untargeted nature of the audit program, water savings were lower than expected. We estimate that the cost of saved water to the City of San Diego was slightly in excess of $500/acre-foot. This cost-effectiveness estimate embeds the critical, and yet untested, assumption that the average savings of 18 gallons per household per day persists for 5 years. This estimate also ignores the long-term benefits of audit programs such as improved customer relations and customer education.

We expect future targeted programs to be substantially more cost-effective in San Diego by generating water at approximately $360/acre-foot. Again, this conclusion rests heavily on the yet untested assumption that audit savings persist for 5 years or more.

Detailed cost-effectiveness calculations suggest three broad conclusions. First, nontargeted programs are in general unlikely to be cost-effective. Second, integrated efforts by the water, energy and sewer utilities can considerably improve the cost-effectiveness of audit programs. The City's innovative partnership with SDG&E serves as a model for other service areas. Lastly, water utilities should integrate post-audit followup efforts into the design of their audit programs from the get go. Post-audit followups are critical for ensuring that audit savings do not fizzle away.

ACKNOWLEDGMENTS

The quality of statistical analysis can only be as good as the data. The extreme care shown by the Water Conservation Program staff of the City of San Diego with respect to program implementation, quality assurance, and proper record keeping were invaluable in performing this evaluation. We would specifically like to thank Marsi Steirer, Mark Broder, and Jo Ellen Jacoby for freely sharing their knowledge, insights, and data with us. Their dedicated cooperation greatly helped us frame the analysis in terms that hopefully increase the relevance of this study to practitioners in the field. We greatly appreciate Mark's willingness to spend many hours over the phone, in spite of his busy schedule, describing the City's audit program database. We would also like to thank Bryan Swauger, who diligently provided all the billing history and meter retrofit data we requested.

This study could not have been carried out without the active cooperation of the Metropolitan Water District of Southern California (MWD). MWD's firm belief in rigorous program evaluation is both unusual and very welcome. In particular, special thanks go to John Wiedmann and Michael Moynahan of the State Water Project and Conservation Division for their unstinting support.

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I. PROGRAM DESCRIPTION

Introduction

Water conservation is a way of life for the residents of San Diego. San Diego is the sixth largest city in the United States, with a population of approximately 1.2 million. Located in a semi-arid region, San Diego is growing rapidly (3.8 percent annually) and imports about 90 percent of its water from Northern California and the Colorado River.[1]

The City of San Diego became an original signatory to the MOU in September 1991. Even prior to signing the MOU, it had an urban water management and conservation plan that contained many of the concepts codified in the MOU. These include residential water audits and conservation pricing. Inclining block rates have been in effect for the residential sector since 1983. When California entered its sixth year of drought in 1992, the City decided to implement the residential water audit component of its conservation plan.

Program Design, Eligibility, and Customer Solicitation

The City of San Diego decided to implement the residential audit program in-house instead of subcontracting the task to a demand-side-management vendor. This decision rested on a belief not only that an in-house program would be more cost-effective but that direct control by the utility would keep the program focus flexible and generate additional information about the utility's customers. In addition, the City of San Diego collaborated with San Diego Gas and Electric (SDG&E) to include an energy management component in the residential audit program. The City designed and managed the program and survey staff, and SDG&E furnished the energy-saving equipment (low-flow showerheads, compact flourescent light bulbs). This partnership allowed the City to split the audit program costs with SDG&E and achieve conservation in two vital areas, water and energy.

Eligibility for participating in the program was restricted to single family households. The first phase of the program implemented in 1992 did not try to bias eligibility in favor of high water users. However, the second phase implemented in 1993 targets the top 20 percent water users.

The City of San Diego disseminated information about the program in several ways. To solicit interest in the audit program, the City included a description of the program on water bills sent to all single family households during program startup. The program description contained a hotline number for receiving detailed information about the program and for scheduling appointments. In addition, the City mailed brochures describing the audit program to over 48,000 single family households selected at random from the single family customer base. Additional information about the program was displayed in prominent public

[1]The City of San Diego, "Preliminary Report of the 1992 City of San Diego Residential Water Survey Program," March 1993.

places and during community events. All these outreach programs resulted in slightly over 2,500 single family households expressing interest in having their homes audited by the water utility's staff. The brochure mailout generated approximately 57 percent of the participants and the water bill messages approximately 26 percent. The rest of the participants heard about the audit program either through audit staff, water conservation educational presentations, friends and neighbors, or through advertisements in the media and at community events.

Analysis of participation motives shows that approximately 73 percent of the participants requested an audit because they wanted to reduce either their water consumption or their water bills. Others participated because they specifically wanted either the energy and water-saving fixtures, or irrigation customization and landscape information.

The Retrofit Kit and Irrigation Customization

The indoor water retrofit kit consisted of showerheads, toilet dams, faucet aerators, and dye tablets. In addition, it included conservation-oriented printed matter and several promotional items, such as a bucket and a conservation magnet. The showerheads were rated at 2.4 gallons per minute (gpm) by the manufacturer, and the toilet dams had a displacement of 1.1 gallons. Both showerheads and toilet dams have a projected service life of 5 years.

The outdoor audit was conducted in two stages. First, auditors analyzed application rates of irrigation systems through physical measurement using catch cans. Based on application rates, soil type, grass type, and climate zone, the auditors then recommended optimum irrigation schedules to the participating households.

Pre-Program Water Savings Estimates

Water savings estimates associated with the Best Management Practices (BMPs) included in the MOU are either guesses or are based on the Brown and Caldwell (1984) study undertaken for the U.S. Department of Housing and Urban Development. The HUD study, as it is commonly called, was one of the first to evaluate water savings achievable through water-efficient plumbing retrofits. Table I-1 shows the MOU's savings estimates for single family residential audits. All the informational inputs that enter into the derivation of these savings estimates are included at the bottom of Table I-1.

Based on the Census, there are on average 2.7 persons per single family household in Southern California. It is also estimated that on average approximately 34.6 percent of total water use in single family households is for outdoor purposes.[2] Combining the above

[2]Metropolitan Water District of Southern California, The Regional Urban Water Management Plan for the Metropolitan Water District of Southern California, 1990, pp. 32.

information with a pre-drought average water consumption of 360 gallons per household per day leads to a savings estimate of 36.8 gallons per day for pre-1980 construction and 21.7 gallons per household per day for post-1980 construction. The calculations underlying these estimates are also shown in Table I-1.

Based upon data from participants, approximately 75 percent of single family housing is of pre-1980 vintage. Taking a weighted average leads to an estimate of indoor and outdoor water savings of 20.5 and 12.5 gallons per household per day, respectively. Added together, these produce total savings of 33 gallons per household per day.

Table I-1 MOU's Water Savings Estimates-Single Family Residential Audits

Source of Savings	Estimated Savings	
	Pre-1980 *Construction*	**Post-1980 *Construction***
Low-flow showerhead retrofits	7.2 gcd	2.9 gcd
Toilet retrofit with dams or bags	1.3 gcd	0.0 gcd
Leak repair	0.5 gcd	0.5 gcd
Landscape audit	10% of outdoor use	10% of outdoor use

INPUTS: Persons per household = 2.7
Irrigation as proportion of total water use = 34.6 percent
Pre-drought average water use = 360 gl./hh/day

CALCULATIONS:
For pre-1980 construction.
Indoor savings = (7.2gcd+1.3gcd+0.5gcd) * 2.7 persons/hh = 24.3 gl./hh/day
Outdoor savings = 360 gl./hh/day * 0.346 (coverage factor) * 0.10 (reduction factor) = 12.5 gl./hh/day
Total savings = 24.3 + 12.5 = 36.8 gl./hh/day.
For post-1980 construction.
Indoor savings = (2.9gcd+0.0gcd+0.5gcd) * 2.7 persons/hh = 9.2 gl./hh/day
Outdoor savings = 360 gl./hh/day * 0.346 (coverage factor) * 0.10 (reduction factor) = 12.5 gl./hh/day
Total savings = 9.2 + 12.5 = 21.7 gl./hh/day.

Had San Diego's program targeted only the highest 20 percent of all water users, the MOU's estimates would have been correspondingly higher. Among San Diego's single family residences, average pre-drought water use among the highest 20 percent water users was approximately 700 gallons per household per day. Based on this usage level, outdoor savings work out to approximately 24.2 gallons per household per day [(700 gl./hhold/day* 0.346 (coverage factor)*0.1 (reduction factor)].[3] Adding in the expected indoor savings of 20.5 gallons produces an average savings estimate of 44.7 (20.5+24.2) gallons per household per day from a targeted program.

Format of the Report

Section II describes the actual retrofit outcomes of the audit program. The performance of pre-existing showerheads turned out to be far different from what is usually assumed in producing mechanical estimates of water conservation. Section III then uses the fixture data collected through the survey to refine the mechanical estimates of water conservation. These modified mechanical estimates are lower than the MOU's estimates. Sections IV and V use statistical models of water demand to estimate water savings. These savings estimates are based on a comparison of audit participants with a control group of nonparticipants. In Section VI we provide tools for evaluating the cost-effectiveness of residential audit programs. Section VII draws conclusions and makes recommendations.

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[3]It may not be very realistic to assume that among the top 20 percent water users, outdoor water use as a proportion of total water use is also 34.6 percent. In all likelihood, the proportion is higher. Unfortunately good information about parameters contained in the MOU is hard to come by. Water planners must beware of such information while assessing the *ex ante* cost-effectiveness of water conservation programs.

II. PRE-EXISTING FIXTURES, IRRIGATION PRACTICES, LEAKAGE AND PROGRAM OUTCOMES

The audit program attempted to save water through three strategies: 1) retrofitting selected plumbing fixtures (showerheads, toilet dams, faucet aerators); 2) examining and customizing irrigation schedules; and 3) identifying leaks. We now summarize the outcomes of these three strategies.[4]

Showerheads

Extremely detailed and high quality data collected from audit participants allowed us to examine the flow rate of showerheads prior to the audit. Auditors measured the flow rate of existing showerheads and found them to be usually different from the rated flows. Many showerheads, although not manufactured to low-flow specifications, had measured flow rates equal to or less than the 2.4 gpm rating of the new replacement low-flow showerheads. Table II-1 shows the distribution of showerheads by flow rate before and after the audit.

Table II-1 Distribution of Low Flow Showerheads before and after the Audit

Showerhead Type	Before Audit	After Audit
<3 gpm	64.0 %	91.0 %
3 to 6 gpm	32.8	8.5
>6 gpm	3.2	0.5
Average number of showerheads per residence = 1.9		

Data in Table II-1 show that even before the retrofit, approximately 64 percent of all showerheads had flow rates less than 3 gpm. The audit program increased the saturation of low-flow showerheads from 64 percent to 91 percent. There are two reasons for this high pre-existing saturation of low-flow showerheads. First, the audit program implemented in 1992 came close on the heels of another plumbing retrofit program implemented by the City

[4]Data regarding number of faucets in a home and whether they had faucet aerators prior to the audit were somewhat incomplete. This is because many homes had more than four faucets, but the questionnaire had room for detailed data on only four. Thus, we are unable to describe the state of faucets before and after the retrofit with precision. The practical consequence of ignoring faucet aerators is small given their low water saving potential.

of San Diego in 1991-92. Approximately 145,000 retrofit kits containing low-flow showerheads, toilet displacement devices and dye tablets were distributed to single family households during this period. Second, in many instances mineral deposits or adjustments to pressure regulators had reduced the flow rate of existing showerheads to under 3 gallons per minute. If residents so desired, auditors replaced old showerheads even if they had flow rates less than 2.4 gpm. Thus, many new low-flow showerheads ended up replacing old low-flow showerheads with no water savings. Since customer relations is an important component of every audit program, this outcome was unavoidable.

Toilets

Examination of toilet volume information collected through the audit shows that a large number of homes already have 3.5 gallons per flush (gpf) toilets instead of 5 to 7 gpf toilets. Of all toilets, approximately 7.9 percent were reported to be of the 1.6 gpf (Ultra Low Flush [ULF]) variety (Table II-2). These ULF toilets were installed relatively recently. Thus, there appears to be much room for cost-effective water conservation through ULF toilet retrofits, provided these retrofits can be targeted toward residences with 5 to 7 gpf toilets.

Table II-2 Distribution of Toilet Types before and after Audit

Toilet Type	Before Audit	After Audit
5 to 7 gpf *without* dams or bags	37.2 %	7.2 %
5 to 7 gpf *with* dams or bags	8.0	38.0
3.5 gpf *without* dams or bags	44.5	39.9
3.5 gpf *with* dams or bags	2.3	6.9
1.6 gpf	7.9	7.9
Average number of toilets per residence = 2.2		

As a result of the audit, the proportion of 5 to 7 gpf toilets without dams declined from 37.2 percent to 7.2 percent. The City did not offer dams to residences with 3.5 gpf toilets because of concerns about reduced performance. Thus, 3.5 gpf toilets were retrofitted with dams only in the few instances where residents specifically requested them.

Outdoor Irrigation

An important purpose of the single family residential audit was to identify and rectify

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excessive irrigation practices. During the audit, wherever possible, a detailed application-rate test of the irrigation system was performed using catch cans. Based on these measured application rates, grass type, soil type, and climate zone, auditors recommended optimum irrigation schedules. Table II-3 displays the outcome of these outdoor irrigation audits for those households that either definitely had some turf area, or their outdoor audit data was incomplete but nevertheless suggested the presence of some turf area. However, for the auditor to recommend an increase, decrease, or no change to the irrigation schedule required the existence of a baseline schedule. Many households were unaware of their existing schedules.[5] Although auditors still recommended a schedule to these households, it remains unclear whether this affected water consumption.

Table II-3 Outcomes of Outdoor Audits

Outdoor Irrigation Recommendations	Proportion
Decrease irrigation schedule	35.6 %
Same irrigation schedule	16.4
Increase irrigation schedule	5.3
No baseline irrigation schedule	8.2
No recommendation, or no catchcan test performed although residence may have turf	34.5

Overall, what proportion of audited homes were found to be over watering? This question cannot be firmly answered with the data at hand because information about the auditor's recommendation was missing for approximately 34.5 percent of all participants with some turf area. In many instances, auditors could not perform application-rate tests for reasons that are somewhat sketchy. Because of legal liability, auditors were directed not to handle the irrigation systems themselves. Instead, they asked residents to switch on the irrigation system to allow them to perform the catch-can application rate tests. If the resident present during the audit did not know how to operate the irrigation system, the application rate tests could not be performed. In some instances, permission to conduct a catch-can test was simply denied the auditor.

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[5]Some of the anecdotal evidence regarding irrigation schedules was rather amusing. In some tenant-occupied residences the irrigation controllers were locked and only the owners had access to these controllers. In another instance, a woman said that only her husband knew the irrigation schedules. Upon inquiry as to the husband's whereabouts, she retorted 'He's dead!'

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Based on information shown in Table II-3 and on some sensitivity analyses we have conducted, at least a third of the participants were overwatering and that proportion could be as high as half. Data in Table II-3 also suggest that at least 8.2 percent of the audited residences with turf area had no idea about their irrigation practices. Again this proportion is in all likelihood higher because many participants that received no irrigation recommendation were the ones without a baseline schedule.

Overall, the data in Table II-3 suggest that sizeable outdoor savings may be possible given the proportion of residences that were found to be overwatering. However, a large number of residences either did not know or did not have an irrigation schedule. Modification of outdoor water use behavior in these latter cases is doubly difficult and would perhaps require greater educational effort and persistent followup.

Leakage

Plumbing leaks or toilet leaks did not appear to be a significant problem among the program participants. Leak testing was an integral component of the residential audit. Auditors examined whether after shutting off all indoor and outdoor plumbing the meter continued to register movement. Using this procedure, they detected leaks in approximately 6 percent of all participating households.

They also used dye tablets to test a large proportion of toilets. Toilet leakage did not appear to be a significant problem among either the 3.5 gpf or the 5 to 7 gpf toilets. Table II-4 summarizes the outcome of toilet leak testing.

Table II-4 Outcomes of Toilet Leak Testing

Toilet Type	Proportion of All Toilets in the Sample	Proportion Tested in Each Category	Of Those Tested, Proportion with Leaks
5 to 7 gpf	45.3 %	68.5%	5.6 %
3.5 gpf	46.8	65.0	4.0
1.6 gpf	7.9	48.5	0.0

Since not all toilets were tested for leaks because some residents denied permission, there remains the possibility of nonresponse bias in estimated leakage rates. For example, of all 5 to 7 gpf toilets, over two-thirds were tested for leaks. Of the 5 to 7 gpf toilets that were tested for leaks, approximately 5.6 percent were found to leak. The leakage rate was slightly lower among the 3.5 gpf toilets that were tested (4 percent) and nonexistent among the ULF toilets. Since age of a toilet is perhaps the best predictor of

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leakage, these patterns accord well with what one would expect.

An important point to note is that once leaks were identified, the information was conveyed to residents in the form of recommendations. Ultimately it was up to the residents to take corrective action.

In the next section, we take information on program outcomes regarding indoor retrofits and derive new, ostensibly more accurate, mechanical estimates of indoor water savings. These savings are then compared to savings based on assumptions of the HUD study as stated in the MOU. We discuss limitations of mechanical estimates and lay the ground for statistical evaluation of conservation programs based on metered water use.

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III. EVALUATION OF WATER SAVINGS

Mechanical Estimates of Water Savings and Their Shortcomings

In Section I, we discussed mechanical estimates of water savings from single family residential audits based on assumptions stated in the MOU (Table I-1). The MOU's estimate of indoor savings (including savings from leak detection) were calculated at 20.5 gallons per household per day. If leak detection savings are excluded, the MOU's estimate of savings possible from showerhead and toilet retrofits alone would be somewhat lower, approximately 19.1 gallons per household per day.

To verify the validity of the MOU's estimates, we reestimated savings from showerhead and toilet retrofits using the household-specific information collected at the time of the audit. This information included flow rates of existing showerheads, whether existing toilets had dams or bags, and household demographics. Given that over 60 percent of showerheads in the participating residences had flow rates under 3 gpm, it should come as no surprise that the refined mechanical estimate is much lower: approximately 13.6 instead of 19.1 gallons per household per day.

We describe below how we derived the refined mechanical estimate of water savings from showerhead and toilet retrofits. Even with detailed household characteristics, many assumptions enter into the derivation of these refined mechanical estimates:

1. Because not all pre-existing fixtures in a residence were similar, nor were all necessarily retrofitted during the audit, some assumptions have to be made about the relative intensity of use that each fixture receives. For example, a residence may have one old higher-flow showerhead and one newer low-flow showerhead prior to the audit. Savings from retrofitting the old showerhead in such a residence would depend on the number of people living there and the relative use each showerhead receives. In the absence of information about fixture usage, we have assumed that all showerheads and toilets receive equal usage.

2. The audit did not attempt to collect data on showering times and number of flushes per person. Therefore, we rely on the HUD study, which found that each person showers for 4.8 minutes a day and flushes a toilet 4 times a day. These assumptions underlie the MOU's estimates. Thus, the refined mechanical estimate presented below differs from the MOU's estimates only with respect to household characteristics.

3. We assume that even if a toilet dam replaces a pre-existing dam, it saves the same amount of water as if there had been no pre-existing dam. Most pre-existing dams or bags had reached the end of their useful lives when they were replaced. In any

event, pre-existing dams were replaced only in a small number of cases. Similarly, if a low-flow showerhead replaces an existing showerhead with a flow rate less than 2.4 gpm, we assume that the retrofit saves no water, not that the retrofit leads to squandering of water. This assumption rests on the premise that if low water pressure causes low flow rates in the pre-existing showerhead, then the low pressure will affect the new low-flow showerhead similarly. In many rental properties, owners adjust the pressure regulator to lower water pressure. By design all these assumptions are on the conservative side. They bias the refined mechanical estimates upward.

Since fixture usage differs from residence to residence, being a function of the number of residents, number of retrofits and type of pre-existing fixtures, we performed calculations for each residence separately and then averaged them. All these assumptions lead to a refined estimate of indoor water savings, excluding leaks, equal to 13.6 gallons per household per day. Because of the assumptions described above, we believe this estimate is biased upward, if at all. Nevertheless, it is substantially below the MOU's estimate of indoor water savings excluding leak detection of 19.1 gallons per household per day.

The above discussion highlights the inherent shortcomings of mechanical estimates. Numerous assumptions have to be made even when good data are available. It is thus necessary to move beyond mechanical estimates and measure savings as reflected at the water meter through statistical analyses. Statistical analyses are not only more reliable, but can also provide insights into program design by identifying the characteristics of households that saved more water and those that saved less. As a result, future programs can be better targeted and made more cost-effective. We turn to these statistical analyses next.

Statistical Estimates of Water Conservation and Their Advantages

Many statistical approaches have been tried to evaluate water conservation programs. As discussed below, the approach used in this study represents one of the most complete and flexible approaches to evaluating conservation programs. The approach explicitly accounts for the complications that the recent drought emergency entails for statistical evaluation of conservation programs. The approach also takes into account unmeasured household characteristics that could affect water use. In analyses based upon survey data, it is always safer to assume that some household characteristics that affect water use remain unmeasured (e.g., attitudes toward water use efficiency).

Casual examination of historical water use cannot distinguish between water saved in response to a residential audit and water saved in response to the drought. The best technique for circumventing this problem is to compare gross water savings of participants to gross water savings of a control group that did not participate in the residential audit program. The difference between gross savings of the participants and control households then is the estimate of the net impact of the audit program. A control group of comparable nonparticipants was available for performing this comparison.

Furthermore, the relationship of water use to household characteristics and climate could be different before, during, and after the drought. To allow for these changing relationships over time, we adopted a three-step approach to estimating gross water savings:

Step 1: Estimate Water Use Models Using Pre-Program/Pre-Drought Data

We estimate models of household water use using data collected only until March 1990. This represents the time period that is not significantly tainted by the drought. It is also a time period unaffected by the residential audit program. The determination of the time period unaffected by the drought was based upon model diagnostics. Both participants and control group households are included in the estimation of these water use models. The water use model relates individual household water use to climate, seasonal patterns, household real-estate characteristics, household socio-demographic characteristics, and the price of water.

As mentioned above, there is always concern about the validity of water use models that rely on self-reported data collected through questionnaires since such data are never free of errors. Rather than sweep these concerns under the rug, we adopted a model estimation procedure that calibrates the demand model to each household to account for unmeasured characteristics of the household. Thus our model yields estimates of how household water use responds to household characteristics on average, and how individual households respond differently from the predicted average response. These household-specific calibration factors yield substantially more accurate household-specific forecasts.

Step 2: Forecast Water Use in the Absence of the Audit Program

After estimating the water demand model, we used it to predict water use during the drought and residential audit program periods. This forecast provides a climate-corrected estimate of what water use would have been if the audit program and drought had not occurred. The total water saved by each household during the drought and audit periods is then the difference between their actual water use and their model forecasted use. To illustrate, Figure III-1 plots the model forecast versus the actual historical mean water use of all households that participated in the audit program during the summer of 1992. Figure III-1 shows that the models fit the data very well during the historical pre-program period. Thereafter, the two curves begin to diverge as expected. Actual water use is less than the use we would expect (forecasted water use) because of the impacts of both the drought and the audit program. These two impacts must be separated to obtain the net impact of the audit program.

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Step 3: Compare Conservation between Participants and Nonparticipants

Estimates of gross water savings between participants and nonparticipants (control group) are compared to address the question of how much more participants saved than they would have in the absence of the program. The comparison is performed through another set of statistical models that correct for any imbalance in the household characteristics of participants and control group households. These models are also used to estimate savings achieved indoors and outdoors. Analyses performed in Step 3 are at the heart of this study. They provide not only estimates of average net water savings resulting from the audit, but also insights into future program targeting.

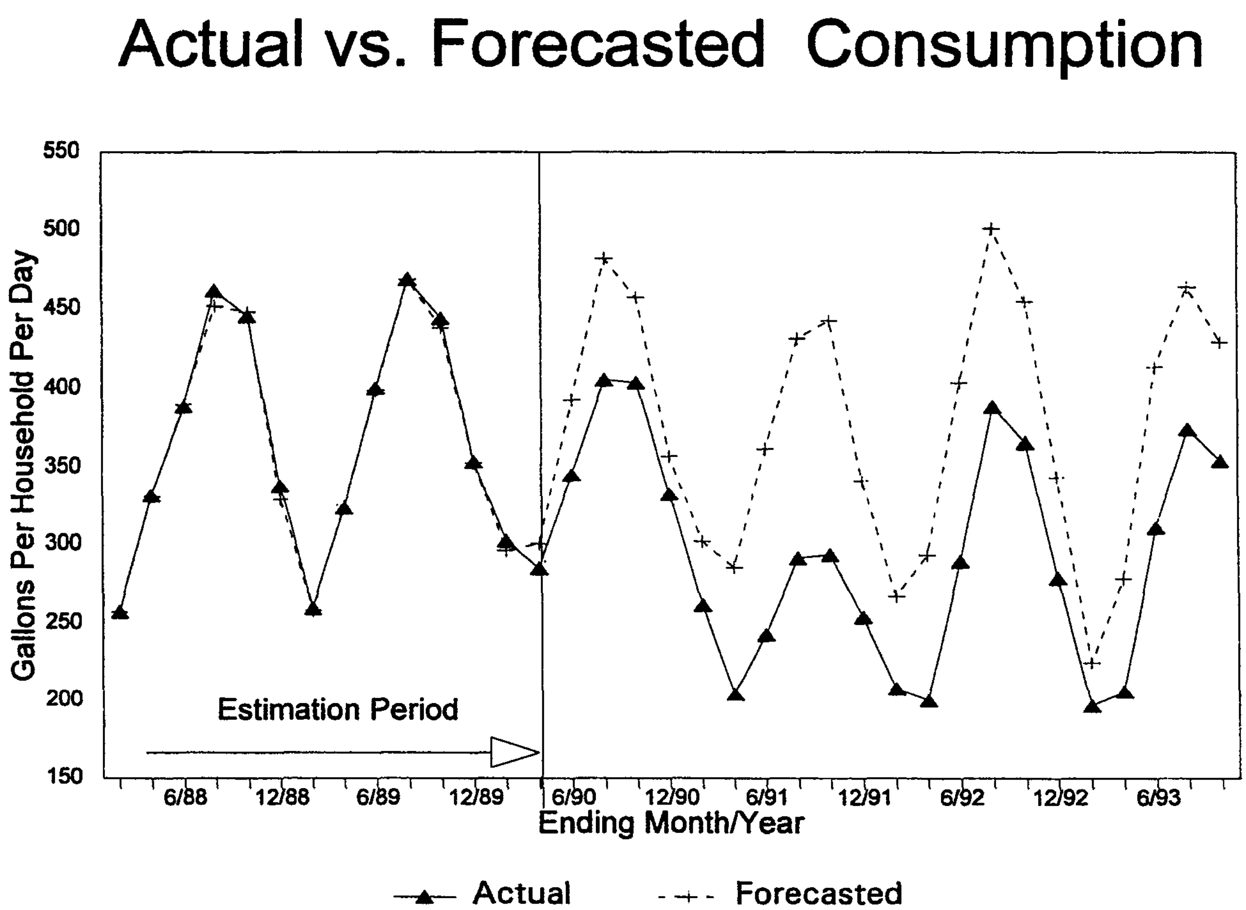

Figure III-1 San Diego Single Family Water Use: Actual Versus Model Prediction

In the next section (Section IV), we turn to the estimation of household water use models (Step 1) and forecasting water use through these models (Step 2). Estimation of net water savings (Step 3) is dealt with separately in Section V.

IV. MODELS OF HOUSEHOLD WATER DEMAND

The water use model estimated to evaluate water savings from San Diego's single family residential audit program relates individual household water use to season, changes in climate, socioeconomic characteristics of the household, physical characteristics of the property, water-using behavior patterns, the price of water, and installation of water-saving conservation devices. The functional relationships among the above factors are estimated from historical household-specific water use data.

A combined demand model was estimated using data from both the audit program participants and the control group nonparticipants. The models are based on billing histories from early 1987 through March 1990. Prior to March 1990, households were not affected by either the drought or the audit program. A pooled model explicitly allowed us to test whether in the estimation period, participant households and control group households were statistically comparable. The model shows that this indeed is the case. Had participant and control households been found to have different water use in the base period, it would raise the possibility that households that decided to participate in the audit program are a self-selected group that, on average, do not resemble other single family households in the City of San Diego.

To estimate the impact of climate on water use as accurately as possible, we allowed the nature of the available water use data from billing system records to dictate the structure of our models, not the reverse. Although water meters are read on a predetermined cycle (usually bi-monthly), the cycles do not represent the same calendar period for each household. Researchers in the past have avoided this problem by changing the structure of the data, either by aggregating water use to an annual level or by prorating water use data to a monthly level. Both techniques attenuate the "peaks" and "valleys" normally displayed by water use and thus wipe out important information that can be used in subsequent estimation of water demand.

To avoid this problem, we specify the conceptual household water use model at a daily level, not a bi-monthly level. By working with daily climate data, we construct an appropriate bi-monthly measure of climate that corresponds to the same calendar period that a household's meter reading represents. Geographic climatic differences are captured by working with two different weather stations, one for the cooler coastal areas of the city and one for the hotter inland areas.

The water demand model can capture separate effects for rainfall and temperature, and it allows for these contemporaneous effects to vary through the year. (Temperature, for example, affects water demand differently in the winter than in the summer.) The water demand model can detect lagged effects of climate; rainfall two months ago may affect water demand today. Thus, working with daily climate data produces an accurate representation of climate on water demand as measured at the meter.

Our estimation methodology also explicitly accounts for the effects of unmeasured household characteristics. This feature substantially increases the accuracy of our forecasts and improves the resolution of our statistical inference.

Lastly, since the statistical analysis is predicated on metered water use, we gathered additional data on when a meter is repaired or retrofitted. Meter repairs or retrofits usually result in an increase in metered water consumption. Most utilities have meter repair and retrofit programs because meter sensitivity to water flow, especially low flow, declines with age. The City of San Diego in their customer billing system maintains a data base that contains information about the last date each household had a meter retrofit. They made this data available to us. Information about meter repairs and retrofits turned out to be quite an important predictor of metered water use.

Model Structure

This section describes the structure of our general residential water demand model and its advantages compared to traditional models. The statistical methodology used to estimate the model is also discussed.

The residential water demand model is of the form:

$$\ln USE_{it} = X_{it}\beta + \epsilon_{it} \qquad (i=1,\dots,N\,;\ t=1,\dots,T) \qquad \textbf{(1)}$$

where USE_{it} is the bi-monthly water use of the i th household in the t th period. There are a total of N households with T meter readings per household. The explanatory variables X include some that vary over time but not over households (seasonal effects and water rates), some that vary over households but not over time (household characteristics), some that vary over both households and time (climatic effects), and interactions among these variables. By including interactions we can, for example, allow households to respond differently to climate depending upon the season of the year and their household characteristics.

The error structure is assumed to be of the form:

$$\epsilon_{it} = \mu_i + \xi_{it} \qquad \textbf{(2)}$$

where

$$\mu_i \sim (\ 0\ ,\ \sigma_\mu^2\ ) \qquad \textbf{(3)}$$

$$\xi_i \sim (\ 0\ ,\ \sigma_\xi^2\ ) \qquad \textbf{(4)}$$

The X and ξ should be independent of each other and of μ. The individual component μ represents the effects of unmeasured household characteristics on household water use. An example of such an unmeasured characteristic might be the water use behavior of household members. This effect is assumed to persist over the estimation period. The second component ξ represents random error. Because μ and ξ are independent, the error variance can be subdivided into two components:

$$\sigma_\epsilon^2 = T*\sigma_\mu^2 + \sigma_\xi^2 \tag{5}$$

This model is accordingly called an error components or variance components model.[6]

We estimate this model using the methods of Henderson (1953) and Fuller and Battese (1974).

Specification of Continuous-Time Demand Functions

In this section we specify the systematic form of the residential water demand functions. Our models have several unique features. First, seasonal and climatic effects are specified as a continuous (as opposed to discrete monthly or bi-monthly) function of time. Though this requires working with daily climate data, it greatly increases the precision of the demand function through a precise time matching of water use and climate. Second, by using separate measures of climate for the coastal and inland geographical areas, additional spatial climatic variation enters into the models. Third, the models permit interactions of time-invariant household characteristics with seasonal and climatic components. Thus, the climatic response of demand can be household specific. Thus the models allow us to determine whether, for example, high income households respond differently to climate than do low income households.

Because household water use is measured on a continuous two-month cycle, our model of water demand uses explanatory variables that match the sixty-one day meter reading cycle. Thus, if a household's meter is read on October 15, the meter reading represents water use in the previous two months, approximately from August 15 to October 15. The associated explanatory variable of precipitation should also represent how much rain fell in this same period. We specify a continuous time form of a demand function that permits a consistent time matching.

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[6]The null hypothesis that there are no household-specific error components was empirically tested using a one-sided Lagrangian Multiplier test as proposed by Honda (1985). The null hypothesis was rejected by this test at the 1 percent significance level. The specification of the household-specific effects as random was tested against the alternative of their being fixed using a Hausman (1978) test. The Hausman test does not reject the random specification of household-specific effects.

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A Fourier series defines the seasonal component of the model. For a given day ***T*** and a harmonic index ***j*** we define the following harmonics:

$$\sum_{j=1}^{6}\left\{\beta_{1,j}\sin\left(\frac{2\pi jT}{365}\right) + \beta_{2,j}\cos\left(\frac{2\pi jT}{365}\right)\right\}, \qquad \text{where} \quad T = (1,\ldots,365) \tag{6}$$

We then take a sixty-one day moving average of each harmonic to yield a consistent measure of constant seasonal component for meter read water use. Because the lower frequencies (j<=6) tend to explain most of the seasonal fluctuation, the higher frequencies can be omitted with little predictive loss.

The models incorporate two types of climate measures: air temperature and rainfall. We use the average maximum daily temperature and the total amount of rainfall in the 61-day meter reading cycle.[7] The 61-day measures of temperature and rainfall are then logarithmically transformed to yield:

$$\ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\} \quad , \quad \ln\left\{\sum_{t=T}^{T-61} Temp_t\right\} \tag{7}$$

These measures of climate in a 61-day period can be reexpressed as a historic mean and departure from historic (geometric) mean. The historical geometric mean applicable for a given 61-day billing period is based on the average of climate that prevailed during similar 61-day periods from 1948 to 1990. Subtracting the (geometric) mean, we express climatic deviations as:

$$\begin{gathered} \ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\} - \overline{\ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\}} \;, \\ \ln\left\{\sum_{t=T}^{T-61} Temp_t\right\} - \overline{\ln\left\{\sum_{t=T}^{T-61} Temp_t\right\}} \end{gathered} \tag{8}$$

[7]Our climate measures are constructed from daily rainfall and temperature readings taken at two NOAA weather stations: 1) San Diego airport near the coast; and 2) Escondido for the inland areas.

By constructing the climatic measures in this deviation-from-mean form, they are made independent of the seasonal effect. (If the means were not subtracted, there would be a strong correlation between season and climate.) Thus, the constant seasonal component of the model captures all constant effects including normal climate effects.

In processing the billing histories, we encountered relatively few meter readings that were estimated. But, these were not ignored. If in the billing history an actual reading followed an estimated reading, the two were combined to create a four-month average daily use. This took care of most estimated readings. For such combined readings, the climate and seasonal variables were also calculated on a 121-day basis instead of the 61-day basis described above. Thus, great care was taken to use as much water use data as possible without tampering with the climate and seasonal patterns implicit in these data.

The model specifies a richer texture in the temporal effect of climate than the usual fixed contemporaneous effect. The temporal specification of climate allows for the contemporaneous effects to vary though the season.[8] In addition, the model allows for lagged effects of rainfall, so that the effect of rainfall two months prior to a billing period can be estimated.

Forecasting Water Demand Using Error Components Models

The error component water demand models yield an estimate of how a given household departs from the systematic prediction of the model. This household-specific calibration factor, μ_i captures the total effect of all unmeasured characteristics for that household. Our estimator of the household-specific factors is given by[9]:

$$\hat{\mu}_i = \left(\frac{\sigma_\mu^2}{\sigma_\epsilon^2} \right) i_t'(USE_i - X_i\beta) \quad \textbf{(9)}$$

Combining the estimated random effect with the forecast from the systematic portion of the water demand model (i.e., $X_i\beta$) produces substantially more accurate household-specific forecasts than forecasts from models that do not estimate and use these calibration factors. Since the accuracy of water savings that result from audit programs greatly

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[8]We allow for seasonality in the climatic effects by interacting the climatic measures with the harmonic terms. The same effect could be achieved, at some loss in model parsimony, by interacting climate with seasonal dummy variables.

[9]Taub (1979) proposed this as the best linear unbiased predictor of μ_i and discusses prediction from this type of model.

depends on the accuracy of estimated total conservation for each household, we believe the use of error components models can be justified on both practical and theoretical grounds. In short, selection of a simpler statistical model would compromise the accuracy of estimated household conservation.

Data For Estimating Water Demand Models

Our evaluation of the City of San Diego's single family residential audit program used data from approximately 1,350 households that participated in the program. In addition, we had approximately 420 nonparticipating (control group) single family households that are representative of the single family residences in the City of San Diego. Many households that participated in the audit program could not be included in this detailed evaluation because critical data were incomplete or inconsistent. In addition, in many cases adequately long billing histories were unavailable because families had only recently moved into their current residences.

Information about characteristics of control group households had been collected earlier for a different study. The amount of information available for the control group households was much less than for the participant households. Thus the water demand model is estimated on only those characteristics that were available for both sets of households.

Table IV-1 describes the basic demographic and property characteristics of the participant and control group single family households that were used for estimating models of residential water demand. Although participant and control group households are not comparable on every household characteristic, these differences balance so that the average pre-drought water use in both groups is very close. Since, the water demand models explicitly account for the household characteristics, we found no *unexplained difference* between the water use of participant and control group households. Some data cleaning had to be undertaken because occasionally we encountered responses that were either unrealistic or incomplete. In cases where households left some questions unanswered, we created categorical variables to indicate the type of missing information. For example, many households did not know the amount of turf area their homes had, but admitted indirectly to having a lawn by either stating that they had a sprinkler system or that they were watering by hand. Rather than hazard guesses about the size of their lawns or whether they truly had a sprinkler or not, we created categorical variables to distinguish such households from the rest.

Lastly, since control group households were selected in 1991 for another study, we checked to see if any of them had participated in other conservation programs since then. We found that some control group households had participated in the City's ULF toilet rebate programs and excluded them from the analysis.

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Table IV-1 Demographic and Property Characteristics of Participant and Control Group Households

Characteristics	Participants	Controls
Mean number of people per household	2.55	3.02
Mean number of toilets per household	2.15	2.17
Mean number of showerheads per household	1.91	1.83
Proportion of owners	88.6 %	89.4 %
Proportion with laundry machines	96.6 %	96.6 %
Proportion with dishwashers	73.2 %	68.3 %
Proportion without turf	32.1 %	27.8 %
Proportion that reported incomplete turf area and irrigation information	32.8 %	31.9 %
Proportion with complete turf area and irrigation information	35.1 %	40.3 %
Of those with complete information, mean turf area (square feet)	3525.7	2670.4
Of those with complete information, proportion with automatic sprinkler systems	44.9 %	31.5 %
Of those with complete information, proportion with manual sprinkler systems	20.0 %	49.4 %
Of those with complete information, proportion with drip irrigation systems	2.7 %	10.1 %
Of those with complete information, proportion watering with hose	32.4 %	9.0 %
Proportion with a pool	8.0 %	13.7 %
Proportion with a spa or hot tub	5.6 %	16.1 %
Proportion located in coastal climate zone	18.7 %	21.6 %
Proportion located in central climate zone	56.3 %	66.4 %
Proportion located in inland climate zone	25.0 %	12.0 %

Estimated Water Demand Model

Table IV-2 presents the estimated household water demand model. The model pools information from both participant and control group households. As mentioned earlier, the model is estimated on water use histories prior to March 1990, the pre-drought and pre-program period. The estimated model is a reduced form demand model whose primary purpose is forecasting. However, the estimated coefficients reveal important information about the role of the different factors that affect household water demand.

The Role of Marginal Price. The City of San Diego has had an inclining two-tiered water rate structure since March 1983. In our analysis, sewer charges do not enter the marginal price of water because sewer charges used to be a flat monthly fee until July 1993. This has now changed. Since July 1993, sewer charges are based upon household water consumption recorded for the most recent winter months.

Water rates declined in real terms somewhat until the end of 1990 and showed modest increases thereafter. Given the small change in the marginal price of water over the model estimation period, we could not estimate a statistically significant price elasticity.

Figure IV-1 shows how the lower tier (lifeline) and the upper tier have moved over time since 1987. For two reasons, modeling the role of price was considerably simplified in this study in spite of inclining block rates. First, the move to inclining block rates occurred much earlier than the time period we analyze in this study. Thus, many statistical issues that arise in modeling the impact of rate structure changes did not arise here. Between 1983 and 1987, households presumably had already adapted to the inclining rate structure. Second, both the lower and upper tiers have moved very slowly over time and at approximately the same pace. Between 1987 and 1993, the lower and upper tier rates increased by 17 percent and 12 percent respectively.

Large differences between lower and upper tier movements over time amount to rate structure changes that would have raised statistical issues about isolating income from price effects of a rate change. However, in the present fortuitous situation the problem essentially reduces to creating an index of price movement for each household that is a weighted average of changes in the lower and upper tiers over time. Thus, a household that always consumed less than 10 HCF per month would have its marginal price change by 17 percent between 1987 and 1993. All other households would have their price index change by 12 to 17 percent depending upon the portion of their water consumption that falls in the lower and upper blocks. The weights were determined from the earliest full year of water use that was available for each household. The weights are, therefore, household specific, do not change over time, and are not tainted by a household's response to the drought or increasing water rates over time.

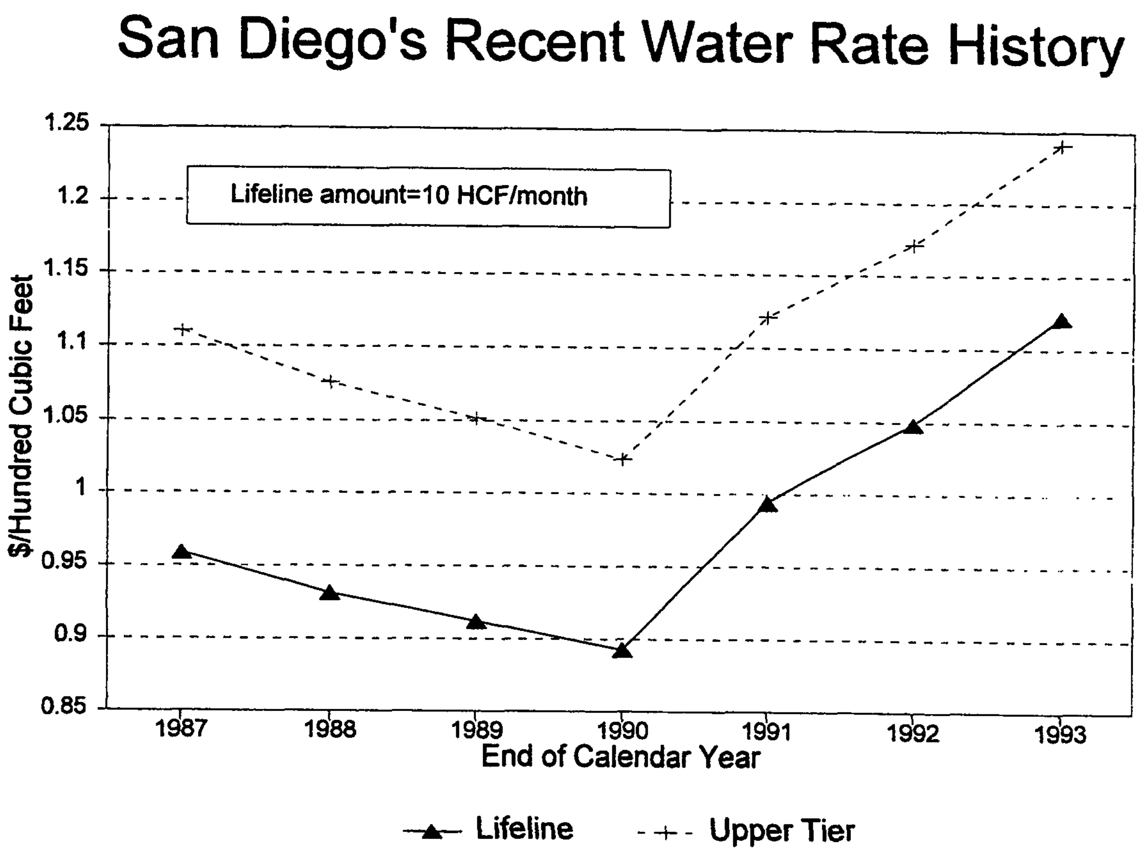

Figure IV-1 City of San Diego: Recent History of Water Rates (Real 1990 Dollars)

Participants and Control Group Households. To separate average water savings achieved by households in response to the drought from the net impact of the audit program, it is necessary to have a well matched control group of households that did not participate in the audit.[10] To this end, it is necessary to show that there were no unexplained differences in the average water use of participant and control group households during the model estimation time period. But, even if this condition is met during the model estimation period, it does not completely rule out the possibility that participant and control group households reacted differently to the drought. In other words, some amount of self-selection bias could still be evident in the forecast period.

Although the coefficient on the control group indicator variable is small and insignificant at the traditionally used 5 percent level of significance, it is still important to examine the presence of self-selection bias in estimates of net water savings. We return to this issue in Section V.

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[10]Since 90 percent of all the audits were performed in a short span of three months, it was not possible to use later participants as controls for earlier participants.

Table IV-2 Estimated Single Family Water Demand Model

Variable	Coefficient	Standard Error	t-statistic
	β	σ	β/σ
Ln(weighted marginal price of water)	-.283	.183	-1.55
Indicator (=1) if control group household	-.043	.023	-1.88
Indicator (=1) if water meter retrofitted	.083	.010	8.42
Indicator (=1) if participant had leaks	.129	.043	2.97
Indicator (=1) if owner occupied	.033	.028	1.18
Ln(number of residents)	.386	.017	22.44
Indicator (=1) if household had pre-existing ULF toilets	-.103	.049	-2.09
Indicator (=1) if household had pre-existing dams or bags	.010	.024	0.42
Indicator (=1) if household had pre-existing LF showerheads	-.022	.021	-1.03
Indicator (=1) if household has a dish washer	.128	.021	6.00
Indicator (=1) if household has laundry machine	.075	.050	1.51
Indicator (=1) if household has a pool	.239	.030	7.94
Indicator (=1) if household has a spa or tub	.090	.033	2.70
Indicator (=1) if household has no turf area	-.330	.058	-5.65
Indicator (=1) if turf related information is incomplete	-.012	.059	-0.20
Ln(turf area)	.072	.016	4.49
Indicator (=1) if household has automatic sprinkler	.396	.037	10.63
Indicator (=1) if household has manual sprinkler	.232	.041	5.72
Indicator (=1) if household has drip irrigation	.332	.073	4.55
First sine harmonic, 12 month (annual) frequency	-.088	.007	-12.19
Second sine harmonic, 6 month (semiannual) frequency	.013	.004	3.29
Fourth sine harmonic, 3 month (quarterly) frequency	-.064	.015	-4.33
First cosine harmonic, 12 month (annual) frequency	-.283	.007	-43.40
Second cosine harmonic, 6 month (semiannual) frequency	-.012	.005	-2.66
Fourth cosine harmonic, 3 month (quarterly) frequency	.014	.014	0.94
Deviation of Ln(temperature) from its bi-monthly mean	1.21	.200	6.02
Deviation of Ln(1+rain) from its bi-monthly mean	-.090	.009	-9.64
Two month lag of rainfall deviation	-.016	.005	-3.07

Variable	Coefficient	Standard Error	t-statistic
	β	σ	β/σ
Temperature deviation * first sine harmonic	.311	.136	2.29
Temperature deviation * first cosine harmonic	-.077	.161	-0.48
Rainfall deviation * first sine harmonic	.019	.005	3.46
Rainfall deviation * first cosine harmonic	-.050	.010	-5.18
Indicator (=1) if household located in central zone	-.034	.023	-1.46
Indicator (=1) if household located in inland zone	.032	.028	1.15
First sine harmonic * central zone indicator	-.012	.008	-1.55
Fourth sine harmonic * central zone indicator	.030	.017	1.75
First cosine harmonic * central zone indicator	-.019	.007	-2.79
Fourth cosine harmonic * central zone indicator	.012	.016	0.73
Rainfall deviation * central zone indicator	.017	.010	1.72
Temperature deviation * central zone indicator	-.040	.190	-0.21
First sine harmonic * inland zone indicator	-.061	.010	-6.11
Fourth sine harmonic * inland zone indicator	.021	.020	1.06
First cosine harmonic * inland zone indicator	-.065	.008	-7.83
Fourth cosine harmonic * inland zone indicator	-.017	.021	-0.82
Rainfall deviation * inland zone indicator	.064	.012	5.56
Temperature deviation * inland zone indicator	1.096	.232	4.72
Mean intercept	5.264	.077	68.06

Dependent Variable	Ln(Gallons per household per day)
Observations	23,328
Number of households	1,781
Intracluster correlation	0.841
R-Square	86.6 percent

Meter Retrofit and Plumbing Leaks. Most utilities have meter repair and retrofit programs that primarily aim at ensuring equity in water billing. But to some extent, meter retrofit programs can also be thought of as conservation programs because they reduce unaccounted for water use. Evaluations of conservation programs that are based upon metered water consumption are sensitive to any changes made to water meters during the evaluation time period. Due to wear and tear, water meters become less sensitive to water flow. As a result, they under-register water consumption. The perceived increase in metered water consumption after a meter retrofit could easily wipe out the effect of a water conservation program, unless the retrofit is explicitly accounted for in the analysis.

As the demand model shows, on average household water consumption increased by 8.7 percent after a meter was retrofitted.[11] Thus the impact of meter retrofits is large and cannot be ignored. However, it should be noted that meter retrofit programs by design target only old meters. In San Diego, meters are retrofitted every 15 years. If meters were retrofitted earlier, or at random, the perceived increase in water consumption will be obviously less.

As part of the residential audit, additional information was collected about plumbing leaks among the participant households. Although similar information is not available about the control group households, we included plumbing leakage information in the model through an indicator variable to assess the seriousness of these leaks. The model shows that households with plumbing leaks on average consumed 13.6 percent more water compared to similar households without leaks. These represent fairly large losses, but apply to only a small number of households. Only 6 percent of all audited households were identified as having significant plumbing leaks.

Home Ownership. It is often hypothesized that since renters usually do not pay their water bill, they are less likely to be water efficient. On the other hand, it is possible that home owners over irrigate because they are more concerned about the outward appearance of their homes. Among San Diego households, there appear to be no statistically significant differences between owners and renters.

Indoor Characteristics. Some households reported having installed ULF toilets and

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[11]This calculation is more complicated than it might appear at first. The estimated coefficient on the meter retrofit indicator variable gives the conditional median percentage change, not the conditional mean percentage change. A small scaling adjustment (see Goldberger, 1968) must be made to arrive at the correct expected percent change of water use: $(\exp(\beta - \sigma^2/2) - 1)*100$. Thus, the expected percent increase in water consumption from having a meter retrofitted is $(\exp(0.083 - (0.01^2/2)) - 1)*100 =$ 8.7 percent. Based upon the average pre-drought water consumption of 360 gallons per household per day, this works out to an increase of 31.3 gallons per household per day.

low-flow showerheads on their own initiative in years preceding the drought. However, accurate installation dates for these voluntary retrofits were not available. At most, households reported only the year in which they installed low-flow fixtures. As a result, savings associated with pre-existing fixtures have most likely been underestimated in the model. For example, households that reported having ULF toilets and low- flow showerheads on average consumed 10.7 percent and 2.2 percent less water respectively. Because of data limitations, these coefficients on pre-existing fixtures are not reliable. They were included with the express purpose of explaining water demand as much as possible to improve the accuracy of the forecasts into the program period.

Other factors that explain indoor water use (such as the number of residents and whether the household has a dishwasher or laundry machine) are, not surprisingly, strong predictors of water demand. Households with dishwashers and laundry machines used 13.6 percent and 7.5 percent more water respectively. Because over 95 percent of all households have a laundry machine, its impact on water use is difficult to measure with precision since the number of households without a laundry machine is so small.

Outdoor Characteristics. Outdoor amenities such as a pool, spa or hot tub, turf area, and irrigation system all have a strong bearing on household water demand. A household with a pool on average consumed 26.9 percent more water compared to other similar households without a pool. The impact of a spa or hot tub is lesser in magnitude (9.3 percent), albeit significant.

Turf area and especially the type of irrigation system a household has appears to be a strong predictor of water demand. Because turf area information was either missing or incomplete in many cases, we once again resorted to flagging such cases through the use of indicator variables. Those households that report no turf area have predictably much smaller levels of water consumption. Households where information was incomplete either on the amount of turf area or on the irrigation system type were grouped into the "missing turf area" category. Thus, the parameter on the impact of turf area and irrigation system type is estimated only for those households that had complete information.

Type of irrigation system appears to be more important in determining water consumption than turf area *per se*. Households that have irrigation systems with automatic controllers have the greatest outdoor water consumption followed by drip irrigation systems and then manually controlled sprinkler systems. All comparisons are with respect to households that reported watering with a hose.

Climate and Season. Demand for water normally follows a cyclical pattern during the course of a year because of changes in climate. Perturbations are produced in these cyclical patterns when climate conditions deviate from their normal values for a given time of year. We estimate both of these effects (i.e., normal climate and deviation from normal)

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separately in our models. The seasonal harmonics included in the demand models represent variation in water demand through the seasons that would be expected in any normal year. We also include variables that represent deviation of actual rainfall and temperature from their normal values to capture the response of water demand to deviations in climate. Lastly, since the effect of deviation from normal climate may have different impacts on water demand at different times of the year, we include interactions between the harmonics and climate deviation variables.

As the water demand model shows, normal variation in water use over the course of a calendar year is complex and therefore necessitates the inclusion of a large number of harmonics in the model. As expected, greater than normal rainfall dampens demand for water while greater than normal temperature increases demand for water. Greater than normal rainfall reduces demand not only in the bi-monthly period in which it occurs, but also in the following bi-monthly period. For example, a 1 percent greater than normal rainfall reduces water demand by 0.09 percent in the contemporaneous period and 0.016 percent in the following period. The model also shows that response of water demand to deviations in climate is not constant but varies somewhat by time of year.

The response of water demand to climate also varies among households depending on whether they are located in coastal or inland areas of San Diego. Since households in the inland area usually have larger turf areas and the climate is also hotter, the response to climate is accordingly steeper. Indicator variables for inland regions are statistically insignificant. This suggests that all differences in water use by climate zone are explained by both differences in household characteristics and differences in climate.

V. ESTIMATION OF NET WATER SAVINGS FROM THE AUDIT

Many conceptual and data issues arise in separating the audit program impacts from household response to the recent drought. Even though we found no significant unexplained differences in water use between program participants and control group households in the base period, this does not necessarily guarantee that their gross savings during the forecast period would have been equal in the absence of the audit program. In other words, households that display similar water using behavior during times of plentiful supply may react differently to adversity because of differing attitudes. These differences are very difficult to measure and are usually unobservable.

In addition, we lacked information about control group households after 1991. Data for households in the control group were collected in 1991 for a different study. From the data, we had good information about plumbing fixtures in these control group households until 1991. However, it would be foolhardy to assume that none of the control group households retrofitted any of their fixtures after 1991 given that the City had an aggressive plumbing retrofit program underway in 1991 and part of 1992. Showerheads were also distributed through the City's ULF toilet rebate program.

We crosschecked all control group households against the list of households that participated in the City's ULF toilet rebate program. Control group households that participated in these programs were eliminated from this analysis. But we cannot completely rule out the possibility that some control group households undertook plumbing retrofits (showerheads and toilet displacement devices) in 1992 that we have no knowledge of. A large number of kits were distributed through the City's plumbing retrofit program, but no formal list of recipient sites was available.

The above mentioned problems, fortunately, are not as debilitating as they appear because one can test for their presence and then factor them into the analysis. Since the demand model was estimated on billing histories prior to March 1990 (pre-drought period) and the audit program did not begin until the summer of 1992, the intervening period allows an examination of whether the gross savings of participants and control group households were dissimilar (Figure V-1). We show later that dissimilar behavior during the drought is fully explained by differences in the observed household characteristics of participants and control group households.

Figure V-1 shows how total (gross) water savings have changed over time in response to the drought. Both participant and control group households saved large amounts of water, especially during the summer. These savings have declined over time as the severity of the drought has diminished. But, average water use has not crept back to its pre-drought level.

After the completion of the audit program, however, participants were consistently saving more water than control group households. Since water meters are read bi-monthly,

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the impact of the audit program becomes apparent only at the end of 1992, approximately two to three months after the program began. Thus, the audit program clearly appears to have made an impact. But calculation of the net impact of the audit program requires accounting for differences in gross savings of the participants and control group households both after the audit program was completed and during the drought.

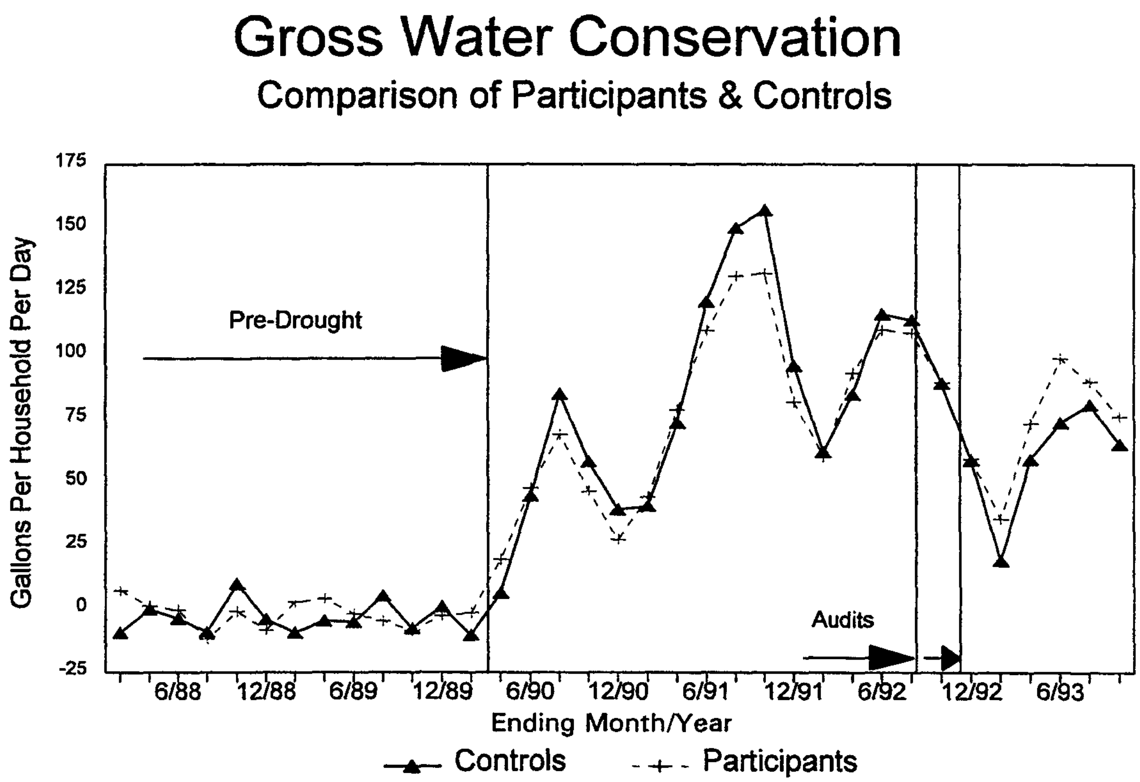

Figure V-1 Comparison of Total Water Conservation During the Drought and After the Audit Program

Overall Average Net Water Savings

To estimate the net impact of the audit program, we estimate another set of statistical models. These models relate gross savings to household characteristics, geographic location and irrigation behavior; indicator variables for bi-monthly time periods; an indicator for control group households; and a participation indicator variable that takes on the value of one for participants after the audit date. Climate and season are excluded from these models because their impact is already netted out by subtracting actual water use from model forecasted water use. The coefficient on the control group indicator measures the average additional water control group households were saving prior to the audit program. Accounting for this pre-existing difference during the drought period provides a truer estimate of net water savings achieved as a result of the audit. Net water savings are measured through the coefficient on the participant indicator variable.

Extensive sensitivity analyses were conducted on the results presented below. These analyses examined whether the net savings estimates were sensitive to any particular time periods or to the inclusion of additional variables in the models. No statistically significant differences were detected. The statistical models of net water savings presented below are based on data starting in November 1990. This cutoff was selected to ensure that we analyze only whole years of data, in this case three, because our ultimate interest is in average annual savings. By including the summer of 1991 in the analysis when control group households were saving substantially greater amounts of water compared to participant households, we effectively estimate an upper bound on net savings.[12] In any event, if the summer of 1991 is excluded from the analysis, the estimate of net savings are not statistically different from the estimates we present below.

Model A (Table V-1) is purely a descriptive model that relates gross conservation over time to indicator variables for different time periods, an indicator variable for control group households, and an indicator variable for participation in the audit program. The results in Model A show that during the drought and before the program, control group households on average saved approximately 7 gallons per day more than those households that later became audit program participants. Capturing this preexisting difference during the drought through the control group indicator variable yields a net water savings estimate of 16.9 gallons per household per day.

In addition, the model also includes an interaction between the participation indicator variable and an indicator variable that represents the summer of 1993 (July-October). This interaction captures the change in the impact of the audit program, if any, approximately nine to twelve months after the program was implemented. The small and statistically insignificant coefficient suggests no diminution, at least over a period of one year.

By including key household characteristics, Model B (Table V-1) attempts to explain why control group households saved more during the drought. As Table IV-1 showed, control group and participant group households do not match on every characteristic. But, once these household differences are taken into account, no statistically significant unexplained difference in pre-drought water use remains in the

[12]The net savings estimates represent upper bounds only for the drought-tainted evaluation period. Once water use creeps back to its pre-drought levels, net savings from the audit could well exceed the estimates presented in this study.

Table V-1 Estimation of Net Water Savings from the Residential Audit

Variable	Model A		Model B	
	Coefficient	t-statistic	Coefficient	t-statistic
Indicator (=1) if control group household	6.99	4.17	1.49	0.86
Indicator (=1) for participants after audit	16.93	5.24	18.09	6.17
Indicator (=1) if participant * indicator for summer of 1993	-1.05	-0.16	--	--
Number of permanent residents in household	--	--	2.54	5.30
Indicator (=1) if household has no turf area	--	--	-23.50	-5.33
Indicator (=1) if household has missing turf related information	--	--	1.43	0.32
Ln(turf area)	--	--	3.59	2.95
Indicator (=1) if automatic sprinkler present	--	--	11.70	4.08
Indicator (=1) if manual sprinkler present	--	--	24.98	9.55
Indicator (=1) if drip irrigation present	--	--	43.07	7.71
Indicator (=1) if pool is present	--	--	23.14	8.60
Indicator (=1) if spa or hot tub is present	--	--	5.95	2.14
Indicator (=1) if located in central zone	--	--	6.12	3.76
Indicator (=1) if located in inland zone	--	--	29.83	13.49
Indicator (=1) if November-December 1990	-28.73	-4.40	-27.17	-5.59
Indicator (=1) if January-February 1991	-19.78	-3.09	-20.25	-4.33
Indicator (=1) if March-April 1991	10.14	1.58	9.72	2.05
Indicator (=1) if May-June 1991	48.01	7.31	48.17	9.83
Indicator (=1) if July-August 1991	74.31	11.12	74.38	14.74
Indicator (=1) if September-October 1991	75.56	11.23	76.02	14.88
Indicator (=1) if November-December 1991	24.46	3.72	25.46	5.19
Indicator (=1) if January-February 1992	-2.33	-0.36	-2.50	-0.53
Indicator (=1) if March-April 1992	24.11	3.71	23.90	4.96
Indicator (=1) if May-June 1992	46.15	6.81	48.01	9.30
Indicator (=1) if July-August 1992	43.16	6.27	42.50	8.01
Indicator (=1) if September-October 1992	23.93	3.30	25.16	4.41

Variable	Model A		Model B	
	Coefficient	t-statistic	Coefficient	t-statistic
Indicator (=1) if November-December 1992	-10.74	-1.58	-8.87	-1.94
Indicator (=1) if January-February 1993	-43.41	-6.54	-42.41	10.16
Indicator (=1) if March-April 1993	-6.56	-0.99	-9.18	-2.22
Indicator (=1) if May-June 1993	14.41	2.08	14.39	3.16
Indicator (=1) if July-August 1993	13.26	2.73	12.35	2.62
Intercept (mean gross conservation)	56.60	9.25	49.24	7.92
R-square	0.10		0.13	

NOTE: Both models are weighted to compensate for heteroscedasticity in the dependent variable, i.e., estimated gross conservation (forecasted-actual water use).

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estimated demand model (Table IV-2). Figure V-1 further attests to this conclusion. Until March 1990, gross conservation among the control and participant groups reflects mainly random error. However, with the advent of the drought, control group households appear to have conserved additional water during the summer months.

Extending the logic of water demand analysis to the analysis of gross conservation, we again find that differences in household characteristics explain the differential drought response between control group households and participants. As discussed below, household characteristics associated with greater gross conservation are sometimes more frequent in the control group and sometimes more frequent in the participant group. But, these differences fully explain the higher gross saving among control group households during the drought because the coefficient on the control group indicator variable (Model B) is small and statistically insignificant. This finding confirms the absence of any significant self-selection bias in our estimate of net water savings.

Better accounting for differences among the control group and participant households also increases the net water savings estimate to 18.1 gallons per household per day. The interaction between the participation indicator variable and an indicator for the summer months of 1993 was included in Model B and once again found to be insignificant. Thus, this interaction was excluded from Model B.

Model B provides insights into the relationship between household characteristics and gross water conservation in response to the drought. These relationships go a long way in explaining the greater gross conservation among control group households. For example, gross conservation increased with the number of residents at the rate of approximately 2.5 gallons per person. On average, control group households had 3 residents compared to 2.55 residents among the participant households (Table IV-1).

Greater savings were achieved outdoors. Residences with large turf areas, especially those located in the inland region, conserved substantially more water during the drought. Residences with either a sprinkler or drip irrigation system saved more water than residences that watered by a hose. For example, residences with drip irrigation on average saved approximately 43 gallons per day more than similar residences watering by a hose. This is not surprising given that prior to the drought, residences watering by hose used the least water as shown in the demand model (Table IV-2). The proportion of residences with manual sprinklers and drip irrigation systems is greater among the control group households possibly explaining the higher gross conservation prior to the audit program (Table IV-1).

Although residences with automatic sprinklers used the greatest amount of water prior to the drought, their savings in response to the drought (only 11.7 gallons per household per day) appear unimpressive. Interestingly, residences with automatic sprinklers appear more frequent among the participant households (Table IV-1).

Residences with a pool, a spa, or a hot tub also appear to have taken measures to cut back on water use because of the drought. Again, a greater proportion of control group households have pools and hot tubs compared to the participant households (Table IV-1).

Above, we discussed all the factors that are consistent with our finding that gross conservation was higher among the control group households during the drought. However, because accounting for household characteristics completely explains the greater gross conservation among control group households, other household characteristics with countervailing impacts must also be present. These are the location and turf size indicators. Among participants a greater proportion came from the inland zone. On average, participants also had greater turf areas. Both of these factors are associated with a higher level of gross conservation prior to the audit.

Overall, key household characteristics fully explain differences in water use prior to the drought and differences in gross conservation during the drought. Thus, comparisons between the control group and participant households after the audit are statistically valid and provide unbiased estimates of net program savings.

Indoor versus Outdoor Impact of Audit

The first phase of San Diego's audit program was a nontargeted program. For future program targeting—such as the highest 20 percent water users as suggested by BMP 1—it is important to assess the portion of the average net savings that resulted from indoor retrofits and the portion that resulted from the landscape audits. Leaks were detected in very few cases, so little direct benefit resulted from the leak detection component of the audit. However, in other service areas with older plumbing and a weaker conservation ethic, leak detection could be an important source of savings.

We addressed the issue of indoor versus outdoor savings by reestimating Model B on residences that did not have any turf area and residences that reported complete turf area and irrigation system information. We found that on average residences without turf saved approximately 12.4 gallons per day after the audit. Expectedly, residences with complete turf related information saved much higher levels of water—approximately 26 gallons per day.

We attempted a further analysis of whether outdoor savings varied as a function of irrigation system type. The data did not provide sufficient resolution to address this question with sufficient precision, but preliminary indicators suggest that the outdoor audit had its greatest effect on residences with automatic sprinklers. There are three logical reasons for why this should be the case. First, residences with automatic sprinklers were using the greatest amount of water before the drought. Second, residences with automatic sprinklers had not cut back as much as residences with manual sprinkler systems or drip irrigation systems during the drought. Lastly, the City mailed followup postcards to participants with automatic and manual sprinklers reminding them of the importance of tailoring their irrigation schedules to prevailing climate. This followup could not have been anything but beneficial.

Implications for Audit Program Targeting

What would net water savings have been if only the highest 20 percent of water users had been targeted through the audit program in San Diego? Based on the results presented above, our best estimate would be approximately 26 gallons per household per day, or somewhat higher. This was the amount saved by participants with complete turf related information. Such participants were generally high water users, though not all fell in the top 20 percent.

We also attempted to address the above question by directly estimating net savings for only those residences that fell in the highest 20 percent bracket of average use prior to the drought. This made sense because the average pre-drought water use among the top 20 percent participating and control group households was very close to the estimate obtained for all the top 20 percent single family water users in San Diego—approximately 700 gallons per household per day. The resulting 80 percent reduction in sample size considerably reduced the level of precision in our savings estimates. As a result, the estimates of net savings were insignificantly different from 26 gallons per household per day, the estimate of savings for participants with complete turf related information.

Thus, overall, San Diego's audit program was quite successful in saving water. In the future, however, audits can be made more effective by targeting residences with large turf area, residences with automatic sprinklers, and residences with high occupancy rates.

VI. COST-EFFECTIVENESS OF RESIDENTIAL AUDIT PROGRAMS

To consider water conservation programs as reliable sources of future water supply, they must be shown to be cost effective. Previous analyses of ULF toilet retrofit programs have indicated that the regional cost of these retrofit programs (ignoring energy or sewer benefits) is slightly over $300 per acre foot. This estimate compares very favorably with alternative supplies available to MWD making ULF toilet retrofit programs one of the most cost-effective conservation programs currently available.

In the case of residential audit programs, two specific areas of uncertainty still remain: 1) savings achievable from a targeted program; and 2) the persistence of these savings over time. Table VI-1 demonstrates the linkage between program cost, initial savings, the persistence of these savings and the cost-effectiveness of conservation programs.

To determine whether a conservation program is likely to be cost-effective, the analyst needs an estimate (or range) of the per-site cost of the program, an estimate (or range) of per-site water savings, and the discount rate. Corresponding to assumptions about program cost, water savings and the discount rate, Tables VI-1 and VI-2 provide the minimum number of years over which these water savings must be realized for the program to generate water at either $300/acre-foot or $500/acre-foot respectively. If persistence of water savings exceeds the breakeven threshold in years presented in Table VI-1, then the program will produce water savings at less than $300/acre-foot or the $500/acre-foot threshold in terms of cost.

The calculations underlying Tables VI-1 and VI-2 ignore any non-water-resource related costs and benefits that may be associated with a water conservation program. Thus, the breakeven thresholds are meant to provide a quick answer to a narrow question. Evaluation of a multi-agency conservation program with multiple costs and benefits to the agencies, or other third parties, should not be performed using Tables VI-1 and VI-2.

An Example: The 1992 City of San Diego Single Family Audit Program

According to the cost estimates we received from the City of San Diego, each audit cost approximately $52. This includes the cost of the survey ($38.70 per site) and the water conservation portion ($13 per site) of the full water and energy retrofit kit. Since we did not evaluate energy savings from the program, the cost of compact bulbs ($14.50 per audit) is excluded from the above cost estimate. As a result of the partnership between the City of San Diego and SDG&E, the City paid for the survey ($38.70 per site) but only $7.60 for the water retrofit kit. Thus, total cost of the program to the City amounted to approximately $46.30 ($38.70 + $7.60) per site.

From the City's perspective, the ratio of per-site audit costs to per-site water savings amount to approximately 2.57 ($46.30/18 gl./hh./day). Corresponding to this ratio at a real discount rate of 5 percent, water savings must persist for approximately 5-6 years for the cost of these water savings to be under $500/acre-foot, and 9-10 years if savings are to be achieved under $300/acre-foot (Tables VI-1 and VI-2). Assuming, that savings persist over 5 years which is the expected lifetime of the water retrofit items, the first phase of the single family audit program generated water for the City of San Diego at slightly over $500/acre-foot. If program costs not borne by the City are also factored in, then the cost of saved water rises considerably above $500/acre-foot. In coming to these conclusions, we have ignored the long-term benefits of improved customer relations and customer education, as also the benefits of data collection that can result in improved design of future conservation programs.

The first year of the City's residential audit was not a targeted program. A targeted program will obviously generate more cost-effective savings. We expect a targeted single family audit program in San Diego to save approximately 26 gallons per household per day, or perhaps even more as ongoing conservation continues to diminish. Assuming costs remain the same, the ratio of per-site costs to per-site savings work out to approximately 1.8 ($46.30/26 gl./hh./day). If savings from a targeted program persist for 5 years, then the cost of saved water from the City's perspective will be approximately $360/acre-foot.[13]

The cost-effectiveness estimates presented here lead to some obvious conclusions. First of all, nontargeted programs are perhaps best avoided because it is very unlikely that program costs could be brought down to levels that would be required to make such programs cost-effective. Second, the City's success in including both water and energy components in their audit program provides an important new direction in the design of residential audit programs. Greater integration of effort among water, energy and sewer utilities can considerably increase the cost effectiveness of audit programs. Of course, to some extent, greater across-utility integration may also conflict with the need for targeting. Residences best targeted for energy audits may not necessarily be the best residences for water audits. These programmatic issues need to be explored further. Lastly, the cost-effectiveness of residential audit programs rests heavily on how persistent these savings are likely to be. Water utilities should give careful thought to post-audit followup to ensure

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[13]The cost of saved water can be derived with a little algebra using information contained in Table VI-1. Assume a conservation program generates water savings at $300/acre-foot at a cost/savings ratio **r** and savings persistence for **n** years. It can be mathematically shown that the same program will generate water savings at $500/acre-foot if the cost/savings ratio increases to (**r***500/300) assuming persistence and the discount rate remain unchanged.

We now apply the above to the case of targeted savings. The ratio of initial per-site cost to per-site daily savings works out to approximately 1.8. From Table VI-1 we see that for a program where water savings persist for approximately 5 years, the ratio must equal 1.5 for the saved water to cost $300/acre-foot. Thus, the cost of saved water from a targeted program works out to $360/acre-foot ((1.8/1.5)*$300/acre-foot).

that the initial impact of the audit does not fade away with time.

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Table VI-1
Minimum Number of Years Water Savings Must Persist for Program to Break Even at $300/Acre-Foot

Dollars / gl./hh./day	Real Discount Rate (percent)							
	3	4	5	6	7	8	9	10
10.00	74.5							
9.50	62.8							
9.00	54.3							
8.50	47.4							
8.00	41.8	76.1						
7.50	36.9	55.8						
7.00	32.7	44.8						
6.50	28.9	37.2	68.4					
6.00	25.6	31.3	44.7					
5.50	22.5	26.6	34.1	67.1				
5.00	19.7	22.6	27.3	37.2				
4.50	17.1	19.2	22.2	27.1	39.6			
4.00	14.7	16.2	18.1	20.9	25.6	38.1		
3.50	12.5	13.5	14.7	16.3	18.7	22.4	30.8	
3.00	10.4	11.0	11.8	12.8	14.0	15.7	18.1	22.3
2.50	8.4	8.8	9.3	9.9	10.5	11.3	12.3	13.6
2.00	6.6	6.8	7.1	7.4	7.7	8.1	8.5	9.0
1.50	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.9
1.00	3.1	3.2	3.2	3.3	3.3	3.4	3.5	3.5

NOTE: Shaded cells indicate that conservation program will never produce water under $300/Acre-Foot.

Table VI-2

Minimum Number of Years Water Savings Must Persist for Program to Break Even at $500/Acre-Foot

Dollars / gl./hh./day	Real Discount Rate (percent)							
	3	4	5	6	7	8	9	10
10.00	25.6	31.3	44.7					
9.50	23.7	28.4	37.7					
9.00	21.9	25.7	32.6	55.5				
8.50	20.3	23.4	28.5	40.3				
8.00	18.7	21.2	25.1	32.4				
7.50	17.1	19.2	22.2	27.1	39.6			
7.00	15.7	17.3	19.6	23.1	29.7			
6.50	14.3	15.6	17.4	19.9	23.9	33.0		
6.00	12.9	14.0	15.3	17.2	19.8	24.3	37.0	
5.50	11.6	12.5	13.5	14.8	16.6	19.3	23.9	40.3
5.00	10.4	11.0	11.8	12.8	14.0	15.7	18.1	22.3
4.50	9.2	9.7	10.3	11.0	11.8	12.9	14.3	16.3
4.00	8.0	8.4	8.8	9.3	9.9	10.6	11.4	12.5
3.50	6.9	7.2	7.5	7.8	8.2	8.7	9.2	9.8
3.00	5.8	6.0	6.2	6.5	6.7	7.0	7.3	7.7
2.50	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.9
2.00	3.8	3.9	3.9	4.0	4.1	4.2	4.3	4.4
1.50	2.8	2.8	2.9	2.9	3.0	3.0	3.1	3.1
1.00	1.8	1.9	1.9	1.9	1.9	1.9	1.9	2.0

NOTE: Shaded cells indicate that conservation program will never produce water under $500/Acre-Foot.

VII. CONCLUSIONS

Many water planners consider residential audits mainly an exercise in customer relations. Water savings, if any, are generally considered small and are not expected to persist over time. On the other hand, water savings estimates as stated in the MOU would lead one to believe that residential audits are highly effective. A detailed analysis of the first phase of San Diego's audit program shows that perhaps the truth lies in between. On average participating households saved 18.1 gallons per day, substantially less than the MOU's estimate of 33 gallons per household per day. There are many reasons for this discrepancy.

First and foremost, even prior to the audit, over 60 percent of all showerheads in the audited homes had flow rates under 3 gallons per minute. These low flow rates resulted either from fixtures with low-flow design or from low water pressure caused by mineral deposits. Thus, installation of new low-flow showerheads obviously did not produce any water savings. If characteristics of plumbing fixtures prior to the retrofit are taken into account, the MOU's water savings estimate falls to 27.5 gallons per day. But, this is still considerably higher than the actual water savings estimated in this study.

Second, although San Diegans' water use has started to creep back up since the official ending of the drought, they were still using approximately 20 percent less water in the summer of 1993 compared to the historical norm corrected for climate. In a situation where residents already conserve large amounts of water in response to water shortage, or the threat of shortage, the impact of a residential audit is likely to be lower.

Third, the City of San Diego has had inclining block rates for the residential sector since 1983. Many residences with large turf areas may already have taken measures to improve their outdoor water efficiency, reducing the effectiveness of an audit. Thus, water savings from residential audits will probably be higher in areas that are hotter, have a flat rate structure, and the homes have large turf areas.

Do savings from residential audits diminish over time? During the one-year time period we analyzed after the audits were completed, we detected no decrease in savings over time. It is difficult to say whether this stability in savings will hold over longer time periods. If the water supply situation continues to improve, participants possibly will lose some fervor with respect to conservation. But it could be hypothesized with equal validity that water use for households that did not participate in the program will creep up faster toward the historical norm, increasing the net savings of the audit program. Only followup evaluations can confirm the outcome.

This evaluation indicates that future audit programs can be made more cost-effective by targeting residences with large turf areas, residences with automatic sprinklers, and residences with high occupancy rates. Our preliminary conservative results suggest that a targeted audit program in the City of San Diego will save approximately 26 gallons per household per day. Savings from a targeted program could rise further as average water use creeps up to its pre-drought levels.

Water savings generated through the first untargeted phase of residential audits cost the City slightly over $500/acre-foot. With the shift in policy in favor of targeted audits, water savings are expected to rise. As a result, the cost of saved water to the City from these targeted programs is likely to drop to approximately $360/acre-foot. These cost-effectiveness estimates are based on the critical, and yet untested, assumption that water savings from audit programs will persist for at least 5 years.

Lastly, estimates of water savings from San Diego's program should be applied to other parts of the state with care because San Diego's climate and rate structure make it very different from many other regions of California.

REFERENCES

Brown and Caldwell (1984), Survey of Water Fixture Use, prepared for U.S. Department of Housing and Urban Development under contract H-5230, Walnut Creek, California.

City of San Diego (1993), "Preliminary Report of the 1992 City of San Diego Residential Water Survey Program," San Diego, California.

Fuller, W. A., and Battese, G. E. (1974) "Estimation of Linear Models with Crossed-Error Structure," Journal of Econometrics, 2, 67-78.

Goldberger, A. S. (1968) "The Interpretation and Estimation of Cobb-Douglas Functions," Econometrica, 35, 464-472.

Hausman, J. A. (1978) "Specification Tests in Econometrics," Econometrica, 46, 1251-1272.

Henderson, C. R. (1953) "Estimation of Variance and Covariance Components," Biometrics, 9, 226-252.

Honda, Y. (1985) "Testing the Error Components Model with Non-Normal Disturbances," Review of Economic Studies, LII, 681-690.

Metropolitan Water District of Southern California (1990), The Regional Urban Water Management Plan for the Metropolitan Water District of Southern California, Los Angeles, California.

Taub, A. J. (1979) "Prediction in the Context of the Variance-Components Model," Journal of Econometrics, 10, 103-108.

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