Embedded Energy in Water Pilot Programs Impact Evaluation

Final Report

Prepared for the California Public Utilities Commission Energy Division

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Abstract

Past research has shown that there is considerable energy that is required to obtain, treat and distribute water supplies to end-use customers. In response to these findings, the California Public Utilities Commission (CPUC) approved the Embedded Energy in Water Pilot programs, through which California's largest energy Investor-Owned Utilities were directed to develop partnerships with water agencies, implement specific water conservation and energy efficiency programs, and measure the embedded energy savings. More specifically, the CPUC required the utilities to partner with water providers to implement jointly funded programs designed to conserve water, use less energy-intensive water or make delivery and treatment systems more efficient and thereby reduce energy used by water providers and wastewater treatment agencies.

This report presents the impact evaluation results for the nine Pilot programs that were implemented by Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas and Electric Company from July 2008-December 2009. For each program, water and wastewater savings were measured via direct metering or analysis of water utility bills, and embedded energy savings were either measured directly or estimated based on the energy intensities of the water and wastewater systems that serve the Pilot participants.

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Introduction and Study Purpose

This report presents the impact evaluation results for the Water Pilot Programs (Pilots) that were implemented by Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric Company (SDG&E). The Pilots were initiated in July 2008 and concluded December 31, 2009.

Past research has shown that considerable energy is required to obtain, treat and distribute water supplies to end-use customers. In October 2006, the Assigned Commissioner to the energy efficiency proceeding issued a ruling soliciting Investor-Owned Utility (IOU) applications for an approximately $10 million one-year pilot "to explore the potential for future programs to capture water-related embedded energy savings."[1] More specifically, the ruling directed the four largest IOUs to partner with one large water provider to implement a jointly funded program designed to maximize embedded energy savings per dollar of program cost.[2] This pilot would focus on efforts that would:

1) Conserve water;
2) Use less energy-intensive water (gravity-fed or recycled versus groundwater, aqueducts or desalination); and
3) Make delivery and treatment systems more efficient

The IOUs initially filed their proposed program designs in January 2007, and the proposed programs were further refined through a series of workshops and supplemental filings. In December 2007, the California Public Utilities Commission (CPUC) approved the Pilot programs (in D. 07-12-050), through which the four largest IOUs would develop partnerships with water agencies, undertake specific water conservation and efficiency programs, and measure the results.[3] This impact evaluation was approved to inform the Commission in determining whether water conservation programs and/or measures should be added to the utilities' energy efficiency portfolio in 2009 – 2011 and beyond.

Programs Evaluated

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[1] October 16, 2006, ACR, R.06-04-010, page 3.

[2] Embedded energy is defined as "the amount of energy needed to acquire, pump, treat, distribute, and operate water treatment and delivery systems for a given amount of water." It excludes the savings directly associated with end-use application.

[3] Decision (D.) 07-12-50, *"Order Approving Pilot Water Conservation Programs Within the Energy Utilities' Energy Efficiency Programs"* in Application 07-01-024.

Following are brief descriptions of the nine Pilots that were evaluated:[4]

1. **PG&E Large Commercial Customers** - This program offered audits to large commercial, industrial and institutional customers to recommend water efficiency improvements. The program also offered financial incentives to help offset the cost of improvements. Types of eligible improvements included: ozone laundry systems, winery and food processing changes, detention facility toilet and shower upgrades, and recycled water retrofit projects. For ozone retrofits in laundry facilities, program approved ozone installers performed the audits. For other water efficiency improvements, audits were conducted by water agency (or city) staff or contractors.

2. **PG&E Low Income High Efficiency Toilets (Single-family)** – This program offered direct install, high efficiency toilets (HETs) to low-income customers living in single-family residences served by PG&E and partner water agencies. Only toilets that flush at 3.5 gallons per flush (gpf) or greater were eligible for replacement.

3. **PG&E Emerging Technologies** – PG&E partnered with two water agencies to integrate real-time electricity consumption data from water pumping into existing SCADA systems. One water agency planned to utilize the energy data in a new water-pumping algorithm that would automatically control a subset of system pumps. The other water agency planned to have system operators manually change the pump operations in response to displayed energy consumption. This program was not designed to conserve water, and instead focused on reducing energy consumption under different flow and pressure conditions.

4. **SCE Low Income High Efficiency Toilets (Multi-family)** – This program offered direct install, high efficiency toilets to low-income customers living in multi-family residences served by SCE and partner water agencies. Only toilets that flush at 3.5 gallons per flush (gpf) or greater were eligible for replacement.

5. **SCE Express Water Efficiency** – SCE partnered with Metropolitan Water District of Southern California (MWD) to deliver pH controllers for cooling towers and Weather Based Irrigation Controllers (WBICs) to commercial customers with chilled water HVAC and/or large landscape irrigation systems. A pH controller is a programmable device that monitors and adjusts the chemistry of the system to reduce water that must be bled from cooling towers. WBICs achieve water savings by switching from manual irrigation to weather based controllers.

6. **SCE Leak Detection** – For this program, detailed water audits that comply with International Water Association and American Water Works Association protocols were completed for three water agencies. These audits identify and validate different types of water volumes (e.g., authorized consumption, metering errors, leakage) that collectively add up to each agency's total water supply for the audit period. The program contractor also

[4] Southern California Gas Company implemented a Gas Pump Testing Pilot Program; however, this program was not evaluated, since the primary goal was to develop testing protocols to guide future testing programs, and not to save water or energy during the program period.

conducted proactive leak detection for each agency, and the agencies repaired all of the found leaks.

7. **SDG&E Managed Landscapes** – SDG&E hired a contractor to install proprietary equipment and software that converts conventional irrigation controllers into controllers that utilize daily evapotranspiration (ETo) and weather information to automatically and dynamically control the amount of water used for irrigation. SDG&E paid for the first year equipment and installation costs at each site, after which participants could sign an agreement with the contractor for continued services. Water savings incentives were also available from MWD, although this was not part of the core program design. The program was conducted in the San Diego region and targeted multifamily apartment complexes, condominiums, office parks, commercial properties, homeowner associations, and estate properties with at least four irrigated acres.

8. **SDG&E Recycled Water Retrofits –** This Pilot increased the use of recycled water by providing capital funding for planned retrofit projects that switched from a potable water source to a recycled water source.

9. **SDG&E Large Customer Audits** – For this Pilot, SDG&E provided capital funding to install water conservation measures at sites that had received prior water audits and where the customer had not yet acted to implement any of the identified measures. The second element of the Pilot developed and implemented new, integrated water/energy audits for large commercial, industrial and institutional high water users in San Diego County, expecting that some of these measures would be installed during the program period.

Evaluation Objectives and Methods

The primary purpose of the evaluation was to identify, estimate and quantify the amount of embedded energy savings (kWh, therms) associated with the water savings arising from the water efficiency measures in the programs approved in D. 07-12-050. So that the energy savings impact of various water saving measures deployed under the pilot programs could be understood, the evaluation was to quantify the amount of energy needed to bring water supplies to end-users' facilities.. During the evaluation scoping, the objectives were further refined and are listed below:

1. To learn if the Pilots do or can result in significant *energy* savings;
2. To provide information that the IOUs can use for water program cost-effectiveness and TRC calculations, and to determine if these water programs should become part of future energy efficiency program portfolios;
3. To provide information to enhance the CPUC's E3 Calculator or new program planning tools for water and embedded energy savings; and
4. To develop and test evaluation methods.

The evaluation of the Pilots had two primary components:

1. **End use water savings measurement.** Most of the evaluations utilized direct water metering of individual measures or housing units (e.g., for SCE HETs) for 2 to 4 weeks before and after

the installations. Some evaluations, such as the SDG&E Recycled Water and Managed Landscapes Pilots, utilized monthly water billing data instead. Each program chapter includes a detailed discussion of the water measurement techniques and sampling that were used.

2. **Embedded energy savings calculations.** This effort required determining the overall energy intensity of the water and wastewater systems that serve the Pilots' participants, then multiplying these energy intensities by the water/wastewater savings. For each Pilot project, the study team identified the relevant retail water and wastewater service providers and sent a survey to these agencies to obtain detailed information about water and wastewater flows and energy requirements. Some agency energy data were obtained from EEW Study 2. A recycled water survey was also developed and sent to the cities with Pilot projects that offset potable demand with recycled water. Data on the energy intensity of various wholesale water agencies were obtained from direct surveys, EEW Study 1, and other studies. While IOU energy savings are of particular interest to the IOUs and the CPUC, the report also includes energy savings from other energy providers, as these can be significant. The evaluation was not scoped to measure or estimate changes in end-user energy consumption, which may have occurred if customers installed or changed on-site equipment to implement water conservation measures or hot water demand was reduced, for instance.

Summary of Key Findings

In general, most of the program evaluations provided useful information about embedded energy savings to inform future analyses of cost-effectiveness and program continuation; notable data limitations are described in the specific program chapters and are summarized below.

Table ES-1 summarizes the annual potable water, wastewater and IOU embedded energy savings that were measured for each of the Pilots. For each program, the table also lists the report chapter where evaluation details are provided, the number of project sites or measures that were evaluated, and the energy portion of the project implementation budget for each program, although program cost-effectiveness was not assessed.

As shown in the table, SDG&E's Large Customer Audits Pilot generated relatively high IOU energy savings from both water and wastewater savings, while SCE's Leak Detection Pilot generated high energy savings by fixing distribution system leaks. PG&E's Large Commercial Customers Pilot also generated high IOU energy savings by reducing wastewater treatment. In contrast, PG&E's Emerging Technologies Pilot did not save any IOU energy from water pumping changes.

Following are some of the key findings from the evaluations of the nine pilot programs:

1. SCE's Leak Detection program appears to offer the greatest energy savings potential (at relatively low cost) among all the Pilot programs. In particular, the energy savings documented in this report are based on leaks that were *actually* repaired during the program period; *potential achievable* water (and energy) savings were estimated to be much higher by the program implementation contractor.

2. PG&E and SDG&E detention facility projects that installed efficient toilets, urinals and toilet flush timers generated high energy savings. Future programs may seek to focus on

these types of projects, pending detailed cost-effectiveness analyses. (For these projects, SDGE&E contributed capital funding whereas PG&E offered rebates based on water savings.)

3. Recycled water retrofit projects can offer large potable water savings, but additional research is needed on the IOU embedded energy in recycled water treatment (which offsets energy savings from potable water). In areas where recycled water treatment does not require significant IOU energy, it may be possible to design cost effective programs based on potable water savings.

4. For the other Pilots, the program costs are likely to exceed the energy benefits, even where embedded energy savings are incomplete (e.g., wastewater for PG&E HETs). That said, additional research is needed on actual program spending, measure lifetimes and potential changes in end-user energy (e.g., new motors, reduced hot water). Cost-effectiveness could be increased by reducing energy IOU program funding levels and/or targeting programs to the most energy intensive water systems (e.g., Lake Arrowhead).

Table ES-1: Summary of Annual Potable Water, Wastewater and IOU Embedded Energy Savings, by Pilot Program

PILOT PROGRAM	IOU BUDGET (A) [1]	PROJECT SITES, MEASURES (B)	EX POST POTABLE WATER SAVINGS (GALLONS/YR.) (C)	IOU EMBEDDED ENERGY SAVINGS – POTABLE WATER (KWH/YR.) (D)	EX POST WASTEWATER SAVINGS (GALLONS/YR.) (E)	IOU EMBEDDED ENERGY SAVINGS - WASTEWATER (KWH/YR.) (F)	TOTAL IOU EMBEDDED ENERGY SAVINGS (KWH/YR.) (D + F)
PG&E Large Commercial Customers (Chapter 3) [2]	$700,000	11 sites	33,719,230	12,417	16,478,711	42,772	**55,189**
PG&E Low Income High Efficiency Toilets (Chapter 4) [3]	$200,000	478 toilets	5,098,320	14,328	5,098,320	Not measured	**14,328**
PG&E Emerging Technologies (Chapter 5)	$341,000	2 water agencies	Not applicable	0	Not applicable	Not applicable	**0**
SCE Low Income High Efficiency Toilets (Chapter 6)	$200,000	276 toilets	1,329,768	5,538	1,329,768	174	**5,712**
SCE Express Water Efficiency (Chapter 7) [4]	$133,000	3 pH controllers	6,351,000	Not measured	6,351,000	9,385	**9,385**
SCE Leak Detection (Chapter 8)	$300,000	3 water agencies	82,923,912	178,143	Not applicable	Not applicable	**178,143**
SDG&E Managed Landscapes (Chapter 9) [5]	$250,000	13 sites	51,772,695	21,275	Not applicable	Not applicable	**21,275**
SDG&E Recycled Water Retrofits (Chapter 10) [6]	$250,000	4 sites	31,847,172	75,205	Not applicable	Not applicable	**75,205**
SDG&E Large Customer Audits (Chapter 11) [7]	$496,000	4 sites	82,081,336	73,710	82,081,336	81,802	**155,512**

[1] Does not include implementation budgets of partner water agencies. Actual program expenditures may be less than these approved budgets.
[2] Does not include IOU embedded energy savings for three water retailers (serving three projects) that did not provide data. Does not include IOU embedded energy savings for two large recycled water projects; no data were provided by the recycled water provider. Does not include IOU embedded energy savings for three wastewater agencies (serving four projects) that did not provide data.
[3] The wastewater agency serving the vast majority of program installations did not provide embedded energy data.
[4] The water retailer for the customer site did not provide embedded energy data. Water and energy savings are artificially high due to poorly maintained cooling towers.
[5] Does not include energy savings from two retail water agencies (serving two sites) that distribute imported treated water from a wholesaler.
[6] Embedded energy savings are from *all* sources (not only SDG&E). Does not include energy savings from one city (serving one project) that did not provide potable water or recycled water data. Two other projects were installed late in the program period and were not evaluated.
[7] Does not include energy savings from one city (serving one project), which did not provide potable water or wastewater data.

Program-Specific Findings

PG&E Large Commercial Customers Pilot Program

PG&E's Large Commercial Customers Pilot generated high potable water savings through recycled water retrofit projects for a private company and a school site, however, additional research is required to understand the embedded IOU energy in the tertiary treatment of recycled water; no data were provided for this evaluation. In addition, there may be high free ridership if recycled water costs significantly less than potable water in PG&E's service territory. This Pilot also achieved high water savings through a detention facility project that installed low-flow toilets with electronic flush valves/timers.

Seven of the 11 program participants were ozone laundry customers, and free ridership for these projects was probably low, as several eligible customers turned down the opportunity to participate (due to firm spending limits in the poor economy), even while the combined PG&E and water agency rebates covered a significant portion of the installation cost. While one ozone laundry project generated negative water savings (for unknown reasons), the other six realized positive savings, illustrating the importance of evaluating a sufficient number of sample sites. One project, a high-efficiency commercial dishwasher, generated large negative water savings because a new trough drain installed at the same time was inadvertently left open each morning before the dishwasher began operations (requiring the dishwasher to intake more water). While this type of problem is easily rectified, a larger sample size would provide more reliable savings estimates.

PG&E High Efficiency Toilets Pilot Program

The calculated embedded energy impacts for the PG&E HETs program are modest but also incomplete, as wastewater treatment data were not provided to the evaluation team. Embedded energy savings from reduced wastewater treatment would need to be measured or estimated in order to understand the full impacts of this type of program. That said, the measured water savings could reasonably be applied to other low-income households with about 5 persons, although water savings could vary more or less than for the SCE HET program, as relatively more non-retrofit toilets remained in the single-family homes, and it is not clear how people used the different models because non-retrofit toilets were not metered.

Although changes in toilet leakage were not considered in the calculated energy savings, leakage was observed to be a prevalent problem with the new toilets and is reducing potential water and energy savings by over 20 percent. Furthermore, this evaluation revealed that future HET programs should not rely on the manufacturer rated flush volumes without additional testing, since the observed flush volumes were higher in this case.

Additional research needs to be conducted prior to implementing a more comprehensive program. In particular, given the low-income target population, it is not known if property owners will install these measures on their own without program assistance; this evaluation found that almost one-third of the existing toilets in the single family homes were already low-flow models. Although program cost effectiveness was not assessed, utility cost-effectiveness could potentially be improved by requiring the property owners to pay a portion of the installation costs.

PG&E Emerging Technologies Pilot Program

PG&E's Emerging Technologies Pilot did not result in measured energy savings, as a planned automatic pumping control algorithm was not implemented at San Jose Water Company during the program period, and system operators at EBMUD did not utilize new SCADA screen displays of real-time energy consumption to manually improve the energy efficiency of pumping. While these strategies may have resulted in energy savings in other places, this was not observed during the Pilots period.

SCE High Efficiency Toilet Pilot Program

The total annual IOU embedded energy savings for the SCE HETs program (5,712 kWh/year) are modest compared to the other programs, in part because relatively few HETs were assessed (276), and also because the energy intensity of the affected wastewater agency is very low (132 kWh/MG). It would be reasonable to extrapolate the calculated water savings findings to a larger program, provided the household characteristics are generally similar to those of the evaluation sample. Thus if future SCE programs served low-income apartment units with two toilets, and retrofit about 90 percent of them, similar water saving results should be expected. (For this Pilot, the evaluation sample was shown to have similar characteristics and toilet installation/usage patterns as the broader local community.)

As with PG&E's HET program, potential water and energy savings are being reduced by leakage. Daily water savings of about 20 gallons/household were found in this evaluation, and would be closer to 30 gallons/household if most of the leaks were repaired (the largest leaks in particular). This evaluation also found that some of the new toilets flush at higher volumes than the manufacturer's ratings.

The owner of the apartment buildings had utilized the program installation contractor to install new toilets at several other company owned sites previously - it is not known if these were low-flow toilets or if rebates were obtained. Additional research is needed to better understand if low-income property owners will install these measures on their own without program assistance. Similarly, it may be possible to increase utility cost-effectiveness by requiring property owners to pay a portion of the installation costs (cost effectiveness was not assessed for this evaluation).

SCE Express Water Efficiency Pilot Program

SCE's Express Water Efficiency Pilot yielded only one pH controllers project, which retrofit 3 cooling towers at one customer site. Importantly, the water and embedded energy savings shown in Table ES-1 should not be extrapolated to other sites or programs, as the cooling towers were operated atypically during both the pre- and post-retrofit periods. In particular, two water bleed controllers were not functioning in the pre-retrofit period, and the towers were being bled manually, resulting in unusually high water use. After the retrofits, the concentration ratios of the three towers were still below the normal target level, reducing potential water savings. Based on operational data from the three towers and data from more typical, properly maintained systems (before and after retrofits), actual water savings at other sites may be closer to 25 percent of those documented in the table.

SCE Leak Detection Pilot Program

SCE's Leak Detection Pilot warrants further consideration for inclusion in regular IOU programs, pending further analysis of cost effectiveness. According to secondary research completed for this Pilot, most water agencies in California do not proactively manage leakage and only react to found leaks, typically after they have become larger.[5] Thus a program that offers proactive leak detection services could potentially generate large net water saving impacts. (The program may not need to offer comprehensive water audits, however, particularly if water agencies are already required to conduct these.) According to the secondary research, about 0.87 million acre-feet of water is lost each year through leaking water distribution pipes in California, and about one-third of this may be economically recoverable. The water savings documented for the three water agencies that participated in this Pilot, however, should not be extrapolated to a broader population of agencies, as these agencies have relatively low levels of leakage. Water savings could be even larger if agencies with relatively more leakage can be encouraged to participate.

SDG&E Large Customer Audits Pilot Program

SDG&E's Large Customer Audits Pilot had four customers install measures, and given the range of equipment installed it is difficult to draw broad conclusions about this program. As with PG&E's Large Commercial Customers Pilot, significant water savings were achieved through low-flow toilets, flush valves/timers and other measures at a large detention facility. This project received significant capital funding from SDG&E through the Pilot, and would not have been completed without this funding. The customers that installed autoclaves and reverse osmosis upgrades and process changes also realized water savings. Two of these customers did not obtain any water saving incentives from Metropolitan Water District for installed measures, but may not have been willing to pay for the free comprehensive water/energy audits offered through the program.

SDG&E Recycled Water Pilot Program

While SDG&E's Recycled Water Pilot generated high potable water savings, it should not be added to the regular program portfolio until more research is conducted. In particular, this program has a relatively high potential for free ridership, since local costs for recycled water are much lower than for potable water; SDCWA had several planned retrofit projects to select program participants from. In addition, more research is required on the intensity of IOU energy in tertiary recycled water treatment (i.e. the incremental energy beyond that needed for standard wastewater treatment). This program evaluation utilized past research on tertiary water treatment in San Diego, as more current detailed energy data could not be obtained for any of the recycled water agencies serving Pilots participants. Lastly, these Pilot evaluation findings should not be extrapolated to a larger program, due to the small sample size and because there was only a modest correlation between actual ETo rates and potable water usage. More importantly, recycled water retrofit projects may differ significantly in scope and by end use, and this Pilot suggests that future public agency projects should target park sites, which have higher water usage than roadsides, for instance.

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[5] *Secondary Research for Water Leak Detection Program and Water System Loss Control Study*, *Final Report*. WSO, December 2009.

SDG&E Managed Landscapes Pilot Program

The evaluation of SDG&E's Managed Landscapes Pilot suggests that water savings of 25 percent are generally achievable, and that these savings are probably due to the vendor's "smart" irrigation technology since no major site changes were noted in the post period. The low correlations between water use and the ETo data are presumably due to few ETo data points, microclimate effects, and/or vendor adjustments to how the ETo data are used by the proprietary software (perhaps even between sites, to develop partially customized watering schedules). Free ridership for this program was probably low, since the program paid for all of the customers' first-year service costs. However, we do not know how many of the participant sites plan to utilize the smart irrigation technology beyond the first free year of service. Additionally, the imposition of mandatory water restrictions in the future will significantly increase free ridership for these projects.

Water Agencies Data Collection

Collecting water and energy data from the water agencies proved to be challenging for both the water agencies and the evaluation team. Water agencies that were involved in conceptualizing the programs from an early stage expected that production and energy data would eventually be required in some form. Other water retailers, however, were not initially aware that they would need to provide data, even if their water wholesaler was a Pilot program partner. In particular, wastewater and recycled water agencies that operate independently of water wholesalers and retailers did not know of the need for energy data until contacted by the evaluators. Despite these challenges, the evaluation team was able to obtain usable data from many of the water agencies that served participating Pilots customers.

Overarching Recommendations

This impact evaluation of the Pilots produced a number of recommendations for future evaluation efforts, including:

1. **Systematically inform *all* of the agencies from which embedded energy data will be required for evaluation purposes.** For this evaluation, some retail water agencies did not provide embedded energy data, and important regional wastewater and recycled water agencies did not provide data. If new embedded energy data are required for future studies or pilot programs, the CPUC and/or the IOUs could make the data submission a prerequisite for programs partnering.

2. **Conduct further research about recycled water, particularly IOU embedded energy for tertiary treatment and retail costs to consumers**. These projects have a relatively high potential for free ridership, since costs for recycled water in some areas are lower than for potable water (in other areas they are similar). In addition, more research is needed on the intensity of IOU energy in tertiary recycled water treatment (i.e., the incremental energy beyond that needed for standard wastewater treatment). This evaluation was unsuccessful in collecting new detailed energy data from three recycled water agencies serving Pilots participants. Throughout much of California, especially Southern California, the energy requirements for potable water are high. Thus, recycled

water is likely to yield significant energy savings. The energy implications of replacing potable water with recycled water, however, will vary among water agencies.

3. **Evaluate larger samples if possible.** The evaluated project samples were generally small due to limited participation and evaluation budget constraints. For some project types such high efficiency commercial dishwashers, pH controllers, and boiler water reuse, there was only one Pilots participant and only one project was evaluated.

4. **Incorporate changes in end-user energy consumption into cost-effectiveness calculations.** Although this evaluation was not tasked with measuring or estimating end-use energy changes, these changes could be significant and offset a portion of the embedded energy savings. Cost effectiveness analyses and/or future studies should attempt to quantify these impacts, to understand the true net energy savings from water conservation programs.

Program-Specific Recommendations

1. **PG&E Large Commercial Customers: Ozone Laundry Systems**

   - **Develop ways to consistently obtain occupancy and/or laundry pounds data to normalize water use.** These data could not be obtained for this evaluation for a variety of reasons (e.g., evaluation activities timing, time constraints among hotel staff). Future studies should try to collect additional data to normalize water use and refine water/energy savings estimates.

2. **SCE Express Water Efficiency: pH Controllers**

   - **Conduct further research about pH controllers.** This evaluation focused on one project where the pH controllers were not properly maintained, which misrepresented likely water savings. While the evaluation was able to estimate achievable water savings, addition research is warranted, unless existing secondary research provides reliable estimates of water savings for this measure.

3. **High Efficiency Toilets - SCE and PG&E**

   - **For HET evaluations where direct metering is conducted, add metering to non-retrofit toilets.** This would provide additional information to understand if/how actual household toilet usage may change after the retrofits (i.e. if some toilet models are preferred).

   - **For HET evaluations where the Flow Trace method is used, conduct on-site verifications to confirm the make and model of the installed toilets.** This is needed to distinguish maladjusted toilets from un-replaced toilets. Furthermore, this would better allow evaluators to apply results from only fully retrofit units to partially retrofit units on a per-toilet basis, if this approach is preferred.

- **Try to develop more predictive models relating household occupancy to toilet usage.** This would require collecting periodic occupancy data over time, and would allow calculated program saving to be applied elsewhere more reliably, as household occupancy can change due to travel, visitors, etc.

- **Do not use manufacturer rated flush volumes for HETs.** Both HET studies found that actual flush volumes differed from these ratings.

4. PG&E Emerging Technologies

- **Ensure that water agencies planning SCADA improvements to save energy have supportive operating conditions and policies.** Program planners need to make sure that operator behavior change is in fact feasible in the specific operating environment; otherwise energy savings are unlikely to result.

5. SCE Leak Detection

- **Conduct real-time field visits to verify repairs of leaks found during program-sponsored leak detection surveys.** Due to logistical and budgetary constraints, this could not be done for this evaluation, but should be considered for future evaluations if energy savings will be claimed.

6. SDG&E Managed Landscapes

- **Conduct further research on the vendor's smart irrigation technology to understand when and why the typical control algorithms may be customized.** This could help refine future estimates of expected water savings, as the evaluation found some unexpected changes in pre/post soil moisture correlations and the vendor may make controller adjustments at future installations.

1 Introduction and Purpose of Study

This report presents the impacts evaluation results for the Water Pilots Programs (Pilots) that were implemented by Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric Company (SDG&E). The Pilots were initiated in July 2008 and concluded December 31, 2009.

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1) Conserve water;
2) Use less energy-intensive water (gravity-fed or recycled versus groundwater, aqueducts or desalination); and
3) Make delivery and treatment systems more efficient

Funding for these programs was to be separate from the 2006-2008 energy efficiency program cycle and the utilities could not get credit for these savings towards their 2006-2008 savings goals, since the primary purpose of measuring such savings is to develop a general understanding of program benefits, rather than affecting rewards or penalties.

The IOUs initially filed their proposed program designs in January 2007, and the proposed programs were further refined through a series of workshops and supplemental filings. In December 2007, the California Public Utilities Commission (CPUC) approved the Pilot programs (in D. 07-12-050), through which the four largest IOUs would develop partnerships with water agencies, undertake specific water conservation and efficiency programs, and measure the results.[8] This impact evaluation was approved to inform the Commission in determining whether such programs and/or measures should be added to the utilities' energy efficiency portfolio in 2009 – 2011 and beyond.

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4. To develop and test evaluation methods.

The impact evaluation of the Pilots had two primary components:

1. **End use water savings measurement.** Most of the Pilot programs involved some form of end-use water savings measurement (primarily through direct metering) to determine the amount of water savings achieved by each project. These measurements were as accurate as possible given the evaluation budget, as developing precise realized impacts for these programs was not the primary focus of this evaluation. End use water savings were calculated for the Pilots on a site-by-site basis, and required metering before and after installation of the water conservation measures.

2. **Embedded Energy Savings calculation.** In addition to the water savings estimates, the report describes the water and wastewater systems affected by each Pilot program and uses this information to estimate embedded energy savings. The water agency systems are described in Appendix 1.2, where the energy intensity of water produced or treated by the agency is calculated. Using these energy intensities, it is then possible to translate the measured water savings into embedded energy savings. These savings estimates are limited to wholesale and retail water supply agencies that provided data for this study.

   Importantly, the energy savings calculations do not consider changes in end-user energy consumption, which may have occurred if customers installed or changed on-site equipment to implement water conservation measures. These types of changes could include new motors to run ozone laundry systems, or new pumps to reuse water on-site, for instance. Estimating changes in end-user energy consumption was not in the scope of this evaluation, but should be considered in program cost-effectiveness calculations.

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[9] CPUC Request for Proposals No. 07 PS 5734. January 2008.

[10] *Embedded Energy in Water Pilot Programs Final Impact Evaluation Plan.* June 16, 2008.

Nine Pilots conducted between July 2008 and December 31, 2009 are covered in this report and are listed in Table 1 along with brief program descriptions.[11]

Table 1: Pilot Program Descriptions

PROGRAMS INCLUDED IN THIS EVALUATION	PROGRAM DESCRIPTION
PG&E Large Commercial Customers Water Pilot Program	PG&E partnered with East Bay Municipal Utility District (EBMUD) and water retailers served by the Sonoma County Water Agency (SCWA) and Santa Clara Valley Water District (SCVWD) to implement the Large Commercial Customers Program. The program offered audits to large commercial and industrial customers to recommend water efficiency improvements at selected facilities. The program also offered financial incentives to help offset the cost of improvements implemented by the customer within the program period. Types of eligible improvements included: ozone laundry systems, winery and food processing changes, hospitality sector bath and shower upgrades, and large customer landscape projects. For ozone retrofits in laundry facilities, program approved ozone installers performed the audits. For other water efficiency improvements, audits were conducted by water agency (or city) staff or contractors. In the ozone laundry element of the program, PG&E contractors installed machinery that adds ozone to water used to do laundry in commercial buildings such as hotels. PG&E and its partners also advocated for the inclusion of recycled water projects, which utilize treated wastewater that has been diverted for reuse rather than returned to a receiving water body. PG&E and the water agencies gave financial incentives to participants that decided to install a recycled water system, and the customers used independent contractors to do the work. In the water audit element of the program, participants were given financial incentives if they hired independent contractors to install recommended equipment.
PG&E Low-Income Direct Install High Efficiency Toilet Replacement Pilot Program	For the Low Income High Efficiency Toilets Program, PG&E partnered with the Santa Clara Valley Water District (SCVWD) to offer direct install, high efficiency toilets (HETs) to low-income customers living in single-family residences (up to a four-plex). PG&E utilized its existing Low Income Energy Efficiency (LIEE) program contractors to identify the target customers and hired a direct install contractor to complete the HET installations. Toilet replacements were available to customers that meet the LIEE criteria for low income, are served by both PG&E and a partner water agency, and have toilet models that flush at 3.5 gallons per flush (gpf) or greater. Ultra Low Flush Toilets were not eligible for replacement. The cost for each HET was estimated to be $280 per toilet. The participating water agencies paid $150 per toilet, and PG&E covered the remaining cost. PG&E paid the contractor for their work directly and invoiced SCVWD for $150 per toilet.
PG&E Emerging Technologies Program	For the Emerging Technologies Program, PG&E partnered with two water agencies to investigate emerging monitoring and telecommunications technologies to determine whether these technologies can help water agencies distribute water more energy efficiently. Before selecting the two water agencies, a preliminary scoping

[11] Southern California Gas Company implemented a Gas Pump Testing Pilot Program; however this program was not evaluated, since the primary goal was to develop testing protocols to guide future testing programs, and not to save water or energy during the program period.

	study was conducted to inventory SCADA related technologies and innovations that hold significant potential for energy savings.[12] Some of the technologies that were investigated included: integration of water flow and energy monitoring to detect water losses, integration of customer metering and SCADA to improve water distribution and energy efficiency, and/or pairing SCADA with programmable logic controllers to optimize pumping efficiency. From the scoping study, PG&E concluded that one of the best opportunities for energy savings is the integration of real-time pump electricity consumption data into existing SCADA systems. This facilitates real-time analysis of pumping system efficiency, which in turn helps system operators optimize energy use. After selecting two water agencies to test the recommended technology, PG&E hired two consultants to assist the agencies with project implementation and data analysis. One water agency planned to utilize real-time energy data in a new water-pumping algorithm that would automatically control a subset of system pumps. The other water agency planned to integrate energy data in their SCADA system, and then rely on system operators to manually change the pump operations in response to displayed energy consumption. This program was not designed to conserve water, and instead focused on reducing energy consumption under different flow and pressure scenarios.
SCE Low-Income Direct Install High Efficiency Toilet Pilot Program	For the Low Income High Efficiency Toilets Program, SCE partnered with the Metropolitan Water District (MWD) and its member water agencies to deliver the direct installation of high efficiency toilets (HETs) for multifamily households in low-income areas within mutual SCE and MWD service territories. Under the program, only toilets flushing at 3.5 gallons per flush (gpf) or higher could be replaced with new HETs. This program was intended to augment and complement PG&E's similar program, which exclusively targeted single-family residences. To offset the costs of the direct installations, MWD provided funding of $165 per HET while participating member agencies contributed $50 per HET. SCE funded the remaining installation costs, estimated at $70-115 per HET, and other costs to assess multifamily units for HET eligibility and suitability. To target multifamily properties, SCE utilized its existing LIEE contractors as well as existing local government partnerships. SCE also coordinated with MWD and its member water agencies with larger low income and multifamily customer bases to identify and reach target customers.
SCE Express Water Efficiency Program	For this program, SCE partnered with MWD to deliver pH controllers for cooling towers and Weather Based Irrigation Controllers (WBICs) to commercial customers with chilled water HVAC and/or large landscape irrigation systems in mutual SCE/MWD service territories. A pH controller is a programmable device that monitors the pH of the water circulating in the cooling tower and adds a mixture of dilute acids and other treatment chemicals in order to maintain a pH in the circulating water below 8.3. This prevents the formation of calcium carbonate scale in the system. By adjusting the chemistry of the system to greatly reduce the risk of scale

[12] SCADA are Supervisory Control and Data Acquisition systems, which typically monitor and store data on water flows, pressure, and storage levels.

	formation it is possible to operate the tower at much higher levels of concentration, which reduces the amount of water that is necessary to bleed from the tower.[13] WBICs achieve water savings by switching from manual irrigation controllers to weather based controllers. Since many irrigation controllers are known to over-irrigate landscaped areas due to how they are programmed, switching to a controller that automatically adjusts the application based on actual weather conditions should save water. To offset the cost of the pH controllers and the WBICs, MWD provided rebates of \$1,900 per cooling tower controller and \$630 per irrigated acre controlled by a WBIC. While MWD is able to give rebates for specific water conservation measures, it is not able to provide technical assistance or design recommendations to customers. Thus, SCE served as the "marketing arm" of the program and incorporated these measures into its existing Express Efficiency nonresidential retrofit rebate program, which is a prescriptive component of the Business Incentives and Services package of energy efficiency programs. Through its customer account executives and other Express Efficiency program delivery channels, SCE marketed the program directly to its customers, providing access to customers previously unavailable to MWD.
SCE Leak Detection Pilot Program	This program analyzed water agency leakage and loss control strategies through primary and secondary research, to learn more about the significance of water losses due to both distribution system and end-user water leaks, and the potential for cost-effective interventions to reduce water losses. For the primary research, detailed top down water audits that comply with International Water Association (IWA) and American Water Works Association (AWWA) protocols were completed for the Las Virgenes Municipal Water District, Apple Valley Ranchos Water Company and Lake Arrowhead Community Services District by Water Systems Optimization Inc. (WSO), under contract to SCE. The top down water audit is a process of identification and validation of the different types of water volumes that collectively add up to each agency's total water supply for the audit period. In a top down audit, all water volume components are evaluated starting with each agency's total system input and working down (through a process of subtraction) to validate water consumption and then identify real water losses. Water system components that were analyzed include: 1. Total System Input 2. Authorized Consumption 3. Apparent Losses 4. Real Losses The final reports included economic cost/benefit assessments to identify appropriate types and levels of intervention (e.g., leak detection/repair work, water pressure management) to reduce water losses in the future. The contractor also demonstrated a variety of techniques to estimate hidden leakage in specific areas. Lastly, for each agency a field leak detection and repair campaign was conducted to show agency staff how leak detection is performed. The contractor

13 Operating the cooling tower with less scale also improves its thermal performance, which reduces the energy consumption of the entire mechanical system to which the tower is attached.

	performed the leak detection and the agencies repaired the all of the found leaks.
SDG&E Large Commercial Audits Water Pilot Program	In the past, SDG&E and SDCWA have conducted audits on large customers, but only focused narrowly on energy and water, respectively. To give customers more comprehensive recommendations for both water and energy usage and (potentially) reduce auditing costs, the two agencies formed a partnership to deliver combined water and energy audits to large water users through a two-phased Pilot program. The first part of the program strategy (Phase 1) was to follow-up on recommendations provided in three large customer audits already completed by SDCWA contractors, upon which the customers had not acted. While these water audits had identified many water savings opportunities, there had been little movement to implement the recommendations due to a variety of customer-specific reasons, such as: lack of funding, competition with other customer priorities, long pay backs, etc. To move high priority, cost effective projects to implementation, SDCWA researched available funding from other water agency incentive programs, and SDG&E provided supplemental capital funding to fill in funding gaps. The second part of the program strategy (Phase 2) developed and implemented an integrated water/energy audit for large customers, where water and energy savings can be significant. Working with an auditing contractor retained through an RFP process, SDG&E and SDCWA coordinated in the development of an integrated water/energy audit template that was used to conduct water/energy audits of commercial, industrial and institutional high water users in San Diego County. Participant recruitment was conducted by SDCWA, the audits contractor and SDG&E account executives.
SDG&E Managed Landscapes Water Pilot Program	The Managed Landscapes Program focused on increasing the efficient use of outdoor potable water used for aesthetic landscapes. According to the program planning documents, about 60 percent of all municipal and industrial water is used on landscaping in an average year, and thus the efficient management of this water use is critical to achieve water and energy savings. This is especially important since nearly half of all landscape water use takes place in May, June, July, and August when treatment and delivery systems are strained to meet demands. This time frame also coincides with the peak electricity demand period. SDG&E solicited competitive bids from water management service companies to implement the program, and the contractor that was selected utilized proprietary equipment and software to convert conventional irrigation controllers into controllers that utilize daily evapotranspiration (ETo) and weather information to automatically and dynamically control the amount of water used for irrigation. Under the final program design, SDG&E paid for the first year equipment and installation costs at each site. After that time, participants could sign a separate agreement with the contractor to provide continued services for an extended period. Water savings incentives were also available from MWD, although these incentives were not part of the core program design. The program was conducted in the San Diego region and targeted multifamily apartment complexes, condominiums, office parks, commercial properties, homeowner associations, and estate properties. To participate in the program, properties had to have a minimum of four irrigated acres and five or less existing irrigation timers, and be approved by SDG&E and MWD.
SDG&E Recycled Water	This program increased the use of recycled water by assisting retrofit projects that switched from a potable water source to a recycled water source. To implement the

Pilot Program	program, the San Diego County Water Authority (SDCWA) and its member agencies identified sites with completed retrofit plans that would allow the customer to switch from potable water usage to recycled water usage during the program period. After the final program participants were selected by SDCWA, SDG&E provided matching capital funding to projects that completed installation and started operations during the program period.

1.1 Report Organization

The remainder of this report is organized as follows: the next section describes the general methods that were used to estimate water savings and embedded energy savings. Following that, separate chapters detail the analysis for each of the Pilots described above. Each of these chapters includes: a program description, a discussion of the data collection and analysis techniques, estimated water savings, estimated embedded energy savings, a discussion of uncertainties and potential biases, and overall findings and recommendations for future evaluations. The concluding chapter contains overall findings and conclusions and provides observations about utilizing these findings for future programs.

A separate process evaluation of the pilot programs has also been completed and is presented in a separate report.[14] Readers should refer to that report for findings related to: the partnerships formation, customer recruitment, customer participation experience and satisfaction, contractor participation experience and satisfaction, and overall program delivery successes and challenges.

[14] *Process Evaluation of the PG&E, SCE, SDG&E and SCG Water Pilot Programs.* ECONorthwest. December 2010. The report will be available at: http://www.calmac.org/.

2 Evaluation approach/Overarching methods

2.1 Water Savings Methodology

Most of the evaluations utilized direct water metering of individual measures or housing units (e.g., for SCE HETs) for 2 to 4 weeks before and after the installations. Some evaluations, such as the SDG&E Recycled Water and Managed Landscapes Pilots, utilized monthly water billing data instead. Each program chapter includes a detailed discussion of the water measurement techniques and sampling that were used.

2.2 Embedded Energy Methodology

A key objective of the study was to develop estimates of the embedded energy savings in water and wastewater for each of the Pilot programs. Embedded energy is defined as the amount of energy needed to acquire, pump, treat, distribute, and operate water treatment and delivery systems for a given amount of water. This savings excludes energy savings directly associated with end-user applications, such as savings in residential or commercial water heating energy or increased energy to reuse water on-site.

This effort required us to determine the energy intensity of the water and wastewater systems that serve the various projects completed for each Pilot program. Energy intensity is defined as the total energy requirements for a given volume of water or wastewater and is often expressed in units of kWh per million gallons (MG) or, for natural gas, in units of therms per million gallons. As noted previously, the focus of this report is the requirements for pumping and treating of water and wastewater. End-use energy requirements, while potentially significant, were beyond the scope of this analysis.

Water and wastewater utilities obtain energy from a variety of sources, including IOU electricity and gas providers, non-IOU providers, and through self-generation, e.g., solar or biogas recovery. The IOU energy savings are of particular interest to the IOUs and the CPUC since current rules require benefits to accrue to the ratepayer class that provided the funding, and it is these benefits that would be considered under current cost-effectiveness rules. Because this analysis has general interest and the values identified here may be used in other analyses, estimates of both the IOU and where possible, total energy intensity of the water and wastewater systems of the Pilot agencies are included. IOU energy is a subset of broader energy benefits, and it is important to understand both when considering the efficacy of the pilot programs.

California has a complex network of retail and wholesale agencies. Many agencies import water from a wholesale agency and supplement these imports with local surface and groundwater. Prior to delivery to the retail service area, however, this water may already have significant embedded energy. Where possible, the energy use by the wholesale agency has been included. As described above, the values identified in this analysis will have general interest and the failure to include these energy inputs would significantly underestimate the energy intensity of the water and the potential energy savings from these programs and measures. Data on the energy intensity of various wholesale water agencies were obtained from direct surveys, the EEW Study 1, and other studies cited in Appendix 1.2.[15]

2.2.1 Data Collection

For each pilot project, the evaluation team identified the retail water and wastewater service providers (Table 2). The evaluation team developed a survey that was sent to these agencies in order to obtain general information about system operations. A recycled water survey was also developed and sent to the Cities of San Diego and San Jose, both of which were involved with pilot projects that offset potable demand with recycled water (see Appendix 1.1 for a copy of the survey instruments). Surveys were supplemented with information from utility websites and urban water management plans and from interviews with conservation and operations staff. While many of the agencies were able to provide the required data, not all of them did, and thus the embedded energy savings are underestimated for some Pilot programs. Each program-specific chapter notes if and how the embedded energy calculations are incomplete.

[15] CPUC Decision 7-12-050, Appendix B, directed Study 1 to: "Develop a model of the functional relationship between water use in California and energy used in the water sector that can be used in a predictive mode: Given a specific water requirement(s) developed from precipitation pattern information, what is the expected energy use." To this end, Study 1 collected historical water and energy data from nine large wholesale water agencies and developed energy intensities for water conveyance (not including treatment) that could be utilized by this evaluation. Detailed information about Study 1 and the evaluation results can be accessed at: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/Embedded+Energy+in+Water+Studies1_and_2.htm.

Table 2: Water Pilot Programs and Associated Water and Wastewater/Recycling Utilities

PILOT PROGRAM	RETAIL WATER UTILITY	RETAIL WASTEWATER/RECYCLING UTILITY
PG&E Large Commercial Customers	Sonoma County Water Agency	Sonoma County Community Services District
	Valley of the Moon Water District	Sonoma County Community Services District
	City of Santa Rosa	City of Santa Rosa
	City of Petaluma	City of Petaluma
	Marin Municipal Water District	Central Marin Sanitation Agency/Sanitary District #2 of Marin County
	City of Milpitas	City of San Jose
	City of Sunnyvale	City of Sunnyvale
	San Jose Water Company	City of San Jose
	East Bay Municipal Utility District	East Bay Municipal Utility District
PG&E Emerging Technologies	No embedded energy evaluation - direct energy savings only	
PG&E High Efficiency Toilets	San Jose Water Company	City of San Jose
SCE High Efficiency Toilets	Irvine Ranch Water District	Irvine Ranch Water District
SCE Leak Detection	Las Virgenes Municipal	N/A for evaluation
	Apple Valley Ranchos	N/A for evaluation
	Lake Arrowhead Water District	N/A for evaluation
SCE Express Efficiency (pH Controllers and Weather-Based Irrigation Controllers)[16]	California Water Service Co. - Dominguez Hills	Los Angeles County Sanitation District
SDG&E Large Customer Audits	Carlsbad Municipal Water District	Encina Wastewater Authority/Carlsbad RW Plant
	Otay Water Department	City of San Diego
	Oceanside	Oceanside
	City of San Diego	City of San Diego
SDG&E Managed Landscapes	City of San Diego	N/A for evaluation
	Otay Water Department	N/A for evaluation
SDG&E Recycled Water	City of San Diego	City of San Diego (North City and South Bay Water Reclamation Plants)
	Carlsbad Municipal Water District	Encina Wastewater Authority/Carlsbad RW Plant

Notes: Wastewater utilities were not contacted for SCE's Leak Detection program because only potable water was conserved and wastewater flows were not affected. Thus, the energy savings are a function of the energy intensity of

[16] No WBIC installations were directly attributable to SCE's program. The water agency listed serves the only pH controllers installation that is attributable to SCE's program.

the water system alone. For the PG&E High Efficiency Toilets program, the vast majority of toilets were distributed in San Jose, and thus the evaluation team focused on this water agency, although some toilets were also distributed in smaller cities.

In addition to general information on system operations, the survey also requested data on the water flows and energy use throughout the water and wastewater systems. Water and energy data were requested at the finest temporal resolutions available for all facilities within the water and/or wastewater systems. Agencies provided water flow data at temporal scales ranging from hourly to monthly. Initial data requests revealed that many utilities had only total monthly energy use data. While some facilities had time-of-use (TOU) meters that tracked on-, partial-, and off-peak energy use, the water utility reported only total energy use to the evaluation team. To ensure that the best data available were obtained, the evaluation team requested energy data directly from the energy provider (i.e., PG&E, SCE or SDG&E). For each utility, we developed a list of all energy meters associated with pumping and treating water/wastewater and submitted data requests to the energy service provider. This approach reduced the time burden placed on water utility staff to collect these data. Water and energy data were collected for the year 2008. This date was chosen for consistency with Embedded Energy in Water (EEW) Studies 1 and 2 so that comparable data could be shared, although 2008 was a drought year and may not represent normal operating conditions for some water systems.

Concurrent with our evaluation efforts, GEI and Navigant were conducting three embedded energy in water studies on behalf of the CPUC and through CIEE. These studies were conceived to better understand water-related energy use, and were approved along with the pilot programs evaluated in this report. All of the studies overlapped in some ways, and project team members were encouraged to coordinate with one another. In particular, EEW Study 2 was charged with estimating energy intensity for 30 water/wastewater systems in California.[17] Seven of these utilities were also involved in the pilot programs. Overlapping agencies included:

- Sonoma County Water Agency
- Marin Municipal Water District
- San Jose Water Company
- East Bay Municipal Utility District
- Los Angeles County Sanitation District
- City of San Diego
- City of Oceanside

[17] CPUC Decision 7-12-050, Appendix B, directed Study 2 to: “1) Develop a representative range of energy intensities for water agencies in California, and representative ranges of energy intensities for the various functional components of the water system in California. 2) Develop a representative range of water energy load profiles for water agencies in California, and representative ranges of energy load profiles for the various functional components of the water system in California.” Detailed information about Study 2 and the evaluation results can be accessed at: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/Embedded+Energy+in+Water+Studies1_and_2.htm.

To ensure consistency with Study 2 and reduce data collection burdens on the participating agencies, the Study Team coordinated with Study 2 on data collection. In particular, Study 2 team members reviewed our data collection instrument before it went into the field and worked directly with the utilities to collect the water and energy data. Most, but not all, agencies listed in Table 2 responded to the survey and provided the necessary water flow and energy information. Agencies that responded are summarized in Appendix 1.2.

2.2.2 Data Processing

Water and energy data were processed using the Water-Energy Load Profiling (WELP) Tool developed for the EEW Study 2. The WELP was developed using Microsoft Access and was designed to produce and store 24-hour energy profiles and calculate energy intensity. Energy load profiles are calculated by individual facility (e.g., a particular groundwater pump) and facility type (e.g., all groundwater pumps). These profiles can be requested for a specific day (e.g., March 18, 2008) and are available for 7 day types: Summer Peak Energy (SPE), Summer Average Water Demand (SAW), Summer High Water Demand (SHW), Summer Low Water Demand (SLW), Winter Average Water Demand (WAW), Winter High Water Demand (WHW), and Winter Low Water Demand (WLW). The DAT produces daily and monthly energy intensity estimates by facility type for each agency. These estimates are reported in units of kWh per million gallons (kWh/MG).

The WELP user interface allows the user to extract daily and monthly energy intensity and daily load profiles. It does not automatically calculate the embedded energy metrics needed for this Water Pilot EM&V Study. As described previously, this Water Pilot EM&V Study requires an overall estimate of each agency's annual energy intensity (kWh/MG). The database, however, can be queried to produce the metrics necessary for this evaluation. This additional processing is described in the next two sections.

2.2.3 Annual Energy Intensity Estimates

For each agency, energy intensity estimates were developed for each phase of the water and wastewater system, including supply, conveyance, treatment, delivery, wastewater collection, wastewater treatment, and wastewater discharge. Each phase is described in greater detail, below.

- **Water supply** refers to the extraction of water from its source to the surface. Energy requirements for water supply depend upon the location of the water relative to the surface and the method of extraction. For surface water, including seawater and recycled water, the energy requirements are effectively zero because the water is already at the surface (although in the case of seawater desalination, treatment energy requirements are high and are captured in the water treatment phase). For groundwater, the energy requirements depend upon the depth from which the water must be pumped and the efficiency of the pumps.

- **Water Conveyance** refers to the transportation of untreated water from its source to a water treatment facility. Energy requirements for conveyance depend primarily on the distance and net elevation that it is pumped, as well as the efficiency of pumps used. In some cases, water needs to be conveyed only a short distance from a surface or groundwater source to the treatment facility. Other times, water is transported long distances and over steep terrain.

- **Water treatment** refers to processes and technologies that treat water to drinking water standards prior to its distribution to homes and businesses. The energy requirements for treatment depend upon the quality of the source water and the technology employed to treat that water.

- **Water distribution** refers to the transport of water from the treatment facility to the customer. Like conveyance, the energy intensity of distribution depends largely on the distance and elevation that water is pumped, as well as the energy efficiency of pumps.

- **Wastewater collection** refers to the collection and transport of wastewater from the customer's home to the wastewater treatment facility. Wastewater collection may be done by gravity, although pumping is required in some areas. The energy requirements for wastewater collection depend upon local geography and pump efficiency.

- **Wastewater treatment** refers to the treatment of wastewater prior to reuse or disposal into the environment. All wastewater must undergo primary treatment to remove solids, oil, and grease and secondary treatment to degrade organic material. If receiving waters require that wastewater effluent contain particularly low nutrient content, or if the wastewater is going to be re-used, it also undergoes tertiary treatment to reduce nitrogen, phosphorus, and other contaminant concentrations. The energy requirements for wastewater treatment depend upon the level of treatment and, because wastewater must be pumped throughout the treatment facility, pump efficiency.

- **Wastewater discharge** refers to the discharge of treatment wastewater into the environment. Wastewater discharge can be done by gravity or may require pumping. While typically small, the energy requirements for wastewater discharge depend upon local geography and pump efficiency.

Annual energy intensity estimates were developed for each phase of the water and wastewater systems by dividing total energy use in 2008 by total water flow during that period. Estimating the denominator in this equation (i.e. the total water flow for each phase), however, can be challenging. Many conveyance and distribution systems, for example, have multiple flow meters located in succession. Adding the flows from each of these flow meters would result in counting a single gallon of water multiple times as it moves through the system, effectively underestimating the energy intensity of the water. Determining the appropriate denominator requires a clear understanding of the water system being evaluated in order to avoid counting the same gallon of water multiple times.

Many utilities receive water from multiple sources with different energy intensities. The energy intensity of supply is then a weighted average of the energy intensity of each water source. Energy intensity estimates for each phase (supply, conveyance, water treatment, and distribution for potable water systems, and wastewater collection, treatment, and discharge for wastewater systems) are then summed to produce system energy intensity estimates.

The following example helps to clarify the calculation approach. We assume Agency A imports treated water from a wholesaler and supplements this with water pumped from groundwater wells. In an average year, 50 percent of the water supply is imported and the remaining 50 percent is from groundwater. Groundwater is relatively clean and requires only minor chlorination before entering the distribution system. No conveyance is required because chlorination occurs at the wellhead. The chlorine injector and the groundwater pump are connected to the same electricity meter and thus there is no way to distinguish the pumping and treatment requirements for groundwater. In total, the energy intensity of groundwater is estimated at 1,000 kWh per million gallons. Treated water is imported from a local wholesaler and put directly into the water distribution system. Based on other studies, it is estimated that the imported water has an energy intensity of 2,000 kWh per million gallons. These energy requirements occur outside of Agency A's service area. Because 50 percent of the water is from groundwater and the remaining 50 percent is from imported water, the average energy intensity of supply, conveyance, and treatment for the retail utility is 1,500 kWh per million gallons. The water distribution system has an energy intensity of 700 kWh per million gallons. In total, the water system has an energy intensity of 2,200 kWh per million gallons (Table 3).

Table 3: Sample Energy Intensity Calculation

WATER SYSTEM PHASE	ENERGY INTENSITY (KWH/MG)
Source	1,500
Conveyance	
Treatment	
Distribution	700
Water System Total	**2,200**

Appendix 1.2 contains profiles for each of the participating water and wastewater agency and the energy intensity estimates. Separate estimates were developed for the water and wastewater systems. Because indoor water conservation and efficiency measures reduce both water demand and wastewater treatment requirements, the energy savings for these measures included the embedded energy of both water and wastewater. Outdoor water conservation and efficiency measures, however, only reduce water demand; wastewater flows are unaffected. Thus, the energy savings associated with these measures include only the embedded energy of water. Separating these estimates allows the CPUC to evaluate the energy savings from water conservation and efficiency measures that reduce indoor and outdoor demand.

Some utilities use natural gas to power pumps or treatment facilities, and reducing water use reduces natural gas consumption. The Study 2 WELP, however, does not include natural gas. Natural gas energy intensity estimates were developed outside of the Study 2 WELP and were calculated for each water/wastewater system phase by dividing total natural gas use by total water flow for 2008. These estimates were developed for the few agencies that used natural gas and are also documented in Appendix 1.2.

2.2.4 Embedded Energy Savings

The embedded energy savings for each pilot program were calculated by multiplying the system energy intensity estimates by the quantity of water conserved for each project and summing the savings. For measures that reduce outdoor water use, only the energy intensity of the water systems is applied. For measures that reduce indoor water use, the energy intensities of both water and wastewater are applied.

2.2.5 Data Limitations

California is home to hundreds of water and wastewater systems that vary in size and complexity. The Metropolitan Water District of Southern California (MWD), for example, is a wholesale agency that provides raw and treated water to agencies throughout Southern California. Water supplies for MWD include the Colorado River Aqueduct, the State Water Project, and several local surface reservoirs, all of which have different energy intensities. Irvine Ranch Water District (IRWD) purchases water from MWD but supplements this water with local sources. Focusing on the water and energy data collected from IRWD excludes the energy that MWD uses to supply treated water to IRWD. EEW Study 1, however, quantified the energy intensity of various wholesale water providers throughout California. During the initial scoping of this evaluation, the CPUC indicated that the data from the studies would be integrated where possible to give a more thorough analysis of the energy intensity of these systems and the potential embedded energy savings from water conservation and efficiency measures. Using data from Study 1 as well as other sources, the evaluation team has attempted to account for some of the energy savings that may occur upstream or downstream of the retail service areas for each project.

This study focuses on energy provided by the IOUs that sponsored this evaluation (PG&E, SCE, and SDG&E). It excludes self-supplied energy (e.g., co-generation and solar) and energy from non-IOU providers, such as the Power and Water Resources Pooling Authority (PWRPA). For some water/wastewater agencies, self-supplied or non-IOU energy is a major energy source. Non-IOU energy use is identified and included, where possible, and we report both IOU and non-IOU energy savings.

3 PG&E Large Commercial Customers Pilot Program

3.1 Program Description

PG&E partnered with East Bay Municipal Utility District (EBMUD) and water retailers served by the Sonoma County Water Agency (SCWA) and Santa Clara Valley Water District (SCVWD) to implement the Large Commercial Customers Program. Large commercial and industrial businesses that are joint customers of PG&E and these agencies were eligible for this program. SCWA retailers that participated in the pilot include the cities of Santa Rosa and Petaluma, the town of Windsor, the Sonoma Valley County Sanitation District, and the Marin Municipal Water District.

The Large Commercial Customer Program offered audits to participating large commercial and industrial customers to recommend water efficiency improvements at selected facilities. The program also offered financial incentives to help offset the cost of the improvements that were implemented by the customer within the one-year duration of the pilot program. For ozone retrofits in laundry facilities, the audit was performed by the ozone vendor. For all other water efficiency improvements, the audits were performed by water agency staff or a contractor. Each audit included (1) a review of existing water bills and facility information, (2) a physical inspection of the customer's facility to observe existing equipment and its operation, (3) preparation of an inventory of water-using equipment, processes and operating times, and (4) identification of options to reduce water use.

The program originally expected 45 to 60 program participants spanning a wide range of business types. Of these, 15 to 20 hospitality laundry ozone systems were projected, however the actual number of ozone laundry projects completed by the end of the program was seven. An assortment of other types of projects was also expected (e.g., food processing changes, winery retrofits), and four of these were completed, so that the final completed project count was 11.

3.2 Methods

3.2.1 Data Collection Methods

A project-specific assessment of annual water savings was prepared for each implemented project (note that originally, the evaluation intended to sample from among the completed projects, but because of the small number of participants by the end of the program, all participating projects were evaluated). The assessment was limited to audit recommendations that were fully implemented by the participant within the time frame of the pilot program. In cases where the project included multiple measures, the data collection and analysis was performed at the measure level.

For each project, PG&E and the affected water utilities provided the evaluation team with all project-specific materials produced for the project to date and a description of performance data (pre-retrofit and post-retrofit) that the utilities and/or the participant collected during project implementation. These materials were reviewed and an internal project-specific scope of work was prepared that described the pre-retrofit and post-retrofit data collection and analysis procedures that were used to produce an annual estimate of water savings achieved for each measure in the selected project. The scope included items such as a detailed description of each measure in the project and how it saves water, an algorithm for calculating annual water savings, a listing of the parameters that must be input to the algorithm, the data sources that were used to specify these parameters and the associated data collection techniques.

The evaluation team completed visits at each site as necessary to collect the pre-retrofit characteristics and performance data specified in the project-specific scope of work. In some cases, the customer or the project implementer was able to provide useful pre data (e.g., number of laundry loads). In other cases, this was not possible because the projects became eligible for evaluation after the measure was installed. Regardless, after each project was installed and commissioned, the site was revisited to collect post-retrofit characteristics and performance data, either through the team's or the customer's metering equipment.

Table 4 lists the 11 completed projects included in the program. Seven of the 11 are laundry ozone systems installed in hotels. In aggregate, these account for 14 percent of the ex ante water savings. Two other projects (P03 and P14) both saved potable water, accounting for 43 percent of the ex ante savings. The remaining two projects (P04 and P12) used recycled water in place of potable water, accounting for 44 percent of the ex ante water savings.[18]

Table 4: Sites Included in PG&E Large Commercial Customers Program M&V Sample

SITE	MEASURES EVALUATED	EX ANTE WATER SAVINGS (GALLONS/YEAR)
P01 – Hotel*	Laundry ozone system	1,698,980
P07 - Hotel	Laundry ozone system	2,564,393
P09 - Hotel	Laundry ozone system	318,290
P15 - Hotel	Laundry ozone system	280,400
P16 - Hotel	Laundry ozone system	214,968
P17 - Hotel	Laundry ozone system	292,000
P18 - Hotel	Laundry ozone system	459,000
P03 - University housing dining hall*	High efficiency dishwasher	535,000
P14 - Correctional facility	Toilet replacement with central flush control	17,614,827
P04 - Medical equipment manufacturer*	Recycled water system	5,947,000
P12 - School district (four schools)	Recycled water system	12,703,818

*Sites with M&V plans included in Appendix 2. The evaluation approach for P01 was also used for the other hotel sites.

3.2.2 Analysis Methods

The analysis methods used in the evaluation of this program varied from project to project, but generally involved summarizing the data, looking for outlier data, observing usage patterns and

[18] The ex ante estimates reported here were obtained from final project tracking tools provided by PG&E after the program ended. Some of these values differ from the ex ante values included in the M&V plans, which were based on initial project scoping reports and the best available estimates at the time the M&V plans were developed.

trends, determining if normalization of the results based on external factors—such as hotel occupancy rates, annual schedules, or weather—was warranted, and finally, calculating the difference between adjusted pre and post usage levels. Additional details about the analysis methods are described in the M&V plans included in Appendices 2.1, 2.2 and 2.3.

The evaluation produced an estimate of annual water savings realized by each completed project under typical weather conditions (if appropriate) with correction for differences as feasible in water usage between the pre and post period due to factors beyond the implementation of the efficiency project. Program-level annual water savings were estimated by summing the individual project results.

3.3 Findings

3.3.1 Water Impacts

Summary of Results

Table 5 shows annual water savings calculated for each sampled site, based on site metering data.

Table 5: Water Impact Estimates

Site	Ex Ante Water Savings (gallons/year) A	Ex Post Water Savings (gallons/year) B	Realization Rate B/A
P01 - Hotel	1,698,980	963,967	0.57
P07 - Hotel	2,564,393	1,767,145	0.69
P09 - Hotel	318,290	441,720	1.39
P15 - Hotel	280,400	375,684	1.34
P16 - Hotel	214,968	290,094	1.35
P17 - Hotel	292,000	13,891	0.05
P18 - Hotel	459,000	-32,524	-0.07
P03 - University housing dining hall	535,000	-607,738	-1.14
P14 - Correctional facility	17,614,827	13,266,472	0.75
P04 - Medical equipment manufacturer	5,947,000	4,033,078	0.68
P12 - School district (four schools)	12,703,818	13,207,441	1.04

Total annual ex post water (and wastewater) savings from implementing the laundry ozone systems at the seven hotels is 3.82 million gallons for a realization rate of 66 percent and accounting for 11 percent of the total ex post savings. The water conservation measures installed at the university dining hall and the correctional facility totaled 12.7 million gallons saved based on ex post analysis for a realization rate of 70 percent and making up 38 percent of the total ex post savings. The recycled water measures at the medical equipment manufacturer and the school district resulted in 17.2 million gallons total ex post savings for a realization rate of 92 percent and comprising over half (51 percent) of the total ex post savings. Overall, total ex post water savings for all 11 projects is 33.7 million gallons for a realization rate of 79 percent.

3.3.2 Individual Site Analysis

This section contains a summary of the analyses for the 11 sampled sites. Because of their similarities, the seven laundry ozone systems are discussed in aggregate in Section 3.3.2.1. The remaining four projects are treated individually.

3.3.2.1 Laundry Ozone Systems (Sites P1, P7, P9, P15 to P18)

Each of the laundry facilities at seven hotels in the San Francisco Bay Area were retrofitted with an ozone injection system. The use of ozone for washing laundry decreases the amount of hot water by using cold water instead and decreases chemicals required which reduces the number of rinses necessary for each load of laundry.[19] There are a total of 23 washers among the seven hotels with a total capacity of 2,510 lbs., and all facilities operate seven days per week year round. The number and capacity of the washers as well as operating hours did not change as a result of the installation of the ozone equipment.

Total evaluated savings for all seven hotels, 3,819,978 gallons per year (GPY), were 66 percent of claimed water savings. Six of the seven hotels showed reductions in total laundry water consumption, and all seven hotels had decreased hot water use and increased cold water use. Because of the way the evaluation was structured and the attendant data limitations, it is not clear why site P18 had negative water savings, although potential causes include changes to the wash formulas or rinse cycles, or system maladjustments (as have been observed at other sites for different evaluations).

The savings are based on a simple difference between annualized average daily water consumed in the pre- and post-retrofit periods. There were not sufficient data to establish correlations between laundry water consumed and hotel occupancy or amount of laundry washed. Thus, the results are not normalized to adjust for changes in pre and post conditions such as occupancy rates.

3.3.2.2 High-Efficiency Dishwasher (P3)

This efficiency project took place in a university housing dining hall and consisted of replacing a Stero Model STPCW three-tank flight-type machine with a Hobart Model FT900D with Opti-Rinse™ flight-type machine.

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[19] As noted earlier in this report, changes in on-site energy use were not included in the evaluation. For ozone laundry systems, additional motors could be required to produce ozone on-site, increasing energy use. In addition, it is possible that the dryer cycle times may have changed due to changes in the washing process, increasing or decreasing energy use.

The evaluation found that water consumption for the dishwashing station increased by 607,738 GPY compared to a claimed reduction of 535,000 GPY, a realization rate of -114 percent. The claimed savings appear to be based on the assumption that the dishwasher operated every day of the year whereas the evaluation found that the dishwasher is in use only 234 days per year. Moreover, the ex ante claim is based on an average savings of 1,717 gallons per day (GPD) which exceeded the metered baseline flow of 1,120 GPD. Additionally, the increased water use appears to be related to a rinse trough using reused water from the dishwasher, which was installed at the same time as the new dishwasher. A continuous flow of water was observed coming from the open rinse trough drain early in the day before the dishwasher began steady operation. Thus, it is likely that additional water is continually being made up by the dishwasher during operation to replace the water being lost through the open rinse trough drain. However, measurement and observation indicate that the projected flow rate of the new dishwasher of 1.5 gpm is reasonable when the trough is not being refilled. Therefore, savings should be achievable if the issue with the rinse trough drain is addressed which can be accomplished by simply ensuring that the drain valve is closed at the start of each day.

3.3.2.3 Replace Toilet and Lavatory Valves with Electronic Controls (P14)

The measure being implemented involves the replacement of both the toilet flush valves and the lavatory valves at a correctional facility. Mechanical valves are being replaced with electronic valves, which have the capability of being limited to a maximum number of flushes per hour for toilets or consecutive minutes for lavatories. The measure is 85 percent complete as of the writing of this report.

Projected annual savings were found to be 13,266,472 GPY for a realization rate of 75 percent. Facilities personnel suggested that they may be able to adjust down the maximum number of flushes per hour or minutes per hour for lavatory usage over time, to increase savings from the current level. Due to security concerns and patent restrictions, flush volumes and frequencies could not be obtained at the desired level of granularity. Therefore, the savings are based on reduction in total water consumption at the facility, adjusted for average population and percentage completion of the project.

3.3.2.4 Recycled Water System (P4)

This recycled water project is at a medical equipment manufacturer, located in the South Bay Area. The efficiency improvement at this facility consists of adding a recycled water supply line that sources water from a local recycled water network to provide makeup water to three cooling towers that reject heat from the HVAC and process cooling systems. In the pre-retrofit condition, the make-up water was supplied by the potable water line.

Using customer-provided meter data and climate zone analysis, the evaluation determined the potable water savings to be 4,033,078 GPY, which is 68 percent of the claimed savings. The ex ante claim was calculated with energy modeling software; however, it did not take into account a new water treatment system for the cooling towers involving water softening which reduces makeup water consumed. Therefore, the claimed savings were overestimated.

3.3.2.5 Recycled Water System (P12)

A school district in the South Bay Area converted existing irrigation systems at four schools to exclusive use of recycled water supplied by a local recycled water network. The project involved installation of new meters and piping at each school to connect to the recycled water distribution system.

The evaluation calculated the potable water savings to be 13,207,441 GPY, or 104 percent of claimed savings. The analysis correlated historical water use to evapotranspiration data to develop a fit for predicting a year's worth of monthly post-retrofit irrigation water use. Historical water use was based on water bills from 2006 to 2009. Evapotranspiration data came from the California Irrigation Management Information System (CIMIS) Union City and Santa Clara County weather stations. Discussions with the school district revealed that, due to the less expensive recycled water, irrigation water use may increase to include athletic fields that had not been irrigated in recent years as a result of budget cuts.

3.3.3 Embedded Energy Impacts

Annual embedded energy impacts were calculated for 9 of the 11 sites by multiplying the *ex post* annual water savings from Table 5 with the energy intensity results for the corresponding water agencies. Energy intensities were calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculations of energy intensities for each agency are shown in more detail in Appendix 1.2.

Water production and energy data were not received for all retail and wastewater agencies. For retail water agencies where data were not received, only wholesale data are used in calculating the embedded energy. These agencies are marked with an asterisk (*) in Table 6 below. For those agencies where no wastewater data were obtained, embedded energy values could not be calculated and those projects are omitted from Table 7 below. Embedded energy could not be calculated for the recycled water projects at sites P04 and P12 because no recycled water data were received from the recycled water provider.

Table 6 shows the electricity and natural gas savings in the potable water system for the nine projects where savings could be calculated. The total electricity saved in potable water systems is 44,851 kWh and the total natural gas saved is 2 therms. Table 7 shows the same energy savings results for wastewater systems. Wastewater total energy savings were 73,546 kWh and 30 therms.

Table 6: Annual Embedded Energy Savings for Potable Water Systems

SITE	WATER AGENCY	IOU ELECTRICITY (KWH/YEAR)	TOTAL ELECTRICITY (KWH/YEAR)	IOU NATURAL GAS (THERMS/YEAR)	TOTAL NATURAL GAS (THERMS/ YEAR)
P01 - Hotel	Sonoma County Water Authority*	5	2,252	0	0
P07 - Hotel	San Jose Water Company	4,966	4,966	0	0
P09 - Hotel	Sonoma County Water Authority*	2	1,032	0	0
P15 - Hotel	Santa Clara Valley Water District*	812	812	0	0
P16 - Hotel	City of Santa Rosa Water System	142	778	0.04	0.04
P17 - Hotel	Marin Municipal Water District	12	20	0	0
P18 - Hotel	East Bay Municipal Utility District	0	-29	0	0
P03 - University housing dining hall	East Bay Municipal Utility District	0	-539	0	0
P14 - Correctional facility	City of Santa Rosa Water System	6,478	35,560	2	2
P04 - Medical equipment manufacturer	South Bay Recycled Water	--	--	--	--
P12 - School district (four schools)	South Bay Recycled Water	--	--	--	--
Total		12,417	44,851	2	2

* No data obtained from retail agency, only wholesale agency data were used

Table 7: Annual Embedded Energy Savings for Wastewater Systems

Site	Wastewater Agency	IOU Electricity (kWh/Year)	Total Electricity (kWh/Year)	IOU Natural Gas (Therms/Year)	Total Natural Gas (Therms/Year)
P01 - Hotel	Sonoma Valley County Sanitation District	2	3,331	0	0
P15 - Hotel	City of Sunnyvale WW	0	9	0	30
P16 - Hotel	City of Santa Rosa WW	915	1,502	0	0
P17 - Hotel	Central Marin Sanitation Agency	15	31	0	0
P14 - Correctional facility	City of Santa Rosa WW	41,841	68,673	0	0
Total		42,772	73,546	0	30

3.4 Discussion of Uncertainty, Threats to Validity, Precision, Potential Biases

Although sources of uncertainty varied between projects, the largest common uncertainty resulted from the use of data from customer-owned meters for portions of the savings analyses. The accuracy and precision of these meters was unknown. Ultrasonic meters were used at two of the projects to measure time-of-use data. These meters were owned by evaluation team contractors and were carefully calibrated, so uncertainty due to inaccuracy and imprecision was considered to be small.

Results from the hotel laundry ozone study could have been bolstered by consistent data collection from all seven hotels. The evaluation team made significant efforts to collect occupancy, load count and pounds of laundry data, but often the customer did not have such data. The plan had been to determine the relationship between occupancy and/or laundry use and water consumption. Unfortunately, this scheme was complicated by the fact that for most of the ozone projects, their completion and inclusion in the program was uncertain until the end of 2009, when the program concluded. Adding sites so late in the evaluation process made it difficult, if not impossible, for us to collect the aforementioned supplemental data at many of the sites. Furthermore, daily or weekly, vs. monthly, occupancy rates and more frequent recording of meter reads may have strengthened the results of the correlation analyses. If a correlation could be established between laundry water use and hotel occupancy, the results could be examined and adjusted for impacts of reduced occupancy due to seasonal variations and economic downturn.

3.5 Discussion of Findings

The evaluation determined that nine of the 11 sampled sites yielded water savings. It is important to note, however, that with a small sample of each efficiency measure, it is difficult to draw firm conclusions about the potential for this type of program.

The highest savings occurred at the detention facility, where plumbing fixtures were upgraded or replaced with low-flow fixtures and new controls, and the school district where potable irrigation water was replaced with recycled water. Due to the ease of installation of the plumbing fixture measures compared to other measures and the large percentage of buildings currently containing conventional higher-flow fixtures, this type of measure should be a focus of any large-scale implementation of the program.

Further study of the application of recycled water for irrigation, particularly with school districts, should be considered to examine whether water use remains the same or increases due to the lower cost or other reasons. In addition, the energy implications of replacing potable water with recycled water will vary among water agencies. Throughout California, wastewater agencies are required to treat wastewater to a high standard before discharging it into the environment. The energy requirements for recycled water would then be the additional treatment required to bring this water to recycled water standards plus any additional pumping required to deliver the water to the customer. The energy requirements for recycled water must then be compared with the energy requirements for potable water. Throughout much of California, the energy requirements for potable water are high. Thus, recycled water is very likely to yield significant energy savings. Detailed analyses are needed to better quantify these savings.

4 PG&E Low-Income Direct Install High Efficiency Toilet Replacement Pilot Program

4.1 Program Description

The PG&E Low-Income Direct Install High Efficiency Toilet (HET) Replacement pilot program was a partnership with the Santa Clara Valley Water District (SCVWD), a wholesale supplier to a number of retail water agencies. Through this program, PG&E leveraged its existing Low Income Energy Efficiency (LIEE) program to identify target customers, manage a direct install contractor, and deliver the HET installation. Replacement toilets were made available to residents who met LIEE criteria for low income, were customers of both a partner water agency and PG&E, and qualified for a water agency rebate (specifically, one or more existing toilets were an older, high-flow toilet with a rated flush volume of 3.5 gallons per flush or more). The HETs were installed at no cost to the participant.

The original program design assumed 900 toilets would be installed in single-family homes throughout the SCVWD service territory. PG&E calculated this population based on the number of low-income customers the LIEE program intended to reach in a year in each of the water agency territories and available budget. PG&E assumed that 30 percent of these homes would already have low-flow toilets and not be eligible for the rebate. Priority was given to the water agencies with the highest energy intensity. The HET selected by the program was the Vortens Loretto RF (Model 3213-3475), rated at 1.28 gallons per flush (gpf). The pilot program retrofitted 478 toilets (53 percent of design population estimate).

4.2 Methods

4.2.1 Sample Design

The evaluation team originally selected a sample size of 30 homes out of the anticipated program population of 900. This figure was chosen as a reasonable compromise between evaluation cost, statistical precision, uncertainties about program participation rates, and variability in toilet usage. All eligible toilets in each sampled home were to be evaluated. No metering data were collected on toilets that were not replaced, e.g. those that were already low flow (1.6 gpf or less). However, flow volume data were collected for all toilets rated at 1.6 gpf, even though they were not part of the study.

Periodically, the program provided lists of recruited homes, from which the evaluation team sampled using predetermined intervals. Because the program participation rates ended up being much lower than expected, the sampling interval was adjusted as necessary during mid-course to meet the sample size goal. When the program concluded, it was found that the program population was poorly defined, preventing case weights from being applied based on sampling intervals to weight the toilet-level results to the population. Instead, simple unweighted averages were developed for the various parameters describing the sample.

Ultimately an M&V sample of 27 homes with 40 retrofitted toilets was obtained. Initially there were 31 homes contacted, but four were eliminated due to ineligible toilets (two sites), inability to gain entry, and language issues. There was one eligible toilet that was not replaced because the occupant wanted to see how the toilet would perform before allowing the other toilet to be replaced. There were also two eligible toilets that were not replaced because space restrictions prevented the HET from being installed. Information on each sampled site is shown in Table 8.

Table 8: Sites Included in PG&E HET M&V Sample

SITE	TOTAL NUMBER OF TOILETS IN HOME	EXISTING LOW FLOW TOILETS (1.6 GPF)	NUMBER OF HETS INSTALLED	NUMBER OF OCCUPANTS IN THE HOUSEHOLD
8	3	2	1	3
28	3	2	1	8
80	4	2	2	8
81	3	0	3	4
84	3	0	3	5
91	2	0	2	3
92	1	0	1	1
96	3	2	1	3
98	2	0	2	3
99	3	1	2	3
100	2	0	2	7
102	2	0	1	6
105	3	2	1	5
112	1	0	1	4
114	2	1	1	4
116	3	2	1	4
120	2	0	1	2
121	2	0	2	9
123	2	1	1	2
130	1	0	1	5
132	2	0	2	5
138	2	1	1	1
140	2	0	2	8
143	2	1	1	7
166	2	0	2	5
169	1	0	1	12
181	3	0	1	4
Total	61	17	40	131
Average	2.3	0.63	1.5	4.84

These data reveal that the average household size of 4.84 is larger than the average of 2.92 for Santa Clara County as reported by the US Census Bureau. Also, less than half the sites had all their toilets replaced and tracked.

4.2.2 Data Collection Methods

Two primary types of data were collected for each sampled toilet. The evaluation team installed flow meters on the supply line for each affected toilet to measure total water use. In addition, the team installed pulse meters to record the time of day when water was used. Data sets from these two distinct sources were compared to validate each other. To make the comparison, the pre and post flushes per day were calculated using both data sources. In cases where there were large differences between the data sets, the team investigated to determine and explain the cause of the discrepancy to ensure all the data were reasonable.

Time-of-use data were originally collected to support estimating key parameters (such as average hourly water savings profiles for different day types and months) in the Embedded Energy Calculator. However, the methodology for estimating embedded energy impacts evolved, when it was determined that there are (variable) lags between water treatment, distribution and consumption (i.e. there is not an exact hourly match). Therefore the hourly profiles were no longer necessary for this purpose, and are not addressed in this report.

Initially tank switches with pulse loggers were installed to record actual flush events, but the switches were found to be unreliable. This style of flush counter was used at only two sites. For all other sites, water meter pulses were logged, where each pulse equaled one gallon. Since the pulse meter did not measure flushes directly, they were determined mathematically with some pulses being split between flushes. For each sample site, pre and post toilet flush volumes were measured. Meter readings at the beginning of the pre and end of the post periods were recorded by the evaluation team; intermediate readings between the pre and post periods were recorded by the program implementer. These two measurements, in conjunction with the number of days in the study period, were used to determine the daily flush count.

For each affected toilet among qualifying households in the sample, the data elements shown in Table 9 were collected. As noted above, there was a change in the flush metering equipment part way through the study. Each part is noted in the table as 2b1 or 2b2.

Table 9: Evaluation Measurements

Description	*Evaluation*
Equipment monitored	1. Toilet cold water supply line 2. Toilet water tank
Parameter measured	1. Total gallons 2a. Flush volume 2b. Flush events (time of use)
Measurement equipment	1. Clark in-line turbine-type totalizing water meter 2a. Calibrated bucket 2b1. Custom-designed float switch (registers change in circuit status each time water level falls) with Hobo event logger. 2b2. One-gallon pulse output from the meter with Hobo event logger.
Installation method	1. Plumbed into toilet water supply line. 2b1. Hooked inside tank. 2b2. Same as 1.
Observation frequency	1. Continuously throughout pre and post metering periods. 2a. Tank flush volumes were measured twice—at the beginning and end of metering for each toilet. 2b1. Each time toilet is flushed (could record 8,000 events) 2b2. Each time 1 gallon has passed through the meter
Measurement duration	1, 2b. At least one month before and after HETs were installed.

In addition to physical measurements and metering, the implementer conducted a characteristics survey with each sampled participant to collect information about changes to toilet use patterns during the pre- and post-retrofit periods. Important topics in the survey included items that could be observed directly, such as:

- Pre toilet fixture characteristics (manufacturer, model, date of manufacture).
- Evidence of leaks (if so, the team attempted to quantify them).

In addition, participants were asked about indirect factors that could have affected the measured results, such as:

- Number and approximate ages (infant, child, adult) of occupants.
- Changes to occupancy (e.g., someone moving out of the house) or occupant distribution (e.g., a teen moving from an upstairs shared bathroom to a downstairs bedroom with dedicated bathroom).
- Temporary events that could affect usage (e.g., plumbing malfunctions, vacations, drought-related water restrictions).
- Satisfaction (e.g., reliability, susceptibility to clogging, need for double-flushing).

4.2.3 Analysis Methods

To estimate average daily water savings from this measure, the following algorithm was used:

Average HET daily water savings (in gallons per day (gpd)) = total gpd savings – gpd leak losses
Total gpd savings = Adjusted flushes/day,post × (gallons/flush,pre – gallons/flush,post × flush factor)
gpd leak losses = (flushes/day,post - adjusted flushes/day,post) × gallons/flush,post
flush factor = flushes/day,post / flushes/day,pre [minimum of 1].

The flush factor was designed to account for an increase in the number of flushes per day (fpd) after the new HET was installed. This was a small effect, but one that was noticed in at least 13 cases. The factor was held to a minimum of 1 because in the cases where the original toilet leaked, the flushes/day values are inflated. Without the flush factor, a site that had increased flush counts in the post period would reap higher savings with each additional flush. Similarly, limiting the flush factor's low value to 1 eliminates any additional savings that may have been achieved by a reduction in the flush count in the post period. However, due to the limitations of the pre data caused by the constant leaking it was decided that taking this conservative approach was best. The adjusted flushes/day is the number of flushes per day calculated by removing the effects of leaks in the post period. The effect and handling of leaks is discussed further below. Our data showed no noticeable changes due to vacations or changes in occupancy in the sample, so our algorithms did not need to account for these types of variations.

4.3 Findings

4.3.1 Water Impacts

The total ex post savings per HET were 36.25 gpd. From that the average leak reduction of 7.0 gpd was subtracted to get the average HET savings of 29.2 gpd. Leaks were noted in 12 cases, and are discussed in more detail subsequently. The HET average savings is 23 percent higher than the program ex ante value of 23.75 gpd. These ex ante savings values are not based on any particular occupancy assumptions, and a direct comparison may be misleading. Without more information about the basis of the ex ante value it is not possible to normalize the findings.

Applying the evaluated unit savings to the number of HETs the program installed (478) yields total evaluated savings for the program of 13,968 gpd using the average unit HET savings only, and 17,328 gpd applying total savings (which includes the net effects of leaks in the standard and high efficiency toilets). The daily water savings from each HET are shown in Figure 1. Three of the HETs resulted in negative savings. This was due to the HET leaking to such a large extent that it outweighed a positive savings/flush. The two sites that have very large savings had higher than average number of occupants and higher than average savings/flush values.

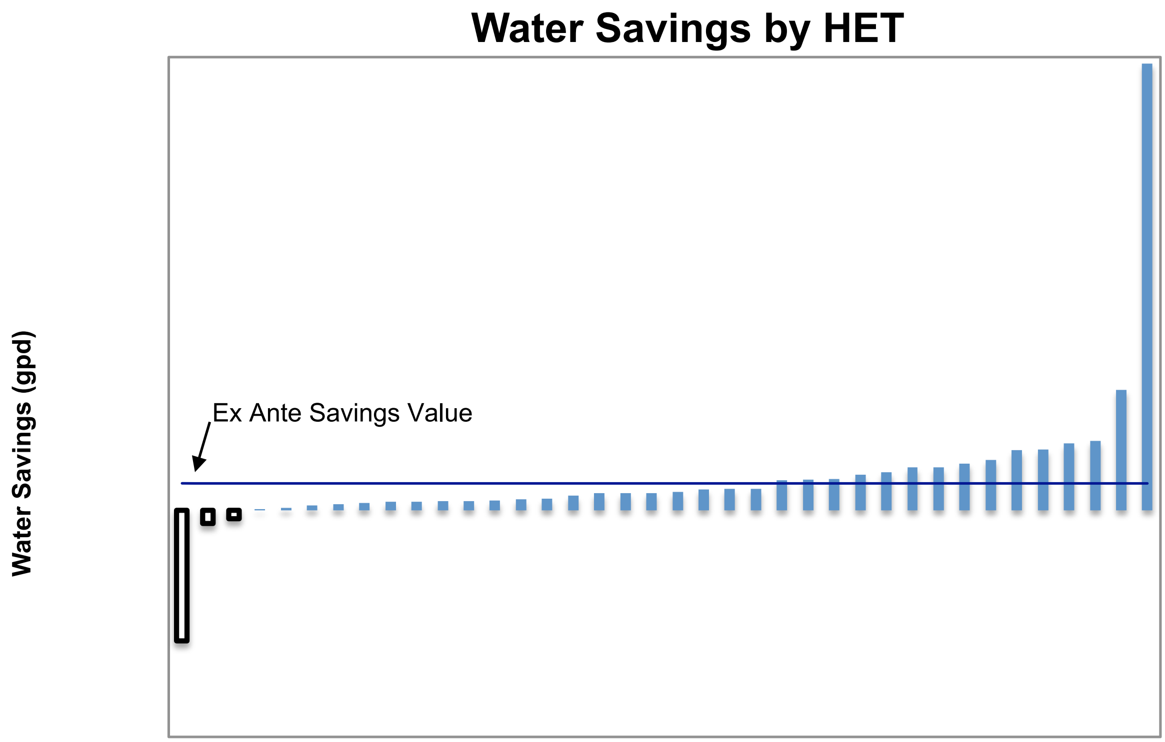

Figure 1: HET Savings Distribution

The water impact estimates for individual HETs in the sample are presented in Table 10.

Table 10: Water Impact Estimates

Site	Flushes /Day	Flushes /Person /Day	Flush Savings (gpf)	Gross Savings (gpd)	Post Leak Losses (gpd)	Net Water Savings (gpd)
8	4.55	1.52	1.76	8.03	0.00	8.03
28	10.49	1.31	1.78	18.62	0.00	18.62
80	6.98	0.87	0.34	2.37	0.00	2.37
80	4.91	0.61	0.87	4.24	0.00	4.24
81	10.57	2.64	0.71	7.46	0.00	7.46
81	8.16	2.04	0.79	6.44	0.00	6.44
81	6.58	1.64	1.27	8.38	3.15	5.22
84	16.62	3.32	0.53	8.78	0.40	8.38
84	23.85	4.77	4.46	106.44	0.00	106.44
84	10.27	2.05	2.65	27.18	0.00	27.18
91	15.32	5.11	2.05	31.34	0.00	31.34
91	3.53	1.18	4.36	15.39	0.00	15.39
92	8.81	8.81	2.51	22.09	3.34	18.75

Site	Flushes /Day	Flushes /Person /Day	Flush Savings (gpf)	Gross Savings (gpd)	Post Leak Losses (gpd)	Net Water Savings (gpd)
96	15.57	5.19	2.43	37.75	0.00	37.75
98*						
98*						
99	3.58	1.19	2.30	8.24	0.00	8.24
99	4.79	1.60	1.54	7.38	0.00	7.38
100	129.73	18.53	3.04	394.38	0.00	394.38
100	23.16	3.31	1.79	41.45	0.00	41.45
102	25.92	4.32	1.07	27.70	0.00	27.70
105	5.60	1.12	2.68	15.02	0.00	15.02
112	22.46	5.62	2.62	58.85	0.00	58.85
114	21.75	5.44	0.70	15.23	26.84	-11.61
116	8.25	2.06	2.41	19.89	1.20	18.69
120	8.74	4.37	1.43	12.45	19.88	-7.43
121	12.55	1.39	0.77	9.66	0.00	9.66
121	9.14	1.02	3.29	30.08	145.31	-115.23
123	12.96	6.48	1.59	20.56	19.77	0.79
130	10.93	2.19	4.92	53.74	0.00	53.74
132	11.62	2.32	1.38	16.04	0.00	16.04
132	13.13	2.63	2.02	26.54	0.00	26.54
138	18.93	18.93	1.90	35.87	23.08	12.79
140	36.46	4.56	1.75	63.81	2.38	61.43
140	18.92	2.36	1.78	33.63	0.00	33.63
143	14.46	2.07	3.09	44.68	0.00	44.68
166	24.31	4.86	2.59	62.84	9.88	52.96
166	7.39	1.48	2.05	15.11	0.00	15.11
169	31.04	2.59	1.60	49.66	11.85	37.81
181	5.40	1.35	1.89	10.22	0.00	10.22
Average	16.51	3.76	2.02	36.25	7.03	29.22
Standard Deviation	20.49	4.03	1.06	63.47	24.13	68.67
Min	3.53	0.61	0.34	2.37	0.00	-115.23
Max	129.73	18.93	4.92	394.38	145.31	394.38

*Meter data from this site were erroneous, so they were discarded.

The number of flushes per person per day varies widely from 0.61 to 18.93. Studies put the average flushes per person per day at around 4 to 6. Many of the sites have what might be considered a low flush per person count. One cause for the low numbers is that there are other toilets in the house, some of which were part of the study and others were not. This can cause both unreported use and uneven use, which can skew the values. For instance the minimum flush count of 0.61 is in a house with another toilet that is not part of the study. Some have higher than average flush counts, which can be explained by extra people using the HET. It is also likely that some of these people simply flush more or less often than others either due to schedules or life choices. All the data were carefully reviewed and appear to be reasonable.

The flush savings in gpf was calculated as the difference between the measured flush volume of the existing toilet and the HET. The savings per flush varied from 0.34 to 4.92 with an average of 2.02. The installed HET has a rating of 1.28 gpf, but the measured average was 1.38 gpf. The overall gpf average of the existing toilets was 3.16. The existing toilets that were rated at 1.6 gpf had a measured average of 2.29 gpf, but they were neither replaced nor included in the study.

The daily water savings for the individual HET's ranged from -115 gallons to 394.38 gallons. As noted previously, the negative savings occur when a HET is leaking. The high savings value was a result of both a high flush count and a higher than average flush savings.

The logging period for each site is included in Table 1 in Appendix 3.2. The data from Site 98 had such large inconsistencies between the two data sources (meter and logger) that they could not be reconciled, and the data were removed from the sample.

4.3.2 Leaks

Using the pulse method to count flushes resulted in leaks being included, thereby skewing the flush counts. The flush counts reported in Table 10 have been adjusted to eliminate the effect of leaks. Two types of leaks were found through analyzing the time-of-use pulse data: constant and periodic. A constant leak manifested itself in the data as slow continual use. This showed up as even use throughout all times of the day, as shown in Figure 1 in Appendix 3.3. A periodic leak showed up in the data as periods of constant high use, which was determined by looking at the number of pulses in a given timeframe with at least one pulse every minute. This is shown in sample data represented in Figure 2 as well as in Table 3 (both in Appendix 3.3). In general, the constant leaks had a small flow rate (less than 0.5 gpm), while the periodic leaks had a large flow rate (more than 3.5 gpm).

Leaks appeared in both the pre and post data. Most leaks in the pre period were constant. There was periodic leaking in the both the pre and post period, though it was more pronounced in the post period. All the post leaks were periodic. The post leaks were probably caused by the flapper not closing properly, allowing the HET to run freely until it was properly closed.

In the pre data, there were four toilets that had obvious constant leaks. Additionally, there were three toilets that had periodic leaks. As the flush count from the pre period played only a small role in the savings calculation, these pre leaks were not analyzed exhaustively.

Leaks in the post data played a significant role. Of the 40 newly installed HETs, twelve (30 percent) experienced periods of leaking lasting more than five minutes, with an average leak time of 80 minutes. Since the periodic leaks could be identified, it was possible to isolate their effects on the post data to determine a more accurate flush count and to quantify the effects of the periodic leaks. Three of the HET toilets leaked so much they increased water usage compared to the original toilets.

4.3.3 Embedded Energy Impacts

Water production and energy data were not collected for small water agencies with little program participation. Instead, all program water savings were applied to the San Jose Water Company. The energy intensity of water from San Jose Water Company was calculated using water production and energy data provided by the agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculation of this energy intensity is described in more detail in Appendix 1.2. The energy intensity of water supplied by San Jose Water Company (2,810 kWh per million gallons) was then multiplied by the 5.1 million gallons of annual water savings for this program (i.e. ignoring the effect of leaks) to arrive at the total energy savings of 14,328 kWh shown in Table 11 below. The potable water system for San Jose Water Company is powered entirely by IOU-provided energy, so the total energy saved is equal to the IOU energy saved in Table 11. Wastewater production and energy data were not received for the San Jose/Santa Clara Water Pollution Control Plant, so wastewater energy savings are not reflected here.

Table 11: Annual Embedded Energy Savings for PG&E HETs Program

	IOU Energy (kWh/Year)	Total Energy (kWh/Year)
Total Energy Savings	14,328	14,328

4.4 Discussion of Uncertainty, Threats to Validity, Precision, Potential Biases

The largest point of uncertainty in the study is the flush count. As noted previously, the method of determining the flush count increased the reported flush count in the event of any leakage. In the case of the post data this effect has been minimized, but it is a source of potential error.

The meter reads gallons and not flushes so there were times a partial flush would be recorded at a different time. For instance if the toilet used 1.4 gallons then that would generate 1 pulse and the 0.4 gallons would be left until the next flush event, which would also record 1 pulse and now 0.8 gallons would be left. Finally on the third flush 2 pulses would be recorded with 0.2 gallons left. This would make it appear that more water flowed through at the time of the third flush. This can slightly skew the time of use data. There is also a very small volume, less than one gallon that was potentially left unrecorded by the pulse meter at the end of the study period.

A flush factor was introduced in an attempt to reduce any effects caused by a change in the daily flush data from the pre to post period. Since there was so much leakage in both the pre and post periods, it is difficult to state with certainty the number of flushes per day. Based on the results of the sites where there was no obvious leaking, the model used seems to provide reasonable results. As stated previously, the flush factor was restricted to values greater than or equal to one due to the leaks inherent in the pre data. This has the effect of eliminating any potential decreases in flushes per day that occurred due to the introduction of the HET. The overall effect of the flush factor was small. If the flush factor was eliminated the savings would be 32.34 gpd or about 11 percent higher and the gpf savings would be 2.22 instead of 2.02 mentioned earlier.

The reported savings value is valid for the average occupancy level found in the low-income households in the study (4.84). The ex ante value did not mention what sort of average household size it was based on. If data became available with which to normalize these findings then they could potentially be used more freely in other situations. That said, the occupancy data have limited use because there can be changes in occupancy caused by travel, illness, or other changes that would cause people to flush more or less than usual, as well as visits by other people, or any other factors that affect the number of flushes in the household. Additionally, since not all toilets in the household were monitored, there could have been shifting of use between monitored and unmonitored toilets which would affect the reported per person flush counts. Future studies should consider also metering non-retrofit toilets in participant households to better understand if toilet usage patterns change.

Of the 61 toilets encountered in the study, 17 were already designated low flow, i.e., 1.6 gpf or less. This brings up the question of why there would be different toilets in a household. One person in the study, for example requested such a trial installation and later wanted the other one replaced as well. More generally, were people installing efficient toilets as other toilets broke or installing just one efficient toilet to try it out? Understanding the barriers or motivations behind these replacements would be helpful for designing successful HET programs and evaluating free ridership.

4.5 Discussion of Findings

A troubling finding from this study is the presence of leaks in the new HETs. As stated previously, 30 percent had leak episodes lasting at least five minutes. If they experience this much trouble when they are new, it creates doubt about their performance as they get older. If the HETs had not leaked, the total savings would have been 24 percent higher. Therefore, it is very important to install HETs that function properly.

Another finding is that both the low flow and HET toilets do not perform as rated. The HETs used 8 percent more water per flush than their rated value. The low flow toilets used 43 percent more water, but they were also older (although their exact age is not known) which may account for the higher volumes to some extent. Both findings make it clear that it is unreliable to use the rated flush volumes.

5 PG&E Emerging Technologies Pilot Program

5.1 Program Description

For this program, the existing SCADA system at East Bay Municipal Utility District (EBMUD) was enhanced with real-time pumping electricity consumption data at three pumping stations, allowing system operators to see and analyze pumping system efficiency and energy intensity (expressed as kWh per million gallons pumped) and potentially reduce energy use in real-time by changing the operating pump combinations. In the past, operators have traditionally tried to equalize pump operation hours. While this was done so that pumps could be replaced at roughly the same time, it this does not optimize the efficient use of pumping energy. To address this issue, this pilot was designed to reduce energy consumption under different flow and pressure scenarios and does not focus on reducing water consumption.

Please note that after the evaluation analysis was completed, it was learned from the implementation contractor that EBMUD had not used the new real-time energy data even though they had been integrated into the SCADA system. As a consequence, there are no energy savings attributable to this pilot. The statistical modeling conducted by the evaluation team confirms this finding and is included in this chapter to provide guidance on future evaluation efforts should new SCADA metrics eventually be used at other water agencies.

The EBMUD pumping stations included in this pilot are shown in Table 12. As shown in the subsequent tables, all of the project pumping plants have multiple pumps, and each plant pumps into a separate pressure zone, or zones, independent of the other plants. Initially, the project also included the Bayview pumping station, although this station was later omitted because the plant would have limited operations in 2009.

Table 12: Project Pumping Station Facilities

PUMPING PLANT (ZONES)	NUMBER OF PUMPS	CAPACITY (MG/DAY)	2008 TOTAL KWH CONSUMPTION
Almond (Almond)	5	15.4	1,772,000
Argyle (Argyle, Verde, Shawn)	3	3.1	673,000
Crockett (Maloney)	4	19.2	759,000

Table 13: Almond Pumping Plant Details

PUMP #	PUMP CAPACITY (MG/DAY)	MOTOR KW	PUMP TYPE
1	3	100	Horizontal Centrifugal
2	3	100	Horizontal Centrifugal
3	6	200	Horizontal Centrifugal
4	5	200	Horizontal Centrifugal
5	5	200	Horizontal Centrifugal

Table 14: Argyle Pumping Plant Details

PUMP #	PUMP CAPACITY (MG/DAY)	MOTOR KW	PUMP TYPE
1	3.2	125	Vertical Turbine
2	3.1	125	Vertical Turbine
3	3.6	125	Vertical Turbine

Table 15: Crockett Pumping Plant Details

PUMP #	PUMP CAPACITY (MG/DAY)	MOTOR KW	PUMP TYPE
1	6.6	150	Horizontal Centrifugal
2	6.4	150	Horizontal Centrifugal
3	6.5	150	Horizontal Centrifugal
4	6.3	150	Horizontal Centrifugal

PG&E hired an independent contractor, Global Energy Partners (GEP), to implement and assess the EBMUD project. Following is an overview of the key steps that were taken to implement the project:[20]

1. Pumping plant screening—15 potential pumping plants were reviewed and reduced to four project sites, considering (expected) ease of equipment installation, availability of historic operations data, and potential operator interest. Plants in the "east of hills" service district utilize an energy management system with strict operating guidelines, and were omitted because they do allow much flexibility for system operators.

2. PG&E electric meter connections—Each project plant has a dedicated PG&E meter, which had to be enabled to provide a pulse output signal that can be received by a remote terminal unit (RTU) at the pumping plant and input into the SCADA system. There is no sub-metering at the pump level. The Almond plant meter was already pulse capable, and new wiring was installed to connect the meter pulse output module to the RTU. The Argyle and Crockett plants required meter upgrades to use new signaling modules. At the Crockett plant wireless technology was used to transmit to the RTU, and hard wiring was used at the Argyle plant. The project did not change the basic pump mechanical operations in any way.

   While the wireless communications initially worked well at the Crockett plant, signal "spiking" problems soon developed, and real-time measured kW would increase to 2,000 to 8,000 kW a few times each day on a regular basis. This signal reception problem was fixed in early January 2010 after the vendor found a programming code error and the equipment was re-installed.

[20] More details about the project implementation steps are documented in the project report authored by GEP, which will be available at www.etcc-ca.com.

3. Pumping energy efficiency tabulated and programmed into SCADA—After EBMUD staff completed the meter connections, the SCADA display was re-programmed to show a new energy efficiency metric, allowing operators to see plant energy consumption and pumping efficiency in real-time. Pumping efficiency factors in both the pressure and flow generated by the pumping plant, where the theoretical hydraulic energy associated with the combined pressure and flow is compared to the actual electrical energy input to calculate an efficiency value. Figure 6 shows the SCADA screen with new energy efficiency metric added for the Almond plant (the efficiency is 0 percent because all the pumps are off).

   Prior to reprogramming the SCADA, EBMUD operations staff also developed a static energy efficiency reference table for each plant and pumping combination, based on systematic pump combination test runs (these values are reproduced in Appendix 4.3).

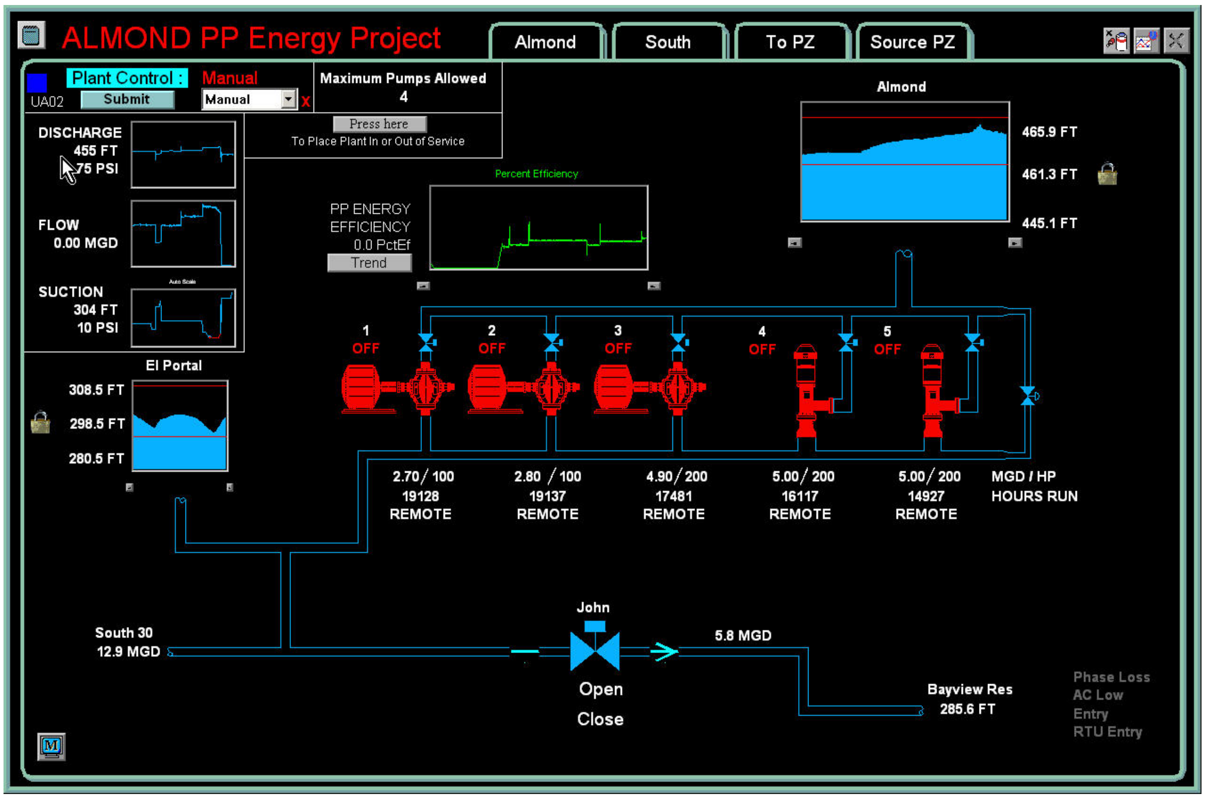

Figure 2: SCADA Screen Display With Energy Efficiency Metric

4. Operator training – In early July 2009 the plant operators received training on how to interpret the new energy efficiency metric and how different pump combinations could improve energy efficiency. In addition, they were given background information about the purpose and schedule of the Pilot program, and other project steps completed to date (e.g., electric meter connections). At the training, the operations supervisor noted that the operators might not be able to dedicate much attention to the new metric, although the operators said they would to try to use it while meeting their other responsibilities.

5. Pumping energy intensity metric programmed into SCADA—Analysis conducted by GEP on the period July through November 2008 (baseline) and 2009 (post period) revealed that the displayed energy efficiency metric could be causing the operators to increase energy consumption/intensity under some conditions (no feedback from the operators was available at this time). This is because as energy efficiency increases, so does the flow rate. The increase in flow rate increases friction through the piping system, which can offset much of the energy savings. In response to these findings, the SCADA display was re-programmed to also show a new energy intensity metric (kWh/million gallons), allowing the operators to focus more precisely on reducing energy consumption. The energy intensity metric was added on the following dates, which mark the start of the second post evaluation period:

    - Almond: December 5, 2009
    - Argyle: December 7, 2009
    - Crockett: January 10, 2010

Figure 3 shows the SCADA screen with new energy intensity metric added for the Almond plant (immediately below the energy efficiency metric).

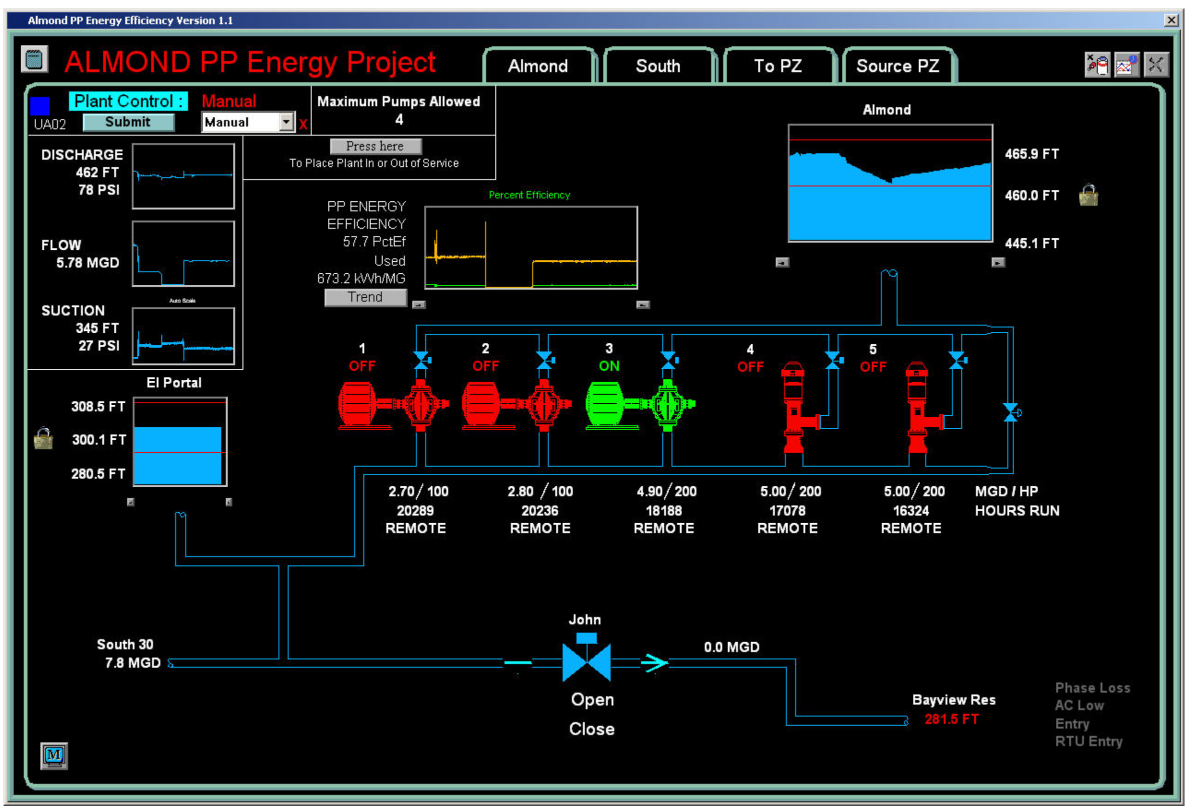

Figure 3: SCADA Screen Display With Energy Efficiency Metric and Energy Intensity Metric

PG&E implemented a second project at four pumping stations at San Jose Water Company with a different implementation contractor (BASE Energy, Inc.). For this project, however, a key goal was to develop and program a new pumping algorithm into the SCADA system, which would *automatically* adjust the pump operations in real-time to optimally reduce energy usage (i.e., it would generally require no monitoring or actions by system operators). To develop the algorithm, San Jose Water Company staff periodically changed the pumping operations at the direction of BASE so different flows, pressures and energy consumption could be tested and measured. While BASE was able to develop the pumping optimization algorithm within the Pilots program period ending December 31, 2009, San Jose staff were unable to program and utilize the algorithm during the Pilot evaluation period, and thus this evaluation did not include the San Jose project.

5.2 Methods

5.2.1 Data Collection Methods

SCADA System Data Collection and Cleaning

All of the pumping stations data were provided by GEP, who received the data from EBMUD. Fifteen-minute interval data were provided for:

- Average flow rate (million gallons per day, MGD)
- Average suction (input) and discharge pressures (psi)
- Average on/off status for individual pumps (numeric value between 1 and 2)
- PG&E metered kW (post period only)[21]
- Real-time monitored kW (post period only)

For the baseline analysis period (July 2008 through February 2009), only monthly PG&E energy data were available for the Almond pumping plant, and thus this station was not included in the regression analyses, discussed subsequently. For the Argyle and Crockett plants, the PG&E data were provided in 30-minute intervals. Fifteen-minute kW values were derived by taking the average of sequential 30-minute period values. No data energy were available for the Argyle station for February 2009.

The evaluation team utilized multiple screening criteria to filter out data reflecting operational and/or measurement anomalies (e.g., measured flows when all pumps appear to be off). Likely causes for these discrepancies include: pump ramp up/down time after being toggled on/off, lags between actual and indicated pump status, water meter lags, and SCADA sampling rates during the intervals. To address these issues, the following data filtering was applied:

1. The pumps on/off indicators were set to integer values by rounding the fractional values for each interval

[21] For the Argyle plant, the evaluation team divided the kW values by 2, since GEP confirmed that the PG&E readings were 100 percent too high.

2. Records with very low PG&E kW draw, typically less than 10 kW, were omitted (i.e., parasitic loads)
3. Records with flow of 0 MGD were omitted
4. Records were omitted if the difference between PG&E kW and the expected kW equals or exceeds 30 percent of the expected kW. The expected kW was determined based on the typical interval meter reading of the specific pumps on/off configuration, in addition to verification with the actual size of the operating pumps (see Formula A.5 in Appendix 4.2)
5. Records were omitted if measured flows were plus/minus 50 percent of expected flows. The expected flows were based on PG&E kW, differential pressure, and the average estimated pump and pump motor efficiencies of the specific interval readings (see Formula A.7)
6. Records with suction and discharge pressure exceeding the typical monthly maximum values by 30 percent or more were omitted, as were records with pressure 30 percent lower than the typical minimum values

Even while the real-time recorded kW in the post period was known to be incorrect for some periods at the Crockett plant when signal spiking occurred, these data were retained to assess if this problem affected operator behavior or not.

Pump Station Operators Survey

All EBMUD pumping plants, including the three in the Pilots project, are remotely operated from the central Oakland control room. Operators work 12-hour shifts from 7:00 am to 7:00 pm, with two operators on duty during the day and one at night. During the day, one operator runs the “west of hills” plants and the other runs the “east of hills” plants. The Pilot project plants are all in the “west of hills” area.

There are 12 total operators that rotate through working in the control room and performing fieldwork. Four operators were responsible for operating the three pumping plants included in the Pilots project.

In February 2010, the evaluation team, in coordination with GEP, developed and submitted a survey to collect qualitative information about how the system operators actually considered and responded to the new energy metrics on the SCADA screen (the survey instrument is included in Appendix 4.4). The survey was submitted to EBMUD’s project manager, who then surveyed each of the four operators who oversee operations at the three project pumping plants. Due to the continuous, 24-hour shift coverage, meeting with each operator would be difficult, and the project manager offered to collect the responses personally as opposed to having the project team visit EMBUD’s operations center multiple times. A written summary of the operators’ responses was ultimately provided directly to GEP in June 2010.

5.2.2 Analysis Methods

Regression Model

Statistical analysis was used to assess if and to what degree the installation of the energy consumption monitoring equipment and SCADA metrics at the Crockett and Argyle pumping stations led to reductions in energy intensity of pumping activities. Potential water savings that may have occurred at the plants were not examined.[22] For each plant, a statistical regression model was developed that related energy intensity to factors that are a priori assumed to influence energy intensity. Energy intensity is defined as kWh of energy consumed per million gallons water flow through the pumping station. The primary factor assumed to influence energy intensity is differential pressure, which is calculated as the discharge pressure of the water pumped through the station minus the suction pressure—the pressure of the water entering the station. To estimate the impact of the two new SCADA metrics, showing first energy efficiency and then energy intensity, we created indicator variables for two "post" periods at the Crocket and Argyle plants. The dates corresponding to the baseline period and each of the post periods for the two plants are shown in Table 16.

Table 16: Dates Associated With New SCADA Metrics at Crockett and Argyle Pumping Stations

PLANT	BASELINE PERIOD	POST PERIOD 1	POST PERIOD 2
Crockett	Jul 1, 2008 – Feb 28 2009	Jul 1, 2009—Jan 9, 2010	Jan 10, 2010—Feb 28, 2010
Argyle	Jul 1, 2008 –Jan 31 2009	Jul 1, 2009—Dec 6, 2009	Dec 7, 2009—Feb 28, 2010

Source: ECONorthwest analysis of data from EBMUD/GEP

In Post Period 1, a new SCADA display screen metric was installed to provide the station operators with information on pumping efficiency. It was believed that this single metric did not provide the operators sufficient information to simultaneously optimize quantity of water pumped and amount of energy consumed. In Post Period 2, an additional metric displaying energy intensity (energy consumption per million gallons pumped) was installed. This second metric provided the station operators with information on energy use for a given rate of water discharge, thus allowing the operators to adjust pump configurations to minimize energy consumption while meeting water demand.

The coefficients on the Post Period 1 and Post Period 2 indicator variables estimated in the statistical model are an estimate of the change in energy intensity associated with the installation of the energy monitoring equipment. The variable for differential pressure serves as a "control" variable, accounting for period-to-period differences in differential pressure. Under the assuming that differential pressure is the primary determinant of energy intensity in water pumping at the two facilities, the estimated coefficients for the post period variables are a *ceteris paribus* ("all else held constant") estimate of the impact of the energy monitoring equipment on energy intensity.

The specification of the statistical model developed for the analysis of each station is as follows:[23]

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[22] The interventions were not designed to conserve water, but rather were intended to save energy per unit of water processed by the pumping stations.

[23] We also estimated models that included the square of differential pressure, but found no increase in explanatory power when the squared term was included.

$$\ln\left(\frac{kWh_i}{MG_i}\right) = b_0 + b_1\ln(DP_i) + b_2PP_1 + b_3PP_2 + b_4PP_1 * \ln(DP_i) + b_5PP_2 * \ln(DP_i) + b_6\ln\left(\frac{kWh_i}{MG_i}\right)_{t-1} + \varepsilon_i$$

Where:

MG = Million gallons of

DP = Differential pressure

PP1 = Post Period 1

PP2 = Post Period 2

$b_1 - b_6$ = Coefficients estimated in the regression model

ε = Random error assumed normally distributed

As indicated in the model specification, the dependent variable, $\left(\frac{kWh_i}{MG_i}\right)$, and the variable for differential pressure were transformed using the natural log transformation. In addition to often providing a better fit to the data than untransformed "levels" data, a convenient characteristic of logarithmic transformation is that the coefficient estimate of the indicator variable for the contest year is an elasticity.[24] Also included as an explanatory variable in the model is the autoregressive (AR) variable $\left(\frac{kWh_i}{MG_i}\right)_{t-1}$. An autoregressive variable, which is simply the dependent variable with each value lagged one or more periods, is a commonly included variable in time series models (such as this) and reflects the fact that the value of the dependent variable in the current period is often in part explained by the value of the dependent variable in one or more previous periods. The most commonly specified form of an AR model is the AR1, specifying a single, one-period lag. This is the specification used in the models we estimated for the Crockett and Argyle plants.

The models were developed using data on kWh use, water flow, and suction and discharge pressure recorded on 15-minute intervals, which were screened as described previously. No model was developed for the Almond plant, since baseline period energy use was only available at a monthly level.

5.3 Findings

5.3.1 Energy Impact Results

Monthly Summary Statistics

Table 17 shows how differential pressure (i.e., discharge pressure minus suction/input pressure), total water flows and energy use varied by month for the Crockett pumping plant during the pre and post periods. The data show that total flows were generally much higher in the post period

[24] An elasticity is a mathematical measure of the percent change in one variable due to a change (either percent, unit, or binary) in another variable.

except in November and February. Energy intensity was also generally higher, and the largest changes (positive and negative) were in months where there were also relatively large changes in average differential pressure between the pre and post periods.

Table 17: Crockett Pumping Plant: Baseline vs. Post Period Energy Intensity

MONTH	BASELINE PERIOD				POST PERIOD				EI CHANGE (%)
	AVG. DIFF. PRESSURE (PSI)	TOTAL FLOW (MG)	TOTAL ENERGY (KWH)	ENERGY INTENSITY (KWH/MG)	AVG. DIFF. PRESSURE (PSI)	TOTAL FLOW (MG)	TOTAL ENERGY (KWH)	ENERGY INTENSITY (KWH/MG)	
July	51.10	62.03	33,285	536.6	55.92	88.27	48,021	544.0	1.38%
August	48.10	57.77	29,145	504.5	57.21	98.77	56,269	569.7	12.93%
September	50.48	39.14	19,814	506.3	51.11	46.23	22,212	480.5	-5.09%
October	44.14	41.18	19,714	478.8	46.44	60.90	31,660	519.9	8.59%
November	57.82	105.88	55,783	526.9	63.03	73.91	45,260	612.3	16.22%
December	68.76	152.61	101,686	666.3	70.19	188.41	129,091	685.2	2.83%
January	64.15	83.24	51,133	614.3	63.50	149.21	91,955	616.3	0.32%
February	70.83	161.56	108,530	671.8	59.32	123.83	67,260	543.1	-19.15%

Table 18 shows how monthly flows, differential pressure and energy use varied by month for the Argyle pumping plant. Compared to the Crockett data, the energy intensities do not vary significantly from month to month. The differential pressures and water flows are also fairly stable, except in October, January and February where production flows decreased substantially during the post period.

Table 18: Argyle Pumping Plant: Baseline vs. Post Period Energy Intensity

Month	Baseline Period				Post Period				EI Change (%)
	Avg. Diff. Pressure (PSI)	Total Flow (MG)	total Energy (kWh)	Energy Intensity (kWh/MG)	Avg. Diff. Pressure (PSI)	Total Flow (MG)	total Energy (kWh)	Energy Intensity (kWh/MG)	
July	72.61	81.15	56,217	692.8	73.23	83.12	58,270	701.0	1.19%
August	73.00	79.55	56,167	706.1	73.13	83.79	59,447	709.5	0.49%
September	73.25	71.14	50,659	712.1	72.55	78.86	55,088	698.6	-1.89%
October	72.32	78.13	55,143	705.8	72.51	56.86	39,593	696.3	-1.34%
November	72.94	61.84	43,824	708.6	73.29	65.91	46,478	705.2	-0.48%
December	73.64	63.91	44,972	703.7	72.64	65.79	45,989	699.1	-0.65%
January	73.30	62.15	43,212	695.3	72.66	38.77	27,337	705.2	1.42%
February	73.91	51.64	NA	NA	73.72	35.10	24,914	709.9	NA

Table 19 shows how monthly flows, differential pressure and energy use varied by month for the Almond pumping plant. For most months, differential pressure and production flows did not change significantly between the pre and post periods. The largest decreases in energy intensity were in October and November. In October, both average differential pressure and production flows decreased in the post period, whereas in November, differential pressure increased during the post period while production remained constant.

Table 19: Almond Pumping Plant: Baseline vs. Post Period Energy Intensity

Month	Baseline Period				Post Period				EI Change (%)
	Avg. Diff. Pressure (PSI)	Total Flow (MG)	total Energy (kWh)	Energy Intensity (kWh/MG)	Avg. Diff. Pressure (PSI)	Total Flow (MG)	total Energy (kWh)	Energy Intensity (kWh/MG)	
July	72.70	206.97	171,590	829.0	74.53	201.39	154,441	766.9	-7.50%
August	71.53	202.79	158,081	779.5	70.46	205.55	161,157	784.0	0.58%
September	71.48	194.02	152,785	787.5	69.78	183.43	143,112	780.2	-0.93%
October	68.96	176.15	156,944	890.9	64.19	154.22	113,856	738.3	-17.14%
November	64.37	142.25	138,763	975.5	69.26	142.87	114,272	799.8	-18.00%
December	64.38	135.55	108,667	801.7	63.32	131.44	100,184	762.2	-4.93%
January	64.60	133.71	106,269	794.8	58.19	124.92	92,046	736.8	-7.29%
February	62.39	119.76	88,303	737.3	62.55	114.82	84,938	739.8	0.33%

Regression Analysis Findings

The regression models for the Crocket and Argyle plants were estimated independently using the Limdep econometrics software program. Identical model specifications (as shown above in section 5.2.2) were used for the Crockett and Argyle analyses and both models were estimated using the method of instrumental variables in order to obtain consistent estimates of the coefficients on the explanatory variables.[25] This desirable quality cannot be assured when the AR1 model is estimated using ordinary least squares regression. The models were estimated with the flow rate as a weighting variable in order to account for the volume of water flow at each observation of energy intensity.

The Durbin H test was used to test for the presence of autocorrelation in the Crockett and Argyle models. In an AR1 model, the typical test for autocorrelation, the Durbin-Watson test is generally not valid. The test statistic is computed as:

$$h = \left(1 - \frac{d}{2}\right)\sqrt{\frac{T}{1 - Ts_c^2}}$$

Where:

d = Durbin Watson Statistic

T = Number of time periods

S_c^2 = Estimated variance of the OLS coefficient on y_{t-1}

Crockett Plant

Regression results for the analysis of the Crockett plant are shown in Table 20. The R^2, which measures the proportion of variation in the dependent variable explained by variation in the explanatory variables, is 0.79, indicating that the model fits the data fairly well.[26] More importantly, all of the estimated coefficients are statistically significant and the coefficient on differential pressure is of the expected sign (positive).

The coefficients on the two post period variables are negative, indicating that energy intensity decreased in each of the post periods. However, the post period variables were interacted with the differential pressure variable in order to capture the complete effect that the introduction of the energy consumption metrics had on energy intensity. The values for the two interaction variables are positive, indicating that differential pressure had a greater positive impact on energy intensity in the post periods than in the baseline period.

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[25] Two-stage least squares (2SLS) regression method was used to estimate the models. For a detailed discussion of why the 2SLS is a consistent estimator for the AR1 model when autocorrelation still exist in the residuals, see Green 1990, Econometric Analysis, 2nd Edition. P435-436.

An estimator is referred to as consistent if the value of the estimated parameters converges to the true value of the parameters as the sample size increases.

[26] The R2 is a somewhat crude measure of model fit, but is commonly reported and generally of interest because of its simplicity of interpretation.

Table 20: Regression Results for Crockett Plant

VARIABLE	COEFFICIENT	ST. ERROR	T-STAT	P-VALUE
Constant	5.629	0.028	199.803	0.000
Ln(Diff Press)	0.180	0.007	26.757	0.000
Post Period 1	-0.668	0.039	-17.099	0.000
Post Period 2	-0.943	0.060	-15.643	0.000
Post Period 1*Ln(Diff Press)	0.164	0.009	17.641	0.000
Post Period 2*Ln(Diff Press)	0.230	0.015	15.847	0.000
RHO[27]	0.905	0.004	245.337	0.000
R2 = 0.79	Durbin H: -15.5		Observations: 16,287	

Source: ECONorthwest analysis of EBMUD/GEP data

Note: Regression estimated using an AR1 specification and weighted based on flow volume for each period

Development of estimates of the impact of the SCADA metrics required a subsequent step and was done using the delta method.[28] Although it is a relatively straightforward matter to calculate point estimates of impacts, the delta method allows one to calculate the standard error associated with each impact estimate based on the variance-covariance matrix estimated in the billing regression.[29] The standard error is used to construct confidence intervals in which the "true" elasticities reside, as well as to perform hypothesis tests.

Table 21 shows the impact (also referred to as elasticity) estimates for the two post periods, calculated at the mean historic value of differential pressure. Table 21 also shows the standard errors calculated using the delta method and associated measures of statistical significance. For both post periods, the impacts are very small (0.8 percent and 0.4 percent, respectively); are of the wrong sign (positive); and are not statistically significantly different from zero. Thus, the data on which the statistical model was developed do not support the hypothesis that energy intensity decreased due to the introduction of the energy consumption metrics at the Crockett plant.

Table 21: Impact (Elasticity) Estimates for Crockett Plant

PERIOD	ELASTICITY	ST. ERROR	T-STAT	P-VALUE
Post Period 1	0.008	0.009	0.893	0.372
Post Period 2	0.004	0.013	0.293	0.770

Source: ECONorthwest analysis of EBMUD/GEP data

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[27] RHO represents the autoregressive parameter. It is in effect an estimate of the correlation between subsequent periods of the error term, $\rho = Corr(\varepsilon_t, \varepsilon_{t-1})$, and serves as a "fix" for the violation of the assumptions of the classic linear regression model (autocorrelation of the error term).

[28] The delta method is used to derive an approximate probability distribution for a function of an asymptotically normal statistical estimator based on knowledge of the variance-covariance of the underlying estimator.

[29] The impact (elasticity) of energy intensity associated for either post period is simply the partial elasticity of energy intensity with respect to that post period.

The pumping stations, of course, operate across a range of values of differential pressure. The results shown in Table 21, however, are calculated at a single point of approximation—the historical mean of differential pressure. Impacts on energy intensity across the historical range of differential pressure were also calculated and are shown in Figure 4. Specifically, Figure 4 shows a range of estimated impacts on energy intensity for both post periods, as well as for the baseline period. The elasticity estimates were calculated at the following values of differential pressure:

± 0.5 standard deviations (69.9 and 53.0)

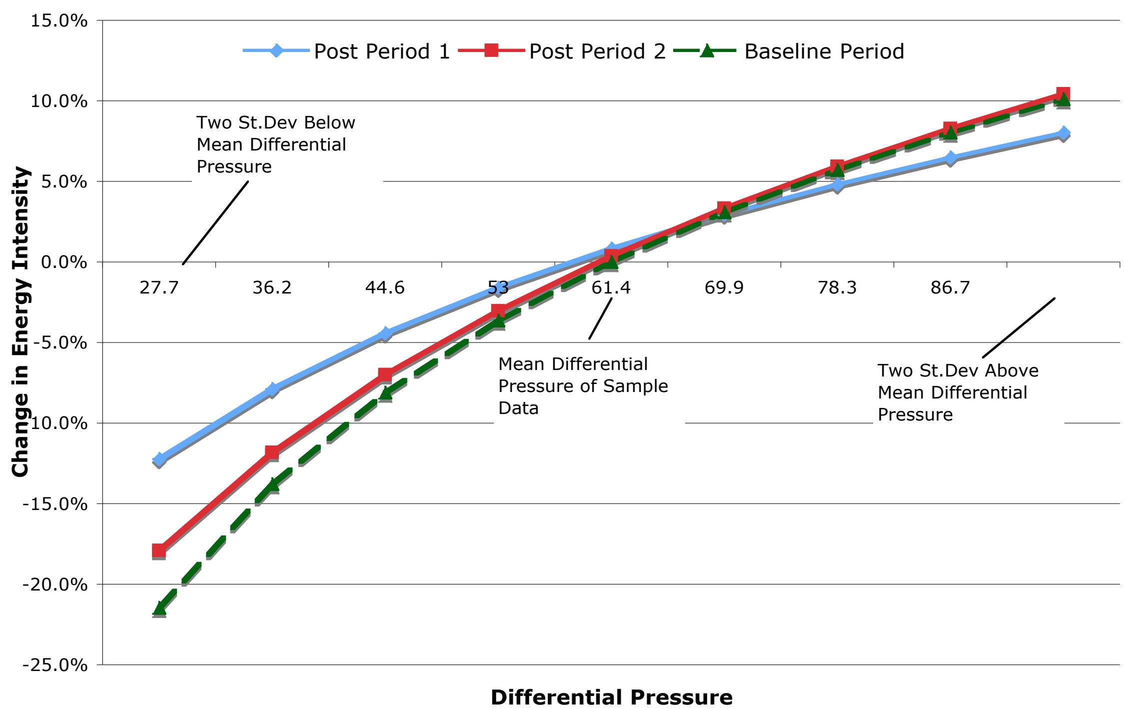
± 1.0 standard deviations (78.3 and 44.6)

± 1.5 standard deviations (86.7 and 36.2)

± 2.0 standard deviations (95.1 and 27.8)

As Figure 4 shows, energy intensity increases as differential pressure increases (relative to the mean differential pressure) and decreases as differential pressure decreases. For lower than average values of differential pressures (to the left of the mean), energy intensity was slightly lower for the baseline period than for post period 2 and much lower than for post period 1. For higher than average values of differential pressure, energy intensity was nearly identical for the baseline period and post period 2 and slightly higher than for post period 1.

Figure 4: Estimated Impact (Elasticity) on Energy Intensity Across the Historical Range of Differential Pressure, Crockett Station



Source: ECONorthwest analysis of data from EBMUD/GEP

Argyle Plant

Regression results for the analysis of the Argyle plant are shown in Table 22. The R^2 is 0.37, indicating that less than half the variation in the dependent variable is explained by variation in the explanatory variables. However, all of the estimated coefficients are statistically significant and the coefficient on differential pressure is of the expected sign (positive). The coefficients on the two post period variables are negative, indicating that energy intensity decreased in each of the post periods. However, the post period variables were interacted with the differential pressure variable in order to capture the complete effect that the introduction of the energy consumption metrics had on energy intensity. The values for the two interaction variables are positive, indicating that differential pressure had a greater positive impact on energy intensity in the post periods than in the baseline period.

Table 22: Regression Results for Argyle Plant

VARIABLE	COEFFICIENT	ST. ERROR	T-STAT	P-VALUE
Constant	3.692	0.083	44.299	0.000
Ln(Diff Press)	0.666	0.019	34.268	0.000
Post Period 1	-1.708	0.129	-13.247	0.000
Post Period 2	-0.499	0.227	-2.197	0.028
Post Period 1*Ln(Diff Press)	0.399	0.030	13.261	0.000
Post Period 2*Ln(Diff Press)	0.118	0.053	2.227	0.026
RHO[30]	0.249	0.009	28.930	0.000
R2 = 0.37	Durbin H: Cannot be calculated		Observations: 13,555	

Source: ECONorthwest analysis of EBMUD/GEP data

Note: Regression estimated using an AR1 specification and weighted based on flow volume for each period

Development of estimates of the impact of the SCADA metrics required a subsequent step and was done using the delta method.[31] Although it is a relatively straightforward matter to calculate point estimates of impacts, the delta method allows calculation of the standard error associated with each impact estimate based on the variance-covariance matrix estimated in the billing regression.[32] The standard error is necessary to test the statistical significance of the estimated impacts.

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[30] RHO represents the autoregressive parameter. It is in effect an estimate of the correlation between subsequent periods of the error term, $\rho = Corr(\varepsilon_t, \varepsilon_{t-1})$, and serves as a "fix" for the violation of the assumptions of the classic linear regression model (autocorrelation of the error term).

[31] The delta method is used to derive an approximate probability distribution for a function of an asymptotically normal statistical estimator based on knowledge of the variance-covariance of the underlying estimator.

[32] The impact (elasticity) of energy intensity associated for either post period is simply the partial elasticity of energy intensity with respect to that post period.

Table 23 shows the impact estimates for the two post periods along with standard errors calculated using the delta method. For both post periods, the impacts are very small (0.16 percent and 0.79 percent, respectively) and are positive indicating that energy intensity actually increased very slightly during the two post periods. The estimated impacts are also statistically significant.[33] Thus, not only do the data on which the statistical model was developed not support the hypothesis that energy intensity decreased due to the introduction of the SCADA metrics at the Argyle plant, they suggest that energy intensity actually increased in the post periods.

Table 23: Impact (Elasticity) Estimates for Argyle Plant

PERIOD	*ELASTICITY*	*ST. ERROR*	*T-STAT*	*P-VALUE*
Post Period 1	0.0016	0.0009	1.84	0.070
Post Period 2	0.0079	0.0019	4.26	0.000

Source: ECONorthwest analysis of EBMUD/GEP data

Figure 5 shows impacts on energy intensity across the historical range of vales of differential pressure for both post periods, as well as for the baseline period. The vertical axis represents the elasticity of energy intensity with respect to a change differential pressure. The elasticity estimates were calculated at the following historical values of differential pressure:

± 0.5 standard deviations (74.0 and 71.9)

± 1.0 standard deviations (75.1 and 70.8)

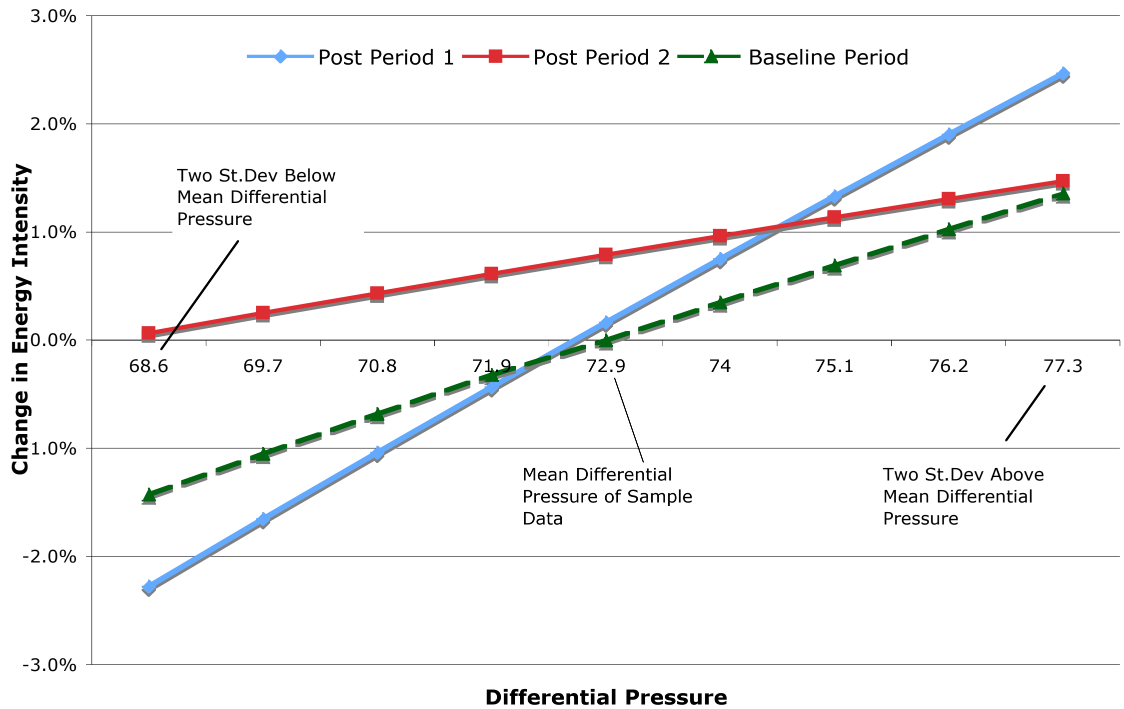
± 1.5 standard deviations (76.2 and 69.7)

± 2.0 standard deviations (77.3 and 68.6)

The dashed line in Figure 5 shows the percent change in energy intensity during the baseline period across the range of values of differential pressure observed during the baseline. The fact that the dashed line is sloped upward indicates that the elasticity (percent change in energy intensity with respect to a one percent change in differential pressure) increases as differential pressure increases. Thus, the elasticity is not constant along the range of values of differential pressure.

[33] The impact estimated for Post Period 1 is statistically significant at the 90 percent confidence level. The impact estimate for Post Period 2 is statistically significant at the 99 percent confidence level.

Figure 5: Estimated Impact (Elasticity) on Energy Intensity Across the Historical Range of Differential Pressure, Argyle Station



Source: ECONorthwest analysis of data from EBMUD/GEP

The lines representing post periods 1 and 2 show how the relationship between differential pressure and change in energy intensity differed in each of the post periods—relative to the baseline period. Figure 5 shows that across the range of historical values of differential pressure, energy intensity was greater during post period 2 than in the baseline. Therefore, we find no evidence of energy savings associated with the introduction of the new energy efficiency and intensity metrics in the SCADA system. For post period 1, energy intensity was greater than in the baseline across most of the historical range of differential pressure.

Operators Survey Responses

Following are key findings from the pumping station operators' survey, which corroborate the findings from the regression analyses. These findings were compiled from the draft project report developed by GEP, since EBMUD feedback was not given directly to the evaluation team.[34]

- The operators had difficulty adjusting to the concept of selecting the most efficient pump (or combination of pumps) versus maintaining even run-time hours, as they have historically done. Overall, they did not use the real-time SCADA feedback much to make instantaneous decisions.

[34] The GEP report does not mention that the operators had any difficulty understanding the metric.

- Because the operators were not forced to participate in the project, and operator performance goals were not linked to positive project results, the operators' level of personal investment varied.
- Conserving energy is a goal, however other factors must be considered first. Required flows are particularly important; if required flows can be met by a more efficient combination then the operator may change the pumps selection. The operators must also consider reservoir levels, water volume changes needed to prevent stagnation, and maintaining zone pressures.
- There is no official operating guide that the operators follow, but there are many guidelines and rules of thumb informally passed on from operator to operator specific to each pumping plant and for the system as a whole.
- The operators cannot commit much time on a daily basis to optimizing energy efficiency, as each day typically includes a range of "emergencies" and unique operating scenarios. Dealing with the unexpected is regular part of an operator's day.
- The surveyed operators do not prefer fully automatic operating systems, and appreciate having the ability to affect energy consumption.

5.4 Discussion of Uncertainty, Threats to Validity, Precision, Potential Biases

The statistical models developed to estimate the impacts of the new SCADA screen metrics on energy intensity were developed using energy and flow data collected on 15-minute intervals. Although the regression results were corroborated by formal feedback from the plant operators (i.e. they did not have time or the operational flexibility to change their behaviors generally), it is unclear if such short-duration data collection was necessary or appropriate for this analysis. Short-duration data can be noisy and contain period-to-period variation that is not relevant to understanding the potential impacts associated with the new SCADA metrics, and may conceal impacts that are apparent when more aggregate (e.g., hourly) data are analyzed. This is especially the case when analyzing time-series data such as gathered from the Crockett and Argyle plants.

The analyses were also based on large amounts of *data*, but potentially little *information*. Well over 10,000 observations were analyzed for each plant. However, these data represent a relatively short period—no more than eight months each of baseline and post-period data. Future evaluations should try to extend the analysis periods if possible, particularly if water utility staff are known to be making concerted efforts to utilize new energy monitoring tools to conserve energy. This would give the operators a longer timeframe to optimize their own behaviors and try to reduce energy consumption over a greater range of operating conditions.

5.5 Discussion of Findings

The potential for the Emerging Technologies Pilot program to save water utility energy by focusing on changing pumping operations has yet to be proven. At EBMUD, the operators did not have much ability (i.e., time, operational flexibility) or incentive to utilize new information to reduce the energy intensity of water pumping, while at San Jose Water Company, the automatic pumping algorithm developed by BASE had not been programmed into the SCADA during the Pilot implementation period.[35]

If the program is to continue in the future, the following implementation strategies should be considered:

1. **Conduct more detailed screening of participating water agencies, to ensure that operators have the ability to select different pump combinations to reduce energy intensity.** For instance, under some conditions, operators might be able to distribute required flows over longer time periods, change reservoir filling levels, or exert more control over suction pressure to reduce differential pressure.[36] The extent to which the operators are able to change system production should be fully understood before providing new tools to monitor energy use.
2. **Utilize different energy monitoring tools.** At agencies where the operators do not have time to frequently monitor real-time energy data displayed on the SCADA, the data could be used to automatically create energy consumption matrices that the operators could reference periodically to assess pumping performance. Alternatively, the agency could implement an automatic pumping algorithm to optimize energy use as is envisioned at San Jose Water Company.
3. **Ensure that water agency staff have an incentive to implement and utilize energy monitoring tools provided through the program.** While EBMUD staff had to contribute time to the project, there was no incentive (other than improvements in pumping efficiency) to encourage operators to actually utilize the new energy monitoring metrics. Increased financial incentives in the form of higher cost sharing by water agencies and/or operator performance bonuses could increase the likelihood of program tools being implemented and utilized. Importantly, water utilities regulated by the CPUC would need CPUC authorization to recover implementation costs.

[35] To test the feasibility of the algorithm and estimate potential energy savings, BASE applied the algorithm to historic pumping operations data and modeled expected changes in energy use. The evaluation team did not have access to these hypothetical results, which were presented to San Jose staff and PG&E, and reportedly showed that energy savings are at least possible based on past operations data.

[36] At EBMUD, rate control regulators are used to divert water flow from the upstream line feeding each plant, and changing these operations can affect the input/suction pressure at each plant.

6 SCE Low-Income Direct Install High Efficiency Toilet Pilot Program

6.1 Program Description

The Southern California Edison (SCE) Low Income Direct Install High Efficiency Toilet Pilot Program was implemented through a partnership with Metropolitan Water District (MWD) and Irvine Ranch Water District (IRWD) to deliver and install High Efficiency Toilets (HETs) for multi-family households in low-income areas within mutual MWD and SCE service territories. As part of this program, 276 toilets were retrofit in 176 low-income multi-family homes. These homes were retrofit with dual flush toilets using two different flush volumes, 1.6 gpf intended for solid waste and 0.8 gpf for liquid waste.[37] Since the flushing pattern of these toilets normally consists of a mixture of large and small flushes we anticipated an average flush volume for the fully retrofit units somewhere between 1.6 and 0.8 gpf. The purpose of the evaluation was to document the observed changes in water use in low-income multi-family homes after being retrofit with HET dual flush toilets.

The study plan called for only toilets with flush volumes greater than 1.6 gpf to be replaced. Toilets that were stamped as 1.6 gpf “ultra low flush” (ULF) units, based on the 1992 Energy Policy Act, were left in place. The result of this was that there should have been only two types of toilets in the post-retrofit sample: homes with only the HET models and homes with a mixture of HET and ULF models. There should have been no toilets flushing at more than ~1.6 gpf.

The target market for this Pilot was families that qualify as low-income households. The California Public Utilities Commission uses criteria for defining low-income status as are defined in the Health and Human Services poverty guidelines for the lower 48 states (HHS, 2008). Two criteria determine this characterization: the number of persons per household and whole-household income level, as shown below:

Poverty Level = number of persons per household * $3600 + $6800

Low-income Threshold = 200% of Poverty Level

Table 24 characterizes the study sample in comparison with a larger sample of individually metered multi-family accounts. This information was obtained from a combination of sources, including billing data, flow trace data, and information provided by the multi-family property manager. For comparison purposes, data from a September 2008 study of individually metered multi-family units is also shown.[38] The IRWD data consisted of the entire population of

[37] The toilets installed were Caroma Sydney 305. Throughout a good portion of this study it was thought that the Caroma Sydney Smart 305, which flushes at 1.28 and 0.8 gpf, was used in the retrofits. Later in the evaluation however, it was verified that the 1.6/0.8 gpf Caroma Sydney Low Profile 305 Round Front Plus model was installed instead, due to the limited space found during the initial site inspections. This evaluation reflects the correct rated flush volume of 1.6/0.8 gpf, although the evaluation plan in Appendix 5.1 references the lower flush volume.

[38] DeOreo, W. B., and Hayden, M. (2008). "Analysis of Water Use Patterns in Multi-Family Residences." Prepared by Aquacraft Inc. for Irvine Ranch Water District, Irvine, CA. (See Table 5, pg. 15 for water use data, Table 12, pg. 31 for population and toilet data)

individually metered multi-family apartments in the Irvine Ranch service area taken from their billing data. The Irvine units were apartments, with virtually no outdoor water use. A mail survey was conducted which provided the data for the number of persons and bathrooms. The water use of the SCE low-income group, while smaller in number, is quite similar to that of the larger group. This demonstrates that the evaluation sample group is not skewed significantly from general multi-family households in the same geographical area.

Table 24: Characteristics of Sample Group

Parameter	*SCE*	*IRWD (2008)*
Number of multi-family homes sampled	41	4657
Average number of people per home	2.7	2.6
Average number of toilets per home	1.8	2.0
Average number of toilets retrofit per home	1.6	NA
Average baseline indoor water use (gphd)	138	147.4
Average Annual Use (kgal/ccf)	50.4 kgal 67.5 ccf	53.8 kgal 71.9 ccf
Average per capita use (gpcd)	51.1	56.7
Income Status	Low	Mixed

6.2 Methods

6.2.1 Data Collection Methods

The water impacts for SCE's HET program were estimated using the flow trace methodology developed by Aquacraft, Inc. The purpose of flow trace analysis is to obtain precise information about water use patterns: where, when, and how much water is used by a variety of devices including toilets, showers, baths, faucets, clothes washers, dishwashers, hand-held and automatic irrigation systems, evaporative coolers, home water treatment systems, leaks, and more. The collected data are precise enough that individual water use events such as a toilet flush, clothes washer cycle or miscellaneous tap use can be isolated, quantified and then identified.[39] This technique makes it possible to disaggregate most of the water use in a residential home and to quantify the effect of many conservation measures, from toilet and faucet retrofit programs to behavior modification efforts. It is also possible to disaggregate water use into more coarse categories. For example, the changes in water use from much larger end user categories with large meters serving their water demands (i.e. industrial facilities) can be measured by demand profile changes in domestic/indoor, process and other category water uses.

The flow trace methodology is based on the fact that there is consistency in the flow trace patterns of most water uses. For example, a specific toilet will generally flush with the same

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[39] Flow trace analysis captures consecutive "double-flush" events as separate flushes.

volume and flow rate day in and day out. A specific dishwasher exhibits the same series of flow patterns every time it is run. The same is true for clothes washers, showers, irrigation systems, etc. By recording flow data at 10-second intervals, a rate determined by Aquacraft to optimize accuracy and logger memory, the resulting flow trace provides accurate data for quantifying and categorizing almost all individual water uses in each study home.

Trace Wizard is a software package developed by Aquacraft, specifically for the purpose of analyzing flow trace data. Trace Wizard provides the analyst with powerful signal processing tools and a library of flow trace patterns for recognizing a variety of residential fixtures. Any consistent flow pattern can be isolated, quantified, and categorized using Trace Wizard including leaks, evaporative coolers, humidifiers, and swimming pools. Once all the water use events have been isolated and quantified and statistics generated, Trace Wizard implements a user defined set of parameters developed for each individual study residence to categorize the water use events and assign a specific fixture designation to each event. Additional detail on the flow trace method and the Trace Wizard software is included in Appendix 5.2.

M&V Meter Sample

This study group of homes was sampled based on local demographic low-income qualifiers, which enabled income thresholds to be identified. Once the list of individually metered low-income multi-family qualifying homes was prepared, a systematic random sampling methodology, (developed by this study's Internal Team) using interval sampling, provided the data logging sample.

Of the 176 low-income multi-family homes retrofit, a sample of 41 was successfully data logged.[40] The retrofit homes were from two apartment complexes in SCE service area. The homes in these complexes are individually metered, meaning each apartment unit has a single water meter serving its domestic indoor uses that is not connected to outdoor usage. Data loggers were fixed to these water meters and their water use was monitored for 14 days before and 14 days after the retrofit so that the changes in water use could be measured, and the impact of the HET's evaluated. The pre-retrofit data were collected between June 29th and July 13th, 2009, and the post-retrofit data set was collected between September 29th and October 14th, 2009.

6.2.2 Analysis Methods

Using the flow trace method and metered data discussed above, the water savings resulting from HET retrofits were estimated using the paired, pre and post-retrofit data from 41 homes, for the following parameters, which were obtained from analysis of the flow trace data.

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[40] The original research plan estimated a sample of 50 homes would be successfully data logged. Prior to the HET retrofit 56 homes were successfully data logged. The design of the HET Pilot only allowed for HET retrofits in homes after installers inspected the existing toilets to determine whether the home had candidate high flush volume toilets. After inspection, 15 more of the pre-retrofit data logged group were removed from the post-retrofit data logging group due to the fact that they were already equipped with 1.6 gpf ULF toilets. Having a smaller sample reduced the accuracy of the results, but a larger sample was not available. While a larger sample might have given more definitive answers, the results from this sample are useful and indicative.

1) Average gallons per day of total domestic use per unit

2) Average gallons per day for toilet flushing per unit

3) Average number of flushes per unit per day

4) Average leakage rates per unit per day

These values were tabulated and paired t-tests were run to determine if there were statistically significant changes in the means at both 90 percent and 95 percent confidence intervals. The differences between the two levels were not great enough to change any of the conclusions of the study. In addition to the statistical analysis of means the data were analyzed using regression techniques to determine whether models based on either the number of toilets replaced, the number of persons per home, or a combination of both gave improved estimates compared to simple averages.

All of the replacement toilets were identical, which simplified the analysis. The hourly water use data for the sample were tabulated and a comparison was made between pre and post water use. Both total water use and toilet use were analyzed.

Because of the relatively short interval of 11 weeks between the pre and post data collection periods it was assumed that occupancy rates were stable. The other assumption made is that the units included in this sample are typical of the low-income multi-family units in this pilot program's general population. While this seems like a reasonable assumption, sufficient data on the general population were not available to verify it. Savings estimates were normalized on the basis of the numbers of toilets replaced and numbers of persons per unit, which will allow the results to be generalized to other similar properties but with different populations and numbers of toilets.

6.3 Findings

6.3.1 Water Impacts

Total Indoor Use

The average baseline (pre-retrofit) water use for the study group was 138.3 gallons per household per day (gphd). This averages 51.2 gallons per capita per day (gpcd), but there is a very weak relationship between the persons per home and the household water use. As shown in Figure 6, the household water use in these units is almost independent of the number of residents reported by the residents. The regression line shows that for one occupant the daily water use is expected to be 75.77 gphd, but that water use rises with the number of occupants raised to the 0.35 power. This may be due to the fact that the residents were not reporting accurate data, or that the number of persons actually living in the units varied from day to day. In any case, as discussed below, it helps explain why models of water savings were not responsive to the number of occupants. (Note that in Figure 6 one outlier, with over 600 gphd was excluded from the data.)

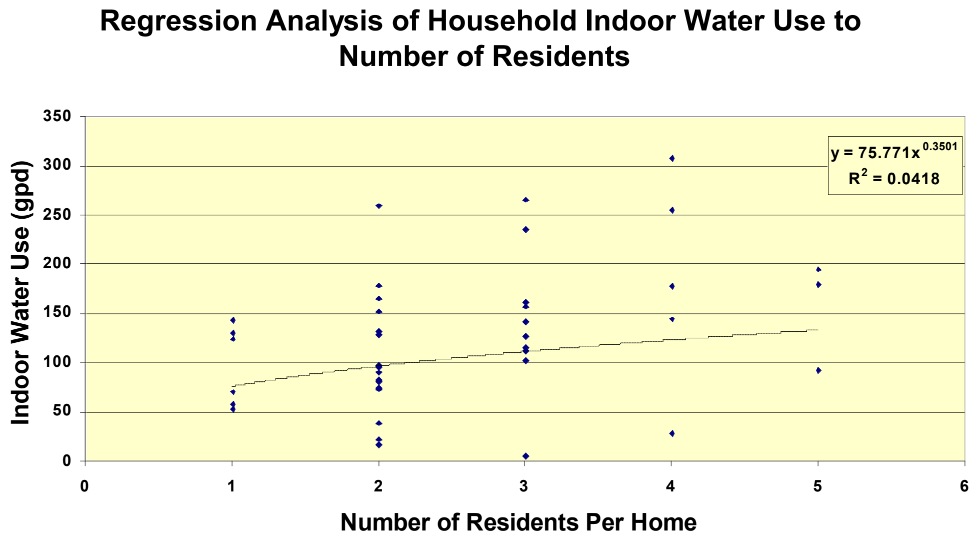


Figure 6: Household Indoor Water Use vs Number of Occupants (Pre-Retrofit)

Figure 7 shows that prior to the retrofits the average indoor water use for the units was 138.3 gphd. After the retrofits the average indoor water use dropped by 20 gallons per household per day (gphd) to 118.0 gphd. However, as shown in Table 25, there was such a high amount of variability in the daily use of the 41 households that this change in indoor water use was not statistically significant at either the 95 percent or 90 percent confidence levels. The change in overall indoor water use ranged from an increase of 328 gphd to a decrease of 204 gphd. The data do, however, suggest a programmatic reduction in indoor use by approximately 20 gpd. Examination of the end use data helps clarify the situation since they focus in on individual uses for which there is less variability.

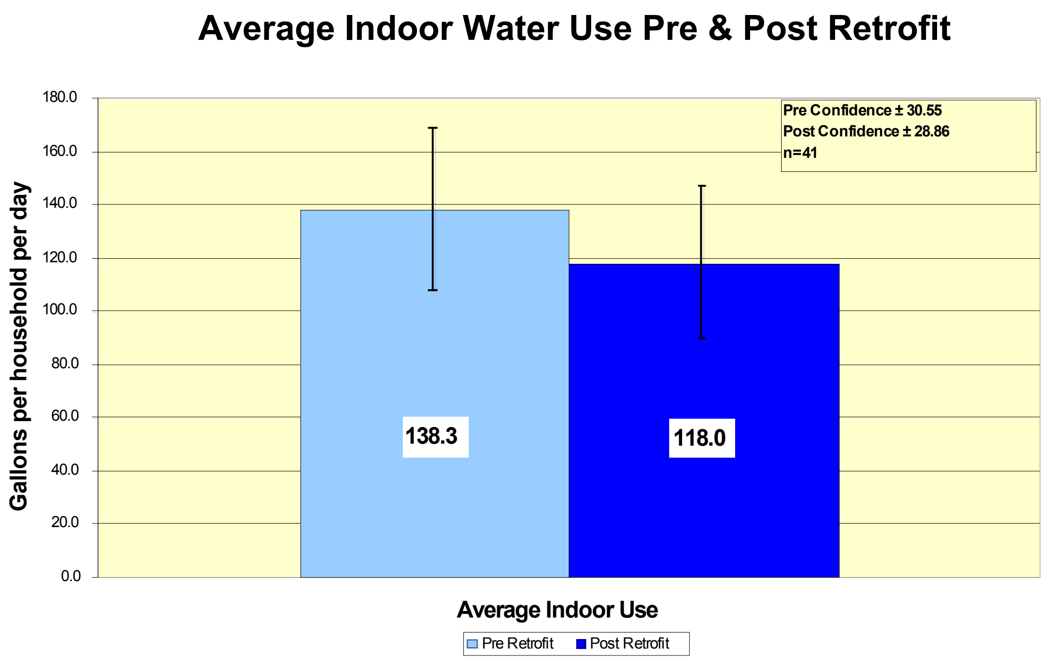


Figure 7: Comparison of Pre/Post Average Indoor Water Use

Table 25: Changes in Total Indoor Use by Unit

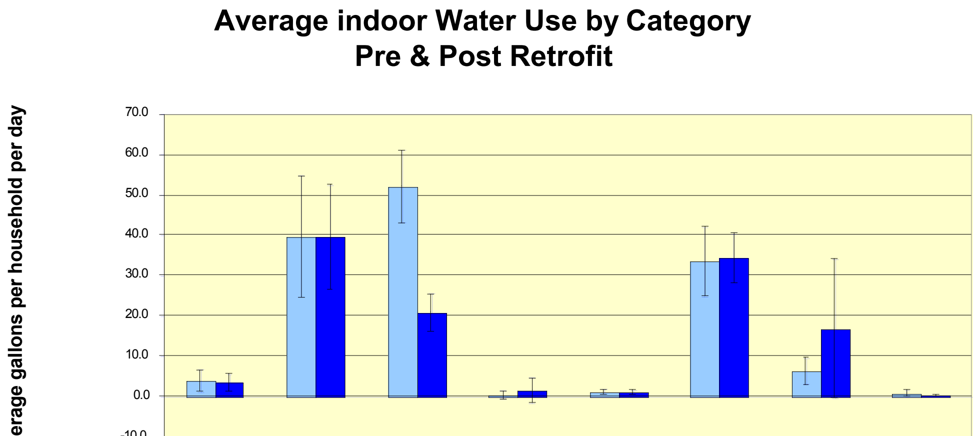
Keycode	Pre-retrofit Indoor (GPD)	Post-retrofit Indoor (GPD)	Change in Indoor Use (GPD)
09M201	579	404	-175
09M202	162	235	73
09M204	256	199	-57
09M205	266	82	-185
09M207	142	108	-34
09M208	166	143	-23
09M210	179	79	-100
09M214	144	126	-17
09M215	53	35	-18
09M216	17	32	15
09M217	125	49	-76
09M219	128	91	-37
09M220	116	88	-28
09M221	153	106	-47
09M222	236	31	-204
09M223	91	44	-46
09M224	260	244	-16
09M225	75	70	-5
09M226	308	162	-146
09M227	96	157	62
09M228	71	65	-5
09M229	131	228	97
09M232	29	73	44
09M233	132	461	328
09M234	145	87	-58
09M237	195	125	-71
09M238	158	82	-76
09M239	179	89	-90
09M240	74	48	-26
09M241	113	101	-12
09M242	39	55	16
09M243	129	120	-8
09M245	83	53	-31
09M250	59	47	-12

KEYCODE	PRE-RETROFIT INDOOR (GPD)	POST-RETROFIT INDOOR (GPD)	CHANGE IN INDOOR USE (GPD)
09M251	103	0	-103
09M252	180	176	-4
09M253	93	135	42
09M254	23	45	22
09M255	81	65	-16
09M256	6	224	219
09M257	98	73	-25
Average	138.28	118	-20.3
Std Dev	99.81	94.30	94.05
Count	41	41	41
95%CI	30.55	28.87	28.79
90% CI	25.64	24.23	24.16

Comparison of End Use Data

Water consumption patterns become clearer when individual end use data are compared, as is done in Figure 8. When individual end uses are compared the data show slight increases in faucet and shower use, a large increase in leaks, and a still larger decrease in toilet use. Of these changes, however, only the toilet use change is statistically significant at either the 95 percent or 90 percent confidence levels. Average daily toilet use dropped from 52.1 gphd to 20.8 gphd as a result of the retrofit. This represented a decrease of 31.2 gphd attributable to the toilet replacement.

When changes in the other end uses are considered it becomes clear that the increases in the faucet, leaks and shower use are masking the decrease in the toilet use. It is interesting to note that if one had only water meter data, from which daily readings were obtained, it would not be possible with a sample of this size to identify any change in water use associated with the retrofit. When the end use data are available, however, the changes in toilet use can clearly be quantified. It is also interesting to note that if only toilet water data were obtained, for example by use of sub meters attached to the toilets it would have been impossible to quantify the change in leakage. If the leaks were occurring in the toilets the sub-meters would have registered them as toilet use (when they may be toilet leaks), and would have underestimated the potential savings from the retrofits. If they occurred elsewhere in the plumbing system the sub-meters would have missed them, and over-estimated the simple toilet savings.



	Bath	Shower	Toilet	Clothes Washer	Dish Washer	Faucet	Leak	Other
Pre Retrofit	4.0	39.7	52.1	0.5	1.3	33.6	6.3	0.8
Post Retrofit	3.5	39.6	20.8	1.6	1.1	34.3	16.8	0.3

Figure 8: Comparison of Pre/Post Retrofit Household Water Use by End Use Category

The data from the 41 homes that were retrofit with HET toilets, and for which valid data were obtained indicate that the retrofit resulted in an average toilet water savings of 31.2 ± 8.2 gphd during the data logging period, or 11,388 gallons per home per year. This represents a 60 percent reduction in average household toilet water use in these study homes.

The histogram in Figure 14 shows the average daily toilet water use in homes before and after HET installs, and Figure 15 shows a histogram of average household flush volumes pre and post retrofit. These figures show a clear shift in both daily average toilet water use and average flush volumes per home.

Looking at all 41 homes in this study the average household flush volumes dropped from 3.84 gpf prior to the retrofit to 1.58 gpf after the retrofit[41]. Figure 15 shows that prior to the retrofit the bulk of the flushes were between 3 and 4.5 gpf, and the after the retrofit the bulk of the flushes were between 0.75 and 1.75 gpf which is where one would expect flush volumes in homes with mixtures of HET and ULF toilets to fall.

Table 26 shows statistics on the post retrofit flush volumes in the study homes. As shown in the table, 29 units (73 percent) had flush volumes less than or equal to 1.5 gpf, which puts these units solidly in the range we would expect for the 1.6/0.8 gpf toilets installed in these units; 7 (18 percent) of the units had average flush volumes between 1.5 and 3.0 gpf, which implies a mixture of HET and non HET devices, or perhaps some adjustment problems; just 4 (10 percent) of the units had average flush volumes greater than 3.0 gpf, which implies either more serious adjustment problems or that older toilets (pre-1994) were not replaced, or that there may be a scaling error in the meter data. One of the units (09M251A2) recorded no flushes during the post

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[41] The analysis in this report focuses on average flush volumes at the household level, not by individual toilet fixture.

retrofit period, so the percentages are based on 40 units for this table. Overall the 95 percent confidence interval was within 5 percent of the mean for these volume measurements.

These findings could be due to a number of reasons. The toilets that were left in place because they were believed to be ULF models might have been malfunctioning and flushing at greater volumes. Similarly, the toilets that were installed by the program may have been malfunctioning and flushing at greater than their 1.6/0.8 gpf design volumes. Finally, it may have been impossible to replace some of the pre-1994 toilets or they may have been missed by the installer. Without doing an in-home verification of each unit, which was outside the scope of the evaluation, it is impossible to say precisely what the actual contributing factors were.[42] Overall, the fact that not all of the post retrofit toilets were flushing at 1.6 gpf or less reduced the effectiveness of the program.

[42] The evaluation plan called for reliance on information supplied by the installers as to the number, makes and models of the replaced toilets.

Table 26: Post Retrofit Average Flush Volumes for Each Unit

KEYCODE	POST RETRO AVG FLUSH VOLUME	POST RETRO TOILET EVENTS	POST RETRO TOILET FLUSH STDEV	95% CI
09M201	2.33	299.00	0.82	0.09
09M202	1.05	117.00	0.35	0.06
09M204	1.37	310.00	0.42	0.05
09M205	1.01	116.00	0.27	0.05
09M207	0.89	238.00	0.29	0.04
09M208	1.06	482.00	0.39	0.03
09M210	1.41	351.00	0.17	0.02
09M214	0.97	176.00	0.37	0.05
09M215	1.10	123.00	0.26	0.05
09M216	1.02	71.00	0.38	0.09
09M217	1.13	49.00	0.35	0.10
09M219	3.10	136.00	1.49	0.25
09M220	1.23	118.00	0.34	0.06
09M221	1.33	251.00	0.28	0.03
09M222	1.65	23.00	0.74	0.30
09M223	1.14	131.00	0.32	0.05
09M224	2.62	260.00	1.54	0.19
09M225	1.21	89.00	0.36	0.07
09M226	3.06	66.00	1.08	0.26
09M227	1.16	84.00	0.39	0.08
09M228	4.55	103.00	0.63	0.12
09M229	3.90	203.00	0.48	0.07
09M232	1.20	161.00	0.36	0.06
09M233	2.47	224.00	2.23	0.29
09M234	1.40	152.00	0.35	0.06
09M237	2.09	230.00	1.14	0.15
09M238	1.33	167.00	0.28	0.04
09M239	1.12	205.00	0.37	0.05
09M240	1.34	59.00	0.36	0.09
09M241	1.22	185.00	0.31	0.04
09M242	1.39	197.00	0.21	0.03
09M243	1.31	141.00	0.26	0.04
09M245	0.97	136.00	0.30	0.05
09M250	0.85	64.00	0.25	0.06
09M251				

KEYCODE	POST RETRO AVG FLUSH VOLUME	POST RETRO TOILET EVENTS	POST RETRO TOILET FLUSH STDEV	95% CI
09M252	1.57	298.00	0.32	0.04
09M253	1.14	238.00	0.36	0.05
09M254	1.64	37.00	0.22	0.07
09M255	1.31	134.00	0.29	0.05
09M256	1.20	264.00	0.38	0.05
09M257	1.25	224.00	0.42	0.05
Average	1.58	172.80	0.50	0.08

In order to show how the above values were derived a portion of the flow trace for unit 09M219A2 has been inserted as Figure 9. According to the data in Table 26 this unit had an average toilet flush volume of 3.10 gpf. Figure 9 shows the flow trace data for a four-hour window from 8AM to 12AM on Sunday, October 4, 2009. There are five toilet events shown in this figure. Their respective volumes are: 3.55, 3.50, 3.52, 1.85, and 3.48 gallons. Note that four of the five flushes are all closely grouped around 3.5 gallons and one stands alone at 1.85 gallons. This suggests that there are either two toilets in use (and one is not a low-flow model), or somehow the dual flush mechanism on the HET unit was seriously malfunctioning. The overall volume of the flow trace was the same as the volume recorded by the water meter, so scaling error in the trace is not a concern.

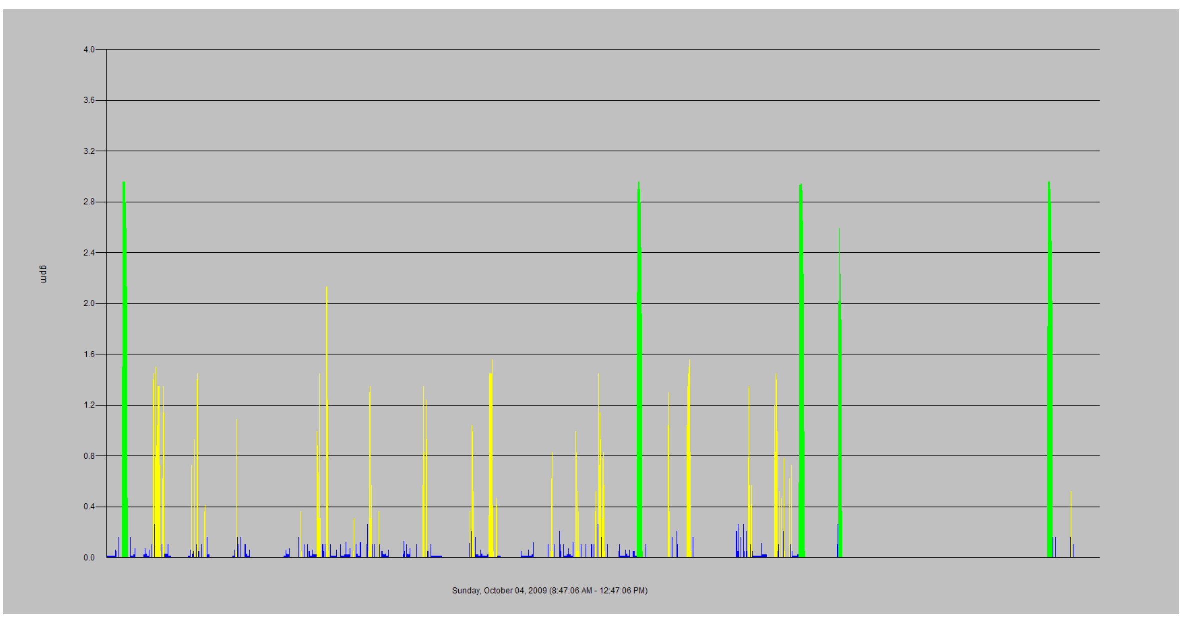

Figure 9: Extracted Portion of Flow Trace for Unit 09M219A2

To further demonstrate how the flow trace analysis identifies toilet flushes, blow-ups of the four large flushes from Figure 9 are shown below in the following four figures. Instead of a 4-hour window these figures show the toilet flushes in a 10-minute window so that their details can be seen. At this scale it becomes clear why the four events were classified as toilet flushes. They all have nearly identical flush volumes within a few hundredths of a gallon. Their peak flows are all between 2.94 and 2.96 gpm, and their durations are all identical at 1 minute 30 seconds. Furthermore, each event has the same distinctive shape with a steep rising limb and a gradual declining limb as the toilet gradually fills and depresses the float valve. In the absence of a scaling error, which would cause all of the volumes in the trace to be amplified, the only rational explanation for these events is that they represent a toilet flushing at around 3.55 gallons.

The question has been asked as to whether high flush volumes might be due to double flushing. Double flushes, however, show up on the trace a two separate flushes occurring back to back. This is because the toilet has to complete its fill before it can be properly flushed again. This creates a set of flushes rather than a single large flush. Occasionally, a toilet flapper may stick open, and this can create a single large flush, but when that happens it tends to be a random event with little consistency in the duration.

It is highly unlikely that there is a scaling error since the water meter registered 1,197 gallons during the logging period and the data logger recorded 1,229, so the two volumes agreed within 3 percent of each other. It is also not credible that someone used a stopwatch and flow meter to duplicate a toilet flush using a bathtub faucet. The odds of someone being able to get precisely the same flow shape, volume, peak flow and duration by hand four times in succession, even if they are trying to do so, are incredibly small. The odds of this happening by chance are zero. Only a mechanical device operating at close tolerances could produce such consistent events.

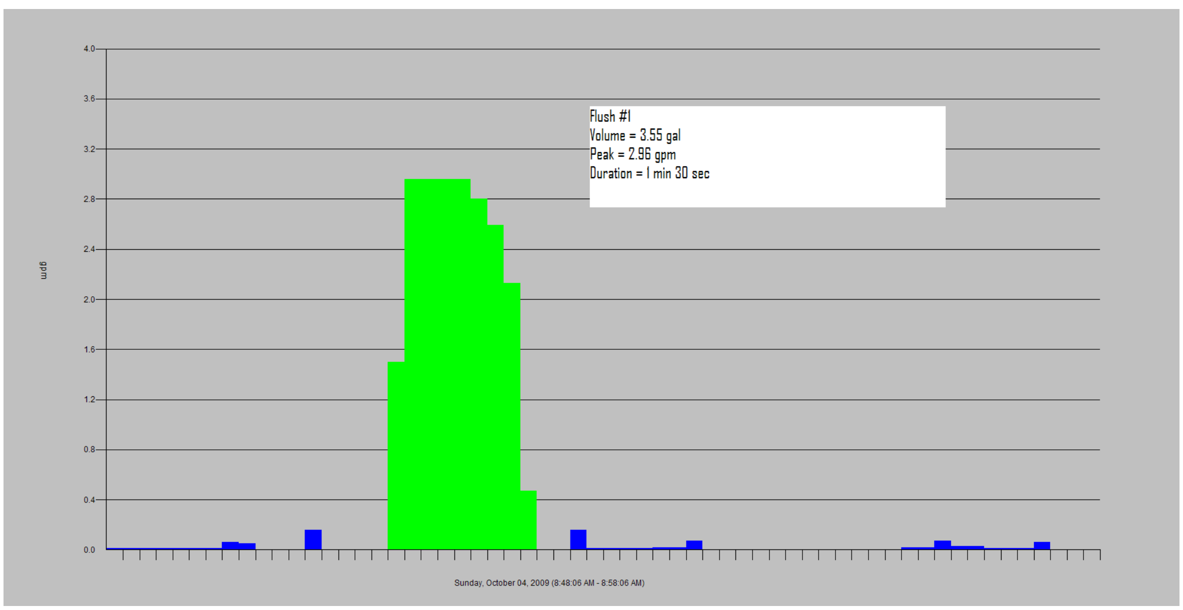

Figure 10: Flush Blow Up 1

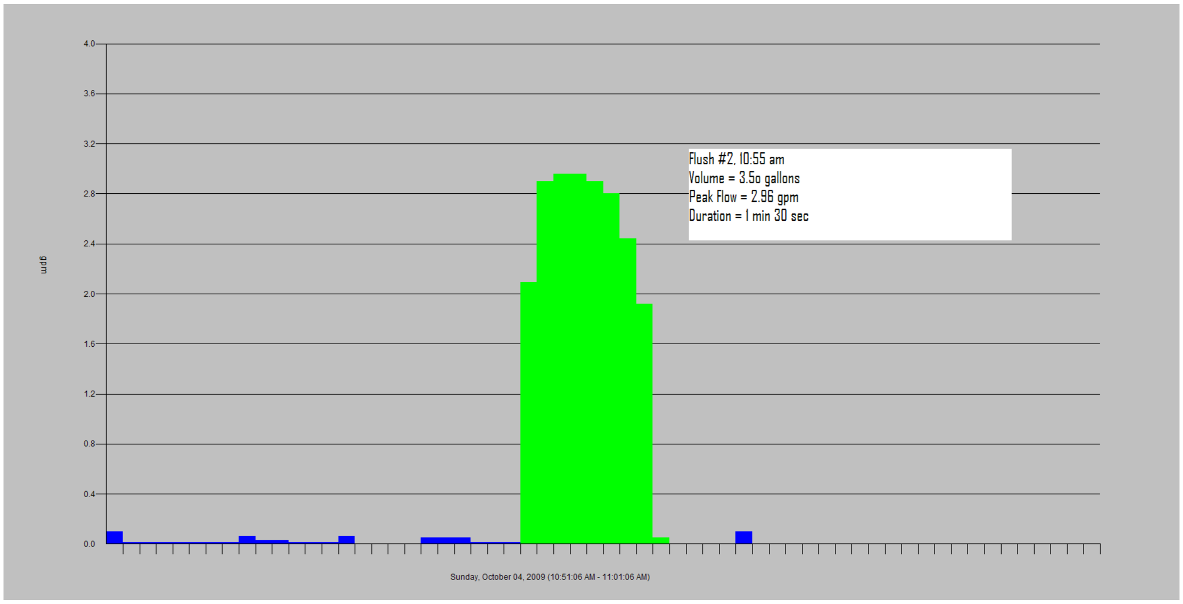

Figure 11: Flush Blow Up 2

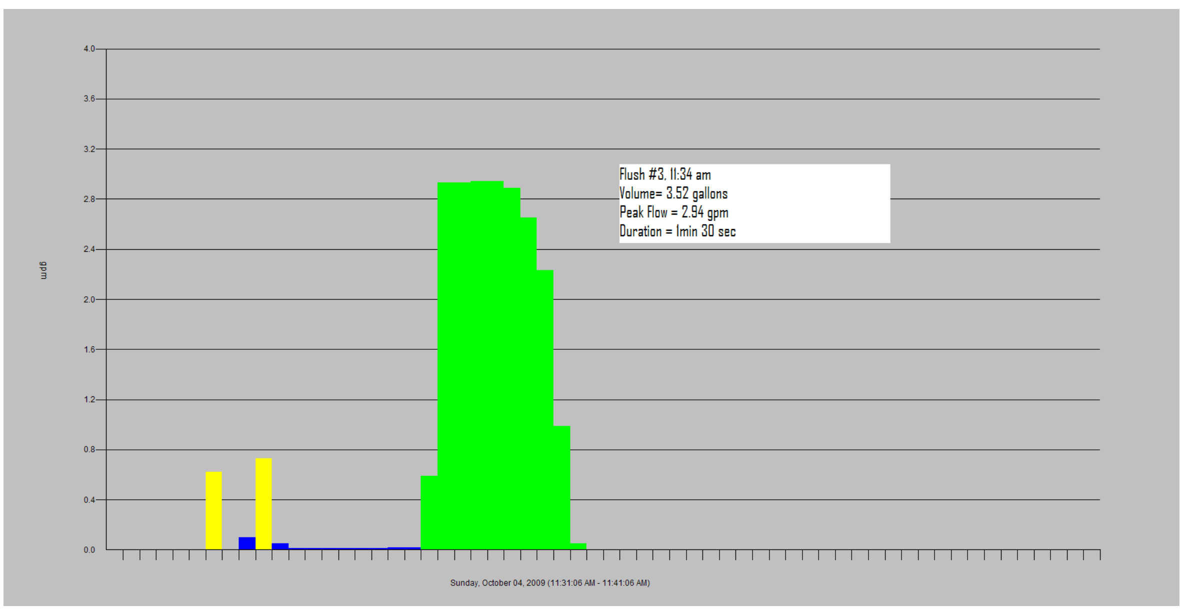

Figure 12: Flush Blow Up 3

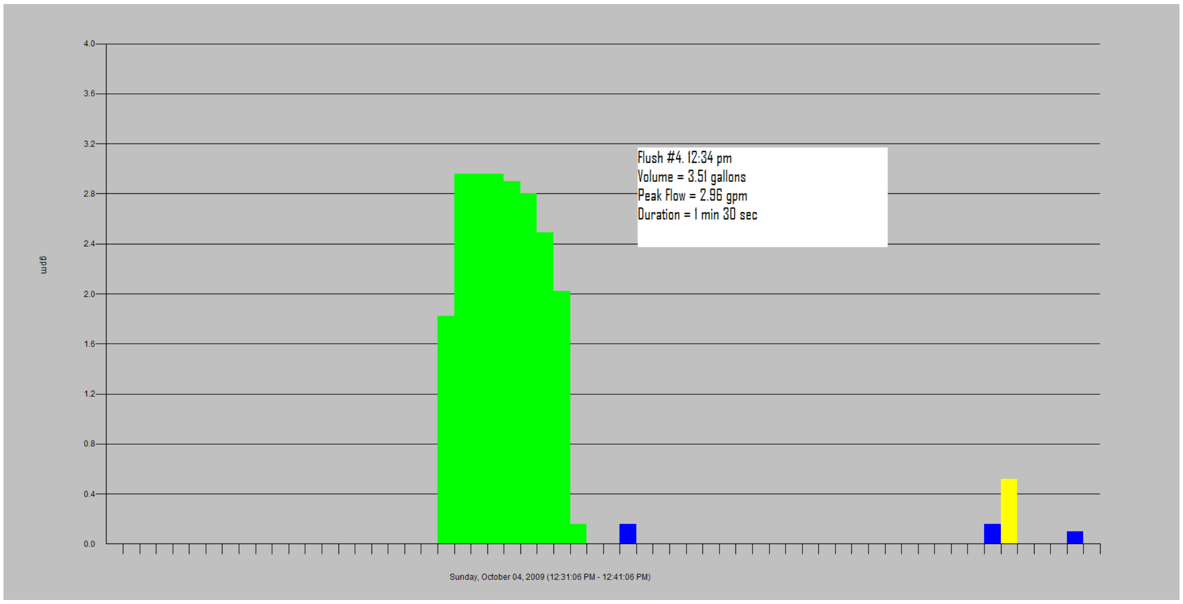

Figure 13: Flush Blow Up 4

It is also possible that the reduction in toilet use was due to a change in the number of times per day the toilets were flushed after the retrofit. The data, however, indicate that the pre retrofit flush rate was 13.42 flushes per day for the study group, and the post retrofit flush rate was 13.52 flushes per day, which is statistically identical. While there may have been variations among the units, overall the reduction in toilet use was not affected by a change in how frequently the residents flushed the toilets. This is also a good indication that the average number of residents remained constant between the two periods.[43]

[43] The property management company provided household occupancy data only one time prior to the installations.

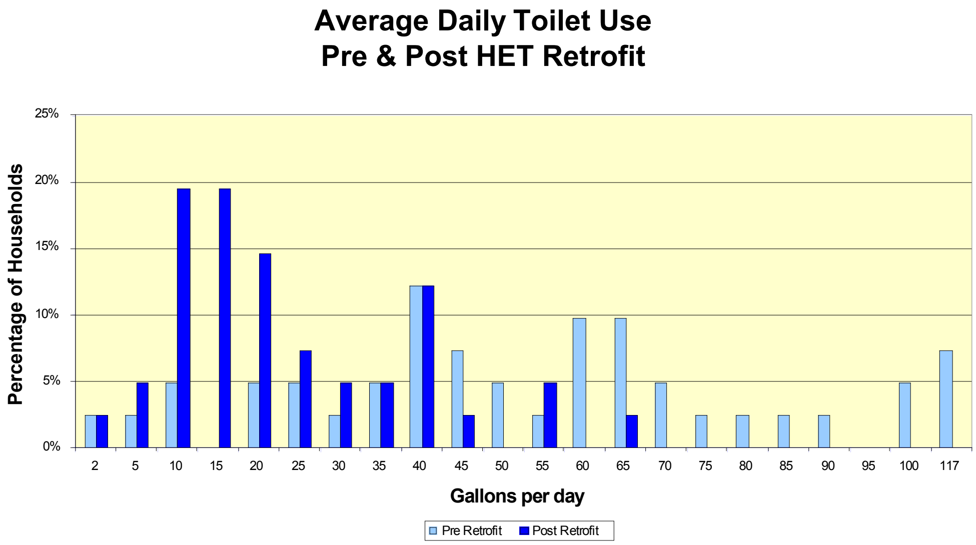

Figure 14 Average Daily Toilet Water Demands Pre/Post Retrofit

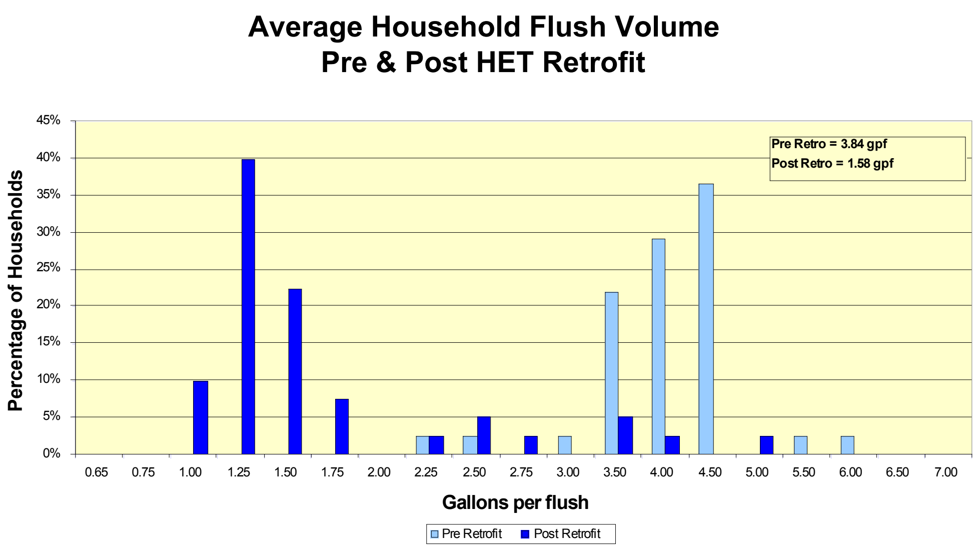

Figure 15 Average Pre/Post Flush Volume

The savings data can be expressed on the basis of average savings per occupant, or average savings per toilet replaced. The average number of toilets replaced per unit was 1.6 and the average number of persons per unit was 2.7. Table 27 shows the toilet use data on a gross level and normalized on the basis of per capita and per toilet replaced data.

Table 27: Average Toilet Use Data

PERIOD	PER HOUSEHOLD (GPD)	PER TOILET (GPD) (AVE = 1.6)	PER CAPITA (GPD) (AVE=2.7)
Pre-Retrofit	52.1	Na	19.3
Post-Retrofit	20.8	Na	7.7
Change	31.3	19.5	11.6

As mentioned above the post retrofit leakage increased by 10.5 gpd from the pre-retrofit level, and this increase caused the net savings in the program to drop by approximately 35 percent, from 31 gphd to 20 gphd. Given the fact that the only change that was made to the apartments in this study was that their toilets were replaced, it is difficult to avoid the conclusion that the increase in leakage is related to the toilet replacement. Consequently, it is important to understand the pattern of the post-retrofit leakage.

Table 28 summarizes the leakage data for the pre and post retrofit periods. It is noteworthy that while the average leakage rate increased, the median rate stayed constant. This indicates that whatever change in leakage occurred did so on a small number of homes. If the leakage rate had changed significantly on a larger number of homes the median value would have increased.

Table 28: Pre/Post Leakage Data

PERIOD	*AVERAGE LEAKAGE (GPD)*	*MEDIAN LEAKAGE (GPD)*
Pre-Retrofit	6.3	2.7
Post-Retrofit	16.8	2.7
Change	10.5	0

In Figure 16 the data show that after the retrofits only 10 percent of the units had leakage rates greater than 18 gpd, but in Figure 17 the data show that these homes contribute 75 percent of the total leakage volume. This information is important since it shows that the leakage is not a general problem with the toilet replacements, but that there is a potential for a small number of installations to generate a large amount of leakage, which if left unaddressed can neutralize a significant proportion of the expected savings from the retrofit program.

To further illustrate the disproportionate impact caused by the large leakers, when the leakage data for each of the 41 homes is examined it shows increases of more than 10 gpd occurred in 5 units, and decreases greater than 10 gpd occurred in 4 units. The other units showed small increases and decreases. Two of the units with increased leakage showed changes of 341 gpd and 91 gpd, respectively. If those two units were excluded, instead of an increase of 10.5 gpd in leakage the group would have had a net reduction in leakage of 0.2 gpd, which would have eliminated the impact of the leakage on the program.

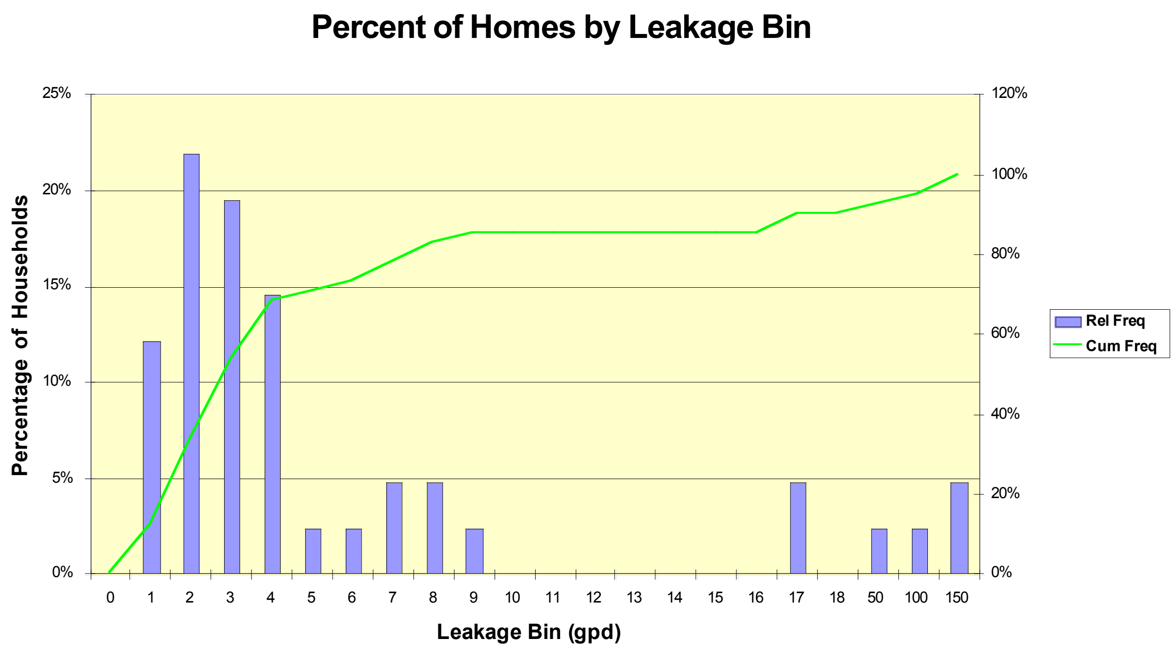

Figure 16: Percent of Customers Falling into Leakage Bins

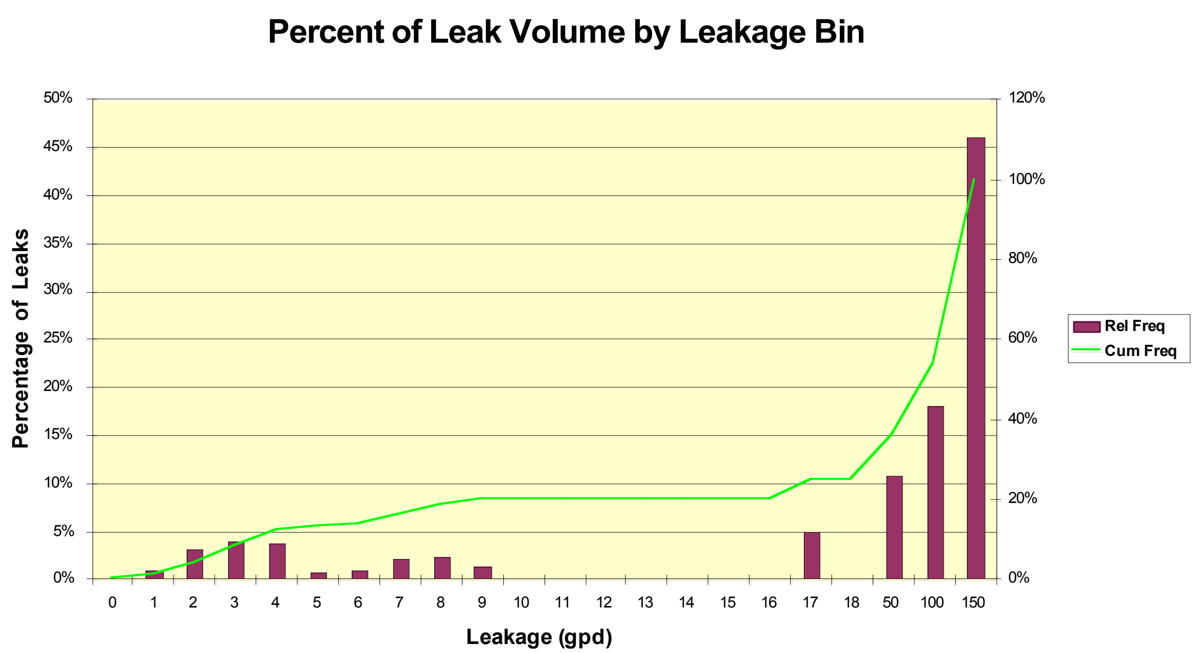

Figure 17: Percent of Leakage Volume Attributable to Leakage Bins

The data show that the average savings in household toilet use was 31.2 gphd. In order to determine whether better estimates of water savings can be derived by relating water savings to the number of toilets replaced or the number of persons per dwelling, statistical analyses were undertaken. Two linear regression models of changes in toilet water use versus both the number of toilets and the number of people were developed, and are shown in Figure 18 and Figure 19.[44] These models were marginally better predictors of savings than the average. A multiple regression using both parameters was also performed. The results for all three models are summarized in

Table 29. [45] For all three models, all of the sample apartment units were included and the regressions did not include the leakage volumes, which were tabulated as a separate water "use".

None of the three models is decisively better than use of the averages. They are all slightly better, and of the three, the best is the multiple regression—Model 3. This model predicts the change in toilet water use as a function of the average number of toilets replaced and the average number of residents in the homes. If one inserts the averages for the number of toilets replaced and residents per home from Table 24 the model predicts a savings of 31.56 gphd, compared to the observed change of 31.2 gphd.

[44] Future evaluations may also consider using non-parametric models to analyze the data, noting the skewed data distribution in Figure 14. That said, Ordinary Least Squares (OLS) regressions are in the class of "robust" estimators, which produce consistent estimated coefficients even when the regression errors appear to be other than perfectly normally distributed. OLS is a powerful statistical method because the basic assumptions underlying the technique--though rarely fully realized in practice--are extremely rigorous. Conversely, non-parametric regression is considered to have less power, thus more (often many more) observations are necessary to make statistical conclusions. With the small data set (n=41), we expect that little would have been learned if non-parametric regression had been employed.

[45] The R-squared value is the proportion of variability in a data set that is accounted for or "explained" by the statistical model; a value of 1.00 indicates that 100 percent of the data variability is explained by the model.

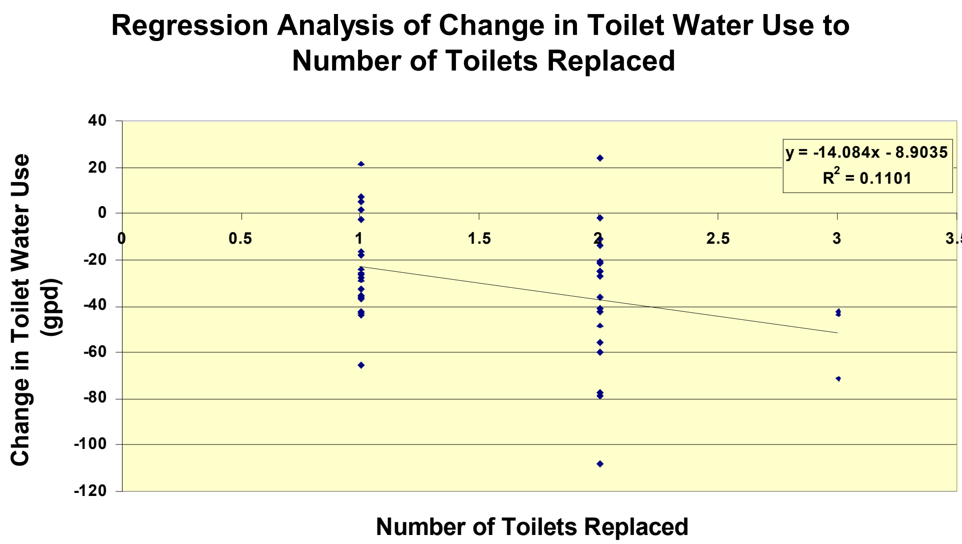

Figure 18: Regression Analysis of Change in Toilet Water Use Versus Reported Number of Toilets Replaced per Unit

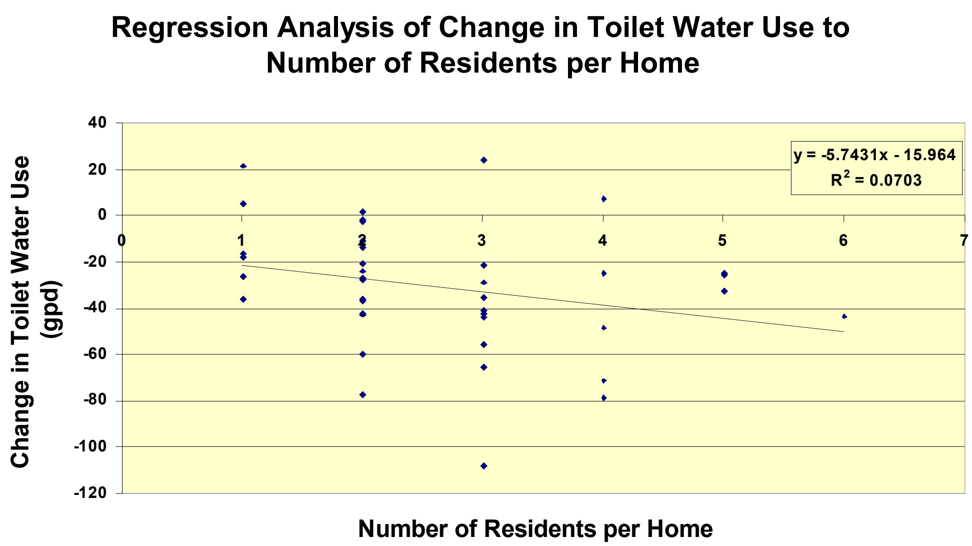

Figure 19 Regression Analysis of Change in Toilet Water Use Versus Reported Number of Persons per Unit

Table 29: Model Parameters

MODEL	DESCRIPTION	FORMULA	R^2
1	Change v toilets replaced	Y= -14.1T - 8.9	0.11
2	Change v no. residents	Y= -5.74R - 15.96	0.07
3	Change v toilets + residents	Y= -3.89 - 11.46T -3.46R	0.13

Annual Savings

A total of 176 apartment units were retrofit with HET toilets as part of this study. Using the data from the from the logging sample we can estimate the total annual water savings attributable to the toilet retrofits. If retrofits. If the assumption is made that the leaks in the units will be repaired and leakage will not be a not be a continuing factor in the water use, then the savings of 31.2 gallons per unit per day can be be extrapolated to 11,388 gallons per unit per year. The total water savings for the entire group of 176 units of 176 units would then amount to 2.0 million gallons per year. If participants are unable to identify or repair identify or repair leaks, then the total water savings for the entire group would be 1.32 million gallons per gallons per year, which represents the as-found conditions. In the absence of additional data we would would recommend using Model 3 from

Table 29 to extrapolate these results to other projects with different number of persons and toilets replaced. Additional data collection to potentially improve the model results is discussed subsequently.

Summary Discussion

There were four important findings in this evaluation:

1. There was a definite reduction in toilet water use associated with the retrofit, which can be described as a function of the number of persons per dwelling units and the number of toilets replaced from

2. Table 29. Total savings from the 176-unit project were found to be 1.32 million gallons per year, and would be 2.0 million gallons per year if large leaks were found and repaired, allowing for a few toilets that cannot be replaced or end up out of adjustment, as occurred in this study.

3. Leakage increased by a substantial amount in two of the units, which increased the average leakage for the group as a whole by 11 gphd.

4. A total of 18 of the study homes were fully retrofit with what appeared to be properly functioning dual flush HETs. These homes achieved an average flush volume of 1.09 gpf.

5. Thirteen of the 41 homes that were reported to be fully retrofit with HET devices in this study had average flush volumes of 1.83 gpf. This is significantly higher than the 1.09 gpf recorded in the 18 homes described in conclusion #3.

As shown in Table 30, the net effect of the toilet retrofit program was a reduction in indoor use in the residences that equaled the reduction in toilet use plus the increase in leakage. Of the three parameters shown in the table the toilet use was the one that was clearly significant from a statistical perspective. The other two categories had too much scatter in their data to prove statistically significant with this sample size.

Table 30: Summary of Changes in Household Water Use After Retrofit

HOUSEHOLD WATER USE CATEGORY	*AVERAGE CHANGE IN USE AFTER RETROFIT*
Total indoor use	-20.3 ± 29 gphd
Toilet flushing use	-31.3 ± 8 gphd
Leakage	11 ± 17 gphd
Toilet flushes per day	-0.08 ± 2.35 fphd

As discussed above, it is hard to avoid the conclusion that the increase in leakage was related to the toilet replacement, due to malfunctioning toilets or problems with the installation. While the measured increase in leakage is an important observation, it does not change the fact there was a clear reduction in toilet water use from the retrofits. The flow trace methodology used in this study accurately quantified the water savings associated with HET retrofits in multi-family homes by disaggregating individual water uses, including leaks.

The data from the individual homes shows that the increase in leakage was due to large increases in just four units. These types of leaks are large enough that they are likely to be found and repaired, so they are by nature transient. The research team does not believe that the fact that leaks developed during the retrofit should outweigh the savings from the toilet retrofits, but the leakage should not be ignored either. In essence, both the leakage and the toilet savings should be considered as inter-related. Any future program quality control should include consideration of how post retrofit leaks will be monitored and repaired in order to insure that the full savings from the retrofits are realized.

The second issue with the results was the residual high average flush volumes found in some homes. The possible explanations for the high flush volumes were discussed previously. From a programmatic perspective it is important to recognize the likelihood that less than 100 percent of the retrofits will be perfect and that there will be some malfunctioning or maladjusted units placed, or that there may be some units with toilets that cannot be replaced. The maximum achievable savings from HET retrofits—assuming that all the HET toilets in this program were properly adjusted and functioning at HET volumes—can be estimated. There were 18 homes that were fully retrofit with what appeared to be properly functioning HET toilets. These homes had an average flush volume of 1.09 gpf. If all of the homes had met this flush volume benchmark then the average water savings would have increased by 6.3 gphd to 37.5 gphd. Table 31 shows the values for the observed and maximum achievable savings from this program's replacement of pre-ULFT toilets with HET toilets.

Table 31 Toilet Water Savings with Original and Alternative gpf Data

	OBSERVED SAVINGS	*MAX ACHIEVABLE SAVINGS*
Water Savings per home per day (gal)	31.2	37.5

Based on the flow trace data collected during the HET evaluation and interpretation of the results under the alternative toilet gpf analysis, the evaluation team recommends that the estimated water savings from this HET replacement program be reported at 31.2 gallons per household per day actual savings, with two caveats: that the maximum achievable savings would be 37.5 gphd had 100 percent of the flushes been at the HET design volumes, and that provisions need to be taken to check for and repair any leaks that develop as a result of the retrofits.

In order to generalize the results of this study to other low-income populations the equation from Model 3 in Model 3 in

Table 29 can be used. Even though this model has a low regression coefficient, it is better than using simple averages, and it relates both key parameters of toilets replaced and population to the anticipated water savings. That said, future studies of HETs in multifamily housing units should attempt to validate this model or develop new and improved models.

6.3.2 Embedded Energy Impacts

Water production and energy data were provided by the water retailer (Irvine Ranch Water District) for both potable and wastewater systems. The energy intensities of potable water (4,196 kWh/MG of IOU energy and 6,851 kWh/MG of total energy) and wastewater (132 kWh/MG of IOU and total energy) were multiplied by the 1.32 MG of annual water savings for the HETs projects to arrive at the annual energy savings shown below in Table 32. Energy intensities were calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculations of energy intensities for each agency are shown in more detail in Appendix 1.2. The total energy savings attributable to the SCE HETs program are 5,712 kWh for IOU energy and 9,218 kWh for energy from all sources.

Table 32: Annual Embedded Energy Savings for SCE HETs Program

	IOU Energy (kWh/Year)	Total Energy (kWh/Year)
Energy Saved from Potable Water System	5,538	9,044
Energy Saved from Wastewater System	174	174
Total Energy Saved	5,712	9,218

6.4 Discussion of Uncertainty, Threats to Validity, Potential Free Ridership

Where HET retrofit projects are concerned, there is always the possibility that some fixtures might not function properly. If pre-post analyses were limited to water billing data, the results of retrofitting homes with HETs would contain an increased level of uncertainty. In this study where flow trace data were collected at each household water meter, it is possible to determine the volume of the flush, but it is not possible to say precisely what actual make and model of toilet was in use. For example, it is known from the flow trace data that there were a certain number of flushes at more than 2.0 gpf in the post retrofit data set. It is not known, however, if this is due to the HET toilets being out of adjustment when installed, tampered with by the residents, or perhaps for unknown reasons some of the toilets could not be replaced.

The most fundamental error associated with the flow trace technique is the meter error. The data loggers do nothing more than count magnetic pulses as the water meter turns and record the number of pulses counted over a specified time interval, which was 10 seconds in this case.

Normally, the small meters used for single residences provide 80 to 100 pulses for each gallon. That is equivalent to 1 to 2 ounces of water per pulse. A toilet that uses 1.6 gallons for a flush will generate between 100 and 160 pulses. Consequently, the data are very precise in terms of the volume recorded. However, if the water meter does not register flow, neither will the data logger. That is why it is important to have properly working water meters installed at the residence for which flow trace data are desired. Normally water meters work well, but when they don't it is apparent from the distortions in the trace. The installers try to run water through the meter when they install the logger in order to observe that the meter is registering flow.

Another potential error in logging is for the data logger to fail to provide an accurate count of the pulses from the meter. In that case the volume recorded by the logger will not agree with the volume shown on the meter register. Each trace is checked to verify that the volumes agree. In some cases it is appropriate to apply a scaling factor to bring them into agreement. Generally, when the logged volume and the register volume agree there is a high probability that the trace itself is accurate, since in this case for each error in one direction there would have to be another error in the opposite direction that precisely cancelled out the first error. This is highly unlikely.

Loggers sometimes pick up electrical interference, which causes spurious spikes in the data. This results in the logged volume being much greater than the register volume. In cases where these spurious signals are isolated they can be edited out of the trace and the rest of the data can be used. When they are generally scattered throughout the trace it is necessary to discard the file. Fortunately, this does not happen very often.

It is also possible for the flow trace analysis to misidentify water events as toilets that are actually something else in the home that has the appearance of a toilet flush. For example, toilet flushes are normally identified by their peak flow rates, which are usually 3-6 gpm, their flush volumes, which for HET models should be below 1.6 gallons, and their durations, which are around 30 seconds. Kitchen and bathroom sinks normally flow at less than the 3 gpm, but someone could open up a bathtub and run it for 30 seconds then immediately shut it off, and that would appear to be a toilet flush on the flow trace. The chances of someone doing this even once are small, but the chances of someone doing this multiple times in precisely the same patterns (as a toilet would do) are extremely low. So, misidentification of this type would be an occasional random error.

Another error that occurs in the analysis is in how toilet flushes get separated from faucet use. It is not uncommon for a faucet to be turned on before the toilet has finished filling. In these cases the analyst has to split the event into a toilet and faucet event. This results in variability in the toilet flush volumes in the tenths of gallons place, and these errors tend to be random in nature.

The issue of leakage is one that needs to be considered. In this pilot study a gross reduction in water use from toilet replacements of 31.2 gphd was observed. At the same time, however, there was an increase of 10.5 gphd due to leaks. This is an area that requires additional study and can only be resolved with a larger sample or by following up on the actual toilets installed and the actual leaks observed. The data do, however, show that leakage control must be considered as part of the program design.

Biases in the data were addressed as part of the sampling plan. The households sampled in this study are representative of the homes in the developments from which they were chosen. The one area where uncertainty remains is in how representative these results are for all low-income multi-family developments. Given the fact that this study measured a fairly predictable mechanical device found in all housing units, there is a good chance that the observed results are applicable to other similar projects where non-ULF toilets are replaced with HET devices. The data for the study project were compared to a larger sample of individually metered multi-family units from Irvine Ranch, and were found to be quite similar to this larger population in terms of household and per-capita use.

The evaluation findings suggest that the average savings value of 31.2 gphd can be used for planning purposes, if programs make a concerted effort to reduce leakage during the installation process. Ultimately, a larger sample of similar projects and/or more intensive site work would help add certainty to the program results by demonstrating their repeatability.

6.5 Discussion of Findings

Following are recommendations regarding how to improve future evaluations of HET retrofit programs:

1. Estimate program savings based on post-retrofit observations that reflect occupancy and behavior with the new equipment.

    a. An alternative analysis (details not shown) that considered only post-retrofit flushes per day and the average flush volume difference between the pre and post periods (at the household level) results in average water savings of 29.4 gphd. These savings are 6 percent lower than the 31.2 gphd that was found by focusing on changes in toilet water usage in the pre and post periods (as was set forth in the evaluation plan). While average flushing frequency remained roughly constant during the pre and post periods *for the sample group in aggregate*, changes at the household level yielded larger water usage changes.

2. On site verification of proper toilet installation should be conducted by the program.

    a. Accurate documentation of precisely what toilets were installed in each unit would eliminate guessing over whether units with residual high volume flushes had old high volume toilets, malfunctioning or missing new HETs, or if there was a problem with the flow trace data. Although not scoped in the evaluation plan for this program, SCE staff conducted on-site inspections of six units, three of which were showing unexpectedly high average flush volumes after the HET installations. These inspections revealed that two units had one less new HET than expected, while one high-volume unit had an additional undocumented new HET. The inspections also revealed that most of the non-program toilets were 1.6 gpf single-flush models, while one was estimated to be 2.5 gpf. No significant HET performance issues were identified, although the solids flush button on one HET gets stuck sometimes.

b. After on-site verification is conducted, program water savings estimates could be refined by considering only fully retrofit units and applying per-toilet savings to partially retrofit units (assuming that the toilets are used equally, and not skewed to a preferred toilet in the partially retrofit homes).

c. In-home inspections and verifications need to be done with care in order to avoid influencing the results of the study. If residents are made aware that their behavior is being monitored (for example by installing individual water meters on their toilets) this could cause them to change behavior. Also, if verification is done prior to the post-retrofit data collection in a way that leads to repairs and adjustments it will not be an objective measurement of the program, but will be part of the program. The best time to do in-home verifications is after the post retrofit data are collected.

d. In-home verifications would help to explain the flow trace data, which is a good reason to do them in future studies.

3. Verification of the number of residents in the units should be obtained as part of the evaluation process.

    a. In this study population data were obtained from the management company as reported by the occupants of the units. The goal of the study was to complete the pre-post analysis in a short enough time that the assumption could be made that the population averaged the same during the pre-post periods. Modeled relationships between persons per household and household water savings, however, proved to be inconclusive. This was attributed to a reluctance of the residents to reveal the real number of persons living in the homes, and a high degree of variability from day to day. Nonetheless, having better population information could reveal stronger statistical relationships and such data would generally be useful. These data could be collected by mail, telephone or in-person interviews.

4. In several cases the average flush volumes in units that had been fully retrofit with HET toilets were measured at more than the rated high flush volume for the toilet, and the observed variation was greater than expected. These findings show that evaluations of HETs cannot rely exclusively on the manufacturers' ratings or else program water savings are likely to be overestimated. Following are some recommendations for improving the accuracy of measured flush volumes.

    a. The flow traces showed the volumes of the toilet flushes and are based on the water meter accuracy. It is rare for water meters to over-register flow; if anything, they under-register when they start to fail. Having toilets installed that are flushing at too high a volume is not unusual; in fact it is common. It is often impossible to determine the exact flush volume of a toilet by looking at it. The best way to determine the volume is to use the water meter to measure an isolated flush volume. This is what the flow traces provide. A properly functioning water meter will provide this information at accuracies of a few percent.

b. The best way to maximize the accuracy of the data is to have the water utility replace old questionable meters in the study group with new meters. The register readings show how much water has passed through the meters, and meters with high volumes can easily and inexpensively be replaced prior to the evaluation study (i.e., before the pre retrofit data are collected.)

c. If it is possible to inspect all toilets (within available budgets) then this information would help clarify the reasons for volume discrepancies. Another option would be to inspect just the units in which suspect flush volumes exist. While this verification is not necessary in order to quantify the water savings, it can be very helpful for understanding the factors that impact the results. For example, knowing the precise details on all of the toilet retrofits would not have changed the results of this evaluation, but it would have at least partially cleared up the source of some of the flush volume anomalies. It is also possible that on-site verification might show that there was a scaling or meter problem in the trace data.

d. In order to provide additional verification of the flow trace technique, assessments like the NREL study cited in the text should be conducted, in which accurate sub-meters are installed on the toilets of a group of test homes and the results of the sub-meters are compared to the results of the data loggers. These would not be part of the evaluation program since intrusive devices such as sub-meters and event counters could potentially affect the behavior of the residents.

e. A rigorous study of HET performance was not in the scope of the work of this project. There are organizations and independent testing labs that specialize in certifying toilet flush characteristics as part of the WaterSense certification program. However, this simply demonstrates that the toilet is capable of flushing at its design volumes, and actual flush volumes will still depend on installation-specific conditions. The flow trace data show the way the toilets operate in real world settings.

5. Regarding the accuracy of the flow trace analysis, its error band, and whether it should be used in the future for these kinds of evaluations:

    a. Flow trace analysis has been shown to work very well for small water meters serving from 1 to 8 residences. The thing that makes the system work well for these customers is that the water meters provide high resolution output in the form of magnetic pulses per gallon that can be recorded by a specialize data logger.

    b. Flow trace analysis is subject to errors, but these are random in nature. The fact that the technique is able to detect small changes in uses like toilets switching from ULFT (1.6 gpf) to HET (1.6/0.8 gpf), and to determine means with small deviations is evidence that errors are not overly broad.

    c. Flow trace analysis offers the significant advantage of not having to enter the customer home. This reduces the chances of influencing behavior and allows for a more truly random sample since customer agreements are not needed to obtain data from the utility water meter.

d. Flow trace analysis monitors all water use in the residence to a degree that would be impossible with a system of sub-meters. Consequently, it was possible to determine that there was a change occurring in both toilet use and leakage in this study group.

e. The best way to validate the flow trace analysis technique follow the system used in the Yarrow Valley and NREL studies cited in this report. Both of these studies found good correspondence between flow trace analysis and hard-wired end-use monitoring.

f. Larger samples would also help reduce the deviation in the data. In this study the target sample was 50 homes, but only 41 ended up in the group, primarily because several of the homes were already equipped with 1.6 gpf or better toilets, which were not program candidates.

7 SCE Express Water Efficiency Pilot Program

The Southern California Edison Company (SCE) in conjunction with the Metropolitan Water District of Southern California (MWD) established the Express Water Efficiency program to encourage the installation of two promising water conservation technologies by its customers. The first of these was the installation of weather based irrigation controllers (WBICs). The second was the installation of pH controllers on cooling towers and evaporative condensers. Both of these technologies have been shown to be effective water conservation measures when installed under the right circumstances. This report describes results of efforts at conducting pilot studies of each of the programs during 2009.

7.1 Program Description

The concept of the WBICs element of the program was to achieve water savings from irrigation systems by switching from manual irrigation controllers to weather based controllers. Since many irrigation controllers are known to over-irrigate their landscapes due to how they are programmed, switching to a controller that automatically adjusted the application should save water.

Aquacraft's proposal for this evaluation was premised on the inclusion of over 1,000 WBIC installations in Southern California, data for which were collected as part of the Statewide Analysis of Weather Based Irrigation Controllers. These data were prepared and an evaluation was made of the performance of the controllers, which was submitted to the project team for its consideration. These data, however, included no sites that participated in the program as a direct result of the actions of the Southern California Edison Express Water Efficiency Program.

As it turned out, the Express Program did not recruit any customers who were willing or able to act as pilot test sites for the WBIC systems. Consequently, we have not included any results for WBICs in this report, although the results from the Statewide Study are available for interested readers.

The pH controller program element aimed to install pH controllers onto cooling towers in order to reduce their water use. Through the program, MWD offered rebates to facilities using cooling towers to retrofit with pH controllers. At this program's only participant site three cooling towers were retrofit and the change in water usage was measured.

A pH controller is a programmable device that monitors the pH of the water circulating in the cooling tower and adds a mixture of dilute acids and other treatment chemicals in order to maintain a pH in the circulating water below 8.3. This prevents the formation of calcium carbonate scale in the system. By adjusting the chemistry of the system to greatly reduce the risk of scale formation it is possible to operate the tower at much higher levels of concentration, which in turn reduces the amount of water that is necessary to bleed from the tower. The reduction of bleed water represents a major water conservation opportunity, which was a primary goal of the Express Water Efficiency program.[46]

This evaluation documents the observed changes in water use in three cooling towers located in Southern California Edison service area territory. All three towers are on the same industrial site and are used to cool refrigeration equipment. The towers were equipped with pH controllers during the month of September 2009.

7.2 Methods

The evaluation team monitored the water use and chemistry of the three cooling towers for approximately 30 days before and after the retrofit so that the changes in water use could be measured, and the impact of the pH controllers evaluated. The pre retrofit data were collected between August 7th and September 5th, 2009, and the final data set was collected between October 15 and November 13, 2009. This report chapter is based on water use data collected during these two periods.

7.2.1 Parameters Used for Evaluation

Bleed Water Use

The fundamental unit of evaluation for this study was the change in bleed water use in gallons per day per ton (GPDT) of cooling load on the system. This approach corrects for the natural and unavoidable changes in heat loading to the system between the pre and post retrofit periods. It also allows the evaluation to project potential water savings from these devices based on a standard and easy to apply unit of loading, such as gallons saved per 100 Tons of cooling load.

Make-up Water (M)

Inflow water, normally from treated municipal supplies, makes up water lost to bleed and evaporation in cooling towers. As part of the evaluation program, each of the three cooling towers in this study was equipped with a pulse generating water meter that provided 1 pulse per 100 gallons of water. None was so equipped prior to the study. The meters were placed on the inflow water lines to the towers so that they recorded all make-up water used to maintain the required water levels in the systems. Portable data loggers were attached to the water meters in order to log the date and time at which each 100 gallon pulse occurred. This provided flow-profile data, which for this report were summarized into gallons per day of make-up water.

Concentration Ratio (CR)

The concentration ratio is the ratio of the salinity in the circulating water to that in the make-up water. It is normally measured using the conductivity, in micro seimens (µS), or the concentration of chloride ions in parts per million (ppm). Without going into a detailed

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[46] Operating the cooling tower with less scale also improves its thermal performance, which reduces the energy consumption of the entire mechanical system to which the tower is attached. These energy savings, while important, were not the focus of this study.

discussion of the workings of cooling towers, knowing the concentration ratio and the gallons of inflow water for a given day allows one to calculate the bleed use and evaporation of the tower for that day based on two standard equations: B=M/CR and E=M-B, which are discussed below.[47] Knowing these parameters allows the daily heat load to be calculated, which provided the information needed for the evaluation.

Calculated Parameters

By knowing the concentration ratio and gallons of inflow water three key parameters can be calculated: the bleed water, the evaporation and the heat load.

- **Bleed Water (B).** Bleed water equals the make-up water divided by the concentration ratio, or B = M/CR. Bleed can alternately be expressed in term of evaporation as B=E/(CR-1).

- **Evaporation Water (E).** The volume of water evaporated from the system equals the make-up water minus the bleed, or E=M-B.

- **Heat Load (H).** Based on the physical properties of water, and after making allowances for heat transfer, every ton of cooling requires approximately 40 gallons of water evaporated per day (ETB, 2009).[48] Therefore, by applying this factor one can obtain a good estimate of the actual heat load for the system in tons.

By knowing the volume of bleed water, and the actual heat load to the system, the normalized bleed water use in gallons per day per ton of heat load can be estimated. These values can be used to compare the operations of cooling systems during periods of varying loads without other data requirements. This was the fundamental evaluation strategy used for this analysis. Since the heat loadings and operations of all cooling towers are constantly changing in response to varying demands this approach was determined to be the most practical and reliable.

7.2.2 Metering and Data Logging

An initial visit was made to the site on August 6, 2009. At that time the water meters were read and data loggers were installed on the meters. Figure 20 shows a typical installation. The data logger is in the plastic case suspended under the meter by a Velcro strap. The water meter provided a pulse to the logger every 100 gallons of flow. The logger recorded the date and time of each pulse for later analysis. The cooling tower is shown in the background. Loggers were

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[47] For a more detailed discussion of tower operations, see: *Aquacraft. (2003). "Demonstration of Water Conservation Opportunities in Urban Supermarkets." California Department of Water Resources/U.S. Bureau of Reclamation, CalFed Bay-Delta Program, Boulder. See discussion on potential water savings in cooling towers.*

[48] 1 Ton cooling tower capacity => 15,000 Btu/hour/Ton = 360,000 Btu/day/Ton.

Therefore,

(360,000 Btu/day/Ton) * (1gallon evaporated/8,092.3 Btu) * (90% heat exchange by evaporation) = 40 gallons evaporated/day/Ton of cooling tower capacity also installed on the circulating pumps, but the data obtained from these were not used for the analysis since the water use data proved sufficient.

During the initial visit it was discovered that the existing bleed controllers on two of the tanks were not functioning. These were conductivity controllers, which were out of service due to malfunctions. Consequently, the two systems were being bled manually, which means that a valve on the bleed tanks was partially opened to permit a steady stream of water to bleed from the systems on a continuous basis. As discussed below, this created a challenge for the evaluation since a manual bleed was not typical of this site prior to the retrofit with pH controllers. Mathematical adjustments were made to the water use to correct for the unanticipated a-priori conditions.

Figure 20: Photo of Water Meter and Data Logger (in case) on Water Supply Line

The conductivity, pH and chloride concentration of the inflow water and circulating water in each tower was measured. Conductivity and pH were measured using a Myron-L portable meter that had been calibrated against pH and conductivity standard solutions immediately prior to the measurements. In addition, the readings were compared to those obtained by the water treatment contractor at the study site. Chloride concentrations were measured using a silver nitrate titration kit supplied by Taylor Chemical Co. These readings were recorded on a data collection sheet, shown in Appendix 6.2. Fields containing information that would identify the study site have been blanked out.

Three conductivity readings were recorded on the inflow and circulating water and the results were averaged. A single chloride test was done on each water source for comparison purposes. The concentration ratios were calculated based on both conductivity and chlorides. The conductivity ratio used for the analysis was the average of these two.

As mentioned above, during the pre retrofit period the concentration ratios of two of the towers was very low (less than 2.0 cycles). This was due to the fact the conductivity controllers that had been used to manage bleed were not working and the systems were operating manually. Manual bleed is not common, and was not the norm for this site prior to the pH controller retrofit, but since some systems are manually operated it was felt that the evaluation should proceed with note made of the situation.

Likewise, during the post-retrofit period the conductivity reading displayed on the pH controllers was significantly higher than the measurements obtained on site using the calibrated test equipment. This suggests that the controllers may have been out of calibration and giving erroneously high conductivity readings. This would explain why the cycles of concentration for the systems were lower than the target level of 6.0. Rather than delay the evaluation while these problems were corrected it was decided to proceed with the study and to correct the results mathematically.

Water use analyses were completed for each tower for the pre and post retrofit conditions. These analyses are shown in Appendix 6.3. The daily water use data are in columns 3 and 10 and the average concentration ratios obtained during the site visits at the beginning and end of the logging period are in columns 4 and 11. These data were used to calculate the daily bleed and evaporation water use and the daily heat loadings. The water use analysis tables calculate the average bleed water use in gallons per day per ton of actual heat load (GPDT). The difference in this value between the pre and post retrofit periods constituted the change in water use that can be associated with the installation of the pH controllers as corrected for changes in the operation of the systems.

7.3 Findings

7.3.1 As Found Water Impacts

The total water use for the three towers before and after the retrofit is compared in Table 33. A comparison of the other water and heat parameters of the towers is shown in Table 34. The data on the left side of Table 34 provide a summary the as-found pre and post make-up water use, the concentration ratios, the bleed use, heat loads and the bleed per ton of heat load for the three towers as observed in the field. This table shows that the simple average of the change in bleed water use per ton of cooling was a reduction of 58 GPDT. For reasons discussed previously and further explained below, however, this is certainly an over-estimate of the savings potential.

The data reveal several anomalies. First there was a drastic reduction in the overall water use for all three towers between the pre and post periods. The average daily use dropped by 78 percent, or 5,698 gpd per tower. This is misleading, however, since there was also a similar reduction in the actual heat loading to the systems, which dropped by 55 percent, or 36 tons per tower. There were many days during the post-retrofit periods when the systems were shut down. This reduction in water use and heat load explains a significant portion of the water use reduction, but not all of it because the water use dropped by a larger percentage than did the heat load. Therefore, even after taking the reduction in use into account there was a reduction in bleed use attributable to the pH control retrofit.

The concentration ratios of the systems all increased from the pre to post retrofit period. They averaged 1.86 prior to the installation of the controllers and 3.86 after the installation. The increase in concentration ratios shows that a reduction in bleed was occurring that was linked to the change in operation of the system rather than due to the decrease in use.

The goal of the operational change was to achieve concentration ratios of at least 6.0 cycles after starting from approximately 3 cycles. The actual post-retrofit concentration ratios, however, averaged only 3.86. As discussed above, a possible explanation for this is that the conductivity readings shown on the controllers, which were recorded on two of the towers during the equipment retrieval, were higher than the readings obtained from the calibrated test meters. This was true of both the meters Aquacraft used and the data reported by the water treatment contractor. The average manually measured conductivity of tower 1 was 3,785 µS while the readout on the controller was 4,600 µS. The conductivity of the inflow water was 838 µS. This means that the concentration ratio calculated from the manual meters was 4.5, while the concentration ratio being used by the controller (based on its internal conductivity meter) was 5.5. The same thing occurred on the second tower, which had a manually measured conductivity reading of 3,488 µS, versus a controller read conductivity of 4,450 µS. This resulted in concentration ratios of 4.16 versus 5.31 for the manual versus controller readings respectively.

The third controller was not equipped with a visual display of conductivity, so it was impossible to obtain a reading on the conductivity being recorded by the controller, but it is assumed that this controller, which had the lowest post retrofit concentration ratio of the three (2.5), was also reading high. If the conductivity probes in the pH controllers were giving false high readings, this would explain why the actual concentration ratios in the systems were less than intended.

It is also important to note that the concentration ratios of towers 1 and 2 were unusually low during the pre retrofit period, averaging 1.41. Field technicians know from examination of these controllers and were told by the water treatment contractor during the first visit that the conductivity control systems on these towers were not functioning properly during this period, and that they were being bled manually. In other words, a valve was simply opened allowing a stream of water to bleed continuously. Such a low concentration ratio is not representative of the typical operation of these types of systems, and needs to be taken into consideration when the results are evaluated, especially because the relationship between bleed water and concentration ratio is governed by the relationship B=E/(CR-1), so as the concentration ratio approaches 1 the bleed rises asymptotically towards infinity. This can greatly distort the water savings calculations.

The fact that the concentration ratios of the three towers were still well below the target level of 6.0 for this type of operation during the post retrofit period would reduce the savings over the potential if they had been brought up to 6 cycles, which was the intent. The low cycles in the post retrofit period were confirmed both by field technician readings and those taken by the water treatment company independently on November 5, 2009, shown in the row labeled "Apollo Post." Consequently, one must conclude that these three controllers were still out of calibration, and had not reached a stable operation during the test period. This leads to the need for the use of some judgment in interpreting the results.

When the bleed, measured in gallons per day per ton of heat loading (GPDT) is examined, it shows that there was an uncorrected reduction of 58 gallons per day per ton of heat load for the towers. Towers 1 and 2 had a reduction of 89 and 82 GPDT. The reduction in tower 3 was only 4 GPDT. The value of 58 GPDT represents the as-found savings for these three pH controllers, and would equal approximately 6.35 million gallons per year for 3 100-ton cooling towers. If one wishes to know the more probable impact of these systems on other cooling towers, however, adjusted values should be used. Using the relationships discussed previously, one can discount the high reductions in towers 1 and 2 due to the manual bleed during the pre retrofit period. Likewise, it was possible to adjust the low reductions in water use in tower 3 due to the low concentration ratio it achieved during the post retrofit period. The results of the normalization process are discussed next.

Table 33:Total Make-up Water Use Comparison

Average Make Up (GPD)	*EC1*	*EC2*	*EC3*	*Average*
Pre	10,853	6,607	4,373	7,278
Post	1,503	1,272	1,966	1,580

Table 34: Water Savings Normalized to Constant Beginning and Ending Concentration Ratios

	As Observed					*Normalized to CR: 2.25→6.0*				
Tower EC1	Evaporation (gpd)	CR	Bleed (gpd)	Heat (Ton/day)	Unit Bleed (GPDT)	Evaporation (gpd)	CR	Bleed (gpd)	Heat (Ton/day)	Unit Bleed (GPDT)
Pre	3,073	1.40	7,683	77	100.0	3073	2.25	2,458	77	32.0
Post	1,156	4.35	345	29	11.9	1156	6.00	231	29	8.0
Change					-88.1					-24.0
Tower EC2										
Pre	1,954	1.42	4,653	49	95.2	1954	2.25	1,563	49	32.0
Post	961	4.09	311	24	13.0	961	6.00	192	24	8.0
Change					-82.3					-24.0
Tower EC3										
Pre	2,789	2.76	1,585	70	22.7	2789	2.25	2,231	70	32.0
Post	1,340	3.14	626	34	18.7	1340	6.00	268	34	8.0
Change					-4.0					-24.0
Average Change in Unit Bleed					**-58.1**					**-24.0**

7.3.2 Theoretical Water Impacts

In order to create a standardized savings estimate based on uniform changes in concentration ratios, a theoretical analysis was done assuming that the typical pH controller installation will be on a system starting with a CR of 2.25 and ending in a CR of 6.0. The same heat loadings as observed in these towers were assumed to occur in the normalized case and then the bleed use was recalculated using the alternate values of CR and the formula B=E/(CR-1). The results of this analysis are shown in the right side of Table 34, which shows a much more modest and realistic savings of 24 GPDT.

Although none of the towers had achieved stable operations of 6.0 cycles of concentration for the post retrofit period, the data clearly show that there was a reduction in bleed water use associated with the change from standard control to pH control. The exact quantity of the predicted reduction is a function of what one considers to be the typical starting and ending concentration ratios when control is changed from standard to pH control water treatment. The average uncorrected reduction in bleed use for the three towers in this study was approximately 58 GPDT, which was distorted by the very low initial concentration ratios of towers 1 and 2. Therefore, 58 GPDT is not a good estimate of savings to be expected from use of pH control technology at this program's study site.

A more reasonable and reliable estimate of the water savings potential is obtained by normalizing the change in water use to uniform initial and final concentration ratios that one would typically expect to find in well operated standard control and pH controlled cooling towers. Because the volume of bleed is inversely proportional to the value CR-1, as the CR increases the change in the bleed decreases from very large values where CR is approximately 1.0 and becoming relatively small as CR increases over values near 6. Due to diminishing returns it is not worth pushing CR values over 6.0, so this was considered the typical target for pH control systems.

Figure 21 shows that if a pH controller was installed that achieved a final CR of 6.0, then the estimated water savings will depend on the initial CR. If the initial CR was 2.0, then the savings in bleed water would equal 32 GPDT. Moreover, these savings would decrease in a non-linear function such that at an initial CR of 3.5 the expected savings would be just 8 GPDT. The precise values of the projected savings are shown in Table 35.

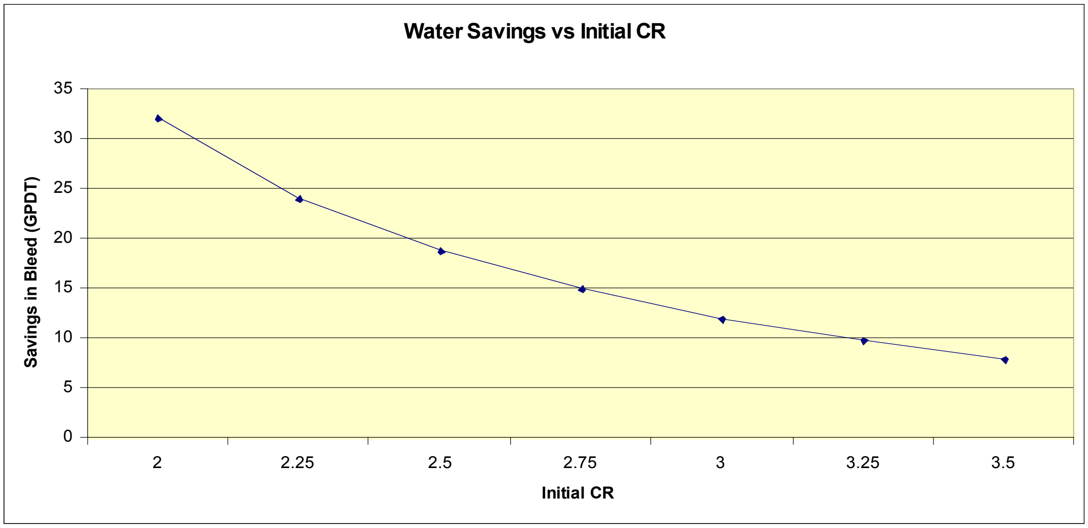

Figure 21: Relationship Between Water Savings (GPDT) and Initial CR for a Final CR of 6.0

Table 35: Water Savings vs Initial CR Values.

INITIAL CONCENTRATION RATIO (CR)	SAVINGS WITH FINAL CR = 6.0
2	32
2.25	24
2.5	18.7
2.75	14.9
3	12
3.25	9.8
3.5	8

The average initial CR's of the three towers in this study was 1.86. This CR is not typical of most well managed standard systems, and it is known that the conductivity controllers on two of the towers were malfunctioning during the pre-retrofit portion of the study, which resulted in very low CR values of ~1.4 due to the manual bleed. Many manufacturers recommend a CR of 3.0 for standard operations, and tower 3, which had a functioning conductivity controller, had an initial CR of 2.8.

Rather than use the raw data from the sites, which projects savings of approximately 60 GPDT, the following approach is recommended.

First, it must be assumed that given proper calibration it would be possible for the controllers to achieve stable and scale-free operations at a concentration ratio of 6.0. This is a reasonable assumption given the high solubility of calcium carbonate at pH values less than 8.3 and the fact that the controllers were able to maintain pH levels below this level. Second, it is not unreasonable to assume that the starting concentration ratios of well-operated standard controllers will be somewhere between 2.5 and 3.0 since operating in these ranges is typical for standard system operations, and is normally recommended by the manufacturers. If one accepts these assumptions, then the water savings estimate would range from 12 to 19 GPDT. A 100 T cooling tower operated consistently over a year would show water savings ranging from 0.44 million gallons to 0.68 million gallons of water per year.

Based on the data collected during the study and the evaluation and interpretation of the results, Aquacraft recommends using a water savings estimate mid way in the savings range (0.44 to 0.68 MG per year for a 100 ton system) for estimating savings from a well run pH control system conversion. This would result in a savings estimate of 0.56 MG per year for a 100 ton cooling tower. This estimate compares very well with the savings calculated for six similar cooling towers studied in Southern California by Aquacraft Inc. in 2003. The reductions in water use in these towers were evaluated when the tower operations were changed from standard control (with CR between 2-3) to pH control (with CR between 5-7). The measured saving for these systems was 0.63 MG/year for a 100 ton system.[49]

Summary of Theoretical Water Impacts

Based on data collected for two 30-day periods prior to and after three cooling towers were retrofit, and considering that the systems appear to not be totally calibrated during the post retrofit data collection period, we estimate that a reduction in bleed water ranging from 12 to 19 gallons per day per ton (GPDT) of heat load per tower can be ascribed to the installation of the pH control systems. This estimate is based on the performance one would expect from a cooling system similar to those included in this study, and moving from an initial concentration ratio of between 2.25 and 3.0 to a final concentration ratio of 6.0. The exact water savings will depend on the initial concentration ratio (CR) of the system being retrofit. The higher the initial CR the lower the expected savings will be. At a rate midway between the suggested range (15.5 GPDT), a 100 ton tower operated consistently over a year will save approximately 0.56 million gallons of treated water per year. This would also achieve a similar savings in wastewater, since the bleed water from these systems normally is discharged to the sanitary sewers.

The combined, theoretical annual savings ascribed to the three cooling towers at this project site are 1.68 MG, which is equal to the normalized savings of 0.56 MG/100 Tons x 3.

7.3.3 Embedded Energy Impacts

Water production and energy data were not provided by the water retailer (California Water Service Company, Dominguez Hills), but operations staff confirmed that water to the project site is imported water from Metropolitan Water District (the retailer also provides groundwater to

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[49] Aquacraft. (2003). "Demonstration of Water Conservation Opportunities in Urban Supermarkets." California Department of Water Resources/U.S. Bureau of Reclamation, CalFed Bay-Delta Program, Boulder. See summary of water savings.

customers from local wells). Energy intensities were calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculations of energy intensities for each agency are shown in more detail in Appendix 1.2. The energy intensity of the water provided by MWD (7,589 kWh/MG) was multiplied by the as-found 6.35 MG of annual water savings for this project to arrive at the total energy savings of 48,184 kWh shown in Table 36 below. (These energy savings should not be expected for other similar projects, due to the operational problems noted in this report chapter.) Wholesale water from MWD does not use any IOU energy in its distribution, so IOU energy saved for the potable water system is equal to 0 kWh.

Table 36 also shows the wastewater energy savings for this project. The wastewater agency is Los Angeles County Sanitation District (LACSD), which has an IOU energy intensity of 1,478 kWh/MG and a total energy intensity of 3,413 kWh/MG. Applied to the 6.35 MG of as-found water savings, the energy savings are 9,385 kWh for IOU energy and 21,673 kWh for energy from all sources.

Table 36: Annual Wholesale and Wastewater Embedded Energy Savings for SCE Express Water Efficiency Program

	IOU ENERGY (KWH/YEAR)	TOTAL ENERGY (KWH/YEAR)
Energy Saved from Potable Water System	0	48,184
Energy Saved from Wastewater System	9,385	21,673
Total Energy Saved	9,385	69,857

7.4 Discussion of Uncertainty, Threats to Validity, Potential Biases

Clearly, the two most significant threats to the validity of this study are the small sample size and the fact that there were operational issues occurring with the systems both before and after the pH controllers were installed. However, the evaluation team does not feel that either factor represents a fatal flaw. Even though the sample is small, it demonstrates well-understood physical principles and is confirmed by data from similar studies conducted in the region. The operational problems with the systems were easily accounted for mathematically and did not prevent determining the likely impacts of the pH control on water use. That said, the data from these installations were inconclusive, and there is a need to return to this site, preferably un-announced, to verify that the operator has been able to bring all three units into proper balance, with pH levels under 8.3 in the circulating water, and concentration ratios of 6.0 or more. This would provide some certainty that the water savings ascribed to the system are more than just theoretical. Post installation verification is an essential step in all such programs.

Technical issues were also identified at the study site's conductivity control systems, which were not functioning properly during the pre-retrofit period, resulting in manual bleeding of the systems. These technical issues were not considered unusual for the complex systems involved with pH controllers and cooling tower operations in general. Having instruments out of calibration, and/or working with old broken controllers is typical. Given the programmatic delay in study site recruitment and the additional time it would have taken to correct these technical issues, the pilot study results were mathematically derived. In spite of these limitations, the resulting theoretical impacts and their underlying assumptions are based on widely documented and accepted industry norms for pH control evaluation. Ideally, however, future evaluations will be able to study cooling towers that are properly maintained both before and after new equipment installations.

This study's estimated (i.e. theoretical) reduction of bleed water represents a major water conservation opportunity, which was a primary goal of the program. Expected water savings per cooling tower are estimated to be 15.5 gallons per day per ton of heat load. Based on a common 100 T tower operating over a year, the estimated annual unit savings of 0.56 MG is a reasonable value. These savings would need to be verified by post installation inspections by independent technicians. Given the widespread prevalence of cooling towers in California, potential savings of over a half million gallons per year per tower are quite significant.

7.5 Discussion of Findings

The site evaluated in this study was recruited into the SCE pilot program through West Basin Municipal Water District, which also provides financial incentives for pH controllers that are available from Metropolitan Water District (MWD). For this project, SCE paid the costs for three new water meters required for the analysis, and West Basin covered the remaining project costs through a combination of MWD rebates ($1,900 per controller) and grant money from California Department of Water Resources (DWR). While the project was essentially free to the industrial customer (except for required staff time), the customer did have initial questions about the safety and operations of pH controller equipment, and was not initially fully committed to installing controllers. Grant money secured from DWR was used to reimburse a project consultant to educate the customer about the safety and operations of pH controllers, and help guide them through the installation.

In the case of pH controllers and WBICs, it appears unlikely that SCE's program, as designed, would have a significant impact on attracting participation or changing the market for this equipment. The original program plan was to have SCE account representatives aggressively promoting the measures to their customers, who would then install controllers or WBICs to save water and obtain rebates from MWD. While some representatives did actively promote the measures, most did not because they are busy promoting many other SCE programs, and water savings obtained through the pilot program would not contribute to representatives' formal energy saving goals.[50] As a result, no program participants were recruited through SCE's formal marketing channels, although SCE did contribute financially to the pH controller project that was installed and evaluated by purchasing meters to assist with monitoring the equipment.

[50] Additional details about customer recruitment are included in the process evaluation of this program.

8 SCE Leak Detection Pilot Program

8.1 Program Description

For SCE's Leak Detection Program, detailed top down water audits that comply with International Water Association (IWA) and American Water Works Association (AWWA) protocols were completed for the Las Virgenes Municipal Water District, Apple Valley Ranchos Water Company and Lake Arrowhead Community Services District by Water Systems Optimization Inc. (WSO), under contract to SCE. Following are the audit periods for the three Agencies:

- Las Virgenes: July 2007 – June 2008
- Apple Valley: January – December 2007
- Lake Arrowhead: May to July 2009

The top down water audit is a process of identification and validation of the different types of water volumes that collectively add up to each agency's total water supply for the audit period. In a top down audit, all water volume components are evaluated starting with each agency's total system input and working down (through a process of subtraction) to validate water consumption and then identify real water losses.

For all three water agencies the same audit approach was utilized:

1. Total System Input was measured – this is the total water produced during the audit period, accounting for water from all sources (e.g., wells, lakes, imported water).

2. Authorized Consumption was validated and subtracted – this is the volume of billed and unbilled water used by authorized customers, for residential, commercial, industrial and institutional purposes. It also includes water exported to other jurisdictions, water used for fire fighting, water granted to special accounts, flushing of mains and sewers, etc. (The remaining water volume after this subtraction is all water losses). To complete this step, WSO analyzed and validated actual customer billing data (by meter size) during, before and after the audit period (to normalize consumption into calendar months), reviewed records of agency water use (e.g., for wells lubrication) and water grants, and developed estimates of some consumption (e.g., fire suppression).

3. Apparent Losses were validated and subtracted—these are due to inaccurate meter readings, data transcription errors, and unauthorized consumption. Importantly, reducing apparent losses will not reduce physical water losses, but will help to recover lost revenue. To complete this step, WSO discussed potential sources of unauthorized use with agencies, reviewed billing data for data handling errors (e.g., incorrectly transferred meter reading data), and analyzed meter testing samples provided by the water agencies to calculate the accuracy of the revenue meter population (by type and size) to identify under-registration.

The remaining water volume after apparent losses are subtracted out is real losses that occur due to physical leaks. These are losses in the pressurized system and storage facilities up until the point of customer use, and are affected by break frequencies, flow rates, and average durations of individual leaks. Real losses have three components:

- Reported leaks are events that are reported to the water agencies by the general public and water agency staff. Breaks and leaks that appear at the surface often have higher flow rates and are typically reported to the water agency even if they do not cause an immediate hazard (e.g., flooding). The duration of reported leaks is usually short.

- Hidden leaks are hidden from above ground view, have moderate flow rates and longer run times. These can be located through active leak detection, and thus is recoverable leakage.

- Background leakage is the continuously running collective weeps and seeps in pipe connections and other facilities that are too small to be detected by conventional acoustic equipment. This leakage can be estimated, but is usually not rectified via direct intervention.

WSO used a variety of techniques to estimate hidden leakage in some specific areas, referred to as District Metered Areas (DMAs). A DMA is a hydraulically discrete part of the distribution network that can be isolated from the rest of the system, and is typically supplied through a single metered line so that total inflow to the area can be measured. DMA water loss measurement techniques included:

1. Minimum Nighttime Flow (MNF) Analysis. Flow into the DMA is measured over 24 hours to identify the minimum flow point (usually 2am to 4am), which is when normal consumption is minimized and leakage comprises the greatest percentage of total demand in the DMA. The leakage flow rate during the MNF period is calculated by subtracting metered nighttime consumption by customers from total demand, and requires that there be no significant non-domestic consumption (e.g., outdoor irrigation) unless it too can be metered.

2. Weekly monitoring. Total supply to the area (e.g., well production) is measured for one week, and storage tank levels and metered consumption is measured at the start and end of the same week. Water losses are calculated by reconciling metered consumption and storage levels against total water supplied.

3. DMA shutdown. An insertion flow meter is installed on the intertie supplying water to the DMA and all boundary valves are closed. After shutting off all customer service connections, any remaining volume measured by the insertion flow meter should be due to running leaks in the DMA. (To verify proper function of the flow meter, artificial demand is created by selectively opening one or more connections).

Importantly, the DMAs chosen to demonstrate these water loss measurement techniques were selected based on the ease of isolating them from the rest of the distribution system, and not because they were necessarily suspected of having high leakage.[51]

Lastly, for each agency a field leak detection and repair campaign was conducted to show agency staff how leak detection is performed and to prove that water savings can be attained. Sonic leak detection was employed to detect vibrations from leaks in pressurized pipes, and leakage volumes were estimated based on the system pressure, size of pipe, sonic characteristics (loudness and frequency) and actual flows from visible leaks.

8.2 Evaluation and Data Collection Methods

Only real losses affect the amount of water being supplied, and therefore the M&V effort focused on real water losses rather than apparent losses. This evaluation focused on reviewing WSO's calculations and use of assumptions directly related to estimating the components of real water losses, which, if repaired or reduced, would lead to embedded energy savings. To do this, we obtained WSO's proprietary water balance and component analysis models and the final reports provided to the water agencies. We then reviewed spreadsheet calculations and methodology, and cross-referenced them with reported values in the final reports.[52]

The evaluation team also conducted one site visit to the Apple Valley Water Agency in March 2009 to observe the district metering process and watch WSO check and calibrate one of the flow meters installed for the selected DMA. The purpose of the visit was to observe how hydraulically discrete areas of distribution systems can be isolated from the rest of system, and to inspect the metering devices and processes to ensure that they are adequate for evaluation purposes.

Due to the nature of the leak detection measurement process, the evaluation team did not conduct any separate metering at the water agencies. Instead the evaluation was limited to verifying the metering process and reviewing and replicating the water savings estimates from the data supplied by WSO. In a few instances the values in the final agency report tables were misstated (but applied or calculated correctly); the correct values are displayed in this report.

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[51] No hydraulically discrete zones could be established for Lake Arrowhead.

[52] *Apple Valley Ranchos Water Company (AVRWC)*, *AWWA STANDARD WATER BALANCE AND AUDIT FOR CALENDAR YEAR 2007, Final Report*. WSO, November 2009.

Lake Arrowhead Community Services District, AWWA STANDARD WATER BALANCE AND AUDIT FOR MAY TO JULY 2009, Final Report. WSO, November 2009.

Los Virgenes Municipal Water District (LVMWD), AWWA STANDARD WATER BALANCE AND AUDIT FOR FY07/08, Final Report. WSO, November 2009.

8.3 Findings

8.3.1 Water Impacts

Reported and Unreported Breaks/Leaks

Each water agency provided the contractor with data on the number of leaks that were repaired during their respective audit period. As it is not possible to record the time difference between when the leaks first occurred and were reported (i.e., awareness duration), the contractor developed average awareness durations, by facility type, in consultation with the water agencies based on estimated ranges from other studies. Similarly, average repair durations were assumed through consultations with water agency staff (i.e., not based on actual records).[53] All assumed durations are documented in each of WSO's AWWA Standard Water Balance and Audit final reports.

Because limited data are available on the actual flow rates of reported leaks, WSO developed and used a list of recommended flow rates that vary by facility type (e.g., pipe size). These rates were based on leakage flow rates data from the United Kingdom, Germany, Brazil, Canada and Philadelphia Water Department.

The evaluation team confirmed that the reported leak frequencies, awareness/repair durations and assumed leak flow rates documented in the contractor's final reports were used in the water loss calculations.

Following is the standardized formula that was used to calculate water losses from reported leaks:[54]

$$AnnualLoss(MG) = (BR \times (AFR \times 60 \times 24 \times TD(AP \div 70)^{0.5}) \div 1{,}000{,}000)$$

Where:

MG = Million Gallons

BR = Number of Annual Breaks Reported by Agencies

AFR (gpm at 70 psi) = Assumed Average Leak Flow Rate

TD (days) = Total Duration (= Awareness Duration + Repair Duration)

AP (psi) = Average System Pressure

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[53] Repair time was aggregated with location time, which is the time it takes for the agency to investigate and locate the leaks so repairs can be conducted.

[54] The exponent represents the relationship between flow and pressure; 0.5 was used for leaks assumed to have fixed size holes (such as bursts), and 1 was used for background leakage with variable sized holes.

The next three tables show the volumes of water losses from reported leaks that were calculated for the three water agencies using the equation discussed above.

Table 37: Apple Valley Repaired Leaks in 2007

MAINS BY SIZE	# OF LEAKS & BREAKS	AVG. LEAK FLOW RATE @70PSI (GPM)	AVG. PRESSURE	AVG. DURATION (DAYS)	ANNUAL LOSS (MG)
Distribution - Diameter 3-inch	13	13.90	82.9	1.00	0.28
Distribution - Diameter 4-inch	337	44.00	82.9	1.00	23.23
Distribution - Diameter 6-inch	285	92.00	82.9	0.50	20.54
Distribution - Diameter 8-inch	86	92.00	82.9	0.50	6.20
Distribution - Diameter 12-inch	47	222.00	82.9	0.50	8.17
Trunk - Diameter > 12-inch	1	222.00	82.9	0.17	0.06
Services <1-inch	246	6.90	82.9	5.50	14.63
Services >1-inch	8	13.90	82.9	4.50	0.78
Total					73.89

Table 38: Las Virgenes Repaired Leaks in Fiscal Year 2007-2008

MAINS BY SIZE	# OF LEAKS & BREAKS	AVG. LEAK FLOW RATE @70PSI	AVG. PRESSURE	AVG. DURATION (DAYS)	ANNUAL LOSS (MG)
Distribution - Diameter 4-inch	1	44.00	115.3	1.50	0.12
Distribution - Diameter 6-inch	4	92.00	115.3	1.00	0.68
Distribution - Diameter 8-inch	3	92.00	115.3	0.75	0.38
Distribution - Diameter 10-inch	1	92.00	115.3	0.75	0.13
Distribution - Diameter 12-inch	6	222.00	115.3	0.75	1.85
Trunk - Diameter > 12-inch	2	222.00	115.3	0.21	0.17
Fittings – Hydrants	12		115.3		3.97
Fittings - Valves	1	6.90	115.3	10.00	0.13
Services <1-inch	18	6.90	115.3	5.00	1.15
Services >1-inch	4	13.90	115.3	5.00	0.51
Total					9.09

Table 39: Lake Arrowhead Repaired Leaks from May to June 2009

MAINS BY SIZE	# OF LEAKS & BREAKS	AVG. LEAK FLOW RATE @70PSI	AVG. PRESSURE	AVG. DURATION (DAYS)	ANNUAL LOSS (MG)
Distribution - Diameter <3-inch	8	13.90	89.5	1.50	0.27
Distribution - Diameter 6-inch	3	92.00	89.5	0.50	0.22
Distribution - Diameter 8-inch	2	92.00	89.5	0.50	0.15
Fittings – Hydrants	3	3.50	89.5	2.00	0.03
Services <1-inch	18	6.90	89.5	4.00	0.81
Services >1-inch	3	13.90	89.5	4.00	0.27
Total					1.76

Each agency also conducted an active leak detection campaign in 2009 as part of their assessment, and the findings of these activities are discussed in a subsequent section of this chapter. For Lake Arrrowhead, this leak detection was conducted *during* the audit period, and thus the leaks that were found and repaired were documented as unreported leaks to further disaggregate real water losses. The volume of found and repaired leaks for Lake Arrowhead was estimated to be 2.69 million gallons during the three-month audit period.

Background Leakage

Background leaks are minor leaks at pipe joints and fittings and small corrosion holes that leak at less than 2.2 gpm at 70 psi. These leaks are undetectable with noise detection technology, and thus must be estimated, considering the general infrastructure condition, length of pipe network, and system pressure. To estimate these loss volumes, WSO applied minimum background leakage rates adopted by the AWWA.[55]

Following is the formula that was used to estimate background leakage in the distribution networks:

$$DistributionBackgroundLeakage(MG) = (LR \times MI \times AP \times ICF \times DAYS) \div 1{,}000{,}000$$

Where:

MG = Million Gallons

LR (gals/mile/day/psi of pressure) = AWWA Background Leakage Rate

[55] These leakage rates are a theoretical minimum, and are based on international studies in places where all detectable leaks were located and repaired. The leakage rates are documented in the final reports, and also: *American Water Works Association. Water Audits and Loss Control Programs. Manual of Water Supply Practices (M36). Third Edition. 2009.*

MI (miles) = Service Miles

AP (psi) = Average System Pressure

ICF = Infrastructure Condition Factor[56]

DAYS (days) = Audit Period Days

The tables below display total annual background leakage from each agency's distribution network. The main source of leakage from all three agencies comes from main to curb-stop service connections. Despite Apple Valley having the most miles of mains and number of services, Las Virgenes experiences the greatest amount of background leakage.

Table 40: Apple Valley Losses from Distribution Network Background Leakage (Audit Days = 365)

Infrastructure Component	AWWA Background Leakage Rate	Miles / Number of Services	Avg. Operating Pressure	ICF	Annual Volume of Background Leakage (MG)
Mains	2.870	461.39	82.9	1.1	44.05
Service Connection: main to curb-stop	0.112	25,572	82.9	1.1	95.27
Total Background Leakage from Distribution Network					139.32

Table 41: Las Virgenes Losses from Distribution Network Background Leakage (Audit Days = 366)

Infrastructure Component	AWWA Background Leakage Rate	Miles / Number of Services	Avg. Operating Pressure	ICF	Annual Volume of Background Leakage (MG)
Mains	2.870	393.56	115.3	1.15	54.8
Service Connection: main to curb-stop	0.112	20,515	115.3	1.15	111.5
Total Background Leakage from Distribution Network					166.3

[56] The ICF reflects the general condition of the infrastructure and is the ratio between actual background leakage and the unavoidable amount of background leakage. An ICF of 1 represents a well-maintained system with infrastructure in good condition. For Apple Valley and Las Virgenes much of the infrastructure was installed in the last 20 years, while 90 percent of Lake Arrowhead's infrastructure is 30 to 60 years old.

Table 42: Lake Arrowhead Losses from Distribution Network Background Leakage (Audit Days = 92)

Infrastructure Component	AWWA Background Leakage Rate	Miles / Number of Services	Avg. Operating Pressure	ICF	Annual Volume of Background Leakage (MG)
Mains	2.870	119.43	89.5	1.9	5.36
Service Connection: main to curb-stop	0.112	7,794	89.5	1.9	13.66
Total Background Leakage from Distribution Network					19.02

None of the water agencies had actual data on the leakage rates of their reservoirs, and therefore an assumed overall leakage rate was developed for each agency based on the judgment of agency engineering staff. A rate of 0.10 gallons/minute/million gallons of reservoir capacity was used for Apple Valley and Lake Arrowhead, while a more conservative rate of 0.25 gpm was used for Las Virgenes.

Following is the formula that was used to calculate background leakage for reservoirs:

$$ReserviorsBackgroundLeakage(MG) = (CAP \times LR \times 60 \times 24 \times DAYS) \div 1{,}000{,}000$$

Where:

MG = Million Gallons

CAP (MG) = Total Reservoirs Capacity

LR (gpm/MG) = Assumed Background Leakage Rate

DAYS (days) = Audit Period Days

The table below displays background leakage from reservoirs for all three agencies. Of the three agencies, Los Virgenes experiences the highest real leakage rate in terms of annual volume lost to total capacity. This is still true if the Lake Arrowhead loss is prorated from 92 to 365 days.

Table 43: Background Leakage from Reservoirs for 3 Water Agencies

Agency (Days)	Total Capacity (MG)	Assumed Background Leakage Rate (gpm/MG)	Annual Volume (MG)
Apple Valley (365)	11.7	0.10	0.61
Las Virgenes (366)	34.33	0.25	4.52
Lake Arrowhead (92)	9.4	0.10	0.12

Total Hidden Losses

Estimated hidden water losses were calculated by simply subtracting reported leakage, unreported leakage and background leakage from total real water losses, as shown in Table 44.[57] The hidden losses calculations were done correctly, based on the aforementioned findings. Total hidden losses for Lake Arrowhead would be approximately 64.3 million gallons after annualizing the amount below, which was for a 92-day audit period.

Table 44: Hidden Water Losses for 3 Water Agencies

REAL LOSS COMPONENT	APPLE VALLEY (MG)	LAS VIRGENES (MG)	LAKE ARROWHEAD (MG)
Total Real Loss Estimate from Water Balance	344.75	342.1	39.87
- Losses from Reported Leaks and Breaks	73.89	9.1	1.76
- Losses from Unreported Leaks and Breaks	0	0	2.69
- Losses from Background Leakage	139.93	170.8	19.14
= Hidden Loss Estimate	130.93	162.2	16.28

Hidden Losses Cost Effectively Detected and Repaired

After calculating total hidden water losses (i.e., recoverable leakage), WSO applied an Economic Evaluation of Leakage (ELL) model to identify the appropriate level of intervention (e.g., survey/repair work) to minimize total costs (i.e., annual cost of leakage control + annual cost of lost water). The evaluation team did not have access to WSO's calculations, however we were able to replicate these calculations based on the report documentation of the formulas used and input assumptions.

Three parameters are needed to perform the calculations:

- Average rate of rise in unreported leakage (RR) – This is the continuing increase in leakage that would occur without any leak repairs. For all agencies, this annual rate was estimated by WSO based on actual leak detection results for each agency (discussed subsequently) and also the aforementioned nighttime district metering, which revealed little leakage in other areas. The average rate of rise is expressed as thousands of gallons/mile of mains/day.
- Cost of leak detection survey intervention (CI) – This was assumed to be $250 per mile of distribution main for all agencies.[58]

[57] WSO reported the Las Virgenes results with less precision than the other two agencies.

[58] This cost does not include repair costs, since it is assumed that water agencies maintain operating budgets to fix found leaks and will proactively do so, so that smaller leaks do not become bigger leaks in the future.

- Cost of real losses (CV) – This is the avoided cost of water supply, and is expressed as dollars/thousand gallons.[59]

Following are the formulas that utilize these parameters:[60]

$$InterventionFrequency(IF, months) = \left[0.789 \times ((CI \div CV) \div RR)\right]^{0.5}$$

$$SystemPercentToSurvey(SP, percentage) = (100\% \times 12) \div IF$$

$$AnnualBudget(AB, \$) = SP \times CI$$

$$RemainingHiddenLosses(HL) = AB \div CV$$

Table 45 shows the calculations results for the three agencies, and shows that economically recoverable leakage was estimated to range from 60 to 116 million gallons per year.

Table 45: Economic Intervention Results for 3 Water Agencies

INPUTS/ASSUMPTIONS	APPLE VALLEY	LAS VIRGENES	LAKE ARROWHEAD[61]
(Approximate) Annual Rate of Rise of Leakage (MG)	33	31	10.7
Survey Detection Costs per Mile	$250	$250	$250
Miles of Distribution Mains	431	322	119
Avoided Agency Cost per 1,000 Gallons	$0.899	$0.598	$8.373
Total Annual Hidden Loss Estimate (MG)	130.9	162.2	64.3
Results[62]			
Intervention Frequency (months)	32.3	35.2	9.8
System Percent to Survey Annually	37%	34%	123%
Annual Budget for Intervention	$39,999	$27,439	$36,577
Remaining Hidden Losses (MG/Yr.)	44.5	45.9	4.4
Potential Recoverable Leakage (MG/Yr.)	87	116	60

[59] For Apple Valley and Las Virgenes, WSO also performed calculations using the retail cost of water, resulting in higher amounts of leakage that should be recovered.

[60] The formula for intervention frequency is incorrectly documented in the reports (the final division is shown as a multiplication), but correctly documented in AWWA Manual 36.

[61] Lake Arrowhead avoided costs are comparatively high and were based on the cost of imported water from CLAWA.

[62] This table shows that actual results documented in the final reports; our results were only slightly different and are likely due to using the approximate rate of leakage volumes noted in the reports.

Active Leak Detection Efforts and Results

Following are details about the field leak detection activities that were conducted for each water agency:

- Apple Valley: The campaign was conducted from April 6th to April 16th 2009, and also on July 24th. Approximately 51 miles of mains were covered, representing 12 percent of the entire distribution network. A total of 28 leaks were detected during the survey. Apple Valley staff selected the specific areas to be surveyed based on their perceptions of relatively high leakage. The Jess Ranch area was also included to verify the results of a DMA measurement using weekly monitoring, which revealed very little leakage.
- Las Virgenes: The campaign was conducted from March 23rd to April 3rd 2009. Eighty-eight miles of mains were covered, representing 22 percent of the entire distribution network. A total of 21 leaks were detected during the survey. Las Virgenes staff selected the specific areas to be surveyed based on their perceptions of relatively high leakage. Included in the survey were 27 miles of the Seminole-Latigo and Three Springs system, which has 33.3 miles of mains. Weekly monitoring was conducted for this DMA before and after the leak detection and repairs in the field.
- Lake Arrowhead: The campaign was conducted from July 13th to July 30th, 2009. Thirty-one miles of mains were covered, representing 26 percent of the entire distribution network. A total of six leaks were detected during the survey. Lake Arrowhead staff selected the specific areas to be surveyed based on their perceptions of relatively high leakage.

The next three tables show the detailed and total annual leakage volumes that were detected by the WSO and repaired by the agencies during the surveys.

Table 8: Apple Valley Leak Detection Efforts and Results

LEAK TYPE	NUMBER OF LEAKS	ESTIMATED LEAK FLOW RATE (GPM)	TOTAL ESTIMATED LEAKAGE LOSSES (GPM)
Valve Leak	5	3@ 3gpm, 1@2.0gpm, and 1@0.5gpm	11.5
Meter Pit Leak	2	1@ 0.5gpm and 1@3gpm	3.5
Service Line Leak (Utility Side)	3	1@ 3gpm, 1@1.5gpm, and 1@0.5gpm	5.0
Service Line Leak (Customer Side)	2	2	4
Main Leak (all 4 inch pipe)	16	2@ 2gpm and 14 @ 3gpm	46
Estimated Recovered Losses			66 gpm
Estimated Recovered Losses			34,689,600 gallons per year

Table 9: Las Virgenes Leak Detection Efforts and Results

LEAK TYPE	NUMBER OF LEAKS	ESTIMATED LEAK FLOW RATE (GPM)	TOTAL ESTIMATED LEAKAGE LOSSES (GPM)
Hydrant Leak	8	7@ 0.5gpm and 1@ 3gpm	6.5
Meter Pit Leak	3	2@ 0.5gpm and 1@ 3gpm	4
Service Line Leak (Utility Side)	3	2@ 0.5gpm and 1@ 3gpm	11
Service Line Leak (Customer Side)	6	3	18
Main Leak (all 4 inch pipe)	1	50	50
Estimated Recovered Losses			71.5 gpm
Estimated Recovered Losses			37,580,400 gallons per year

Table 10: Lake Arrowhead Leak Detection Efforts and Results

LEAK TYPE	NUMBER OF LEAKS	ESTIMATED LEAK FLOW RATE (GPM)	TOTAL ESTIMATED LEAKAGE LOSSES (GPM)
Main Leak (10 inch pipe)	6	1@ 0.03gpm, 1@ 0.24gpm, 1@ 2.0gpm and 3@ 6gpm	20.27
Estimated Recovered Losses			20.27 gpm
Estimated Recovered Losses			10,653,912 gallons per year

Comparison with DMA Measurements

Overall, very little leakage was found during the initial DMA measurements in Apple Valley and Las Virgenes, likely due to the young infrastructure age and good maintenance and pressure management practices. In addition, one area had unexpectedly high levels of regular night-time use (e.g., irrigation) making it difficult to estimate leakage. Thus the active leak detection campaigns generally covered other areas of the service districts.

No leaks were detected in the field for the Jess Ranch area of Apple Valley, which is consistent with the very low level of leakage that was estimated from the prior DMA measurement (8.6 gallons/service connection/day).[63]

In the Seminol-Latigo area of Las Virgenes, leaks detected and repaired in the field were estimated to save approximately 1.1 million gallons per week. In comparison, weekly DMA measurements taken before and after the active leak detection and repairs estimated water savings of approximately 700,000 gallons per week. WSO notes that the differences between the two water savings estimates are likely due to:

[63] Weekly water supply, consumption and storage level changes are shown in the Apple Valley and Las Virgenes reports but not replicated here.

- Approximations inherent in the field leak detection process;
- Metering imprecision in the DMA area - the customer meters only read to the nearest one hundred cubic feet (748 gallons); and
- A large leak that is included in the 1.1 million gallons estimate (with an estimated flow rate of 50 gallons per minute, or 500,000 gallons per week). This leak visibly erupted after the initial DMA measurement, and was likely running at a lower flow rate before it erupted and was repaired. (Table 45 does not include the volume of this large leak because it was not detected through field leak detection (i.e., program intervention) like the other leaks.)

Water Savings from Pressure Management

For each agency, WSO also conducted analyses of pressure management options that could potentially yield water savings. Under some conditions, these savings can exceed savings achieved through active leak detection. The evaluation team did not review these calculations, as changing the water system pressures would change the pumping operations and energy use of the system, and it was beyond the scope of this evaluation to estimate embedded energy savings at different water pressure levels. The water savings discussed in this section are for illustrative purposes.

Pressure management can reduce real water losses by reducing the flow rates of background leakage and large leaks and breaks. It can also reduce the frequency of breaks by reducing stress on the system, although it is not possible to precisely predict the reduction in break occurrences. Other benefits from pressure management include: reduced repair costs and customer service costs, reduced inspection costs for reported breaks, and reduced risk of supply interruptions.

WSO took the following general steps to model potential pressure management strategies and calculate water savings:

- Current pressure settings at pressure relief valve (PRV) stations were reviewed and fixed outlet pressure settings were adjusted.
- Selected PRVs were identified for retrofits to vary pressure according to demand.
- Primary and secondary pressure zones with large pressure variations were subdivided into smaller pressure zones.
- Pressures were reduced in selected zones, and water savings were estimated.
- Costs were estimated for detailed design studies, new PRV stations, isolation valves, additional PRV maintenance and repairs, and further pressure optimization refinements.
- A 10-year net present value (NPV) analysis was completed using a discount rate of 4 percent.

Table 46 shows the estimated water savings that would result from new pressure management strategies and infrastructure, and shows that annual water savings could range from 32 to 82 million gallons per year. For Apple Valley and Las Virgenes, these savings are dependent on valuing water at *retail* cost; valuing water at lower avoided costs results in negative NPV values that do not justify the infrastructure investments. For Lake Arrowhead, the estimated savings of 32 million gallons per year reflect the avoided cost of importing water from CLAWA.

Table 46: Water Savings from Pressure Management for 3 Water Agencies

CHANGES/RESULTS	APPLE VALLEY	LAS VIRGENES	LAKE ARROWHEAD
Initial Average System Water Pressure (psi)	82.9	115	89.5
Proposed Average System Water Pressure (psi)	69	90	75
Estimated Annual Water Savings (MG)	73	82	32

Water Savings Summary

Table 47 summarizes the actual and potential water savings that were estimated for the three water agencies. Embedded energy savings are calculated for both the estimated water savings achieved through actual leak repairs, and also for leakage that could be recovered cost-effectively, to illustrate the potential for greater energy savings if the agencies implement ongoing leak detection campaigns as recommended by WSO.

Table 47: Annual Water Savings for Embedded Energy Estimates for 3 Water Agencies

SOURCE OF WATER SAVINGS	APPLE VALLEY (MG)	LAS VIRGENES (MG)	LAKE ARROWHEAD (MG)
Water Saved from Program Leak Detection and Repairs	35	37	11
Potential Water Saved from Future Detection and Repair of Hidden Leaks	87	116	60

8.3.2 Embedded Energy Impacts

Embedded energy impacts were calculated for the three agencies using the water savings shown above in Table 47 and the energy intensity of water produced by each agency. Energy intensities were calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. More detailed descriptions of these agencies and the calculations used to arrive at their IOU and total energy intensities are included in Appendix 1.2. Table 48 shows the energy savings results for all energy sources for the three agencies. Energy savings were calculated for water savings achieved through actual leak repairs, and also for leakage that could be detected and repaired in the future.

Table 49 shows the results of similar calculations using just the IOU energy used by each agency. Since Apple Valley uses only IOU energy in their water system, the energy savings for that agency are unchanged between the two tables. Las Virgenes and Lake Arrowhead both import a portion of their water from wholesalers that use non-IOU energy in the production of the water, and so their estimated energy savings are larger in Table 48 than Table 49.

Table 48: Annual Retail and Wholesale Embedded Energy Savings for 3 Water Agencies – All Energy Sources

ENERGY SAVINGS FROM ALL SOURCES	APPLE VALLEY (KWH/YEAR)	LAS VIRGENES (KWH/YEAR)	LAKE ARROWHEAD (KWH/YEAR)	TOTAL (KWH/YEAR)
Energy Saved from Program Leak Detection and Repairs	76,973	355,557	65,258	497,788
Potential Energy Saved from Future Detection and Repair of Hidden Leaks	193,575	1,100,519	368,527	1,662,621

Table 49: Annual Retail and Wholesale Embedded Energy Savings for 3 Water Agencies – IOU Energy Only

ENERGY SAVINGS FROM IOUS	APPLE VALLEY (KWH/YEAR)	LAS VIRGENES (KWH/YEAR)	LAKE ARROWHEAD (KWH/YEAR)	TOTAL (KWH/YEAR)
Energy Saved from Program Leak Detection and Repairs	76,973	71,170	30,000	178,143
Potential Energy Saved from Future Detection and Repair of Hidden Leaks	193,575	220,285	169,417	583,277

8.4 Discussion of Uncertainty, Threats to Validity, Potential Biases

WSO calculated 95 percent confidence limits for total real water losses based on the accumulation of error of derived values, using the formula:

$$1.96 \times SQRT(VarianceTotalSystemInput + VarianceAuthorizedConsumption + VarianceApparentWaterLosses) \div VolumeOfRealLosses$$

The results are 16.7 percent for Apple Valley, 81.6 percent for Las Virgenes and 11 percent for Lake Arrowhead. The limit for Las Virgenes is particularly high because real losses are very small relative to total system input, total authorized consumption, and their related variance. According to WSO, well-managed systems with accurate metering and low leakage seldom have confidence limits of less than +/- 15 percent.

One of the key assumptions used in estimating background water losses (and thus recoverable hidden losses) is the Infrastructure Condition Factor, which represents the overall quality of the distribution infrastructure. This value can range from 0 (no background leakage) to 2.2 (the theoretical maximum), and would require extensive fieldwork to define precisely.

For each agency, WSO conducted sensitivity analyses to see how total hidden losses would change when different ICFs were assumed to estimate background leakage. For Apple Valley, for instance, total hidden losses would be 270 million gallons with an ICF of 0, compared to -8.4 million gallons (which is impossible) with an ICF of 2.2. In the end, WSO used an ICF of 1.1 for Apple Valley to reflect the generally young age of the infrastructure and low levels of leakage found in particular areas. Overall, it appears that WSO has used reasonable ICF assumptions based on infrastructure conditions noted in the reports. No additional work was done as part of the evaluation to confirm the ICF values used by WSO.

According to secondary research conducted by WSO for this pilot program, Apple Valley and Las Virgenes have low levels of overall leakage relative to other agencies in California, while Lake Arrowhead also has leakage that is below the statewide average.[64] Although future proactive leak detection was found to be economically feasible for all three agencies, these agencies should not be used to extrapolate potential water savings to other agencies, where infrastructure conditions and management practices could be significantly different. That said, future program offerings may primarily attract water agencies that are most inclined to proactively manage their infrastructure (and have lower leakage), since both infrastructure maintenance and water audit participation require dedication of staff resources.

8.5 Discussion of Findings

As noted in the final reports, Apple Valley and Lake Arrowhead do not have proactive leak detection policies or practices, and Las Virgenes only inspects a small portion of its system periodically. Thus the leaks that were proactively detected by WSO and repaired by agency staff can be attributed to participation in the Leak Detection Pilot.

The agencies participating in this program received comprehensive water audits and system evaluations, in addition to demonstrations of DMA leakage measurement techniques and active leak detection. To improve program cost effectiveness in the future, the program may need to incorporate lower cost screening methods and a structured approach to identify and prioritize water agencies with relatively more economically recoverable leakage, as not all water agencies will be optimal candidates for proactive leak detection.

IOUs that implement leak detection programs in the future may wish to have utility staff or contactors conduct real-time field visits to verify repairs of leaks found during program-sponsored leak detection surveys. In addition, the AWWA M36 manual describes a range of techniques that could be employed to refine estimates of leaks found and repaired. For larger ruptures, for instance, changes in metered flows may be measurable in DMAs, in master meters at treatment plants, in SCADA systems or at other metered points. Small leaks can be measured by simply filling a container of known volume to calculate the flow rate. The AWWA manual also includes lookup reference tables that provide flow rates that vary by breach type (break, longitudinal/circumferential crack, circular hole), size and water pressure, and also calculation formulas if the size of the breach can be accurately measured in the field.

[64] The average statewide infrastructure leakage index (ILI, ratio of actual real losses to estimated unavoidable real losses) is 3.2 among the 17 agencies for which data were available; the three participant agencies have ILIs between 1.6 and 2.6. *Secondary Research for Water Leak Detection Program and Water System Loss Control Study*, *Final Report*. WSO, December 2009.

9 SDG&E Large Customer Audits Pilot Program

9.1 Program Description

The SDG&E Large Customer Audits Pilot Program was a partnership between SDG&E and the San Diego County Water Authority (SDCWA). SDCWA supplies water to its 23 retail agencies in the San Diego region, which in turn deliver the water to individual homes and businesses throughout the county. Large commercial and industrial businesses that are joint customers of SDG&E and any of SDCWA's retail agencies were eligible for this program. This program had two distinct components:

- Phase I - Three previous audits. SDCWA, in partnership with Otay Water District (OWD), had contracted with Water Management, Inc. to examine water and energy savings at three sites. While these existing, completed water audits identified numerous water savings opportunities, there had been little or no movement to implement the recommendations. The first component of the pilot program had SDG&E and SDCWA review these previous audits and identify additional energy savings opportunities. SDG&E and SDCWA then worked together to overcome customer resistance to implementing the audit recommendations, and SDG&E provided funding for improvements that could not be funded through other water agency incentive programs.

- Phase II - New integrated water/energy audits. SDCWA and SDG&E coordinated the development of a comprehensive water/energy audit. SDG&E issued a Request for Proposal to create the combined Water/Energy Audit and conduct 7-10 in-depth audits of commercial, industrial or institutional high water users in San Diego County. Both water and energy savings opportunities were included in these audits, and nine were completed during the program period.

To be eligible for funding, proposed improvements had to be entirely new, with no work completed or underway. In addition, the proposed improvements had to have an expected life of at least five years and at least a two-year simple payback period.

Any improvements implemented prior to December 31, 2009 were included in this evaluation. There were four projects completed within this timeframe: S1 Detention Facility, S2 Research/Production Facility, S3 Research/Production Facility, and S4 Research/Production Facility.

9.2 Methods

9.2.1 Data Collection Methods

A project-specific assessment of annual water savings was prepared for the implemented project at each of the sampled sites. The assessment was limited to audit recommendations that were fully implemented by the participant within the time frame of the pilot program. In cases where the sampled project includes multiple measures, the data collection and analysis was performed at the measure level.

For each sampled project, SDG&E and the affected water utilities provided the evaluation team with project-specific materials and a description of performance data (pre-retrofit and post-retrofit) that the utilities and/or the participant collected during project implementation. These materials were reviewed and an internal project-specific scope of work was prepared describing the pre-retrofit and post-retrofit data collection and analysis procedures that were used to produce an estimate of annual water savings for each measure in the selected project (see Appendix 8 for detailed M&V plans for the four evaluated sites). The scope included items such as a detailed description of each measure in the project and how it saves water, an algorithm for calculating annual water savings, a listing of the parameters that must be input to the algorithm, the data sources that were used to specify these parameters and the associated data collection techniques.

The evaluation team completed site visits at each sampled site to collect the pre-retrofit characteristics and performance data specified in the project-specific scope of work. When the scope specified the collection of water usage data during the pre-retrofit period, it usually involved time-of-use, device-level measurement at the point of consumption. After the project was installed and commissioned, a second site visit was done to collect the corresponding post-retrofit characteristics and performance data specified in the scope of work. All water usage data specified in the scope to be collected during the post-retrofit period usually involved time-of-use, device-level measurement at the point of consumption. Measurement periods varied between sites from 1 week to multiple months depending on what was appropriate for each site.

After all analyses were completed for the sampled projects, an estimate of the program-level savings was prepared by extrapolating the results from the individual projects to the entire population using the methods specified in the sampling plan.

Table 50: Sites Included in SDG&E Large Customer Audits M&V Sample

SITE	MEASURES EVALUATED	EX ANTE WATER SAVINGS (GALLONS/YEAR)
S1 Detention Center [65]	Flush Valves; Low Flow Toilets, Urinals and Showerheads	33,159,780
S2 Research/Production Facility	Autoclave Upgrade; Reverse Osmosis System Upgrade	4,378,285
S3 Research/Production Facility	Boiler Makeup Water	19,126,000
S4 Research/Production Facility	Reverse Osmosis System Upgrade	27,000

9.2.2 Analysis Methods

The analysis methods used in the evaluation of this program varied from project to project, but generally involved summarizing the data, looking for outlier data, observing usage patterns and trends, determining if normalization of the results based on external factors--such as annual schedules, or weather—was warranted, and finally, calculating the difference between adjusted

[65] The ex ante water savings for this site differ from those reported in the M&V plan in Appendix 8.1, as the measure unit counts were updated when additional project information became available; the M&V plan was not updated. The updated ex ante estimate utilized the same per-measure savings values given in the original Phase I audit.

pre and post usage levels. The project-specific results presented below provide specific details of the analyses performed.

The evaluation produced an estimate of annual water savings realized by each completed project under typical weather conditions (if appropriate) with correction for differences as feasible in water usage between the pre and post period due to factors beyond the implementation of the efficiency project. We estimated program-level annual water savings by simply summing the individual project results.

9.3 Findings

9.3.1 Water Impacts

Summary of Results

Table 2 shows annual water savings calculated for each sampled site, based on site metering data.

Table 51: Water Impact Estimates

SITE	EX ANTE WATER SAVINGS (GALLONS/YEAR)	EX POST WATER SAVINGS (GALLONS/YEAR)	REALIZATION RATE
S1 Detention Center	33,159,780	74,530,262	2.25
S2 Research/Production Facility	4,378,285	5,292,405	1.21
S3 Research/Production Facility	19,126,000	2,183,984	0.11
S4 Research/Production Facility	27,000	74,685	2.77
Total	56,691,065	82,081,336	1.45

Differences between ex ante and ex post savings varied widely. Realization rates for each site are shown in Table 2. The overall realization rate for these four projects combined was 1.45.

9.3.2 Individual Site Analysis

This section contains a summary of the analysis methods and savings calculations for each of the four sampled sites.

9.3.2.1 Detention Center (Site S1)

This detention center consists of low- and high-security facilities, where existing toilets and urinals were replaced with low-flush units, as well as timer-operated flush valves, which can be controlled remotely by prison staff. Monitoring and verification activities took place between June 2009 and March 2010, including the key element where ultrasonic meters were installed to log pre and post measure water usage for three different types of buildings

Calculated savings for all measures was 74,530,262 gallons per year, which is substantially greater than the 33,159,780 gallons per year that were estimated. A large part of the unexpected savings is attributed to the discontinuation of constantly flowing urinals in both the Area 1 and Area 2 facilities. Constantly flowing urinals were not mentioned in the original (Phase 1) audit, but are calculated to have consumed approximately 25 million GPY. The balance of unexpected savings is attributed to better than expected results for the electronic flush valve control systems installed in the cell blocks. This measure not only reduced the gallons per flush, but also reduced the permitted number of flushes per hour per cell, which appears to have substantially reduced the frequency of flushes.

9.3.2.2 Research/Production Facility (S2)

The program audit of this research/production facility identified two measures, autoclave trap cooling water conservation kit installations and pure water system upgrades. There are four autoclaves and two pure water systems.

For Measure 1, autoclave trap cooling water conservation kit installations, savings were found by taking the difference between the pre and post-installation flow rate for each of the four autoclaves, multiplying by their respective daily operation hours. The total savings found, 4,849,563 gallons per year, was 135 percent higher than the claimed savings. There are two probable reasons for the difference. The first is that only three autoclaves were included in the audit and the fourth, discovered afterward by the installer, is included in the evaluation.[66] The second reason is that the post-installation flow rate is lower than anticipated, reducing water use by an average of 85 percent as opposed to 80 percent used in the ex ante calculation.

For Measure 2, pure water system upgrades, savings were determined by taking the product of the average daily pre-install water consumption, the pre-install recovery rate and the difference between pre- and post-install reject ratios. The total savings found, 442,842 gallons per year, were 56 percent of the claimed savings. The recovery rates for each system were improved from 46 percent to 62 percent, not the 75 percent used in the ex ante estimate. Originally, a second stage was proposed; however, instead of a second stage on the reverse osmosis systems, a recirculation loop was installed on each system.

Total savings for this site were 5,292,405 gallons per year, yielding a realization rate of 121 percent.

9.3.2.3 Research/Production Facility (S3)

The program audit of this research/production facility identified potential water reuse opportunities in which wastewater from four separate high-quality discharge streams could be rerouted to supply boiler makeup water to displace use of potable water. The evaluation site inspection revealed that only one of those four potential discharge streams was reclaimed for boiler makeup water use.

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[66] We presume that the auditor inadvertently overlooked the fourth unit, which should have been included in the audit. Therefore we have included the savings for this unit, although these savings could also be considered as spillover if the program were to claim energy savings (which was not allowed).

Savings were determined by measuring the reclaimed water flow and taking a daily average. The water savings were found to be 2,183,984 gallons per year (5,984 gallons per day). This is significantly less than the ex ante estimate of 19,126,000 gallons per year (52,400 gallons per day), for a realization rate of only 11 percent. The audit seems to have overestimated the amount of wastewater available for reuse because it was based on all four potential high-quality discharge streams being used. If we compare the evaluation results to the stream that was diverted for reclaim water, according to the audit there was a potential of 14,000 gallons per day, which is more than twice the actual amount.

9.3.2.4 Research/Production Facility (S4)

The efficiency improvement at this research/production facility consisted of recalibrating the reverse osmosis (RO) units that produce pure water, since they were observed to be running at a less-than-optimal recovery rate. Minor adjustments to the production settings resulted in more efficient production and less wastewater.

Logged water use data were provided by the site for the pre-implementation period of August 2009–September 2009. During the first site visit, water meters were installed on each of the units and collected post-implementation data from October 2009 to January 2010. We also collected run-time data for all eight RO units, and combined these data with flow data to develop robust profiles of pre and post usage. During the initial and final site visits, the settings on the RO units and water use were also recorded. The logged/metered data were considered sufficient to characterize the entire year's worth of data, as there is no known seasonal variability at the site and the units connect to storage tanks for RO product water, so maintenance can be done without interrupting usage.

The water savings were found to be 74,685 gallons per year (205 gallons per day), which is greater than the 27,000 gallons/year (74 gallons per day) predicted in the application. The evaluation team believes that the found savings were greater because the program underestimated the total water use at the facility, and with more water use there was more potential for savings.

9.3.3 Embedded Energy Impacts

Embedded energy impacts were calculated for all four sites by multiplying the *ex post* annual water savings from Table 51 with the energy intensity results for the corresponding water agencies. Energy intensities were calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculations of energy intensities for each agency are shown in more detail in Appendix 1.2.

Water production and energy data were not provided by the City of Carlsbad or Encina Wastewater Authority, which are the retail and wastewater agencies providing service to site S2. Because of this, only wholesale water data from the San Diego County Water Authority is used in calculating the embedded energy for site S2. There is likely an IOU-provided energy component to the water distributed by the City of Carlsbad, but it is not reflected here. For the same reason no embedded energy savings could be calculated for the wastewater system for site S2, as is reflected in Table 53.

Table 52 shows the energy savings in the potable water system for all projects analyzed for this pilot program. The total annual energy saved in potable systems is 73,710 kWh of IOU energy and 685,141 kWh for energy from all sources. Table 53 shows the annual energy savings results for wastewater systems. The total energy savings for wastewater was 81,802 kWh of IOU energy, which is the only type of energy used in those wastewater systems.

Table 52: Embedded Energy Savings for Potable Water Systems

Site	Water Agency	IOU Energy Savings (kWh/Year)	Total Energy Savings (kWh/Year)
S1 Detention Center	Otay Water District	72,990	629,284
S2 Research/Production Facility	San Diego County Water Authority*	0	39,503
S3 Research/Production Facility	City of Oceanside Water System	692	15,852
S4 Research/Production Facility	City of San Diego Water Authority	28	502
Total		73,710	685,141

* No data obtained for retail agency, only wholesale agency data were used

Table 53: Embedded Energy Savings for Wastewater Systems

Site	Wastewater Agency	IOU Energy Savings (kWh/Year)	Total Energy Savings (kWh/Year)
S1 Detention Center	City of San Diego Wastewater	78,386	78,386
S2 Research/Production Facility	Encina Wastewater Authority	--	--
S3 Research/Production Facility	City of Oceanside Wastewater System	3,338	3,338
S4 Research/Production Facility	City of San Diego Wastewater	79	79
Total		81,802	81,802

9.4 Discussion of Uncertainty, Threats to Validity, Precision, Potential Biases

Although sources of uncertainty varied between projects, the largest common uncertainty resulted from the use of data from customer-owned meters for portions of the savings analyses. The accuracy and precision of these meters was unknown. Ultrasonic meters were used at three of the four sites to measure time-of-use data. These meters were owned by evaluation team contractors and were carefully calibrated, so uncertainty due to inaccuracy and imprecision was considered to be small.

9.5 Discussion of Findings

The evaluation determined that all four program participant sites yielded savings, and that at three of the four sites, savings were much higher than anticipated by the utility, suggesting that the program may be more beneficial than originally thought. These results suggest that significant savings may be realized if the pilot program is implemented on a large scale. It is important to note, however, that with a population of four implementing a wide range of projects, it is difficult to draw firm conclusions about the potential of such a program.

10 SDG&E Managed Landscapes Pilot Program

10.1 Program Description

The Managed Landscape Water Pilot Program (MLPP) consisted of converting conventional irrigation controllers into controllers that utilized daily evapotranspiration (ETo) and weather information to control the amount of water used for irrigation. The pilot project focused on efficient use of outdoor potable water used for aesthetic landscapes. A total of thirteen sites in the San Diego area were involved in the pilot program; four of which were selected for evaluation. All four samples were selected after the pilot period had ended. Participants included multifamily apartment complexes, condominiums, office parks, commercial properties, homeowner associations, and estate properties. All sites were owned by third parties. SDG&E issued a competitive bid solicitation to implement this pilot, and a water management service company was selected to install and monitor the systems at each site.

For most of the sites, all metered water was used for irrigation. In only one case, some water was used for irrigation and some was used for other end-uses such as restrooms, drinking water fountains or laundry areas. The former type of project is referred to as having a dedicated end-use meter. The latter type of project is referred to as having a mixed end-use meter. The water savings achieved by the use of the vendor’s technology is indifferent to the type of end-use metered project since the water savings are only on the irrigation systems. Due to the substantially greater cost to evaluate a project with a mixed end-use meter, only sites with dedicated irrigation meters were sampled for this evaluation. Any bias introduced by this screening criterion was expected to be negligible.

All of the projects in the MLPP involved the installation of the vendor’s irrigation control system on managed landscapes. The specific control schemes used are proprietary to the vendor, were not disclosed to us, and are not discussed in this report. Because all of the projects involved implemented this same water saving measure, the same procedure was used to evaluate each sampled project.

10.2 Methods

10.2.1 Data Collection Methods

Pre-measure water usage data from billing meters (gathered by the vendor from the water utility for each site) were obtained from 2006 up to the month that the measure was implemented. Post-measure data were obtained from the same billing meters from the month that the measure was implemented up to December 2009. Vendor-supplied billing meter data were spot checked with billing meter data obtained directly from the water utilities to ensure the accuracy of the vendor data.

Factors such as recent or planned changes in vegetation, mulching and irrigation area were investigated during pre-measure on-site interviews and by telephone interviews at the end of the post-measure period. Due to budget constraints, site observations could not be made for the post-measure period. No site changes that would affect the amount of irrigation water needed were reported at any of the four sampled sites. Therefore, no adjustments to the amount of water savings calculations were made due to these factors. The M&V plan describing this procedure in detail is attached in Appendix 10.1.

Time of use metering was not implemented at the four sampled sites. Instead, daily, weekly, and annual irrigation schedules were obtained from staff and used to develop time of use inputs for the embedded energy savings model.

10.2.1.1 Data Requirements

- **Pre-Work Plan Program Data** - Monthly (or bi-monthly) utility water billing data for all customer accounts from 2006 up to the month that measure was implemented. This required knowing the locations of all sites and the account numbers of all water meters serving the irrigation systems and the implementation dates of the measures.
- **Post- Work Plan Program Data**–One year of utility water billing data for the study group during the 2009 irrigation season. This required knowing the locations of all sites and the account numbers of all water meters serving the irrigation systems and the implementation dates of the measures.
- **Program Participant Data** – The number, type and location of participant properties in the study.
- **ETo/weather Data** – Corresponding to the time period for which pre and post billing data were obtained to aid in measuring the effectiveness of the ETo-based controllers. CIMIS station and or other nearby weather station data.
- **Timing of Use –** Obtained from examination of irrigation schedules.

The use of billing data greatly simplified the analysis. In addition, excluding combined water meters from the study increased the accuracy of the results for the irrigation-only meters. The greater the similarity among the management plans used for each site, the better the reliability of the water savings estimates.

Table 54 lists sites used in the M&V sample.

Table 54: Sites Included in PG&E Large Commercial M&V Sample

SITE	MEASURES EVALUATED	INSTALLATION DATE
M1 Residential Development	Irrigation system control upgraded for 5 irrigation meters	4/6/2009
M2 University	Irrigation system control upgraded for 1 irrigation meter	11/25/2008
M3 Residential Development	Irrigation system control upgraded for 5 irrigation meters	11/25/2008
M4 Residential Development	Irrigation system control upgraded for 4 irrigation meters	11/25/2008

10.2.2 Analysis Methods

The baseline water usage was calculated as the sum of the average monthly usage for each month of the year (averaged over the pre-measure period of January 2006 to the month the measure was implemented).

Savings were calculated as the difference between the annual baseline water usage and annual post-measure water usage for each month and summed to obtain annual water savings. The annual savings was then divided by the total affected acres to obtain savings in gallons per acre per year.

The vendor used a similar approach to calculating savings, except that the baseline period used was January 2003 (and in some cases a few months of 2002 data) up to the measure implementation month rather than January 2006 up to the measure implementation month. The vendor's approach is less accurate as it includes a greater number of operational changes, physical changes (differences in vegetation), and weather changes that would have taken place in previous years and therefore does not reflect as closely the water usage directly prior to implementation of the measure. It is important that the baseline water usage represent as much as possible the water usage that would have occurred had no changes been made. It is also important that more than a single year's worth of data are used to account for unknown anomalies that might have occurred in the year prior to the measure implementation. The selected baseline period is thought to be the best compromise between the two extremes of too little data and data going back too far.

For each site, linear ETo correlations were developed for both the baseline and post-measure periods. These correlations were not used in actual savings calculations, but instead were intended to represent a measure of the effectiveness of installing the ETo-based controllers. Theoretically, the effectiveness can be seen as an improvement in the R^2 value of the correlation between the baseline and post-measure data. Uncertainties pertaining to these correlations are discussed in section 10.4 below.

10.3 Findings

10.3.1 Water Impacts

Table 55 shows annual water savings calculated for each sampled site.

Table 55: Water Impact Estimates

Site	Ex Post Annual Water Savings (Gal)	Savings per Acre	Percent Savings
M1 Residential Development	2,080,245	301,922	24.6%
M2 University	805,097	224,888	28.8%
M3 Residential Development	4,922,962	990,536	48.5%
M4 Residential Development	4,679,737	727,797	37.6%

The vendor-calculated savings were year-to-date savings based on, in most cases, less than a year's worth of post-measure data. Table 56 shows a comparison between ex ante (vendor-calculated) and ex post (evaluation) savings for the same year-to-date periods. Table 56 also shows realization rates that were calculated for each of the four sampled sites. The overall average realization rate was slightly higher than one (1.004). This realization rate was used below to extrapolate annual evaluation savings to the other nine non-sampled sites.

Table 56: Water Impact Estimates for Vendor-Defined Year-to-Date Period

Site	YTD Period	YTD Ex Ante Water Savings (Gal)	YTD Ex Post Water Savings (Gal)	Realization Rate for YTD Period
M1 Residential Development	May09-Aug09	1,387,540	1,221,983	0.88
M2 University	Jan09-Sept09	1,073,380	744,509	0.69
M3 Residential Development	Dec08-Aug09	1,769,020	3,460,123	1.96
M4 Residential Development	Jan09-Aug09	4,155,888	2,997,236	0.72
Average		2,096,457	2,105,963	1.004

In general (3 of 4 cases), ex post savings were less than ex ante savings. As explained above, the only difference in the calculation method between ex post and ex ante savings was the period used for the baseline. Although the baseline period used in the evaluation is thought to reflect more accurately the actual usage, had no changes been made, the average realization rate across the four sampled sites shows that on average there was little difference between vendor savings and evaluation savings.

In the three cases where ex post savings was lower than ex ante savings, there is no definitive trend among all three that would indicate that factors influencing annual usage variations were related among the three sites. Factors influencing these variations, as well as those influencing the variations seen in the fourth site (where ex post savings was higher than ex ante savings) are unknown. Interviews with staff and pre-installation site visits did not help to reveal these factors.

A similar condition exists for the nine non-sampled sites. Vendor data for these nine sites were examined and no definitive trend, either up or down, was observed.

10.3.2 Individual Site Analyses

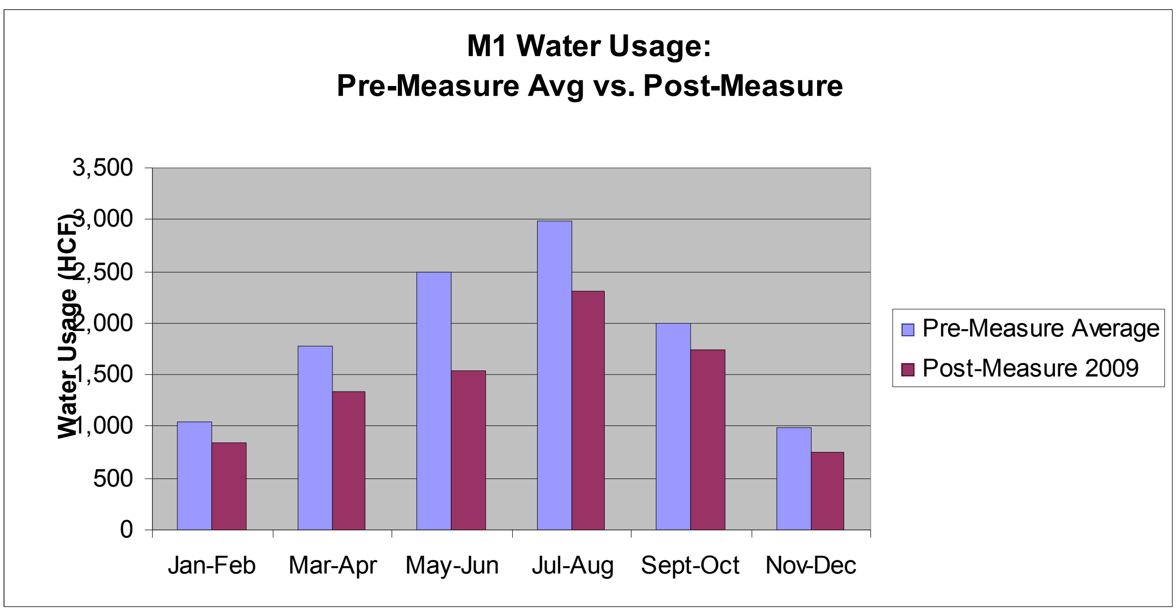
This section contains a summary of the analyses for each of the four sampled sites.

10.3.2.1 M1 Residential Development

The M1 residential development property is located in La Jolla and contains 6.89 acres of irrigated land which includes turf, shrubs, and trees. This site is managed by a large property management firm. The irrigation control system was replaced on five potable water meters. The new system controls irrigation using daily evapotranspiration data from the Torrey Pines weather station.

Evaluation savings were calculated for each bi-monthly period as the difference between pre-measure data averaged over three years (January 2006 up to the measure implementation month) and 2009 post-measure data. Eight months of post-measure water usage data were available (reported as four bi-monthly values). The two bi-monthly values that were not available were estimated by applying the average percent reduction in water usage of the four available values to the baseline values for these months. Total savings were 2,080,245 gallons per year or 301,922 gallons per acre per year (24.6 percent savings). Contrary to expectations, no correlation ($R^2 = 0.06$) was found between evapotranspiration and water usage for the post-measure period. The lack of correlation may be due to reasons discussed in section 10.4.

Figure 1. Pre- and Post-Measure Water Usage for M1 Residential Property

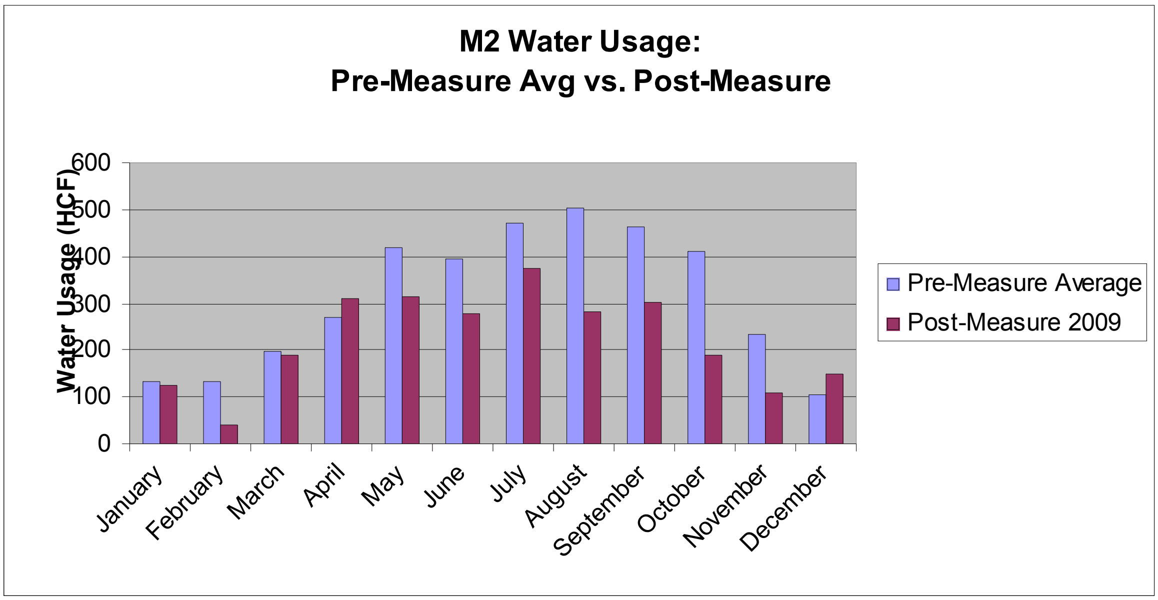


10.3.2.2 M2 University

The M2 university site is a university campus located in the San Diego area and contains 3.58 acres of irrigated land, which includes turf, shrubs, and trees. This site is managed by the university. The irrigation control system was replaced on two potable water meters. A large leak was detected on the second meter, so this meter was dropped from the analysis. The new system controls irrigation using daily evapotranspiration data from the San Diego II weather station.

Evaluation savings were calculated for each month as the difference between pre-measure data averaged over 3 years (January 2006 up to the measure implementation month) and 2009 post-measure data. Thirteen months of post-measure water usage data were available. Total savings were 805,097 gallons per year or 224,888 gallons per acre per year (28.8 percent savings). This savings is lower than it would have been due to the removal of the water meter with the leak from the analysis. As expected, a strong correlation was found between evapotranspiration and water usage for the post-measure period (R^2=0.82).

Figure 2. Pre- and Post-Measure Water Usage for M2 University

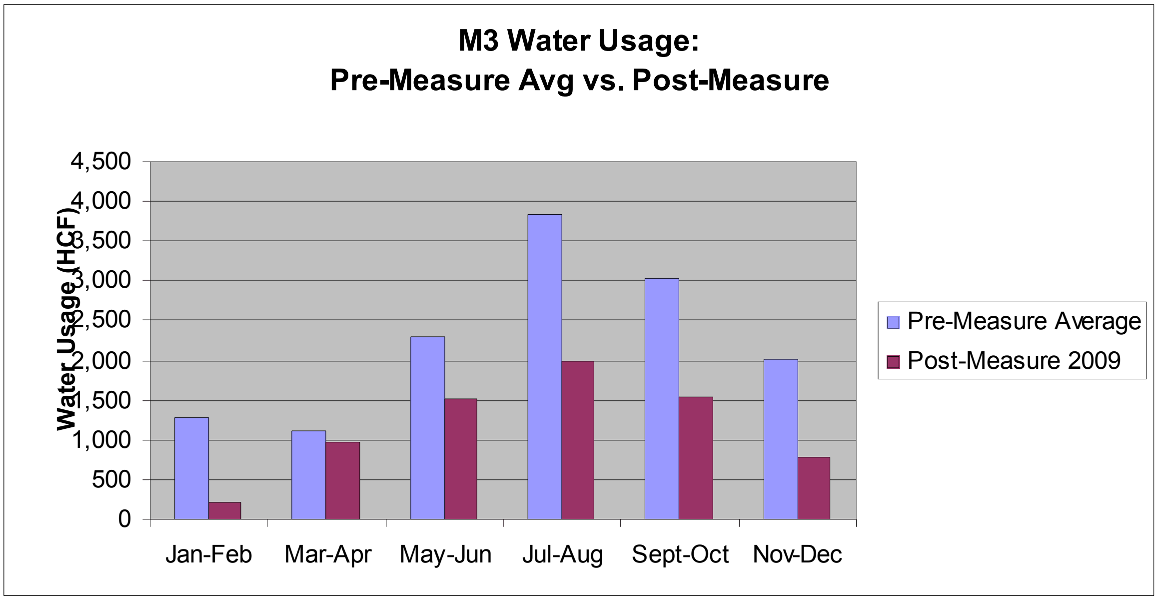


10.3.2.3 M3 Residential Development

The M3 residential property is located in San Diego and contains 4.97 acres of irrigated land which includes turf, shrubs, and trees. This site is managed by the homeowners association for the property. The irrigation control system was replaced on five potable water meters. The new system controls irrigation using daily evapotranspiration data from the Otay Lake weather station.

Evaluation savings were calculated for each bi-monthly period as the difference between pre-measure data averaged over 3 years (January 2006 up to the measure implementation month) and 2009 post-measure data. Total savings were 4,922,962 gallons per year or 990,536 gallons per acre per year (48.5 percent savings). Twelve months of post-measure water usage data were available. A weak correlation (R^2 = 0.45) was found between evapotranspiration and water usage, which may be due to reasons discussed in section 10.4 below.

Figure 3. Pre- and Post-Measure Water Usage for M3 Residential Property

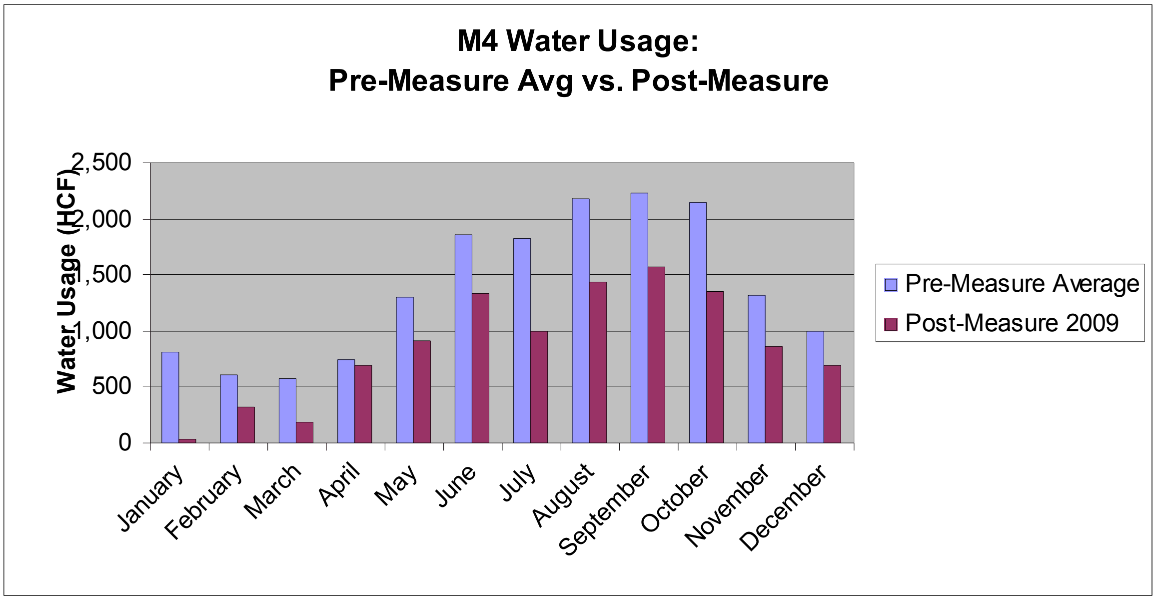


10.3.2.4 M4 Residential Development

The M4 residential property is located in El Cajon and contains 6.43 acres of irrigated land which includes turf, shrubs, and trees. This site is managed by a large property management firm. The irrigation control system was replaced on four potable water meters. The new system controls irrigation using daily evapotranspiration data from the Otay Lake weather station.

Evaluation savings were calculated for each month as the difference between pre-measure data averaged over 3 years (January 2006 up to the measure implementation month) and 2009 post-measure data. Thirteen months of post-measure water usage data were available. Total savings were 4,679,737 gallons per year or 727,797 gallons per acre per year (37.6 percent savings). Contrary to expectations, a very weak correlation was found between evapotranspiration and water usage for the post-measure period (R^2 =0.28). The lack of correlation may be due to reasons discussed in section 10.4 below.

Figure 4. Pre- and Post-Measure Water Usage for M4 Residential Property



10.3.3 Program Extrapolation

The annual savings realization rate calculated from the four sampled sites (see Table 3 above in Section 10.3.1) was used to extrapolate annual savings for the remaining nine sites. Data available for these sites included vendor-calculated year-to-date savings in HCF, measure installation date, and date of the last meter reading. One of the non-sampled sites, M12 Residential Development, contains meters with mixed end-uses. In this case, the water usage due to non-irrigation end-uses was estimated by the vendor to be around 10 percent and was deducted from the savings calculation. For the extrapolation, the vendor annual savings was estimated from the vendor year-to-date savings for each of the nine sites by using the following equation:

Equation 1: Calculation of Non-Sampled Site Annual Vendor Savings

$$S_{annual} = S_{YTD} \times 365 / (D_{last\ read} - D_{installation})$$

Where:

S_{annual} = Annual Vendor Savings, HCF

S_{YTD} = Year-to-Date Vendor Savings, HCF

$D_{last\ read}$ = Date of last meter read, day of year

$D_{installation}$ = Date of measure installation, day of year

The evaluation annual savings for each of the nine sites was then calculated by multiplying the vendor annual savings by the average realization rate (1.004). The results are shown in Table 57.

Table 57: Annual Evaluation Savings – All Sites (Including Extrapolation to Non-Sampled Sites)

Site		Meter Type	Vendor YTD Savings (HCF)	Last Meter Read Date	Measure Installation Date	Elapsed Days	Calculated Vendor Annual Savings (HCF)	Calculated Annual Evaluation Savings (HCF)	Savings per Acre (HCF/Acre)
M1 Residential Development	**Sampled Site**	Dedicated						2,781	404
M2 University	**Sampled Site**	Dedicated						1,076	301
M3 Residential Development	**Sampled Site**	Dedicated						6,582	1,324
M4 Residential Development	**Sampled Site**	Dedicated						6,256	973
M5 Residential Development	Non-Sampled Site	Dedicated	3,152	12/20/2009	11/25/2008	390	2,950	2,962	642
M6 Apartment Complex	Non-Sampled Site	Dedicated	6,478	12/18/2009	11/25/2008	388	6,094	6,118	836
M7 Residential Development	Non-Sampled Site	Dedicated	1,288	12/31/2009	6/4/2009	210	2,239	2,248	502
M8 Apartment Complex	Non-Sampled Site	Dedicated	8,893	12/14/2009	11/25/2008	384	8,453	8,487	908
M9 Residential Development	Non-Sampled Site	Dedicated	7,324	1/15/2010	7/2/2009	197	13,570	13,624	1,243
M10 Residential Development	Non-Sampled Site	Dedicated	6,504	12/14/2009	11/26/2008	383	6,198	6,223	932
M11 Residential Development	Non-Sampled Site	Dedicated	5,949	2/9/2010	4/1/2009	314	6,915	6,943	1,403
M12 Residential Development	Non-Sampled Site	Mixed	1,637	1/4/2010	3/27/2009	283	2,111	2,120	1,009
M13 Residential Development	Non-Sampled Site	Dedicated	2,175	1/11/2010	6/15/2009	210	3,780	3,795	492
Totals								69,215	884[1]

[1] Average HCF/Acre

As shown in Table 57, the total evaluation savings for the pilot project was 69,215 HCF per year. This equates to 141,843 gallons per day. The average savings per acre was 884 HCF/Acre-yr. This was higher than the average savings per acre for the four sampled sites (561 HCF/Acre).

The most likely explanations for this are either higher baseline usage or lower post-measure usage for the non-sampled sites as compared to the sampled sites.

10.3.4 Embedded Energy Impacts

Embedded energy impacts were calculated for the 4 sampled sites by multiplying the *ex post* annual water savings from Table 55 with the energy intensity results for the corresponding water agencies. Energy savings for the 9 non-sampled sites were calculated using the same approach with the Calculated Annual Evaluation Savings shown in Table 57. Energy intensities were calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculations of energy intensities for each agency are shown in more detail in Appendix 1.2.

Water production and energy data were not obtained from Vallecitos Water District or the City of Poway. However, Vallecitos Water District imports 100 percent of its water from San Diego County Water Authority (SDCWA) and the City of Poway imports about 99.5 percent of its water from SDCWA as well. For these two sites, the energy intensity of water provided by SDCWA (7,464 kWh per million gallons) was multiplied by the annual water savings for each site.

The remaining 11 sites obtain water through the City of San Diego Water Authority or Otay Water District. The energy intensity calculations for these agencies are discussed in more detail in Appendix 1.2. The City of San Diego Water Authority produces water at an energy intensity of 6,726 kWh per million gallons, of which 381 kWh per million gallons is IOU-provided energy. Otay Water District produces water at an energy intensity of 8,443 kWh per million gallons, of which 979 kWh per million gallons is IOU-provided energy.

As shown in Table 58 below, the total annual energy savings for all 13 participant sites is 21,275 kWh for IOU energy and 365,054 kWh for energy from all sources. These energy savings result from reduced water consumption since less water is pumped from the source, less water is treated to the level of potable water, and less water is pumped through the distribution system.

Table 58: Annual Embedded Energy Savings for SDG&E Managed Landscapes Sites

SITE	WATER AGENCY	IOU ENERGY SAVINGS (KWH/YEAR)	TOTAL ENERGY SAVINGS (KWH/YEAR)
M1 Residential Development	City of San Diego Water Authority	793	13,991
M2 University	City of San Diego Water Authority	307	5,415
M3 Residential Development	City of San Diego Water Authority	1,877	33,110
M4 Residential Development	Otay Water District	4,583	39,513
M5 Residential Development	Otay Water District	2,170	18,707
M6 Apartment Complex	City of San Diego Water Authority	1,744	30,778
M7 Residential Development	City of San Diego Water Authority	641	11,309
M8 Apartment Complex	City of San Diego Water Authority	2,420	42,696
M9 Residential Development	City of San Diego Water Authority	3,884	68,539
M10 Residential Development	City of San Diego Water Authority	1,774	31,306
M11 Residential Development	Vallecitos Water District	0	38,763
M12 Residential Development	City of Poway	0	11,836
M13 Residential Development	City of San Diego Water Authority	1,082	19,092
Total		21,275	365,054

10.4 Discussion of Uncertainty, Threats to Validity, Precision, Potential Biases

Data from existing billing meters were used in the savings analysis. The accuracy and precision of these meters was unknown and is therefore a source of uncertainty in the results. Other unknown factors may have affected the water usage and could include unknown or unreported malfunctions in hardware (leaks in sprinkler heads, pipes, heads stuck open or closed, etc.) or software (improper or overridden control system settings).

Uncertainty existed in ETo correlations due to only a small number of data points available (in one case four data points were used). Unknown sources of uncertainty may also be affecting ETo correlation accuracy. These include possible microclimate effects (weather station data being significantly different than site weather data even though they are a short distance from each other). Other uncertainty exists due to characteristics of the vendor control scheme. For instance, weighting factors are often used to change the degree to which ETo influences irrigation amounts. These types of control characteristics are unknown because the vendor's control program is proprietary.

Water restrictions were put in place in July of 2009. However, none of the four sampled sites changed their water usage control algorithm as a result of the restrictions. It was believed that by using the vendor control system that it achieved the objectives of the water restrictions. If water restrictions remain in-place for the longer term, it is expected to reduce the savings of any future projects that install the vendor irrigation control system.

Uncertainty also existed in the use of extrapolation to estimate evaluation savings for the nine non-sampled sites. The uncertainty is mitigated somewhat by the fact that the sample size is large relative to the population (a sample of four with a population of thirteen).

The extrapolation calculation used a ratio of days the site was monitored to total days in a year (365) to calculate the vendor annual savings from the vendor year-to-date savings. This does not take into account the varying monthly demand in water usage and therefore introduces some uncertainty. However, this remains a reasonable way to calculate this value as monthly data were not available for the entire period for the nine sites that were not sampled.

10.5 Discussion of Findings

Significant savings were realized through this program at each of the four sampled sites. The average percent savings over the pre-measure usage was 35 percent. The lowest percentage of water savings for any controller/site was 25 percent. Since non-evapotranspiration-based irrigation controllers were replaced with evapotranspiration-based controllers, the correlation between evapotranspiration and water usage was expected to become stronger after the measures were implemented. However, as discussed previously in the individual site analyses, this did not appear to be the case for the M1 and M4 sites. At the M1 site, the vendor reported tampering on some of the controllers by someone on-site which resulted in controllers being inactive for a period of time (up to 5 weeks in one case). However, this likely had a small effect on the overall ETo correlation. A leak was detected on a meter at the M4 site (affecting two controllers) but the effect of the leak is unknown. Table 59 shows a comparison between pre- and post-measure R^2 values for the ETo vs. water usage correlations.

Table 59: Pre- and Post-Measure ETo vs. Water Usage Correlation R^2 Values

Site	Pre-Measure R^2	Post-Measure R^2
M1 Residential Development	0.23	0.06
M2 University	0.51	0.82
M3 Residential Development	0.22	0.45
M4 Residential Development	0.30	0.28

Both the M1 and M4 showed significant water savings despite a worsening of the ETo correlation after measure implementation. This indicates that either other unknown factor(s) were involved in water use reduction or unknown factors influenced the correlation, which otherwise would have been valid without these influences. Further, more detailed investigation would be needed to determine what these factors/influences were (see the uncertainty section above for a discussion of unknown factors). To ensure that future programs are viable, it will be important to establish that the vendor technology is indeed functioning as intended. It is also important to realize that control systems of this type tend to degrade from their design intent over time due to things like settings being changed or overridden. This creates the potential for savings to correspondingly degrade over time.

11 SDG&E Recycled Water Pilot Program

11.1 Program Description

This pilot program, which was developed in conjunction with the San Diego County Water Authority (SDCWA), increased the use of recycled water by assisting retrofit projects that switched from a potable water source to a recycled water source. Recycled water receives conventional wastewater treatment and then is subjected to additional treatment in order to be authorized by the California Department of Health Services to be used for irrigation. In many cases, the additional energy to produce and distribute recycled water can be lower than the energy required to acquire, treat and distribute potable water.

To implement the program, SDCWA and its member agencies identified sites with completed retrofit plans that would allow the customer to switch from potable water usage to recycled water usage during the program period. Several entities expressed interest in participating in the pilot program. The criteria for selecting participants included customer type, readiness to proceed, projected savings per site, and projected implementation costs. The SDCWA and its retailers identified sites with completed retrofit plans ready for submittal to regulatory agencies for approval, as well as projects that could be implemented immediately following regulatory approval. After the final program participants were selected by SDCWA, SDG&E provided matching capital funding to projects that completed installation and started operations during the program period.

Six sites were selected to participate in the pilot program, consisting of highway/road right-of-way areas and park areas. Previously, all six sites had used potable water for irrigation. By participating in the program, those sites discontinued using potable water for irrigation and instead use treated wastewater (recycled water). This resulted directly in potable water savings and indirectly in embedded energy savings. Based on a 30-year life for each project, the program hoped to achieve potable water savings of 2,100 million gallons.

11.2 Methods

11.2.1 Data Collection Methods

Recycled water systems were installed and operating at all six participant sites by the program deadline. Two projects, however, experienced several delays and were completed much later than the others, and thus annual water potable savings were evaluated for four sites. Both the pre-retrofit and the post-retrofit data were analyzed. Water utility data for potable water and recycled water use were obtained for both the pre- and post-retrofit periods of data collection. It was decided that, where possible, actual post-retrofit recycled water usage would not be used to determine savings. Instead, savings was defined as the potable water usage that would have been expected during the post-retrofit year had no changes been made. To support calculation of expected usage, monthly evapotranspiration (ETo) data were obtained from local weather stations for these same periods. Additional information was gathered during pre- and post-retrofit site visits. This included staff interviews and obtaining operations logs and site plans.

Ex ante savings for the four evaluation sites are shown in Table 60. The ex ante savings were estimated as simply the potable water usage for the year prior to measure implementation.

Table 60: Sites Included in Recycled Water Program M&V

SITE	MEASURES EVALUATED	EX ANTE WATER SAVINGS (GALLONS/YEAR)
R1 Roadside	1 irrigation meter changed to recycled water	5,865,318
R2 Roadside	1 irrigation meter changed to recycled water	6,517,020
R3 City Park	2 irrigation meters changed to recycled water	10,101,381
R6 City Park	2 irrigation meters changed to recycled water	8,472,126

11.2.2 Analysis Methods

Three years of historical potable water use data were aggregated by month. Evapotranspiration vs. water usage correlations were developed for the pre-retrofit period. In most cases, a correlation was found between monthly evapotranspiration (ETo) data and monthly pre-retrofit water usage. In two cases (R3 and R6) the correlations were not strong, but were considered valid enough to use. For each site except R1 Roadside (see below), the correlation was used with monthly ETo data for the pre-retrofit period to estimate the amount of potable water use that would have been expected had no changes been made. The sum of the 12 months of expected water use was calculated and represents the annual potable water savings for that site. The annual potable water savings for each site was then divided by the total affected acreage at the site to obtain the annual water savings per acre.

For the R1 Roadside site, pre-retrofit data at the site did not yield a usable ETo correlation, so therefore these data could not be used to calculate expected water usage, as was done for the other three sites. Post-retrofit data at the site were also unavailable as the recycled water sub meter was malfunctioning. To account for this, data from the main meter upstream of the sub meter were obtained for pre- and post-measure periods. Pre-measure main meter and sub meter data were used to determine the average percent of sub-meter water usage to main meter water usage for each month. This was then applied to the post-measure main meter data for each month to obtain an estimate of post-measure sub meter water usage.

11.3 Findings

11.3.1 Pre-Measure Potable Water Use

Figure 7 shows the total annual average potable water use prior to measure implementation, based on site meter data. These values represent the usage at each sampled site, which was determined by averaging potable water use from 2006 to the changeover to recycled water. For all sampled sites except the R1 Roadside site, the pre-measure period extended partially into 2009. In these cases, each pre-measure month from 2009 were averaged into the overall number for the corresponding month.

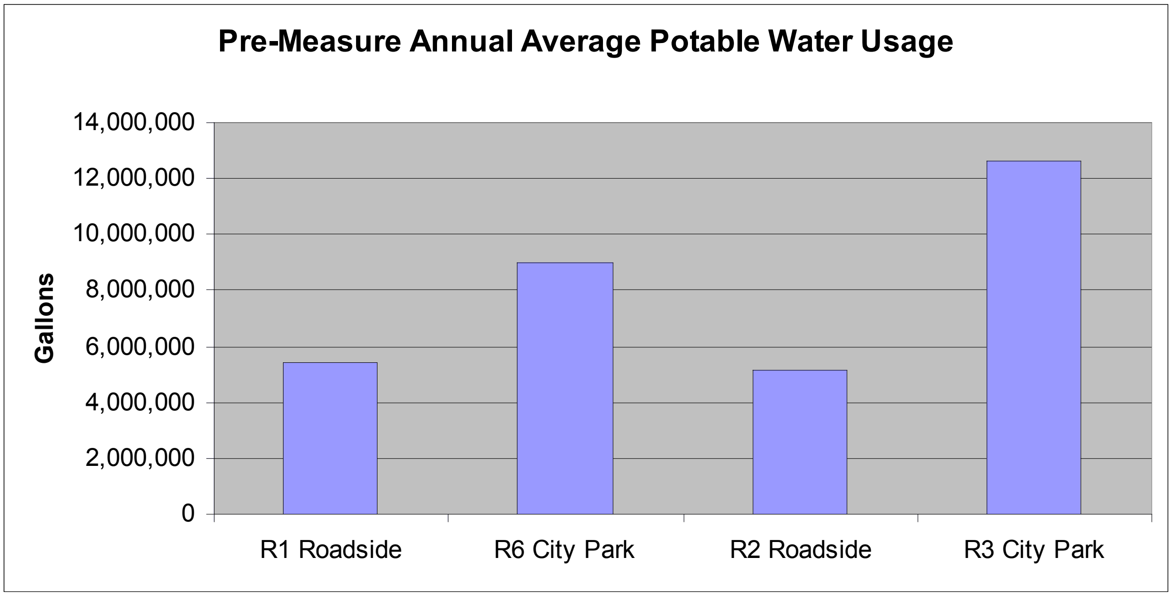


Figure 22: Pre-Measure Annual Average Potable Water Usage

11.3.2 Post-Measure Actual & Expected Recycled Water Use

The post-measure expected (not actual) recycled water usage for each sampled site is shown in Figure 8. The post-measure actual usage was not used in the savings calculation, as it did not represent the expected water usage (i.e. the usage that would have occurred had no change been implemented). As described previously, the expected water usage was calculated using the pre-measure ETo vs. water usage correlation for each site and post-retrofit ETo data for the implementation year for each site. This was done for all sites except the R1 Roadside site, where a valid ETo correlation did not exist.

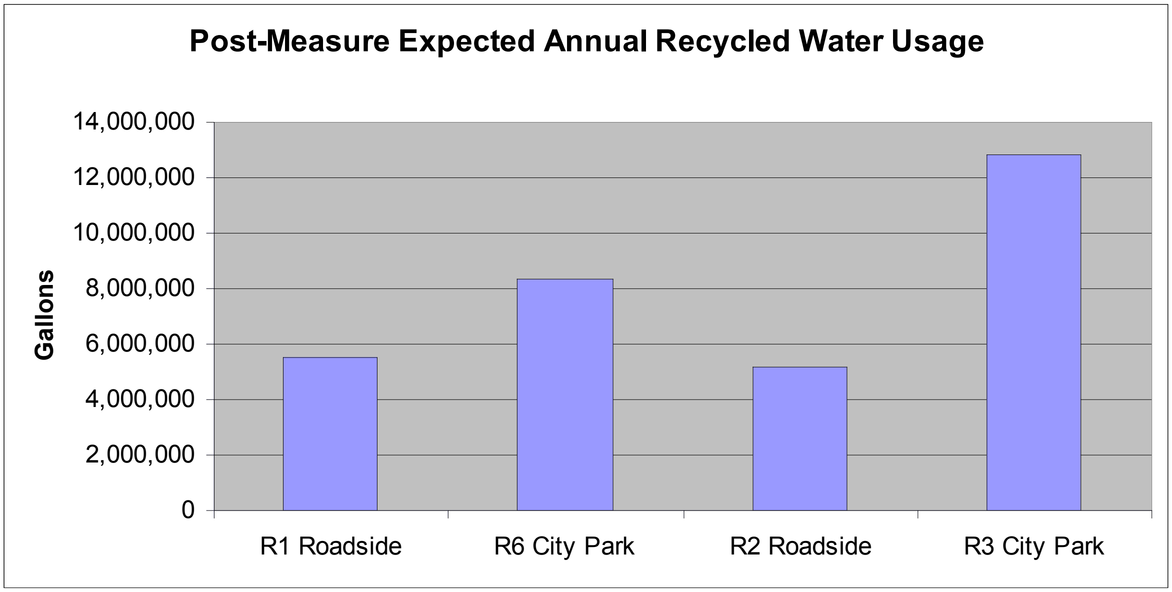


Figure 23: Post-Measure Expected Annual Recycled Water Usage

11.3.3 Water Use per Acre

Figure 3 shows the water use by acre for the pre- and post-measure conditions. Water use per acre is a good measure of the intensity of water usage. The intensity depends upon many factors including type of vegetation, overall climate, the site type, the method of irrigation control, etc. The figure shows that intensity was much higher for the two parks (R3 and R6) than for the two roadside areas. This may be due to the presence of turf in the park areas. Also, since parks are frequented by more people, a higher priority may be placed on keeping the vegetation healthy (as opposed to roadside areas which little or no foot traffic). Each factor that can affect water use is discussed in more detail below.

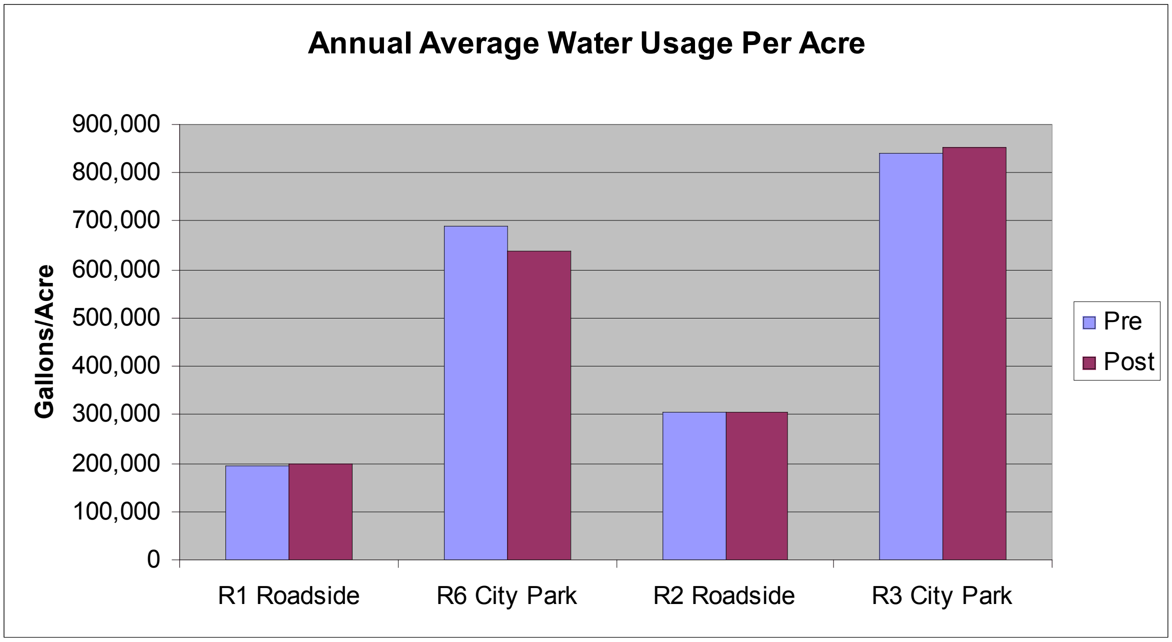


Figure 24: Annual Average Water Use per Acre

- Vegetation Type: Vegetation types were similar for all four sites and included shrubs, trees, ground cover, and some turf. In general, large turf areas (baseball fields, etc.) were not irrigated with recycled water for health reasons, and the potable water meters serving these areas were separate from those affected by this project. Some smaller turf areas were irrigated by recycled water at the two park sites.

- Climate: Although weather data gathered for the analyses were obtained from different weather stations around the area, all sites were in or near San Diego, so the climate was very similar for each.

- Usage Types: Of the four sampled sites, two were roadside areas and two were parks. The park areas included some turf, which requires more irrigation than other types of vegetation.

- Method of Control: Three of the sites (R1, R3, and R6) used weather-based control systems to control the irrigation. ETo data from a local weather station were used to determine the intensity of irrigation. For the fourth site (R2), a simple time clock was used to control irrigation (a strong ETo correlation was still found at this site). For all four sampled sites, no changes were made to the control systems when the conversion to recycled water was made.

- Water Restrictions: Water restrictions were imposed in the San Diego area in June 2009. These restrictions do not apply to the use of recycled water. For three of the four sampled sites, the conversion was made either before or during the same month that water restrictions went into effect. The fourth site (R6) was outside of the area covered by the restrictions.

- Unknown Factors: Unknown factors may have affected the irrigation intensity and could include unknown or unreported malfunctions in hardware (leaks in sprinkler heads, pipes, heads stuck open or closed, etc.) or software (improper or overridden control system settings).

Table 61 shows annual water savings calculated for each sampled site.

Table 61: Water Impact Estimates

SITE	EX ANTE WATER SAVINGS (GALLONS/YEAR)	EX POST WATER SAVINGS (GALLONS/YEAR)	REALIZATION RATE
R1 Roadside	5,865,318	5,549,313	0.95
R2 Roadside	6,517,020	5,170,932	0.79
R3 City Park	10,101,381	12,804,177	1.27
R6 City Park	8,472,126	8,322,750	0.98
Total	30,955,845	31,847,172	1.03

In all cases except R3, ex post savings was less than ex ante savings. The ex post savings takes into account the weather for the implementation year. The lower ex post savings is likely due to a reduced need for irrigation in the implementation year as compared to the ex ante year. It is not clear why ex post savings for R3 was higher than ex ante savings. Realization rates are shown in Table 61. The overall realization rate for the four sites was 1.03.

11.3.4 Individual Site Analysis

This section contains a summary of the analyses for each of the four sampled sites.

11.3.4.1 Roadside (Site R1)

This roadside site is located in San Diego, California and contains 28 acres of irrigated roadside land, which includes shrubs, trees, and ground cover. One potable water meter was replaced in December 2008 with one recycled water meter. The evaluation calculation resulted in 5,549,313 gallons (198,190 gallons/acre) per year of potable water savings.

11.3.4.2 Roadside (R2)

This roadside site is located in San Diego, California and contains 17 acres of irrigated roadside land, which includes shrubs, trees, and ground cover. One potable water meter was replaced in June 2009 with one recycled water meter. The evaluation calculation resulted in 5,170,932 gallons (303,429 gallons/acre) per year of potable water savings.

11.3.4.3 City Park (R3)

This city park site is located in San Diego, California and contains 17 acres of irrigated land, which includes turf, shrubs, trees, and ground cover. Two potable water meters were replaced in June 2009 with two recycled water meters. The evaluation calculation resulted in 12,804,177 gallons (853,612 gallons/acre) per year of potable water savings.

11.3.4.4 City Park (R6)

This city park site is located in a small town near San Diego and contains 16 acres of irrigated land, which includes turf, shrubs, trees, and ground cover. Two potable water meters were replaced in September 2009 with two recycled water meters. The evaluation calculation resulted in 8,322,750 gallons (640,212 gallons/acre) per year of potable water savings.

11.3.5 Embedded Energy Impacts

Embedded energy impacts for the four sites analyzed in this study were calculated by subtracting the incremental embedded energy used for recycled water (i.e. for additional treatment over and above conventional wastewater) from the embedded energy of potable water saved to arrive at net embedded energy savings. The embedded energy for both types of water was calculated by multiplying the *ex post* annual water savings from Table 61 with the energy intensity results for the corresponding water agencies.

The energy intensity for potable water was calculated using water production and energy data provided by each agency to arrive at an estimate of IOU-provided energy and total energy required per million gallons of water produced. The calculations of energy intensities for each agency are shown in more detail in Appendix 1.2. The incremental energy intensity for San Diego recycled water was taken from the California Sustainability Alliance report prepared by Navigant Consulting, as described in Appendix 1.2.

Potable and recycled water production and energy data were not provided for the City of Carlsbad, so the embedded energy savings for site R6 could not be calculated. For the remaining sites, the City of San Diego Water Authority provided data and embedded energy results for those are shown below in Table 62. IOU energy could not be separated out from other sources of energy for recycled water treatment, so savings in Table 62 only reflect total energy saved from all sources. It should be noted that a large portion of the energy at the North City Reclamation Plant in San Diego comes from landfill gas co-generation.

Table 62 shows that the annual embedded energy savings for the SDG&E Recycled Water Pilot were 75,205 kWh of energy from all sources.

Table 62: Annual Embedded Energy Savings of SDG&E Recycled Water Pilot Sites

SITE	WATER AGENCY	TOTAL ENERGY SAVINGS (KWH/YEAR)
R1 Roadside	City of San Diego Water Authority	17,741
R2 Roadside	City of San Diego Water Authority	16,531
R3 City Park	City of San Diego Water Authority	40,934
R6 City Park	City of Carlsbad Water	--
Total		75,205

11.4 Discussion of Uncertainty, Threats to Validity, Precision, Potential Biases

As described above, data from water utility meters were used in the savings calculation. While the utility meters are likely to be reasonably accurate, the level of accuracy and precision of these meters is unknown, therefore some uncertainty exists regarding the exact quantification of the water use data.

Weather data (ETo) used in the analysis were obtained from the California Irrigation Management Information System (CIMIS). ETo data were used from the most representative weather station for each site. However, micro-climate impacts can vary between the weather station and the site resulting in some reduction in the accuracy between the ETo value at the weather station and the ETo value at the site.

The water usage vs. ETo correlation discussed above is a linear regression that produced a wide range of R^2 values. As values move further from a perfect correlation of R^2=1.0, the uncertainty due to the use of regression increases. R^2 values are shown in Table 63 for each sampled site.

Table 63: Water Usage vs. Evapotranspiration Correlation R^2 Values

SITE	R^2 VALUE
R1 Roadside	N/A
R2 Roadside	0.81
R3 City Park	0.65
R6 City Park	0.50

11.5 Discussion of Findings

The objective of the pilot program to generate potable water savings was realized. All six sites were converted from the use of potable water to the use of recycled water for irrigation within the time frame of the program. The energy implications of replacing potable water with recycled water will vary among water agencies. Throughout California, wastewater agencies are required to treat wastewater to a high standard before discharging it into the environment. The energy requirements for recycled water would then be the additional treatment required to bring this water to recycled water standards plus any additional pumping required to deliver the water to the customer. The energy requirements for recycled water must then be compared with the energy requirements for potable water. Throughout much of California, especially Southern California, the energy requirements for potable water are high. Thus, recycled water is very likely to yield significant energy savings. Detailed analyses, however, are still needed to quantify these savings.

If implemented on a large scale, a program to support the conversion of sites that use potable water for irrigation to using recycled water for irrigation is likely to be very popular. The cost of recycled water is currently much lower than the cost of potable water ($0.80/HCF vs. $3.66/HCF) in the program area. Thus, once the cost for converting from use of potable water to use of recycled water is amortized, a customer would realize substantial cost savings by using recycled water for irrigation, if using the same volume of water. Alternatively, a customer could use more recycled water than potable water and still realize some cost savings. A second benefit to the use of recycled water vs. potable water is that the number of nights per week that recycled water can be used for irrigation is not as limited as the nights per week that potable water can be used for irrigation. For these reasons, significant free ridership should be expected.

The cost and convenience considerations described above could lead to customers using more recycled water than the amount of potable water they would have used. If that occurs, it could affect the amount of embedded energy savings achieved by converting from potable water to recycled water. In addition, if future water restrictions impose additional constraints on the use of potable water for irrigation, the embedded energy savings achieved by any site converting from potable to recycled water would be further reduced.

Based on the small sample of project sites that were evaluated, the usage intensity appears to be much greater for parks than for roadside areas. This means that for the same first cost for conversion to use of recycled water, there are much more energy and water savings for parks than for roadside areas. It is recommended this observation be investigated further, as it may mean that future full-scale programs would achieve greater savings if targeted to park sites.

12 Key Findings and Recommendations

In this section we summarize some of the key findings from the Pilots, and list some high-level recommendations for future evaluations. Since the nature and outcomes of the various Pilots differed significantly, however, readers should still refer to the specific program evaluation chapters for additional details. In general, most of the program evaluations provided useful information about embedded energy savings to inform future analyses of cost-effectiveness and program continuation; notable data limitations were described in the specific program chapters and are summarized below.

Table 64 summarizes the annual potable water, wastewater and IOU embedded energy savings that were measured for each of the Pilots. For each program, the table also lists the report chapter where evaluation details are provided, the number of project sites or measures that were evaluated, and the energy IOU portion of the project implementation budget for each program, although program cost-effectiveness was not assessed.

As shown in the table, SDG&E's Large Customer Audits Pilot generated relatively high IOU energy savings from both water and wastewater savings, while SCE's Leak Detection Pilot generated high energy savings by fixing distribution system leaks. PG&E's Large Commercial Customers Pilot also generated high IOU energy savings by reducing wastewater treatment. In contrast, PG&E's Emerging Technologies Pilot did not save any IOU energy from water pumping changes.

12.1 Summary of Key Findings

Following are some of the key findings from the evaluations of the nine pilot programs:

1. SCE's Leak Detection program appears to offer the greatest energy savings potential (at relatively low cost) among all the Pilot programs. In particular, the energy savings documented in this report are based on leaks that were *actually* repaired during the program period; *potential achievable* water (and energy) savings were estimated to be much higher by the program implementation contractor.

2. PG&E and SDG&E detention facility projects that installed efficient toilets, urinals and toilet flush timers generated high energy savings. Future programs may seek to focus on these types of projects, pending detailed cost-effectiveness analyses. (For these projects, SDGE&E contributed capital funding whereas PG&E offered rebates based on water savings.)

3. Recycled water retrofit projects can offer large potable water savings, but additional research is needed on the IOU embedded energy in recycled water treatment (which offsets energy savings from potable water). In areas where recycled water treatment does not require significant IOU energy, it may be possible to design cost effective programs based on potable water savings.

4. For the other Pilots, the program costs are likely to exceed the energy benefits, even where embedded energy savings are incomplete (e.g., wastewater for PG&E HETs). That said, additional research is needed on actual program spending, measure lifetimes and potential

changes in end-user energy (e.g., new motors, reduced hot water). Cost-effectiveness could be increased by reducing energy IOU program funding levels and/or targeting programs to the most energy intensive water systems (e.g., Lake Arrowhead).

Table 64: Summary of Annual Potable Water, Wastewater and IOU Embedded Energy Savings, by Pilot Program

Pilot Program	IOU Budget (A) [1]	Project sites, Measures (B)	Ex Post Potable Water Savings (Gallons/Yr.) (C)	IOU Embedded Energy Savings – Potable Water (kWh/Yr.) (D)	Ex Post Wastewater Savings (Gallons/Yr.) (E)	IOU Embedded Energy Savings - Wastewater (kWh/Yr.) (F)	Total IOU Embedded Energy Savings (kWh/Yr.) (D + F)
PG&E Large Commercial Customers (Chapter 3) [2]	$700,000	11 sites	33,719,230	12,417	16,478,711	42,772	**55,189**
PG&E Low Income High Efficiency Toilets (Chapter 4) [3]	$200,000	478 toilets	5,098,320	14,328	5,098,320	Not measured	**14,328**
PG&E Emerging Technologies (Chapter 5)	$341,000	2 water agencies	Not applicable	0	Not applicable	Not applicable	**0**
SCE Low Income High Efficiency Toilets (Chapter 6)	$200,000	276 toilets	1,329,768	5,538	1,329,768	174	**5,712**
SCE Express Water Efficiency (Chapter 7) [4]	$133,000	3 pH controllers	6,351,000	Not measured	6,351,000	9,385	**9,385**
SCE Leak Detection (Chapter 8)	$300,000	3 water agencies	82,923,912	178,143	Not applicable	Not applicable	**178,143**
SDG&E Managed Landscapes (Chapter 9) [5]	$250,000	13 sites	51,772,695	21,275	Not applicable	Not applicable	**21,275**
SDG&E Recycled Water Retrofits (Chapter 10) [6]	$250,000	4 sites	31,847,172	75,205	Not applicable	Not applicable	**75,205**
SDG&E Large Customer Audits (Chapter 11) [7]	$496,000	4 sites	82,081,336	73,710	82,081,336	81,802	**155,512**

[1] Does not include implementation budgets of partner water agencies. Actual program expenditures may be less than these approved budgets.
[2] Does not include IOU embedded energy savings for three water retailers (serving three projects) that did not provide data. Does not include IOU embedded energy savings for two large recycled water projects; no data were provided by the recycled water provider. Does not include IOU embedded energy savings for three wastewater agencies (serving four projects) that did not provide data.
[3] The wastewater agency serving the vast majority of program installations did not provide embedded energy data.
[4] The water retailer for the customer site did not provide embedded energy data. Water and energy savings are artificially high due to poorly maintained cooling towers.
[5] Does not include energy savings from two retail water agencies (serving two sites) that distribute imported treated water from a wholesaler.
[6] Embedded energy savings are from *all* sources (not only SDG&E). Does not include energy savings from one city (serving one project) that did not provide potable water or recycled water data. Two other projects were installed late in the program period and were not evaluated.
[7] Does not include energy savings from one city (serving one project), which did not provide potable water or wastewater data.

12.2 Program-Specific Findings

12.2.1 PG&E Large Commercial Customers Pilot Program

PG&E's Large Commercial Customers Pilot generated high potable water savings through recycled water retrofit projects for a private company and a school site, however, additional research is required to understand the embedded IOU energy in the tertiary treatment of recycled water; no data were provided for this evaluation. In addition, there may be high free ridership if recycled water costs significantly less than potable water in PG&E's service territory. This Pilot also achieved high water savings through a detention facility project that installed low-flow toilets with electronic flush valves/timers.

Seven of the 11 program participants were ozone laundry customers, and free ridership for these projects was probably low, as several eligible customers turned down the opportunity to participate (due to firm spending limits in the poor economy), even while the combined PG&E and water agency rebates covered a significant portion of the installation cost. While one ozone laundry project generated negative water savings (for unknown reasons), the other six realized positive savings, illustrating the importance of evaluating a sufficient number of sample sites. One project, a high-efficiency commercial dishwasher, generated large negative water savings because a new trough drain installed at the same time was inadvertently left open each morning before the dishwasher began operations (requiring the dishwasher to intake more water). While this type of problem is easily rectified, a larger sample size would provide more reliable savings estimates.

12.2.2 PG&E High Efficiency Toilets Pilot Program

The calculated embedded energy impacts for the PG&E HETs program are modest but also incomplete, as wastewater treatment data were not provided to the evaluation team. Embedded energy savings from reduced wastewater treatment would need to be measured or estimated in order to understand the full impacts of this type of program. That said, the measured water savings could reasonably be applied to other low-income households with about 5 persons, although water savings could vary more or less than for the SCE HET program, as relatively more non-retrofit toilets remained in the single-family homes, and it is not clear how people used the different models because non-retrofit toilets were not metered.

Although changes in toilet leakage were not considered in the calculated energy savings, leakage was observed to be a prevalent problem with the new toilets and is reducing potential water and energy savings by over 20 percent. Furthermore, this evaluation revealed that future HET programs should not rely on the manufacturer rated flush volumes without additional testing, since the observed flush volumes were higher in this case.

Additional research needs to be conducted prior to implementing a more comprehensive program. In particular, given the low-income target population, it is not known if property owners will install these measures on their own without program assistance; this evaluation found that almost one-third of the existing toilets in the single family homes were already low-flow models. Although program cost effectiveness was not assessed, utility cost-effectiveness could potentially be improved by requiring the property owners to pay a portion of the installation costs.

12.2.3 PG&E Emerging Technologies Pilot Program

PG&E's Emerging Technologies Pilot did not result in measured energy savings, as a planned automatic pumping control algorithm was not implemented at San Jose Water Company during the program period, and system operators at EBMUD did not utilize new SCADA screen displays of real-time energy consumption to manually improve the energy efficiency of pumping. While these strategies may have resulted in energy savings in other places, this was not observed during the Pilots period.

12.2.4 SCE High Efficiency Toilet Pilot Program

The total annual IOU embedded energy savings for the SCE HETs program (5,712 kWh/year) are modest compared to the other programs, in part because relatively few HETs were assessed (276), and also because the energy intensity of the affected wastewater agency is very low (132 kWh/MG). It would be reasonable to extrapolate the calculated water savings findings to a larger program, provided the household characteristics are generally similar to those of the evaluation sample. Thus if future SCE programs served low-income apartment units with two toilets, and retrofit about 90 percent of them, similar water saving results should be expected. (For this Pilot, the evaluation sample was shown to have similar characteristics and toilet installation/usage patterns as the broader local community.)

As with PG&E's HET program, potential water and energy savings are being reduced by leakage. Daily water savings of about 20 gallons/household were found in this evaluation, and would be closer to 30 gallons/household if most of the leaks were repaired (the largest leaks in particular). This evaluation also found that some of the new toilets flush at higher volumes than the manufacturer's ratings.

The owner of the apartment buildings had utilized the program installation contractor to install new toilets at several other company owned sites previously - it is not known if these were low-flow toilets or if rebates were obtained. Additional research is needed to better understand if low-income property owners will install these measures on their own without program assistance. Similarly, it may be possible to increase utility cost-effectiveness by requiring property owners to pay a portion of the installation costs (cost effectiveness was not assessed for this evaluation).

12.2.5 SCE Express Water Efficiency Pilot Program

SCE's Express Water Efficiency Pilot yielded only one pH controllers project, which retrofit 3 cooling towers at one customer site. Importantly, the water and embedded energy savings shown in Table 64 should not be extrapolated to other sites or programs, as the cooling towers were operated atypically during both the pre- and post-retrofit periods. In particular, two water bleed controllers were not functioning in the pre-retrofit period, and the towers were being bled manually, resulting in unusually high water use. After the retrofits, the concentration ratios of the three towers were still below the normal target level, reducing potential water savings. Based on operational data from the three towers and data from more typical, properly maintained systems (before and after retrofits), actual water savings at other sites may be closer to 25 percent of those documented in the table.

12.2.6 SCE Leak Detection Pilot Program

SCE's Leak Detection Pilot warrants further consideration for inclusion in regular IOU programs, pending further analysis of cost effectiveness. According to secondary research completed for this Pilot, most water agencies in California do not proactively manage leakage and only react to found leaks, typically after they have become larger.[67] Thus a program that offers proactive leak detection services could potentially generate large net water saving impacts. (The program may not need to offer comprehensive water audits, however, particularly if water agencies are already required to conduct these.) According to the secondary research, about 0.87 million acre-feet of water is lost each year through leaking water distribution pipes in California, and about one-third of this may be economically recoverable. The water savings documented for the three water agencies that participated in this Pilot, however, should not be extrapolated to a broader population of agencies, as these agencies have relatively low levels of leakage. Water savings could be even larger if agencies with relatively more leakage can be encouraged to participate.

12.2.7 SDG&E Large Customer Audits Pilot Program

SDG&E's Large Customer Audits Pilot had four customers install measures, and given the range of equipment installed it is difficult to draw broad conclusions about this program. As with PG&E's Large Commercial Customers Pilot, significant water savings were achieved through low-flow toilets, flush valves/timers and other measures at a large detention facility. This project received significant capital funding from SDG&E through the Pilot, and would not have been completed without this funding. The customers that installed autoclaves and reverse osmosis upgrades and process changes also realized water savings. Two of these customers did not obtain any water saving incentives from Metropolitan Water District for installed measures, but may not have been willing to pay for the free comprehensive water/energy audits offered through the program.

12.2.8 SDG&E Recycled Water Pilot Program

While SDG&E's Recycled Water Pilot generated high potable water savings, it should not be added to the regular program portfolio until more research is conducted. In particular, this program has a relatively high potential for free ridership, since local costs for recycled water are much lower than for potable water; SDCWA had several planned retrofit projects to select program participants from. In addition, more research is required on the intensity of IOU energy in tertiary recycled water treatment (i.e. the incremental energy beyond that needed for standard wastewater treatment). This program evaluation utilized past research on tertiary water treatment in San Diego, as more current detailed energy data could not be obtained for any of the recycled water agencies serving Pilots participants. Lastly, these Pilot evaluation findings should not be

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[67] *Secondary Research for Water Leak Detection Program and Water System Loss Control Study*, *Final Report*. WSO, December 2009.

extrapolated to a larger program, due to the small sample size and because there was only a modest correlation between actual ETo rates and potable water usage. More importantly, recycled water retrofit projects may differ significantly in scope and by end use, and this Pilot suggests that future public agency projects should target park sites, which have higher water usage than roadsides, for instance.

12.2.9 SDG&E Managed Landscapes Pilot Program

The evaluation of SDG&E's Managed Landscapes Pilot suggests that water savings of 25 percent are generally achievable, and that these savings are probably due to the vendor's "smart" irrigation technology since no major site changes were noted in the post period. The low correlations between water use and the ETo data are presumably due to few ETo data points, microclimate effects, and/or vendor adjustments to how the ETo data are used by the proprietary software (perhaps even between sites, to develop partially customized watering schedules). Free ridership for this program was probably low, since the program paid for all of the customers' first-year service costs. However, we do not know how many of the participant sites plan to utilize the smart irrigation technology beyond the first free year of service. Additionally, the imposition of mandatory water restrictions in the future will significantly increase free ridership for these projects.

12.3 Water Agencies Data Collection

Collecting water and energy data from the water agencies proved to be challenging for both the water agencies and the evaluation team. Water agencies that were involved in conceptualizing the programs from an early stage (e.g., Sonoma County Water Authority, Apple Valley) expected that production and energy data would eventually be required in some form. Other water retailers, however, were not initially aware that they would need to provide data, even if their water wholesaler was a Pilot program partner. In particular, wastewater and recycled water agencies that operate independently of water wholesalers and retailers did not know of the need for energy data until contacted by the evaluators. Most of the agencies did eventually provide data; some started to and then ceased communications, while others politely declined to provide data citing staff constraints and/or confidentiality concerns. In some cases, water conservation managers may have been informed of potential data collection efforts, but the actual keepers of the data (e.g., operations staff) were not aware when contacted by the evaluators.

All of the water agencies were surprised at the detailed level of data that were requested, and the amount of staff time required to collect and clean the data. The data collection survey requested the most detailed data available (preferably hourly) for water flows and associated energy use for all stages of the water supply chain—source water collection, conveyance, treatment and distribution. In addition, the survey asked for system schematics, details of the water treatment process, and a description of how operations could change under different conservation scenarios. The same data were requested if the water agency had only one participating customer or many.[68]

In the end, most of the agencies were able to provide only monthly water/wastewater production data, and energy data were requested instead from the IOUs after collecting and confirming the energy accounts with the water agencies. Despite these steps to simplify the data collection, the water agencies sometimes had to involve up to five staff persons to collect data for different facilities or facility types, electric accounts, etc. Sometimes this required significant staff time, and then additional time was needed to review the data with the evaluators. On the technical side, some water agencies were not able to easily disaggregate water flows (e.g., distribution and treatment) and all of the energy accounts had to be reviewed to omit ancillary uses (e.g., lighting, administrative offices) to the extent possible. Despite these challenges, the evaluation team was able to obtain usable data from most of the water agencies that served participating Pilots customers.

12.4 Recommendations

12.4.1 Overarching Recommendations

This impact evaluation of the Pilots produced a number of recommendations for future evaluation efforts, including:

1. **Systematically inform *all* of the agencies from which embedded energy data will be required for evaluation purposes.** For this evaluation, some retail water agencies did not provide embedded energy data, and important regional wastewater and recycled water agencies did not provide data. If new embedded energy data are required for future studies or pilot programs, the CPUC and/or the IOUs could make the data submission a prerequisite for programs partnering.

2. **Conduct further research about recycled water, particularly IOU embedded energy for tertiary treatment and retail costs to consumers**. These projects have a relatively high potential for free ridership, since costs for recycled water in some areas are lower than for potable water (in other areas they are similar). In addition, more research is needed on the intensity of IOU energy in tertiary recycled water treatment (i.e., the incremental energy beyond that needed for standard wastewater treatment). This evaluation was unsuccessful in collecting new detailed energy data from three recycled water agencies serving Pilots participants. Throughout much of California, especially Southern California, the energy requirements for potable water are high. Thus, recycled water is likely to yield significant energy savings. The energy implications of replacing potable water with recycled water, however, will vary among water agencies.

[68] For the PG&E HETs program, for instance, water and energy data were only collected for one water agency, which serves the vast majority of program participants. For other programs, however, there might only be one customer participant in each of multiple cities, and the evaluators tried to obtain data from each of these cities.

3. **Evaluate larger samples if possible.** The evaluated project samples were generally small due to limited participation and evaluation budget constraints. For some project types such high efficiency commercial dishwashers, pH controllers, and boiler water reuse, there was only one Pilots participant and only one project was evaluated.
4. **Incorporate changes in end-user energy consumption into cost-effectiveness calculations.** Although this evaluation was not tasked with measuring or estimating end-use energy changes, these changes could be significant and offset a portion of the embedded energy savings. Cost effectiveness analyses and/or future studies should attempt to quantify these impacts, to understand the true net energy savings from water conservation programs.

12.4.2 Program-Specific Recommendations

2. **PG&E Large Commercial Customers: Ozone Laundry Systems**
    - **Develop ways to consistently obtain occupancy and/or laundry pounds data to normalize water use.** These data could not be obtained for this evaluation for a variety of reasons (e.g., evaluation activities timing, time constraints among hotel staff). Future studies should try to collect additional data to normalize water use and refine water/energy savings estimates.
3. **SCE Express Water Efficiency: pH Controllers**
    - **Conduct further research about pH controllers.** This evaluation focused on one project where the pH controllers were not properly maintained, which misrepresented likely water savings. While the evaluation was able to estimate achievable water savings, addition research is warranted, unless existing secondary research provides reliable estimates of water savings for this measure.
4. **High Efficiency Toilets (SCE and PG&E)**
    - **For HET evaluations where direct metering is conducted, add metering to non-retrofit toilets.** This would provide additional information to understand if/how actual household toilet usage may change after the retrofits (i.e. if some toilet models are preferred).
    - **For HET evaluations where the Flow Trace method is used, conduct on-site verifications to confirm the make and model of the installed toilets.** This is needed to distinguish maladjusted toilets from un-replaced toilets. Furthermore, this would better allow evaluators to apply results from only fully retrofit units to partially retrofit units on a per-toilet basis, if this approach is preferred.

- **Try to develop more predictive models relating household occupancy to toilet usage.** This would require collecting periodic occupancy data over time, and would allow calculated program saving to be applied elsewhere more reliably, as household occupancy can change due to travel, visitors, etc.

- **Do not use manufacturer rated flush volumes for HETs.** Both HET studies found that actual flush volumes differed from these ratings.

4. PG&E Emerging Technologies

- **Ensure that water agencies planning SCADA improvements to save energy have supportive operating conditions and policies.** Program planners need to make sure that operator behavior change is in fact feasible in the specific operating environment; otherwise energy savings are unlikely to result.

5. SCE Leak Detection

- **Conduct real-time field visits to verify repairs of leaks found during program-sponsored leak detection surveys.** Due to logistical and budgetary constraints, this could not be done for this evaluation, but should be considered for future evaluations if energy savings will be claimed.

6. SDG&E Managed Landscapes

- **Conduct further research on the vendor's smart irrigation technology to understand when and why the typical control algorithms may be customized.** This could help refine future estimates of expected water savings, as the evaluation found some unexpected changes in pre/post soil moisture correlations and the vendor may make controller adjustments at future installations.