CALIFORNIA SINGLE-FAMILY RESIDENTIAL WATER USE EFFICIENCY STUDY

WATER USE EFFICIENCY PROPOSAL

SECTION B- PROPOSITION 50

January 11, 2005

Submitted to:

California Department of Water Resources
Office of Water Use Efficiency
1416 Ninth Street, Room 338, Room 338
Sacramento, CA 95814

Submitted by:

Irvine Ranch Water District
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California Single-Family Residential Water Use Efficiency Study

Project Information

The State of California withdraws over 6.1 billion gallons of fresh water each year for public water supplies. While this represents only 16% of total freshwater withdrawals,[1] these withdrawals tend to be the highest quality water taken from the most ecologically sensitive streams in the state: such as the delta of the San Joaquin and Sacramento Rivers. Single family residential water use comprises the largest single category of urban water use in California, and offers tremendous potential for savings as part of a well-informed statewide municipal water conservation effort. The key to better management of residential water demands is better understanding of efficiency measures already in place and accurate measurement of usage patterns in typical homes. Obtaining these measurements and projections is the goal of our proposed project.

The proposed California Single-Family Residential Water Efficiency Study is a statewide water use research project that includes detailed analysis of the water use patterns and existing efficiency in 780 homes located in the most populous counties in the State. The primary applicant is the Irvine Ranch Water District (IRWD), of Irvine, CA, but a total of 10 separate water agencies will be participants and will contribute cash and in-kind services to the project.

The research team is lead by ***Aquacraft, Inc. Water Engineering and Management***, a firm that has pioneered the application of scientific data collection and analysis methods to water use and water efficiency projects. **William DeOreo, P.E.** and **Peter Mayer, P.E.**, the principals at Aquacraft will head the effort. ***Stratus Consulting***, a leading environmental and economics research group lead by **John Whitcomb, Ph.D.** and **Jim Henderson, M.S.** will handle survey design and statistical modeling duties. Evaluation of the study findings as they pertain to the overall water supply conditions in California will be handled by the ***Pacific Institute***, lead by **Dr. Peter Gleick** and **Gary Wolfe, Ph.D., P.E.**, noted experts on water efficiency potential in the region. California-based water conservation expert **John Olaf Nelson** will be the project's senior advisor. **Bill Gauley, P.Eng** of ***Veritec Consulting*** will assist with data analysis quality assurance and quality control.

IRWD will sign inter-governmental agreements with the other participating water agencies and all funds from the state and the participating agencies will be collected and distributed by IRWD and used to pay the project expenses. In addition to the inter-governmental agreements, IRWD will sign a contract with the prime consultants, Aquacraft, Inc. which will obligate the Consultants and their subcontractors to perform all of the work specified in this proposal according to the task descriptions, cost breakdowns and schedules contained herein. The California Urban Water Conservation Council will organize a PAC for the project which will review and advise on the work progress.

[1] "Estimated Use of Water in the United States in 2000", USGS Survey Circular , Reston VA

Statement of Work, Section One: Relevance and Importance

This project will have multiple benefits for the State of California and will likely be used as a critical benchmark for residential efficiency efforts over the next 20 years. One of the major goals of the CALFED program is to reduce urban water demands both directly in the Bay Delta System and indirectly by reducing demands for water from the system throughout the State. The California Single-Family Residential Water Use Efficiency Study will:

- Provide critical local information on indoor and outdoor single-family water use efficiencies both as a benchmark for current conditions and to evaluate all future residential efficiency programs
- Provide a sound basis for estimating how much of the future urban water demands of the State of California can be met through conservation
- Provide information on the current market penetration rates of high efficiency fixtures and appliances in single family homes
- Identify the rate of adoption of high efficiency devices by California homeowners
- Quantify the degree to which water conservation opportunities (both indoor and outdoor) in the single-family sector have been exhausted, and the remaining water that might be saved from improved efficiency in single-family homes throughout the state.
- Provide critical information for assessing how well key BMP's adopted as part of the 1991 Memorandum of Understanding have been implemented, and how much water savings can be attributed to these efforts.
    - Specifically the following BMPs will be assessed: BMP 1, Residential Water Surveys; 2, Residential Plumbing Retrofits; 6, High-efficiency washing machine adoption, and 14, ULFT replacement programs.
- Provide baseline demand data for analysis of a wide range of water conservation programs and systems such as ET controllers, hot water recirculation systems, and energy use analyses.
- Provide key data that can be used by the many California cities seeking to update their Urban Water Management Plans
- Provide guidance for allocation of resources and efforts by identifying areas with the most promising conservation potential and the most successful programs.

The Issue – Essential Water Use Data

It has been nearly 10 years since the Residential End Uses of Water study (REUWS), conducted by Aquacraft, Inc. and sponsored by the AWWA Research Foundation published detailed information on the water use patterns of single-family households in 12 cities within the U.S. and Canada. Four of the 12 participating cities in that study were located in California. The REUWS data set showed reasonable consistency in indoor water use across the country, and also revealed a relatively low penetration rate of high efficiency fixtures and appliances. The REUWS also provided important information about irrigation patterns and application rates compared to net evapotranspiration.

The Residential End Uses of Water study has been used and cited repeatedly by conservation professionals over the past 10 years and has been an important foundation for establishing demand projections and conservation potential. Over the next 10 years, California will embark upon the

largest water efficiency implementation effort every undertaken in the U.S. In order to prepare the most strategic and effective efficiency programs possible and to accurately evaluate the impact of these programs, detailed baseline data that is specific to California is required.

The California Single-Family Residential Water Efficiency Study will build upon the REUWS and will provide a much needed focus on California. Some of the key questions that will be answered include: How much water is currently used in the single-family sector for each specific end use (toilets, showers, clothes washers, dishwashers, faucets, baths, irrigation, swimming pools, leaks, evaporative cooling, etc.)? What is the relative efficiency of this use? How has water use changed over the past 10 years? Which water conservation programs have been the most successful in improving single-family water efficiency? What are the current irrigation efficiencies across the state, and how much progress has been made in improving landscape water use?

This essential information will greatly assist long-range water planning efforts. That is why so many California water providers are participating and contributing to this study. These providers want to better understand the existing water use patterns of their customers and the amount of water savings still available from indoor and outdoor efficiency programs. In California, where water conservation is essential to meeting the goals of the Bay Delta M.O.U. it is necessary to address these issues in a large, systematic study of current single-family residences located throughout the state.

The single-family sector is of tremendous importance, but the researchers also understand the necessity of obtaining similar information on California's multi-family and ICI customers as well. Future research projects will focus on these customers, but will require different research methods and approaches because of a range of technical issues. Because single-family demands constitute the largest segment of municipal demands and have been the focus of many conservation efforts, it makes sense to tackle this research area first.

Project Description and Background

California Single-Family Residential Efficiency Study is a Section B Proposal

This proposal is directed at Section B of the California Department of Water Resources Proposal Solicitation Package, which seeks to fund projects that include *basic and applied research* rather than implementation. Under the list of eligible projects that D.W.R. wishes to see undertaken the second category is entitled: "Urban water use efficiency feasibility studies, research and development, pilot or demonstration projects." This project will use a combination of flow data logging and end use analysis, customer surveys, and statistical analyses to create a current and comprehensive data set of single-family water use in California that will provide information needed by water planners at a local level and across the state. This proposal addresses the specific urban water use efficiency studies identified as most relevant in the proposal solicitation package.

Results Will Provide Dynamic Picture of Water Use Patterns

The purpose of this project is to obtain accurate end use water consumption data from a large sample of approximately 780 single-family homes. Homes will be selected randomly in groups of 60 home sample units. Three of the 10 participants will sample from 2 units, giving the study a total of 13 sample units. Table 1 shows the details on the participants. Each of these has provided a letter of commitment, which is attached to the proposal in Appendix G. The sample units are

distributed evenly between southern and northern California (7 units in the South and 6 units in the north). As shown in Table 2 these communities represent nearly 1.5 million service connections and water deliveries of 1.88 million acre feet. In addition, the participating agencies cover more than 16 state assembly districts, 12 state senate districts and 9 congressional districts. We suspect that this proposal has the greatest geographical scope of any DWR will be considering.

Table 1: Participants in California single family water study

Water Provider	Contact Person	Phone Number	Email	Units
Beverly Hills	Renee Schrader	(310) 285-2467	rschrader@beverlyhills.org	
Davis Water	Jacques DeBra	(530) 757-5679	water@dcn.davis.ca.us	1
East Bay MUD	Richard Harris	(510)287-1675	rharris@ebmud.com	2
Irvine Ranch WD [a]	Fiona Sanchez	(949) 453-5325	sanchezf@irwd.com	1
Las Virgenes WD	Randall Orton	(818) 880-4110	rorton@lvmwd.com	1
Los Angeles Dept of Water and Power	Tom Gackstetter	(213) 367-0936	thomas.gackstetter@water.ladwp.com;	2
Redwood City	Manny Rosas	(650)780-7468	mrosas@redwoodcity.org	1
San Diego City and County	Rose Smutko	(858) 522-6756	rsmutko@sdcwa.org	2
San Francisco Public Util.	Dana Haasz	(415) 551-4739	dhaasz@sfwater.org	1
Sonoma County Water	Lynn Hulme	(707) 547-1909	lynnh@scwa.ca.gov	1
			Total Units (60 homes ea)	13

Table 2: Service Connections and Water Delivered by Participants

Agency	Service Connections	AcreFeet/Yr
IRWD	86,660	86,267
San Francisco PUC	170,770	93,000
San Diego County Water Authority	135	643,960
Sonoma County Water Agency*	91,608	53,170
Davis	16,269	15,100
Las Virgenes WD	20,021	30,846
Los Angeles DWP	672,011	681,381
Beverly Hills	10,647	12,805
East Bay MUD	378,000	250,000
Redwood City	22,919	12,931

TOTAL	**1,469,040**	**1,879,460**

The study results will allow household water use to be characterized on several levels. First, per capita and per household use by specific end use will be quantified along with irrigation application rate and leakage. Second, indoor and outdoor water use efficiency will be compared to levels measured in the past and those that have been measured from homes equipped with high efficiency fixtures, appliances, and irrigation systems. These results will provide crucial information on how much of the water savings from plumbing codes, retrofits and irrigation efficiency measures has been captured, and what potential savings remain to be achieved.

What Participants Will Get from the Study

Each participating agency will receive a complete water use analysis performed on a random sample of homes from their service area. End use consumption data will be collected from each home in the sample and complete water use profile will be developed. The data to be obtained from each study home includes: two years of historic billing data, two weeks of flow trace data disaggregated into component end uses, detailed customer level information including the number and ages of residents, the fixtures and appliances in each home, irrigation methods, measured irrigated area, landscape characterization and other relevant data. These data will be combined with other information on the local climate, economics and the activities of the water provider with respect to pricing and conservation programs. Each participating agency will receive a report detailing residential water use patterns in their service area as well as critical information on the efficiency of this water use.

Household Water Use Information Provided

The household water use will be disaggregated into end uses and expressed as gallons per household and (where appropriate) per capita per day (and per year) for:

- Toilets
- Showers
- Clothes washers
- Dishwashers
- Leaks
- Baths
- Miscellaneous faucet use
- Water treatment
- Irrigation

The efficiency of use will be determined for each house in the study by calculating:

- Flush volume of toilets (gal. per flush)
- Flushing frequency (flushes per day)
- Typical shower flow rates (gpm)
- Typical sink faucet flow rates (gpm)
- Typical shower volumes (gal.)
- Typical dishwasher volume (gal./load)
- Typical clothes washer volume (gal./load)
- Frequency of use for clothes washers and dishwashers

- Irrigation application rate for turf and non-turf landscape compared to theoretical irrigation requirement based on the characteristics of the landscapes.

Information from surveys and other sources will be used to develop relationships between household use and important parameters such as the residents per home, age of home, the presence of high efficiency fixtures and appliances, the size of the home, the irrigated area in turf and non-turf, the type of irrigation controller used, the presence of rain shut off devices, local ET, participation in agency sponsored conservation program, etc.

California BMP's Addressed

The data from this study will be highly useful for preparation of required Urban Water Management Plans, and will have special relevance to at least four of the urban water management BMP's.

BMP 1 : Residential Surveys/Landscape Water Use

All homes in the samples that have ever participated in a utility sponsored survey or audit program will be identified (wherever possible). Using these data it will be possible to estimate both the percentage of homes in the community that have participated in a program (independently from utility records) and, most importantly, whether there are any discernible differences in water use between survey and non-survey homes (where all other factors have been held constant.)

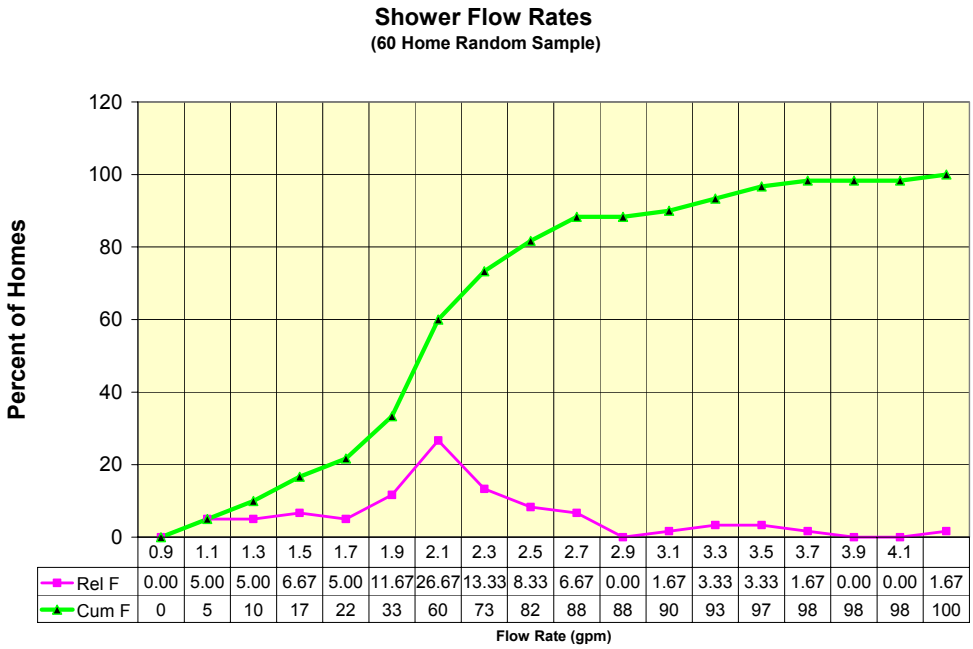
Outdoor use is another area in which there is a real need for more accurate data. Many manufacturers of irrigation controllers claim that customers are applying grossly more water than their landscapes require, and that there are enormous potential savings available from better control devices (such as ET controllers or soil moisture sensors). The results of this study will help confirm or modify these assertions, and will provide a much clearer picture of current application rates as a percentage of theoretical requirements in single-family landscapes, and potential savings from better irrigation control.

BMP 2: Residential Plumbing Retrofits

The goal of this BMP is to replace the showerheads, faucet aerators, and toilet flappers with high efficiency devices until at least 75% of the pre 1992 homes are so equipped. The data from the sample will determine the actual presence of low flow showers and faucet aerators, and will provide clear information about toilet flush volumes and the percent of homes with 1.6 gpf fixtures.

Figure 1 shows an analysis of shower flow rates in 60 randomly chosen homes in Seattle, WA studied by Aquacraft in 2003. These data show that 82% of the homes had average shower flow rates of 2.5 gpm or less. The average shower flow rate in the homes was 2.1 gpm with a 95% confidence interval of 0.18 gpm. This implies that the actual flow rates (at the 95% confidence level) are between 1.92 and 2.28. These results support the contention that these homes would meet the penetration goal of 75% of pre 1992 homes with 2.5 gpm showers. Based on these results, a showerhead replacement program would *not* produce much additional water savings and resources would best be put elsewhere.

Information at this level of detail can be created for each of the participating California study cities so that results can be compared and correlated against local conservation efforts (discussed below). Since the homes can be chosen totally at random, they will be free of selection bias, and should be representative of the populations from which they were drawn.



	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	
Rel F	0.00	5.00	5.00	6.67	5.00	11.67	26.67	13.33	8.33	6.67	0.00	1.67	3.33	3.33	1.67	0.00	0.00	1.67
Cum F	0	5	10	17	22	33	60	73	82	88	88	90	93	97	98	98	98	100

Figure 1: Example of information provided on shower flow rates

How does the sample size affect the confidence interval? If we assume that a given population of homes has a 75% penetration rate of high efficiency shower heads, and there are 100,000 homes in the population, then the confidence interval around the mean is shown in Figure 2 for sample sizes ranging from 30 to 960 homes. This shows that a random sample of 60 homes will be sufficient to identify the 75% penetration rate with a 95% confidence interval of ± 9.2%. If we double the sample size to 120, this will double the cost of the data collection and analysis effort, but will reduce the confidence interval by only 29% to ± 6.5%. This is why a sample size of 60 was chosen as a size that will balance the accuracy requirements with the need for economy in the study. These confidence intervals are unaffected by increasing the size of the population, and the decrease as the population gets smaller. So, they represent the maximum intervals we would expect for populations having actual penetration rates of 75%. Conversely, if the real penetration rates are smaller than 75%, then the results from the sample will show this, and lead to the conclusion that additional shower replacement work is warranted.

The challenge in getting good results lies not in the size of the sample so much as in making the sample representative of the actual service area. The easiest way to do this is to draw the sample from the entire population of customers, and insure that every customer has an equal chance of being included in the study.

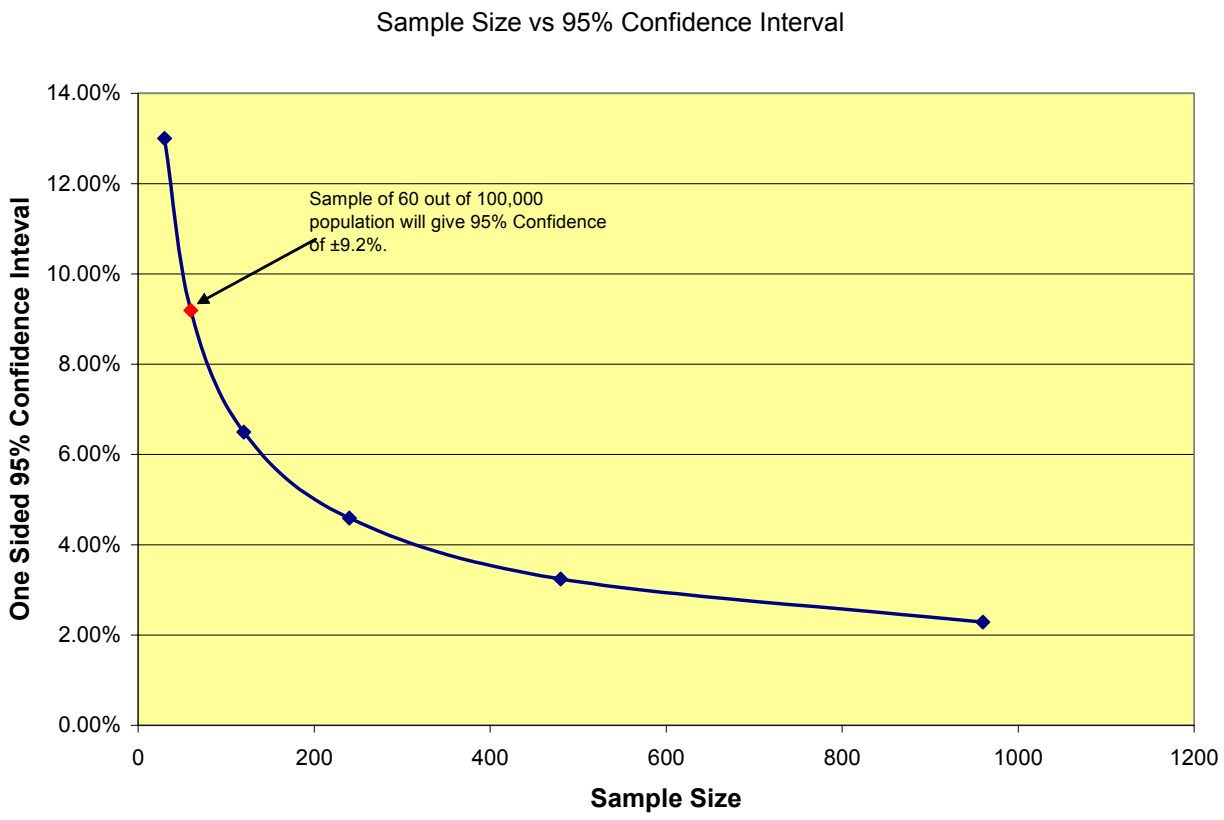


Figure 2: Confidence Interval vs Sample Size

BMP 6: High Efficiency Clothes Washer Retrofits

The Residential End Uses of Water Study (REUWS)[2] reported that less than 1 in 100 homes had high efficiency clothes washer (as determined by the gallons per load). The data from the California Single-Family Residential Water Efficiency Study will provide accurate information on the current penetration rates of these appliances, and will show the rate at which their presence has increased since 1997.

BMP 14: ULFT Replacement Programs

Because so much effort has been made in this area, many people believe that all of the potential savings are already "in the bag" from toilet replacement. The data from this study will accurately determine what percentage of homes have no ULFT's, some ULFT's and all ULFT's in each service area, and will help determine if this is really an area with no conservation potential, or if more work is still warranted. Except for a few flushes that randomly get masked by other uses, all of the toilet flushes for each home will be identified and then the number of flushes falling into various volume bins will be determined to create histograms of toilet flush volumes in each home. Homes with all ULFT's will show 100% at 1.6~ gal or less. Toilets with a mixture will shows distributions with peaks around 1.6 and 3.5 gpf plus even larger peaks for older and larger toilets using 5 or even 7 gpf. Home with no ULFT's will lack the 1.6 gpm peak.

[2] Aquacraft, Inc. "Residential End Uses of Water Study". American Water Works Association Research Foundation (1999)

Potential BMP: Hot Water Recirculation Systems

The California Single-Family Residential Water Use Efficiency Study will provide a baseline data set for evaluating the impact of hot water recirculation systems. Customers in the study that report a noticeable wait time for hot water, and who indicate a willingness to participate, will be asked to participate in a separate, future study of hot water recirculating systems. This will help determine whether or not to make this BMP part of the actual list.

Baseline for Additional Evaluations

Water Studies

An added benefit of the California Single-Family Residential Efficiency Study is that the baseline data collected here will provide a foundation for future research and evaluation. Participants have already suggested using the results to evaluate the effectiveness of ET controllers in reducing irrigation waste and to a study of the impacts of on-demand hot water systems in reducing waste in faucet and shower use. Similarly, results from the REUWS study have been used for everything from the sizing of home water filtration systems to risk analysis for radon. None of these applications had even been considered when the study was begun and a similar response is expected in California. It is difficult to underestimate the utility of a large data set of end water uses obtained from a representative sample across the entire state.

Energy Studies

The linkage between water and energy efficiency is becoming increasingly important. Every aspect of water use from pumping, potable treatment, system distribution, heating, appliance use, and wastewater treatment requires energy. Future energy shortages could also create water shortages and this relationship needs to be better understood. The study sample selected for this project can be linked to energy use surveys, such as the Residential Energy Consumption Survey, currently administered on a nationwide basis by the Energy Information Agency. Use of the data and sample from the water study in this way will provide tremendous synergy and efficiency for other related information needs.

Proposed Project Answers Specific Information Needs

The Proposal Solicitation Package lists several types of information for which projects are sought within the area of urban water efficiency. The project described in this proposal will cover several of these areas, as discussed below.

Estimate past, present and future water savings in the urban sector

Indoor Use

Information will be gathered on indoor water use patterns disaggregated by specific end use. Usage for both the individual purposes and for overall household use will be categorized according to efficiency level. Because data are available at the level of individual fixture and appliance, it is possible to measure efficiency parameters such as gallons per flush or gallons per load of clothes to determine the percentage of homes with high efficiency fixtures and appliances.

Information from previous research has shown that typical single-family homes use approximately 150 gpd for combined indoor uses. Homes that have been retrofit as part of controlled studies on the impacts of high efficiency plumbing fixtures and use only about 90 gpd, a 40% savings. By collecting end use data from random samples of homes in various California communities it will be possible to show where the typical single-family home in the state appears on this efficiency continuum, which also makes it possible to project future potential savings from interior retrofits.

As an example of how these data will help clarify the efficiency patterns in the homes please examine Figure 3. This shows the distributions of average daily household use in three sample groups from Seattle, WA: a random sample of homes called the Market group, homes prior to a retrofit, and homes after a full indoor retrofit. The conclusion from this analysis is that *there is still plenty of potential for additional indoor water savings in the overall population* of single-family homes in Seattle since the Market group distribution (blue) is much closer to the Pre-retrofit (green) than the Post-retrofit study (light blue) group.

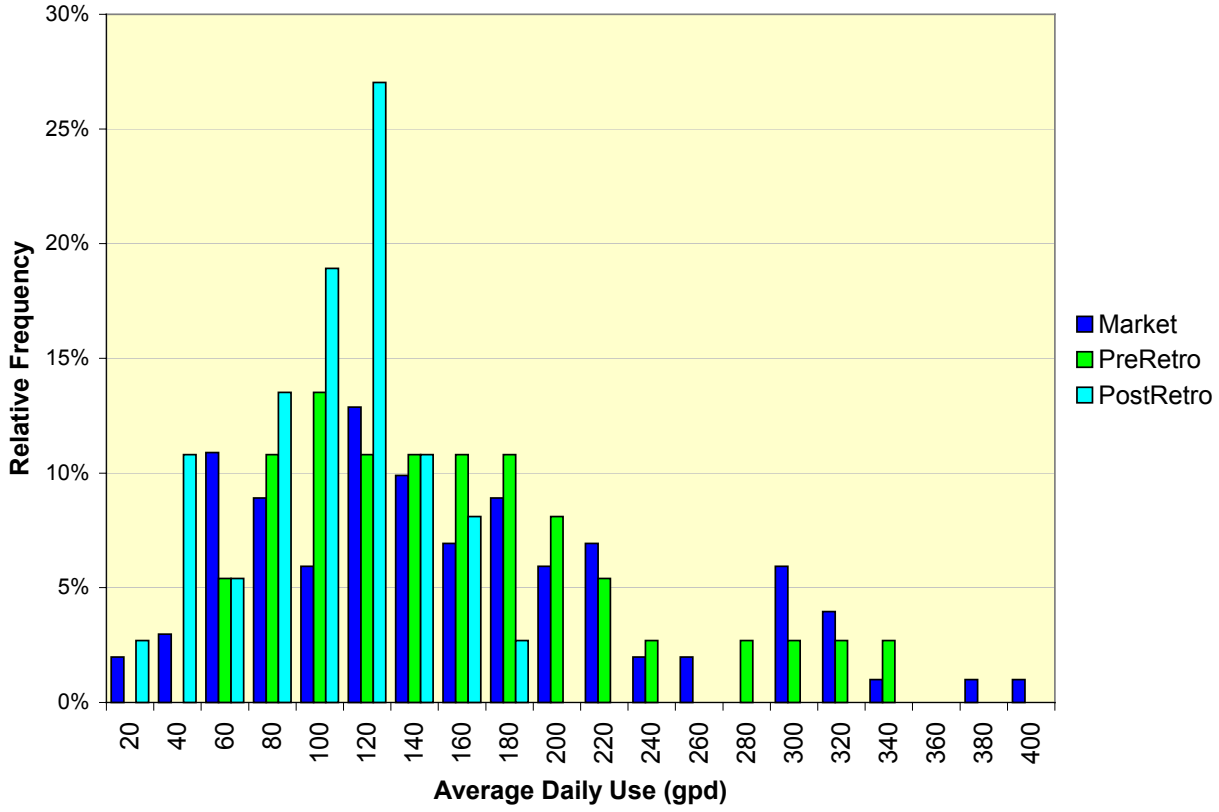


Figure 3: Example of efficiency comparisons for indoor household use – Seattle, WA

Another example of how the data can be used at the household level is shown in Figure 4. This shows that the average daily indoor use for the random sample group in Seattle was 153 gpd. Compare this to the household use of the retrofit group and it becomes very clear that the general population of single-family homes still has excellent untapped potential for indoor water conservation. The typical home can reduce its indoor use by approximately 30% and achieve the level of water efficiency measure in the post-retrofit group through interior retrofits. This is the

type of evaluation that will be done with data from California Single-Family Residential Efficiency Study for each participating agency and for the state as a whole.

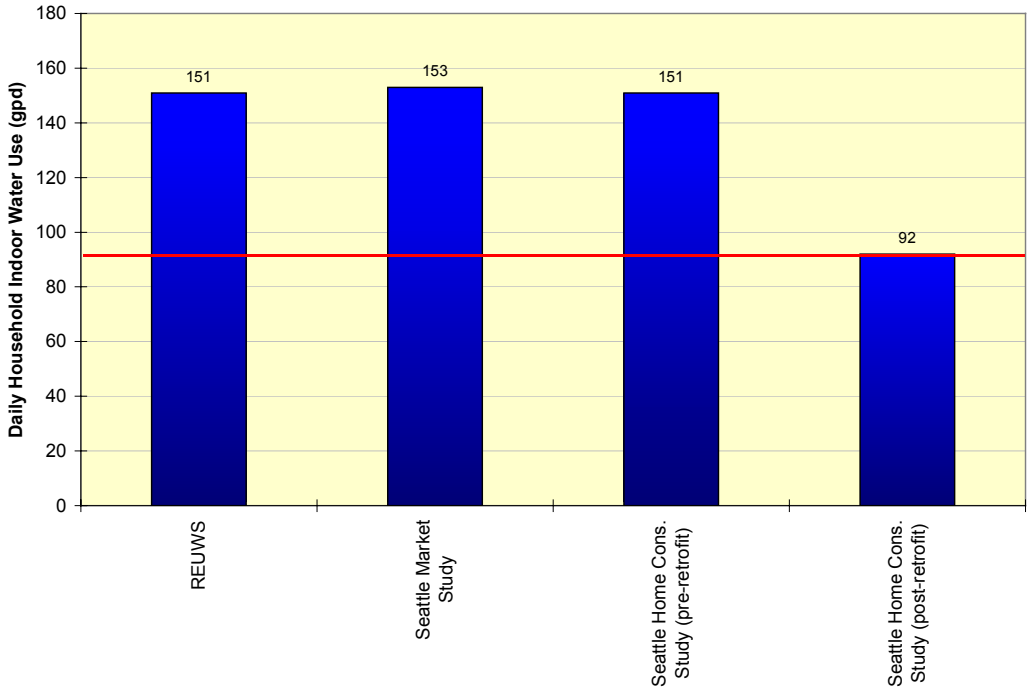


Figure 4: Comparison of household indoor use from Seattle, WA

Outdoor Use

The information provided by the flow trace analysis technique allows single-family use to be accurately disaggregated into indoor and outdoor use, so the impacts of irrigation can be identified and examined separately. Logged indoor use is annualized and then subtracted from metered consumption data for the same household. This provides an accurate estimate of the monthly and annual outdoor use at the homes. These data are then linked to the detailed measurements of the landscape area from each study home. From this, overall application rates and irrigation efficiencies (in terms of ratios of actual application to theoretical irrigation requirements) will be determined over the course of a year. The result will be accurate estimates of irrigation efficiency previously unavailable.

Data from the REUWS showed that as a whole, indoor use varies little over the year, so for most homes in the study, this approach will provide accurate data on indoor-outdoor water use splits. This information will be combined with data on measured irrigated areas of turf and shrubs and local ET to determine how well California home owners are tailoring their irrigation applications to theoretical irrigation requirements based on a wide range of ET zones in the sample. This will also provide an essential benchmark on present and future potential water savings from improved irrigation efficiency.

Figure 5 provides an example of the way that the outdoor use was evaluated with respect to efficiency in the Residential End Uses of Water study. This shows the distribution of irrigation

application as a percent of net ET for the 1,188 REUWS study homes. In that study landscaped areas were estimated from lot size, not measured. A key activity in the proposed study will be to measure irrigable and irrigated landscape area data necessary to make accurate assessments of the real irrigation efficiencies in California. Figure 5 places homes into various irrigation efficiency bins and shows that half of homes applied less than 50% of the ET requirement to their irrigable landscapes. In the California Single-Family Residential Efficiency study researchers will compare the application rate as a percent of the theoretical irrigation requirement for each site. The data will be prepared for the state as a whole and in different cities and/or with different water management situations, irrigation methods and systems and controllers.

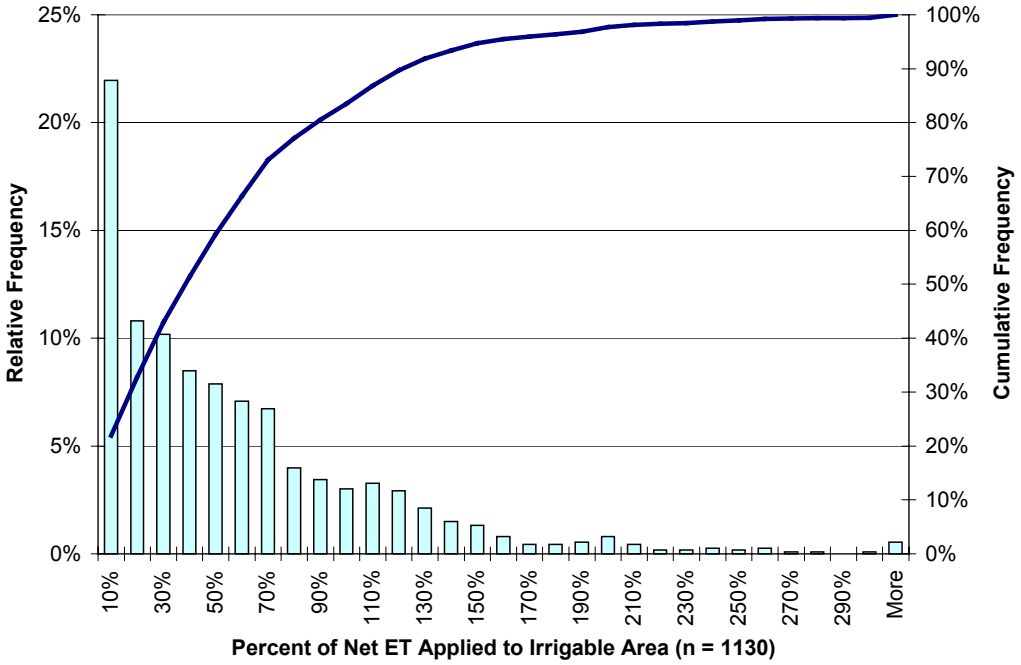


Figure 5: Example of histogram of irrigation application as percent of net ET

In the California Single-Family Residential Water Use Efficiency Study, the research team will use information from the household surveys, landscape measurements, and measured water use to develop relationships between factors such as the value of the house, the type of irrigation controller, the cost of water and irrigation efficiency. The research will also show how many homes are overwatering or under-watering, and how much water the group as a whole could save if everyone achieved a target irrigation efficiency. Homes with smart irrigation controllers will be identified as a group so that their performance can be compared to the other homes.

Monitoring and evaluation of water use efficiency projects to validate results and make recommendations for future projects

This is an important area of interest for the study. The diverse group of homes and communities in the sample will allow examination of a range of indoor and outdoor and water conservation programs employed by the participating water agencies. Some utilities have conducted major plumbing and appliance retrofit incentive programs, and others have spent virtually nothing in this area, choosing instead to rely on natural replacement. Similarly, some agencies have made efforts

in outdoor conservation while others have not. The impact of the various conservation efforts on indoor and outdoor use can be compared with the data.

Statement of Work, Section Two: Technical/Scientific Merit, Feasibility

This proposal is based on sound and proven scientific methods. This same basic methodology was used for the landmark AWWARF Residential End Uses of Water Study and numerous other studies of residential water use in the United States, Australia, Great Britain, and Canada. Please see Appendix F for a detailed description of the data collection and analysis techniques and an extensive list of references for projects that have utilized this technology.

Description of Specific Work Tasks for Project

This project is divided into nine major task elements. Each task is described below along with the information each participating water agency will contribute to the task. The research team includes national experts in residential water use patterns and data collection, survey design, and water resources analysis. Task assignments are generally divided as follows:

- ***Aquacraft, Inc. Water Engineering and Management*** – Project management and primary responsibility for Tasks 1, 3, 4, 6, and 9.
- ***Stratus Consulting*** – Tasks 2, 5, 7, and 9
- ***Pacific Institute –*** Tasks 8 and 9
- ***John Olaf Nelson Water Resources Management*** – Senior project advisor, QAQC, Task 9.

Task 1: Study Group Selection and Water Agency Data

Using procedures supplied by the research team the water agencies will select a sample of 1000 single-family homes from their service areas using a systematic random sampling process. Included with each sample (n=1000) will be essential data such as account number, name, address, water meter make and model, and at least one full year of historic water billing and consumption data. The 1000-home sample will provide a snapshot of single-family water use in each participating study site and will be used to select a random subset of 70 homes (60 prime homes and 10 back-ups) for participation in the end use study. *Customer confidentiality will be strictly maintained throughout the study* – no personal information, addresses, or names, etc. will ever be reported. The water use of each sample group (n=70) will be compared to the original group (n=1000) to insure that usage characteristics are statistically similar and thus representative of the broader population.

In order to place the single-family water use in perspective, the research team will also obtain annual reports of deliveries by the water agencies to each of their customer categories so that we can characterize single-family water use in comparison to other categories such as multi-family, commercial, industrial etc.

The list of selected customers (n=70) will be given to the utilities, who will consult with their mapping and GIS departments in order to obtain the best possible site map and/or aerial photo of the study homes. Preferably these will be provided in computer readable form so that they can be analyzed more easily. Wherever the quality of the mapping information is sufficient it will be used

to determine the lot size, the irrigable area, and the actual irrigated areas of turf and non-turf landscapes. Swimming pools will be identified and measured at this step. Even when mapping is deemed accurate enough for area determination, *all information will be ground verified during the site visits*.

All participating water agencies will send a letter (prepared by the consultant team) to each household selected for the study, informing them that they have been randomly selected to participate in an important statewide study of single-family water use. The letter will describe the study and the research procedures and will inform the household that a member of the study team will place a data logger on their water meter and will measure the amount of turf and non-turf landscaping in their yard. The letter will explain how important this information is to the State for future management of its water supplies and will urge the customers to cooperate. The letter will also give the customers *an opportunity to decline* to participate in the study by calling a toll free number. Customers declining will be replaced from the pre-selected list of random alternates. In this way the final set of at least 65[3] study homes will be selected from each participating agency.

Task 2: Survey Design

There will be two survey questionnaires implemented for this study: one for water customers and a second for participating water utilities. This objective of the customer survey is to obtain information on the stock of water using devices at the home as well as basic demographic information that might influence water use and water efficiency decisions.

The customer survey will be designed as a mail survey although it will be implemented through in-person interviews, telephone calls, and through direct mail. The customer survey will solicit information on the number and type of toilets, showers/baths, dishwashers, clothes washers, water softeners, filtration systems, swimming pools, hot tubs, water features, and other related water consuming devices found in the home. It will also include questions about the irrigation methods employed, plant materials, irrigation habits, and other questions about outdoor use.

The demographic component of the customer survey will include standard socioeconomic data questions about the age and size of the home, number and age of occupants, income, owner or renter occupied, and identification of water bill payer. The survey will also solicit information about attitudes towards local water conservation and efficiency programs.

To assist us developing a comprehensive and efficient survey, the research team will review of other residential end use surveys to inform choices of most effective questions to help explain water use. Some questions may also be included in the surveys to assist with future follow-up studies. For example, customers may be asked whether they notice the wait time for hot water in their homes. The survey could also solicit interested participants for a study of on-demand hot water systems.

After identifying the content of the survey, we will develop corresponding questions. Although most of the questions will be straight-forward, some will require more careful design to avoid confusion (e.g., focused on outdoor water use). A draft survey will be circulated among all

[3] In order to obtain 60 good traces loggers will be placed on 65 homes. This allows for some normal failures in the logging process.

interested parties (e.g., project advisory committee and water agency staff) to get feedback. As a last step of quality assurance, the team will conduct a one-day focus group with 5-10 customers of one of the participating utilities in order to pre-test the customer survey.

The customer survey process will consist of five steps.

1. A letter will be sent from each utility (on letterhead) to each of their targeted homes explaining the study and its importance and providing an opportunity to opt out.
2. The customer survey will be delivered or mailed to each site at the time of the research team visits the house to install the data logger. Occupants of the household will be directly contacted by the technician via the front door. The technician will carry official identification as discussed in the introduction letter. The occupant will be offered the chance to fill out the survey via an interview process at that time, or they will be supplied with a postage paid envelope to return the completed survey at their convenience. The technician will request to make landscape area measurements of all irrigated areas on the property.
3. For homes where the technician cannot make direct contact, the third step will be to leave a survey package on the door.
4. If within two weeks the survey has not been completed, the forth step will be to mail a second copy of the survey to the home with a reminder letter (and a $2 monetary incentive).
5. If after two more weeks there is still no reply, the last step will be to telephone and ask occupant to provide the answers to the questions.

This extensive follow-up approach is warranted given the high cost of collecting end use data with loggers and the importance of getting an unbiased sample to make the most accurate inference of the results.

The utility survey will solicit information on the Best Management Practices (BMP's) being addressed by the utility and the types of conservation programs operated and incentives offered. Information on sources of water for the community and water rates also will be collected. The utility survey will be pre-tested with personnel from participating agencies via e-mail and telephone.

Task 3: Data Logging and Site Visits

The flow recorders (aka: data loggers) will be brought to the site and installed on the water meter of the study homes by members of the research team. It usually takes 2-3 days to visit 60 individual homes. At each study site this process will be completed as quickly as possible so that the data collection period for each home will be as similar as possible. The flow recorders will be programmed to record flows every 10 seconds and will have a memory capability of at least 15 days (135,000 10-second records). A detailed description of the flow recording and flow trace analysis process in provided in Appendix F. For quality assurance and quality control purposes approximately 10% of the recorded flow traces will be independently disaggregated and analyzed by Veritec Consulting and the results compared to ensure accuracy.

Next, in order to obtain or verify data on landscape size the technician will return to the homes to complete the survey and landscape audits. The technician will knock on the door and attempt to complete the customer survey. If customers are not home, another copy of the survey will be left behind with a self addressed stamped envelope. Before leaving the technician will obtain landscape measurements.

The data loggers will be retrieved at the end of the two-week data collection period, downloaded and readied for the next study site. The utilities may accompany the field technicians during some or all of the site visits at their discretion. Past experience with this type of work suggests that the entire data logging/field visit process can be accomplished in 15 working days for each participating agency.

Task 4: Flow Trace Analysis and Database Construction

The successfully downloaded flow traces will be disaggregated into component end uses using Aquacraft's Trace Wizard program, currently in its 4.0 release version. This system of analysis has been proven in past studies to provide highly detailed information on specific end-use of water. Each distinct water use or "event" will be categorized as to its most probable end use by comparing its flow/duration characteristics to those of the fixtures and appliances recognized in the homes. The statistics stored for each event includes the time and date of the start, the duration, volume, peak flow rate and mode flow rate.

All data obtained for this study including end use data, water billing data, customer survey data, landscape audit data, climate data, etc. will be stored in a single project database developed using Microsoft Access™.

The project database will be a relational database contain a set of linked tables. This database will be a powerful tool for extracting information and conducting analyses. The following tables are anticipated to be included in the database:

Customer Information Table. This table will contain a unique ID number (keycode) for each customer (but no names or addresses) as well as information about each participating customer. The keycode field will be used as a primary link to data in other tables.
Water Utility information Table. This will include the information on the characteristics of each water agency in the study. Geographic, climate, and census information will be included along with information on water and wastewater rates, and conservation programs implemented. These will be useful when looking for relationships between local conservation programs and water use or market penetration rates. It is possible that there will be more than one water provider in some service areas.
End use water event table. This table includes the individual disaggregated water events recorded from each home. It is anticipated that more than nearly 1 million events will be logged in this study (assuming a total of 720 homes are logged). Each event will be identified by keycode, use type (toilet, shower, faucet, clothes washer, dishwasher, irrigation, etc.), volume, date, start time, duration, peak flow and mode flow. This represents the core of the information derived from the logging effort.
Daily summary table. This is a table derived from the water event table that provides summaries of daily use by end use for each home. This is a very useful table for doing many statistical analyses.
Daily Climate Data. The best available daily weather data for each home during the logging periods from the nearest calibrated station will be obtained so that analyses can be performed against weather parameters where relevant.
Customer Survey Response Table. The responses to the survey questions for individual homes will be entered into these tables.

Water Agency Survey Response Table.
Weather Station Table. This will contain the monthly temperature, rainfall and ET data for each of the weather stations located near the study homes that covers the same period as the historical billing data.
Water Billing Data Tables. The periodic water use data from the sample frames (n=1000) will be stored in tables so that water use from the sample frame can be compared against the usage in the smaller sample of logged homes. This is useful for verification and characterization of the homes in each community.
Additional tables as required.

Task 5: Survey Response Analysis

The completed customer surveys will be forwarded to Stratus Consulting for tabulation. Stratus will contract with a specialty survey firm to input the results into a database using advanced quality control procedures (double entry data system). This will consist of an automated CATI software interface and a double checking of entries by two people to maximize accuracy. The survey firm also will handle the reminder mailings and the telephone follow-up. When all of the survey responses are tabulated they will be linked to the water use database using the keycode. The results of the survey will be tabulated and summarized as a chapter in the final report. This information will be a key ingredient to Task 7 work.

Task 6: Data Analysis and Descriptive Statistics

The water use database will be used to create several detailed analyses of both indoor and outdoor water use. Indoor use will be analyzed with respect to average daily household and per-capita use for total indoor consumption and for each end use. The efficiency levels of the toilets, dishwashers and clothes washers will be characterized for each home in terms of the gallons per flush and gallons per load. Showers and faucets will be characterized in terms of their average flow rate. This information will be used to place the houses into efficiency categories according to the fixtures and appliances present.

Outdoor use will be characterized by the volume of water applied to the landscape compared to the theoretical requirements determined from the landscape characteristics obtained during the site visits and prevailing climate data. A landscape coefficient will be calculated for each household in the study. The landscapes for the 720 homes will be compared to the standard from the California Friendly Landscape Program in order to estimate the water savings that would occur if these principles on overall irrigation application developed for that program were followed in all of the homes.

Task 7: Modeling

In this task water use and survey data will be analyzed in concert to develop multivariate regression models that explore the relationships between indoor and outdoor household water use (as the dependent variable) and the various explanatory variables such as the number of persons in the home, the age and size of the home, the presence of high efficiency fixtures and appliances. **Table 3** shows the types of variable that will be included in the modeling process. Outdoor parameters will include factors such as the irrigable area, the actual irrigated area of turf and shrubs, the type of irrigation system and irrigation controller, the price of the water, etc. Multivariate regression models will be developed for total use and for individual end uses.

Through the modeling effort the research team will explore and statistically quantify factors influencing indoor and outdoor water use using multivariate regression models. The results of this task will provide a clearer understanding of the key drivers impacting water use, and a direct means for generating inferences of potential water savings in the future.

Models will be prepared of household indoor water use as a function of the number of residents, size and age of home, penetration of high efficiency fixtures and appliances, cost of water, etc. Models of individual end uses and frequency of uses will also be prepared looking for relation ships that will be helpful in creating water demand forecasts.

For outdoor water use, researchers will evaluate both total outdoor water use and efficiency of use. Total water use will be modeled using explanatory variables such as total irrigated area, landscape type, presence of a pool, type of sprinkling system, type of irrigation controller, presence of a rain shut-off device, local evapotranspiration and effective rainfall, the price of water, household income, and house age. Irrigation efficiency, defined as actual irrigation application divided by a theoretical application requirement, will also be modeled. The theoretical requirement equals the water needed to irrigate a given landscape if water supply is not limiting and reasonable irrigation efficiencies are applied. The ratio of actual application to theoretical requirement will be referred to as the site application efficiency (SAE). The more the SAE exceeds 1.0, the greater the amount of waste on the site. Excess water use contributes to run off or percolation losses. This information is very important and, to our knowledge, has not been consistently and rigorously quantified before.

Table 3: Typical Dependant and Explanatory Variables for Statistical Analyses

Dependant Variables	Explanatory Variables
Indoor Household Use (gphd)	Number/age of residents
	Size of home
	Age of home
	Presence of ulf toilets
	Presence of high efficiency washer
	Household income
	Shower flow rates
	Faucet flow rates
	Evaporative coolers
	Cost of water
Outdoor use (gphy)	Total irrigable area
Irrigation Efficiency (actual/theoretical app)	Total irrigable area (lot size minus building and pavement area)
	Area of turf, measured
	Area of non-turf, measured
	Presence of pool
	Use of automated sprinkler system
	Presence of Smart Irrigation controller
	Presence of rain shut off device
	Has home been audited
	Local ET
	Cost of water

Task 8: Analysis of Statewide Implications

Numerous previous reports from both the California Department of Water Resources (including all previous "California Water Plans") as well as independent research groups have highlighted data constraints as a key unresolved issue in water conservation programs. The data collected and modeled in the previous tasks will be of enormous value to water planners and policy makers at both the local and state level in addressing these constraints. In this task, the data collected from the California Single-Family Residential Water Efficiency Study will be used to address these and other questions:

- What percentage of the potential water conservation in the single-family category has already been captured, and what percentage is still available?
- What are the most important end-uses of water that require additional conservation programs and incentives?
- How effective have past regional and local conservation programs been?

The answer to these questions will have important implications about the design of future water management programs and allocation of resources.

Tasks 6 and 7 will show how water use in existing homes compares with "optimal" indoor and outdoor performance based on the literature, available technology, and previous water demand studies. The factors that affect water use and efficiency will be identified as well. In Task 8 researchers will make projections about the savings that could be achieved were all of the homes to achieve the best level of practically achievable efficiency. The homes will naturally fall into groups such as "conserving", "non-conserving" and "inefficient". The percentage homes falling into each category will help reveal the state of efficiency for single-family homes as a group and the potential for improvements in efficiency, with more specific information at the regional and agency level. If, for example, all or most of the homes in the study are already highly water efficient then there is little additional to be gained from conservation efforts. On the other hand, if the opposite is shown to be true, and few homes are rated as highly efficient then this information may help local agencies design smart and effective future programs and state planners to improve forecasts.

Developing a realistic assessment of the potential for water conservation in the largest urban demand sector – single-family homes - is the single most important objective of this study.

Task 9: Report Writing

The research team will prepare a comprehensive final report that describes the goals, objectives, research methods and results of the study. The report will include an executive summary that can be used as a "stand alone" document summarizing key results. The report will be professionally edited by technical editor and document production staff. The research team will deliver 50 printed and bound copies of the report, but the bulk of the report distribution will be handled electronically. The final report will be disseminated via the internet in PDF format through available web portals such as the DWR, CUWCC, AWWA, and others. Papers on the results will be presented at appropriate water conferences.

Statement of Work, Section Three: Monitoring and Assessment

A good implementation program should document the water saved as a result of a particular program or device. For the research project proposed here, the monitoring and assessment is really the quality assurance program for the data collection and analyses. This task involves all of the activities undertaken to assure that the data obtained are accurate and the analyses are dependable. We will institute a complete set of quality assurance and quality control (QAQC) measures to insure that errors are avoided within each task. QAQC procedures are listed in Table 4.

Of particular importance is the QAQC procedures developed for flow trace analysis. In order to ensure accurate and reproducible disaggregation of end uses, approximately 10% of the recorded flow traces will be independently analyzed by Veritec Consulting and the results will be compared by John Nelson (independently of either Aquacraft or Veritec) to see how well they agree. The desired level of agreement would range from very high when it comes to answering objective questions about the presence or absence of ULF toilets, high efficiency clothes washers and the average flow rate for the showers. We would also expect a high degree of agreement about the total indoor/outdoor household use during the logging period. More variation would be expected in classification of ambiguous events such as bathtub uses and miscellaneous faucet use.

This QA step will involve Aquacraft, Veritec and John Olaf Nelson. Technicians from both Aquacraft and Veritec will analyze the flow traces without consulting each other. They will then send their results to John Nelson, who will make the comparisons. This will insure any modifications or adjustments of the results by the individual analyst firms. John will determine the percent of variation in the results using criteria established at the start of the study.

The ability to demonstrate that the results of the data logging studies provide consistent and reproducible results for the core questions about water use in single family homes will allow this technique to be used with confidence throughout the state to obtain accurate information on household water use and the penetration rates of high efficiency fixtures and appliances. The ability to obtain these data from purely random homes will allow the results to be free from the selection bias that plagues studies based on surveys and volunteers.

Another excellent QA measure that will be pursued in this study is to deliberately select some homes from those that have been previously visited as part of market penetration studies. We know that such studies have been done in the service area of the Metropolitan Water District of Southern California and the East Bay Municipal Water District. Others may also be present in the service areas of the other participants, which we will determine as part of the selection process. By choosing homes that have been “manually” inspected we can compare the results obtained from the data logging to those obtained through the site visits. We will also be able to show the spectrum of additional detail provided by the data logging that is not provided by the site visits. The logging studies will show not just the presence or absence of certain fixtures, but will show how frequently they are used and the percentage of household water use for which each accounts. In homes with a mixture of standard and ULF toilets we will be able to show the percentage of flushing for which each type of toilet is responsible, which will help to determine any diminishing returns from replacement of additional toilets.

Many toilets are designed to flush at 1.6 gpf, but actually flush at significantly higher volumes. This might occur when the float valve is improperly adjusted causing the tank to overshoot the water line. Also, ULF toilets can still have leaky flappers or flappers that fail to close properly. The data logging study will give definitive information about these types of problems where a site visit can at best identify them by chance (if they are occurring during the site visit) and in a qualitative manner.

Table 4: QA Measures

TASK	NAME	QA Measures to be Taken
1	Study Group Selection	Insure that sample frames are random. Trim out the top and bottom 5% Verify that sample groups match water use characteristics
2	Survey Design	Review of literature and testing surveys with utility participants
3	Data logging; site visits	Replace old meters, compare logged and metered volumes, test meters against measured volumes, use of aerial photos and site measurements for landscape area.
4	Flow trace analysis/DB assemble	Verify volumetric match of meter and logger Each trace analyzed and checked independently by analyst and supervisor Use of survey information as check on water use Verify keycode information on sample of records Veritec Consulting will independently analyze a random selection of up to 10% of the recorded flow traces Some homes will be selected from those previously studied for penetration rates through site visits. The results will be compared.
5	Survey response analysis	CATI double entry data system, Reminder mailing and follow-ups Telephone contacts as last resort
6	Statistical Analysis	Verify samples of customer information against original survey documents. Verify summary tables against water event database
7	Modeling	Standard statistical verification procedures: e.g. residual testing, auto-correlation testing etc.
8	Statewide Implications	Compare results of this study to literature for reasonableness
9	Report	Professional editing and checking

Qualifications of the Applicants and Cooperators

The research team will consist of Aquacraft, Inc., who will be overall project managers and in charge of logging, flow trace analysis, database construction and statistical analyses; Stratus Consulting, who will consult on survey development and econometric modeling, Pacific Institute, which will investigate the statewide implications of the results, Veritec Consulting who will perform independent QAQC on recorded flow traces, and John Olaf Nelson, who will act as senior advisor to the project team. These firms are located in Colorado, California and Canada, and all have extensive experience in urban water demand management. The key personnel will be William DeOreo of Aquacraft, who will be principal investigator and project manager; John Whitcomb and Jim Henderson, for Stratus; Dr. Peter Gleick, for Pacific Institute, Bill Gauley,

P.Eng. for Veritec, and John Olaf Nelson. These firms have conducted many similar studies and their resumes and company statements of qualifications are attached as Appendix D. Please see Appendix E for resumes.

Outreach, Community Involvement, and Acceptance

This project has the potential to be of great interest to the general public. Many people are interested in water use behaviors and it is anticipated that this project should have a high degree of public awareness, which could be fostered through press releases and other media outlets. The notion of a statewide study that involves communities from all areas of the state should be highly compelling. The study should create an increased awareness of the importance of residential water efficiency as part of the statewide water balance, and should provide an excellent opportunity for public education on the importance of good urban water management.

In order to help promote the project the team will set up a web-page for the project on Aquacraft's web site (with links to other acceptable locations) giving an explanation of the project goals, updates on the progress, and interesting interim results and facts obtained in the course of the work.

Innovation

The use of flow recorders and flow trace analysis to obtain highly detailed information on single-family water use is not new, and has been used for the past 10 year in numerous studies. However, the use of this technology on a purely random samples of homes in order to assess water efficiency level of the customers is fairly new, and has been implemented only in Seattle to this point. The combination of data logging to obtain precise water use information with random samples of customers will produce a data set virtually free of the type of selection bias that plagues traditional survey studies. Surveys and water billing data will provide backup information, but won't we relied upon for answers to the central questions addressed in the study, which are about the overall efficiency of the residential water use.

Benefits of Project

This research project will provide accurate and un-biased data on current single-family water use in a representative sample of homes in California. It will provide data that can be compared to both "standard" and "conserving" homes in order to judge how far the state has come in meeting the efficiency goals for both indoor and outdoor water use. By looking back at the data obtained in 1997 and 1998 for the AWWA REUWS study it will be possible to provide information on the replacement rates of water consuming fixtures in single-family households.

The data will be pooled to evaluate the performance of the state as a whole, and it will be split in order to compare the performance of the individual water agencies. This will help identify the most successful programs around the state.

The study group selected as part of this project can serve a vital role in future water planning in California. This sample can be studied on a periodic basis in the future. This will provide a time series analysis of how water usage and water efficiencies are changing over time. Much the same approach is used by the U.S. Energy Information Services Administration when they track the energy use of a scientifically selected sample of homes in the United States.

While the researchers do not claim any direct water savings as part of the California Single-Family Residential Efficiency Study itself, this project will provide the information needed to support, direct, and verify the entire effort of residential water conservation throughout the state. It will point out how far the state as a whole has come and what savings can yet be achieved. It will also point out where the efforts have been most (and least) successful, and will help make the water conservation programs throughout California more effective.

Specific Information made available by this study will include:

- Daily household use data from the sample broken down into indoor and outdoor use
- Distributions of indoor household use
- Household and per capita use broken into individual end uses, including: toilets, showers, clothes washers, faucets, dishwashers, leaks, baths and outdoor uses
- Volumetric measurements of actual verses design fixture use (toilets, clothes washers, showers, faucets, dishwashers, etc.)
- The percentage of homes using high efficiency toilets, faucets, showers dishwashers and clothes washers
- The percentage of homes with one ULF toilet or more up to those with exclusively these types of fixtures.
- Relationships between household water use and key explanatory variables such as the age of the home, number of residents, presence of high efficiency devices, size and type of landscape and irrigation control technology.
- An overall picture of where single-family domestic water use lies on the efficiency continuum, and the remaining savings potential
- Information on current outdoor use patterns - application rates, local ET data, and factors that affect irrigation use
- Detailed information on irrigation efficiency based on water use and measured landscape size
- Relationships between total lot size, irrigable areas and irrigated areas, with percentages of turf and non-turf plant types
- An understanding of how adoption of the California Friendly Landscape Program would impact water demands across the state.
- Baseline data on irrigation use as a function of irrigation method (manual vs. automatic), application technology (spray, drip, etc.), type of irrigation controller, and presence of system enhancements such as rain shut offs.
- An assessment of water efficiency programs and BMPs implemented in California – which ones have achieved savings and which ones haven't
- The data collected in this study will serve as a springboard for future studies on new technologies such as ET controllers and on-demand hot water systems and energy consumption surveys.
- The sample of homes in this study can be re-logged after a period of years in order to determine how use patterns have changed, and which programs have had the most success in increasing efficiencies of use.

Schedule and Costs

We estimate that the total time frame for completion of this project will be 25 months. The majority of time will be taken up with data collection and analysis. The following table shows the anticipated dates and durations for each task, and is based on the assumption that the work can begin on April 3, 2005.

Table 5: Project Schedule

ID		Task Name	Duration	Start	Finish
1		Start Work	1 day	Mon 4/3/06	Mon 4/3/06
2		Study Group Selection	60 days	Tue 4/4/06	Mon 6/26/06
3		Survey Design	30 days	Tue 4/4/06	Mon 5/15/06
4		Site Visits & Data Collection	270 days	Tue 5/16/06	Mon 5/28/07
5		Survey Analysis	270 days	Tue 6/27/06	Mon 7/9/07
6		Water Use Analysis	270 days	Tue 6/27/06	Mon 7/9/07
7		Modelling	60 days	Tue 7/10/07	Mon 10/1/07
8		Statewide Implications	60 days	Tue 10/2/07	Mon 12/24/07
9		Final Report Preparation	90 days	Tue 12/25/07	Mon 4/28/08

The estimated cost for the study with 10 participating water agencies and 13 sample groups is $1,062,03 of which $255,000 (24%) will be contributed by the 10 agencies. California DWR will be asked to contribute $807,013. A summary of these costs is provided in Table 6. In addition, each participating utility will contribute approximately 60 hours of labor as in-kind services. We recognize that the funding request from DWR represents a substantial portion of the funds available for the current round of funding, but would like to point out that this project is not for a single agency, but a group of 10 water agencies throughout the State, and will benefit both the agencies and the entire state.

Table 6 shows how the cost split and timing of expenditures for the agencies and the DWR is set up. Because of the long lead time needed for budgeting within most agencies it is very desirable for the agency contributions to be delayed until 2007 and the early work on the project to be funded largely by DWR. This will allow sufficient time for the agencies to handle the budgeting for their contribution. The resulting contribution from DWR would be $205,865 in 2006 and $601,148 in 2007. The remaining $255,000 for the project will come from the cash contributions from the participating agencies.

The supporting tables contained in Appendix C are based on 12 sample sites. The budget summary provides discrete 12 month increments as requested. The costs for the project have been entered into the requested table C-1. However, since many of the line items in Table C-1 are really not compatible with the types of costs incurred in this type of research effort we have also included cost breakdowns based on more typical consulting cost items. Table 7 shows the summary of labor and expense costs by task, Table 8 shows the hours budgeted for each task.

Over 11,000 hours (5.5 work years) have been allocated to this project, which points out the level of effort and commitment that will be put into the project. Finally, Table 9 shows the expenses by category for each task. These tables show exactly where the money for this project will be spent, and on for what purpose.

Summary

This proposal, sponsored by the Irvine Ranch Water District, is for what we believe will be a ground-breaking analysis of the past, present and future water use patterns for the single family residential water users throughout the state. Using random samples of homes along with survey, mapping, site visit, and billing data we will determine precisely how the current homes in the states fall on the efficiency curve, what factors affect the efficiency of use, and how much potential remains for developing supplies of water for the state from conservation as opposed to new depletions from the state's limited water resources.

This data will have direct and indirect bearing on the goals of the Bay Delta agreement. Every acre foot of water that can be saved by existing customers is one that can be used to support new economic development without increasing the burdens on the streams and groundwater supplies available to the state. By identifying the current levels of efficiency it will help focus and motivate new efforts at achieving higher efficiency, and it will also help direct those efforts to the most effective programs.

The data collected as part of this study will be compared to data collected in the REUWS study from 1997 to see how penetration rates have changed over time. Future studies of the homes in the group will allow analysts to see how conditions may change in the future. The complete database will be available to researchers and will be used for many purposes of which we can not currently guess.

In terms of benefits and costs, while it is impossible to clearly define a specific savings for this type of measurement and evaluation study we could make an assumption that by virtue of having better information on the existing levels of efficiencies it will be possible for the agencies to better target their conservation efforts. If this targeting results in just a ½% increase in the savings, this would result in the conservation of 9,350 acre feet out of the 1.87 million acre feet delivered by these agencies. The total cost of the project is $1.062 million, so the unit cost per acre foot would be $113 capital cost for the saved water. These savings, if multiplied across the state would bring the unit cost down to a few dollars per acre foot of saved water. This is the least expensive water available, even if the assumed savings are off by an order of magnitude.

Table 6: Cost Summary and Annual Breakdowns (April 3, 2006 start date)

		Project Costs			Agency/CDWR Split		Annual Breakdown		
TASK	DESCRIPTION	Labor	Expenses	Total	Agencies	CDWR	CDWR Yr 1	CDWR Yr 2	Agencies Yr 2
1	Study Group Selection	$ 50,490	$ -	$ 50,490	$ -	$ 50,490	$ 50,490	$ -	$ -
2	Survey Design	$ 21,240	$ 4,135	$ 25,375	$ -	$ 25,375	$ 25,375	$ -	$ -
3	Data Logging and Site Visits	$ 272,820	$ 125,950	$ 398,770		$ 398,770	$ 90,000	$ 308,770	$ -
4	Flow Trace Analysis and DB Const	$ 285,350	$ -	$ 285,350		$ 285,350	$ 40,000	$ 245,350	
5	Survey Response analysis	$ 40,590	$ 11,110	$ 51,700	$ 4,672	$ 47,028	$ -	$ 47,028	$ 4,672
6	Data Analysis and descriptive statistics	$ 43,695	$ -	$ 43,695	$ 43,695	$ -	$ -	$ -	$ 43,695
7	Multivariat Modelling	$ 65,550	$ 10,273	$ 75,823	$ 75,823	$ (0)	$ -	$ (0)	$ 75,823
8	Analysis of Statewide Implications	$ 47,850	$ -	$ 47,850	$ 47,850	$ -	$ -	$ -	$ 47,850
9	Report writing	$ 81,350	$ 1,610	$ 82,960	$ 82,960	$ -	$ -	$ -	$ 82,960
	TOTAL FOR PROJECT	$ 908,935	$ 153,078	$ 1,062,013	$ 255,000	$ 807,013	$ 205,865	$ 601,148	$ 255,000

APPENDIX A: Project Information Form

2004 Water Use Efficiency Proposal Solicitation Package

APPENDIX A: Project Information Form

Applying for: ✓ Urban ❑ Agricultural

1. (Section A) **Urban or Agricultural Water Use Efficiency Implementation Project**
   - ❑ (a) implementation of Urban Best Management Practice, #_____
   - ❑ (b) implementation of Agricultural Efficient Water Management Practice, #_____
   - ❑ (c) implementation of other projects to meet California Bay-Delta Program objectives, Targeted Benefit # or Quantifiable Objective #, if applicable _____
   - ❑ (d) Specify other: _____

2. (Section B) **Urban or Agricultural Research and Development; Feasibility Studies, Pilot, or Demonstration Projects; Training, Education or Public Information; Technical Assistance**
   - ✓ (e) research and development, feasibility studies, pilot, or demonstration projects
   - ❑ (f) training, education or public information programs with statewide application
   - ❑ (g) technical assistance
   - ❑ (h) other

3. Principal applicant (Organization or affiliation): Irvine Ranch Water District

4. Project Title: Statewide Study of Water Use Efficiency

5. Person authorized to sign and submit proposal and contract:

Name, title	Paul Jones II General Manager
Mailing address	P.O. Box 57000
	Irvine, CA 92619-7000
Telephone	949 453-5010
Fax.	949 453-1228
E-mail	jones@irwd.com

6. Contact person (if different):	Name, title.	Fiona Sanchez Conservation Analyst
	Mailing address.	P.O. Box 57000
		Irvine CA 91619-7000
	Telephone	949 453-5325
	Fax.	949 453-5354
	E-mail	sanchezf@irwd.com

7. Grant funds requested (dollar amount): *(from Table C-1, column VI)*	$761,668
8. Applicant funds pledged (dollar amount):	$235,000
9. Total project costs (dollar amount): *(from Table C-1, column IV, row n)*	$996,668
10. Percent of State share requested (%) *(from Table C-1)*	76%
11. Percent of local share as match (%) *(from Table C-1)*	24%
12. Is your project locally cost effective? *Locally cost effective means that the benefits to an entity (in dollar terms) of implementing a program exceed the costs of that program within the boundaries of that entity.* *(If yes, provide information that the project in addition to Bay-Delta benefit meets one of the following conditions: broad transferable benefits, overcome implementation barriers, or accelerate implementation.)*	❑ (a) yes ✓ (b) no

11. Is your project required by regulation, law or contract?
If no, your project is eligible.

If yes, your project may be eligible only if there will be accelerated implementation to fulfill a future requirement and is not currently required.

Provide a description of the regulation, law or contract and an explanation of why the project is not currently required.

- ❑ (a) yes
- ✓ (b) no

12. Duration of project (month/year to month/year): April/06 to March/08

13. State Assembly District where the project is to be conducted: 6, 7, 8, 12, 13, 16, 21, 41, 66, 70, 73-79

14. State Senate District where the project is to be conducted: 2, 3, 8, 9, 11, 23, 33, 35-40

15. Congressional district(s) where the project is to be conducted: 6, 8, 9, 12, 14, 30, 48-52

16. County where the project is to be conducted: Orange, Los Angeles, San Diego, Alameda, Contra Costs, Marin, San Francisco, San Mateo, Sonoma, Ventura, Yolo

17. Location of project (longitude and latitude) Statewide

18. How many service connections in your service area (urban)? 1,450,000 All agencies

19. How many acre-feet of water per year does your agency serve? 1,870,000 All agencies

20. Type of applicant (select one):

- ❑ (a) City
- ❑ (b) County
- ❑ (c) City and County
- ❑ (d) Joint Powers Authority
- ✓ (e) Public Water District
- ❑ (f) Tribe
- ❑ (g) Non Profit Organization

- ❑ (h) University, College
- ❑ (i) State Agency
- ❑ (j) Federal Agency
- ❑ (k) Other
  - ❑ (i) Investor-Owned Utility
  - ❑ (ii) Incorporated Mutual Water Co.
  - ❑ (iii) Specify _____

21. Is applicant a disadvantaged community? If 'yes' include annual median household income.

    (Provide supporting documentation.)

- ❑ (a) yes, _____ median household income
- ✓ (b) no

APPENDIX B: Signature Page

2004 Water Use Efficiency Proposal Solicitation Package

By signing below, the official declares the following:

The truthfulness of all representations in the proposal;

The individual signing the form has the legal authority to submit the proposal on behalf of the applicant;

There is no pending litigation that may impact the financial condition of the applicant or its ability to complete the proposed project;

The individual signing the form read and understood the conflict of interest and confidentiality section and waives any and all rights to privacy and confidentiality of the proposal on behalf of the applicant;

The applicant will comply with all terms and conditions identified in this PSP if selected for funding; and

The applicant has legal authority to enter into a contract with the State.

_____	_____	_____
Signature	Name and title	Date

Appendix C: Cost Details

Table 7 : Costs by task

SUMMARY OF COSTS BY TASK:				
TASK	DESCRIPTION	Labor	Expenses	Total
1	Study Group Selection	$50,490		$50,490
2	Survey Design	$21,240	$4,135	$25,375
3	Data Logging and Site Visits	$272,820	$125,950	$398,770
4	Flow Trace Analysis and DB Const	$285,350		$285,350
5	Survey Response analysis	$40,590	$11,110	$51,700
6	Data Analysis and descriptive statistics	$43,695		$43,695
7	Multivariat Modelling	$65,550	$10,273	$75,823
8	Analysis of Statewide Implications	$47,850		$47,850
9	Report writing	$81,350	$1,610	$82,960
	TOTAL FOR PROJECT	$908,935	$153,078	$1,062,013

Table 8: Hours by task

TASK	DESCRIPTION	LABOR DETAILS RATE	RATE	RATE	RATE	RATE	Total
	Rate Code	1	2	3	4	5	
	Houly Rate	$125	$90	$65	$55	$45	
		Senior Engineer (Hrs)	Project Engineer (Hrs)	Analyst (Hrs)	Tech (Hrs)	Research Assist. (Hrs)	(Hrs)
1	Study Group Selection	22.00	22.00	704.00			748.00
2	Survey Design	96.00	12.00	24.00	120.00		252.00
3	Data Logging and Site Visits	132.00	88.00	3060.00		1100.00	4380.00
4	Flow Trace Analysis and DB Const	44.00	1795.00	1820.00			3659.00
5	Survey Response analysis	198.00	176.00				374.00
6	Data Analysis and descriptive statistics	35.00	278.00	220.00			533.00
7	Multivariat Modelling	232.00	290.00		190.00		712.00
8	Analysis of Statewide Implications	120.00	120.00			490.00	730.00
9	Report writing	270.00	405.00		80.00	150.00	905.00
	Total Hours Estimated	1149.00	3186.00	5828.00	390.00	1740.00	12293.00

Table 9: Expenses by category and task

DETAILS OF DIRECT EXPENSES

TASK	DESCRIPTION	Cat 1 Supplies	Cat 2 Equipment	Cat 3 Services or Consultants	Cat 4 Travel	Cat 5 Rental	Cat 6 Other Direct Expenses	Total
1	Study Group Selection	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2	Survey Design	$ 1,560	$ -	$ -	$ 1,175	$ -	$ 1,400	$ 4,135
3	Data Logging and Site Visits	$ -	$ -	$ -	$ 70,750	$ 51,600	$ 3,600	$ 125,950
4	Flow Trace Analysis and DB Const	$ -	$ -	$ -	$ -	$ -	$ -	$ -
5	Survey Response analysis	$ 710	$ -	$ 10,400	$ -	$ -	$ -	$ 11,110
6	Data Analysis and descriptive statistics	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7	Multivariat Modelling	$ 273	$ -	$ -	$ -	$ -	$ 10,000	$ 10,273
8	Analysis of Statewide Implications	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9	Report writing	$ 1,610	$ -	$ -	$ -	$ -	$ -	$ 1,610
12		$ -	$ -	$ -	$ -	$ -	$ -	$ -
	TOTAL FOR PROJECT	$ 4,153	$ -	$ 10,400	$ 71,925	$ 51,600	$ 15,000	$ 153,078

Appendix C-1: DWR Cost Table

	Category (I)	Applicant Share (II)	California Bay Delta Program Share) *Grant* (III)	Total Project Costs (IV) (II + III)	CDWR Annual Contributions 2006	2007
(a)	Administration, Consulting, Analysis					
	Salaries, wages			$ -		$ -
	Fringe benefits			$ -		$ -
	Supplies		$ 4,153	$ 4,153	$ 4,153	$ -
	Equipment					$ -
	Consulting services	$ 10,000	$ 10,400	$ 20,400	$ 10,400	$ -
	Travel	$ 20,000	$ 51,925	$ 71,925	$ 51,925	$ -
	Other		$ 5,000	$ 5,000	$ 5,000	$ -
(b)	Planning/Design/Engineering	$ 92,050	$ 735,535	$ 827,585	$ 134,387	$ 601,148
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$ 51,600		$ 51,600		$ -
(d)	Materials/Installation/Implementation			$ -		$ -
(e)	Implementation Verification			$ -		$ -
(f)	Project Legal/License Fees			$ -		$ -
(g)	Structures			$ -		$ -
(h)	Land Purchase/Easement			$ -		$ -
(i)	Environmental Compliance/Mitigation/Enhancement			$ -		$ -
(j)	Construction			$ -		$ -
(k)	Other			$ -		$ -
(l)	Monitoring and Assessment			$ -		$ -
(m)	Report Preparation	$ 81,350		$ 81,350		
(n)	**SUBTOTAL (a +…… +m)**	$ 255,000	$ 807,013	$ 1,062,013	$ 205,865	$ 601,148
(o)	Contingency (specify % used; example: 5 or 10)	$ -	$ -	$ -	$ -	$ -
(p)	**TOTAL** (n +o)	$ 255,000	$ 807,013	$ 1,062,013	$ 205,865	$ 601,148

Appendix D: Statements of Qualifications

Aquacraft, Inc.

Water Engineering and Management

General

Founded in 1990, Aquacraft, Inc. is an engineering firm dedicated to increasing water use efficiency in the United States. As populations grow this is essential in order to reduce the impact that human activities have on the environment. We look for projects that seek to apply scientific methods to the study of urban water demands, and their management as an active element in water resources planning. The firm has also developed significant tools for collection, analysis and modeling of water demands in an integrated manner.

Aquacraft pioneered the use of flow trace analysis to measure how water is used in a variety of urban settings. We have developed large databases of disaggregated water use from both the residential and commercial sectors and database applications to evaluate demands. We use these data to create reality-based models of municipal water use and projections of demand with and without conservation. Aquacraft is a recognized national leader in evaluating the effectiveness of water conservation measures for reducing long-term water demands.

Obtaining data on water use is just part of the problem. Understanding the interrelationships between water system demands, capital spending and system financing is another key element. Aquacraft has developed several demand forecasting and models that integrate the impacts of water conservation on future demands, and to compare overall system costs under demand management and traditional supply side operations. Integrated models of this type provide a vehicle to fairly compare all the costs and benefits of alternative operation scenarios.

Through our consulting and research work, Aquacraft has a wide network of contacts in the water industry and an understanding of important water policy issues. We have supported the work of the Water Conservation Division of the AWWA. Both Peter Mayer and Bill DeOreo are active members of this division through our participation in the work of the committee on Planning, Evaluation, and Research and the committee on Water Efficiency Programs and Technology. Aquacraft is also a member of the Irrigation Association.

Aquacraft Staff

William B. DeOreo, M.S., P.E., President Bill DeOreo is the founder and principal engineer of Aquacraft. With over 25 years of experience as a water engineer in Colorado, he specializes in water resources planning and management. Bill graduated from Boston University and the University of Colorado, Boulder. He is a member of American Society of Civil Engineers, American Water Works Association, and the American Geophysical Union.

Peter Mayer, M.S., P.E., Vice President
Peter Mayer joined Aquacraft as a partner in 1995 after earning a Master's degree in civil engineering from the University of Colorado, Boulder. He specializes in conservation planning, water demand forecasting and analysis, database development, technical writing, and development of computer applications for water management. He is a member of AWWA and AWRA.

Leslie Martien, Water Resources Engineer
Leslie Martien joined Aquacraft in 2002 after completing her Bachelor of Science in Water Resources and Environmental Engineering at the University of Colorado. She won the Donald Mackison Award from the University of Colorado for Excellence in Writing on Science and Society. Leslie has developed water efficient landscape designs and worked on system planning projects evaluating new conservation technologies. She is a certified irrigation auditor and a member of AWWA.

Matt Hayden, Application Developer and WR Engineer
Matt Hayden joined Aquacraft in 2004 after completing his Bachelor of Science from the University of Colorado College of Engineering with a major in Applied Math and a minor in Environmental Biology. He was a National Merit Scholar and has exceptional computer programming and application development skills. His work with Aquacraft focuses on development of computer applications for water management.

Services Provided

Water Demand Analysis

At Aquacraft, we believe that the foundation of a sound demand management program is accurate information on the specific end uses of water, which allows one to both predict the theoretical impacts of water management options, and to measure their actual savings efficiently.

To provide the type of information needed to better understand demands, Aquacraft, Inc. has pioneered a method for collecting and disaggregating water use information from municipal customers through a single flow trace obtained from the customer's water meter. Using Trace Wizard©, a signal processing software package developed by Aquacraft, information on where and how customers are using water can be easily obtained. In single family homes Trace Wizard helps disaggregate water use into all of the major end uses (e.g. toilets, showers, clothes washers, irrigation, leaks etc.)

In larger commercial and industrial customers Trace Wizard is a tool that can be used to differentiate between domestic uses, process uses, continuous uses (cooling, etc.) and irrigation. For more precise analysis we recommend sub-metering large fixtures such as cooling towers and R/O systems.

Since 1994 Aquacraft has obtained flow trace data on thousands of single family homes and hundreds of commercial, industrial and institutional users. The information for these traces have been placed into end-use and peak demand databases which, when combined with survey information provide excellent data on where, when, and how water is being used by a wide variety of customers.

Database and Software Application Development

Aquacraft develops database and software applications for tracking and evaluating water use. Our staff has substantial software development, engineering, and project management talent. In 2004 Aquacraft developed a web-based database for the US Environmental Protection Agency to track potential water efficient products for the proposed "Water Star" market enhancement program.[4] Aquacraft's database applications for studies such as the *Residential End Uses of Water* (1999, AWWA) and the more recent Seattle, EBMUD, and Tampa residential retrofit studies (2000-2004, US EPA) have been used by consultants, researchers, and utility professionals to evaluate water conservation effectiveness. Aquacraft's Trace Wizard© Water Use Analysis Software application has been used by researchers and utility professionals in the United States, Europe, Australia, and the Middle East to evaluate residential, non-residential, and irrigation of water use.

[4] To view this application visit: www.aquacraft.com/waterstar. Username: guest Password: 1234

Water Conservation Planning

Once data has been collected and a model created, the next logical step is to apply this information to real life situations. We have begun the process of applying the vast amount of information collected in Aquacraft's research work to the creation of cost-effective long term water efficiency programs for urban providers. Aquacraft develops water conservation plans that include the long-term impacts of water conservation on both the water supply, capital requirements and financial aspects of utility operation. Aquacraft is an approved consultant for the California Urban Water Conservation Council.

Integrated Water Demand and Financial Modeling

Aquacraft is a leader in integrated resource planning. We developed the demand forecasting and system operations model for the Colorado Water Conservation Board's CIRCE model, which was one of the first attempts to integrate the impacts of water conservation programs on water operations, system revenue, and long term finances. We have used successors to this model to assess the impacts of various conservation scenarios for clients such as Boulder, Westminster and Thornton, Colorado.

Other Capabilities

Aquacraft can provide services related water rights engineering (including expert testimony), hydraulic analysis and calibration of hydraulic models, environmental data collection, peak demand evaluation, and statistical analysis.

How to Contact Us

Phone:	(303) 786-9691
Fax:	(303) 786-8337
E-Mail	mailto:deoreo@aquacraft.combill@aquacraft.com
	mayer@aquacraft.com
Web Address:	www.aquacraft.com

Aquacraft, Inc. Billing Rates

Professional Engineer/Expert Testimony	$150 per hour
Senior Engineer	$125 per hour
Project Manager	$105 per hour
Project Engineer	$95 per hour
Analyst	$65 per hour
Technician	$55 per hour
Administrative	$45 per hour

Recent Projects and References

EPA Water Efficiency Market Enhancement Program (2004 – 2005)
Working with D&R International and ERG, Aquacraft assisted in the design of the market enhancement program (aka "Water Star"), and played a key role in evaluating products and product categories that could receive an efficiency label. Aquacraft developed a web-based database for this project that has been used by the project team and EPA to collect and track information on efficient products and categories.
Contact: Mr. John Flowers, US EPA (202) 564-0624

National Multiple-Family Submetering and Allocation Billing Program Study (2002-2004)
Aquacraft lead a team that examined the impacts of submetering and RUBS billing in the multi-family sector. This national study is of critical importance to the water industry and provides some of most statistically rigorous examinations of the impacts of metered and allocation billing. The study looked at the entire phenomena of submetering and allocation billing techniques examining the potential water savings, regulatory issues, utility concerns, water rates, and regulatory climate.
Contact: Mr. Richard Bennett, EBMUD (510) 287-0597

University of Colorado – Student Housing Performance Contract (2003)
Working with the Brendle Group and the Siemens Corporation, Aquacraft conducted an investment grade audit of irrigation systems on the CU Boulder campus and provided technical support for interior retrofit audits. Numerous facility improvement measures were identified that should greatly improve irrigation efficiency at CU.
Contact: Ms. Judy Dorsey, the Brendle Group (970) 207-0058

AwwaRF Value of Water Study (2003)
Working with Stratus Consulting, Aquacraft developed case studies and provided end use information for the Value of Water Study, funded by the American Water Works Association Research Foundation.
Contact: Mr. Robert Raucher, Stratus Consulting (303) 381-8000

Weather-Based Irrigation Controller Research and Support (2001-2003)
Since 2001 Aquacraft has evaluated and tested the WeatherTRAK sprinkler control system – an advanced sprinkler controller that adjusts irrigation based on prevailing weather conditions. Results from the studies showed this system does an excellent job of managing irrigation water demands and had good customer acceptance. In 2003, Aquacraft began working as manufacturers representatives for WeatherTRAK and Hydropoint Data Systems in Colorado. Aquacraft has supervised installation of numerous WeatherTRAK controllers and promoted the technology as a useful water saving tool. **Contact: Mr. Chris Manchuck, Hydropoint (707) 769-9696**

EBMUD and Tampa Interiror Retrofit Projects (2001-2003)
These projects carefully evaluated the impact of interior plumbing and fixture retrofits on single family homes. A sample of approximately 30 homes was selected in each city and baseline water use and customer information data were obtained. Next the homes were

retrofit with best-available-technology toilets, clothes washers, showerheads, and faucet aerators. Post retrofit water data were collected and analyzed using flow trace analysis technology. The results show precise impacts of high efficiency plumbing fixtures and appliances on single family homes on a per household and per capita demand basis. Customer satisfaction ratings were also obtained. **Contacts: Mr. Richard Bennett, EBMUD (510) 287-0597, Sandra Anderson, Tampa (813) 274-7435**

Water Efficient Home Web Site (www.h2ouse.org**) (2002-2003)**
Working with the California Urban Water Conservation Council, Aquacraft developed substantial content for the virtual water efficient home web site. Aquacraft also assisted in developing the original design for the award winning site.
Contact: Ms. Mary Ann Dickinson, CUWCC, (916) 552-5885

Colorado Department of Human Services Water Rights Study (2003)
The Department of Human Services has been charged with achieving a 20% reduction of all utilities in the current fiscal year. Aquacraft is working in association with Long Energy to determine the water rights available to DHS and the most efficient use and distribution of their water resources. **Contact: Mr. Dave Piatek, DHS (303) 866-7297**

Pinellas County Utilities Water Conservation Opportunities Study, (2002)
Pinellas County Utilities, located just west of Tampa, Florida, has an active water conservation and alternative supplies program. They came to Aquacraft and asked, "where can we go from here to save water?" This study measured water use in samples of single-family and multi-family homes and made recommendations for future water conservation programs that could achieve the most savings in this specific community.
Contact: Mr. Wayne West, PCU (727) 464-3677

Water Conservation in Urban Supermarkets, (2001-2003)
Urban supermarkets are major water users, especially their cooling equipment for refrigeration. This study looks at use of various water treatment systems on the coolers to reduce water used for bleed, and use of high efficiency plumbing fixtures and faucet controllers in the rest of the store to reduce water use.
Contact: Debra Gonzales, California DWR (916) 651-7026

Dacono Water Supply and Conservation Plan, (2001-2002)
The Town of Dacono, Colorado anticipates significant growth in the coming years and needs to plan for a secure water future. Aquacraft developed a long-term water demand forecast and conservation model that projected the impact of future development on supply for the town. We also created a subdivision demand forecasting tool that the Town can use to determine how much water and what water rights a new development must dedicate as a condition of incorporation.
Contact: Ms. Karen Cumbo, City Manager (303) 833-2317 x125

Irrigation Demand Study for East Cherry Creek Valley Water District (2001-2002)
The East Cherry Creek Water District (ECCWD), located near Aurora Colorado plans to build a raw water distribution system in the next few years, but was uncertain how much

land could be irrigated given the limitations of their water rights, storage, and pumping capacity. Aquacraft used micro flow metering technology to measure peak demand in 29 different irrigation systems that could potentially be served by the raw water system. These results were used to develop a model to help size the system and determine how much land can be served by the system.
Contact: Mr. Dave Kaunisto, District Manager ECCWD (303) 693-3800 x 29

Water Conservation Plan for City of Bozeman, MT, (2001)
The City of Bozeman is situated in Gallatin Valley of Montana at the headwaters of the Missouri River. Growth rates are high and the citizens place a very high value on the quality of their environment. Mr. DeOreo developed an integrated water demand/financial model, which showed the impacts of various water conservation options on the both water demands, capital spending and system finances. This model allowed the town to assess the potential of water conservation to delay several water treatment and storage projects.
Contact: Mr. Rick Hixson, Bozeman Water Dept. (406) 582-2380

Seattle Water Conservation Retrofit Study (1999-2000)
This study demonstrated that indoor home water use can be reduced by more than a third – to under 40 gallons per person per day (gcd) – simply by installing water-efficient plumbing fixtures and appliances. Building on the AWWA Research Foundation's Residential End Uses of Water study, and with funding from EPA, Seattle Public Utilities used the innovative flow trace analysis technology to measure precisely how cold and hot water was used inside 37 homes. Then, after the homes were outfitted with water-efficient appliances and fixtures, water use was measured again, showing 37% savings. Equally important -customers tended to be more satisfied with their new high efficiency fixtures than they were with their old equipment. The study included selected brands of efficient clothes washers, toilets, showerheads, and faucet aerators. Seattle Public Utilities and the U.S. EPA funded this project.
Contact: Mr. Tim Skeel, Seattle Public Utilities (206) 386-9084

Commercial and Institutional End Uses of Water, AWWARF,(1998-2000)
This study set out to collect and analyze data on commercial and institutional end uses of water in five cities. This study developed information on the most significant commercial and institutional customers in typical municipal water systems and the purposes for which these customers use water. Aquacraft performed detailed water audits and implemented a variety of water use measurement programs to determine where water is used in these settings. Report is available for purchase from AWWA.
Contact: Mr. Robert Allen, AWWARF (303) 347-6103

Residential End Uses of Water Study, AWWARF, (1996-1999)
In this three year project, funded in combination by the American Water Works Association Research Foundation and 14 cities across the US and Canada, disaggregated water use data were obtained from nearly 1200 single family residences. In addition to characterizing water use in the single-family sector, these data were used to develop a model of residential water use based on the demographic characteristics of the households and the specific water using fixtures and appliances present.

The database developed for this study includes a table of over 1.9 million individual water use events that have been analyzed according to end use, volume, start time, flow rate, and duration. These were obtained from scientifically selected samples from the single-family residential customers in each city. The database also includes a table of daily use for each household and extensive survey information that provides information on physical and demographic characteristics.
Contact: Mr. Robert Allen, AWWARF, (303) 347-6103

Industrial, Commercial, and Irrigation Water Study and Conservation Plan, Westminster, CO, (2000-2001)
The goals of this project were to evaluate ICI water demands in Westminster, identify and evaluate potential conservation programs, develop a long range conservation plan and demand tracking tools, and pilot test various conservation measures.
Contact: Mr. Bob Krugmire, City of Westminster (303) 430-2400 x 2181

Analysis of Southern Nevada Xeriscape Project, (1998-2000)
Aquacraft performed a detailed evaluation of a Xeriscape conversion program in Las Vegas. Fifty participants in the program were compared against 50 traditionally landscaped customers. Flow trace analysis techniques were used to separate indoor and outdoor consumption in the 100 study houses. Significant savings were found among Xeriscape homes. Report is available from Aquacraft.
Contact: Ms. Janet Rosales, Southern Nevada Water Authority (702) 259-8158

Water Conservation Futures Study, City of Boulder, CO, (1998-2000)
The City of Boulder is fortunate to have an abundant supply of high quality water, and they do not project any shortages in water supply between current conditions and build out. Nonetheless, the City recognizes that there are demand management issues to address both from the perspective of equity in the billing system and in the need to identify other potential uses for its water resources (such as in-stream flow maintenance). Aquacraft is part of the team hired by the City to conduct an analysis of the future of water conservation in Boulder. **Contact: Mr. Paul Lander (303) 441-4081**

Water Conservation Plan, City of Thornton, CO, (1998)
The City of Thornton is faced with one of the highest growth rates in Colorado, and a very expensive new water supply. The impacts of water conservation on their system could be dramatic. Aquacraft, in conjunction with HDR consultants completed a water conservation plan for Thornton to determine the impact of a range of conservation measures on the City's water supply. All conservation measures will be compared to the City's structural alternatives in terms of yield and cost.
Contact: Mr. George Oameck, Project Manager, HDR, (402) 399-4938

Water Efficiency in Water Wise and Standard New Homes, (1999-2000)
Aquacraft conducted a study in Westminster Colorado to determine how water use in specially designed "Water Wise" homes compares with other new homes built at the same time. This project will measure the impact of the 1993 Federal plumbing codes compared

to homes equipped with advanced efficient plumbing fixtures including conserving clothes washers and re-circulating hot water systems. Aquacraft's flow trace analysis technique was used to measure end uses in each of the 40 participating study homes. **Contact: Mr. Kelly DiNatale (303) 430-2400**

Tucson Older ULF Toilet Study, (1998-1999)
Aquacraft provided hardware, software, and technical support for a project that evaluated the performance of ULF toilets that were placed into service in the early 1990s. It was suspected that these fixtures no longer operate at a flush volume of 1.6 gallons, thus potentially reversing conservation savings.
Contact: Mr. Tom Babcock, City of Phoenix, (602) 261-8377

Evaluation of Soil Moisture Sensors in Field Applications, (1996-1998)
Working with the City of Boulder, Aquacraft tested the efficacy of the Watermark soil moisture sensor system in a variety of settings including single-family residential, multi-family residential, commercial, and urban parks. Results show that these devices, while not perfect, can be an effective tool for controlling automatic irrigation systems and limiting application rates to ET. **Contact: Mr. Paul Lander, (303) 441-4081**

Comparison of Demand Patterns among Residential and CI Customers, Westminster, CO, (1997-1998)
Westminster, Colorado is a growing community in the Denver metropolitan area. The city is working on the development of a cost of service based rate system. In order to assist with this effort Aquacraft has collected flow trace data on a series of single family, multi-family, irrigation, and commercial accounts during peak demand period for the City. These data have been used to develop daily and hourly peaking factors for each category and a set of normalized demand parameters for use in projecting demands in future customers. **Contact: Mr. Kelly DiNatale (303) 430-2400**

High Water Use Analysis, WSV Ltd. (1998)
The WSV Partners own several multifamily housing communities in the United States. Two of them, Sunset Ridge and Northgate in Denver appeared to be using excessive amounts of water. Aquacraft performed water use analyses of both complexes and using flow trace analysis quantified the indoor, outdoor use and leakage. Both projects were found to have significant leakage, and specific strategies were developed for repair of existing leaks and for identification of future leaks as soon as they exceed tolerable levels.
Contact: Mr. Tom Williams, (214) 373-3907

Westminster, Peak Demands Study, (1996)
As part of its water planning process, the City of Westminster needed information on daily and hourly peaking factors for its major classes of customers. Aquacraft conducted a baseline study of peak use in single family, multifamily, irrigation, and commercial/industrial customers for the City. This study generated peak use factors as ratios to average day demands and in terms of gallons per day per unit.
Contact: Mr. Kelly DiNatale (303) 430-2400

Centennial Valley Water GIS, (1996-1997)
In order to determine the amount of wastewater being generated from an area of mixed development in Louisville, CO., Aquacraft developed a geographical information system which linked water billing and mapping information, thus allowing determinations to be made on deliveries of treated water to areas tributary to any specified portion of the sanitary sewer system. This system showed in which areas large discrepancies existed between measured wastewater flows and treated water deliveries and identified areas of probable I&I into the sanitary sewer system. **Contact : Mr. Carmine Iadarola (303) 932-6910**

Westminster Residential Water Use Study, (1995-1996)
Using Aquacraft's flow trace analysis capabilities, 60 single-family residential customers, divided into three distinct age groups, were sampled. The data traces from the meters were disaggregated into end uses so that the variations in water use in homes of different ages could be investigated. A primary goal of the study was to determine whether new homes, built to exceed the 1991 Energy Policy Act standards used less water per unit than other homes in the system. **Contact: Kelly DiNatale (303) 430-2400**

Heatherwood Retrofit Study (1995)
Using the baseline data collected in 1994 as the starting point 14 out of the 16 homes in the Heatherwood study group were retrofit with high efficiency toilets, showers, and faucets. Four of the homes received horizontal axis clothes washers. Three weeks of end use data were collected and disaggregated and then compared against the pre-retrofit data in order to quantify the precise impacts of the retrofit on the individual water use category. **Contact: Mr. Paul Lander (303) 441-4081**

Heatherwood End-Use Study, (1994)
This project involved development of a pilot scale customer information system using a GIS. Another important aspect of this project was the use of data loggers to acquire consumption profiles from a select study group (chosen using the CIS system), which were then disaggregated into their individual components through signal processing techniques. This information provided accurate determination of percent of water devoted to individual purposes in single family residential customers. The effectiveness of soil moisture sensors for irrigation scheduling on automatic sprinkler system was also investigated. **Contact: Mr. Paul Lander (303) 441-4081**

MCDB Water Use Study, (1994)
The University of Colorado faced a wastewater Plant Investment Fee of $219,000 for an expansion to the Molecular Cellular and Developmental Biology building on the Boulder Campus. A detailed study and water audit of the water and wastewater flow patterns and waste loadings was conducted which determined that the appropriate charges would be $52,000, a savings of $167,000. **Contact: Mr. Tom Cowing (303)492-5684**

Colorado Water Conservation Model, (1992-1993)
In order to implement the 1991 Water Conservation Act, the State of Colorado authorized the development of an integrated water system operations and economic model (CIRCE)

which will allow system managers to asses both the hydrologic and financial consequences of alternative water management strategies. This allows an objective assessment of the relative benefits of both structural (supply side) and non-structural (demand side) projects. **Contact: Ms. Chris Bridges (303) 866-3441**

Partial List of Clients

American Water Works Association Research Foundation
Arizona Municipal Water Users Association, AZ
Arkansas River Ranch LLC
California Urban Water Conservation Council
California Department of Water Resources
City of Boulder, CO
City of Dacono, CO
City of Greeley, CO
City of Lompoc, CA
City of Phoenix, AZ
City of San Diego, CA
City of Santa Paula, CA
City of Scottsdale AZ
City of Tampa, FL
City of Tempe, AZ
City of Thornton, CO
City of Westminster, CO
Denver Board of Water Commissioners, Denver CO
East Bay Municipal Water District
East Cherry Creek Valley Water District
Eugene Water and Electric Board, OR
Hillsborough County Water Department, FL
Irvine Ranch Water District
Las Vegas Valley Water District
Las Virgenes Municipal Water District, CA
Metropolitan Water District of Southern California, CA
Pinellas County Utilities
Regional Municipality of Waterloo, Ontario
San Diego County Water Authority
Seattle Public Utilities, WA
Southern Nevada Water Authority
Tampa Bay Water
U.S. Bureau of Reclamation
U.S. Environmental Protection Agency
University of Colorado, Boulder

PACIFIC INSTITUTE

Research for People and the Planet

About the Pacific Institute

Introduction

The Pacific Institute is dedicated to protecting our natural world, encouraging sustainable development, and improving global security. Founded in 1987 and based in Oakland, California, we provide independent research and policy analysis on issues at the intersection of development, environment, and security. Our aim is to find real-world solutions to problems like water shortages, habitat destruction, global warming, and environmental terrorism.

Our Strengths

Since our founding, we've become known for independent, innovative thinking that cuts across traditional areas of study. Our interdisciplinary approach not only helps us make connections that others miss, it also enables us to bring opposing groups together to forge effective real-world solutions.

Our Programs

The Pacific Institute currently has five main areas of research: Water and Sustainability, Environment and Security, Community Strategies for Sustainability and Justice, Economic Globalization and the Environment, and Global Change.

The *Water and Sustainability Program* works on a wide range of water-related issues – from improving efficiency of water use and anticipating the impacts of climate change, to studying water privatization and ensuring that the billions of people without access to basic water or sanitation services are not forgotten.

The *Community Strategies for Sustainability and Justice Program* integrates the Pacific Institute's research skills with the strengths of community-based groups to democratize decision making, protect human health, and foster environmental justice.

The *Economic Globalization and the Environment Program* studies the effects of the increasingly integrated global economy on the environment and society. Current work focuses on performance-based regulatory innovation, and on the policy implications of international environmental standards, such as ISO 14000.

The *Environment and Security Program* examines the effects of environmental issues like climate change and water shortages on national and international security, and studies non-traditional threats like environmental terrorism and the ecological impacts of war.

The *Global Change Program* focuses on the impacts of climate change on water supplies, wildlife, the environment, and human society, and works to educate policymakers and the public.

More information on our programs and publications can be found online at: http://www.pacinst.org

Pacific Institute at a Glance

Funding

As an independent, tax-exempt nonprofit we fund our work primarily through foundation grants and individual donations. Institutional funders have included the Ploughshares Fund, the MacArthur Foundation, the Rockefeller Brothers Fund, the Hewlett Foundation, and many more. We have also worked with agencies including the U.S. Environmental Protection Agency and the United Nations Environment Programme (a full list of sponsors and partners is available online).

Mission

The Pacific Institute is dedicated to protecting our natural world, encouraging sustainable development, and improving global security.

Methods

We conduct research, publish reports, recommend solutions, and work with decisionmakers, advocacy groups, and the public to change policy. A list of recent publications can be found online at http://www.pacinst.org/reports

Vision

We envision a world where the basic needs of all people are met, where resources are managed sustainably and the natural world protected, and where conflicts over resources are resolved in a peaceful and democratic fashion.

Current Research

Institute staff are currently working on a wide range of projects that include protecting water resources, reducing diesel pollution, improving resource efficiency, studying the impacts of globalization, and reducing the threat of conflict over resources.

Offices

Our main office is located in Oakland, California. We have satellite offices located in Washington, DC and Boulder, Colorado.

Budget

$1.6 million (2001)

Tax Status

The Pacific Institute is a tax-exempt 501(c)3 organization established in 1987.

Websites

www.pacinst.org • www.worldwater.org • www.globalchange.org • www.waterwords.org

For more information

Voice: 1 (510) 251-1600, Facsimile: 1 (510) 251-2203
General information: pistaff@pacinst.org
Media-related inquires: media@pacinst.org

Stratus Consulting: Corporate Qualifications

Stratus Consulting provides comprehensive, multidisciplinary expertise in economics, management, and environmental sciences. In the water sector, Stratus Consulting provides strategic planning, regulatory analysis, valuation, and costing services to address the high profile public policy and resource management issues facing today's water community. The firm has earned a reputation as a leading contributor to informed decision-making in public water supply and wastewater-related practices, policies, and regulations. We promote the sound management of water resources by blending a unique mix of technical skills in economics, public health risk assessment, statistics, ecological sciences, and security planning.

Stratus Consulting has extensive familiarity with California water issues including water conservation, water valuation and costing, water reuse and natural resource damage assessment through work for California clients including the California Urban Water Conservation Council, Metropolitan Water District of California, Contra Costa Water District, East Bay Municipal Utility District, and the California Department of Fish and Game. Stratus Consulting has significant partnering relationships on projects for the American Water Works Association Research Foundation and the WateReuse Foundation with California entities including the Los Angeles Department of Water and Power, the San Francisco PUC, Orange County Water District, West and Central Basin Municipal Water Districts, Inland Empire Utilities Agency, Dublin San Ramon Services District, Santa Clara Valley Water District, and the National Water Research Institute.

Our staff of 60 includes nationally recognized experts in water resource management and related fields. Noted for superior research, leadership, and client support, Stratus Consulting researchers are supported by in-house library services, a document production department, and a full complement of computational tools, including a GIS system. Our clients include state, federal, tribal, and international government agencies, research institutes, utilities, and law firms.

Bios

John Whitcomb, PhD is an economist/statistician who has worked with over 100 water agencies on projects related to water pricing, water conservation intervention analysis, benefit-cost evaluation, and risk assessment. He has been the project manager of four projects conducted for the California Urban Water Conservation Council regarding toilet water savings, handbooks on implementing best management practices (BMP 5 and 9), and designing programs to minimize participant freeriders. He has also been the principal investigator of major studies measuring customer understanding and sensitivity to water pricing in Florida, Texas, the Southwestern U.S. (Arizona, California, and Nevada), and Brazil. John has worked on numerous projects involved with identifying avoided costs, typically in the context of water conservation programs. This includes a detailed study of alternative costs for the El Paso Water Utilities and identification of a variety of direct and indirect avoided costs associated with water recycling as part of study for the American Water Works Association Research

Foundation. Dr. Whitcomb holds a BA in economics and geography from the University of California, Santa Barbara and a PhD in geography and environmental engineering from the Johns Hopkins University.

James L. Henderson, senior economist at Stratus Consulting, specializes in water conservation analysis, water resource planning, river basin modeling, and cost-benefit analysis. Mr. Henderson conducted a study of the functioning of aging ultra-low-flush (ULF) toilets in Tucson, and quantified the water savings, cost-effectiveness, and patterns of participation for the ULF rebate program under which those toilets were originally installed. Jim has also conducted research into water demand modeling, water customer response to changes in water quality, and water management under drought conditions. He has a BA in economics from Colorado College, and an MS in agricultural and resource economics from the University of Arizona.

Project Blurbs

Ultra-Low Flush Toilet Freerider Study

Client: California Urban Water Conservation Council (2001-2002)

Conducted the largest study ever done on conservation program freeriders in the water industry. Project investigated freeriders associated with ultra-low flush toilet (ULFT) programs offered by water agencies in California. Freeriders are program participants who, without the ULFT program, would still have replaced their toilets. Agencies do not get incremental conservation benefits from serving freeriders because the conservation would have happened irrespective of the program. Project included a literature review (mainly focused on what has been learned in the energy industry), market research via empirical data collection and analysis of 1,032 single-family and 298 multiple-family ULFT program participants, and development of ULFT program recommendations to minimize freeriders and, hence, maximize program cost-effectiveness.

Landscape Best Management Practices 5 Procedures Handbook

Client: California Urban Water Conservation Council(1998-1999)

Senior staff at Stratus Consulting managed a project creating a handbook to help water agencies with understand and successfully administer landscape conservation programs in accordance with a California best management practice (BMP). Chapters include programs on developing water budgets based on landscape area, water surveys/audits, and financial incentives. Topics include using innovative landscape measurement techniques, program cost development, and cost-effectiveness. The handbook's intended audience is the water conservation coordinator at a water agency.

Commercial, Industrial, and Institutional (CII) Best Management Practices 9 Procedures Handbook

Client: California Urban Water Conservation Council(1998-1999)

Authored a handbook assisting water agencies with understanding, designing, and implementing commercial, industrial, and institutional (CII) conservation programs in accordance with a California best management practice (BMP). Chapters address characterizing CII customers, ULFT replacement, water use surveys, and water use performance targets. Handbook's intended audience is the water conservation coordinator at a water agency.

Contra Costa Water District Conservation Monitoring Studies

Client: Contra Costa Water District (1991-1999)

Stratus Consulting senior staff conducted various statistical evaluations to support financial planning, engineering peak-design decisions, and measurement of water conservation savings. One set of studies measured long-term persistence in water savings from both residential and landscape audit programs. Another assignment addressed weather normalization of daily water production and monthly-billed water use data. Stratus Consulting also provided protocols for data collection tasks to enhance monitoring and evaluation of water conservation program, including ultra-low-flush toilet projects.

Water Savings from Ultra-Low-Flush Toilets in CII Sector

Client: California Urban Water Conservation Council (1996-1997)

Stratus Consulting managed a project evaluating the water savings associated with ultra-low-flush toilets at 1,370 commercial-industrial-institutional (CII) sites for a project funded by the California Urban Water Conservation Council. The results show that water savings vary significantly among different CII subclasses. A highly successful telephone survey (over 80% participation rate) was used to collect data from CII customers about water use and satisfaction with ULF toilets. The project also developed a method that water agencies can use to estimate the number of toilets within different CII subclasses for their service areas. The combination of per-fixture water savings and toilet count estimates allows water planners to gauge potential local agency water savings from ULF toilet installations.

Evaluation of the Metropolitan Water District CII Survey Database

Client: Metropolitan Water District of Southern CA (1997)

Stratus Consulting senior staff provided a review of the Metropolitan Water District's Commercial-Industrial-Institutional (CII) Water Use Survey Program. The review was based on analysis of a database containing detailed information from 902 CII water surveys conducted between 1991 and 1996. The database is believed to be the largest and most extensive developed to date concerning water use information for individual CII sites. The report describes key findings and provides guidance on designing and implementing cost-effective water conservation programs for the CII sector. It also offers a set of next steps for future evaluation.

Analysis of Functioning of Aging Ultra-Low-Flush Toilets in Tucson

Client: City of Phoenix (1998-2000)

Senior staff at Stratus Consulting examined the functioning of ultra-low-flush toilets installed under Tucson Water's ULF toilet rebate program using data loggers to record household water use. Logged water use data were supplemented with a survey of homeowners. The ULF toilets examined were about one-third of the way through their average useful life. The study was designed to quantify the frequency and severity of problems previously reported only anecdotally. Toilet problems such as high flush volumes, frequent double flushing, and recurring flapper leaks were quantified and compared to non-ULF toilet problems in the same households.

Santa Clara Valley Water District Landscape Water Audit Program (1995-1996)

Stratus Consulting senior staff, in conjunction with Agtech Associates, designed and conducted a large landscape water audit program for the Santa Clara Valley Water District's multiple retailers. The project included software development and a market (baseline) survey.

Tucson Ultra-Low-Flush Toilet Rebate Program Analysis

Client: Tucson Water (1994)

Senior staff quantified the water conservation savings and cost effectiveness of the City of Tucson's ultra-low-flush toilet rebate program using statistical analysis. Patterns of participation also were analyzed geographically to identify locations where the program could be concentrated to increase water savings per rebate.

Appendix E: Resumes

WILLIAM B. DeOREO, P.E. , Aquacraft, Inc.

President and Principal Engineer

Aquacraft, Inc. Water Engineering and Management
2709 Pine Street, Boulder, CO 80302.

WORK EXPERIENCE
President and Principal Engineer, Aquacraft, Inc. Water Engineering and Management 1990-present.
Principal Engineer, Hydrosphere Resource Consultants, Inc., Boulder, Colorado, 1985-1990
Water Resource Engineer Wright Water Engineers, Denver, Colorado, 1980-1985
Utility Project Coordinator, City of Boulder, Boulder, Colorado, 1978-1980

AFFILIATIONS
American Society of Civil Engineers
American Water Works Association
Chi Epsilon, Tau Beta Pi. National Engineering Honor Societies

EDUCATION
Bachelor of Arts, Biology, Boston University (1971)
Bachelor of Science, Civil and Environmental Engineering, University of Colorado, Boulder (1975)
Master of Science, Civil and Environmental Engineering, University of Colorado , Boulder (1978)

QUALIFICATIONS
Mr. DeOreo has been actively practicing water engineering since 1978 after receiving his Master Degree in Civil and Environmental Engineering from the University of Colorado, Boulder. He has worked both in the public sector and as a private consultant. His main interests are in development of innovative supplies of water for municipal uses, improving the yield of urban water systems through better water planning and management, integration of urban water uses into watershed analyses, and development of computer based applications to assist with water planning. Mr. DeOreo is a member of the Planning and Evaluation sub-committee of the AWWA Water Conservation national committee.

SELECTED PROJECTS

Evaluation of Water Conservation Systems for Supermarket Cooling Systems (2001-2003)
Value of Water Study, AWWARF Report (2003)
Evaluation of Sub-metering in Multi-Family Housing for Water Conservation (2003-2004)
Analysis of Performance of WeatherTRAK ET Irrigation Controller in 3 . (1999-2002)
Evaluation of Irrigation System Efficiency, University of Colorado (2003)
Evaluation of Drought Plan, City of Boulder (2003)
Penetration Study of Water Conserving Fixtures and Appliances, City of Seattle (2003)
Seattle Retrofit Study (2001)

CII Demand Assessment and Conservation Plan, Westminster, CO, (2000-01)

Water Conservation Plan for Bozeman, Montana (2001)

Irrigation Demand Analysis, East Cherry Creek (2001-2002)
East Bay MUD Conservation Retrofit Study, (2002)
Tampa Retrofit Study (2003)
Demand Analysis for the University of Colorado, (2000)
CII Demand Assessment and Conservation Plan, Westminster, CO, (2000-01)
Commercial and Institutional End Uses of Water, AWWARF,(1998-2000)
Colorado Water Management Model (1993)

PUBLICATIONS

- DeOreo, W.D., Gentilli, M., Mayer, P.W. *Water Conservation Opportunities in Urban Supermarkets.* Water Sources Conference, AWWA, Austin, TX 2004
- DeOreo, W.D., Mayer, P.W. and Hixson, R. *Conservation in Paradise—How Water Conservation Works for the City of Bozeman Montana.* Proceedings of AWWA Annual Conference, New rleans, LA 2002
- Mayer, P.W., DeOreo, W.B. and Kaunisto, R., *Raw Water Irrigation – System Sizing Poses an Interesting Problem*, Proceedings of AWWA Annual Conference, New Orleans, LA 2002
- Qualls R.J., Scott, J.M., DeOreo, W.B. *Soil Moisture Sensors for Urban Landscape Irrigation: Effectiveness and Reliability.* AWWA Journal, June 2001
- W.B. DeOreo, A. Dieteman, T. Skeel, P. Mayer, et. al. 2001. *Retrofit Realities.* Journal AWWA, March 2001.
- W.B. DeOreo, P.W. Mayer, J. Rosales, et.al. 2000. Impacts of Xeriscape on Single Family Residential Water Use. Proceedings of Fourth Decennial National Irrigation Symposium, Phoenix, AZ.
- P.W. Mayer, W.B. DeOreo, et. al. 1999. *Residential End Uses of Water.* AWWA Research Foundation, Denver, Colorado.
- W.B. DeOreo and P.W. Mayer, "Conservation Potential in Outdoor Residential Water Use." Proceedings of Conserv99, Monterey, CA, 1999.
- W.B. DeOreo, P.W. Lander, R. J. Qualls, J.M. Scott, "Soil Moisture Sensors: Are They a Neglected Tool?" AWWA Annual Conference Proceedings, Dallas, 1998
- D. M. Lewis, W.B. DeOreo, K. DiNatale, " Case Study: Flow Trace Analysis to Determine Irrigation Efficiency in a Large Municipal Water User." AWWA Annual Conference Proceedings, Dallas, 1998.
- P.W. Mayer, W.B. DeOreo, E.W. Opitz, J. O. Nelson, "Residential End Uses of Water: Project Update, Year Two." AWWA Annual Conference Proceedings, DallasTX.

PETER W. MAYER, P.E., Aquacraft, Inc.

Vice President and Project Engineer

Aquacraft, Inc. Water Engineering and Management
2709 Pine Street, Boulder, CO 80302.

WORK EXPERIENCE
Vice President and Project Engineer, Aquacraft, Inc. Water Engineering and Management 1995-present. (Registered Professional Engineer, Colorado)
Editor, WiserWatch Online Conservation Journal, 2002-present
Editor, Calvert Independent. 1988-1990

AFFILIATIONS

American Water Works Association

Chair – WaterWiser Steering Committee
Member – Water Conservation Division, Technology and Policy Committee, Internet Advisory Board
American Water Resources Association

EDUCATION
Master of Science, 1995, Water Resources Engineering, Department of Civil, Environmental and Architectural Engineering, University of Colorado, Boulder.
Bachelor of Arts, 1986 Oberlin College, Oberlin Ohio. Anthropology (Honors).

SELECTED PROJECTS

- National Multiple Family Submetering and Allocation Billing Program Study, (2002-2004)
- EPA Residential Retrofit Studies, (2000-2004)
- Pinellas County Utilities Water Conservation Opportunities Study, (2002)
- Virtual Water Efficient Home Web Site, (2001-2002)
- Irrigation Demand Study for East Cherry Creek Valley Water District, (2001-2002)
- CII Demand Assessment and Conservation Plan, Westminster, CO, (2000-01)
- Commercial and Institutional End Uses of Water, AWWARF, (1998-2000)
- Water Conservation Plan, City of Thornton, CO, (1998-2000)
- Demand Analysis for the University of Colorado, (2000)
- Water Conservation Futures Study, City of Boulder, CO, (1998-1999)
- Water Efficiency in Water Wise and Standard New Homes, (1999-2000)
- Residential End Uses of Water Study, AWWARF, (1996-1999)
- Comparison of Demand Patterns among CI and SF Customers, Westminster, (1997-1998)
- Analysis of Southern Nevada Xeriscape Project, (1998-2000)
- Westminster, Peak Use Study, (1996)
- Westminster Residential Water Use Study, (1995-1996)

PUBLICATIONS

Mayer, P.W, et. al. 2004. National Submetering and Allocation Billing Program Study – Project Overview and Preliminary Results. Proceedings of the Water Sources Conference 2004, Austin, TX., Proceedings of the AWWA Annual Conference, Orlando, FL.

Towler, E., P.W. Mayer, et. al. 2004. *Completing the Trilogy – Impact and Acceptance of Retrofit Conservation Products.* Proceedings of the Water Sources Conference 2004, Austin, TX.

Chesnutt, T.W., and P.W. Mayer, 2004. *Water Budget-Based Rate Structures: A New Look at an Old Idea.* Proceedings of the Water Sources Conference 2004, Austin, TX.

DeOreo, W.B., M. Gentili, and P.W. Mayer, 2004. *Advanced Cooling Water Treatment Pays for Itself in Urban Supermarkets.* Proceedings of the Water Sources Conference 2004, Austin, TX.

Mayer, P.W., W. DeOreo, and W. West, 2003. *Conservation Opportunities - A Florida Community Takes Stock*. Proceedings of the AWWA Annual Conference Anaheim, CA.

Mayer, P.W. et. al. 2002. *Great Expectations – Actual Water Savings with the Latest High-Efficiency Residential Fixtures and Appliances.* Proceedings of the Water Sources Conference 2002, Las Vegas, NV.

Mayer, P.W., W.B. DeOreo, & D. Kaunisto. 2002. *Raw Water Irrigation – System Sizing Poses an Interesting Problem.* AWWA Annual Conference Proceedings. Denver, CO.

Mayer, P.W., W.B. DeOreo, A. Dietemann, and T. Skeel. 2001. *Residential Efficiency: The Impact of Complete Indoor Retrofits*. AWWA Annual Conference Proceedings, Washington, D.C.

Maddaus, L.A., & P.W. Mayer. 2001 *Splash or Sprinkler? Comparing Water Use of Swimming Pools and Irrigated Landscapes.* AWWA Annual Conference Proceedings, Washington D.C.

W.B. DeOreo, A. Dieteman, T. Skeel, P. Mayer, et. al. 2001. *Retrofit Realities.* Journal American Water Works Association, March 2001.

DeOreo, W.B., P.W. Mayer, J. Rosales, et.al. 2000. *Impacts of Xeriscape on Single Family Residential Water Use.* Proceedings of Fourth Decennial National Irrigation Symposium, Phoenix, AZ.

Mayer, P.W., K. DiNatale, and W.B. DeOreo. 2000. *Show Me the Savings: Do New Homes Use Less Water?* AWWA Annual Conference Proceedings. Denver, CO.

Mayer, P.W., W.B. DeOreo, et. al. 1999. *Residential End Uses of Water.* American Water Works Association Research Foundation, Denver, Colorado.

Mayer, P.W. and W.B. DeOreo. 1999. *Conservation Potential in Outdoor Residential Water Use.* AWWA Annual Conference Proceedings. Chicago, IL.

John Whitcomb, Stratus Consulting

Areas of Qualification

Water demand analysis, impact evaluation, water and sewer pricing, customer market research, econometric research, resource planning, benefit-cost evaluation, software development, risk assessment, strategic planning, regulatory support

Employment History

- Senior Economist, Stratus Consulting Inc., Boulder, CO, 2003-present; Senior Associate, 1998-2003
- Senior Associate, Hagler Bailly, Boulder, CO, 1996-1998
- Independent Consultant, 1992-1996
- Consultant, Brown and Caldwell Consultants, 1989-1991

Education

- Johns Hopkins University, PhD, Geography and Environmental Engineering, 1988
- University of California, Santa Barbara, BA, Economics and Geography, 1984

Professional Experience

California Urban Water Conservation Council (2001-2003). Conducted the largest study performed on conservation program freeriders in the water industry. This project investigated freeriders associated with ultra-low flush toilet (ULFT) programs offered by water agencies in California. Freeriders are program participants who, without the ULFT program, would still have replaced their toilets. Agencies do not get incremental conservation benefits from serving freeriders because the conservation would have happened irrespective of the program. Project included a literature review (mainly focused on what has been learned in the energy industry); empirical data collection and analysis of 1,032 single-family and 298 multiple-family ULFT program participants; and development of ULFT program recommendations to minimize freeriders and, hence, maximize program cost-effectiveness.

El Paso Water Utilities Board (1998-2002). Evaluated and organized a water resources master plan. Services included economic assessment of a number of water supply and demand options including recycling, agricultural buyouts, water mining, desalination, dry-year leasing, and a variety of conservation programs. One area of conservation research included a detailed evaluation of a cash-for-grass program. El Paso has designed and implemented an aggressive program to reduce long-term and peak water use.

California Urban Water Conservation Council (2000-2001). Authored a handbook assisting water agencies with understanding, designing, and implementing commercial, industrial, and institutional (CII) conservation programs in accordance with a California best management practice (BMP). Chapters address characterizing CII customers, ULFT replacement, water use surveys, and water use performance targets. Handbook's intended audience is the water conservation coordinator at a water agency.

City of Westminster (2000-2001). Worked with Aquacraft Inc. to develop an industrial, commercial, and irrigation water study and conservation plan. Project goals included

evaluating ICI water demands in Westminster, identifying and evaluating potential conservation programs, developing a long-range conservation plan and demand tracking tools, and pilot testing various conservation measures.

San Antonio Water System (1999-2000). Investigated ramifications of using customer-specific water budgets as part of the water rate structure. Water budgets consisted of an indoor component and an outdoor component varying with lot size and evapotranspiration. Engagement included facilitating six public meetings with stakeholders to convey information, evaluate options, and discuss advantages and disadvantages.

California Urban Water Conservation Council (1998-1999). Authored a handbook assisting water agencies with understanding, designing, and implementing landscape conservation programs in accordance with a California best management practice (BMP). Chapters address water use budgets, water surveys/audits, and financial incentives. Specific topics include innovative landscape measuring techniques, projecting program costs, and making conclusions on cost effectiveness. Handbook's intended audience is the water conservation coordinator at a water agency.

Selected Publications and Presentations

Estimating Water Price Elasticity, ACII Ultra-Low-Flush Toilet Retrofit Programs, and Customer Awareness About the Price of Water, *Proceedings of Conserv99*, Monterey CA, February 1999.

How Does Water Pricing Affect Customer Behavior?, proceedings of AWWA Mid-Winter Conference, Austin TX, February 1998.

Water Savings from the Installation of Ultra-Low-Flush Toilets in Commercial, Industrial, and Institutional Settings (with M.E. Eiswerth, M. Hollis, and D. Mitchell). 1997. *Proceedings: 1997 Annual Conference of the American Water Works Association*, Volume B: Water Resources. Denver, CO: American Water Works Association.

James Henderson, Stratus Consulting

Areas of Qualification

Environmental economics, water conservation analysis, water demand analysis, benefit-cost evaluation, river basin modeling, regulatory policy analysis, emission control modeling

Employment History

- Senior Economist, Stratus Consulting Inc., Boulder, CO, 2003-present; Senior Associate, 2002; Associate, 2000-2001
- Research Specialist, The Water Resources Research Center, University of Arizona, Tucson, 1996-1999; Graduate Research Assistant, 1994-1995,
- Regional Recharge Program Manager, Arizona Department of Water Resources, Tucson Active Management Area, Tucson, 1997-1998
- Consulting Project, with Bonnie Colby, PhD, University of Arizona, Tucson, 1994-1995
- Graduate Research Assistant, Department of Agricultural and Resource Economics, Tucson, AZ, 1992-1994

Education

- University of Arizona, MS, Agricultural and Resource Economics, 1997
- The Colorado College, BA, Economics, 1988

Professional Experience

At Stratus Consulting, Mr. Henderson has worked on several projects evaluating benefits and costs associated with water resource use. Mr. Henderson is currently developing an economic framework for analyzing the full range of direct and indirect benefits and costs associated with water recycling/reuse projects for the WateReuse Association. Mr. Henderson also is developing a financial planning module for development of a decision support system for water supply planning on a project for the American Water Works Association Research Foundation (AwwaRF). This module will allow water utilities to evaluate the long range financial impacts of alternative water supply planning scenarios. He assessed benefits of regulation to reduce impingement and entrainment of aquatic organisms in cooling water intake structures for power plants under section 316b of the Clean Water Act. For this project, he developed a societal revealed preference approach for valuing endangered fish species in the San Francisco Bay-Delta. He also assessed benefits from recreational boating for a water rights court case involving a kayak course in Golden, Colorado.

As a research specialist at the University of Arizona's Water Resources Research Center, Mr. Henderson evaluated water conservation savings, cost-effectiveness, and participation patterns in Tucson water's ultra-low-volume toilet rebate program using statistical analysis. Mr. Henderson also collected and analyzed data on performance of ultra-low-volume toilets using data-loggers and software for analysis of residential end uses of water. He co-authored a study of sustainability of water resources in the Tucson area, which explained and analyzed all water use aspects in Tucson in a nontechnical language as part of an initiative to lend University of Arizona expertise to addressing local water problems. Mr. Henderson also performed cross-sectional analysis of water demand in Tucson.

As the regional recharge program manager for the Arizona Department of Water Resources, Mr. Henderson completed the analysis for and writing of the Regional Recharge Plan for the Tucson Active Management Area — a collaborative planning document for artificial recharge of groundwater. He prepared the report for the Arizona Water Banking Authority of the Regional Recharge Plan to help the Bank with recharge site selection in the Tucson area.

As a graduate research assistant for the Department of Agricultural and Resource Economics at the University of Arizona, Mr. Henderson developed a computer model of the Colorado River Basin for use in a drought-game exercise for the Severe Sustained Drought Project and for his MS thesis using Stella II and GAMS modeling programs.

Selected Publications

Repetto, R. and J. Henderson. 2003. "Environmental Exposures in the US Electric Utility Industry." *Utilities Policy*. Volume 11. pp. 103-111.

Henderson, J., R. Raucher, and J. Whitcomb. 2002. "A Self-Insurance Strategy for Setting Priorities in Water Utility Infrastructure Investments." In *Assessing the Future: Water Utility Infrastructure Management,* D.M. Hughes (ed.). American Water Works Association.

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Henderson, J.L. and W.B. Lord. 1995. "A Gaming Evaluation of Colorado River Drought Management Institutional Options." *Water Resources Bulletin*. October. pp. 907-924.

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Education

Doctorate (PhD).	University of California, Berkeley, Energy and Resources, 1986.
Master of Science (MS).	University of California, Berkeley, Energy and Resources, 1980.
Bachelor of Science (BS).	Yale University, in Engineering and Applied Science, 1978. Cum laude, with distinction.

Professional Employment

Pacific Institute for Studies in Development, Environment, and Security.
Co-Founder and President. 1987-present
MacArthur Foundation Research and Writing Fellowship.
Fellowship in International Peace and Security. 1988-90.
MacArthur Foundation Fellow in International Security.
Social Science Research Council/MacArthur Foundation. Post-doctoral position at the Energy and Resources Group, University of California, Berkeley. 1986-88.
University of California, Berkeley.
Research Associate in the Energy and Resources Group. 1983-86.
Office of the Governor of California.
Deputy Assistant for Energy and Environment. 1980-82.
University of California and Lawrence Berkeley Laboratory.
Energy and Resources Group, Research and Teaching Associate. 1980-81. Ecology Research Group Assistant, Energy and Environment Division. 1978-80.

Honors, Awards, Fellowships

- Named MacArthur Fellow. October 2003
- Elected to Phi Beta Delta: Honor Society for scholarly achievement in international education. April 2003.
- Appointed to Water Science and Technology Board, National Academy of Sciences, Washington. June 2001.
- Named by the BBC as a "visionary on the environment" in its Essential Guide to the 21st Century.

- Elected Academician of the International Water Academy, Oslo, Norway. October 1999.
- MacArthur Foundation Research and Writing Fellowship. 1988-90.
- Social Science Research Council-MacArthur Foundation Post-Doctoral Fellow in International Peace and Security Studies, June 1986 to June 1988.
- San Francisco Chronicle, one of "90 People to Watch in the '90s."
- *Cum laude*, Yale University 1978; *Distinction*, Engineering and Applied Science

Current Public and Professional Service

- Water Science and Technology Board, National Academy of Sciences, 2001-present.
- Public Advisory Committee: California Water Plan 2003. Department of Water Resources, 2001-present
- Board of Directors: Pacific Institute for Studies in Development, Environment, and Security, 1988-present.
- Editorial Board, Annual Reviews of Energy and the Environment, 2001-06
- Editorial Board, Climatic Change, 1990-present.
- Editorial Board, Water Policy, 1997-present
- Advisory Council, International Water Academy, Oslo,Norway, 2003-05.
- Scientific Advisor: IMAX Film "The Water Planet," 2003-present

Past Public and Professional Service

- Co-Chair: Water Sector: National Assessment of the Potential Impacts of Climatic Variability and Change on the United States, 1998-2000.
- Board of Directors: International Water Resources Association, 1997-2000.
- Global Environmental Change Committee, American Geophysical Union, 1993-98.
- Public Advisory Forum: American Water Works Association, 1993-98.
- 1990 Water Task Group, Second World Climate Conference, Geneva, Switzerland.
- Advisor, Comprehensive Freshwater Assessment, Stockholm Environment Inst., 1996-97.
- Advisory Board: documentary film *Cadillac Desert* 1995-97
- Advisory Committee: Climate Institute's Environmental Refugee Program, 1993-95.
- Board of Directors: Environmental Science and Policy Institute, 1991-97.
- Climate and Water Panel, American Association for the Advancement of Science, 1986-90.
- Co-Chair, Working Group 2, Advisory Group on Greenhouse Gases, WMO/UNEP, 1989-91.
- Committee on Science & International Security, American Association for the Advancement of Science, 1993-95.
- Editorial Board, Environment and Security, 1993-2001.
- Editorial Board, Encyclopedia of Life Support Systems, 1997-2002.

- Editorial Board, Encyclopedia of Global Change (Oxford University Press), 1996-2000.
- Editorial Board: Global Change and Human Health, 1999-2003
- Interim Board of Directors: Middle East Water Information Network, 1994-96
- Project Steering Committee: IUCN (World Conservation Union): Water Demand Management in Southern Africa, 2000-03.
- Scientific Review Group, President's Council on Sustainable Development, 1994-96.
- Surface Water Committee, American Geophysical Union, 1992-93.
- Working Group VIII Special Report, United States-Soviet Agreement on Protection of the Environment, 1989-90.

A full publications list is available upon request.

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EDUCATION AND REGISTRATIONS

1998-1999, Visiting Scholar
Center for Conservation Biology, Stanford University

1997-1998, Post-Doctoral Fellowship,
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Ph.D. 1997, Agricultural and Resource Economics,
University of California at Berkeley
Major Field: Environmental Economics
Minor Field: Public Economics

M.S. 1984, Civil Engineering, Stanford University
Major Field: Water Resources Engineering
Minor Field: Environmental Engineering

B.Sc. 1982, Renewable Energy Engineering Technology
Jordan College, Cedar Springs, Michigan

Classical Liberal Arts (Great Books Curriculum)
St. Johns College, Santa Fe, New Mexico

Government and Economics
Harvard University, Cambridge, Massachusetts

California Registered Civil Engineer (No. 41252)
California Contractors License C46 (inactive) -- Solar Specialty (No. 486178)

PROFESSIONAL HISTORY

2000-Present **Principal Economist and Engineer** at the Pacific Institute for Studies in Environment, Development, and Security

2000-2001 **Visiting Professor**, Monterey Institute of International Studies

1998-2000 **Director of the Incentives Program**, Redefining Progress. Mr. Wolff directed five professionals performing public policy research on incentive tools for solving environmental problems.

1995-1998 **Consultant.** While enrolled in graduate school Mr. Wolff continued to consult to municipal government, non-profit organizations, and private clients seeking assistance with projects involving both engineering and economics skills.

1986-1994 **Founder and Principal Engineer,** 3E Engineering, Fremont, California. From inception until sale in 1994 Mr. Wolff directed the activities of a staff of civil and environmental engineers, certified engineering geologists, environmental scientists, and recycling specialists. Projects were primarily project analysis and design and construction management services for municipal government and special purpose agencies such as Cities and wastewater or solid waste management authorities. A project list and references are available upon request.

1986-1987 **Environmental Engineer,** Central Contra Costa Sanitary District, Martinez, California. As a member of the design division Mr. Wolff participated in analysis and design of many treatment plant and collection system improvements.

1984-1986 **Water Resources Control Engineer,** San Francisco Bay Regional Water Quality Control Board, Oakland, California. Mr. Wolff analyzed the impacts of alternative regulatory policies on wastewater treatment plants, landfills, and industrial polluters in the San Francisco Bay Area, and reviewed performance of self-monitoring programs and compliance with discharge permits.

1982-1983 **Solar Contractor,** Sundu Solar Systems, Grand Rapids, Michigan. Mr. Wolff designed and installed commercial and residential solar energy space and water heating systems.

1981-1982 **Energy Conservation Analyst,** under contract to Michigan Consolidated Gas Company, Grand Rapids, Michigan. Mr. Wolff served as an energy auditor in the federally mandated Residential Conservation Service.

AFFILIATIONS

- Former President, Alameda County Recycling Board (Board of Supervisors Appointee)
- Former Chair, East Bay Municipal Utility District (EBMUD) Demand Management Advisory Committee
- Executive Committee, U.S. Bureau of Reclamation Desalination Research Roadmap Project
- Co-Chair, Board of Directors, Waterkeepers of Northern California
- Member, American Economics Association (AEA)
- Member, American Society of Civil Engineers (ASCE)
- Member, American Solar Energy Society (ASES)
- Member, International Association for Water Quality (IAWQ)
- Member, International Ecological Engineering Society (IEES)
- Member, International Society for Ecological Economics (ISEE)
- Member, Northern California Recycling Association (NCRA)
- Member, Water Environment Federation (WEF)

Appendix F: Flow Trace Data Collection and Analysis

The following section is reprinted from the Residential End Uses of Water study (1999, AWWA).

END USE DATA COLLECTION

Overview

The development of compact, battery powered, waterproof data loggers with extended memory capabilities along with advancements in personal computing made this research effort possible. The data loggers provided precise flow data at 10 second intervals and the computers allowed researchers to collect and analyze more than 288,000,000 data points over the course of the entire study consuming more than 6 gigabytes of computer storage memory.

With data logging technology now available, precise data on where water is used inside a residence can be collected in a simple non-intrusive manner, directly from the water meter (DeOreo, Heaney, and Mayer 1996; Mayer and DeOreo 1995; Mayer 1995; Dziegielewski, 1993b). Each logger is fitted with a magnetic sensor which is strapped to the water meter of each study residence. As water is used inside the home, it flows through the water meter spinning the internal magnets. The sensor picks up each magnetic pulse as water moves through the meter and the logger counts the number of pulses detected and stores the total every 10 seconds. The logger has sufficient internal memory and battery life to record for more than 14 days at the 10 second interval.

Using the physical characteristics of each specific brand and model of water meter, the magnetic pulse data is transformed into instantaneous flow data for each 10 second interval. This flow trace is precise enough to detect the individual flow signatures of each type of appliance and plumbing fixture in the residence, and that of the outside hoses and sprinklers. Using a custom signal processing software package called Trace Wizard, each flow trace was disaggregated into its component end uses: toilets, showers, clothes washers, dishwashers, baths, faucets, irrigation, leaks, evaporative coolers, etc.

Data Logging Equipment

Research was conducted into available data logging equipment that could meet the harsh conditions needed for this type of study. Based on the recommendation of staff at Seattle Water, a participating utility, the data logger ultimately used in this study was evaluated and subsequently selected for use. The logger selected was the Meter-Master 100EL manufactured by the F.S. Brainard Company of Burlington, NJ. The Meter-Master 100EL logger, shown in Figure F.1, offered the essential combination of data storage capacity, battery life, and ease of use. A total of 110 loggers were for use in the study. Only 100 loggers were used at a time at each study site and the extras provided backup if any logger failed to operate properly and had to be sent for repairs.

The data loggers used in this study are compact and sit comfortably out of sight in the meter box or pit during the logging period. Installation took between 3 and 7 minutes per logger (not including travel between houses) depending on the location and condition of the meter box. These loggers can be installed on most magnetic-driven water meters on the market although the positioning of the sensor varies by brand, model and, size. Adapters are also available so that the loggers can be used with mechanical meters, but magnetic-driven meters were a requirement for participation in this study and participating utilities replaced any meters that were not compatible with the logging system. Seattle Public Utilities chose to replace all of the water meters in their study group in an effort to improve accuracy and ease of installation. At other study sites, several incompatible meters were replaced by the utility with newer magnetic-drive meters for the study.

The basic assumption behind the data logging system in that the water meter is accurately recording flow volume. The logger is not truly measuring flows, but rather only records the spinning movement of the magnetic piston inside the water meter as water flows through the meter. The loggers records the number of magnetic pulses counted in a 10-second interval and once the data is downloaded, a the data logger control program automatically converts the pulse count into flow using the exact specifications of each water meter. Most of the water meters used in this study provided resolution of between 50 and 120 magnetic pulses per gallon. When the logger is downloaded, the logged volume is compared to meter readings taken at the time of installation and removal to ensure the accuracy of the flow trace.

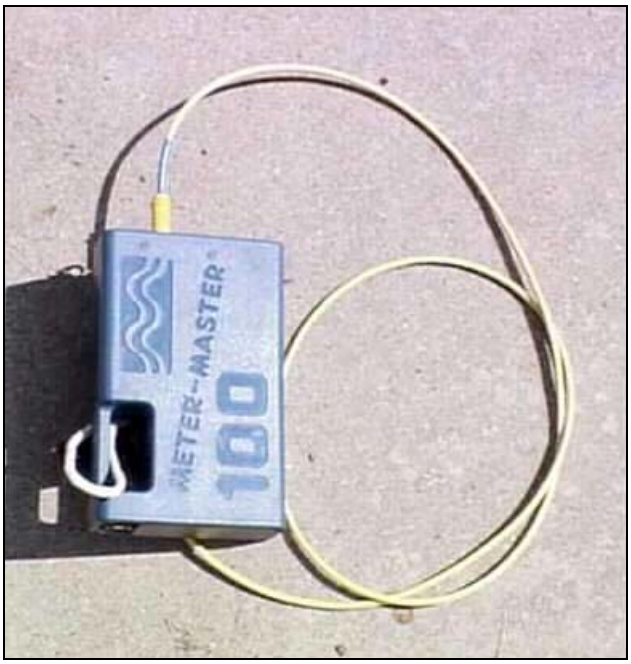

Figure F.1 One of the 110 data loggers used in the study

The loggers were shipped from site to site in specially designed padded cases and the data logger installation schedule was set up to accommodate downloading, recharging, and shipping time.

Logger Installation

Logger installation followed a routine pattern at each study site using a team of two installers: one consultant from the project team, and a representative from the utility. It was rapidly discovered that the bulk of the time during logger installation was spent driving between different study sites rather than on installing the actual hardware which took very little time. A three or four day installation schedule was developed for each site with routing between study houses carefully planned to minimize driving time. The installation team could typically install five loggers per hour.

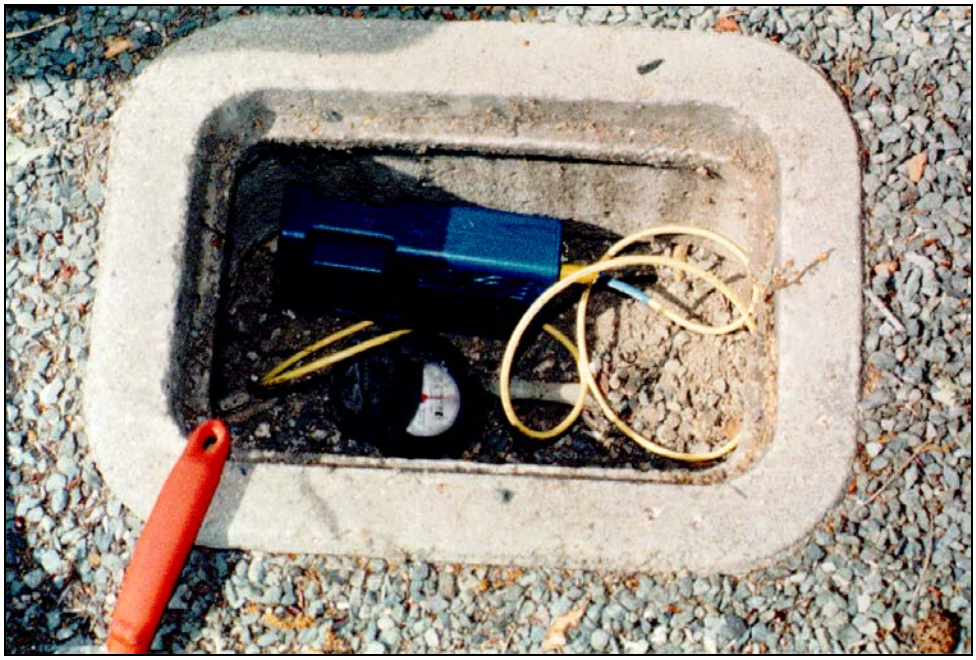

Figure F.2 Brainard data logger in the meter pit

At the study residence one installer would open the meter box and prepare the meter and meter environment for the logger. The other installer readied the logger and recorded the following data for each study residence: date, time, logger number, meter brand, meter model, and starting meter reading. The sensor was fixed to the meter with a heavy Velcro strap and then the logger was turned on. The data logger responds to being turned on with two second flash of a red light so the installers were aware if the logger was working. Next, a small amount of water was run through an outside hose bib and a properly installed logger and sensor responded again with a red light flash indicating that magnetic pulses were being picked up and recorded by the logger. This insured that the installation was completed properly and the equipment was functioning at the time of installation. Finally the logger was placed in the meter box (or hung from a strap in deep meter pits) and the cover was replaced. A typical logger and sensor installation is shown in Figure F.2.

END USE DATA ANALYSIS

Flow Trace Analysis

Perhaps the most detailed and painstaking part of this research effort was the analysis of the end use data collected with the data loggers. Nearly 2400 continuous flow traces were recorded for this study (1200 homes for two seasons) and each was analyzed individually using Aquacraft's copyrighted software package Trace Wizard.

The concept of flow trace analysis was first noted by Dr. Benedykt Dziegielewski who suggested that a single data logger attached to a residential water meter might yield data which could be disaggregated into its individual end uses (Dziegielewski, et.al., 1993b). The idea is based on the fact that there is consistency in the flow trace patterns of most residential water uses. A specific toilet will generally flush with the same 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 is accurate enough to quantify and categorize almost all individual water uses in each study home.

The application of flow trace analysis to quantify residential water use was successfully implemented for the first time in the 1994-95 Heatherwood Study in Boulder, Colorado (DeOreo and Mayer, 1994; Mayer, 1995; Mayer and DeOreo, 1995). During subsequent studies in Boulder and Westminster, Colorado, Aquacraft refined the flow trace analysis process and tested new hardware and software which would make it possible to collect and analyze such precise data from a large sample (DeOreo, Heaney, and Mayer, 1996).

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. In this study this was accomplished by recording flow rates from a magnetic driven water meter every 10 seconds using specially designed data loggers. This data is precise enough that individual water use events such as a toilet flush or a clothes washer cycle or filling up a glass of water from the kitchen tap can be isolated, quantified and then identified. The recorded flow trace data is precise enough to distinguish between even relatively similar events such as toilet leaks and faucet use. This technique makes it possible to disaggregate most of the water use in a single-family residence and to quantify the effect of many conservation measures, from toilet and faucet retrofit programs to behavior modification efforts.

Meter-Master Data Loggers

A key to the success of the Residential End Uses of Water Study was obtaining a reliable data logger capable of enduring the extreme conditions in the water meter pit and with sufficient memory to store two weeks of data at 10 second intervals which amounts to more than 120,000 individual records. Data loggers from F.S. Brainard and Company of Burlington, New Jersey provided the only viable option. Furthermore, Brainard was willing to

develop their Meter-Master for Windows software in tandem with Aquacraft's Trace Wizard package so that they work in together as part of a water meter data acquisition system.

Trace Wizard

Trace Wizard is a 32-bit 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. Trace Wizard is integrated with the Meter-Master for Windows software, which comes with the F.S. Brainard data logging system.

Analysis with Trace Wizard is currently a multi-step, iterative process. First Trace Wizard takes the raw gallons per minute flow data from the Meter-Master for Windows program and disaggregates the data into individual water use events from the smallest leak to the largest automatic sprinkler session. During the event calculation process, Trace Wizard calculates a specific set of statistics about each water use event. These statistics are: start time, stop time, duration, volume (gal), peak flow rate (gpm), mode flow rate (gpm) and mode frequency. All of these statistics are included in the final database of water use events.

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. These parameters can include the volume, duration, peak flow rate, and mode flow rate of each specific fixture. For example, a toilet may be defined as using between 3.25 and 3.75 gallons per flush, the peak re-fill flow rate is between 4.2 and 4.6 gpm, the duration of flush event is between 30 and 50 seconds, and the mode flow rate is between 4 and 4.5 gpm. Similar parameters are established for each of the fixtures found in the household. This simple signal processing routine runs quickly and assigns a fixture category (toilet, shower, clothes washer, etc.) to each water use event. The routine is re-run by the analyst frequently during the analysis process as the parameters are "fine tuned" to fit the fixtures in each specific house. The analyst uses the survey response data detailing the specific water-using appliances and fixtures in the house to build the parameter file which assigns fixtures to water use events. The graphical interface of Trace Wizard allows the analyst to visually inspect water use events and build the parameter file so that it correctly identifies as many of the water use events as possible. When working for the first time with data from a residence it takes a trained analyst approximately one hour per week of data to complete flow trace analysis using Trace Wizard. Once an accurate parameter file has been created for that specific residence, the analysis time can be reduced significantly.

Trace Wizard is also capable of recognizing simultaneous events that frequently occur in residential households. For example, if someone is taking a shower in one bathroom and someone else in the house flushes the toilet and uses a faucet, Trace Wizard is able to separate these three distinct events through a set of user defined parameters.

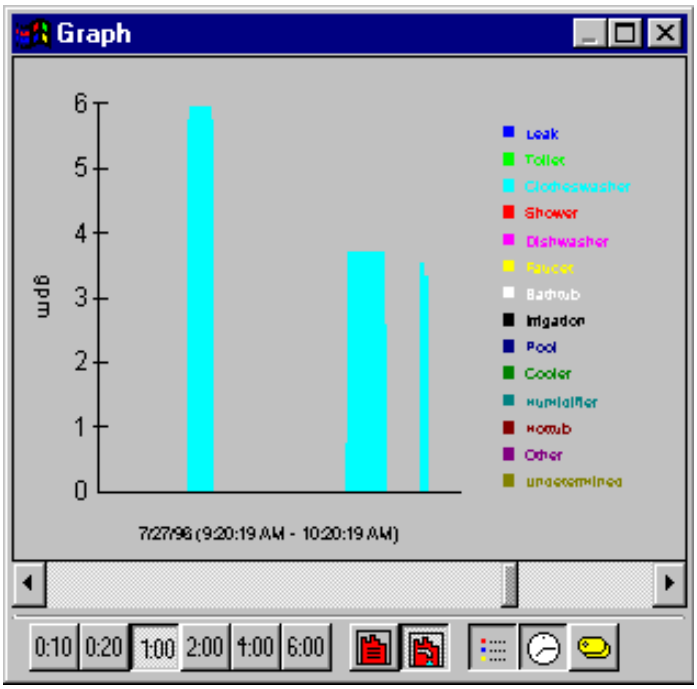

Figure F.3 Sample flow trace from Trace Wizard showing a one hour view. Water events depicted include a three cycle clothes washer.

Figure F.3 shows a one hour portion of a typical flow trace in Trace Wizard. The three light blue spikes are clothes washer cycles. The first is the wash cycle, the second is a rinse cycle, and the third is a spin cycle. Note that the times shown on the graph's x-axis are the time interval depicted in the graph. In Figure F.3 this is a one hour time interval. The Trace Wizard graph has six time interval settings: 10 minutes, 20 minutes, 1 hour, 2 hours, 4 hours, and 6 hours. The analyst may use any of these "views" during the flow trace analysis process.

Figure F.4 shows two toilet flushes, miscellaneous faucets, and another three cycle clothes washer. The first green spike in a toilet flush with a refill rate of approximately 5 gpm. The small yellow spikes are miscellaneous faucet uses and the small dark blue spike is a leak. The three light blue spikes are clothes washer cycles. A second toilet flush occurs during the first clothes washer cycle and is easily distinguished by Trace Wizard as a simultaneous event.

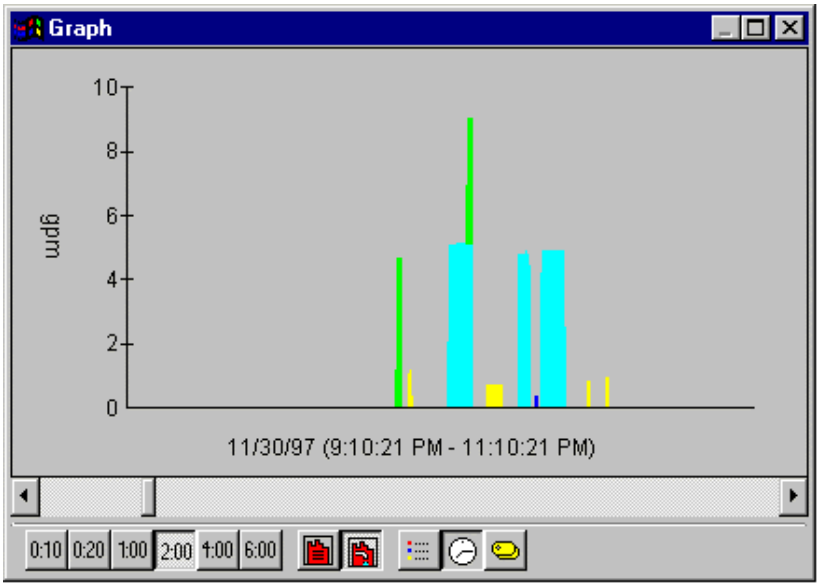

Figure F.4 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include two toilet flushes, a three cycle clothes washer, and several faucets.

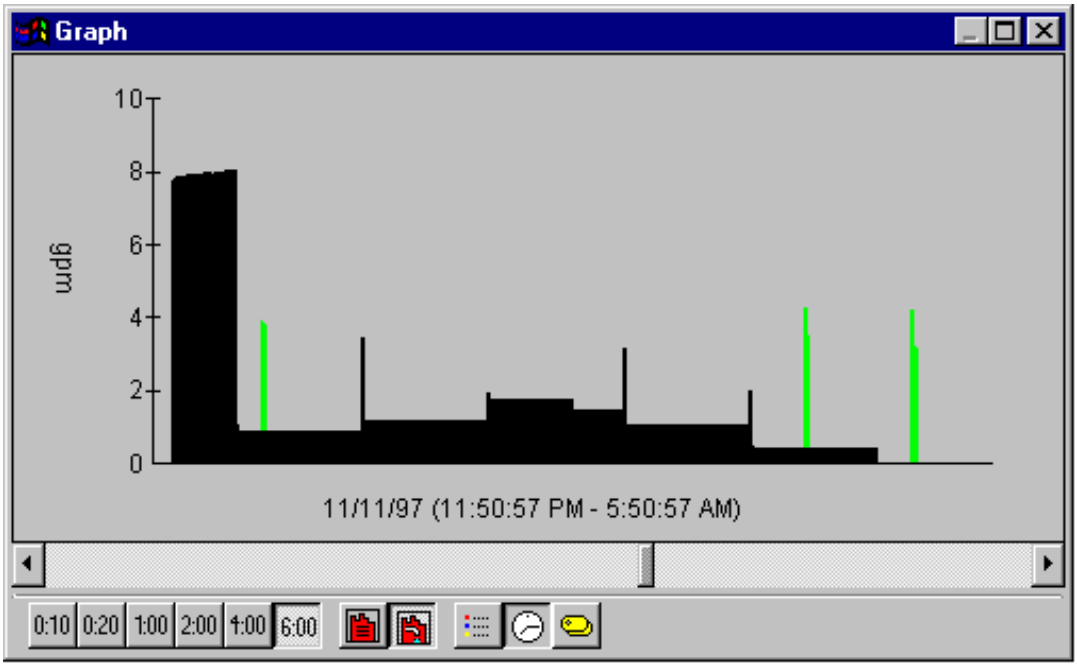

Figure F.5 Sample flow trace from Trace Wizard showing a six hour view. Water events depicted include a multi-zone automatic irrigation system and three toilet flushes.

Additional simultaneous water use events can be seen in Figure F.5 taken from a study home in Phoenix, AZ. Here, in a six hour view, two toilet flushes can be observed occurring

simultaneously with a seven-zone drip/combination irrigation system. The irrigation system zones are clearly delineated by small and consistent differences in flow rate over the 4.5 hour irrigation session. The first zone with an 8 gpm flow rate is a turf area and the remaining six zones cover different drip irrigation areas.

At the conclusion of analysis, the final product is a database of water use events which have been given fixture identification. This database is created in the Microsoft Access 7.0 or 97 formats and can be further analyzed using either version of Access or any compatible database product. The seven-zone irrigation event from Figure F.5 will appear in the database as a single water use event as will each of the three individual toilet flushes.

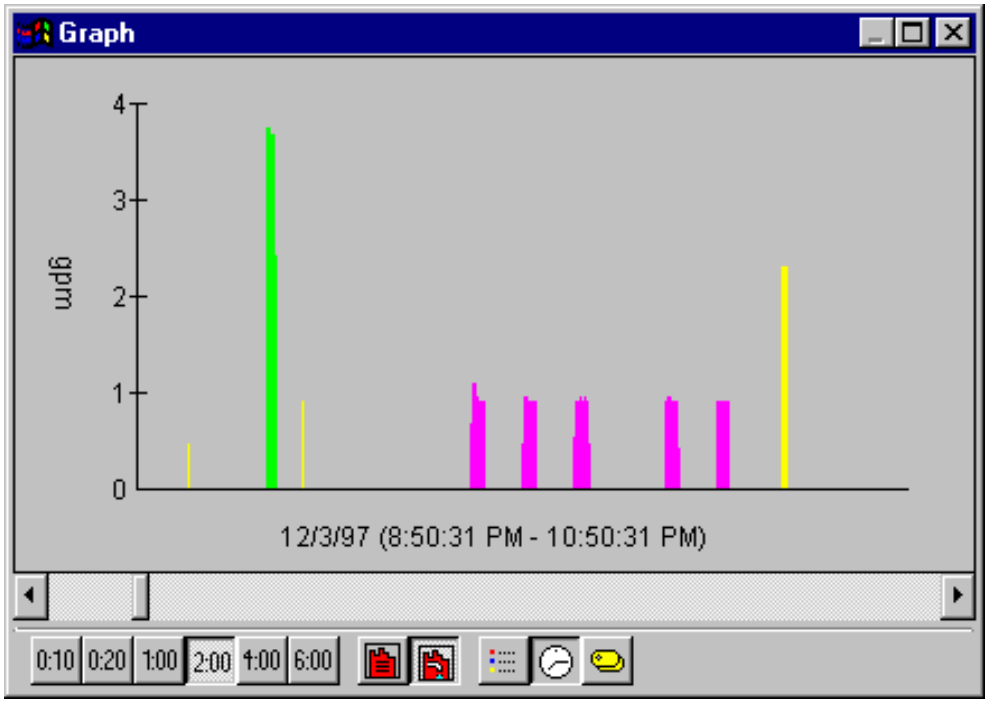

Figure F.6 Sample flow trace from Trace Wizard showing a two hour view. Water events depicted include a toilet flush, a five cycle dishwasher, and various faucet uses.

Figure F.6 shows a typical five cycle dishwasher that was run between approximately 9:30 and 10:30 p.m. Dishwashers typically have between three and eight cycles and use a total of between 8 and 20 gallons for a full load. They are easy to distinguish because of their box-like shape and consistent volume, flow rate, and duration.

Figure F.7 shows the capability of Trace Wizard's simultaneous event calculating routine. The red shower event is typical of bath/shower combination traces. The water is started in the bath for about 30 seconds while the temperature is adjusted then the shower diverter valve is pulled and the water starts to flow through the showerhead – in this case a low-flow head which restricts the flow to 2.5 gpm. The shower continues for about 10 minutes at this consistent flow rate until the water is shut off. What makes this example

unusual are the blue clothes washer extraction and rinse cycles which are plainly visible on top of the shower. The second set of extraction cycles occur shortly after the shower had ended.

Once analysis was complete the flow trace data was stored in two separate databases – an individual database for the city where the data was recorded and a project wide database which includes data from all 12 study sites. All databases for this study were developed in Microsoft Access.

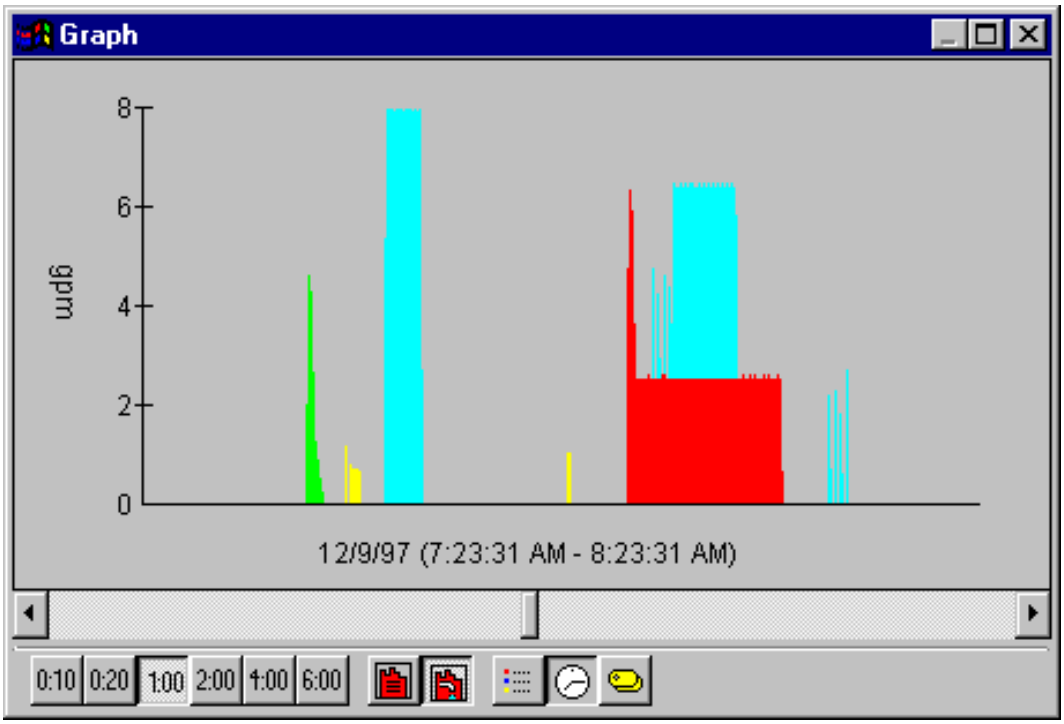

Figure F.7 Sample flow trace showing a one hour view. Water events depicted include a toilet flush, multi-cycle clothes washer, and shower.

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Appendix G: Letters of Commitment from Participating Agencies