Determining Waste of Water and Energy in Residential Hot Water Distribution Systems

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Statement of Work. Section One: Relevance and Importance

This project has two main goals and objectives:

- To measure how much water and energy is wasted in hot water distribution systems (HWDS) in California residences and

- To investigate the effectiveness of current retrofit options in reducing this waste of water and energy.

Two types of waste are present in residential HWDS. The first type of waste is water, cooled off hot water in the distribution system from a previous draw is discarded until the water being drawn reaches the desired temperature. This type of waste occurs most often in showers and sinks . The second type of waste is the energy used to heat the water. It is wasted as hot water cools down in the distribution system after a draw. The cooled off hot water is drawn and discarded, or used cold. This type of energy waste occurs at sinks, showers, clothes washers, dishwashers, and other hot water uses.

Lawrence Berkeley National Laboratory (LBNL) will measure the quantity and temperature of delivered water at one-second intervals during every hot water draw in a representative sample of single-family homes. We will do this to determine the actual water and energy efficiency of the residential HWDS. This will be done before and after a retrofit is applied to find out how effective the retrofit is.

This project will contribute toward the California Bay-Delta Program goal of advancing the implementation of cost-effective urban water conservation. HWDS waste water and cause inconvenience to occupants. Increasing our knowledge of the performance of residential HWDS is necessary to design cost-effective projects aimed at reducing the water use waste of those systems. Determining the best approach to implement potential water use efficiency actions directed at HWDS requires knowledge about the water use efficiency of HWDS and the effect of retrofits.

Our work with local and regional entities means that in the future they will be able to: (1) assess the costs, benefits, and feasibility of potential water use efficiency projects targeted at the waste of water from HWDS; and (2) determine the best approach to implement water use efficiency actions targeted at the waste of water from HWDS. The participation of the California Energy Commission (CEC) and gas utilities means they will be able to implement programs to address the waste of energy from HWDS.

Every year, Americans consume on average 63,000 gallons of water per household for indoor residential consumption. This is equivalent to 69.3 gallons of water per capita per day.[1] Studies have been conducted to measure general outdoor and indoor (i.e., fixtures, tubs, toilets, etc.) residential water consumption. Past studies estimated water end uses and have found that the greatest indoor water end uses can be attributed to fixtures, such as showers and sinks, which use hot water. The wait time for water to get warm enough before it can be used for showers or washing is one of the greatest sources of water loss.

According to one recent study perhaps as much as $1,000,000,000 worth of water and energy is wasted in all California residences every year because of poorly designed HWDS.[2] Given such huge potential for water and energy savings, it is surprising to find no studies have directly measured this loss. In fact, most relevant studies have only measured water consumption for residential end uses. Currently, there are no implementation programs addressing the problem of poorly designed HWDS in the residential sector. This innovative study proposes to directly measure the waste of water and energy caused by current HWDS to accurately determine the potential for energy and water savings.

Implementation of the retrofit option, if demonstrated to yield energy and water savings, could provide a means for cost-effective water conservation in the state of California. If we find significant water and energy savings, implementation programs could be developed for state wide use. The California Urban Water Conservation Council (CUWCC) will be participating in this project and has agreed to assist getting the results disseminated to the water community and to evaluate a best management practice for this.

Additionally, the findings of this project will be used in future efforts to provide new construction guidelines to reduce water and energy waste. By providing the information needed to design efficient residential HWDS in new homes, this project could lead to additional benefits. One way that widespread implementation could be put into effect for new construction is through changes to the Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24). These building energy efficiency standards were established in 1978 in response to a legislative mandate to reduce California's energy consumption. Modifications to the standards are adopted by the CEC every three years. The results of this study are intended in part to influence those standards to reduce energy consumption in California's new homes.

This research effort has the potential to contribute to offsetting some of the $1,000,000,000 that Californians spend every year for water, waste water treatment and energy waste caused by residential HWDs. This project could lead to multiple future benefits for consumers and the Bay-Delta region if the research from this project clearly demonstrates water savings potential and leads to future implementation of urban water use efficiency projects. The significant

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[1] Meyer, Peter W., William B. DeOreo, Eva M. Opitz, Jack C. Kiefer, William Y. Davis, Benedykt Dziegielewski and John Olaf Nelson. Residential End Uses of Water, 1999. AWWA Research Foundation, Report No. 90781, pg 84.

[2] Klein, Gary and James D. Lutz. (2005). Hot Water Distribution System Scoping Study. California Energy Commission. 2005

number of houses that could effectively apply the retrofit option have the potential to yield large savings, which could help to preserve the amount and quality of water in the Bay-Delta.

This project not only will determine the potential for water savings, it will also determine the potential energy savings. The energy savings findings of this project have the potential to influence new construction guidelines. Because of the large amount of energy that is used to heat domestic hot water throughout the state, the CEC will consider providing match funding for 50 percent of the project costs, to research the potential energy savings from improved HWDS. Because of the expected funding from the CEC, we're asking the Department of Water Resources to fund one half of the budget of this proposal.

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

This project has two main objectives: (1) to measure how much water and energy is wasted in hot water distribution systems in California residences and (2) to investigate the effectiveness of current retrofit options in reducing this waste of water and energy.

This project will fulfill these objectives by installing a measurement system consisting of a collection of wireless submeters to measure the temperature and flow of water in residential HWDS. The study is composed of three main parts, a mail survey, a pilot phase and a field study of 40 new and 40 existing houses. In partnership with water utilities, mail surveys will be sent out to representative single-family homes to collect demographic data and to establish a recruitment pool. The field study protocol consists of three steps: pre-retrofit measurements, application of the retrofit and post-retrofit measurements. The temperature and flow of hot water through the distribution system will be measured by a collection of sensors and wireless submeters installed at every point of use and at the water heater. After the performance of the system has been measured, an on-demand recirculation system will be retrofit on the HWDS system. The pilot phase will be conducted on nearby homes of volunteers to develop the protocol. Once the protocol has been confirmed, this will be followed by the full-scale field study.

Since a project of this nature has not been conducted before, only a crude estimate of the potential savings is possible. We estimate that 5.2 gallons of water is wasted per day per house. (See Appendix 1, Sample Size Calculation for a discussion of this calculation of water loss.) Assuming this research demonstrates a potential to reduce average daily water loss to 1 gallon, which means a savings of 4.2 gallons per day per household. If this average daily water savings were applied to all single-family residences built in California since 1980 the potential water savings per year are 3.4 billion gallons. This would be a significant contribution toward the California Bay-Delta Program goal of advancing the implementation of cost-effective urban conservation.

This is a research proposal submitted under section B of the request for proposals. This work is not a "project" as defined by CEQA, California Code of Regulations, Title 14, Division 6, Chapter 3, Section 15378. This is a research and development project to measure water and energy waste of HWDS under pre- and post-retrofit conditions for only 80 houses and does not fulfill the criteria of a project where "… the whole of an action, which has a potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment....".

2.1 Hypothesis

The hypothesis that underlies the work for this project is that a significant amount of residential hot water use is waste and that techniques exist to reduce that waste. A significant amount of indoor residential water use, 25.2 gallons of water per household per day, is from fixture utilization.[3] Unfortunately, the design of typical HWDS means that a certain amount of this water is wasted. In addition to the wasted water a significant amount of energy for water heating is also wasted.

Two types of waste are present in residential HWDS. The waste of water that has cooled off in pipes since the previous draw and therefore is discarded and the wasted energy as hot water cools down in the distribution system after a draw. Both of these types of waste occur in showers. The waste of water can also occur in sinks when users discard cooled off water until the hot water being drawn reaches the temperature they desire.

Waste of heat also occurs in situations where heated water that has cooled off is drawn and used cold. Warm water may have been preferred, but the user wasn't willing to wait for it. Or the user may just have wanted water, and didn't care what temperature it was. This commonly occurs with hand washing, when users don't wait for the hot water they are drawing to reach the tap they are using. This type of waste also occurs with machine uses such as clothes washers and dishwashers. These machines use whatever temperature water is delivered. Even more energy is wasted with dishwashers that have their own internal heater. The cooled off hot water in the pipes (that has already been heated once by the water heater), is reheated by the dishwasher to be hot enough for sanitizing dishes.

This project will measure the quantity and temperature of water used for every hot water draw in a representative sample set of residential single-family homes. The temperature of the water will be measured at the point of use and also at the water heater, the inlet to the hot water distribution system. From the data collected in this process, the team will determine the actual water and energy efficiency of the residential hot water distribution system for every hot water draw. The wait time until hot enough water gets to showers and sinks will be measured. The temperature and flow of water going into the water heater will be measured as well as the temperature of the water coming out of the water heater. The energy consumption of the water heater will be measured. This will allow the actual field efficiency of the water heater to be determined.

This study is composed of three main parts, a mail survey, a pilot phase and a full-scale study. The mail survey will gather demographic data about existing homes and be used to recruit participants for the field study. During the pilot phase auditing protocols and data measurement techniques will be developed in the laboratory and tested on five homes in the Bay Area. During the field study data will be collected from eighty homes throughout

[3] Meyer, Peter W., William B. DeOreo, Eva M. Opitz, Jack C. Kiefer, William Y. Davis, Benedykt Dziegielewski and John Olaf Nelson. Residential End Uses of Water, 1999. AWWA Research Foundation, Report No. 90781, pg 86

California. Forty homes will be existing homes, the other forty homes will be in new housing development sites.

2.2 Background

Currently, there are no implementation programs addressing the problem of poorly designed HWDS in the residential sector and very few studies have investigated this problem. Most relevant studies have only measured water consumption for residential end uses.

An extensive examination of residential indoor and outdoor water consumption is reported in the AWWA study.[4] It focused on four main objectives: (1) provide specific data on the end uses of water in residential settings across the continent, (2) assemble data on disaggregated indoor and outdoor uses, (3) identify variations in water used for each fixture or appliance in according to a variety of factors, and (4) develop predictive models to forecast residential water demand. We have used the results of this study as the basis for the estimates of losses from HWDS.

Two other relevant studies investigated indoor residential high-efficiency plumbing retrofits.[5] [6] The homes in these studies were retrofitted with high efficiency toilets, clothes washers, showerheads, and faucets. Hot water use was measured separately for a subset of the houses in these studies. Another study examined the effect of retrofit application of on-demand recirculation pumps.[7]

These studies investigated water consumption and retrofits at the household level. They used flow trace analysis on whole house water consumption to identify the end use types of individual draws. They did not measure water consumption at individual use points. Nor did these studies did not measure the temperature of the water delivered to the use points.

Another study looked at on-demand recirculation pumps in 5 houses in Palo Alto.[8] Unfortunately the sample for this study was houses built before 1950, so in addition to using a very small sample, the houses were not representative of recent housing construction practices in California.

ASHRAE funded a research project to develop measurement tools and techniques to characterize domestic hot water (DHW) consumption by individual end use and end

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[4] Meyer, Peter W., William B. DeOreo, Eva M. Opitz, Jack C. Kiefer, William Y. Davis, Benedykt Dziegielewski and John Olaf Nelson. Residential End Uses of Water, 1999. AWWA Research Foundation, Report No. 90781,
[5] P. W. Mayer, W. B. DeOreo, and D. M. Lewis, "Seattle Home Water Conservation Study: The Impacts of High Efficiency Plumbing Fixture Retrofits In Single-Family Homes," Aquacraft, Inc. December 2000 2000.
[6] P. W. Mayer, W. B. DeOreo, E. Towler, and D. M. Lewis, "Residential Indoor Water Conservation Study: Evaluation of High Efficiency Indoor Plumbing Fixture Retrofits In Single-Family Homes In The East Bay Municipal Utility District Service Area," Aquacarft, Inc. July 2003 2003.
[7] De La Piedra, J., *Hot Water Recirculation Pilot Study*, 2002, Santa Clara Valley Water District. <http://www.valleywater.org/media/pdf/Hot_Water_Recirc_report.pdf>
[8] M. R. Ally, J. J. Tomlinson, and B. T. Ward, "Water and Energy Savings using Demand Hot Water Recirculating Systems in Residential Homes: A Case Study of Five Homes in Palo Alto, California," Oak Ridge National Laboratory, Oak Ridge, TN ORNL/TM-2002/245, October 21, 2002 2002. < http://www.ornl.gov/~webworks/cppr/y2001/rpt/115441.pdf>

use location.[9] The research project included a field test of the data collection and analysis methods on a small sample of residences, and developed an online web-enabled database entry and query system to provide access to the collected DHW usage data. Unfortunately the sample was very small, only 5 residences. The houses were typical of construction styles in Nebraska. They all had water heaters in basements, which is very different from the typical construction style in California.

The project proposed here will measure the flow and temperature at every use point at one-second intervals in 80 houses throughout California. We will determine how much water is used, and how long it takes to get hot water to the use point. From changes to the mix of hot and cold water flow rates, we will also be able to tell when someone started using the hot water. This will allow us to accurately calculate the water and energy efficiency of the HWDS for every hot water draw event before and after the application of a retrofit on-demand recirculation system. By carefully investigating the problem of poorly designed HWDS and measuring performance of a retrofit that may solve this problem, this project has potential to identify water savings that could contribute to California Bay-Delta goals.

2.3 Methods

Data collection includes three components: a mail survey, a pilot phase and a field study. The mail survey serves to gather demographic data about existing homes and recruit participants for our study of existing homes. The pilot phase serves as a tool to test the installation, measurement and retrofit protocols. Any deficiencies discovered during this phase will be worked out before proceeding to the field study. The field study will be the full-scale study using the pilot phase tested installation, measurement and retrofit protocols. Similar protocols will be used in the field studies of new and existing homes.

2.3.1 Mail Survey

In partnership with local water utilities located throughout California, we will mail surveys to customers identified by water utilities. The survey will be coordinated with each water utility working with this project. East Bay Municipal Utility District (EBMUD) will assist with customer identification and outreach efforts. San Diego County Water Authority will coordinate activities with their member agencies to find viable residential customers to participate in the project. The survey will include questions on the age and number of inhabitants, the number of bathrooms, the number of fixtures, house size and age, location. This survey will be used to narrow down our sample to homes that fit the study’s criteria and as a solicitation tool for recruiting volunteers to participate in the field the study. The mail survey will also be used to extrapolate the HWDS losses for the total population from the results of the field study.

Mail surveys will not be done for the new construction sample because the occupants will not yet be in the houses when the measurement equipment is installed.

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[9] D. K. Tiller and G. P. Henze, "1172 - TRP: Metering Residential Hot Water by End-Use: Development of Standard Protocol," University of Nebraska - Lincoln, Architectural Engineering 2004, Final Report to American Society Heating Refrigeration and Air-conditioning Engineers (ASHRAE).

2.3.2 Pilot Phase

The purpose of the pilot phase is to get experience with the field aspects of the measurement process and collect actual data to develop the automated data collection and processing protocol. Review and shakedown of the audit protocols, field tests, and equipment installation will also be an important part of this phase of the project. The project team, in consultation with sub-contractors will write up detailed field installation and decommissioning protocols. These will be reviewed with the Project Advisory Committee (PAC) before any installation or measurement starts in the field study.

Houses used in the pilot study will be those of volunteers from LBNL, and perhaps from EBMUD. Incentive for volunteers will be the retrofit on-demand circulation pump which will remain in the house after the test. Priority will be given to volunteers with houses built after 1980.

A web accessible database will be built to hold the collected data. During this phase we will also collect relevant hot water draw data from previous studies.

2.3.3 Field Study

The field study will measure the performance of the HWDS for all hot water draws in the selected houses for several weeks. The selection will include two samples, one of forty existing homes and another of forty new homes. For existing homes, the study will work with clusters of homes by utility district. About ten homes will be measured in each utility district. The exact number will vary depending on the relative size of the different agency customer base and fraction of newer homes. These homes will be selected by using the mail survey.

For new construction, homes will be solicited through cooperation and partnership with California housing developers and water utilities. The measurement system will be installed prior to the move-in of the homeowner. Measurement in new developments will allow us to do comparisons of nearly identical houses. The plumbing of the HWDS will be structured for on-demand recirculation systems. The retrofit will be applied after occupants have been in the house for several weeks to compare pre- and post-retrofit performance.

The main incentive for participation in the study will be the retrofit. The selection criteria for inclusion in the study will be: a) homes over 1,600 square feet, b) more than one occupant, and c) constructed after 1980. This information will be in the information collected in the mail survey sent out to existing homes. Homes that fulfill the criteria will be randomly sampled and solicited for inclusion in the study. In addition, the occupants will be guaranteed maintenance of the on-demand recirculation system for one year after completion of the study and will be granted access to the results of the study.

Table 1. Tasks

Tasks	Duration	Start	Finish	Cost
Mail Survey	100 days	12/15/05	5/3/06	$235,620
Pilot Phase	131 days	12/15/05	6/15/05	$308,550
Field Study (new homes)	222 days	3/23/06	1/26/07	$521,730
Field Study (existing homes)	290 days	4/24/06	6/1/07	$682,550
Meetings and Deliverables	350 days	1/2/06	5/4/07	$117,810

Table 2. Deliverables

Deliverable	Date
Project Initiation Report	12/14/05
Final Report on Mail Survey	5/3/06
Final Report on Pilot Phase	6/15/06
Final Report on Field Study (new homes)	1/26/07
Final Report on Field Study (existing homes)	6/1/07
Progress Reports	monthly
Project Advisory Committee Minutes	monthly

2.4 Procedures

This section describes the mail survey, pilot phase and field study in more detail and provides a description of the procedures and equipment to be used in each task.

2.4.1 Mail Survey

The survey questions will be adapted from a questionnaire developed for the AWWA 1999 report on residential water use.[10] The survey will include questions on the age and number of inhabitants, number of bathrooms and fixtures, the house size and age, and the location. This survey will be a useful tool to narrow down our sample to homes that fit the study's criteria and as a solicitation tool for recruiting volunteers to participate in the existing homes sample of the field study.

The mail survey will be administered in partnership with local water utilities in California. California will be divided into regions based on the major water utilities. Water utilities in the study will provide a list of representative homes and addresses for the survey. We will send approximately 1,000 surveys per utility to existing homes with an expected 33% response rate. The mail survey will include a self-addressed stamped envelope to encourage response and a description of the study. Two or three follow up attempts will be made to non-responders to encourage response.

2.4.1.1 Deliverables

The mail survey phase lasts for approximately 3.5 months. During this period, memos will be written monthly during the mail survey portion of this phase, summarizing preliminary

[10] Meyer, Peter W., William B. DeOreo, Eva M. Opitz, Jack C. Kiefer, William Y. Davis, Benedykt Dziegielewski and John Olaf Nelson. Residential End Uses of Water, 1999. AWWA Research Foundation, Report No. 90781, Appendix A

findings from each water utility district as they arrive. At the end of the mail survey, a detailed report will be given to DWR which will include a description and sample of mail survey along with a summary of findings.

2.4.2 Pilot Phase

The main purpose of the pilot study is to test and debug the installation protocols and data collection and processing procedures. The measurement protocols, including installation of metering and data acquisition equipment, HWDS audit, field test of the water heater recovery efficiency, and installation of the retrofit on-demand recirculation pump and controls will be the same as in the main part of the study. The data collection period for each house being measured in the pilot phase will be much shorter than in the main phase, perhaps as little as two weeks per house. Results will be generated, but are not expected to be particularly relevant by themselves. The importance will be in making sure the entire process is working correctly.

2.4.2.1 Data Acquisition System

The measurement system will consist of sensors installed at every hot water end use and at the water heater. The intent is to identify every hot water draw during the data collection period. The flow rate and temperature of water delivered to the domestic hot water distribution system from the water heater will be recorded in 1 second intervals during draws. This will be compared to the temperature of the water drawn at the end use point, again recorded at 1 second intervals during draws. The amount and volume of water drawn at the use point before it gets hot will be calculated as well as the amount of energy that is lost by the hot water on the way to the use point.

The collected data will include flow rates and temperatures from every hot water end use point during draws. Anticipated hot water use points are sinks, showers, tub/showers, dishwashers, and clothes washers. The data will be collected with wireless submeters that have been modified to report at one second intervals during flow events. These submeters are used across the country (except in California) by apartment building owners who want to submeter water use for individual apartment units that were not originally built with individual water meters. The wireless submeters are designed to be very unobtrusive. Hopefully occupants will not even notice their presence once they’ve been installed.

Whole house water flow rates will be collected with a magnetic pulse counter and wireless data transmitter installed on the water utility meter. The flows will be recorded in one second intervals during draws. A similar system, using a special magnetic pulse generator, will be attached to the gas meter to record whole house gas draws. Gas consumption during gas draw events will also be recorded at one second intervals.

Water flows into the water heater will be measured. This will be with a utility-type water meter, with a magnetic pulse pickup. Water temperature will be measured at the inlet and outlet of the water heater. The flow of water into the water heater will be recorded at one-second intervals during hot water draw events along with the temperatures of the water entering and leaving the water heater. Data will only be kept for those periods when draws are occurring.

The ambient temperature near the water heater and the flue temperature will be also be measured. The ambient temperature will be read every few minutes, because it is not expected to change very rapidly. The flue temperature needs to be read every second, but will only be recorded after there's a sudden jump in temperature (when the water heater starts firing). It will be recorded at one-second intervals until there's a sudden temperature drop (when the water heater stops firing). Between firings, the flue temperature can be recorded every few minutes. This flue temperature will be a proxy for the temperature of the water at the top of the tank during standby periods.

Weather data will be collected from the nearest weather station to determine if outdoor temperature has any impact on hot water usage patterns.

An additional wireless sensor to record the water flow and temperature out of the on-demand recirculation pump will be installed as part of the retrofit process. This will indicate when the pump is running. Plumbing configurations will to let flow rate during the line priming events by the recirculating pump to be picked up as a hot water draw event at the water heater.

The project team will measure pump standby and on-cycle power consumption when they come back to do the decommissioning. The pump power consumption in the two operating modes does not change during the measurement period, so this one-time measurement of power can be applied to the entire measurement period to calculate total pump energy consumption.

We will install inexpensive computers with cell modems at every house. The computer will collect all incoming data from the wireless central receiver and the data acquisition board into daily data files. Once a day, the files will be downloaded over the cell phone modem to a computer at LBNL.

Table Collected Data – per house

Measured Item	**Quantity Measured**	**Measurement Points**	**Frequency**
Hot Water End Uses			
	Water Flow Rate	12 to 20	1 second
	Water Temperature	12 to 20	1 second
Whole House Water Meter			
	Water Flow Rate	1	1 second
Water Heater			
	Water Flow Rate	1	1 second
	Water Temperature	2	1 second
	Flue Temperature	1	1 second & 5 minutes
	Ambient Air Temperature	1	5 minutes
Whole House Gas Meter			
	Gas Flow Rate	1	1 second
Recirculation Pump			
	Water Flow Rate	1 to 2	1 second

	Water Temperature	1 to 2	1 second
Entire House			
	Outdoor Air Temperature	1	5 minute

2.4.2.2 Data Processing

The processing of data at LBNL will be automated. The categorization of hot water draw events will be similar to that used in the ASHRAE RP-1172 project.[11]

The amount of wasted water will be calculated for shower and tub/shower hot water draw events and long draws at faucets. We assume that when people want to use hot water for showers, the cold water drawn from the hot water line is discarded until the water is hot enough and the consumer is ready to enter the shower. We assume that all hot water that is drawn before the hot and cold water flow is mixed to a steady intermediate temperature is wasted. We will examine the longer faucet draws for similar patterns. When those patterns are found, the cooled off hot water used in that draw event will be assumed to have been discarded as waste as well.

The energy delivered to the water heater is the heat content in the gas consumed by the water heater, both by the pilot light and by the main burner. Energy delivered to the domestic hot water distribution system is the mass of water drawn from the water heater adjusted for the increase in water temperature provided by the water heater. The energy delivered by the domestic HWDS is the mass of water drawn at the use point adjusted by how much higher the temperature of the water at the use point is than the household water to the water heater. All of these calculations will be integrated over the duration of the draws at 1 second intervals. The energy efficiency at the water heater is the ratio of delivered energy to consumed energy. The energy efficiency of the HWDS is the ratio of delivered energy to input energy, both measured as the heat content of the water. The water efficiency of the HWDS is the ratio of the non-discarded water to total water drawn. These efficiency ratios will be calculated for every draw.

2.4.2.3 Database

Measurement data from the field study will be automatically returned to LBNL for processing and entry into a database. This database will be created using PHP or MySQL and will be accessible to all project team members, and eventually to participating homeowners so that they are able to monitor their own water and hot water use. All the data coming in from the field will be automatically checked. Any missing or unreasonable data will be directed to project members for further examination. A project member will be responsible for reviewing data daily to detect any indicators of equipment malfunction.

The project team will use the database from the ASHRAE research project RP-1172 and modify it to work with the extra data fields relating to waste and efficiency.[12] The web front

[11] D. K. Tiller and G. P. Henze, "1172 - TRP: Metering Residential Hot Water by End-Use: Development of Standard Protocol," University of Nebraska - Lincoln, Architectural Engineering 2004, Final Report to American Society Heating Refrigeration and Air-conditioning Engineers (ASHRAE).

end built for that project will be modified to be useful to water and energy utilities. A flow trace signal analysis will be done on data sets from other studies (such as the Aquacraft studies for Seattle Water[13], EBMUD[14], Santa Clara Valley Water District[15] , and Palo Alto[16], ASHRAE RP-1172, heat pump water heater studies by EPRI[17], Kempton study[18] and possibly others) that include high time resolution flow rates of hot water draws. This data doesn't include waste and efficiency data from the hot water draws, but will be useful in preliminary understanding of the timing and patterns of hot water draws. It should also be possible to get shower and long faucet draw hot water waste information out these data sets using the same technique as was done in the Scoping Study.[19]

At some point we may offer the homeowners weekly graphs of their hot water use, although this may be something we want to do after the measurement is over, so as not to unintentionally influence their behavior.

2.4.2.4 Deliverables

Deliverables for this phase of the project will be reports on the protocols developed for the installation of measuring and data collection equipment, the HWDS audits, the field test of the water heater recovery efficiency, and the installation of the retrofit on-demand recirculation pump and controls. Sample results will be included to determine if the format or processing should be changed for the main field study phase.

2.4.3 Field Study

The protocols developed and perfected during the pilot phase will be scaled up for the field study phase of the project. The type of equipment that was finalized in the pilot phase will be

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12 D. K. Tiller and G. P. Henze, "1172 - TRP: Metering Residential Hot Water by End-Use: Development of Standard Protocol," University of Nebraska - Lincoln, Architectural Engineering 2004, Final Report to American Society Heating Refrigeration and Air-conditioning Engineers (ASHRAE).

13 Peter W. Mayer, William B. DeOreo, and D. M. Lewis, "Seattle Home Water Conservation Study: The Impacts of High Efficiency Plumbing Fixture Retrofits in Single-Family Homes," Aquacraft, Inc., Report 2000.

14 Peter W. Mayer, William B. DeOreo, Erin Towler, and D. M. Lewis, "Residential Indoor Water Conservation Study: Evaluation of High Efficiency Indoor Plumbing Fixture Retrofits in Single-Family Homes in the East Bay Municipal Utility District Service Area," Aquacraft, Inc. Water Engineering and Management, Report 2003.

15 De La Piedra, J., *Hot Water Recirculation Pilot Study*, 2002, Santa Clara Valley Water District. <http://www.valleywater.org/media/pdf/Hot_Water_Recirc_report.pdf>

16 M. R. Ally, J. J. Tomlinson, and B. T. Ward, "Water and Energy Savings using Demand Hot Water Recirculating Systems in Residential Homes: A Case Study of Five Homes in Palo Alto, California," Oak Ridge National Laboratory, Oak Ridge, TN ORNL/TM-2002/245, October 21, 2002 2002. < http://www.ornl.gov/~webworks/cppr/y2001/rpt/115441.pdf>

17 Andrew Lowenstein and C. C. Hiller, "Disaggregating Residential Hot Water Use," *ASHRAE Transactions*, vol. 102, 1996.

Andrew Lowenstein and C. C. Hiller, "Disaggregating Residential Hot Water Use – Part II," ASHRAE Transactions, vol. 104, 1998.

18 W. Kempton, "Residential Hot Water: a Behaviorally-Driven System," *Energy*, vol. 13, pp. 107-114, 1988.

19 Klein, Gary and James D. Lutz. (2005). Hot Water Distribution System Scoping Study. California Energy Commission. 2005

used throughout this phase. The procedures and equipment will be the same for both the new and existing home samples.

There will be three different visits to each house during the measurement phase. During the first visit the measurement equipment will be installed. The second visit will be to retrofit the hot water distribution system with an on-demand re-circulation pump, and the third will be to decommission and remove the measurement equipment.

2.4.3.1 Equipment Installation

LBNL will contact the home occupants and arrange a time for the initial audit and installation of the measurement equipment. For new houses, LBNL will coordinate activities with the developers.

The first team will be an LBNL technician and a water utility employee. They will install selected portions of the data acquisitions system, set up the central wireless receiver and the computer. The first team will also install a pulse counter and wireless energy monitor on the whole house water meter. This lets the central receiver get flow data for the total water to the house.

The second team will consist of a certified plumber contracted through Wellspring. They will install the wireless flow and temperature meters at every hot and warm water end use point in the house. The meter location will be noted, and sent to LBNL so we know which location the data is coming from. The subcontractor won't have to do anything with the central receiver. As a check they will turn on each of the hot water uses for a few seconds and then have LBNL call-in to the computer to get the data. The LBNL person and the on-site installer can then compare notes to make sure everything is working.

It would be nice if the first and second teams were at the house at the same time, but this isn't absolutely necessary. At the end of the study period, the first team would come back, remove the sensors and decommission the site.

The third team will be contracted through Metlund Systems. They'll come in about half way through the monitoring period and install a retrofit on-demand recirculation system. The retrofit consists of a high performance circulating pump, internal zone valve and electronic circuit board that controls the temperature of the hot water distribution flow. Since the on-demand recirculation system only works on the demand of the user and the electronic thermosensor controls the temperature activation, the actual run time of the pump is extremely limited. The third team will instruct the occupants on how to use it appropriately. They'll test it first to make sure it's working appropriately.

The first and second team will install a magnetic pulse logger and wireless transmitter at the water meter for the whole house. Similar equipment will be installed at the gas meter. They will also install a water meter with a magnetic pulse logger to measure water flows into the water heater. This will involve disconnecting the pipes to and from the water heater. This should not be too hard. Because of earthquake concerns, water heaters in California are typically installed with flex lines that can easily be removed with wrenches after the water is turned off. While the flex lines are disconnected, the team will install temperature sensors for the water going into and out of the water heater. They will also install sensors to measure ambient temperature near the water heater and the flue temperature of the water heater.

Data from the measurement equipment will be collected by a low-cost computer. The computer will be located near the water heater. During installation the technicians will attach a monitor and keyboard to the computer. When the system is verified to be working the keyboard and monitor will be removed by the technicians and used at the next house. The computer will be equipped with a cell phone modem and an uninterruptible power supply (UPS). Part of the set up process at LBNL will be loading the operating system and automated software onto the computer. The automated software will collect the data and download it daily to LBNL. In the event of a power outage, the UPS will let the computer save any files to the hard drive before it shuts down. The computer will be programmed to automatically start the data collection process when power is restored. To avoid clock drift, the computer will do a daily time check to reset its internal clock when it contacts LBNL to download the previous day's data.

Sensors from meters on and near the water heater will be wired directly to a data acquisition card, which is in turn attached to the computer. The wireless sensors will be reserved for data acquisition at hot water use points and the whole house water and gas meters.

The central receiver will send data packets from the wireless submeters directly to the serial port of the computer, during draw events. The data will be stored in daily files. The data packets from the central receiver will contain one-second flow (measured as pulses) and temperature data and an identifier indicating the source and time of the signal. The whole house water meter and the gas meter will not include temperature data.

The data files will consist of three types of events. There will be water draws, gas draws, and water heater firings. Continuous data streams will be kept of the ambient air temperature around the water heater and water heater flue temperature. The recirculation pump runs will look like a hot water draw event, because the return water will be plumbed through water meter on the inlet to the water heater. Whole house water draws will be recorded the same way as other draws. Except for the ambient air temperature and flue temperatures during standby (which will be at 5 minute intervals) all the data will be at one-second intervals.

Each hot water draw in this data set will be summarized. The summary data will include the date and time the draw started, the fixture location, the flow rate (maximum, mode, and total), time until temperature reaches 105 ºF, for showers, tub/showers, and long draws at sinks, the time until water starts being used (a step reduction in the flow rate of hot water will be taken to indicate when someone starts using the water), the wasted volume of water, wasted energy (energy as hot water put into the HWDS that didn't make it to the point of use), water efficiency of the draw, and energy efficiency of the draw.

A temperature and flow rate profile of water into and out the HWDS at one second intervals will be associated with every draw.

2.4.3.2 Initial Site Visit Activities

The first team will administer a follow up survey questionnaire, make a sketch the floor plan of the house, confirm all the indoor water using fixtures and fittings, conduct a HWDS audit and field test the recovery efficiency of the water heater.

The team will take digital photos of the house, the water heater and the water meter after the instrumentation is installed. The home occupant survey will be a repeat of the mail survey questionnaire. The audit will include a quick measurement of the house size and number of stories as well as location of bathrooms, kitchens, sinks, clothes washer, dishwasher, etc. If possible, we will collect information about the type of HWDS and where it's installed (attic, between floors, under slab, or crawl space).

After the whole house and water heater measurement equipment is installed and working the first team will do an audit of the HWDS by measuring the flow and time to get hot water at the farthest fixture. This would be the sink closest to the location the homeowner identifies as taking the longest to get hot water. We want to do this on the sink that will be retrofitted later. Then the flow and time to get hot water at other fixtures will be measured as well. The audit will use a short handheld microweir or other handheld measuring device. It will have a wireless water flow meter and temperature sensor built in. The data will automatically get sent back to the central receiver and be stored on the computer. The handheld microweir will have an audible signal that indicates when the water temperature of 105 ºF has been reached. The flow indicator in the microweir doesn't have to be that accurate, because the hot water flows will be measured by the flow meter on the water heater.

The HWDS audit should give us enough information to make a good estimate of the HWDS location.

This information will give us an indication of the structure of the HWDS. It will also be used later to help identify the characteristics of houses where a retrofit of an on-demand re-circulation pump makes best sense.

After the audit has been done, the team will do a field test of the recovery efficiency of the water heater. This requires turning the control of the water heater to pilot and running hot water out of the fixture nearest to the water heater until it's cold. When the water is running cold, that indicates the water heater is totally emptied of hot water and full of cold water. At that point the control on the water heater is set back to normal operation. The water heater will then fire until the tank is recharged with hot water. The measured temperature of the last water going into and out the water heater while it is still in pilot mode will be used to estimate the tank temperature at the time the firing starts. The flue temperature reading will be the record of when the water heater is firing. All this data will be being recorded by the sensors that were installed previously. The gas consumption will be collected wirelessly from the gas meter. The heat content of the gas will be obtained from the gas utility for that house. The time the water heater fires multiplied by the gas flow rate and adjusted by the heat content of the gas gives the energy input into the water heater during recovery. The change in heat content of the water in the water heater multiplied by the actual volume of the water heater yields how much heat was put into the water. The ratio of these is the recovery efficiency, as measured in the field. We may need to make a short hot water draw after the water heater stops firing to measure the temperature of water in the water heater. Standby power consumption can be directly observed and measured if the occupants leave the house for a couple days at anytime during the measurement period.

2.4.3.3 Retrofit On-demand Recirculation Pump

The third team will install an on-demand recirculation pump about half-way through the study period. This is a pump system that brings hot water to the fixture quickly by drawing water through the hot water line from the water heater. It returns the cooled off hot water back to the water heater through the existing cold water line. This water is otherwise normally discarded down the drain. The on-demand recirculation pump is usually installed under the sink farthest from the water heater. At the push of a button, it circulates the ambient house temperature water back to the water heater through the cold water line. When a predetermined set point temperature (usually 5°F above room temperature) is reached in the line near the fixture the pump stops automatically and hot water is available at the faucet. The pump may be operated by a switch placed next to the fixture or by a remote control.

A wireless flow and temperature submeter will be installed to measure the pump's operating time. This team will test the installation to make sure the pump and the submeter are working properly. They will also instruct the house occupants on the use of the on-demand recirculation pump.

2.4.3.4 Decommissioning

At the end of the measurement period the first team will return to the house to remove all the measurement equipment. They will also make a one-time measurement of the recirculating pump power draw during operation and standby. The on-demand recirculation pump will left in the house for the occupants. A final project evaluation questionnaire will be given to the occupants.

2.4.3.5 Deliverables

The Field study lasts for approximately 15 months. Presentation and a short report of results will be given to DWR after each phase of the Field Study: installation, retrofit and decommission has been completed. At the end of the field study, a detailed final report will be given to DWR which will include the following: (1) an executive summary, (2) methodology, (3) pre-retrofit results, (4) post-retrofit results, (5) analysis of costs and benefits, (6) conclusions and recommendations and (6) appendices. A presentation will accompany the final report.

2.5 Equipment

The following equipment will be needed for each house being measured in the pilot phase and field study.

The list of pre-installation equipment covers the equipment that will be assembled, set-up and tested at LBNL before being installed at the houses participating in the field study.

2.5.1 Pre-Installation Equipment

- personal computer (PC)
- uninterruptible power supply (UPS)
- cell phone modem
- data collection board (with at least 5 channels)
- central wireless receiver

2.5.2 Field Equipment

The equipment listed in this table will be installed in every house by the research team during the field study portion of the project. The set of equipment installed in new and existing homes will be the same. This equipment will be installed by one of the three project teams. The first set will be installed by the LBNL technicians and will be connected directly to the data collection computer. The wireless submeters will be installed by the Wellspring team. The on-demand recirculation pumps will be installed by the Metlund team.

- water flow meter (1)
  (This could be an in-kind contribution from the water utilities.)
- magnetic pulse detectors (2)
- wireless data transmitters (2)
- water temperature sensors (2)
- air temperature sensor (1)
- flue temperature sensor (1)
- wireless submeters with water temperature sensors (12-20)
  (Depends on the number of hot and warm water points of use in each house.)
- on-demand recirculation pump (1)
- pump controls (1)

2.6 Facilities

Two types of facilities will be used for this study. The first are in-house facilities and the second are the houses to be measured in this study.

The in-house facilities are located at LBNL, Building 90 4th Floor. This location will be used to set-up and test the data collection computers before they are installed in the field. The central data collection and analysis will also be done at the LBNL offices. This facility will be the host site for the web server which will be the front end for the database of collected information.

During the pilot phase 5 houses of volunteers near LBNL will be used to test out the equipment and protocols. The field study will consist of 80 houses divided into two samples. The first sample will consist of new houses. The project team will work with housing developers and water utilities to find these houses. The second sample set will be existing houses of water utility customers. The field study houses will be located in high growth regions of California.

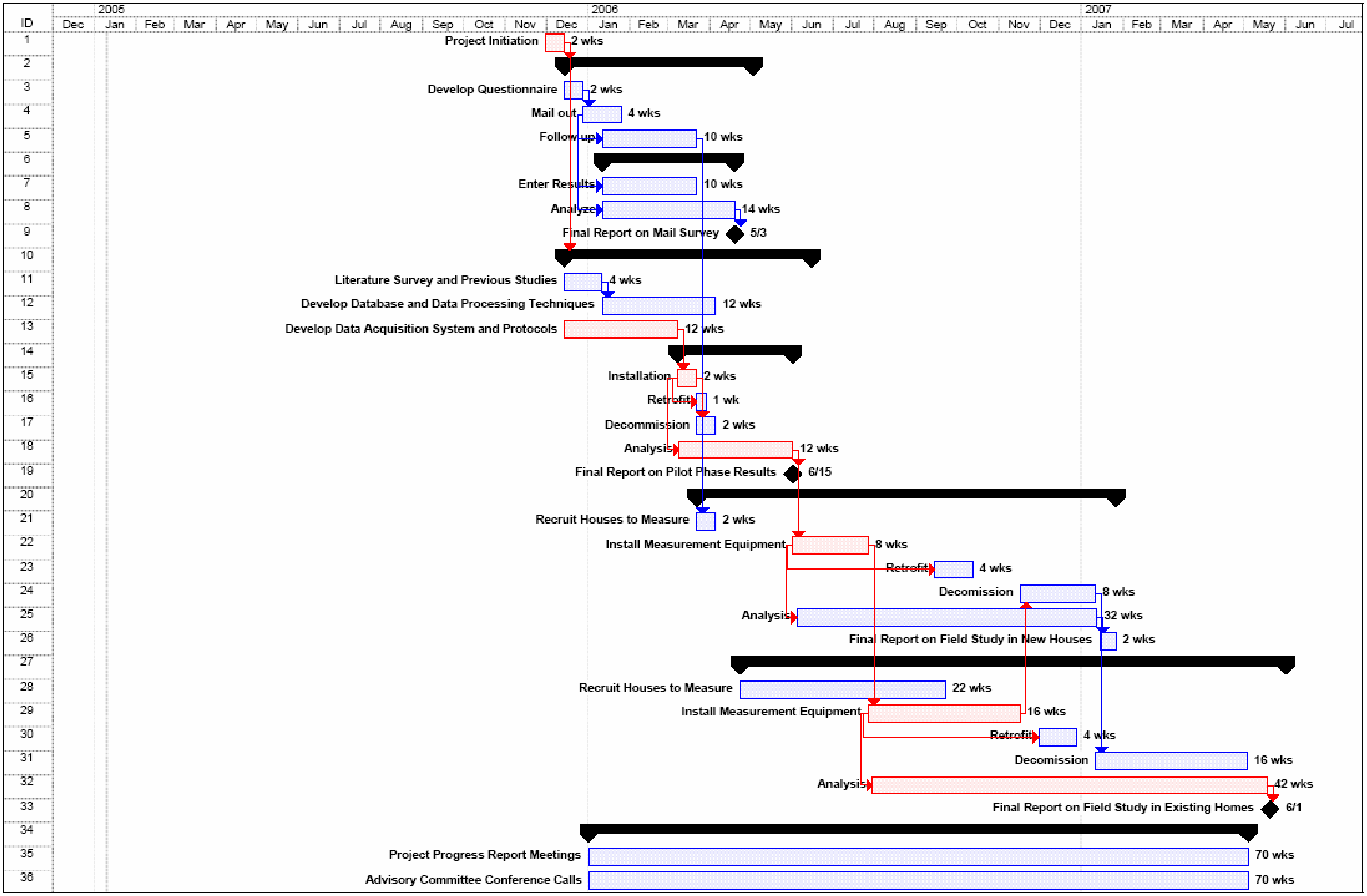
2.7 Project Plan and Work Schedule

The study is composed of three main parts, a mail survey, a pilot phase and a field study of 40 new and 40 existing houses. In partnership with water utilities, mail surveys will be sent out to representative single-family homes to collect demographic data and to establish a recruitment pool. The project protocol consists of three steps: pre-retrofit measurements, apply the retrofit and post-retrofit measurements. The temperature and flow of hot water through the distribution system will be measured by a collection of sensors and wireless submeters installed at every point of use and the water heater. After the performance of the system has been measured, an on-demand recirculation system will be retrofit on the HWDS system. The pilot phase will be conducted on nearby volunteered homes to develop the protocol. This will be followed by the full-scale field study.

The proposed project plan and work schedule is shown in Table 3 and the following Gantt chart. The major phases of the project are bolded in Table 3. Total costs are shown for each of the major phases of the project. (Half of these costs are expected to be covered by California Energy Commission sponsorship.)

Table 3. Project Plan and Work Schedule

Tasks	Duration	Start	Finish	Cost
Project Initiation	2 weeks	Thu 12/1/05	Wed 12/14/05	
Mail Survey	**100 days**	**Thu 12/15/05**	**Wed 5/3/06**	**$235,620**
Develop Questionnaire	2 weeks	Thu 12/15/05	Wed 12/28/05	
Mail Out	4 weeks	Thu 12/29/05	Wed 1/25/06	
Follow Up	10 weeks	Thu 1/12/06	Wed 3/22/06	
Analysis	70 days	Thu 1/12/06	Wed 4/19/06	
Enter Results	10 weeks	Thu 1/12/06	Wed 3/22/06	
Analyze	14 weeks	Thu 1/12/06	Wed 4/19/06	
Final Report on Mail Survey	2 weeks	Thu 4/20/06	Wed 5/3/06	
Pilot Phase	**131 days**	**Thu 12/15/05**	**Thu 6/15/06**	**$308,550**
Literature Survey and Previous Studies	4 weeks	Thu 12/15/05	Wed 1/11/06	
Develop Database and Data Processing Techniques	12 weeks	Thu 1/12/06	Wed 4/5/06	
Develop Data Acquisition System and Protocols	12 weeks	Thu 12/15/05	Wed 3/8/06	
Pilot Field Study	61 days	Thu 3/9/06	Thu 6/1/06	
Installation	2 weeks	Thu 3/9/06	Wed 3/22/06	
Retrofit	1 weeks	Thu 3/23/06	Wed 3/29/06	
Decommission	2 weeks	Thu 3/23/06	Wed 4/5/06	
Analysis	12 weeks	Fri 3/10/06	Thu 6/1/06	
Final Report on Pilot Phase Results	2 weeks	Fri 6/2/06	Thu 6/15/06	
Field Study (40 new houses)	**222 days**	**Thu 3/23/06**	**Thu 1/26/07**	**$521,730**
Recruit Houses to Measure	2 weeks	Thu 3/23/06	Wed 4/5/06	
Install Measurement Equipment	8 weeks	Fri 6/2/06	Thu 7/27/06	
Retrofit	4 weeks	Fri 9/15/06	Thu 10/12/06	
Decommission	8 weeks	Fri 11/17/06	Thu 1/11/07	
Analysis	32 weeks	Mon 6/5/06	Fri 1/12/07	
Final Report on Field Study in New Houses	2 weeks	Mon 1/15/07	Fri 1/26/07	
Field Study (40 existing homes)	**290 days**	**Thu 3/23/06**	**Fri 6/1/07**	**$682,550**
Recruit Houses to Measure	22 weeks	Thu 4/24/06	Wed 9/20/06	
Install Measurement Equipment	16 weeks	Fri 7/28/06	Thu 11/16/06	
Retrofit	4 weeks	Fri 12/1/06	Thu 12/28/06	
Decommission	16 weeks	Fri 1/12/07	Thu 5/3/07	
Analysis	42 weeks	Mon 7/31/06	Fri 5/18/07	
Final Report on Field Study in Existing Homes	2 weeks	Mon 5/21/07	Fri 6/1/07	
Meetings and Deliverables	**350 days**	**Mon 1/2/06**	**Fri 5/4/07**	**$117,810**
Project Progress Report Meetings	70 weeks	Mon 1/2/06	Fri 5/4/07	
Project Advisory Committee Conference Calls	70 weeks	Mon 1/2/06	Fri 5/4/07	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2005
2006
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Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
1 Project Initiation 2 wks
2
3 Develop Questionnaire 2 wks
4 Mail out 4 wks
5 Follow-up 10 wks
6
7 Enter Results 10 wks
8 Analyze 14 wks
9 Final Report on Mail Survey 5/3
10
11 Literature Survey and Previous Studies 4 wks
12 Develop Database and Data Processing Techniques 12 wks
13 Develop Data Acquisition System and Protocols 12 wks
14
15 Installation 2 wks
16 Retrofit 1 wk
17 Decommission 2 wks
18 Analysis 12 wks
19 Final Report on Pilot Phase Results 6/15
20
21 Recruit Houses to Measure 2 wks
22 Install Measurement Equipment 8 wks
23 Retrofit 4 wks
24 Decomission 8 wks
25 Analysis 32 wks
26 Final Report on Field Study in New Houses 2 wks
27
28 Recruit Houses to Measure 22 wks
29 Install Measurement Equipment 16 wks
30 Retrofit 4 wks
31 Decomission 16 wks
32 Analysis 42 wks
33 Final Report on Field Study in Existing Homes 6/1
34
35 Project Progress Report Meetings 70 wks
36 Advisory Committee Conference Calls 70 wks

Statement of Work, Section Three: Monitoring and Assessment

It is important to make clear that this project is in some sense entirely a monitoring project, and that measurements of residential water and energy consumption will be taken during both the pilot and field study.

The methods and procedures of this project have built-in monitoring and assessment systems. This acts to reduce potential additional costs of a full-scale monitoring system. Memos, reports and presentations will be provided to DWR throughout the project. A more detailed explanation follows below.

3.1 Monitoring Plan

The monitoring plan will follow the three phases of this project: Mail Survey, Pilot Phase and Field Study. The team will have a kick-off meeting with PAC to review the study design and the goals and objectives of the study. This first meeting will take place at LBNL. The LBNL team will hold weekly meetings to discuss progress made during the study. Every month during the entire project, the team will produce a memorandum marking the progress of the study and goals accomplished. These monthly progress memorandums and minutes of PAC meetings will be sent to DWR. Monthly PAC meetings will be held by telephone as conference calls.

Mail Survey
A mail survey will be sent to select utility customers as part of this project. After the survey is completed, a report will be written about the findings. This report will be reviewed by PAC and then delivered to DWR.

Pilot Phase
During the pilot phase, the entire protocol will be followed at five houses of LBNL volunteers. A detailed report of the proposed measurement protocol to be followed in the pilot phase will be completed before equipment installation starts for the pilot phase. A written report of the entire pilot phase results and recommendations will be delivered at the end of this phase. Both reports will be reviewed by PAC and then delivered to DWR.

Field Study
During the field study phase the installations in the houses being measured will take place in a staggered manner. Installation will be done in sets of ten houses for each utility or development. During this portion of the study, the team will be submit a weekly report of activities and progress. Home occupants will be given satisfaction surveys at the end of their participation to ensure that the study has been conducted professionally. Monthly progress reports with interim findings will be submitted to DWR. In addition, larger final report and a presentation will be given to the Department of Water Resources at the end of the project.

Team Evaluation
Every six months during the length of the study, the project manager will do a review of each team member's job performance. The evaluation will include input by PAC as appropriate. Participant comments will be included in the team's performance evaluation as appropriate.

3.2 Evaluation

3.2.1 Baseline
The baseline water and energy losses will be measured in the field study before the retrofit is implemented. These losses will be extrapolated to all applicable houses to give an estimate of statewide losses. The error of the pre-retrofit average daily water loss will be calculated to a 95% confidence level. This baseline water loss will also be compared to the pre-project estimates.

3.2.2 Effects of Retrofit
We expect that this retrofit will lower water and energy consumption, so we would expect to see a reduction in total water and energy use by the house. We expect that implementation of the retrofit, if demonstrated to yield energy and water saving, could provide a means for cost-effective water conservation in the state of California.

Water and energy losses will be measured after the retrofit. A comparison for each house of the water and energy losses before the retrofit will determine the savings from the retrofit. The pre- and post-retrofit losses will be adjusted to account for differences in entering water temperature, weather and season for each house. Savings differences between houses will be examined to determine the effect of such factors as location, house size and age, number of bathrooms, number and age of occupants, etc. From these calculations the potential state-wide water and energy savings of this retrofit will be estimated.

3.3 Evaluation of Success in Relation to Project Goals and Objectives
This study has two main goals and objectives: 1) to measure how much water and energy is wasted in hot water distribution systems in California residences and 2) to investigate the effectiveness of current retrofit options in reducing this waste water and energy.

The evaluation of this project will be based on how well we measure the water and energy waste in California homes due to HWDS design. The evaluation of the investigation of the effectiveness of retrofits will be based on how clearly we demonstrate the potential savings, or lack thereof. The evaluation of this project will not be based the size of the savings due to the retrofit.

3.4 Data

3.4.1 Data Handling
All houses and occupants will be assigned numerical identification at the beginning of the study. At no time during data analysis will occupant's addresses or personal information

be included in reports. In the reports, house locations will be resolved only to the zipcode level. Confidentiality agreements will be made with participants so that they know their full rights. Participants can withdraw from the study at anytime. All the human subject protocols required for LBNL will be followed.

3.4.2 Storage

All paper documents will be kept in a locked file cabinet at LBNL. All data kept in databases or on LBNL computers will be password protected. Any information sent over the Internet will be encrypted to ensure the privacy of participants. Confidential data will be available only to LBNL team members. Periodic security and bug checks will be performed.

3.4.3 Accessible to DWR and Others

A password protected online database of all data will be available to DWR and the PAC team members. Occupants will be allowed to review data regarding only their own house and overall project findings.

3.5 Reports

A detailed report describing the proposed measurement protocol will be written before the pilot phase measurements. A report describing the results of the pilot phase will be completed before the field study is started. Reports on the findings of the field study will be written for both the new construction and existing home samples. A final report will describe the findings of the entire project. Every month during the Field Study phase of the project, data will be assessed and preliminary data analyses will be submitted.

3.6 Estimated Costs of Monitoring and Assessment Plan

The cost of the monitoring and assessment plan has already been included in the overall budget for this proposal. All of the cost will be labor and is estimated to be approximately 10% of the total cost of the project.

4.1.Cost/Benefit Analysis

A thorough cost/benefits analysis of the retrofit will be included in the final report. This will include an evaluation of effectiveness of the retrofit for each house type in each represented region.

Qualifications of the Applicants and Cooperators

An interdisciplinary team has been assembled for this project. Each member of the team is uniquely qualified to provide support and expertise to this project ranging from environmental policy to mechanical engineering to field technician. The ultimate goal of the team is conduct research that will assist in achieving California's Bay-Delta goals by measuring how much water and energy is wasted in hot water distribution systems (HWDS) in California residences and by investigating the effectiveness of current retrofit options in reducing this waste of water and energy.

The lead agency is Lawrence Berkeley National Laboratory (LBNL). The modification and installation of wireless submeters will be done by Wellspring International, a leader in wireless submeter technology. The retrofit application of on-demand recirculation pumps will be done by Metlund ACT, who developed the technology.

The CEC will consider providing match funding for 50 percent of the project costs. Gary Klein, who is advisor to Commissioner John L. Geesman of the CEC, will be actively participating on the PAC. The CUWCC will contribute in kind time to assist getting the results disseminated to the water community and evaluated as a best management practice. MaryAnn Dickinson, the executive director of the CUWCC, will be a member of PAC. John Koeller, a consultant with many years experience in the water conservation field, and Larry Weingarten, an expert at water heater maintenance and author of The Water Heater Handbook, will both serve on the PAC.

EBMUD, San Diego County Water Authority and San Francisco Public Utilities Commission have agreed to support this project. (See letters of commitment in Appendix III.) EBMUD will assist with customer identification and outreach, provide use of water meters, participate in the PAC, and provide technical assistants. San Diego County Water Authority will provide in-kind support for the project's field measurement activities by coordinating activities with their member agencies to find viable residential customers to participate in the project. San Francisco Public Utilities Commission will also participate in the project. Representatives of these water utilities will be on the PAC.

Additionally, representatives of the investor owned gas utilities, Pacific Gas & Electric and Southen Califorina Gas (Sempra Utilities) will be participating on the PAC as well. For regulatory reasons, investor owned utilities are not permitted to provide in kind support for research projects.

Lawrence Berkeley National Laboratory (LBNL)
The key personnel for LBNL will be John Stoops (as Principal Investigator), Jim Lutz (as project manager), Peter Biermayer and Gabrielle Wong-Parodi.

Dr. Stoops joined the Energy Analysis Department of Lawrence Berkeley National Laboratory as a program manager in April of 2001. His responsibilities have focused on the analysis and program management of national energy efficiency standards for commercial HVAC equipment and electrical distribution transformers. For more than 22 years Dr. Stoops was associated with Battelle, Pacific Northwest National Laboratory in Richland, Washington and Washington, DC. where his research career focused on the analysis of energy efficiency in commercial buildings with a strong emphasis on field data collection and empirically based evaluation. Throughout his career the connection between energy and the environment as implemented through governmental policy has been paramount. He has been able to combine his interests in irrigated agriculture with his technical expertise. He was co-author of a successful proposal to NOAA to apply long-term weather forecasts to drive proactive water trading in an irrigation system. He co-led a project focused to the application of demand side management and integrated resource planning techniques developed for the electric utility industry to the problem of water allocation. He led the evaluation of an irrigation scheduling program. The scope of this multiple year project included an evaluation of energy and water savings on the farms, distribution energy savings resulting from the saved water and then the potential for energy production from the water remaining behind the dams on the Columbia River.

The project manager will be James Lutz. Mr. Lutz is Assistant Group Leader of the Energy Efficiency Standards Group at LBNL. He is a Staff Research Associate working primarily on efficiency standards for residential appliances for the U.S. Department of Energy. He has been with LBNL since 1990. Mr. Lutz was the lead author of the Technical Support Document for the energy efficiency standards for residential water heaters issued in 2001 and is currently product co-manager for furnace and boiler standards analysis. He is also the LBNL coordinator for India for the Collaborative Labeling and Appliance Standards Project (CLASP), which is assisting other countries in developing standards and labels for appliances. Mr. Lutz was the project lead for the HWDS roadmapping project for the CEC and Tennessee Valley Authority.

Mr. Lutz is a registered Professional Engineer and licensed general building contractor in the State of California. He is active in ASHRAE, as a member of the Service Water Heating Technical Committee, currently serving as chair of Standard Project Committee 118.2, Method of Testing for Rating Residential Water Heaters. He is also a member of ASME, ASPE, and AWWA.. Mr. Lutz has a B.S. in Engineering Science from California Polytechnic State University, San Luis Obispo and a B.A. in Sociology from Stanford University.

Peter J. Biermayer, M.S., will provide guidance for the implementation of the measurement equipment and data acquisition systems in the pilot phase and field study. Mr. Biermayer is a Staff Research Associate at Berkeley National Laboratory. As part of his analysis on Department of Energy clothes washer standards, he has forecast the price of marginal water and wastewater rates to the consumer. Water usage and the life-cycle cost savings of more efficient clothes washers played an important part in the Department of Energy rulemaking process. In a previous position at BR Laboratories, he performed many tests on plumbing fixtures and water conserving devices for the CEC with the purpose of evaluating or enforcing water conservation regulations. He received his M.S. in Mechanical Engineering from California State University, Fullerton in 1982...

Gabrielle Wong-Parodi Gabrielle Wong-Parodi will direct the mail survey and provide analytical support for the project .Ms. Wong-Parodi is a Research Associate at LBNL where she has worked since 2002. She has been involved with furnace and boiler energy efficiency standards and with the international energy efficiency standards group. Ms Wong-Parodi received a B.A. in Psychology from University of California, Berkeley in 2003. She is applying for graduate study in energy and environmental programs.

All the key LBNL personnel are members of the Energy Efficiency Standard Group (EESG) at LBNL. EESG has played a key role in the technical analyses for the U.S. Department of Energy rulemakings on appliance efficiency standards for more than 23 years. EESG's role is to provide technical and economic analyses of alternative standards levels in support of DOE, which selects the levels that ultimately become law. This activity identifies the feasibility and cost of engineering design changes that could increase energy efficiency for specific products (e.g., clothes washers or water heaters); analyzes scenarios in which these technologies are adopted; and assesses potential impacts on consumers, manufacturers, utility companies, the nation, and the environment. Mr. Lutz was the manager for the analysis effort for the update of the federal water heater efficiency standards that took effect in January 2004. Mr. Biermayer was responsible for the analysis effort for clothes washers. The first stage of the new energy efficiency standards for clothes washers took effect in January 2004, the second stage will become effective in January 2007.

LBNL has assembled a Water and Energy Technology Team (WETT), including resource engineers, scientists and economists, with the capability to address water and wastewater challenges both domestically and internationally. In addition to their work on energy efficiency standards, the key personnel of this project also participate in WETT, whose mission is to achieve sustainability through efficient technologies and integrated management of water and energy resources. WETT develops tools that regional water authorities can use to evaluate the impact that conservation programs have on managing demand for growing populations. These tools can be used to design rate structures and conservation programs and evaluate the impact that these programs have on particular constituencies.

One of the projects undertaken by WETT was developing a scoping study and roadmap for a Residential Hot Water Distribution System Research. The scoping study gathered information and data from past work and recommendations for improvements to residential hot water distribution systems. The roadmap identified and prioritized the research and implementation procedures and plans for a future research project to focus on improvements in the efficiency and effectiveness of residential hot water distribution systems. This effort was funded by the CEC and the Tennessee Valley Authority. Mr. Lutz was the manager for that project.

LBNL has been a leader in science and engineering research for more than 70 years; located on a 200 acre site in the hills above the University of California's Berkeley campus. LBNL holds the distinction of being the oldest of the U.S. Department of Energy's National Laboratories. The Lab is managed by the University of California, operating with an annual budget of more than $500 million (FY2004) and a staff of about 3,800 employees, including more than 500 students. LBNL conducts unclassified research across a wide range of scientific disciplines with key efforts in fundamental studies of the universe; quantitative biology; nanoscience; new energy systems and environmental solutions; and the use of integrated computing as a tool for discovery.

Wellspring International
Wellspring International will provide and install the wireless submeters to determine water flow and temperature at every hot water point of use. Wellspring Wireless is a full-service utility submetering and manufacturing company operating nationwide. They provide water and energy submetering utility billing services for apartment homes. The

background of Wade W. Smith, the chief executive officer, and other key executives of their management team are listed in Appendix II

Advanced Conservation Technology Inc. (ACT) Metlund Systems
Metlund Systems will provide and install the retrofit on-demand recirculation pumps and controls. ACT Inc.Metlund Systems was founded in 2001in Costa Mesa Ca. after several years of studying water and energy issues of residential homes and small commercial buildings. The main focus was on water and energy products that could be installed in either existing or new construction buildings. Metlund D'Mand Systems have met the Standards for UL and IAPMO Electrical and International Plumbing codes. Metlund D'Mand Systems have also met the rigorous Australian Codes and Regulations for the WATERMARK Label through the SAI Government Standards. Larry Acker has worked at ACT Inc. since 1990 and developed Metlund Systems.

Outreach, Community Involvement, and Acceptance

During the pilot phase, meetings with California water agencies, homebuilders and plumbers will be held in order to assess the best way to target retrofits. During this time, LBNL will convene the Project Advisory Committee to discuss project goals. They will help us decide how to most effectively disseminate the results of the study to homeowners and homebuilders.

The results of this project will help water and gas utilities define appropriate incentive programs to encourage their customers to design better HWDS. Participation by EBMUD, San Diego County Water Authority and San Francisco Public Utilities Commission will assure that results can be used by water agencies. CUWCC assist getting the results disseminated to the water community and evaluated as a potential best management practice. The involvement of Pacific Gas and Electric and Southern California Gas as part of the team will assure that retrofit measures, if shown to save energy, will become part of gas conservation programs as well.

The CEC will consider providing match funding for 50 percent of the project costs. The Energy Commission will use the results of this project to refine the HWDS aspects of California's building energy code, the Energy Efficiencies Standards for Residential and Non-Residential Buildings.

Innovation

Nearly $1 billion per year is estimated to be spent on wasted water and energy that can be attributed to the way residential domestic hot water distribution systems are built.[20] This problem seems to be worse in newer homes. This project will contribute toward the California Bay-Delta Program goal of advancing the implementation of cost-effective urban water conservation. We will measure the waste of water and energy in residential

[20] Klein, Gary and James D. Lutz. (2005). Hot Water Distribution System Scoping Study. California Energy Commission. 2005

domestic hot water distribution systems. The purpose of collecting this information is to accurately determine the amount of this waste, to evaluate a current retrofit technology that alleviates this problem and to provide solid guidance on how to build new houses to reduce this problem. Determining the best approach to implement potential water use efficiency actions directed at HWDS requires knowledge about the water use efficiency of HWDS and the effect of retrofits.

One of the key features of this project that marks it as innovative is that it is designed to address both water and energy. The institutional arrangements behind this project will be among the first to bring together agencies working on the water and energy sides of residential HWDS, in this case, the California Energy Commission and DWR. At the implementation level, the Project Advisory Committee will be bringing water utilities and gas utilities together to provide guidance on the project direction.

The innovative technical aspect of this project is that the amount of water and energy used and usefully delivered during every hot water draw event will be recorded at 1 second resolution with wireless submeters. Temperatures of hot water at the use point during actual use have rarely been measured. No one has ever measured the temperatures of hot water draws at the use point this frequently before. This will allow us to calculate the amount of wasted water and energy from every hot water draw event as well as the water and energy efficiency of the domestic hot water distribution system for every draw.

Benefits and Costs

Benefits

This is a research proposal submitted under section B of the request for proposals. It is a research project to measure water and energy waste of HWDS under pre- and post-retrofit conditions for only 85 houses. Therefore the direct benefits will accrue only to those houses.

The indirect, long-term benefits are potentially much larger, if the research proposed for this project demonstrates that widespread implementation programs are justified. These implementation programs could potentially achieve significant water quantity benefits to the Bay-Delta System.

Because this research has not yet been done, only a crude estimate of the potential savings is possible. Assuming this research reveals a savings of 4.2 gallons per day per household is possible, means a savings of about 1500 gallons per household per year. If this average savings were possible for all 2.2 million single-family residences built in California since 1980, then the potential water savings per year would be 3.4 billion gallons.

Costs and cost sharing

The total cost of this project is estimated to be $1,870,000. Because this project researches the potential to reduce both water and energy losses in California residences it is of interest to both the water conservation and energy efficiency communities. The California Energy Commission has offered enthusiastic support for this proposed project. Given the importance of the water-energy connection in California, the Energy Commission will consider providing match funding for 50 percent of the project costs. (See letter in Appendix III.) Because of this level of expected cost sharing, the grant request to DWR is one half of the total or $935,000.

Breakdown of costs in Table C-1 and LBNL budget sheet

Salaries, wages and fringe benefits: $752,408 total; $376,204 DWR share
Labor costs will cover the following staff and activities: As principal investigator for the project, John Stoops have overall responsibility for the project. James Lutz will be responsible for the technical direction of the project. He will also guide the analysis of the data coming from the pilot phase and field study. Peter Biermayer will provide guidance for the implementation of the measurement equipment and data acquisition systems in the pilot phase and field study. Gabrielle Wong-Parodi will direct the mail survey and provide analytical support for the project. Two LBNL technicians will install the measurement equipment in the pilot phase and the field survey. Administrative and computer support are also included in the labor costs.

Equipment Costs: *$164,050 total; $82,025 DWR share*
For the total project LBNL will install measurement equipment in 85 houses. The cost of the sensors and the data acquisition system is projected to cost $1930 per house. The 5 houses of the pilot phase and 40 of the 80 houses of the field study will be instrumented in FY '06 . This equipment will cost $86,850. The remaining 40 houses in the field study phase of the project will be instrumented during FY '07. The cost of equipment for the field study portion of the project will be $77,200.

Subcontracts: *$241,675 total; $120,838 DWR share*
LBNL will subcontract with Wellspring International to install the wireless submeters at every hot water end use point in every house in the study. The cost per house to install the wireless submeters is budgeted at $1,855. The standard wireless submeters that Wellspring International currently installs for its customers will need to be redesigned. The engineering costs for this design work is projected to be $50,000. Wellspring International will install wireless submeters in the 5 houses of the pilot phase and 40 of the 80 houses of the field study in FY '06. Wireless submeters will be installed in the remaining 40 houses in the field study phase of the project during FY '07.

The retrofit application of the on-demand recirculation pump and controls by Metlund will cost $400 per house. The retrofit will be applied to the 5 houses instrumented in the pilot phase and 40 of the 80 houses of the field study during FY '06. The retrofit will be applied to the remaining 40 houses in the field study phase of the project during FY '07.

Travel: $44,100 total; $22,050 DWR share
There are 3 components to the travel budget for this project. The main component is the cost for installers to visit houses to install measuring equipment and once again to remove it. The

installers will work on a cluster of 5 homes for each trip they make. They will spend one day at each house. This travel cost includes the cost of a hotel, a rental car & airfare to the site of the cluster. We are projecting an average cost of $250 per visit to each house. In FY '06 the installers will visit 45 houses (5 in the pilot phase and 40 installations in the field study) for a total cost of $11,025. In FY '07, the installers will visit the 40 remaining houses in the field study to install the measuring equipment. At the end of the project, they will visit all 80 houses in the field study to remove the measuring equipment. The FY '07 cost of travel for installers will be $29,400

The remaining costs are for travel to meetings in Sacramento and to conferences including the national AWWA and Conservation Committee meetings.

Miscellaneous: $55,232 total; $27,616 DWR share
The budget for miscellaneous costs includes laboratory and office space, electricity charges and miscellaneous costs such as telephone, and computer use

Other Costs: *$612,535 total; $306,268 DWR share*
These represent burdens, overheads and other required Department of Energy charges explained on the LBNL budget sheet and accompanying description following Table C-1.

PLACEHOLDER PAGE FOR EXCEL BUDGET SHEET

PLACEHOLDER PAGE FOR LBNL BUDGET SHEET

Brief Explanation of Costs included in LBNL Budgets

Salaries and wages are presented in accordance with costing practice for all Department of Energy (DOE) programs. The direct labor rates are based on actual payroll salaries. The salaries are escalated each year to allow for merit increase and career advancement. The escalation factor used for FY06 through FY07 is 3%.

Fringe benefits are a direct cost at LBNL. The fringe benefit rates for staff at LBNL differ according to employment status. The LBNL career rate is estimated at 23.0% in FY06 and 23.5% in FY07. These rates are approved by DOE and they are consistent with rates charged for all work at LBNL.

Burdens, Overheads and other required Department of Energy Charges

Organization Burden is charged at the rate of 17% on total salaries and fringe benefits. The purpose of this burden is to distribute the cost of management and supervision of division activities.

A procurement burden of 5.1% is charged on purchased supplies and services (including permanent equipment) and electricity.

A travel burden of 14% is charged on all travel costs.

A General rate of 46% is charged on total direct costs except for equipment, purchased supplies, travel and electricity. The purpose of this rate is to distribute the costs incurred for the general management and administration of the laboratory including the costs of maintaining the Laboratory site.

A rate of 6% is charged for the Laboratory Director’s Research and Development Program.

A Safeguards & Security Charge of 0.82% is applied to all direct costs. This charge is used to recover a pro rata share of DOE direct funded costs from projects funded by other sponsors.

The Lab’s Federal Administrative Charge of 3% is waived for state agencies.

Appendix I Sample Size Calculation

This section describes how we determined the sample size needed in order achieve results that can be reliably extrapolated to the general California population. In order to estimate the required sample size, we used indirect estimates of the amount of water wasted from the data in REUWS. We applied the algorithms explained in Lutz (2004)[21] to determine water loss from showers and draws at sinks lasting longer than one minute. We excluded all water draws less that 1/1000 gallons and greater than 1,000 gallons as outliers. We took the mean (5.22 gallons) and standard deviation (3.75 gallons) of the daily averages of this estimated waste from all 1200 homes in REUWS.

To derive an estimate of how large our sample size needs to be to provide significant results, we used the following equation.

$N = [Z_{\forall/2} * \Phi / E]^2$

Where,

N	=	sample size,
$Z_{A/2}$	=	level of significance corresponding to a confidence level,
Φ	=	standard deviation of the representative sample, and
E	=	standard error

In this statistical technique to determine sample size, we utilized the Z-score (a method of standardizing the scores to the population mean). We used error levels (1/4 of a gallon and 1/2 of a gallon) that would bring us to a 95% confidence interval that our results reflect those of the population. Decreasing the confidence level, or increasing the acceptable error size reduces in the number of houses that need to be sampled.

Table 2   Results of Sample Size Calculations

Error	¼ gallon	½ gallon
Sample Size	**29.4**	**14.7**
Recruit	**40**	**20**

Our calculations show that to get a sample average daily waste within ¼ gallon of the average daily waste of the entire population at a 95% confidence level would require measuring 30 homes. To be within ½ gallon of the population mean, we need a sample of 15. To make sure we get the actual number of houses we need to meet a ¼ gallon error, we are proposing to recruit 40 houses.

Because these sample sizes are based on estimated levels of waste, actual results from the study will have a different level of accuracy.

[21] J. D. Lutz, "Feasibility Study and Roadmap to Improve Residential Hot Water Distribution Systems," presented at American Water Works Association Conference, Orlando, Florida, 2004.

Appendix II - Resumes

Appendix III – Letters of Participation and Commitment

Applicant: Ernest Orlando Lawrence Berkeley National Laboratory

Project Title: Determining Waste of Water and Energy in Residential Hot Water Distribution Systems

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Section B Projects - Fill in shaded areas of Column I-IV only

Table C-1: Project Costs (Budget) in Dollars)

	Category (I)	Project Costs $ (II)	Contingency % (ex. 5 or 10) (III)	Project Cost + Contingency $ (IV)	Applicant Share[1] $ (V)	State Share Grant $ (VI)	Life of investment (years) (VII	Capital Recovery Factor (VIII)	Annualized Costs $ (IX)
	Administration[2]								
	Salaries, wages	$610,354	0	$610,354	$305,177	$305,177	0	0.0000	$0
	Fringe benefits	$142,054	0	$142,054	$71,027	$71,027	0	0.0000	$0
	Supplies	$0	0	$0	$0	$0	0	0.0000	$0
	Equipment	$164,050	0	$164,050	$82,025	$82,025	0	0.0000	$0
	Subcontract services	$241,675	0	$241,675	$120,838	$120,838	0	0.0000	$0
	Travel	$44,100	0	$44,100	$22,050	$22,050	0	0.0000	$0
	Misc. (including space and electricity)	$55,232	0	$55,232	$27,616	$27,616	0	0.0000	$0
	Other[3]	$612,535	0	$612,535	$306,268	$306,268	0	0.0000	$0
(a)	Total Administration Costs	$1,870,000		$1,870,000	$935,000	$935,000			$0
(b)	Planning/Design/Engineering	$0	0	$0	$0	$0	0	0.0000	$0
(c)	Equipment Purchases/Rentals/Rebates/Vouchers	$0	0	$0	$0	$0	10	0.0000	$0
(d)	Materials/Installation/Implementation	$0	0	$0	$0	$0	0	0.0000	$0
(e)	Implementation Verification	$0	0	$0	$0	$0	0	0.0000	$0
(f)	Project Legal/License Fees	$0	0	$0	$0	$0	0	0.0000	$0
(g)	Structures	$0	0	$0	$0	$0	0	0.0000	$0
(h)	Land Purchase/Easement	$0	0	$0	$0	$0	0	0.0000	$0
(i)	Environmental Compliance/Mitigation/Enhancement	$0	0	$0	$0	$0	0	0.0000	$0
(j)	Construction	$0	0	$0	$0	$0	0	0.0000	$0
(k)	Other (Specify)	$0	0	$0	$0	$0	0	0.0000	$0
(l)	Monitoring and Assessment	$0	0	$0	$0	$0	0	0.0000	$0
(m)	Report Preparation	$0	0	$0	$0	$0	0	0.0000	$0
(n)	**TOTAL**	$1,870,000		$1,870,000	$935,000	$935,000			$0
(o)	Cost Share -Percentage				50	50			

1- Applicant share is funding from the CEC

2- excludes administration O&M.

3- includes LBNL burdens and overhead see attached LBNL Budget Sheet

Applicant:

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Table C-2: Annual Operations and Maintenance Costs

Operations (1) (I)	Maintenance (II)	Other (III)	Total (IV) (I + II + II)
$0	$0	$0	$0

(1) Include annual O & M administration costs here.

Table C-3: Total Annual Project Costs

Annual Project Costs (1) (I)	Annual O&M Costs (2) (II)	Total Annual Project Costs (III) (I + II)
$0	$0	$0

(1) From Table C-1, row (n) column (IX)
(2) From Table C-2, column (IV)

Table C- 4: Capital Recovery Table (1)

Life of Project (in years)	Capital Recovery Factor
1	1.0600
2	0.5454
3	0.3741
4	0.2886
5	0.2374
6	0.2034
7	0.1791
8	0.1610
9	0.1470
10	0.1359
11	0.1268
12	0.1193
13	0.1130
14	0.1076
15	0.1030
16	0.0990
17	0.0954
18	0.0924
19	0.0896
20	0.0872
21	0.0850
22	0.0830
23	0.0813
24	0.0797
25	0.0782
26	0.0769
27	0.0757
28	0.0746
29	0.0736
30	0.0726
31	0.0718
32	0.0710
33	0.0703
34	0.0696
35	0.0690
36	0.0684
37	0.0679
38	0.0674
39	0.0669
40	0.0665
41	0.0661
42	0.0657
43	0.0653
44	0.0650
45	0.0647
46	0.0644
47	0.0641
48	0.0639
49	0.0637
50	0.0634

(1) Based on 6% discount rate.

Applicant:

THE TABLES ARE FORMATTED WITH FORMULAS: FILL IN THE SHADED AREAS ONLY

Table C-5 Project Annual Physical Benefits (Quantitative and Qualitative Description of Benefits)

	Qualitative Description - Required of all applicants[1]				**Quantitative Benefits - where data are available** [2]
	Description of physical benefits (in-stream flow and timing, water quantity and water quality) for:	Time pattern and Location of Benefit	Project Life: Duration of Benefits	State Why Project Bay Delta benefit is Direct[3] Indirect [4] or Both	Quantified Benefits (in-stream flow and timing, water quantity and water quality)
Bay Delta					0
Local				**Not applicable.**	

[1] The qualitative benefits should be provided in a narrative description. Use additional sheet.

[2] Direct benefits are project outcomes that contribute to a CALFED objective within the Bay-Delta system during the life of the project.

[3] Indirect benefits are project outcomes that help to reduce dependency on the Bay-Delta system. Indirect benefits may be realized over time.

[4] The project benefits that can be quantified (i.e. volume of water saved or mass of constituents reduced) should be provided.