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Peak Electricity Impacts of Residential Water Use

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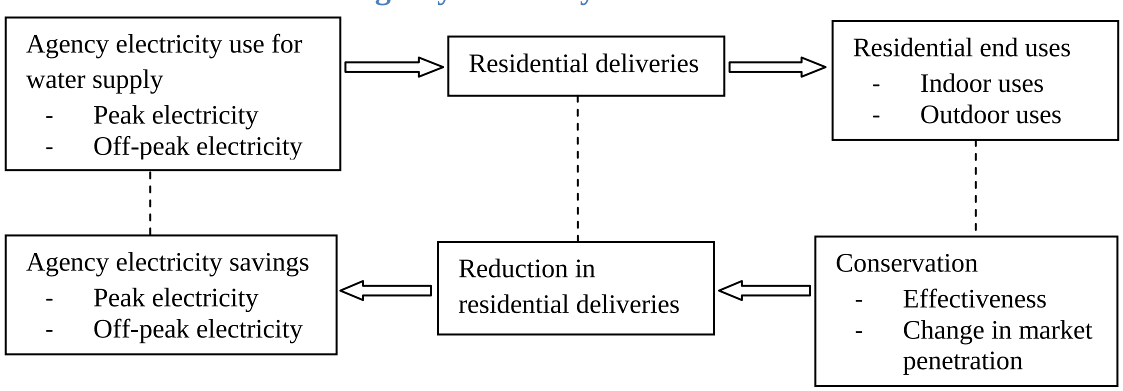
Summary

In this report, we investigate the link between residential water use and peak water district electricity use, accounting for the influence of local storage capacity, climate, and other district characteristics. There are three reasons why it is important to understand this link. First, this knowledge will make it possible to better design conservation efforts to reduce electricity and water use during costly peak periods. Second, this information will help utilities anticipate joint peak water use and peak electricity use, both prevalent on hot days of the year. Third, this information will help water districts to evaluate the effect of current conservation programs on district electricity use, and to implement conservation programs to mitigate associated costs. Study insights may also help the State anticipate and plan for long run impacts of climate change on peak water and electricity use.

Questions addressed through this study include:

- What is the relationship between local storage and the proportion of on-peak and off-peak electricity use for water supply across California water districts?
- How does the hour-by-hour relationship between water deliveries and district electricity use for supply vary across districts?
- How does implementation of conservation programs impact on-peak and off-peak electricity use?

Connections between water agency electricity use and residential water demand



Peak energy use to meet residential water demand and the water conservation impact on energy use will differ across water districts, depending on climate, water end uses, water sources, and the size and configuration of the water system. We concentrate on two determinants of the water conservation impact on energy use that have been somewhat overlooked in the past: water source and storage capacity. California water districts differ widely across these variables. There are districts that rely virtually entirely on surface water, but also districts that rely entirely on groundwater. There are districts with no above-ground local storage (in the form of reservoirs or tanks), but also districts with several days' supply of local storage. Water supply source and local storage are related issues, as water districts often have local storage for surface water and are less likely to have local storage if they rely primarily on groundwater.

Water districts with substantial local storage are to a large degree insulated from daily patterns of residential water demand, allowing these districts to manage and plan their water supply related electricity use. This highlights the added benefit of local storage (additional to the obvious primary benefit of secure local water supply): reducing peak electricity use and associated electricity costs. The availability of local storage is a metric that could be used to target conservation measures to specific water districts or regions with substantial current peak electricity use for water supply. It also highlights the importance of having water districts on time-of-use electric rates to provide the appropriate incentives for timing electricity use.

Based on hourly electricity use profiles for five California water utilities, we calculate the amount and proportion of on-peak and off-peak electricity use for water supply for average summer use. For these water utilities, we also calculate the ratio of local storage to daily delivery. We find variation across water districts in terms of temporal pattern of electricity use for water supply and a negative relationship between volume of storage and proportion of peak electricity use.

In addition to this general analysis of California water utilities, we consider two primary methods used by specific water utilities to manage peak electricity demand: local storage and conservation programs. We present case studies of water - electricity relationships and peak electricity management in two specific utilities: East Bay Municipal Utility District and the City of Fresno Water Division.

The first case study focuses on the use of local storage to manage peak electricity use in East Bay Municipal Utility District (EBMUD). We analyze hourly profiles of water deliveries and electricity for pumping to local storage in several residential areas in EBMUD. We discuss the revealed relationships between storage, peak electricity, and water demand in these areas, and estimate the peak electricity savings attributable to current water system operation practices utilizing storage.

The second case study focuses on the peak electricity impacts of residential water conservation in Fresno. We evaluate the electricity and peak electricity savings associated with current conservation programs and discuss the potential for using a recently installed automated meter reading (AMR) system as a means to reduce future water demand and water supply-related electricity costs and peak electricity use.

Table of Contents

Table of Figures

Table of Tables

1. Introduction: Motivations and the CA Water-Energy Relationship

In this report, we investigate the link between residential water use and peak water district electricity use, accounting for the influence of local storage capacity, climate, and other district characteristics. There are three reasons why it is important to understand this link. First, this knowledge will make it possible to better design conservation efforts to reduce electricity and water use during costly peak periods. Second, this information will help utilities anticipate joint peak water use and peak electricity use, both prevalent on hot days of the year. Third, this information will help water districts to evaluate the effect of current conservation programs on district electricity use, and to implement conservation programs to mitigate associated costs. Study insights may also help the State anticipate and plan for long run impacts of climate change on peak water and electricity use.

Questions addressed through this study include:

- What is the relationship between local storage and the proportion of on-peak and off-peak electricity use for water supply across California water districts?
- How does the hour-by-hour relationship between water deliveries and district electricity use for supply vary across districts?
- How does implementation of conservation programs impact on-peak and off-peak electricity use?

In the rest of Section 1, we discuss California climate projections and their implications for water and water-related energy use, as well as laying out the framework in which we discuss the relationship between water and energy. In Section 2, we focus on peak electricity use to meet residential water demand; we discuss previous work, propose theories of peak electricity use determinants, and present analysis of electricity profiles across water districts.

Sections 3 and 4 present the results of case studies on two primary methods used by specific water utilities to manage peak electricity demand: local storage and conservation programs. Section 3 presents a case study conducted on water and electricity data obtained from the East Bay Municipal Utility District; we explore the relationship between residential water demand and electricity for local pumping in this water district, focusing on the role of local storage in limiting peak electricity demand and the associated electricity cost savings. Section 4 presents a case study evaluating achieved and potential peak electricity savings of residential water conservation measures in the City of Fresno.

Climate projections and implications for water and energy

Changes in California's climate over the next quarter of a century are expected to increase demand for water while reducing water availability in the summer. Climate models and scenarios project a range of potential average summer temperature increase of 0.7 to 3.8 °F by the 2030s (Cayan, Maurer et al. 2006). Higher temperatures are associated with increased evapotranspiration, leading to increased use of water for irrigation, as well as increased water demand for other purposes.

Projections of changes in precipitation are less certain, ranging from substantial decreases to substantial increases. There is consensus that more precipitation is likely to be in the form of rain rather than snow and that snowmelt will begin earlier in the year (Cayan, Maurer et al. 2006). Since the snowpack acts as a natural reservoir, loss of snow and earlier snowmelt will both reduce late-summer surface water availability. Surface water supplies will become less certain and aquifer levels will fall if groundwater is increasingly used to meet demand.

Higher temperatures will also be associated with increased use of air conditioning during the electric peak period, with projected increases in peak electric demand of 1% to 4.8% by the 2030s, and this increase in demand is likely to be met by an increase in peak period prices (Cayan, Luers et al. 2006).[1] Policies to combat climate change, such as increased use of renewables and placing a price on greenhouse gas emission, will also increase the price of electricity. Real California electricity prices are, on average, expected to be 17% higher in 2020 than they were in 2008 (Aquacraft Inc. 2009).

Under these circumstances, conservation in general will become increasingly necessary. To mitigate electricity costs, incentives should be provided to promote conservation during the peak period, when the benefits to the state of California are greatest.

Focusing the water – energy framework

There are relationships between water and energy throughout all segments of the California water supply system: reservoirs provide water and are a source of hydropower; to reach locations in central and southern California, energy is expended by major water projects to pump water through the Delta and over the Tehachapi Mountains; water districts use energy for treatment, pressurization, and wastewater treatment; additional energy is expended by commercial, industrial, agricultural, and residential end users to pump, purify, cool, or heat water.

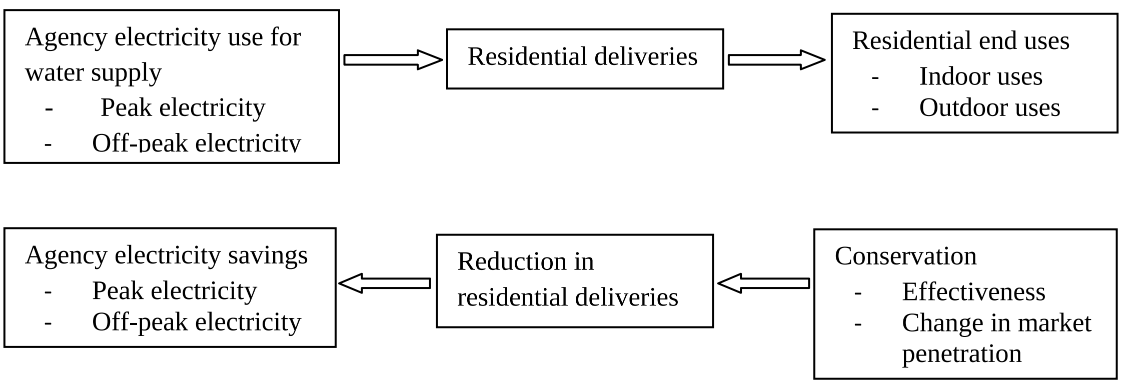
In this report, we focus on electricity used locally by water agencies to meet residential water demand. This includes electricity to pump groundwater, to pump surface water to elevation within the water agency's service area, and to pressurize the water distribution system. We do not analyze the following: energy expended within the major water projects before reaching a

[1] For consideration, current electricity costs for groundwater provision in the City of Fresno are approximately $0.15 per kWh for 10PM to 8AM, $0.20 for 8AM to 12PM and 6PM to 10PM, and $0.36 for 12PM to 6PM.

water agency's infrastructure; energy used to treat wastewater; or energy used to purify, heat, or cool water by residential end users.

Figure 1-1 provides a framework for considering the interaction between residential water demand and related water agency electricity use. Water agencies pump and treat water using peak or off-peak electricity, which is then delivered to residential customers who use it for various indoor and outdoor end uses. The timing of water agency electricity use will be related to the timing of residential demand based on the configuration of the water system. Correspondingly, residential customers may conserve water, which then translates to water agency savings of peak or off-peak electricity for water pumping and treatment, again determined by the configuration of the water system.

Figure 1-1 Connections between water agency electricity use and residential water demand



One rationale for focusing on these specific energy uses is that the energy impact of this segment of the water system has been relatively little studied, compared to end use or the major water projects. Also, as water districts are generally on a time-of-use electricity schedule, a better understanding of the linkages between the time of residential water demand and the time of water agency electricity use to meet that demand can reveal possibilities for reducing peak period electricity use and related costs. This can potentially benefit both the water agency (in the form of reduced energy costs) and the state of California (in the form of reduced load on the electric grid during peak periods, lowering the chance of brown outs or the need to import electricity).

The impact of water use on electricity use, in terms of timing and quantity, will vary by water district, depending on such factors as climate, types of end uses, surface water or groundwater use, and local storage capacity.

Review of water conservation

Water agencies currently use a variety of price-based and non-price-based methods to encourage residential water conservation. In general, increasing price is a more cost-effective means of reducing water demand compared to non-price conservation programs. However, price increases often meet with significant public resistance, and non-price conservation methods are more commonly used by water utilities throughout the country. Non-price conservation programs include restrictions on quantities of water per customer, bans on certain types of water use like car washing, and water efficiency incentives (Olmstead and Stavins 2007).

Rebates encourage the adoption of high efficiency equipment

Indoor water efficiency improvements, such as increasing the stock of high efficiency toilets, showerheads, and faucet aerators, will reduce residential water demand and the volume of wastewater that must be treated. Table 1-1 presents typical rated water use of low and high efficiency water-using equipment.

Table 1-1 Rated water use of low and high efficiency equipment

Equipment Type	Low Efficiency	High Efficiency
Toilet	3.5 gallons per flush	< 1.28 gallons per flush
Faucet aerator	2.2 gallons per minute	< 1.5 gallons per minute
Showerhead	2.5 – 5.5 gallons per minute	< 1.5 gallons per minute

source: (Sonoma County Water Agency 2009)

On average, high efficiency toilets are rated to use only 37% as much water as low efficiency toilets use, and high efficiency faucets and showerheads are rated to use 68% and 27-60% as much water respectively as their low efficiency counterparts (Sonoma County Water Agency 2009). However, in practice, changes in end-user patterns of water use can reduce the savings achieved through retrofits of water-using equipment. For comparison, a study that measured pre- and post-retrofit indoor water use found that after the installation of efficient equipment households used 62% as much water for clothes washing, 42% as much for flushing toilets, 96% as much for showers, and 87% as much for faucets as they did before (DeOreo, Dietemann et al. 2001).

Use restrictions can effectively reduce outdoor water use in the short term

Empirical analysis has shown that use restrictions have significantly reduced water demand in the San Francisco Bay Area (Corral, Fisher et al. 1999). Restrictions on the irrigation of turf grass and car washing are the most common forms of this conservation method. Alternatively, outdoor water use may only be allowed on certain days of the week; however, this may simply encourage people to use excess water on the approved days to make up for the days in between when they cannot water their yards. Use restrictions are more appropriate for emergency situations than long-term conservation strategies.

Limiting turf area, switching to native or climate-appropriate plants, grouping plants by their need for water, and limiting irrigation to the minimum amount necessary can significantly reduce outdoor water use compared to current average landscape irrigation demand. A survey of water conservation studies suggests that switching to efficient landscaping and irrigation can reduce outdoor water use by 10-43% (Barta 2004).

Information programs improve customers' understanding of the value of water

Empirical analysis has shown that information programs have substantially reduced residential water demand (Corral, Fisher et al. 1999). Other studies have also highlighted the conservation effectiveness of making water use and per-unit water cost readily apparent on residential water bills (Olmstead and Stavins 2007). A survey of non-price conservation programs suggests that public education alone can reduce water consumption by approximately 5%, primarily through outdoor water conservation (Barta 2004).

Education and outreach include advertisement, seminars and lectures, training for landscapers and contractors, and making water use and per-unit water cost readily apparent on residential water bills. These programs aim to change the water use behavior of end users, which is inherently difficult to do. Education and outreach can effectively reduce demand during a temporary shortage, but often have a more modest impact on water demand in the long run.

Water demand and conservation impacts on peak electricity

Studies of energy use for water supply in California typically focus on total energy use or embedded energy per unit of water in various parts of the water supply system. Water conservation impacts on energy, if discussed, are also generally discussed in terms of total energy use avoided. We briefly summarize two recent reports that focus on the relationship between water demand and peak electricity use.

Water supply impact on peak-day electricity demand

A study published in 2007 sought to determine the peak day electricity demand for California investor-owned utilities related to water demand (House 2007). Using peak day electricity demand data, hourly electricity demand profiles for agricultural, commercial, and residential users were constructed. Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric service areas are included in the study. In all three service areas, electrical demand was found to follow an hourly profile with bimodal peaks in the morning and evening similar to the hourly pattern of urban water use.

It is estimated that the electricity demand for water supply in California is greater than 2,000 MW on days of peak electrical demand, 40% of which is attributable to water agency electricity. Approximately 500 MW of water agency electrical demand is attributable to providing residential water service.

Conservation impact on peak electricity use

The second study of note investigates the potential for shifting water demand out of the peak electric period of noon to 6 PM on weekdays during the summer (House 2011). This case study focuses on hot, dry, groundwater-supplied Coachella Valley Water District (CVWD). It demonstrates that in a water system whose electric demands follow water delivery requirements (such as CVWD which relies upon groundwater pumping) a reduction in on-peak water deliveries will result in a reduction in on-peak electrical demands.

Automatic meter reading (time-of-use) water meters were installed for 148 participants (102 residential, 22 landscape irrigation, 24 commercial); half of the participants of each type were educated on methods of conserving water and shifting water use out of the peak period, as well as receiving a $25 incentive to attempt to conserve. Water use data was collected from each participant at fifteen minute intervals during a pre-study period in May, the study period of June – July, and a post-study period in October. Major findings include: substantial reduction in peak period (50%) and total (17%) water use for residential customers with time-of-use meters; time-of-use water monitoring is useful for leak detection, which accounts for about 5% of total water use; the post-study-period data collection suggests that the intervention group continued to use less water after the program ended, though the effect diminished.

2. Understanding the Peak Electricity Use of Individual Water Districts

Peak energy use to meet residential water demand and the water conservation impact on energy use will differ across water districts, depending on climate, water end uses, water sources, and the size and configuration of the water system.

Water district differences

The split of residential, commercial, industrial, and agricultural end uses will have a substantial impact on potential water and energy savings by determining the appropriate conservation measures. Numerous previous studies review conservation measures for specific end uses and evaluate their effectiveness, so we do not focus on this determinant of conservation-related energy savings (Mayer, DeOreo et al. 2000; Mayer, DeOreo et al. 2003; Barta 2004; Mayer, DeOreo et al. 2004; Olmstead and Stavins 2007). Throughout the rest of this report, we focus on either total water demand or residential water demand, applying insights from previous work. Climate strongly affects the per capita or per household volume of water use and the summer – winter water use differential. For example, in Fresno, single family residential demand ranges between 241 – 298 gpcd; Sacramento averages 282 gpcd; San Francisco averages 62 gpcd (U.S. Environmental Protection Agency 2004; U.S. Geological Survey 2004; City of Fresno 2008)

Here we concentrate on two determinants of the water conservation impact on energy use that have been somewhat overlooked in the past: water source and storage capacity. California water districts differ widely across these variables. There are districts that rely virtually entirely on surface water, but also districts that rely entirely on groundwater. There are districts with no above-ground local storage (in the form of reservoirs or tanks), but also districts with several days' supply of local storage. Water supply source and local storage are related issues, as water districts often have local storage for surface water and are less likely to have local storage if they rely primarily on groundwater.

Relationship between storage and water district peak electricity use

Water districts with substantial local storage are to a large degree insulated from daily patterns of residential water demand, allowing these districts to manage and plan their water supply related electricity use.

Storage and timing of electricity use

Assuming water districts are on time-of-use electric rates and seek to minimize electricity costs when possible, we hypothesize that water districts with substantial local storage will use little on peak electricity while those with little local storage will use more on peak electricity. With no local storage, a water district must pump and treat water when the water is demanded by end users; to the degree that the water end use profile includes use within the peak electricity time period, districts without local storage will likely need to use on peak electricity to meet water demand.

This highlights the added benefit of local storage (additional to the obvious primary benefit of secure local water supply): reducing peak electricity use and associated electricity costs. The availability of local storage is a metric that could be used to target conservation measures to specific water districts or regions with substantial current peak electricity use for water supply. It also highlights the importance of having water districts on time-of-use electric rates to provide the appropriate incentives for timing electricity use.

There are several trade-offs to consider regarding local storage. While substantial local storage can reduce or eliminate the need to use peak electricity for water supply, the cost of peak electricity should be compared to the cost of building additional local storage. Also, the greater the amount of local storage compared to average water demand, the longer water will be held on average, leading to the potential for water quality issues.

Evaluation of energy-water load profiles

Using data collected for a California Public Utilities Commission study, we demonstrate a relationship between a water district's volume of local storage and the use of electricity for water supply activities during the peak electricity period (GEI Consultants and Navigant Consulting 2010). This database includes hourly electricity use by "functional component" of the water system (such as raw water supply, booster pump, or wastewater treatment); critical-peak, partial-peak, and off-peak hours for each major electricity provider; district daily water flow deliveries. Supplementary information for this study includes the total volume of local storage of treated water. Local storage volume was estimated from water district reports when not available from this database.

Based on hourly electricity use profiles that can be generated from the database, we calculate the amount and proportion of critical-peak, critical- plus partial-peak, and off-peak electricity use for water supply for average summer use. From summer daily average water flow and total volume of treated water storage we calculate the ratio of local storage to daily delivery (Table 2-1). We find variation across water districts in terms of temporal pattern of electricity use for water supply and a negative relationship between volume of storage and proportion of critical- or partial-peak electricity use (Figure 2-1).

Table 2-1 Local Storage to Daily Demand Ratio and Peak Electricity Use across Districts

	Storage / Avg Demand	On-peak % of total	On- and partial-peak % of total
East Bay MUD	3.56	5%	33%
San Jose WC	1.35	13%	42%
Contra Costa WD	1.18	19%	50%
Suburban Water Systems	0.53	21%	57%
Coachella Valley WD	0.10	26%	64%

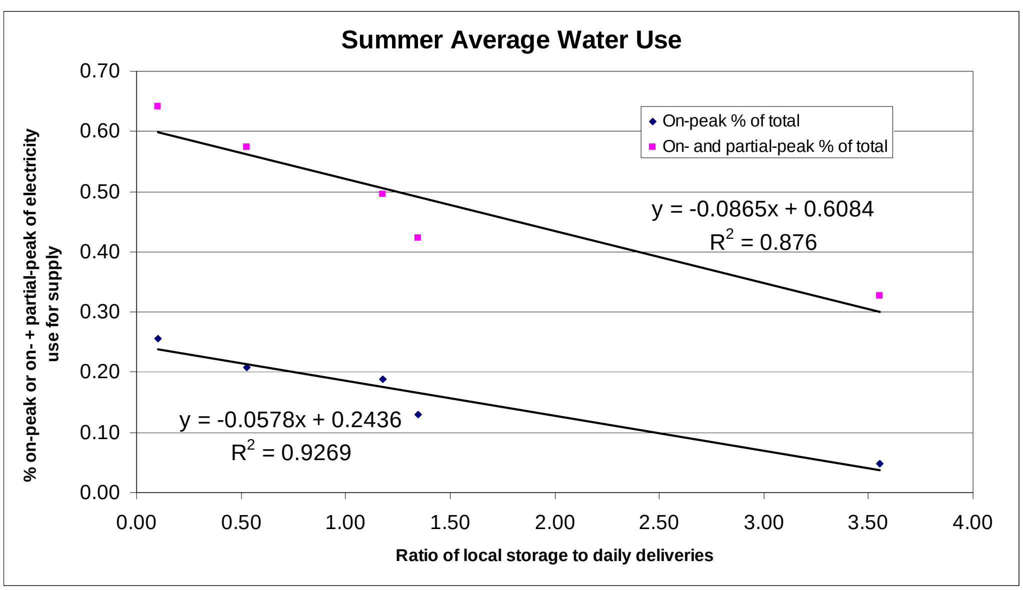
We then estimate the relationships the relationships between the percent of peak electricity used and the availability of local storage using the following equations:

$$(1) \quad \left(\frac{\text{Critical-peak Electricity}}{\text{Electricity}}\right) = \alpha + \beta\left(\frac{\text{Local Storage}}{\text{Daily Delivery}}\right)$$

$$(2) \quad \left(\frac{\text{Critical-peak} + \text{Partial-peak Electricity}}{\text{Electricity}}\right) = \gamma + \delta\left(\frac{\text{Local Storage}}{\text{Daily Delivery}}\right)$$

Based on analysis of this database, the ratio of local storage volume to average summer daily deliveries appears to be a strong indicator of on-peak and partial-peak electricity use for water supply pumping and distribution. The ratio of local storage volume to daily delivery alone is a strong predictor of the on-peak percent of a water district's electricity use for supply activities.

Figure 2-1 Relationship between peak electricity use and local storage capacity



The ability to shift supply-related electricity use from the peak electricity time period is also apparent comparing the daily profiles of electricity use by a district with substantial local storage (i.e. East Bay Municipal Utility District) to districts with little local storage (Suburban Water Systems and Coachella Valley Water District). These districts must pay critical-peak electricity rates from noon to 6 PM during the summer, but each reacts to this in a different way (Figure 2-2 to Figure 2-4).

Figure 2-2 East Bay Municipal Utility District Electricity Profile

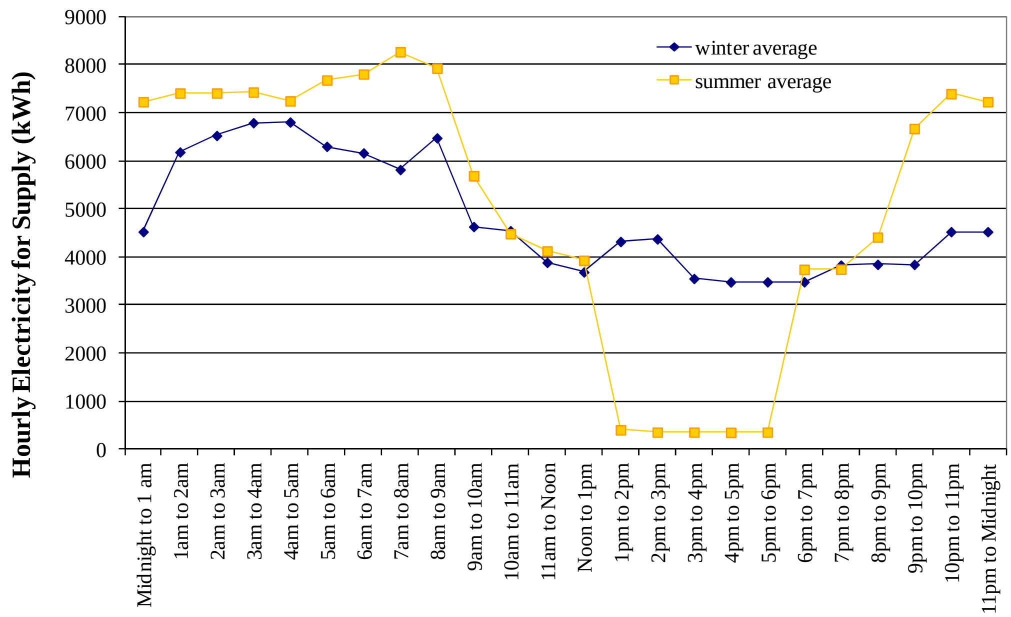


Figure 2-3 Suburban Water Systems Electricity Profile

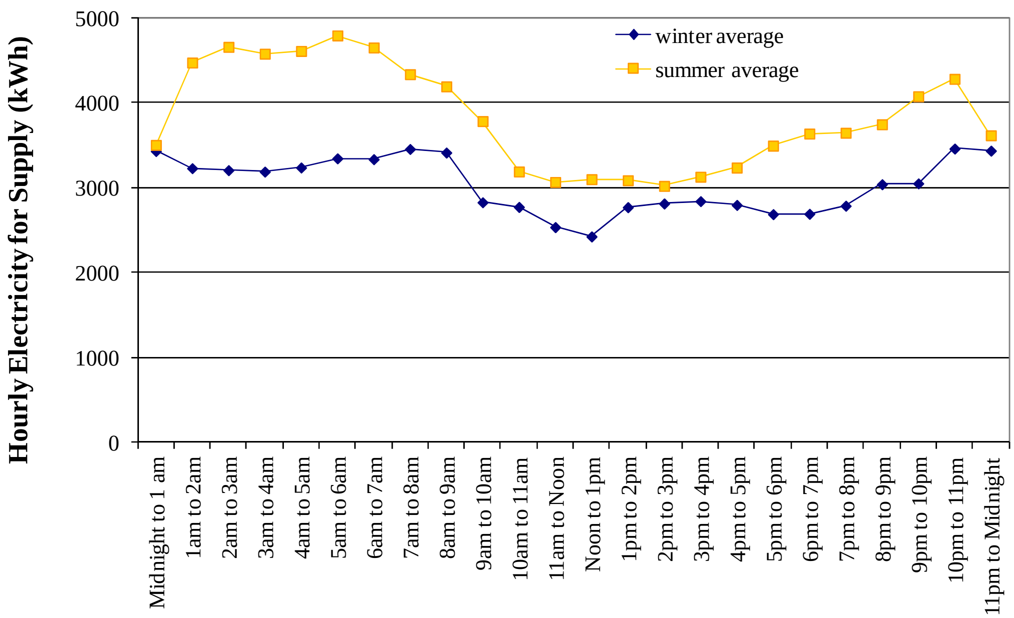
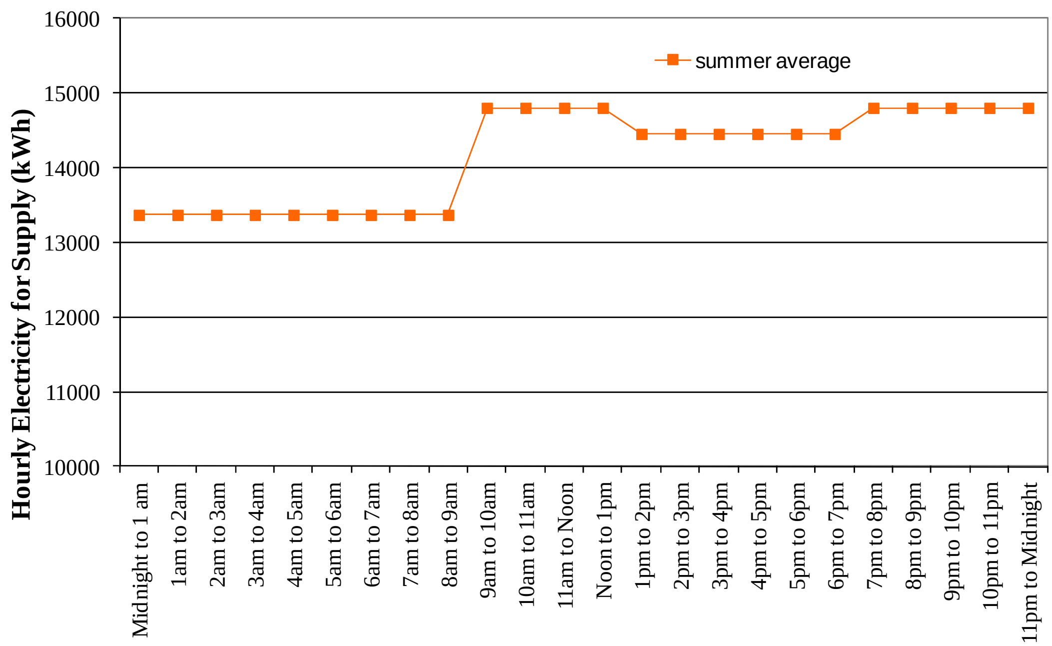


Figure 2-4 Coachella Valley Water District Electricity Profile



East Bay Municipal Utility District reacts to this by pumping to local storage during the off peak hours of the early morning; it then delivers water primarily from local storage via gravity throughout the partial- and critical-peak periods, using almost no critical-peak electricity. Suburban Water System has a limited amount of local storage available; it appears to pump to storage throughout the non-peak hours, but still must do a significant amount of pumping during the peak hours. Given its very minimal amount of local storage, Coachella Valley Water District is not able to significantly shift its electricity use out of the peak period

We recognize that the relationship demonstrated in this analysis represents only a small number of water districts, and that peak electricity use is likely influenced by factors other than local storage, such as climate, elevation, and the types of businesses served by the water district. This exercise is primarily intended to support the existence of a correlation between district peak electricity use and relative volume of local supply, rather than to estimate the magnitude of the effect of local storage on peak electricity use.

To better understand the relationship between storage and peak electricity use, we need to obtain hourly water delivery profiles as well as hourly electricity profiles. We demonstrate potential uses of water and electricity profiles in the case studies in Section 3 and Section 4.

3. Case Study 1: East Bay Municipal Utility District

Summary

The East Bay Municipal Utility District (EBMUD) serves as an example of a water district with a primarily surface water supply source and extensive local water storage. EBMUD water system operation data over the course of several years reveal connections between water demand and district electricity use.

This case study focuses on residential water demand and water supply-related electricity use in several EBMUD pressure zones. The EBMUD water system is highly complex; the service area is divided into many pressure zones, each pressure zone with a combination of local storage reservoirs and pumping stations. A pressure zone can have any of the following combinations of storage and pumping: one pumping station and one reservoir, multiple pumping stations and multiple reservoirs, multiple pumping stations and one reservoir, or one pumping station and multiple reservoirs. We focus on residential pressure zones with relatively simple systems in order to accurately align water deliveries and electricity use for pumping.

The EBMUD service area is divided into approximately 120 pressure zones, each pressure zone with a combination of local storage reservoirs and pumping stations. For several pressure zones, we received the following data from EBMUD's supervisory control and data acquisition (SCADA) system, for approximately the last 10 years:

- Average hourly reservoir level (feet)
- Average hourly flow rate of water pumped into the pressure zone (MGD)
- Average hourly electric demand for pumping (kW)
- Reservoir elevations (feet) and volumes (million gallons)
- Pressure zone schematics, describing configuration of pumping stations and reservoirs

To evaluate the relationships between water demand and electricity use in each of these EBMUD pressure zones, we construct hourly profiles of these variables from the data described above. All EBMUD pressure zones have a substantial amount of local storage compared to average water demand, so we expect minimal use of peak electricity for water pumping and strong reliance on stored water during the peak electric period.

To investigate the "value" of storage, we compare actual electric demand and electricity cost by time period to the theoretical scenario in which the electric demand profile perfectly follows the water demand profile, as would be expected in a situation with no local storage. The cost difference between these scenarios provides an estimate of electricity cost savings attributable to water operation practices utilizing storage. We average cost savings of approximately 10 - 20% attributable to use of local storage to shift the timing of electric demand.

Introduction

The East Bay Municipal Utility District (EBMUD) serves as an example of a water district with a primarily surface water supply source and extensive local water storage. EBMUD water system operation data over the course of several years reveal connections between water demand, district electricity use, and temperature.

The scope of this case study

This case study focuses on residential water demand and water supply-related electricity use in several EBMUD pressure zones. EBMUD serves an area in Alameda and Contra Costa Counties, encompassing a population of approximately 1.3 million people (East Bay Municipal Utility District 2011). The EBMUD water system is highly complex. The service area is divided into many pressure zones (each serving a band of constant elevation), each pressure zone with a combination of local storage reservoirs and pumping stations. A pressure zone can have any of the following combinations of storage and pumping: one pumping station and one reservoir, multiple pumping stations and multiple reservoirs, multiple pumping stations and one reservoir, or one pumping station and multiple reservoirs. Pressure zones are also linked together, such that water is pumped or gravity fed between zones. We focus on residential pressure zones with relatively simple systems in order to accurately align water deliveries and electricity use for pumping.

In this case study, "electricity" refers only to the electricity use associated with water supply and "electricity savings" refers only to reductions in electricity use for water supply. Residential end use water conservation is also associated with reductions in use of electricity for heating, cooling, and in-home treatment of water. This type of electricity savings has been extensively studied and is documented in numerous other publications.

This case study focuses on the residential sector for several reasons. First, water use in the residential sector is fairly homogenous across customers (compared to industry- and business-specific water use patterns in commercial and industrial applications), allowing for fairly accurate analysis of aggregated data. Second, several residential pressure zones have relatively simple systems, allowing us to accurately model water and electricity use profiles. Also, the majority of water use in EBMUD is by residential customers, so electricity use associated with residential use represents a substantial portion of EBMUD electricity for water supply.

Electricity and water use profiles

We follow the previous works described in Section 2 in constructing time profiles of residential water demand and associated water district electricity use (Aquacraft Inc. 2009; GEI Consultants and Navigant Consulting 2010; House 2011). We define an electricity profile as the hourly electricity used by EBMUD (in kWh) required to provide residential water service. We define a water use profile as the hourly residential water deliveries of EBMUD (expressed either in million gallons or acre-feet).

Background: water supply and demand in the East Bay Municipal Utility District

The EBMUD service area is divided into approximately 120 pressure zones (each serving a band of 100 feet of elevation), each pressure zone with a combination of local storage reservoirs and pumping stations. A pressure zone can have any of the following combinations of storage and pumping: one pumping station and one reservoir, multiple pumping stations and multiple reservoirs, multiple pumping stations and one reservoir, or one pumping station and multiple reservoirs. Pressure zones are also linked together, such that water is pumped or gravity fed between zones. In total, EBMUD's water distribution network includes approximately 140 pumping plants and 170 treated water storage reservoirs, with a total capacity of 830 million gallons (GEI Consultants and Navigant Consulting 2010).

Characteristics of the EBMUD's water supply

EBMUD's primary source of water is the Mokelumne River, though it also depends on local runoff from East Bay area watersheds (East Bay Municipal Utility District 2011). From the Mokelumne River, the Mokelumne Aqueducts conveys water to Pardee Reservoir, from which it is then conveyed to local storage and treatment facilities. There are six major water treatment plants: Walnut Creek, Lafayette, Orinda, Upper San Leandro, San Pablo, and Sobrante. Water not immediately sent to a water treatment plant is stored in local reservoirs: Briones, Chabot, Lafayette, San Pablo, and Upper San Leandro. In a normal water year, local runoff provides approximately 15 to 25 MGD; EBMUD diverts up to 325 MGD from the Mokelumne River, subject to water availability. Though it does not generally use groundwater, EBMUD is engaged in the process of banking excess wet-year surface water in the Bayside Groundwater Facility for subsequent dry-year extraction; this could potentially yield annual production of 1 MGD of groundwater. EBMUD may expand this groundwater project in the future.

Characteristics of the EBMUD's water demand

The majority of water demand in EBMUD is due to residential water users (46% singly family residential and an additional 17% multifamily residential); industrial and commercial are the next largest water users, at 17% and 9% of demand, respectively (East Bay Municipal Utility District 2011). In recent years, total average daily water demand has been approximately 210 MGD, with a decrease to approximately 180 MGD in 2010 due to water restrictions imposed for drought management. Water demand varies substantially by season, with single-family residential users consuming nearly twice as much water in the summer as in the winter due to landscape irrigation.

Of total annual residential water use, outdoor uses represent approximately 32%, while indoor uses represent the remaining 68% (East Bay Municipal Utility District 2011). Indoor water use can be further disaggregated as follows: 20% toilets, 19% clothes washers, 19% showers, 19% faucets, 14% leaks, 5% baths, 1% dishwashers, 3% other uses.

EBMUD electric rate schedule

Most EBMUD accounts are on the PG&E A-6 electric rate schedule for Small General Time-of-Use Service, which applies to commercial customers with a maximum demand of 200 kW or greater for three consecutive months with an interval data meter (PG&E 2012). The peak, partial peak, and off-peak time periods of this rate schedule are defined as follows:

SUMMER (Service from May 1 through October 31):

- Peak (0.43995 $/kWh): 12:00 noon to 6:00 p.m. Monday through Friday (except holidays)
- Partial-peak (0.22498 $/kWh): 8:30 a.m. to 12:00 noon Monday through Friday (except holidays) and 6:00 p.m. to 9:30 p.m.
- Off-peak (0.13840 $/kWh): 9:30 p.m. to 8:30 a.m. Monday through Friday, all day Saturday, Sunday, and holidays

WINTER (Service from November 1 through April 30):

- Partial-Peak (0.15247 $/kWh): 8:30 a.m. to 9:30 p.m. Monday through Friday (except holidays)
- Off-Peak (0.12840 $/kWh): 9:30 p.m. to 8:30 a.m. Monday through Friday (except holidays), all day Saturday, Sunday, and holidays

The following holidays are considered off-peak: New Year's Day, President's Day, Memorial Day, Independence Day, Labor Day, Veterans Day, Thanksgiving Day, and Christmas Day.

Water and electricity relationship in select EBMUD pressure zones

Data and analysis methodology

The EBMUD service area is divided into approximately 120 pressure zones, each pressure zone with a combination of local storage reservoirs and pumping stations. For several pressure zones, we received the following data from EBMUD’s supervisory control and data acquisition

(SCADA) system, for approximately the last 10 years (East Bay Municipal Utility District 2000 - 2011):

- Average hourly reservoir level (feet)
- Average hourly flow rate of water pumped into the pressure zone (MGD)
- Average hourly electric demand for pumping (kW)
- Reservoir elevations (feet) and volumes (million gallons)
- Pressure zone schematics, describing configuration of pumping stations and reservoirs

To evaluate the relationships between water demand and electricity use in each of these EBMUD pressure zones, we construct hourly profiles of these variables from the data described above. All EBMUD pressure zones have a substantial amount of local storage compared to average water demand, so we expect minimal use of peak electricity for water pumping and strong reliance on stored water during the peak electric period. The following intermediate calculations were required to construct the hourly profiles.[2]

Reservoir gallons per foot elevation:

$$\frac{Operating\ volume}{(Operating\ elevation - Bottom\ elevation)} = Reservoir\ gal/ft$$

Hourly water demand:

$$Water\ demand\_t =$$
$$(Pumping\ plant\_t)x((41{,}666.7\ gal)\ /\ mgd) + (\ 〚Reservoir\ level〛\ \_(t-1) -$$
$$(Reservoir\ level\_t\ )x(Reservoir\ \ gal\ /\ ft)$$

Hourly electricity use:

$$Electricity\ use = (Pumping\ plant\ elec.demand_t)x(1\ hour)$$

Round Hill Pressure Zone

Round Hill pressure zone is located east of the Berkeley – Oakland hills, serving residential users on approximately 510 acres at about 800 feet of elevation. There is one pumping plant feeding into the zone and one treated water storage reservoir with a maximum capacity of 0.6 million gallons.

Hourly summer electric demand profiles over the course of 8 recent years establish the timing of electricity use in Round Hill pressure zone (Figure 3-1). Though there is substantial variation between the years, electric demand is generally greatest during the off-peak electric period and reaches a minimum during the peak electric period of noon to 6PM. Quantity and cost of electricity for pumping in recent years is summarized by electric time period in

[2] Due to metering and other data errors, approximately 7% of flow data points would suggest negative flow. These data points are excluded from the analysis.

Table 3-1, confirming that the majority of electric demand occurs during off-peak and partial-peak periods.

Figure 3-1. Round Hill Pressure Zone Summer Electricity Profiles

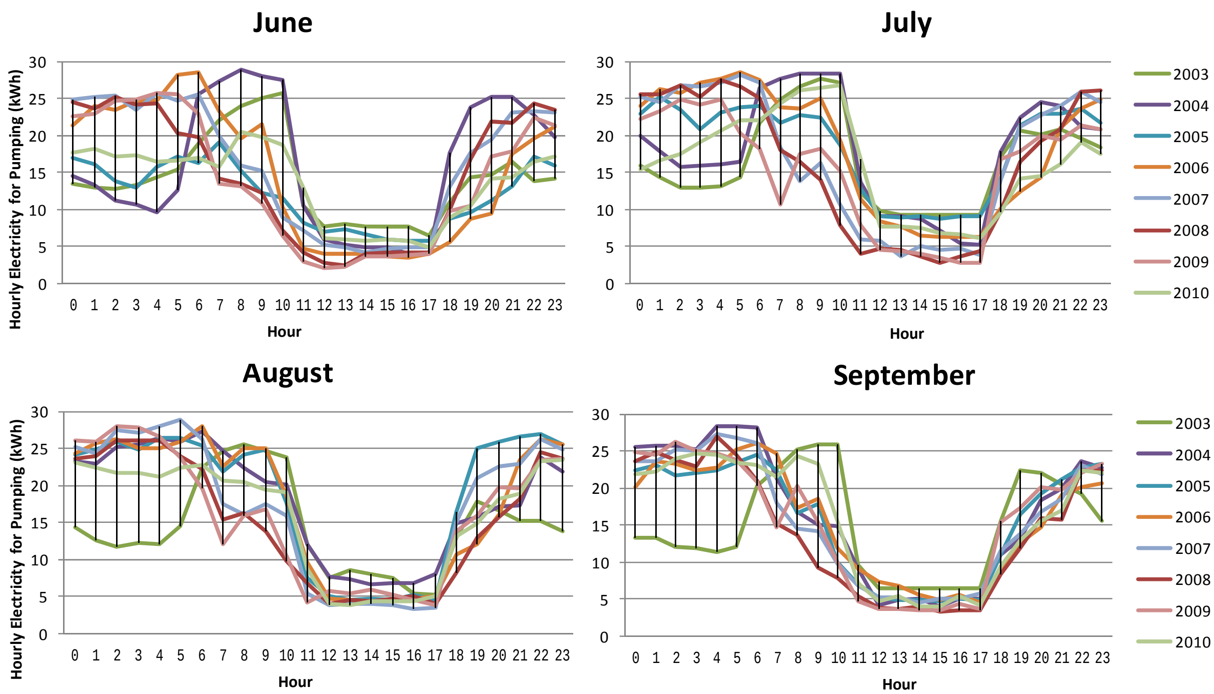


Table 3-1. Round Hill June – September Electricity Use Summary (2007-2009)

Type of Electricity	2007		2008		2009		Avg % of Total
	kWh	$	kWh	$	kWh	$	
Off-peak	32,988	$4,565	30,995	$4,290	29,913	$4,140	68%
Part-peak	12,323	$2,772	10,057	$2,263	11,755	$2,645	25%
On-peak	3,380	$1,487	2,886	$1,270	2,896	$1,274	7%
Total	48,690	$8,825	43,939	$7,822	44,564	$8,059	100%

The findings presented in
Table 3-1 and Figure 3-1 alone are not sufficient to confirm electricity cost savings due to the use of local storage. For this, we must compare the timing of electric demand for pumping to the timing of water demand, using the hourly water profile for Round Hill pressure zone (
Figure 3-2). Note that water demand displays a somewhat bimodal pattern, with a strong peak in the morning and secondary peak in the evening.

Table 3-2 breaks down the timing of water demand by the electric time period. While only 7% of electric demand associated with water supply occurs during the electric peak period, 17% of water demand occurs during this time, demonstrating that local supply has allowed the shifting of electricity use out of the peak period.

Figure 3-2. Round Hill Pressure Zone Summer Water Profiles

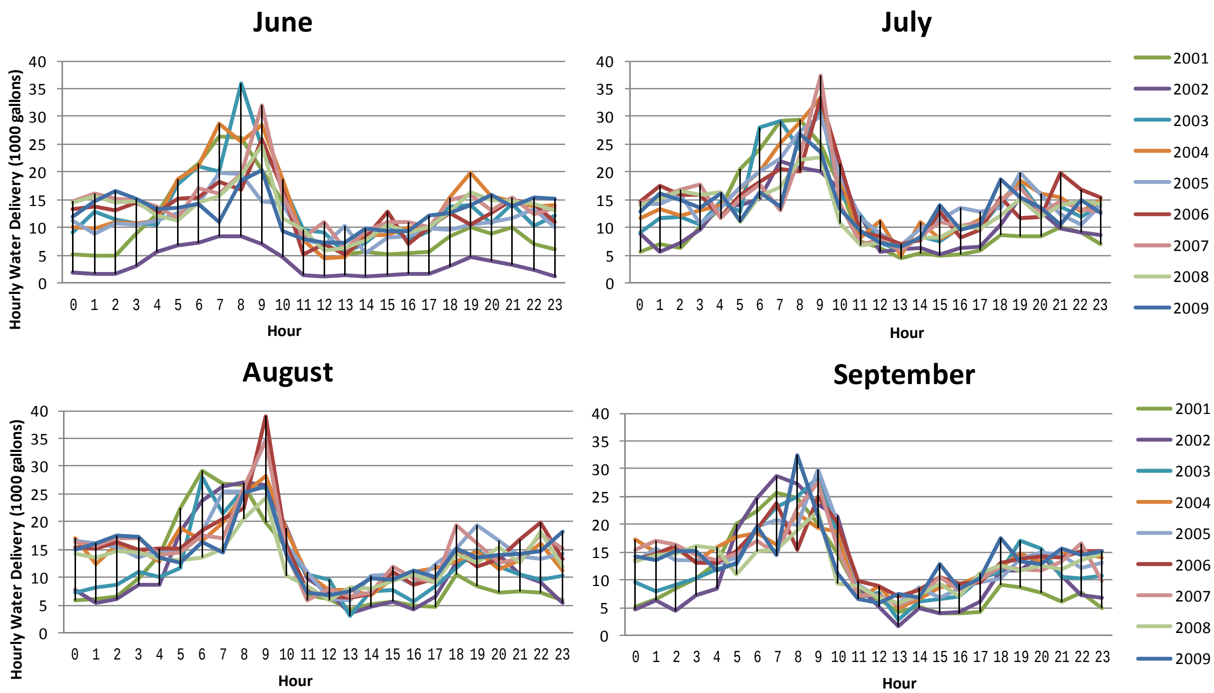


Table 3-2. Round Hill June – September Water Demand Summary (2007-2009)

Time Period	2007 (1000 gallons)	2008 (1000 gallons)	2009 (1000 gallons)	Avg % of total
Off-peak	16,550	16,303	16,011	46%
Part-peak	14,398	12,202	13,131	37%
On-peak	6,003	5,673	6,191	17%
Total	36,950	34,178	35,333	100%

To investigate the “value” of storage, we compare actual electric demand and electricity cost by time period to the theoretical scenario in which the electric demand profile perfectly follows the water demand profile, as would be expected in a situation with no local storage (Table 3-3). The cost difference between these scenarios provides an estimate of electricity cost savings attributable to water operation practices utilizing storage. The use of local storage allows EBMUD to shift 5,542 kWh out of the partial-peak time period and 4,720 kWh out of the peak time period each summer on average, reducing strain on the electric grid and reducing electricity costs. This savings of peak electricity equates to and average savings of $1903 each summer, or a 20% electricity cost reduction as compared to a scenario in which pumping occurs at the time of water demand.

Table 3-3. Round Hill Electricity Use Comparison

Time Period	Elec. avg % of total	Avg elec. cost ($)	Water avg % of total	Cost if elec. used at time of water use	Cost Savings
Off-peak	68%	$4,332	46%	$2,911	-$1,420*
Part-peak	25%	$2,560	37%	$3,807	**$1,247**
On-peak	7%	$1,344	17%	$3,420	**$2,077**
Total	100%	$8,235	100%	$10,138	**$1,903**

*Note that current operation practices increase the amount of off-peak electricity use, leading to a larger portion of cost incurred during the off-peak period. In total, this off-peak cost increase is outweighed by partial-peak and peak period savings.

Acorn Pressure Zone

Acorn pressure zone is located east of the Berkeley – Oakland hills, serving residential users on approximately 200 acres at about 1000 feet of elevation. There is one pumping plant feeding into the zone and one treated water storage reservoir with a maximum capacity of 1.2 million gallons.

Hourly summer electric demand profiles over the course of 9 recent years establish the timing of electricity use in Round Hill pressure zone (Figure 3-3). Quantity and cost of electricity for pumping in recent years is summarized by electric time period in Table 3-4.

Figure 3-3. Acorn Pressure Zone Summer Electricity Profiles

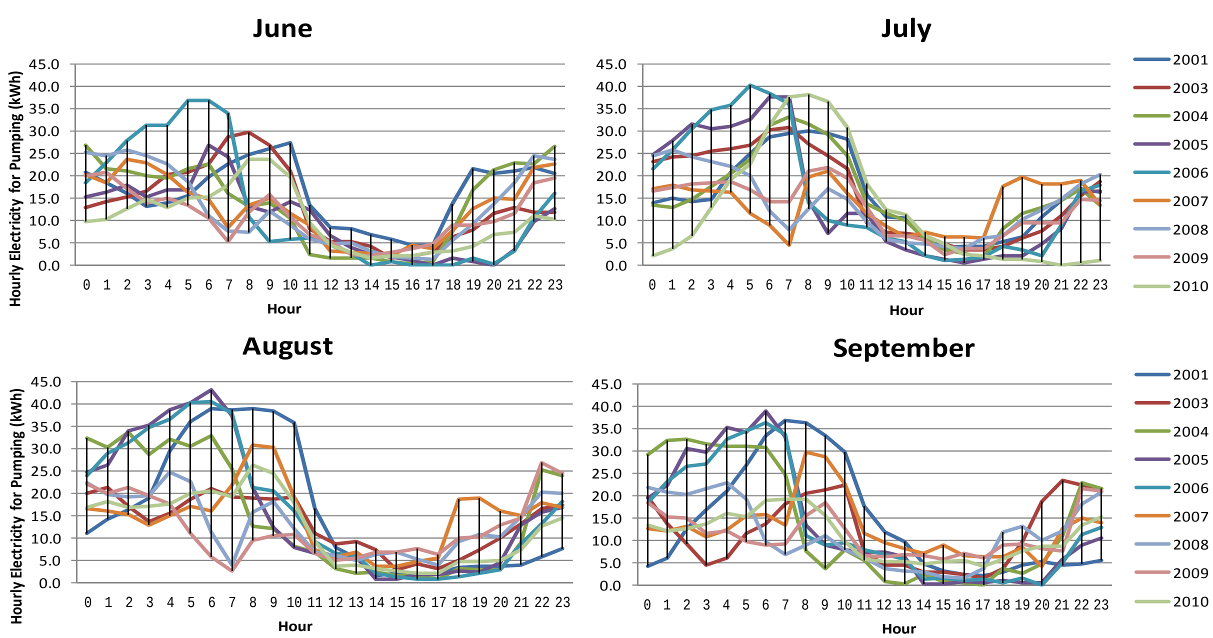


Table 3-4. Acorn Pressure Zone June – September Electricity Use Summary (2008-2010)

Type of Electricity	2008		2009		2010		Avg % of Total
	kWh	$	kWh	$	kWh	$	
Off-peak	25,335	$3,506	20,579	$2,848	18,719	$2,591	61%
Part-peak	9,109	$2,049	9,872	$2,221	11,660	$2,623	29%
On-peak	2,993	$1,317	3,887	$1,710	3,168	$1,394	10%
Total	37,436	$6,872	34,338	$6,779	33,547	$6,608	100%

We compare the timing of electric demand for pumping to the timing of water demand, using the hourly water profile for Acorn pressure zone (Figure 3-4). Table 3-5 breaks down the timing of water demand by the electric time period in recent years. While only 10% of electric demand associated with water supply occurs during the peak electric period, 16% of water demand occurs during this time, confirming that local supply has allowed the shifting of electricity use out of the peak period.

Figure 3-4. Acorn Pressure Zone Summer Water Profiles

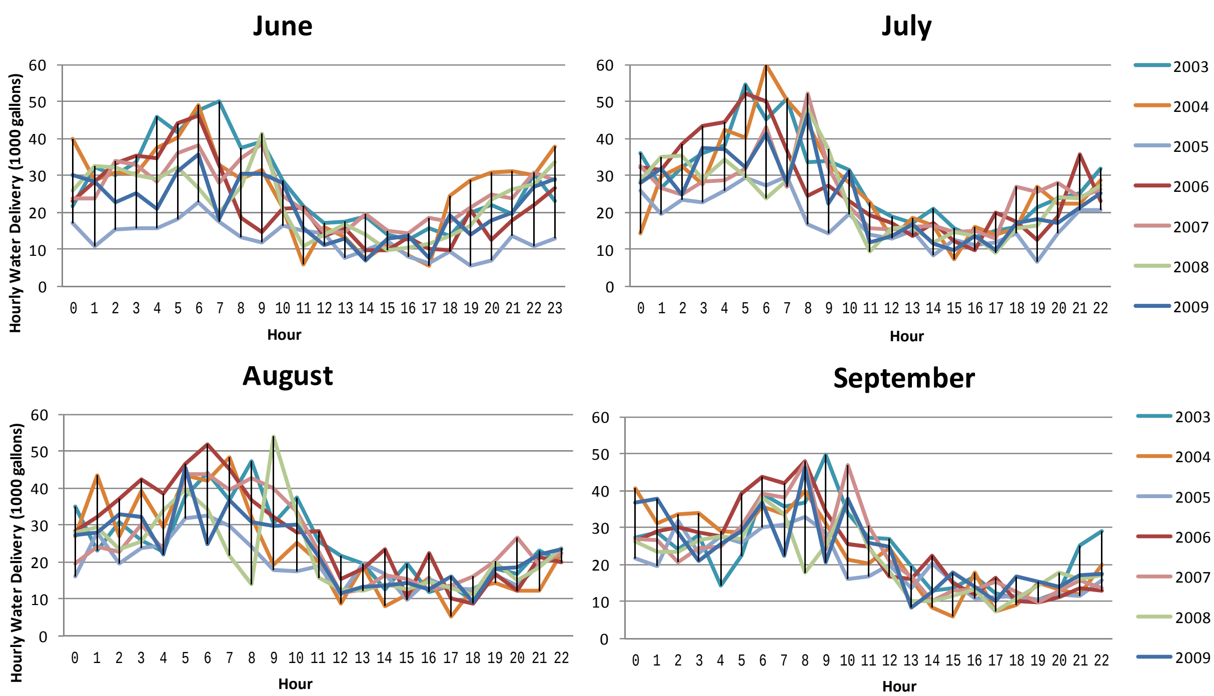


Table 3-5. Acorn June – September Water Demand Summary (2007-2009)

Time Period	2007 (1000 gallons)	2008 (1000 gallons)	2009 (1000 gallons)	Avg % of total
Off-peak	30,808	30,470	30,320	51%
Part-peak	22,864	18,617	19,029	34%
On-peak	10,284	9,162	8,976	16%
Total	63,956	58,248	58,326	100%

Again, we compare actual electric demand and electricity cost by time period to the theoretical scenario in which the electric demand profile perfectly follows the water demand profile, as would be expected in a situation with no local storage (Table 3-6). The use of local storage allows EBMUD to shift 1,553 kWh out of the partial-peak time period and 2,178 kWh out of the peak time period each summer on average, reducing strain on the electric grid and reducing electricity costs. This savings of peak electricity equates to and average savings of $791 each summer, or a 12% electricity cost reduction as compared to a scenario in which pumping occurs at the time of water demand.

Table 3-6. Acorn Electricity Use Comparison

Time Period	Elec. avg % of total	Avg elec. cost ($)	Water avg % of total	Cost if elec. used at time of water use	Cost Savings
Off-peak	61%	$2,982	51%	$2,465	-$516*
Part-peak	29%	$2,298	34%	$2,647	**$349**
On-peak	10%	$1,473	16%	$2,432	**$958**
Total	100%	$6,753	100%	$7,544	**$791**

*Note that current operation practices increase the amount of off-peak electricity use, leading to a larger portion of cost incurred during the off-peak period. In total, this off-peak cost increase is outweighed by partial-peak and peak period savings.

Berkeley View Pressure Zone

Berkeley View pressure zone is located west of the Berkeley – Oakland hills, serving residential users on approximately 360 acres at about 1100 feet of elevation. There is one pumping plant feeding into the zone and one treated water storage reservoir with a maximum capacity of 1.02 million gallons.

Hourly summer electric demand profiles over the course of 6 recent years establish the timing of electricity use in Berkeley View pressure zone (Figure 3-5). Quantity and cost of electricity for pumping in recent years is summarized by electric time period in Table 3-7.

Figure 3-5. Berkeley View Pressure Zone Summer Electricity Profiles

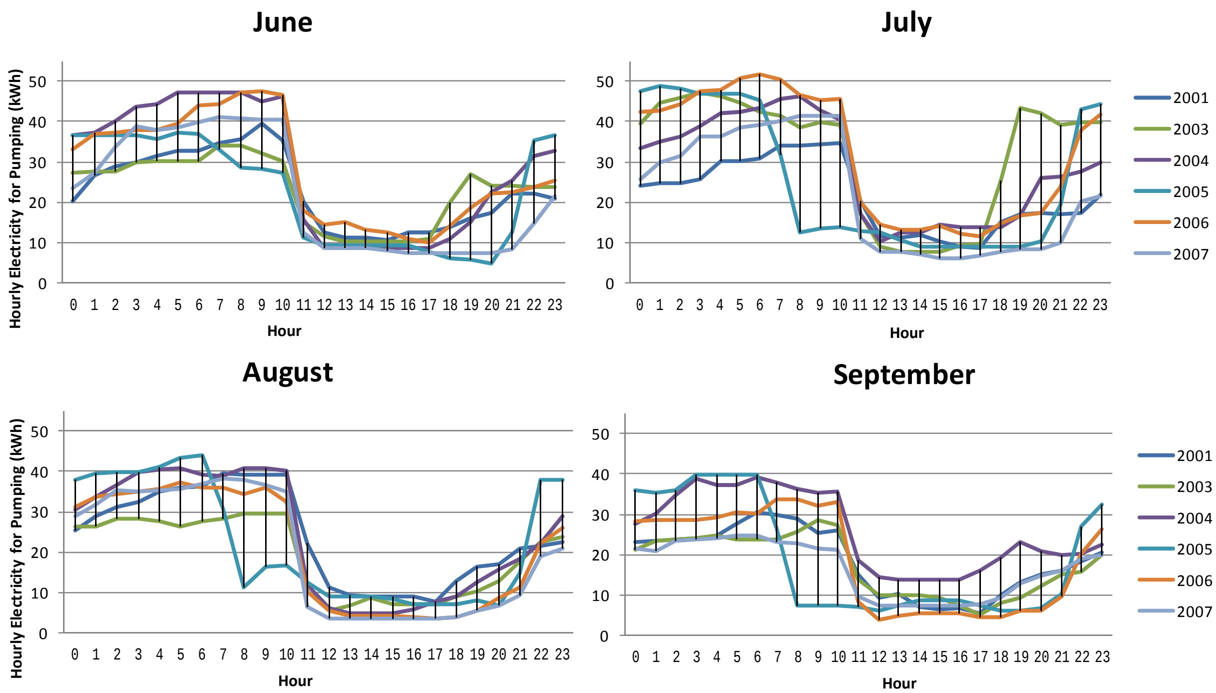


Table 3-7. Berkeley View Pressure Zone June – September Electricity Use Summary (2001, 2006-2007)

Type of Electricity	2001		2006		2007		Avg % of Total
	kWh	$	kWh	$	kWh	$	
Off-peak	35,831	$4,959	45,680	$6,322	37,313	$5,164	61%
Part-peak	20,441	$4,599	20,603	$4,635	17,103	$3,848	30%
On-peak	7,148	$3,145	6,406	$2,818	4,789	$2,107	9%
Total	63,420	$12,703	72,688	$13,776	59,204	$11,119	100%

Notes: In our data set for Berkeley View, there are many missing or suspect data points in the 2008-2010 data. We report approximate electricity use and electricity cost for the most recent years with full data (2006, 2007). Results are reported for 2001 because data for this year appears most reliable; we do not have historical electricity prices for EBMUD and estimate 2001 electricity cost as if the current rate schedule had been in effect.

Water data for Berkeley View contained more metering errors than for the other two pressure zones. Approximately 24% of potential data points had to be removed from the set because of null readings for water flow and/or reservoir level. The Berkeley View reservoir consists of two tanks. While our data includes readings for both tanks, one shows almost no change in water level throughout the analysis time period. Because of this poor data quality, we do not evaluate the water profile of Berkeley View. Instead, we estimate the peak electricity and electricity cost savings achieved if the Berkeley View water profile is similar to that of Acorn and Round Hill. As Berkeley View is located in a different part of the EBMUD service area, it is possible that its water profile in fact differs from those of Acorn and Round Hill, but given that Acorn and Round

Hill's profiles are very similar and all three pressure zones are residential, we believe this is provides a reasonable approximation.

We compare actual electric demand and electricity cost by time period to the theoretical scenario in which the electric demand profile perfectly follows the average water demand profile of Acorn and Round Hill storage (Table 3-8). We estimate that the use of local storage allows EBMUD to shift 3,615 kWh out of the partial-peak time period and 4,574 kWh out of the peak time period each summer on average, reducing strain on the electric grid and reducing electricity costs. This savings of peak electricity equates to and average savings of $1,692 each summer.

Table 3-8. Berkeley View Electricity Use Comparison

Time Period	Elec. avg % of total	Avg elec. cost ($)	Water avg % of total	Cost if elec. used at time of water use	Cost Savings
Off-peak	61%	$5,482	48%	$4,348	-$1,133*
Part-peak	30%	$4,361	35%	$5,174	**$813**
On-peak	9%	$2,690	16%	$4,703	**$2,012**
Total	100%	$12,532	100%	$14,225	**$1,692**

*Note that current operation practices increase the amount of off-peak electricity use, leading to a larger portion of cost incurred during the off-peak period. In total, this off-peak cost increase is outweighed by partial-peak and peak period savings.

4. Case Study 2: Achieved and Potential Peak Electricity Conservation in the City of Fresno

Summary

The City of Fresno will face several interconnected challenges over the next 10 to 15 years: growing demand for water, uncertain water supply, and increasing electricity costs. The growing demand for water will be fueled by a growing population, and will likely be exacerbated by increasing temperatures and altered precipitation due to climate change. Additional electricity will be required to pump and treat this additional water, as well as to pressurize the water distribution system. Electricity represents a substantial portion of the variable cost of water supply. During the period of peak electric demand (12 to 6 PM) electricity costs are up to twice as high as in other time periods, so emphasizing conservation that will reduce peak electricity use for water supply is a cost-effective strategy.

This case study focuses on residential conservation, specifically through the use of an automated meter reading (AMR) system, as a means to reduce future water demand and water supply-related electricity costs. AMR technology collects water consumption data at regular intervals and transfers it to the water district. We discuss short, medium, and long term strategies for enhancing the water, electricity, and peak electricity savings achieved through the AMR system that Fresno is currently installing for its residential customers. By early 2013, all residential customers will be billed monthly at a volumetric rate based on AMR data.

Experiences in electric utilities and other water districts have demonstrated that AMR can reduce resource use through customer information provision, and in the case of water districts, leak detection. We evaluate the following options for utilization of the AMR system:

- Implementing a leak detection program based on hourly AMR data
- Improving customer information provision through the billing system
- Establishing a pilot study of the impact of in-home displays on water use in Fresno
- Providing detailed customer information through web, in-home display, and mobile device, pending the outcome of the pilot study
- Implementing seasonal rates, so long as summer supply continues to be expensive and constrained
- Tracking key indicators to determine if time-of-use water rates are appropriate

Based on an evaluation of expected water conservation, city electricity cost savings associated with reduced water demand, up-front and operating costs, and likelihood of customer acceptance, these strategies are projected to cost-effectively narrow the gap between sustainable water supply and water demand in 2020 (Table 4-1).

In the long term (2020 and later), Fresno may want to consider using the AMR system to implement seasonal water rates to target summer demand or time-of-use water pricing to target the electric peak period, if leak detection and information strategies have not proved sufficient to bring demand in line with supply. Careful attention should be paid to customer price response to volumetric rates and to electricity price trends, per capita water use, and the amount of total demand supplied by groundwater in the intervening years to determine whether seasonal or time-of-use rates will in fact be appropriate and necessary.

Table 4-1 AMR strategy summary

Implementation time frame	Strategy	2020 water savings (AF/yr)	Electricity cost savings ($/yr)
Short term	Leak detection	2,090	$142,000
Medium term	Billing system information	1,250 to 6,220	$81,500 to $911,800
	Detailed information	10,580 to 23,400	$703,000 to $1,504,000

* compared to a potential supply deficit of 25,500 to 48,400 AF/yr in 2020, as described later in this case study

If sufficient summer water supply continues to be difficult to achieve, a seasonal water rate structure may be appropriate for Fresno. Under a seasonal rate structure, the volumetric rate charged for water consumption would be higher during the summer months than during the rest of the year. This creates an incentive to reduce summer water use and can help to offset higher water supply costs from using marginal water sources. Table 4-2 presents estimates of the summer price increase above baseline that may be needed to conserve additional water not addressed by the leak detection and information strategies.

Table 4-2 Seasonal pricing summary (2020)

Information-related conservation*	Supply deficit**	Additional conservation required (AF/yr)	Price increase above baseline (%)
High	Small	0	0
Low	Small	9,100	40%
High	Large	14,900	66%
Low	Large	37,800	167%

* as shown in Table I, there is a range of projected conservation impacts from leak detection and information-based programs. “High” means that this scenario assumes that a substantial amount of water is already conserved; “low means that little water has already been conserved.
** the exact amount of future supply deficit is uncertain and may be large or small (25,500 to 48,400 AF/yr)

If peak electricity costs continue to contribute strongly to the cost of water supply, time-of-use water rates may be appropriate for Fresno. Under time-of-use rates, the higher cost to the city of providing water during the 12 – 6PM time period can be reflected by a proportionally higher water price during that time period. As 2020 draws closer, changes in per capita water use, reliability of water supply, seasonal variation in demand, and peak electricity costs for water provision will show which, if either, of these price structures would be most appropriate for Fresno.

While maintaining a sufficient and sustainable water supply will take effort, with a combination of customer support, information programs, and appropriate pricing, Fresno will be able to ensure that water supply will meet demand. Throughout the process, Fresno must be mindful of the incentives created for its customers, aiming always to promote efficient use of water and discourage waste.

Introduction

The City of Fresno will face several interconnected challenges over the next 10 to 15 years: growing demand for water, uncertain water supply, and increasing electricity costs. The current installation of an automated meter reading (AMR) system for all residential customers presents a unique opportunity to improve water conservation activities and to ensure the sufficiency of future water supply.

The scope of this case study

This case study focuses on residential water and water supply-related electricity conservation strategies utilizing automated meter reading (AMR) to meet future water demand. Other types of conservation strategies or supply side strategies are not considered in detail here, though some of these strategies will likely be used in tandem with AMR to equate future water supply and demand in Fresno. While appliance and fixture rebates will continue to reduce water and related electricity use and should remain a part of Fresno's conservation policy, AMR presents a new and powerful tool to inform residential customers and encourage conservation. In other cities and water districts, substantial water conservation, waste reduction, and peak electricity savings have been achieved through full scale AMR installation and pilot programs.[3] Now that Fresno is in the process of installing an AMR system for all residential customers, what remains is to determine how to incorporate the data provided by AMR into Fresno's broader conservation policy.

In this case study, "electricity" refers only to the electricity use associated with water supply and "electricity savings" refers only to reductions in electricity use for water supply. Residential water conservation is also associated with reductions in use of electricity for heating, cooling, and in-home treatment of water. This type of electricity savings has been extensively studied and is documented in numerous other publications.

This case study focuses on the residential sector for several reasons. First, Fresno is in the process of installing an AMR system for all residential customers, to be completed by the end of 2012, making evaluation of implementation possibilities for this system timely. Second, water use in the residential sector is fairly homogenous across customers (compared to industry- and business-specific water use patterns in commercial and industrial applications), allowing for fairly accurate analysis of aggregated, city-wide data. Finally, residential use represents the majority of water use in Fresno, so even modest residential conservation can have a significant impact on total water demand.

[3] See, for example, Wallenstein, D. and A. Chastain-Howley (2008). "Pressure Zone Audits Pinpoint Water Loss." Opflow.

Uncertainty of future supply sufficiency

The Fresno Urban Water Management Plan projects future water supply and demand for the city through the year 2030 (City of Fresno 2008). While this document concludes that Fresno will have sufficient supply to meet demand through 2030, several assumptions made by the plan deserve closer evaluation. Included in the projections are two assumptions regarding decreases in per capita water use. If neither of these two assumptions is correct, rather than having sufficient supply to meet demand in 2020, Fresno may have a significant shortfall, which would necessitate either increased (and unsustainable) reliance on groundwater or the purchase of water from other water districts.

The Fresno UWMP assumes a 5% reduction in per capita water use beginning in 2010 and an additional 5% reduction in per capita water use beginning in 2020. No rationale is provided to explain the expectation of these changes in residential water use habits. The strategies described in this report should be viewed as possible ways to achieve this conservation.

The Fresno UWMP also assumes that beginning in 2013, volumetric pricing will induce an additional 2% per year reduction in per capita water use, up to a sustained total reduction of 10% after 5 years (2017 onwards). However, as the volumetric rate structure has been designed to be bill-neutral for most customers, there is reason to doubt that a price response of this magnitude will be achieved without future modification to the rate structure. A portion of the 10% reduction in per capita water use expected to be induced by volumetric rates may need to be achieved through other means. Table 4-3 compares the expected total water demand if the above mentioned conservation assumptions are or are not manifested in the future. Without conservation, Fresno is likely to experience a supply shortfall of 25,500 to 48,400 AF/yr by 2020.

Table 4-3 Projected Fresno water demand (2020)

Scenario	Total water demand (AF/yr)	Residential water demand (AF/yr)
10% per capita decrease + 10% price response	206,400	150,600
10% price response only	229,300	167,333
Current per capita use	254,778	185,926

Source: calculated based on (City of Fresno 2008)

The certainty of water supply projections should also be considered. There are two elements of supply to evaluate: total surface water availability and treatment plant capacity. The City of Fresno is expected to have access to up to 212,000 AF of surface water in future wet years, including water from the Kings River and the Central Valley Project. However, in dry years, Fresno is entitled to only 79,500 AF of surface water; this is far less than expected demand, and the volume of water needed to make up the difference cannot be sustainably provided by groundwater.

The second constraint on supply is the capacity of surface water treatment facilities. Fresno currently operates one surface water treatment plant with a rated capacity of 30 million gallons per day (MGD), though it only provides 20 MGD on average and a maximum of 27.5 MGD. Fresno plans to expand its surface water treatment capacity to 120 MGD by approximately 2020, but it is likely that, as with the current treatment facilities, the full rated capacity will not be achieved in operation. If future surface water treatment facilities are operated similarly to the current surface water treatment plant, Fresno will likely be able to supply 80 to 110 MGD of surface water on average (89,000 to 123,000 AF/yr). As total demand is currently approximately 171 MGD in the summer and may grow to 276 MGD in 2020, groundwater will remain an important component of summer water supply, without additional expansion of Fresno's surface water infrastructure.

Background: water supply and demand in the City of Fresno

Features of Fresno's location, water supply, and customers influence its water use patterns and its ability to promote conservation. Though it has the right to divert water from the Kings River, the majority of water supplied by Fresno is currently groundwater. Fresno water demand is primarily residential, with some commercial, but little industrial demand. Much of Fresno's water use is attributable to landscape irrigation and to the operation of water-using appliances and fixtures. The warm and dry weather that persists for the greater part of the year encourages extensive irrigation. Until early 2013, residential water use in Fresno will be unmetered, thus providing no price incentive for water use awareness or conservation among customers.

Characteristics of the City of Fresno's water supply

Groundwater currently makes up about 88% of the City of Fresno's water supply. Over 140 wells are managed with a supervisory control and data acquisition (SCADA) system, designed to maintain necessary pressure, minimize the use of inefficient pumps, and manage the drift of plumes of contaminated groundwater. The groundwater level in Fresno has declined an average of 1.5 feet per year since 1990, leading to a corresponding increase in electricity use for pumping (City of Fresno 2008).[4]

Over recent years, the City of Fresno has increased its reliance on gravity fed surface water. It has several potential sources of surface water, including an agreement with nearby Fresno Irrigation District. Up to 90,000 AF/yr are available from the Kings River, but the availability of this water will be substantially reduced in dry years. Approximately 28,000 AF/yr of surface water are treated at the Surface Water Treatment Facility, which is limited by a treatment capacity of about 30 MGD (City of Fresno 2008). Currently, most surface water is used for

[4] While well depths vary across the city, the water levels of most wells in Fresno are currently between 180 and 300 feet deep.

groundwater recharge or sold to other water districts, though there are plans to use more surface water directly for supply in the future.

One important implication of Fresno's reliance on groundwater is that electricity for water pumping is consumed only shortly before the water is delivered. In systems with substantial volumes of treated water storage, this link between the time of electricity use for pumping and the time of water consumption is less straightforward. In a water system like Fresno's, a reduction in water consumption during the peak electricity period will result in a reduction in peak electricity use. Currently, during the summer months, peak electricity makes up approximately 16% (30 MWh) of total electricity for water supply. The breakdown of peak to total water demand follows a similar pattern, with approximately 16%, 31 million gallons of total water demand occurring during the 12PM to 6PM time period.[5]

Characteristics of the City of Fresno's water demand

The City of Fresno serves a population of approximately 500,000[6], which is growing at a rate of about 1.9% annually (City of Fresno 2008). The City of Fresno produced a total of 157,600 AF of water in 2005, and demand is expected to grow to 255,000 AF/yr in 2020. If patterns of water use remain similar over the next 15 years, this suggests that 63 million gallons of water demand will fall during the 12PM to 6PM electric peak period each summer day in 2020. Water use in Fresno is primarily residential, with about 73% of water demand attributed to single and multi-family residences; commercial use and large landscape irrigation are the next largest contributors to water demand. Peak period residential demand includes both indoor and outdoor uses (Table 4-4)[7].

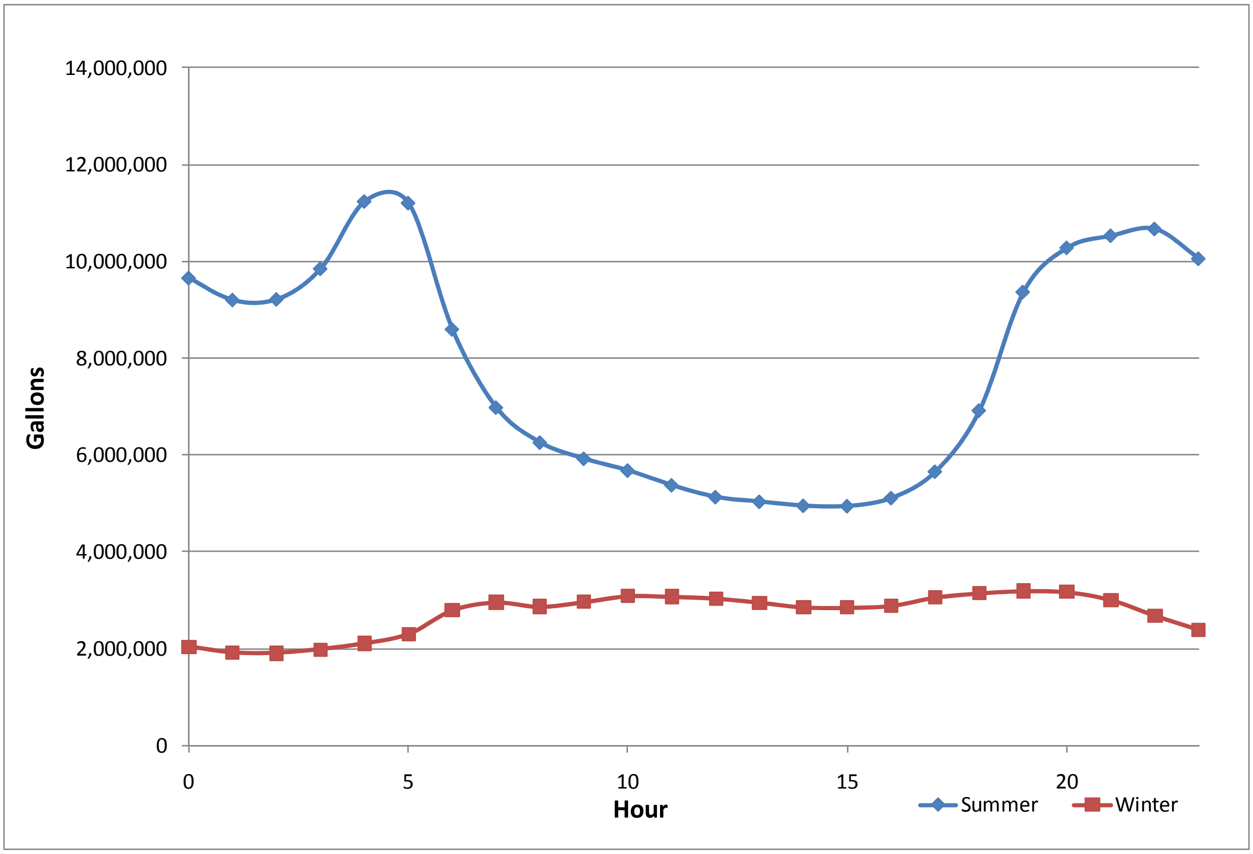
Table 4-4 Estimated daily peak period (12 to 6 PM) water and electricity consumption by end use

	Water (gallons/day)	Electricity (kWh/day)
Clothes washer	7,554,000	6,560
Dish washer	356,000	310
Toilet	6,620,000	5,760
Leak	641,000	560
Outdoor	13,150,000	12,690

[5] Estimated from Fresno system data, 2010-2011.
[6] The population served is less than the total population of Fresno because portions of Fresno are independently supplied, including Fresno State University
[7] Outdoor use is estimated based on the difference between summer and winter demand; all winter demand is assumed to be indoor because little irrigation is needed in that season. Volume by indoor use is estimated by applying average end use percent of total indoor use for West Coast cities to Fresno systems data 2010-2011. Mayer, P. and W. DeOreo (1999). Residential End Uses of Water, Aquacraft, Inc.

Per capita water production averages 300 gallons per capita per day (gpcd), with single family residential demand estimated to be 271 gpcd.[8] While this water demand is somewhat high compared to the state average of 181 to 228 gpcd or that of cooler regions, it is not unusual for a Central Valley city.[9] Water demand, and particularly summer daytime water demand have been somewhat reduced through several conservation programs, evaluated later in this case study. High water demand is largely the product of a warm dry climate, with summer temperatures on average in the 80s and about 11 inches of rain per year (City of Fresno 2008). Summer residential water demand is approximately three times as large as winter demand, primarily due to landscape irrigation (Figure 4-1).

Figure 4-1 Summer and winter total average hourly residential water use



Like many Central Valley cities, water delivered to residential customers in Fresno is not currently metered. Pricing is based on lot size; single family residential customers are charged a

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[8] Per capita production ranges between 269 – 332 gpcd; single family residential demand ranges between 241 – 298 gpcd. City of Fresno (2008). City of Fresno Urban Water Management Plan.

[9] For comparison, coastal San Francisco averages 62 gpcd (SF UWMP) and Sacramento, another Central Valley city, averages 282 gpcd. U.S. Environmental Protection Agency. (2004). "How We Use Water In These United States." Retrieved February, 2011, from http://esa21.kennesaw.edu/activities/water-use/water-use-overview-epa.pdf, U.S. Geological Survey. (2004). "Estimated Use of Water in the United States in 2000." Retrieved February, 2011, from http://pubs.usgs.gov/circ/2004/circ1268/htdocs/table05.html.

flat rate of $18.59 per month for the first 6000 square feet of lot and $0.185 per additional 100 square feet of lot. A conversion to metering residential accounts is now under way, and Fresno anticipates a water demand decrease of 10% per capita over the next 5 years (2% per year) as customers become accustomed to metering (City of Fresno 2008). However, as the volumetric rate structure has been designed to be both revenue-neutral for the City of Fresno and bill-neutral for its customers (compared to the current billing structure), it is unlikely that such strong price-related conservation will be achieved.[10]

Analysis of existing conservation measures

Fresno currently has two major conservation policies: a ban on daytime landscape irrigation during the summer and a rebate program for water efficient clothes washers and toilets.

Irrigation ordinances reduce peak electricity use

Research on the effects of mandatory water-use restrictions generally focuses on whether or not the restriction achieves a reduction in the total amount of water consumed. A survey of the relevant literature suggests that mandatory restrictions on outdoor water use vary dramatically in impact across locations and program specifics, with a range of water-use reduction from 0% to 29% (Olmstead and Stavins 2007). While aggregate conservation is a desirable goal, the shifting of water use to off-peak periods (even without a decrease in the total amount consumed) is valuable to water districts relying on groundwater for supply.

Fresno's irrigation ordinances reduce peak electricity use for water supply by confining the majority of irrigation to the nighttime period when water loss through evaporation is minimized. There are seasonal limits on residential landscape watering times and frequencies, including a 6 AM - 7PM irrigation ban in place throughout the summer months and an absolute ban on irrigation on Mondays in the summer. Water demand and associated electricity use for supply during the peak period of 12-6 PM is lower than at any other period of the day (
Figure 4-2)[11].

[10] While there will be a positive marginal price of water under the volumetric rate structure, Fresno has expended serious effort to communicate average bill-neutrality to customers to convince them that they will be just as well off under volumetric pricing. The more customers believe in bill-neutrality, the less likely they are to immediately try to conserve under volumetric rates. Some degree of price response is likely in the long run; whether it will amount to a full 10% conservation is uncertain. The planned volumetric rate ($0.61 per 100 cubic feet) is also quite low.

[11] High estimate assumes that in any given hour, the difference between summer and winter water use is outdoor use (likely an overestimate); low estimate assumes that in any given hour, the difference between summer irrigation days and non-irrigation days is outdoor use (likely an underestimate); each hourly value of the average estimate is the mean of that hour's high and low estimates.

While a comparison with winter water usage patterns suggests that the peak period irrigation ban is not universally obeyed, the positive impact of the policy is clearly shown by comparing the daily summer pattern of water use between Fresno and an average of 6 West Coast cities that do not have the same type of stringent irrigation restrictions (Mayer and DeOreo 1999) (see

Figure 4-3).

In areas without irrigation restrictions, outdoor water use occurs throughout the day and on average 23% of total daily outdoor water is consumed during the peak period between 12PM to 6PM. Only 10% of total daily outdoor water is consumed during the peak period in Fresno. Compared to allowing irrigation throughout the day, Fresno's peak period irrigation ban saves an estimated 16 MWh of peak period electricity per day throughout the summer. If all of this irrigation is shifted to off peak times, this is equivalent to an electricity cost savings of approximately $2,900 per day, or $170,000 over the course of a summer. This should be considered a lower bound estimate on the electricity cost savings of the peak period irrigation ban; it is likely that some irrigation that would have taken place during the peak period is foregone entirely rather than shifted to the off peak period (House 2011).

Figure 4-2 Fresno summer outdoor water use profile

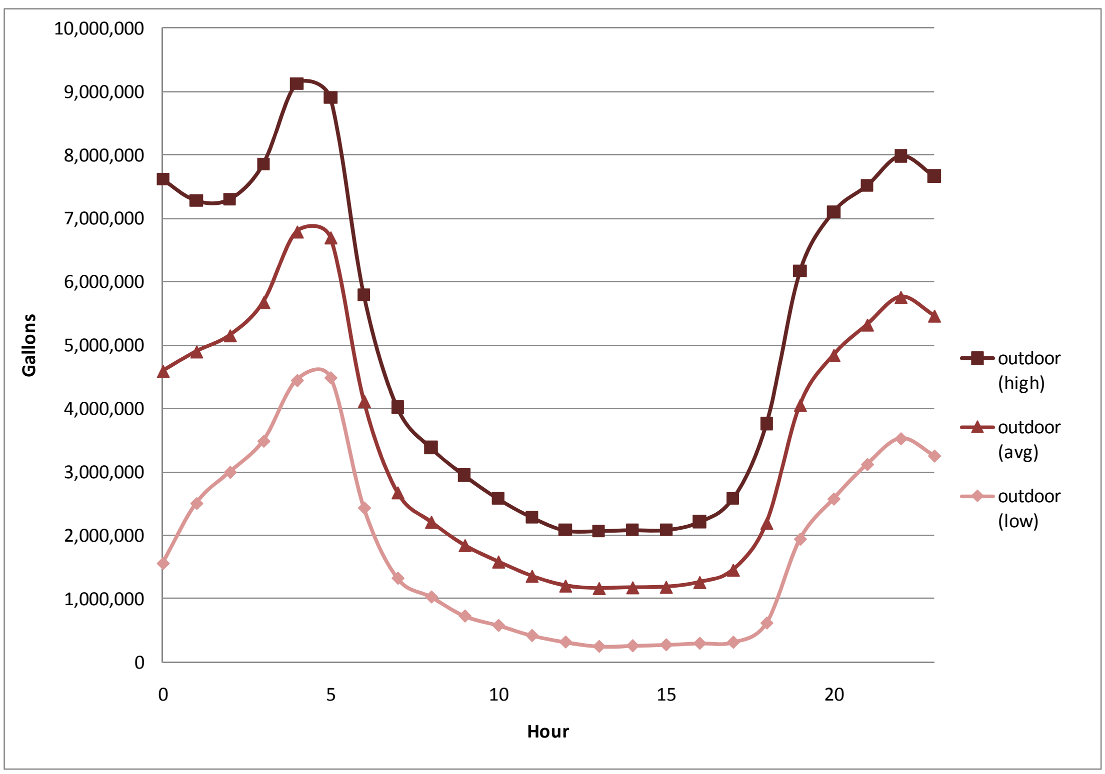
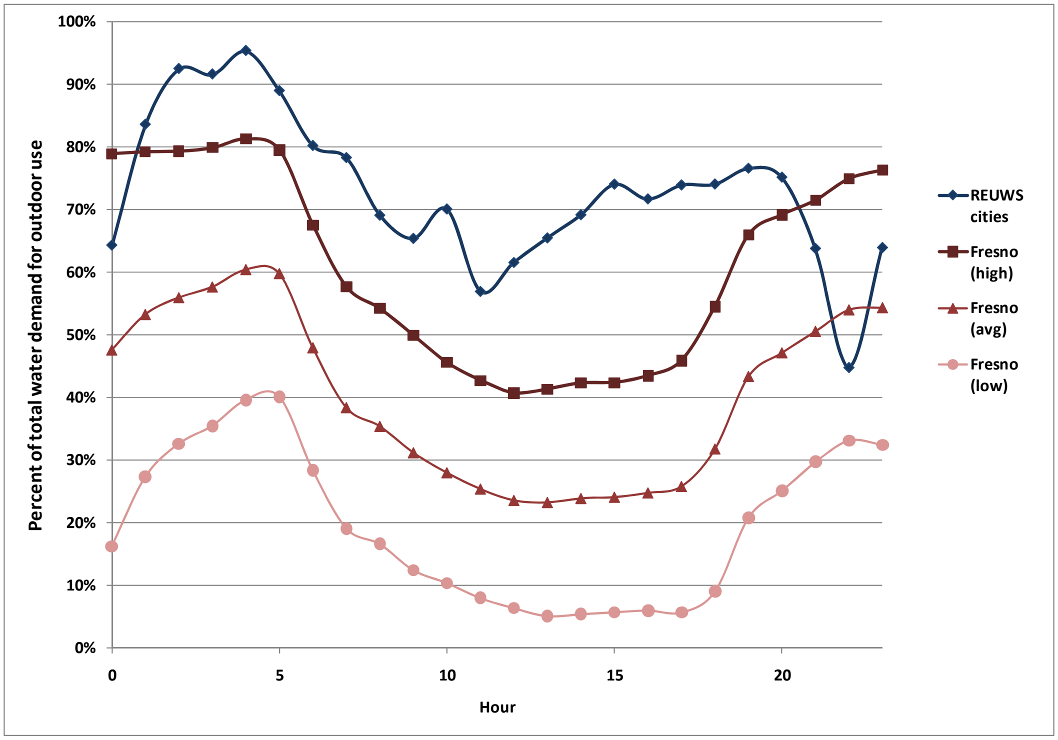


Figure 4-3 Summer average irrigation day water profile comparing Fresno and West Coast cities



Appliance and fixture retrofits reduce water consumption and peak electricity use

In Fresno, summer indoor water use accounts for only 40-60% of total summer residential use, but due to the landscape ordinances described in the previous section, indoor water use accounts for the majority of peak period use. Like many California water districts, Fresno offers low flow shower heads and faucet aerators to its customers at no cost. Additionally, rebates of $75 and $100 provide incentive for customers to replace old toilets and clothes washers with new water-efficient models.

Appliance and fixture retrofits can dramatically reduce water consumption

The efficiency gains from appliance and fixture retrofits can be substantial. On average, high efficiency toilets are rated to use only 37% as much water as low efficiency toilets use, and high efficiency faucets and shower heads are rated to use 68% and 27-60% as much water respectively as their low efficiency counterparts (Sonoma County Water Agency 2009).

However, efficiency gains *in use* can be significantly lower than the differences in rated efficiency between original and retrofit fixtures and appliances would suggest. Field studies of pre- and post-retrofit indoor water use provide a conservative estimate of the potential water savings from indoor retrofits (Table 4-1). Increased intensity of use (double-flushing of toilets, longer showers, reduction in size of laundry loads) can result in a smaller actual decrease in water use than that projected from efficiency ratings.

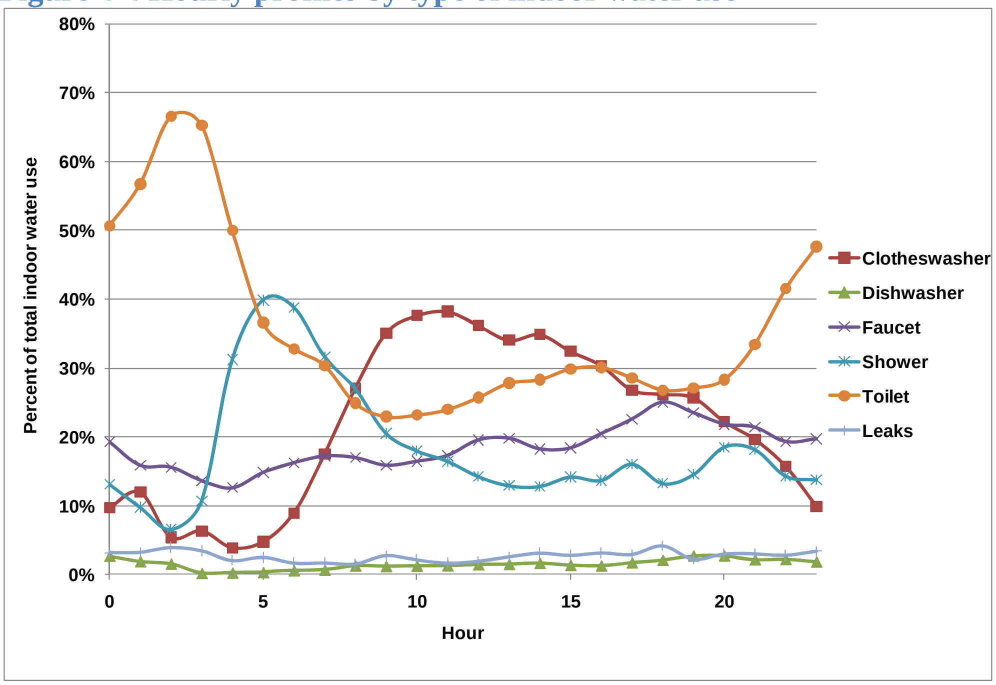
Table 4-5 Pre- and post-retrofit consumption of water-using equipment

	Baseline (gpcd)	Post-retrofit (gpcd)	% change
Clothes washer	14.5	8.6	40%
Faucet	9.7	8.2	16%
Shower	11.2	9.5	14%
Toilet	18.9	8.5	55%
Leak[12]	17.0	4.9	71%
Total	75.7	43.8	42%

source: (Mayer, DeOreo et al. 2000; Mayer, DeOreo et al. 2003; Mayer, DeOreo et al. 2004)

Retrofits of old and inefficient fixtures and appliances have the benefit of reducing both peak period electricity use and total water demand. The daily use profile differs across fixtures and appliances, and will impact the amount of peak electricity reduction achieved through retrofits. During the 12PM to 6PM peak period, clothes washers and toilets constitute the majority of indoor residential water use (Figure 4-4). While leaks on average compose a small fraction of water use during the peak period, this water consumption is problematic because it is often unnoticed by the consumer and serves no useful purpose.

Figure 4-4 Hourly profiles by type of indoor water use



source: (Mayer and DeOreo 1999)

[12] Reduction in leaks is largely due to removal of old leaky toilets and discovery of toilet-related leaks.

Using rebates to induce appliance and fixture replacement

Toilets and clothes washers are the primary indoor uses of water during the electric peak period. This water use can be targeted by either shifting the time of use through behavior change (e.g. waiting until later in the day to do laundry) or by replacing old, water-intensive toilets and clothes washers.

The precise number of high efficiency clothes washers and toilets in Fresno is not known. Since the rebate program began in 2006, rebates were provided for 3717 high efficiency clothes washers and 1177 ultra low flow toilets.[13] Fresno currently offers rebates of $75 and $100 to provide incentive for customers to replace old toilets and clothes washers with new water-efficient models.

While the price premium of high efficiency clothes washers varies across washer capacity and other features, on average, a high efficiency clothes washer costs $150 more than a standard efficiency clothes washer (NPD 2008).[14] Toilet prices are highly variable and depend largely on brand and style, but it is likely that the $75 rebate represents a significant portion of the ultra low flow and standard toilet price differential.

Based on an expected useful lifetime of 14 years (Department of Energy 2000), each fixture rebate will likely save several hundred thousand gallons of water and hundreds to thousands of kilowatt hours of electricity for water supply during the operational life of the fixture. Based on current and projected electricity prices (Aquacraft Inc. 2009), it appears that Fresno saves approximately $84 in electricity costs for each clothes washer replacement and $258 in electricity costs for each toilet replacement (Table A2). The fact that electricity cost savings appear to be somewhat less than the rebate amount provided for clothes washers does not necessarily suggest that the rebate amount is too high because there are values to water savings other than reduced electricity use for supply, including customer electricity savings, reduced need for supply expansion, less wear on pumps and other infrastructure, and reduced strain on the aquifer. The substantial electricity cost savings from toilet retrofits does suggest that it may be worth increasing the rebate amount to further encourage the adoption of ultra low flow toilets.

[13] It should be noted that this represents a very small portion of the total toilets and clothes washers in Fresno. With 110,000 households and approximately 0.8 clothes washers and 2 toilets per household in California, there are approximately 83,000 clothes washers and 210,000 toilets in Fresno. The number of customers that have voluntarily upgraded to efficient models is not known. U.S. Energy Information Administration (2005). Residential Energy Consumption Survey.

[14] PG&E also offers a clothes washer rebate of $50, up to a total rebate of $125 when combined with water agency rebate. Pacific Gas & Electric. (2011). "Appliance Rebates." Retrieved February, 2011, from http://www.pge.com/myhome/saveenergymoney/rebates/appliance/.

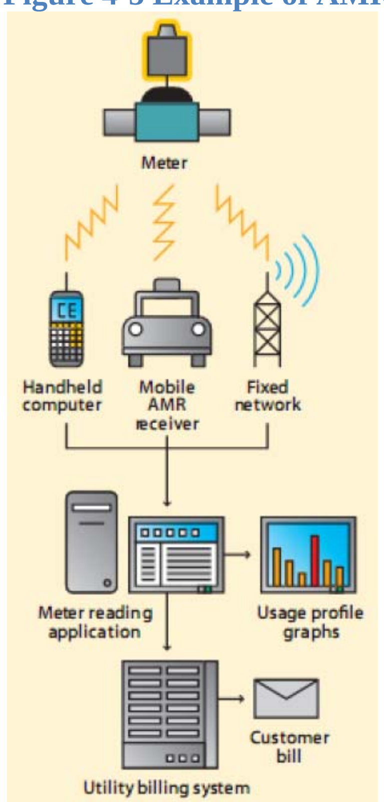
Table 4-6 Lifetime impacts of rebate program

	Water savings (1,000 gallons)	Fresno electricity savings (kwh)	Fresno elec cost savings
Each clothes washer	278	457	$ 84
Each toilet	539	1,403	$ 258
All clothes washers	1,034,884	1,698,935	$ 313,821
All toilets	634,898	1,651,716	$ 303,148

Addressing potential supply shortfall through AMR

Automatic meter reading (AMR) technology collects water consumption data at regular intervals and transfers it to the water district. The meter or a meter interface unit can store this data for later retrieval with mobile receivers or it can be transmitted directly to the water district's central data management system through a fixed network of transmitters that transfers data from customer meters to a central database. The data collected is used to create accurate billing figures for customers. Data can also be used by water district staff to settle bill disputes or provided directly to customers to allow them to track their water use (Figure 4-5).

Figure 4-5 Example of AMR system



source: (House 2010)

In other cities and water districts, substantial water conservation, waste reduction, and peak electricity savings have been achieved through AMR installation and pilot studies.[15] Now that Fresno is in the process of installing an AMR system for all residential customers, what remains is to determine how to incorporate the data provided by AMR into Fresno's broader conservation policy.

Evaluating AMR possibilities in Fresno

To be a successful tool for Fresno, the AMR system must cost-effectively provide information to the utility and customers, providing a means to uncover opportunities for conservation. Regardless of the numerous expected benefits of AMR, it will only succeed as a water and electricity conservation tool if it is accepted and understood by customers.

Reductions in water and electricity use

The expected reduction in water, total electricity for water supply, peak electricity for water supply, and electricity cost for Fresno are important factors to consider in AMR implementation. Along with the magnitude of the impact on water and electricity use, the certainty of the impact is a vital point for consideration. Because consumer behavior and price responses are difficult to model accurately, vary over time, interact with many factors beyond a water district's control, and can differ dramatically across communities, conservation strategies that rely on changes in consumer behavior are inherently more uncertain. However, if lasting changes in consumer behavior can be achieved, the resulting conservation can be substantial.

System costs

More complex use of AMR systems requires more manpower and thus more payroll expense than simple volumetric water use data compilation and monthly billing. This could include additional data analysts and conservation experts. Additional information infrastructure, including software and hardware, will increase initial and maintenance costs. However, these costs may be largely offset by the savings that can be achieved through the collection, analysis, and dissemination of detailed water use information.

Information provision

While there are some actions that Fresno can take to use AMR to improve end use conservation that rely almost purely on water district staff, most strategies will depend at least in some degree on the actions of residential customers. When used effectively, data collected through AMR can be used to better communicate water use trends to customers and elicit conservation (McCormick and Welser 2009). While the current billing structure of quarterly bills based on a flat per-property charge definitely provides too little information for customers to see the impact of individual water use activities, more data does not necessarily equal more

[15] For example: House, L. (2011). Time-of-Use Water Meter Effects on Customer Water Use, California Energy Commission. **CEC-500-2011-023**. Chastain-Howley, A. and D. Wallenstein (2007). Using an AMR System to Aid in the Evaluation of Water Losses: A Small DMA Case Study at East Bay Municipal Utility District, USA.

conservation. For instance, most customers would not have the time or interest to analyze a full month of minute by minute water use data in tabular form. The information provided to customers should be readily understandable and not require significant effort on their part to interpret.

Consumer acceptance

Consumer acceptance of the AMR system will depend on various factors, including changes in bill amounts, clarity of the explanation of changes, safety and privacy concerns, time or effort they must expend to adapt, the spread of burdens or benefits across different groups of customers, and the amount of control they have over their water bill amount. The metering pilot and first quarter of meter installations that have already taken place suggest that Fresno's residents are overall fairly willing to accept metering, and the effort expended to inform customers of the conversion process and the critical need for water conservation and accountability has likely contributed to the so far successful implementation.

The acceptance of AMR for water may be influenced by current efforts of PG&E and other utilities to switch over to smart metering of electricity. The conversion to smart metering of electricity has been mismanaged in some instances, and faces two primary obstacles that will be relevant to AMR for water: insufficient provision of information for consumers and consumer distrust of wireless devices. An issue that is more specific to Fresno's circumstances is the consumer acceptance of moving from a flat quarterly fee to volumetric monthly billing. Consumer distrust of wireless devices creates a potential complication for a water district that wishes to upgrade its metering system to AMR. However, reaction to the metering pilot suggests that Fresno's residents are overall willing to accept metering, and largely do not associate their new water meters with PG&E's electricity smart meters (City of Fresno 2011).

Another aspect of consumer response to AMR is the concern for privacy and control. Advanced metering infrastructure, which allows for two-way communication between the water district and customers' water meters, gives the water district the ability to detect unauthorized water use and turn off the water supply to a specific meter if necessary (House 2010). While a system like this would theoretically allow for greater control of the water supply and thus greater reductions in peak period water use, it is also less likely to be accepted by customers and more likely to be viewed as an infringement on privacy.

AMR implementation strategies for Fresno

Fresno is currently in the process of installing AMR meters for all residential customers, which will be read four times per day over a fixed network. By early 2013, all residential customers will be billed monthly at a volumetric rate. The volumetric rate was designed to be revenue neutral, compared to current flat monthly charges, and a pilot study suggests that across a range of customers, bills under the flat charge and volumetric rate pricing schemes would be very similar for average water use amounts (City of Fresno 2010).[16] AMR data will be used primarily for billing, bill dispute resolution, and possibly to supplement the water audits currently offered to customers.

Possible modifications of the AMR system include more frequent meter reads, improved information provision through customer bills, adding a customer web interface or other information display, and implementing seasonal or time-of-use water rates. The following sections evaluate these strategies in terms of water, electricity, and peak electricity savings beyond those of the simple bill-related implementation that Fresno is currently following. All water, electricity, and electricity cost values represent the expected savings compared to a baseline scenario of using AMR simply for the purposes of volumetric billing.

Short term: leak detection through utility intervention

One benefit of transmitting meter data at an hourly time step is the ability to identify leaks, which will appear in a customer's water use profile as an absence of any zero consumption hourly readings (Chastain-Howley and Wallenstein 2007). Leaks that may have gone unnoticed by the customer, such as a running hose or broken toilet in a rarely used bathroom, can trigger intervention by the water district, reducing reliance on customer awareness and initiative (Talend 2009). This will reduce costs for both the customer and the water district.

With the planned four read times per day, some degree of leak detection may still be possible if nighttime reads are consistently unexpectedly high. Increasing the number of daily data points will improve leak detection capabilities. Leaks detected by anomalies in customer data can trigger automatic notification through email, alerting the customer to the likelihood of a leak and the estimated leak rate, which would suggest what type of leakage problem the customer should be looking for. Alternatively or in parallel, Fresno staff could call customers who appear to have leaks.

The ability to identify leaks depends on the accuracy of the water meter and the resolution of the data collected. With hourly reads, once the new meters are installed Fresno should be able to detect any leak larger than a slowly dripping faucet. While ideally all leaks would be identified and repaired, some will be too small to detect, some will be identified in customer water use data but their cause will not be discovered, and some will be identified but customers will not fix them. Conservatively assuming 50% of customer-side leaks can be identified through AMR and repaired by the customer, Fresno could save at least 1,440 AF/yr of water and $82,900 per year on electricity costs for water supply (Table 4-7).

[16] New rate structure includes a fixed charge based on meter size and a volumetric rate of 61¢ per 748 gallons of water.

Table 4-7 Potential AMR savings through leak detection (2011 and 2020)

	Year	Water savings (daily gallons)	Summer electricity savings (kWh/day)	Summer electricity cost savings ($/day)	Estimated annual savings ($/yr)	Estimated annual water savings (AF)
Total	2011	1,285,000	1,300	$ 275	$ 82,900	1,440
Total	2020[a]	1,682,000	1,900	$ 470	$ 142,000	2,090
Peak	2011	289,000	280	$ 100	$ 6,010	_
Peak	2020[a]	420,000	410	$ 170	$ 10,200	_

source: Fresno system data, leak profile for West Coast cities from (Mayer and DeOreo 1999)
[a] This estimate assumes that customers do reduce per capita water consumption by 10% in response to volumetric billing

If incorporated early in the process of developing and adopting the database of AMR information that will be used for customer billing, there will be very little additional cost to initiating this strategy. It is very likely that this functionality of the AMR data could improve the effectiveness of employees currently working on customer water audits and bill dispute resolution, and that it would, rather than requiring additional expense, increase the productivity of workers already available and on payroll. By catching leaks as they are happening, later billing disputes can be avoided, along with their costs in terms of employee time and effort.

Short term: key points and considerations

Anomalies in customer data collected through AMR can reveal the presence of household leaks, and can trigger customer notification through email, noting the suspicion of a leak and the leakage rate. Even with significant effort involved in setting up and running the system, this strategy is expected to provide cost-effective conservation (Table 4-8).

It should be noted that this strategy represents only a slight improvement in information provision to the customer; customers must rely on alerts from Fresno, and still receive little information on their water use habits. However, it does have the advantage of targeting water consumption from which no one derives benefit.

Customer acceptance of AMR-based leak detection is expected to be comparable to that of the AMR system in general. Customer feedback from the metering pilot program and city-scale installation so far indicates that AMR has been well accepted. In this case Fresno's intervention is purely informational and intended to be helpful to the customer.[17] Customers do not want to have to pay for water they are not receiving benefit from, and are quite likely to be willing to turn off forgotten hoses and running toilets when these problems are brought to their attention.[18]

[17] A variation of this strategy could include reminders and inquiries to customers with high midday water consumption during the summer, which may be an indicator of irrigation during the restricted period. This would be less well accepted because it could be seen as somewhat invasive by customers.
[18] East Bay MUD provides leak alerts for customers with smart meters via email notices. They report that the majority of customers respond quickly to these notices and the system is generally well accepted.

Table 4-8 Conservation summary: leak detection

	Projected 2020 savings (AF/yr)	Projected electricity cost savings ($/yr)
Leak detection	2,090	$ 142,000

* compared to potential supply deficit of 25,500 to 48,400 AF/yr in 2020

Medium term: customer information and education

Rather than relying purely on the utility to identify leaks and excessive water use among the residential customers, the customers can contribute to conservation efforts by tracking and monitoring their own water use and costs, if given the proper tools. Some useful information can be provided to residential customers through the new monthly billing system; this should be a relatively simple modification to existing practice, but also of limited effectiveness. In addition to this limited information provision through the billing system, more in-depth water use information can be conveyed through one of several real-time data presentation systems.

Limited information provision and conservation efforts

General conservation information programs have been found to substantially reduce water demand (Corral, Fisher et al. 1999). One method that has proved particularly effective is making water use quantities and costs readily apparent on water bills (Olmstead and Stavins 2007). Variations include comparisons between current and previous year's use for each month, comparisons with city or neighborhood averages, and reporting usage in terms of more readily understandable units like gallons as well as billing units. This type of information can help to put water conservation in a more meaningful context for the customer. An extensive survey on non-price conservation programs suggests that, on average, this type of information provision can elicit lasting conservation on the order of 5% (Barta 2004).[19][20]

Due to a history of high water use, it is uncertain that Fresno's residential customers will be quite so responsive; a range of response scenarios are explored. The high estimate of savings corresponds to a scenario in which all conservation takes place indoors, and so is in effect year round; this scenario also assumes 5% conservation. The low estimate corresponds to a scenario in which only 20% of the conservation takes place indoors, and outdoor water conservation only affects total consumption in the summer months; this scenario assumes only 2.5% conservation (Table 4-9).

[19] With AMR, bills could be used to inform customers not just of their total volume of water use, but also of their water use during electric peak and off-peak periods, even if the same volumetric rate is still applied to both time periods. Clearly requesting customers to shift water use to off-peak times and providing suggested methods might result in additional peak period conservation, but this is highly uncertain given the lack of a price incentive.

[20] For example, people may put a brick or similar displacement device in toilet tanks to reduce flush volume, install faucet aerators, or simply become slightly more aware of the benefit of turning off faucets when they aren't immediately being used.

Table 4-9 Potential AMR savings through simple information provision, water conservation (2011 and 2020)

	Year	Summer water savings (daily gallons)	Summer electricity savings (kWh/day)	Summer electricity cost savings ($/day)	Estimated annual savings ($/yr)	Estimated annual water savings (AF)
Total	2011 [a]	1,689,000 to 8,447,000	1,720 to 8,610	$ 342 to $ 1,710	$ 47,700 to $ 531,200	855 to 4,277
Total	2020	2,458,000 to 12,290,000	2,510 to 12,530	$ 584 to $ 2,976	$ 81,500 to $ 911,800	1,245 to 6,223
Peak	2011 [a]	277,000 to 1,385,000	270 to 1,340	$ 96 to $ 481	$ 5,800 to $ 28,900	--
Peak	2020	403,000 to 2,016,000	390 to 1,950	$ 163 to $ 817	$ 9,800 to $ 49,000	--

Source: based on (Barta 2004) and Fresno system data, assumes 2.5% conservation
[a] While impacts from this strategy would not manifest until at least late 2014, 2011 data is presented here as a concrete example of the magnitude of impact that should be expected from the first year of this strategy

If it is put into effect as volumetric billing begins, there will be little additional cost from implementing this more useful kind of information dissemination through monthly bills. While the effort to incorporate year to year and city or neighborhood average comparison into the billing system would need to occur before volumetric billing begins, significant impacts are not expected to be seen for the better part of a year, while a baseline level of use is established. Therefore, this is treated as a medium-term strategy.

Extensive information provision and conservation efforts

Rather than relying on monthly reminders through the billing system to induce conservation, Fresno could provide its customers with up to date hourly information on their water use. Other electric and water utilities provide this information through real-time charts and tables accessed on the utility's website. As an alternative to a web interface, display units can receive periodic data from the meter and display it on a small screen in the customer's house in hourly, daily or monthly totals (Badger Meter 2011) (see

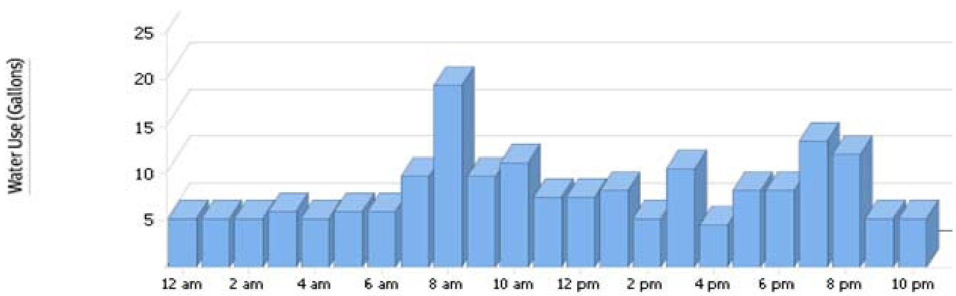
Figure 4-6). While this option has the benefit of providing information to customers who do not have computer and internet access, these units retail for approximately $96 each, which must be weighed against the potential savings induced by providing information to customers.[21]

[21] This should be viewed as an upper bound on the cost of these units. A discount of 25-40% off of the retail price would likely be applied to an order of many units.

Figure 4-6 Example of an in-home water use display

The absence of any time period with zero water consumption, as shown in the example below (Figure 4-7), will alert both the utility and customer to the likely presence of a leak.

Figure 4-7 Example of customer information presentation



Hourly or periodic water use charts can also effectively inform customers about their patterns of water demand and the impact of their water use habits. If provided with a method to track their water use in real time, customers may be able to identify waste and significantly reduce their water use. A study on inducing conservation through AMR and customer information provision in Coachella Valley demonstrated that it may be possible to achieve substantial peak period savings and overall conservation (House 2011).[22]

In this case study, peak period water use was reduced by 50% and total water use was reduced by 17%, suggesting that a combination of time-shifting and forgone use may take place. This is an upper bound estimate on the potential to reduce peak period water use, as it is based on a study where customers volunteered to participate and in a district with no irrigation restrictions, two factors that would tend to increase the potential for peak period conservation. However, if, as water system data suggests, there is significant outdoor water use in Fresno during the peak period in spite of irrigation restrictions, a customer interface would allow this water use to be identified and potentially shifted to the off-peak period, resulting in significant electricity cost

[22] This study provided customers with their hourly water use data, but did not implement a time-of-use price structure.

savings. A response of just half the magnitude of that demonstrated in Coachella Valley would still result in substantial savings (Table 4-10). The high estimate of savings corresponds to a scenario in which all conservation takes place indoors, and so is in effect year round. The low estimate corresponds to a scenario in which only 20% of the conservation takes place indoors.

Table 4-10 Potential AMR savings through extensive information (2011 and 2020)

		Summer water savings (daily gallons)	Summer electricity savings (kWh/day)	Summer electricity cost savings ($/day)	Estimated annual savings ($/yr)	Estimated annual water savings (AF)
Total	2011 [a]	14,360,00	14,640	$ 2,489	$376,000 to $874,000	7,270 to 16,090
Total	2020	20,893,000	21,300	$ 5,673	$703,000 to $1,504,000	10,580 to 23,400
Peak	2011 [a]	4,572,000	4,410	$ 750	$ 45,000	--
Peak	2020	6,652,000	6,420	$ 2,697	$ 161,800	--

(Source: adapted from (House 2011) and Fresno system data 2010-2011)

[a] While impacts from this strategy would not manifest themselves until at least late 2014, 2011 data is presented here as a concrete example of the magnitude of impact that should be expected from the first year of this strategy

The most costly option for providing all residential customers with detailed water use information is for Fresno to purchase an in-home display for each of the 110,000 households.[23] The least costly option for providing detailed water use information to residential customers is a website through which each customer can access data associated with their account. Because some customers will not be able to afford computers or internet service, or will be unfamiliar with accessing information online, it would improve the equity of this strategy to provide in-home displays for these customers. Recently, mobile device (iPod/iPhone, Android) apps have become available that allow customers remote access to water use data. These apps are generally inexpensive (several dollars, at most) and provide an additional avenue of water use data access that can be used in conjunction with in-home displays and a website.

Providing customers with their detailed water use data through a website or in-home display empowers customers to understand and take control of their water use and costs. As demonstrated in electric utilities using AMR, customer acceptance is likely to be high as long as customers understand how to access their information.

As this strategy depends almost entirely on customer behavioral response to information and the request to conserve, the projected impact is highly uncertain. Given that residential customers in a similar climate responded very strongly to detailed information (House 2011), providing in-home displays or a website that tracks hourly customer water use will likely have at least some impact on conservation. However, there may be other factors, such as types of landscaping, size

[23] It would theoretically not be necessary to purchase all units in order to achieve a substantial market penetration rate of in-home displays; informing customers of the availability and usefulness of these devices and offering a rebate of a portion of the cost may be sufficient to encourage a high level of adoption. There is too little data available currently to accurately estimate the necessary size of such a rebate, but this is an option in the early years of volumetric pricing through surveys and a pilot study of customer response to in-home displays.

of houses and yards, size and age composition of families, and general environmental awareness that differ between Fresno and the case study area of Coachella Valley. These factors could influence (either upwards or downwards) the customer response to detailed information. By projecting an impact only half as strong as that observed in Coachella Valley and assuming that much of the conservation may be of outdoor water, the estimate presented above is intended to be conservative; however, given the degree of uncertainty, it is possible that water and electricity savings are still overstated. This initial estimate suggests that detailed information provision through AMR may be a cost-effective conservation strategy for Fresno, but given that annualized costs, particularly for full provision of in-home displays, are quite high and the conservation impact is highly uncertain, this strategy should be further investigated through a pilot study of residential customer conservation response to in-home displays in Fresno before proceeding to wide scale implementation.

Medium term: key points and considerations

If provided with the necessary information, customers can contribute to conservation efforts by tracking and monitoring their own water use and costs. Especially under a volumetric rate structure, customers have incentive to conserve; their ability to do so depends on water utility choices. By providing the information needed to make informed decisions, but not restricting customer's choices, water utilities demonstrate respect for customers' judgment. Conservation strategies like this that rely on persuasion rather than restriction or coercion are generally better accepted and more effective (Marandu, Moeti et al. 2010).

While limited information provision through the billing system is expected to achieve cost-effective conservation, it may be of an insufficient quantity to meet a potential supply shortfall in 2020. Adding more extensive information provision through in-home display, internet, and mobile device is expected to greatly increase conservation (Table 4-11).

An important factor for the success of a complex implementation of AMR that relies on end user response is to ensure that residential customers fully understand how their new meters and monitors work. Experience in electric utilities suggests that providing an in-home display can dramatically improve customer acceptance and response to AMR by giving them access to the information that they need to modify their usage patterns (Smart Meters 2009). Satisfaction with AMR tends to increase with familiarity with the system (Sustainable Business 2010). The reliance on end user response increases the uncertainty of this strategy. It remains vital to communicate to residential users the value of conserving.

Table 4-11 Conservation summary: customer information

	Projected 2020 savings (AF/yr)	Projected electricity cost savings ($/yr)
Limited customer information	1,250 to 6,220	$81,500 to $911,800
Extensive customer information	10,580 to 23,400	$703,000 to 1,504,000

* compared to potential supply deficit of 25,500 to 48,400 AF/yr in 2020

These two types of information provision are not mutually exclusive. Both can be applied simultaneously and may reinforce each other by exposing the customer to water use information more often. However, there will likely be some overlap between the impacts of the two types of information; the net impact of limited and extensive customer information is expected to be less than the sum of the two considered individually. [24]

Long term: encouraging conservation through pricing

Beginning in early 2013, Fresno's residential customers will no longer be billed a flat quarterly charge for water, but rather a monthly amount based on their volume of water consumption. While substantial effort has been expended to educate customers about volumetric billing and their new water meters, it will take time for residents to become accustomed to this new system. Before 2020, it is unlikely residential customers will have fully adjusted their water use habits to suit the volumetric rate or that they will be receptive to further major changes in rate structure.

These analyses of the possible impacts of seasonal and time-of-use water rates are highly preliminary, and are intended primarily to highlight the usefulness of these alternative rate structures and raise key considerations that need to be addressed and evaluated before implementing one of these rate structures. More thorough analysis of these rate structures and possibly pilot programs or voluntary rates will be necessary before city-wide implementation can be considered.

The major concerns in implementing a new price structure are somewhat different than those of the information-related policies described in the previous sections. An effective price structure will equate marginal price with long-run marginal cost of supply, provide a strong price signal to induce conservation, and equitably raise sufficient revenue for the water district. Both seasonal and time-of-use water rates can meet these criteria if carefully implemented. We present preliminary estimates of the magnitude of price increase that may be necessary, but all estimates should be revaluated and updated closer to 2020, as many changes may occur in the meantime.

Constraints on water rate changes

Any change in water rates requires a vote of the Fresno City Council, supported by an advisory committee composed of concerned citizens. Because of California Proposition 218, to change rates (and likely to change rate structure, if it is perceived as a change in rates) Fresno is required to mail information regarding the proposed fee to every property owner, hold a hearing at least 45 days after the mailing, and reject the proposed fee if written protests are presented by a majority of the affected property owners (Legislative Analyst's Office 1996).

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[24] There may, in fact, be some overlap with the impact of the leak detection program as well; better information will improve the customers' ability to identify leaks. The degree of overlap is uncertain.

California Proposition 26, which requires a 2/3 majority vote for taxes and fees, should not apply because water rates fall into the exemption category: “a charge imposed for a specific government service or product provided directly to the payer that is not provided to those not charged, and which does not exceed the reasonable costs to the local government of providing the service or product” (Legislative Analyst's Office 2010).

Seasonal water rates

A relatively simple change in pricing structure to encourage conservation would be to impose seasonal water rates, with higher volumetric charges during the summer months. This price structure discourages over-irrigation and, in the long run, encourages the use of climate-appropriate landscaping by charging a noticeably higher rate during the months of highest demand for water. In the absence of large treated water storage facilities, which Fresno lacks, seasonal water rates can help to match variations in demand to seasonal variations in supply (Narayanan, Beladi et al. 1987). Another benefit of seasonal water rates is that the price in the season of highest water demand can be linked to the additional cost required to provide water in that season. This can include higher electricity costs and the operations, maintenance, and capital costs of facilities required only to meet summer demand (American Water Works Association 2000). Seasonal water rates are not yet common among water utilities, but are not particularly rare either; for example, Boulder, CO uses a seasonal tiered rate structure (Loehman 2008).

In the past, many water districts have not initiated seasonal pricing because water meters were only read once per quarter and seasonal pricing is most effective with monthly or more frequent billing cycles, which provide customers with better feedback on their water use and allow for experimentation and improvement in water use activities during a single summer (American Water Works Association 2000). Districts would be forced to weigh the advantages of seasonal pricing against the cost of more frequent meter readings and billing (Narayanan, Beladi et al. 1987). Making modifications to the billing system requires time and effort. However, since a substantial overhaul of the billing system will soon be necessary when volumetric billing begins, it may be worthwhile to either set up the mechanisms to calculate bills using seasonal prices (but initially set prices for all seasons the same) or to at least keep the future implementation of seasonal prices in mind to ensure that it will not create a difficult change in the billing system later.

The impact of seasonal water rates will depend on the residential price elasticity of demand for water. The price elasticity represents the consumer response to the price they face. Previous studies of the residential price elasticity of demand for water report a range of values between -0.064 and -0.51 (Dale, Fujita et al. 2009). This range of values suggests that a 10% increase in the price of water will result in a 0.64% to 5.1% decrease in water consumption. A price elasticity of -0.33 is used to estimate TOU price impacts on peak period water use in Fresno; this value was calculated in a study of households facing uniform marginal prices, the price structure that will be used in Fresno (Olmstead and Stavins 2007).[25] This fairly elastic value is also chosen because much of the summer water use in Fresno is discretionary outdoor use, which tends to be more elastic than indoor water use.[26]

The appropriate summer rate to apply in 2020 will depend on Fresno's costs and the amount of water conservation it hopes to induce through the higher summer price. This in turn will depend on the available summer water supply and the amount of conservation achieved through the information-related strategies described above. If the supply deficit turns out to be close to the low-end estimate of 25,500 AF/yr and information-related conservation is high, there will likely not be a need to impose seasonal water rates in order to equate supply and demand in 2020. Other combinations of deficit and conservation response would require some price-related conservation. Because the supply of water is most constrained in the summer, this additional conservation would ideally take place during the summer months.[27] Based on a residential price elasticity of demand of -0.33, this suggests the following percentage increase in summer price above the 2020 baseline price (Table 4-12).[28]

Table 4-12 Additional conservation needed to equate supply and demand (in 2020)

Information-related conservation	Supply deficit	Additional conservation (AF/yr)	Price increase above baseline (%)
High	Small	0	0
Low	Small	9,100	40%
High	Large	14,900	66%
Low	Large	37,800	167%

There can be a tradeoff between the strength of the price signal and the equity of the rate structure; applying a higher summer rate to all summer use may induce more conservation, but it will also mean that necessary water use will become more expensive, placing a burden on low income customers. An alternative structure would set a threshold level of necessary use above which the higher summer rate applies. Because of household level variation in income and quantity of necessary water use, it is important to allow customers to appeal their water rates if

[25] Necessary alterations to the single volumetric rate between 2013 and 2020, to ensure that Fresno obtains sufficient revenue, will be useful for estimating a Fresno-specific residential price elasticity of demand for water.
[26] A residential price elasticity of demand for water of -0.064 to -0.1 would be a reasonable estimate for indoor winter use. The appropriate residential price elasticity of demand for summer outdoor use is likely in the range of -0.2 to -0.4.
[27] Because of the time scale involved, virtually no shifting of water use between summer and non-summer water use is expected. There may, however, be some conservation activities to decrease summer use that also decrease non-summer use (e.g. replacing landscaping or fixtures).
[28] % price increase estimated as: (additional conservation)/[(summer baseline use)*0.33]. Based on the price of water Fresno plans to use starting in 2013, these % price increases would correspond to total price per 100 cubic feet of water of $0.86, $1.01, and $1.63, respectively.

they find them particularly burdensome and to offer lower rates for low-income customers (Loehman 2008).

In general, there is a strong argument for the equity of seasonal pricing. Water use that strains the capacity of the system creates the highest cost to supply and is thus assigned the highest price. While this change in price structure would need to be approved by the Fresno City Council (and due to Proposition 218, would need to be unopposed by Fresno residents), the equitable nature of this pricing structure and its ability to minimize system costs and avoid future infrastructure costs may make it somewhat more palatable to the community than other changes in price, such as a flat rate increase.

Time-of-use water rates

Time-of-use (TOU) rates are common among commercial and industrial electricity users, and are in some cases available for residential electricity. TOU water rates have not yet been used, but depending on the water supply conditions in 2020, may be appropriate for Fresno. Under a TOU rate structure, the volumetric price of water would be different during different times of the day. For instance, depending on water supply constraints, the water peak period could mirror the electric peak period of 12 – 6PM on weekdays. Time periods with higher supply costs or during which the city wants to encourage conservation would be assigned a higher price.

Instituting TOU rates would be a novel and innovative step, but because it is an untried method among water utilities, careful planning and evaluation will be necessary first to ensure that it is the right price structure to pursue. The following factors should be tracked over next 10 to 15 years to determine whether TOU water pricing is appropriate and necessary in Fresno:

- **Surface water supply:** The Fresno UWMP assumes that through expansion of the current Surface Water Treatment Plant and construction of an identical plant, a substantial portion of 2020 water demand will be met with surface water. Since the existing treatment plant does not operate at full capacity, it is likely that projected treated surface water supply has been overestimated. Surface water supply also depends on precipitation patterns and the timing of snowmelt. The proportion of total demand met by surface water should be tracked on a monthly basis. If surface water can meet only 50% or less of the summer demand in 2020 (requiring greater groundwater withdrawals than current to make up the remainder), TOU pricing should be further explored.
- **Peak period electricity:** Both the proportion of peak electricity use and the corresponding operating cost should be tracked. An increase in the proportion of peak electricity, due to increased reliance on groundwater or shifts in the timing of water demand and / or an increase in the cost differential between peak and off-peak electricity could suggest the viability of TOU water rates.

- **Response to volumetric pricing:** The Fresno UWMP assumes that volumetric pricing will have reduced per capita water demand by 2020, *all else equal*. However, there are many factors beyond water price that could alter per capita water demand, and it is possible that in spite of volumetric pricing, per capita demand may remain constant or even increase due to other factors. Since the initial price structure is intended to be bill-neutral, volumetric pricing may not create a strong price response. In this case, revision of the price structure will be necessary. Also, changes in demand corresponding to changes in the volumetric rate over time can help to reveal residential customer price responsiveness.

At a minimum, there must be a strong association between the timing of water demand and the cost of water supply to support the use of a TOU rate structure. The following preliminary calculations assume that this connection between time of water use and cost is due to peak electricity costs, but there are conceivably other ways that water use timing and supply cost could be linked that would suggest different delineations between peak and off-peak periods.

Studies of customer price response to residential electricity TOU rates may help to illuminate important considerations for designing TOU water rates. Customer response to TOU rates is more complex than customer response to non-time-varying volumetric rate structures (e.g. flat or increasing block rates), and cannot be simply modeled with a price elasticity of demand. Relevant factors include: price elasticity across a range of prices, time and length of the peak period, ratio and absolute difference between peak and off-peak prices,[29] elasticity of substitution between peak and off-peak periods, and perceived permanence of the rate structure (Charles River Associates 2005; Tiedemann and Sulyma 2009).[30][31]

If peak electricity use for water supply remains a major concern in Fresno, it may make sense to implement TOU water rates based on the differences in peak and off-peak electricity costs, defining the peak water use period as 12 – 6PM and assigning a peak to off-peak water price ratio to match that of Fresno's electricity costs. Currently, peak electricity costs Fresno about $0.36 per kilowatt-hour, while off-peak electricity averages $0.17, a peak to off-peak ratio of approximately 2.1 to 1. Assuming that the elasticity of substitution between peak and off-peak water use is similar to that of peak and off-peak electricity use,[32] peak period water demand is

[29] Large peak to off-peak price ratios have been found to produce a stronger shifting response.

[30] Tiedemann (2009), evaluating response to TOU electric rates in British Columbia, Canada, reports an elasticity of substitution between peak and off-peak periods of -0.187. This implies that for a 10% increase in the ratio of peak to off-peak price, customers shifted almost 2% of their electricity use out of the peak period.

[31] Charles River Associates (2005), studying several forms of time-dependent residential electricity price structures in California, including TOU, reports an elasticity of substitution of -0.063 to -0.09.

[32] The elasticity of substitution between peak and off-peak periods may be different for water than for electricity. Currently there is no empirical evidence available to evaluate this assumption. Differences in the time-dependence of water-using and electricity-using activities may make substitution in one easier than the other. However, the fact that the residential price elasticity of demand for electricity is similar to that of water suggests that customer price response is similar for these two resources. A study of residential price elasticity of demand for electricity for

expected to decrease substantially when switching from a single time-independent volumetric rate to TOU (Table 4-13).[33] Whether this water is conserved or simply shifted to the off-peak period will depend on the specific nature of the methods used to decrease peak period use.

Table 4-13 Projected peak period water decrease from TOU

Elasticity of substitution	% decrease in peak period water use	Conservation (AF/yr)
-0.063*	13%	9,400
-0.187**	39%	32,400

* source: (Charles River Associates 2005), ** source: (Tiedemann and Sulyma 2009)

One of the most common reasons for a negative customer response to time-of-use (TOU) electric rates is the concern that their bill will be substantially higher under TOU (Sustainable Business 2010). Peak and off-peak rates must be carefully designed and gradually implemented to maintain the proper customer incentives and allow time for customers to adapt. Ideally, customers who do not change their habits would not be overwhelmed by an immediate, large increase in their bill, but customers who do shift from peak to off peak would see a reduction in their bill. By gradually phasing in a change in billing structure (over the course of a summer, for example), customers will have time to experiment with their water use. Another option would be to release dual bills for several months, continuing to charge the flat volumetric rate, but also presenting the customer with the amount their bill will be under TOU if they continue in their current water use patterns.

If Fresno's water provision costs are time dependent, a strong argument can be made for the equity of a TOU rate structure. Assuming that peak period water is more expensive to supply, if peak period water is not priced higher than off-peak, any customers who primarily use off-peak water will effectively be subsidizing peak water users. As described above for seasonal rates, allowances will likely need to be made to ensure that all customers are able to meet their water consumption needs.

Sufficient customer water use information is an important component of successful implementation of TOU rates; TOU will not be accepted by residents unless they have sufficient information to determine how they should alter their water use activities in the face of a time varying price of water. With hourly or more frequently updated information, customers are more

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California reports a value of –0.29, well within the range of estimates for the price elasticity of demand for water. Bernstein, M. A. and J. Griffin (2006). Regional Differences in Price-Elasticity of Demand for Energy, National Renewable Energy Laboratory.

[33] % decrease in peak period water use = (elasticity of substitution)*(change in peak to off-peak price ratio) conservation amount = (total projected water use) - (projected peak use)*(1 - % decrease in peak use) – (projected off-peak use)*(1 – 0.29*[% decrease in peak use]), based on Tiedemann (2009), which found that TOU rates led to 29% as much conservation in the off-peak period as in the peak period

likely to find ways to limit their peak period water use. TOU water rates should not be implemented unless the detailed customer information strategy (website, in-home displays, mobile device apps, or a combination of all three) has already been successfully adopted. To raise rates during the peak period without providing customers with a way of determining their peak period use would be unfair and unacceptable to them.

If water supply costs continue to be time dependent and strongly linked to the time of customer water use, it may be worthwhile to offer a voluntary time-of-use water rate, to gauge the feasibility and customer acceptance of such a pricing structure before attempting to convert to time-of-use water pricing for all customers.

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