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Opportunities for Automated Demand Response in California Agricultural Irrigation

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Environmental Technologies Area

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DISCLAIMER

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ABSTRACT

Pumping water for agricultural irrigation represents a significant share of California's annual electricity use and peak demand. It also represents a large source of potential flexibility, as farms possess a form of storage in their wetted soil. By carefully modifying their irrigation schedules, growers can participate in demand response without adverse effects on their crops.

This report describes the potential for participation in demand response and automated demand response by agricultural irrigators in California, as well as barriers to widespread participation. The report first describes the magnitude, timing, location, purpose, and manner of energy use in California. Typical on-farm controls are discussed, as well as common impediments to participation in demand response and automated demand response programs. Case studies of demand response programs in California and across the country are reviewed, and their results along with overall California demand estimates are used to estimate statewide demand response potential. Finally, recommendations are made for future research that can enhance the understanding of demand response potential in this industry.

Keywords: Agriculture, irrigation, demand response, load shifting, grid flexibility

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EXECUTIVE SUMMARY

The pumping of water for agricultural irrigation is a significant component of California's electrical demand. The amount of energy used annually for agricultural water is uncertain, but has been estimated as 6.4 or 10 terawatt hours (TWh) in 2003, and peak day electrical demand has been estimated at 1,200 megawatts (MW) in 2007, with the vast majority of this demand in Pacific Gas and Electric Company's territory. For comparison, this represents approximately 4% of California's total electricity consumption, and 2% of its peak demand. Based on the load growth estimates of the California Energy Commission, these values are estimated to be 8.3 TWh in 2015, with a peak load of over 1,300 MW. These numbers are expected to grow to 9.0 TWh and over 1,400 MW of peak load by 2020.

Even these values may be conservative, as the ongoing California drought will increase agricultural electricity usage. In a drought, growers must augment dwindling surface water allocations by pumping groundwater, which requires more energy per unit of water. Additionally, sustained groundwater pumping during a drought increases the energy intensity of groundwater as pumps must pull water from deeper in the water table. The combination of these factors in a sustained drought can double the energy intensity of irrigation water.

This large magnitude of electrical demand presents an opportunity for demand response (DR), strategies in which customer loads react to conditions in the electrical grid or power markets. Agricultural load is highly concentrated in the summer months, coincident with the peak demand of the grid as a whole. Figure ES-1 shows the annual load profile for a large subset of Pacific Gas and Electric Company's agricultural customers.

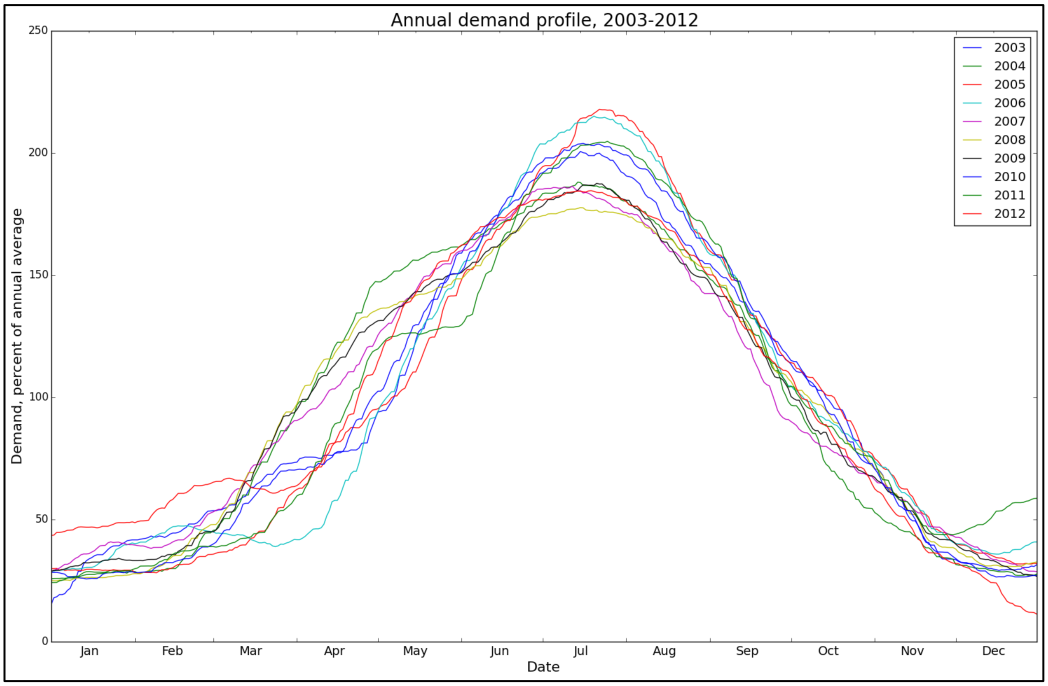


Figure ES-1: Annual demand profile for a subset of PG&E agricultural customers, 2003-2012

Demand response programs tailored toward agricultural irrigation customers have been successfully launched in many utilities throughout the Midwest and western United states; notable examples that have published their approaches and results include Idaho Power's Irrigation Peak Rewards program, Rocky Mountain Power's Irrigation Load Control program, and Southern California Edison's Agricultural and Pumping Interruptible tariff. Table ES-1 shows details of the implementation of these.

Table ES-1: Summary of irrigation demand response programs

Utility	Program Name	Dates of Case Studies	Shed Rate	Largest Shed Magnitude
Pacific Gas and Electric Company	Aggregator Managed Program	June 2011—Sept. 2013	68% (average)	15 MW (8/9/2012)
	Capacity Bidding Program	June 2011—Sept. 2013	76% (average)	9.2 MW (7/10/2012)
	Peak Day Pricing	June 2011—Sept. 2013	35% (average)	906 kW (7/19/2013)
Southern California Edison	Agricultural and Pumping Interruptible	2008, 2010—2012	57%-85% (by event)	40 MW (7/29/2010)
Idaho Power	Irrigation Peak Rewards	2005, 2007—2012	*Not available*	221 MW (7/9/2010)
Rocky Mountain Power	Irrigation Load Control (Idaho)	2009—2011, 2013	*Not available*	247 MW (2009 avg.)
	Irrigation Load Control (Utah)	2009—2013	*Not available*	49 MW (2010 avg.)
Midwest Energy	Pump Curtailment Rider (Pump$mart)	2010—2013	*Not available*	23 MW (controlled)
NV Energy	Interruptible Irrigation Service	2009—2013	~70% (est.)	~25 MW (7/19/2009)
Golden Spread Electricity Cooperative	Irrigation Load Control	2009—2012	*Not available*	58 MW (7/6/2012)

However, there exist constraints that limit the participation of growers in DR programs. These constraints include:

- **Insufficient irrigation capacity**: many farms have irrigation systems that are sized to just barely meet crop water demands during the peak of summer, and may even be under-sized, precluding participation in DR events. This constraint can be mitigated by upgrading irrigation systems or reconfiguring systems to operate more efficiently.
- **Insufficient flexibility of water delivery**: farms that receive surface water deliveries are often not allowed to change their delivery schedule without significant advance notice. This constraint can be relaxed with greater flexibility from irrigation districts.

- **Insufficient flexibility of application method**: certain irrigation methods (e.g., flood irrigation) are not as flexible in stopping and re-starting irrigation as others (e.g., sprinkler irrigation). This constraint can be mitigated by changing irrigation methods.
- **Insufficient flexibility of labor**: since many irrigation methods require onsite labor to oversee or operate irrigation equipment, this labor must be willing to adjust their schedule as necessary to participate in demand response events. This constraint can be mitigated by the installation of automated and/or remotely controlled irrigation systems.
- **Insufficient communications and controls**: successful demand response load sheds require that the grower is notified of the event with sufficient time to adjust pumping loads, and this notification results in successful control of the pumps. This constraint can be mitigated by installing automated controls and communication equipment.
- **Insufficient financial incentives**: As growers are first and foremost operating a business, the financial incentives must make DR participation compelling. This constraint can be mitigated by increasing the incentives available to growers and by reducing the costs to automate, control, and connect irrigation systems.

Despite these constraints, irrigation demand response programs have been successful. In the review of DR programs, shed rates of 80 percent are common (relative to baseline load), and participation rates have been as high as 20 percent. When these values are applied to the estimated peak load of irrigation pumps in California, they represent approximately 160 MW of DR potential in 2015, and an anticipated 175 MW of DR potential in 2020. The technical potential (assuming full participation) could be as much as 1 gigawatt (GW) in 2015, and 1.1 GW in 2020.

This potential is large, but it must be exercised carefully. Many of the major crops grown in California are high-value crops (e.g., orchards, vineyards, nut trees, vegetables), and therefore the cost of irrigation electricity is a smaller fraction of the value of the crops, compared to crops such as grains or hay. This means DR participation entails a higher risk-to-reward ratio to growers of high-value crops, and consequently these growers may be less willing to participate. In addition, agricultural distribution feeders often have low diversity in their types of customer loads, and the exercise of a large number of irrigation pumps on a single feeder can cause over-voltage issues, as has been seen in Rocky Mountain Power's Irrigation Load Control program. This issue can be ameliorated by strategic staging of pump shutdowns by the exercising entity (e.g. the utility or an aggregator).

Further research to improve the robustness of this topic could include:

- An updated study on the current electricity consumption related to agricultural water
- More detailed information on the population of California growers, e.g., crops grown, water sources, irrigation methods, presence of automation
- Surveys of large growers to determine their motivations (or lack thereof) for participating in demand response

CHAPTER 1: Introduction

1.1 Background

Pumping water for agricultural irrigation represents a significant component of California's electrical demand. The amount of energy used annually for agricultural water in uncertain, but has been estimated as 6.4 or 10 terawatt hours (TWh) (Burt, Howes, & Wilson 2003, California Energy Commission 2014). Peak day electrical demand is estimated at 1,200 megawatts (MW), and the vast majority of this demand resides in Pacific Gas and Electric Company (PG&E) territory (House 2007). The California Energy Commission (Energy Commission) estimates the total electricity consumption in 2003 at 263 TWh (Energy Commission 2014), and the California ISO estimates the peak load in 2007 at 48.6 GW (California ISO 2015), so agricultural pumping represents approximately 2.4% of the state's total energy consumption (based on the CEC energy consumption estimates) and 2.5% of its peak load.

This large magnitude of electrical demand presents an opportunity for demand response (DR). This potential has been harnessed in several utility territories across the western United States. Idaho Power runs a program, Irrigation Peak Rewards, that dates back to 2004. Irrigation Peak Rewards initially incentivized installation of timers to reduce load automatically during peak load hours, and later added an option for radio-enabled controls, which allowed load sheds to be dispatched automatically, and a manual dispatch option for very large customers. Rocky Mountain Power operates programs in Utah and Idaho, shedding a significant amount of load. These programs were accomplished using a mixture of automated timers, manual event-based dispatch, and automated event-based dispatch. In California, Pacific Gas and Electric Company offers several demand response programs to agricultural customers, incentivizing installation of controls to shed load during peak demand events, and Southern California Edison has an Agricultural and Pumping Interruptible tariff.

To encourage participation, automated load-control devices are often installed by the utility, or installed by the customer or a third-party and reimbursed by the utility. Automated demand response (Auto-DR), a strategy in which loads are shed automatically in response to grid control signals unless the customer opts out, allows quicker, more reliable load sheds with less effort required by grid operators and growers alike. This is contrasted with manual DR, in which a customer must act to shed load, and semi-automated DR, in which a customer has pre-programmed load shed strategies but still must act in order to shed load (opting in rather than opting out). Auto-DR has the potential to be used for ancillary services, which are growing in importance due to the load uncertainty and variability caused by the integration of large shares of renewables (Watson *et al*. 2012; MacDonald *et al.* 2012). To successfully participate in ancillary services, however, the pumps must be highly-flexible and able to be controlled with very little advance notice. This could be a challenge though, since the use of automated controls in agricultural irrigation is not currently widespread.

Two aspects determine the potential for DR in California agricultural irrigation: (1) the baseline load potentially available for shedding, and (2) what fraction of the baseline load can be expected to be shed during events. This report focuses on determining these amounts. Estimates of historical agricultural irrigation electricity consumption and load profiles are used to estimate baseline demand throughout the state and throughout the year. Literature reviews and consultations with agricultural irrigation experts are used to estimate shed potential and describe the agricultural constraints that may impede effective DR participation. Finally, conclusions are made and recommendations for future study are listed.

1.2 Report Organization

Chapter 1 introduces the topic and the scope of this report.

Chapter 2 describes the magnitude, timing, location, purpose, and manner of electricity use in California agricultural irrigation.

Chapter 3 describes typical irrigation controls.

Chapter 4 describes the constraints to effective participation in demand response.

Chapter 5 describes DR strategies, reviews several DR programs and their results, and estimates the potential available in California.

Chapter 6 concludes and offers suggestions for future research.

2.0 Energy Use

2.1. Magnitude of Energy Use

Estimates of agricultural pumping energy consumption vary widely between sources. Electrical energy used for irrigation in California has been estimated by the Irrigation Training & Research Center (ITRC) as approximately 10 million megawatt-hours per year, or 10 terawatt-hours (Burt *et al.* 2003). This includes energy used by irrigation districts to pump surface water and groundwater, energy used on-farm for groundwater pumping and booster pumping, and energy used to convey water to irrigation districts. The Energy Commission estimates are lower, approximately 6.4 TWh for 2003 (California Energy Commission 2014). Their estimates include "crops", "irrigation water pumping", and "livestock". The variance in estimates could be due to differences in methodology, categorization, and/or data availability.

The Energy Commission predicts an annualized growth rate of approximately 1.6 percent per year from 2014 through 2024, as seen in Figure 1. They estimate the total energy consumption of agricultural irrigation to be 8.3 TWh in 2015, and to grow to 9.0 TWh by 2020. These load growth estimates may significantly underestimate the load growth since 2013, due to the ongoing California drought; the ITRC has estimated that average energy intensity for agricultural water can be twice as high during a sustained drought, compared to a baseline year (Burt and Howes 2005).

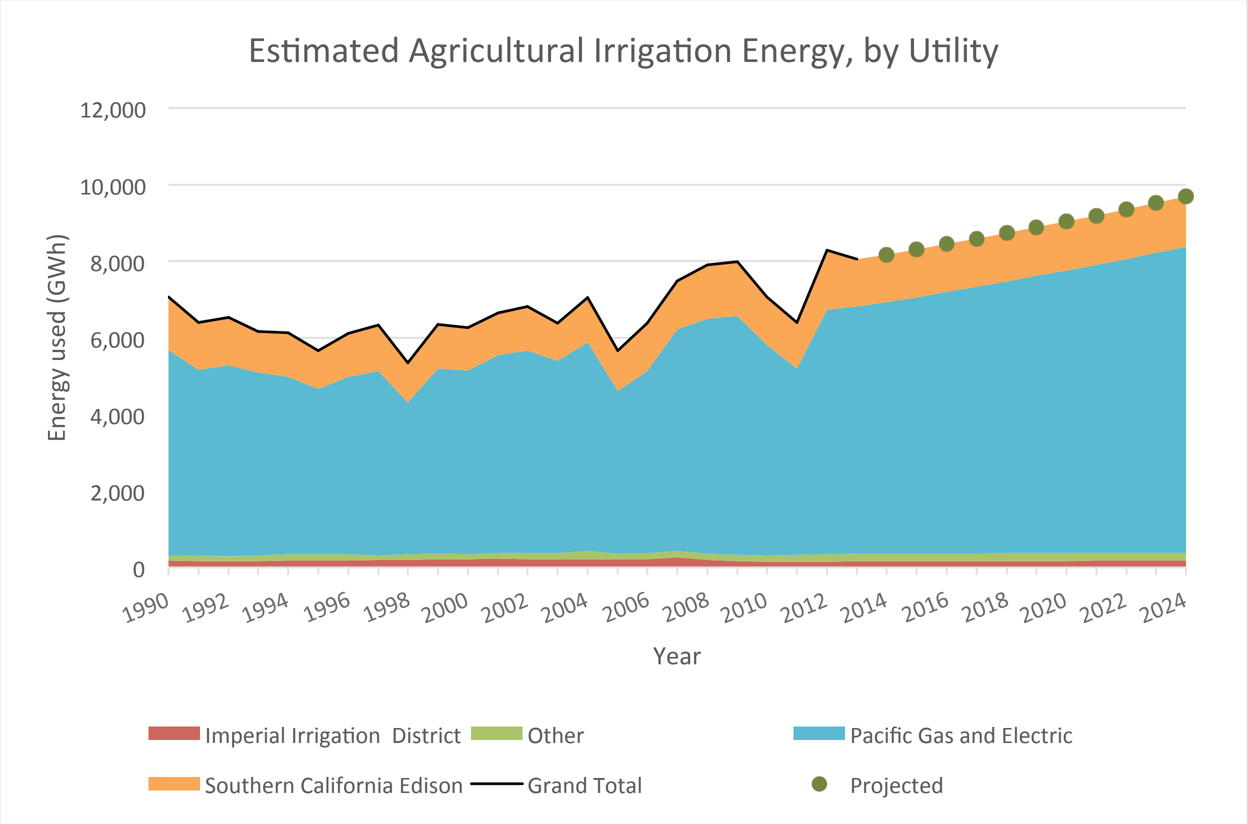


Figure 1: Estimated energy use for agricultural water, by utility.

2.2. Timing of Energy Use

As noted by House (2007), approximately 80 percent of California's peak agricultural demand comes from Pacific Gas & Electric's service territory. In 2013, the Demand Response Research Center (DRRC) requested agricultural customer information from PG&E as a part of the Agricultural Irrigation Demand Response Estimation project. PG&E provided a list of 106,501 agricultural customer account numbers, with location data, North American Industry Classification System (NAICS) code, energy consumption for the last 12 months, and peak demand in the last 12 months. By filtering out customers with an uncertain location (based on recorded latitude and longitude), overly general or explicitly non-crop NAICS codes, less than 12 months of data, and those who averaged less than 1 kilowatt (kW) of demand in the previous year, a subset of this list was developed, containing 24,385 meter numbers. Energy and demand data was requested for these meters, spanning the 10 years 2003—2012. The average demand profile for each year is shown in Figure 2. The average daily demand profile for each year is shown in Figure 3.

For each year studied, the peak daily load occurred in July, and the energy used on the peak day was 75—125 percent higher than the annual average, as can be seen in Figure 2. From November through February, energy consumption was typically less than 50 percent of the average. For each year, a majority of the energy consumption occurred in the four month period spanning May—August.

There is a daily load profile with some diurnal variation, where loads are above average from approximately 7am—4pm (peaking about 15 percent higher than the average), and below average during the rest of the hours (with a minimum of about 15 percent lower than the average). This pattern can be seen in Figure 3.

As can be seen, agricultural energy use is rather flat with regard to time-of-day, but is highly seasonal, peaking with the overall California grid peak demand in the summer.

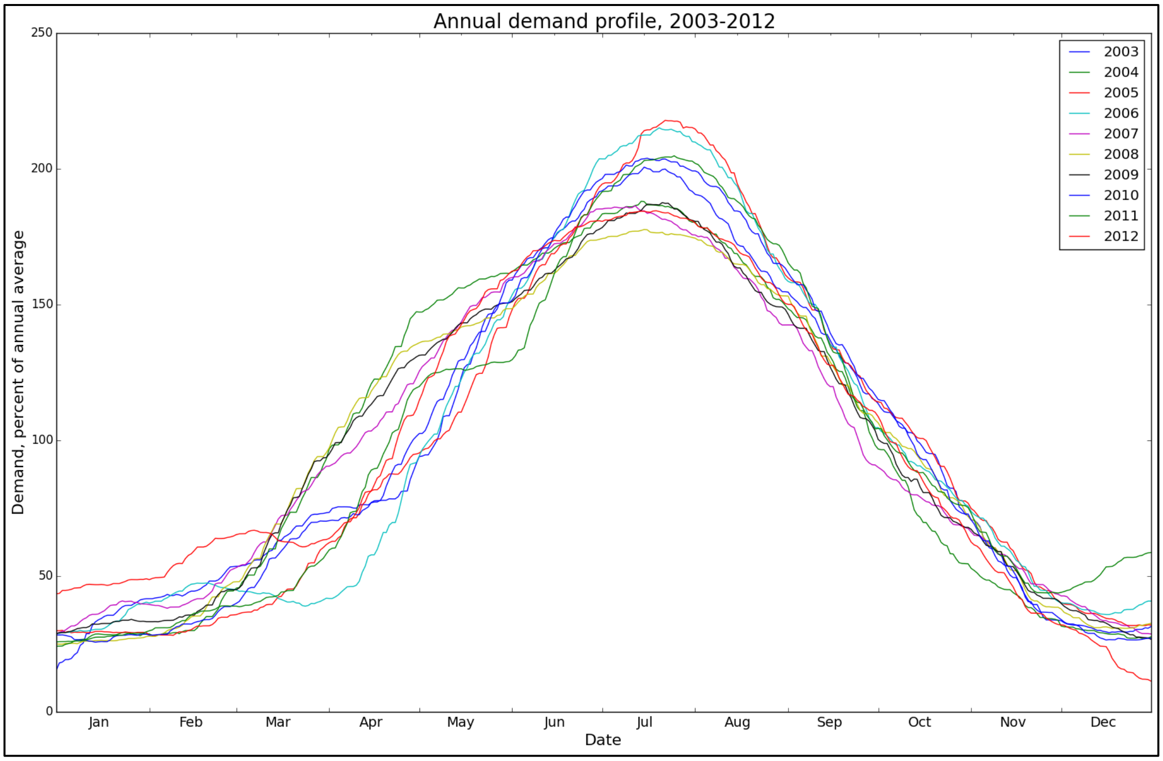


Figure 2: Estimated daily demand, relative to average, for each day 2003—2012

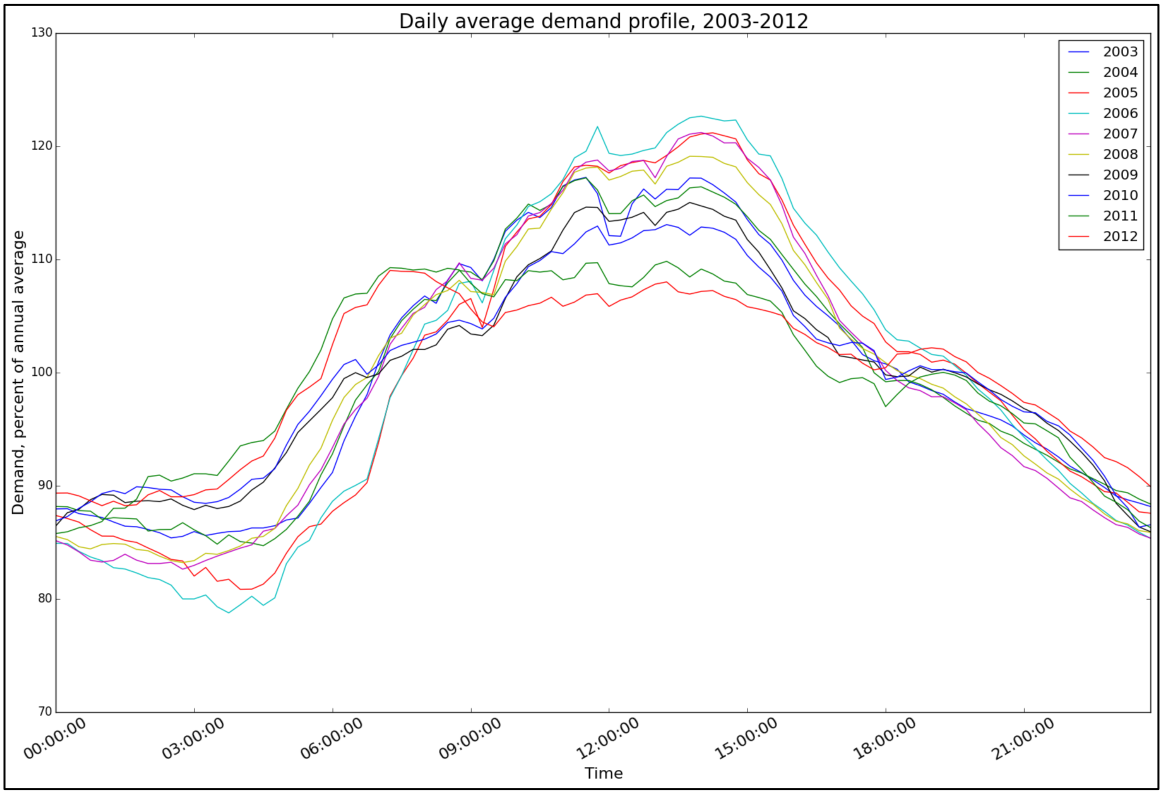


Figure 3: Average daily demand profiles for interval meters, 2003—2012

2.3. Location of Energy Use

Table 1 shows the disaggregation of estimated energy use by location, as described in Marks *et al.* (2013). This disaggregation is based on a set of evapotranspiration zones (ETo zones), originally developed by the California Department of Water Resources (CA DWR) and modified by the Irrigation Technology and Research Center at Cal Poly San Luis Obispo. These zones are shown in Figure 4.

Table 1: Electrical energy use by ETo zone

ITRC-modified DWR ETo zone	Zone Description	Total Electricity used by Zone (MWh/year)	Percentage of Total Electricity used by Zone
1	Coastal Plains, Heavy Fog	75,816	0.7%
3	Coastal Valleys and Plains	510,638	5.0%
4	South Coast Inland Plains	79,339	0.8%
6	Upland Central Coast	549,877	5.4%
8	Inland San Francisco Bay Area	39,957	0.4%
9	South Coast Marine-to-Desert Transition	342,767	3.4%
10	Central Coast Range	332,007	3.3%
12a	Northeast Sacramento-San Joaquin Valley	636,932	6.3%
12b	Southeast Sacramento-San Joaquin Valley	277,606	2.7%
14	Mid-Central Sacramento Valley	1,180,809	11.6%
15	North & South San Joaquin Valley	4,330,978	42.6%
16	West Side San Joaquin Valley	1,373,811	13.5%
18	Imperial Valley	429,388	4.2%
	Total	**10,159,900**	**100.0%**

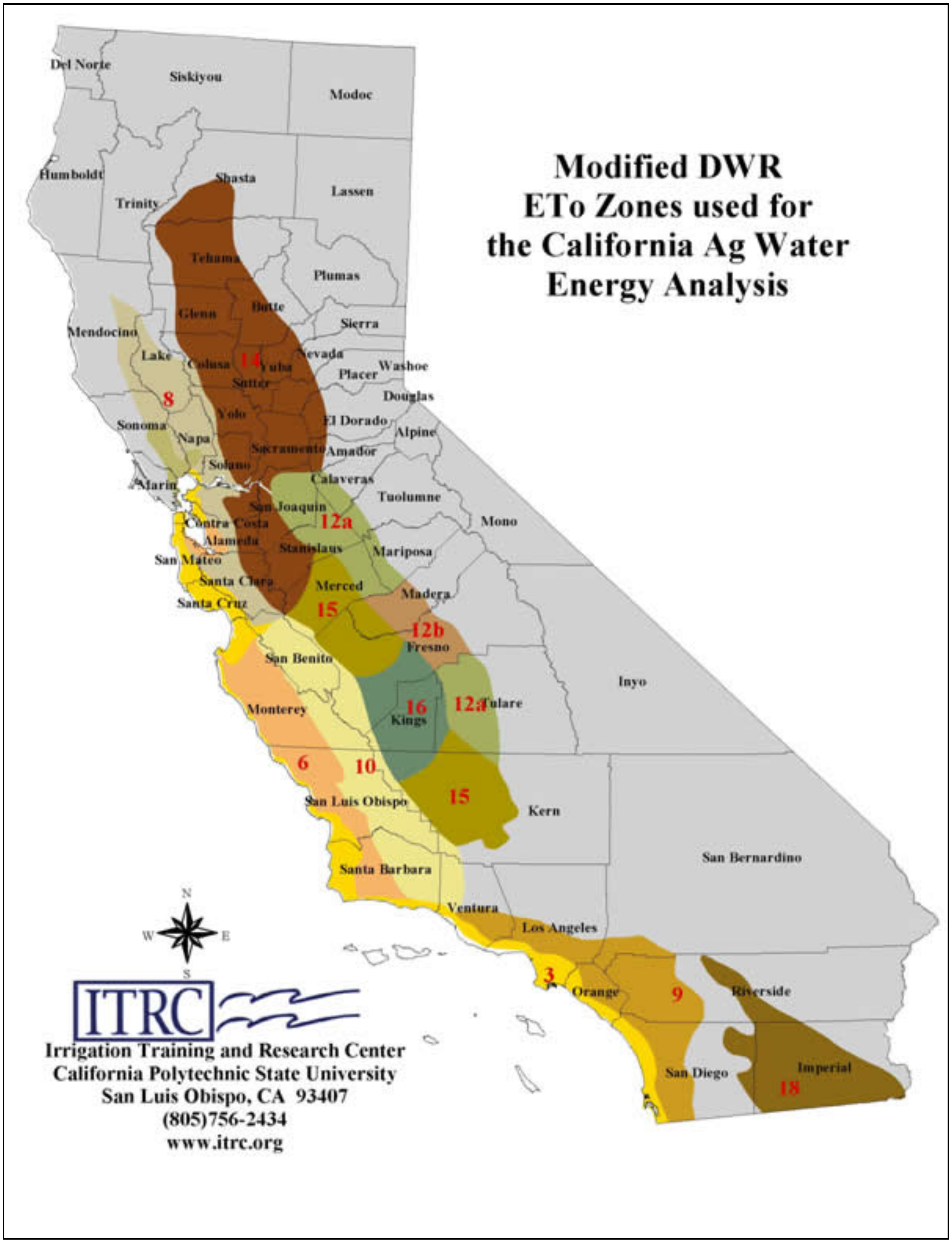


Figure 4: Modified DWR ETo Zones used for the California Agricultural Water Energy Analysis

Source: Burt, Howes, & Wilson, *California Agricultural Water Electrical Energy Requirements*, 2003

2.4. Purpose of Energy Use

According to the United States Department of Agriculture's (USDA) *2013 Farm and Ranch Irrigation Survey*, over two-thirds of irrigated acreage in California is used to grow four categories of crops: orchards, vineyards, and nut trees; hay; rice; and vegetables. The acreage and percentages of each crop are shown in Table 2. Orchards, vineyards, and nut trees represent over 30 percent of the total. The CA DWR also periodically conducts a survey of crops grown, surveying a randomly selected subset of their list of growers. Table 3 shows the results from their most recent survey in 2010. The results of that survey show an even higher share of orchards, vineyards, and nut trees, with those three categories representing 45 percent of the irrigated acreage.

However, different crops have different water requirements (due to biology), different water energy intensities (due to the different locations and sources of water available), and different application efficiencies and distribution uniformity (due to different irrigation methods). Therefore, the relationship between crop acreage and crop energy consumption is difficult to determine.

Table 2: Irrigated acreage of crops in California in 2013. Source: USDA

Crop	Irrigated acres	% of total
Orchards, vineyards, nut trees	2,576,601	31%
Hay (Alfalfa & Other)	1,101,598	13%
Rice	1,051,374	13%
Vegetables	1,018,036	12%
Corn	515,912	6%
Pastureland	433,570	5%
Wheat for grain or seed	339,188	4%
Tomatoes	283,287	3%
Cotton	274,834	3%
Lettuce and romaine	197,716	2%
All other crops	501,208	6%

Table 3: Irrigated acreage of crops in California (sampled) in 2010. Source: CA DWR

Crop	Irrigated acres	% of total
Tree crops (besides Almonds and Pistachios)	195,110	16%
Almonds & Pistachios	180,061	15%
Vineyards	179,382	15%
Alfalfa	161,252	13%
Grains	109,875	9%
Corn	102,040	8%
Other Truck Crops	92,661	8%
Tomatoes	49,608	4%

Pasture	42,050	3%
Other Field Crops	39,519	3%
Cotton	37,155	3%
Other	38,537	3%

2.5. Manner of Energy Use

There are three main methods that growers use to irrigate their fields: gravity systems, sprinkler systems, and drip, tickle, or low-flow micro sprinklers. Of these, gravity systems are the least energy-intensive, but are also the least water-efficient; drip, trickle, or low-flow micro sprinklers are the most water-efficient, but have significantly higher energy intensity. Table 4 shows the reported irrigated acreage of farms in California, according to the 2013 and 2008 Farm and Ranch Irrigation Surveys. Totals sum to greater than 100 percent because some farms use multiple irrigation methods. Since 2008, there has been an increase in the percentage of irrigated acreage using each method, suggesting that growers are diversifying their irrigation methods.

Table 4: Acres irrigated by method in California, 2008 & 2013

Method	Acres irrigated (2013)	% of total acres (2013)	Acres irrigated (2008)	% of total acres (2008)
Gravity	4,539,426	60%	4,189,852	57%
Sprinkler	1,662,125	22%	1,367,179	19%
Drip/Micro/Trickle	2,783,022	37%	2,336,130	32%
Subirrigation	Not reported		66,282	1%
Total	7,543,928		7,329,245	

Source: USDA

Over a longer timescale, however, there has been a noticeable shift away from gravity and sprinkler irrigation and toward drip irrigation. From 1994 to 2008, the number of acres irrigated using gravity and sprinkler systems fell 19 percent and 26 percent, respectively. During the same period, the number of acres irrigated by drip irrigation increased 150 percent. Though the use of subsurface irrigation increased slightly (19 percent), it was used on less than 1 percent of the irrigated acreage in California during this time period (Center for Irrigation Technology 2011).The shift away from gravity irrigation is associated with an increase in energy intensity, since gravity systems have the lowest energy intensity, but is partially offset by the shift away from sprinkler irrigation, which has the highest energy intensity. Burt *et al.* (2003) estimate the sprinkler booster pump discharge pressure as ranging from 50-70 PSI, depending on region, while the drip/micro discharge pressure is estimated as 34-55 PSI. Booster pumps are not typically required for gravity irrigation. These discharge pressure translate into booster pump energy intensities of 0-14 kWh/AF for gravity irrigation, 147-269 kWh/AF for drip/micro irrigation, and 217-342 kWh/AF for sprinkler irrigation.

3.0 Controls

Historically, agricultural pumps have been controlled manually. However, due to advances in communications and control equipment, growers are increasingly using remote control of pumps as well as soil moisture sensors to determine when and how much to irrigate.

Several methods are used to decide when to irrigate fields, as can be seen in Figure 5, which shows data from the USDA's Farm and Ranch Irrigation Survey from the years 2003, 2008, and 2013. Although the use of crop condition, feel of soil, and personal calendar schedules have remained the dominant methods, the use of soil moisture sensors has grown from 10 percent in 2003 to 17 percent in 2013 and the use of daily evapotranspiration reports grew from 8 percent to 12 percent in the same period.

The use of data-driven methods (soil or plant moisture sensing, evapotranspiration reports, scheduling services, etc.) to influence irrigation timing and quantity enables the option of automated demand response, since these data can be input to and acted upon by automated controllers. Growers will still most likely oversee the irrigation schedule, but knowing that there is a 'buffer' between the current condition of the crop or soil moisture and minimum limits may make growers more comfortable with curtailing irrigation for demand response purposes.

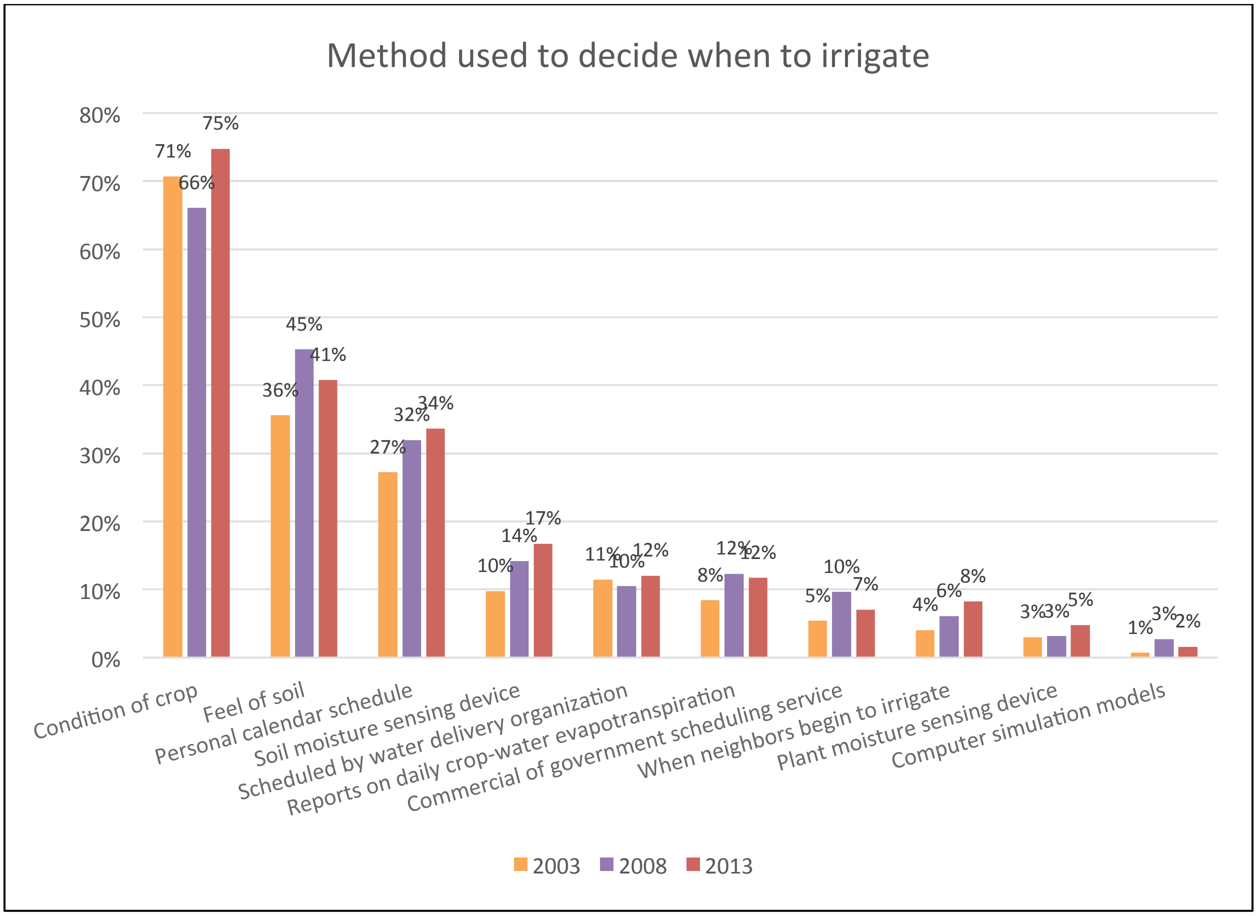


Figure 5: Methods used by farmers in California to decide when to irrigate

4.0 Constraints

Based on a literature review and consultations with irrigation experts, this study found six main deterrents to effective participation in DR programs. These six deterrents are insufficient:

- Irrigation Capacity
- Flexibility of Water Delivery
- Flexibility of Labor
- Flexibility of Application Method
- Communications and Controls
- Financial Incentives

Each is described further in the following subsections.

4.1. Insufficient Irrigation Capacity

The purpose of irrigation is to maintain soil moisture levels in the range conducive to healthy crop development. As water leaves the soil due to evaporation from the soil surface and transpiration from plant surfaces (together deemed evapotranspiration, or *"ET"*), this water must be replaced through irrigation. There is a moisture buffer in the effective root zone of the soil, but if evapotranspiration occurs faster than irrigation, the soil will lose moisture, approaching or surpassing the level at which crop damage begins. Though some crops are intentionally under-watered during part of the growing season for quality reasons (e.g., wine grapes, tomatoes) and there are other uses for irrigation water in (e.g., salt leaching and frost protection), in general irrigation is used to offset evapotranspiration.

Many farms have irrigation systems that are sized to just barely meet ET rates at the peak of summer, and some are even undersized relative to peak ET, since smaller systems are generally cheaper and the soil moisture can enable a limited 'ride-though' of under-application. Since shedding load for demand response involves reducing irrigation temporarily, which is typically replaced by additional irrigation before or after a DR event, if the irrigation system is already operating at capacity there is no chance to replace the lost irrigation. With no opportunity to replenish the soil moisture levels after participating in an event, the grower will be disinclined to shed load. However, evapotranspiration rates are lower at the beginning and end of the growing season, so a grower with an undersized irrigation system may still be able to participate on a limited basis.

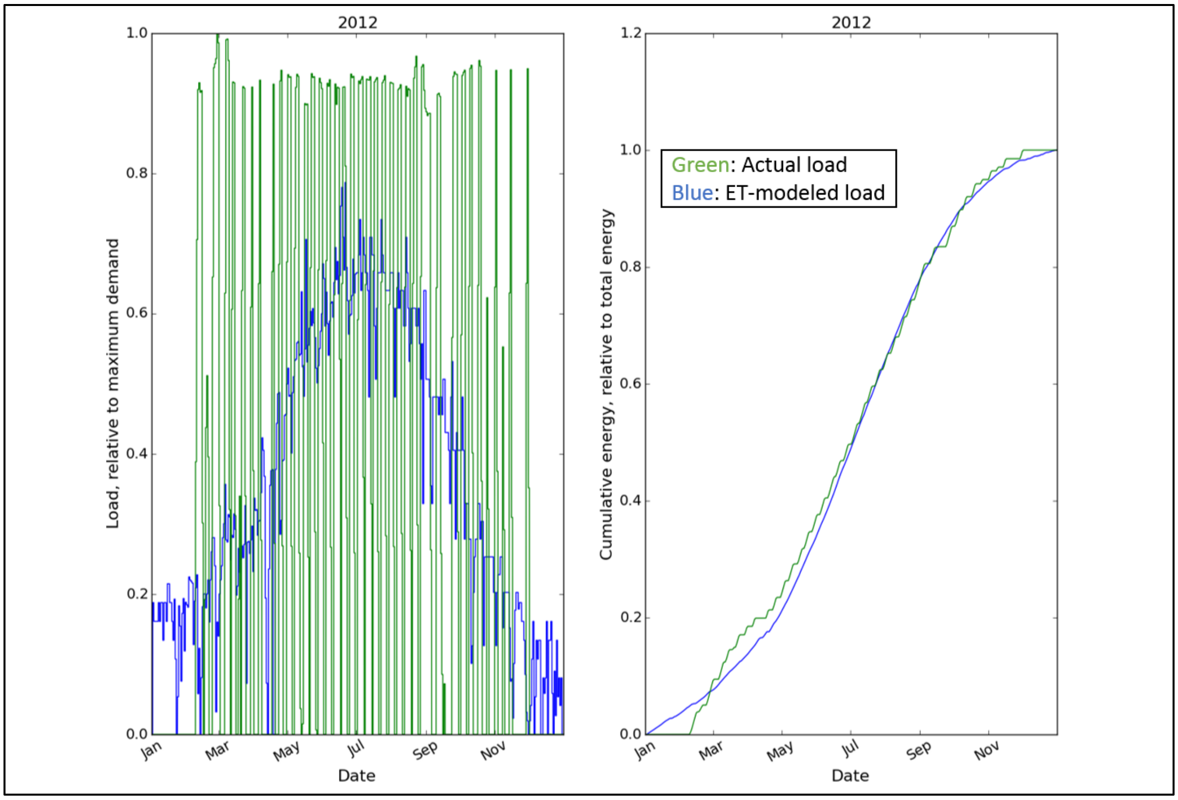
Several factors can limit a grower's irrigation capacity. First is the source of water; for example an irrigation district with a maximum deliverable flow rate. Second is the pump capacity. Given a certain pumping system, and a certain power rating for a pump, the pump can only establish a certain flow rate. Third is the capacity of the irrigation system itself: the water delivery method has a certain maximum flow rate determined by the system piping and the absorption rate of the soil. The smallest irrigation capacity (measured in volumetric flow rate) of these three factors is the limiting factor for irrigation capacity.

One way to determine if a grower is reaching their irrigation capacity is to use historical interval demand data. For sites with insufficient capacity during the peak of summer, the pump(s) will operate at maximum capacity for days at a time at a constant demand. This constant value can be inferred as the irrigation capacity (measured in kilowatts), and it can be used to determine times when the grower is unlikely to be willing to shed load, and times when he or she may be more willing.

Potential solutions for insufficient capacity include installation of new equipment and changes to equipment operation for greater efficiency. Many pumps on California farms are run very inefficiently (Burt 2011), and greater flow rates could be achieved with improved operations, creating greater irrigation capacity. The Center for Irrigation Technology at California State University, Fresno, developed and currently manages the Advanced Pump Efficiency Program, offering education, technical assistance, and incentives for pumping system efficiency tests and retrofits.

Figures 6a and 6b show the annual load profiles of two growers; one with little excess irrigation capacity and one with much excess irrigation capacity. For each figure, the left chart shows the demand in each 15-minute interval, and the right chart shows the cumulative energy use. The green trace is real data, and the blue is modeled based on historical evapotranspiration.

Even when growers do have excess capacity, irrigation practices may result in soil moistures periodically approaching the lower limit of the desired range; this is especially pronounced in low-frequency irrigation methods. If the soil moisture is already close to its minimum when a demand response event is called, the grower may not be willing to risk damage to their crop by postponing irrigation, even if they have excess capacity to catch up later. This can be alleviated by higher-frequency irrigation practices.



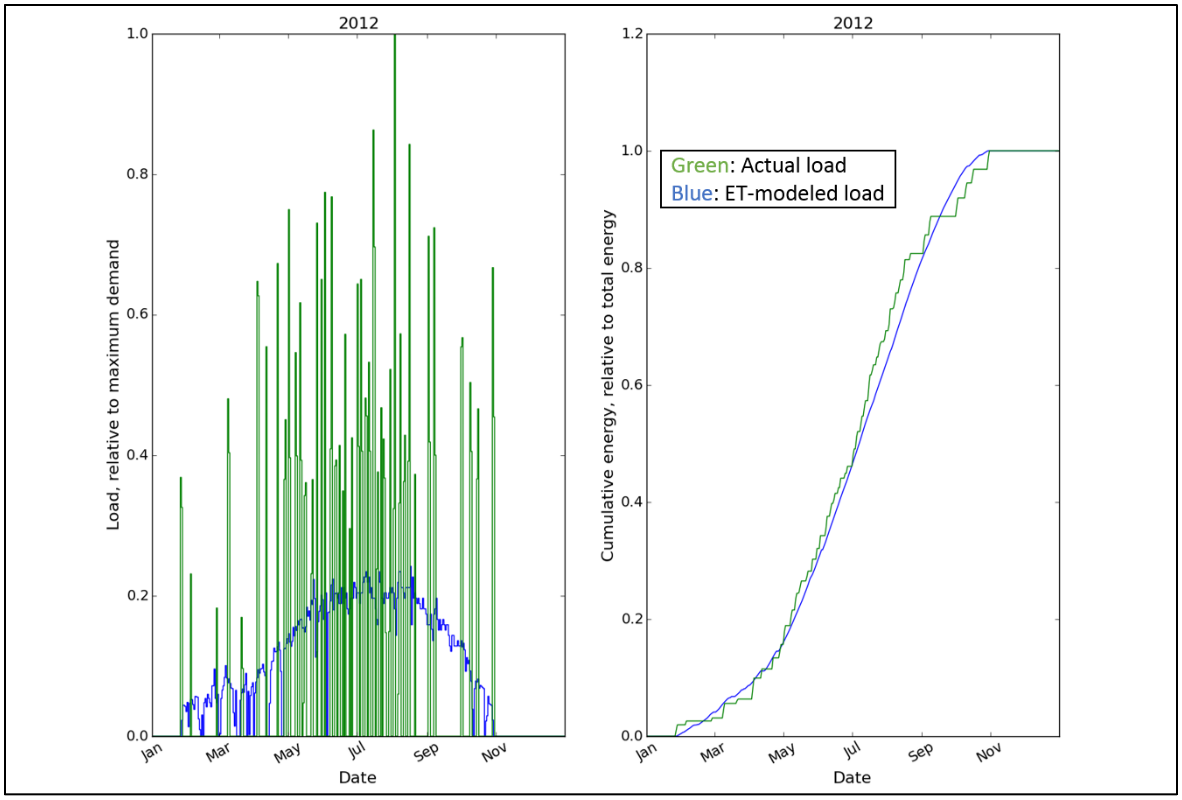


Figure 6a (above): An example of a grower with little excess irrigation capacity
Figure 6b (below): An example of a grower with plenty of excess irrigation capacity

4.2. Insufficient Flexibility for Water Deliveries

For growers who receive water from an irrigation district, there may not be scheduling flexibility to stop withdrawing water during a DR event (ITRC 2002). One practice used to enable demand response for growers who are faced with this inflexibility is to install buffering reservoirs. Water that would have been pumped onto the field is deposited in the reservoir instead, and then pumped from the reservoir onto the field after the event is over. Therefore, the use of booster pumps is shifted out of event hours. This practice is especially well suited to center-pivot irrigation, as the corners of the field are typically otherwise unused. However, the high value of land in California's agricultural regions may preclude this practice, as there is little unused land and economics may not support the conversion of arable land to storage reservoirs.

In the ITRC's 2002 survey of non-federal California irrigation districts (17 total), the following information on flexibility was found:

- Only 4 of 16 responding districts allowed shutoffs of scheduled water deliveries without advance notice. Of those that required notice, they required an average 13 hours advance notice.
- 3 of 15 responding districts reported that district personnel were required to be present to open and close turnouts 100 percent of the time. For all responding districts, personnel needed to be present an average of 62 percent of the time.
- Of 10 responding districts, all required advance notice before a change in flow rate is made during a withdrawal event. The average amount of advance notice required was 19 hours.

Together, these responses indicate the difficulty in changing irrigation schedules to respond to DR events for growers receiving water from irrigation districts.

4.3. Insufficient Flexibility of Application Method

Many methods are used to apply water to irrigated fields. These include:

- Gravity (flood) irrigation, in which water is applied to one part of the field, and flows to the rest of the field via gravity
- Sprinkler irrigation, in which water is sprayed onto the field, either via fixed sprinklers, or moveable center-pivot or linear-move sprinklers
- Drip/micro irrigation, in which water is pumped into a network of small flexible tubes, with holes to release water directly onto the soil at the base of the crops
- Subsurface irrigation, in which the water is pumped into a network of pipes and applied directly to the root zone of the crops

Some irrigation methods are more suited to interruption than others. Drip/micro irrigation tends to lead to smaller root balls, which consequently translates to a lower buffering capacity for reduced irrigation. For flood irrigation, stopping and re-starting irrigation can lead to poor application uniformity, as the locations closest to the application point will receive more water than usual due to percolation of the irrigation water from the surface. Sprinkler irrigation is the most flexible.

4.4. Insufficient Flexibility of Labor

For irrigation methods that require labor, the labor force may not be willing to extend or reschedule their hours on short notice. Flood irrigation and hand-move sprinkler systems in particular are labor-intensive. Hand-move systems, as the name suggests, require labor to move them across the field to achieve even water coverage. With flood irrigation, labor must be used to ensure water is not leaking out of the irrigated area. As irrigation automation is not yet prevalent, most growers must be on-site to manually activate pumps, regardless of the irrigation method.

4.5. Insufficient Communications and Controls

Even if the grower is willing and able to shift load, automated control strategies do not have perfect success rates. For example, in Idaho Power's Irrigation Peak Rewards Program in 2008, roughly 15—20 percent of pump load did not shut off when requested, despite being enabled with automatic controls (Idaho Power 2008). In 2009, roughly 15 percent of load equipped with automatic timers did not shut off, roughly 15 percent of load equipped with automatic dispatch controllers did not shut off, and roughly 50 percent of load enrolled under the manual dispatch option did not shut off. Idaho Power solved this problem by switching to a more reliable communications provider, and migrating customers to automated dispatch.

4.6. Insufficient Financial Incentives

As growers are first and foremost operating a business, the financial incentives must make DR participation compelling. Factors affecting the financial incentives of growers include:

- Program Design
- Equipment Wear and Tear
- Risk to Crops

The willingness of a grower to shed load in response to a DR call is dependent on the call details. Growers may be more willing to shift load in a DR event if non-participation is penalized, but fewer growers may decide to enroll in such a program. The frequency, timing, and duration of calls also have an impact on willingness to participate in programs and to shift load when events are called.

Depending on the irrigation system design, growers may be unwilling to start and stop pumps. Deep groundwater wells in particular can be very expensive, and are thought to have a limited number of starts/stops before damage or failure. If the expected value of the well's damage (failure cost * failure probability) is higher than the incentives to participate, then participation is financially unwise. Even moderate or shallower wells can incur some damage from increased start/stops, and so can the pumps, unless they have soft start/stop capabilities.

Finally, there is the risk to the crops themselves. Crops that are particularly water sensitive, or that lack the ability to "catch up" on missed irrigation will suffer from DR events more than resilient crops. Deep effective root zones yield a greater buffering capacity than shallow ones. Crops with a low value per acre are best suited to DR, as there is a lower risk for the same amount of reward (assuming similar irrigation practices).

5.0 Demand Response Opportunities

5.1. Strategies

5.1.1 Changing Irrigation Times

The simplest demand response strategy is to shift load from event hours to non-event hours. This can be accomplished easily for farms utilizing groundwater for irrigation, as they have complete control over the timing of irrigation, subject only to labor constraints and spare irrigation system capacity. Water not pumped during the event hours is instead pumped after the event, or can be scheduled to occur before the event if enough advance warning is given.

For growers utilizing surface water, rescheduling hours of pumping may be more difficult. Irrigation districts have differing levels of flexibility with regards to delivery scheduling, so growers may need to continue pumping during an event in order to receive their water allotment from the district.

5.1.2 Changing Irrigation Sources

If water storage exists at a particular farm, or if the grower has the option to irrigate using either groundwater or surface water, switching irrigation sources may be a viable DR strategy. Though groundwater pumping offers the grower maximum flexibility, it is also the most energy intensive and thus expensive form of irrigation. Irrigating using stored water (for example in an on-site or nearby reservoir) or surface water during an event will allow crop water needs to be met while at the same time reducing demand on the grid.

5.2. Upstream Benefits

For those growers who receive water from an irrigation district and participate in a DR event where they curtail pumping, the benefits of participation extend beyond the farm itself. Assuming there is enough time to coordinate a cancelled delivery with the irrigation district, the aggregate load on the grid can also be reduced because the irrigation district needs to pump less water through its network. Of California's estimated 10 terawatt-hours used for agricultural irrigation water, almost 20 percent of this energy is consumed by irrigation districts to pump water or to convey water to irrigation districts themselves (Burt 2003). In this way, DR strategies at one farm can have a multiplicative effect on overall load reductions. However, as most DR events are short and the time constants of water moving through irrigation districts are large, these load reductions may not overlap with the times of grid need.

5.3. Case Studies

A number of case studies have been conducted detailing the successes and challenges in agricultural irrigation DR programs. The details of these studies are summarized in Table 5 and described further in each sub-section.

Table 5: Summary of irrigation demand response programs

Utility	Program name	Dates of Study	Shed rate	Largest Shed Magnitude
Pacific Gas and Electric Company	Aggregator Manager Program	June 2011–Sept. 2013	68%	15 MW (8/9/2012)
	Capacity Bidding Program	June 2011–Sept. 2013	76%	9.2 MW (7/10/2012)
	Peak Day Pricing	June 2011–Sept. 2013	35%	906 kW (7/19/2013)
Southern California Edison	Agricultural and Pumping Interruptible	2008, 2010–2012	57%–85% (by event)	40 MW (7/29/2010)
Idaho Power	Irrigation Peak Rewards	2005, 2007–2012	*Not available*	221 MW (7/9/2010)
Rocky Mountain Power	Irrigation Load Control (Idaho)	2009–2011, 2013	*Not available*	247 MW (2009 avg.)
	Irrigation Load Control (Utah)	2009–2013	*Not available*	49 MW (2010 avg.)
Midwest Energy	Pump Curtailment Rider (Pump$mart)	2010–2013	*Not available*	23 MW (controlled)
NV Energy	Interruptible Irrigation Service	2009–2013	~70%	~25 MW (7/19/2009)
Golden Spread Electricity Cooperative	Irrigation Load Control	2009–2012	*Not available*	58 MW (7/6/2012)

5.3.1. Pacific Gas and Electric Company

Based on demand data from Pacific Gas and Electric's (PG&E's) agricultural customers, as well as information from PG&E on event dates and times, a detailed analysis of the performance of PG&E agricultural customers was performed.

From June 21, 2011 through September 10, 2013, there were 71 demand response events for which the Lawrence Berkeley National Laboratory (LBNL) dataset contains interval data for agricultural irrigation customers. Of these, 15 were Aggregator Managed Portfolio (AMP) events, 22 were Capacity Bidding Program (CBP) events, and 34 were Peak Day Pricing (PDP) events. Due to overlaps of calls, there were 37 days of events: 15 in 2011, 11 in 2012, and 11 in 2013.

If load sheds are measured using the 3/10 baseline (the average demand of the three days of highest energy consumption, from the previous ten non-event weekdays), load sheds were achieved in 62 of 71 events. CBP events generated the most load shed with a weighted average shed of 76 percent, AMP program events have a weighted average shed of 68 percent, and PDP events have a weighted average shed of 35 percent. The weighting for these averages is the baseline loads; if not weighted the average sheds are 68 percent, 67 percent, and 41 percent for CBP, AMP, and PDP, respectively. These and other summary numbers are shown in Table 6.

Table 6: Event data for the AMP, CBP, and PDP program, June 2011–September 2013

Program Name	Number of Events	Average Duration	Average Shed (kW)	Average Shed % (weighted)	Minimum Shed %	Maximum Shed %
AMP	15	3.3 hrs.	5657 kW	68%	45%	85%
CBP	22	3.3 hrs.	3104 kW	76%	5%	99%
PDP	34	4.4 hrs.	385 kW	35%	4%	87%

No significant trend was observed in participation rates by time of year, as seen in Figure 7. However, when participation rates are plotted against the baseline demands, as seen in Figure 8, there is a significant relationship. For events in which the baseline demand is less than 3 MW, shed percentages are highly variable, while events in which the baseline demand is greater than 3 MW all have participation rates above 60 percent.

Further insight can be gained by disaggregating the results by program. For PDP, in which all baseline demands are less than 3 MW, a significant negative correlation is seen between baseline demand and shed percentage, as seen in Figure 9 ($r^2=0.56$, $n=27$, $p<0.001$). For AMP and CBP, a significant negative correlation is seen for those events in which the baseline demand is greater than 3 MW, as seen in Figures 10 and 11 (AMP: $r^2=0.63$, $n=9$, $p<0.02$; CBP: $r^2=0.75$, $n=12$, $p<0.001$). When filtering out the events in which the demand was less than 3 MW, and plotting the participation rate of those events by date, a pattern emerges: participation rates for both AMP and CBP are higher at the beginning and end of the season than they are in the middle (August and July), as seen in Figure 12. This is to be expected, as these are the months with highest baseline demand, when the water demand of irrigated crops is closest to the irrigation system capacity.

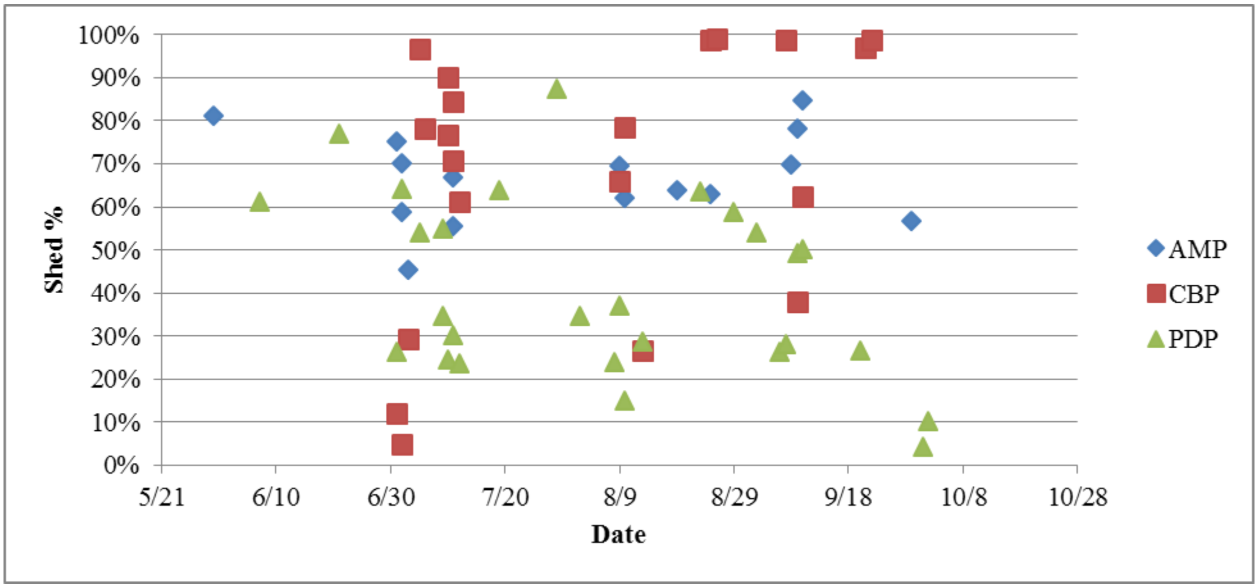


Figure 7: Participation rates, by program and date

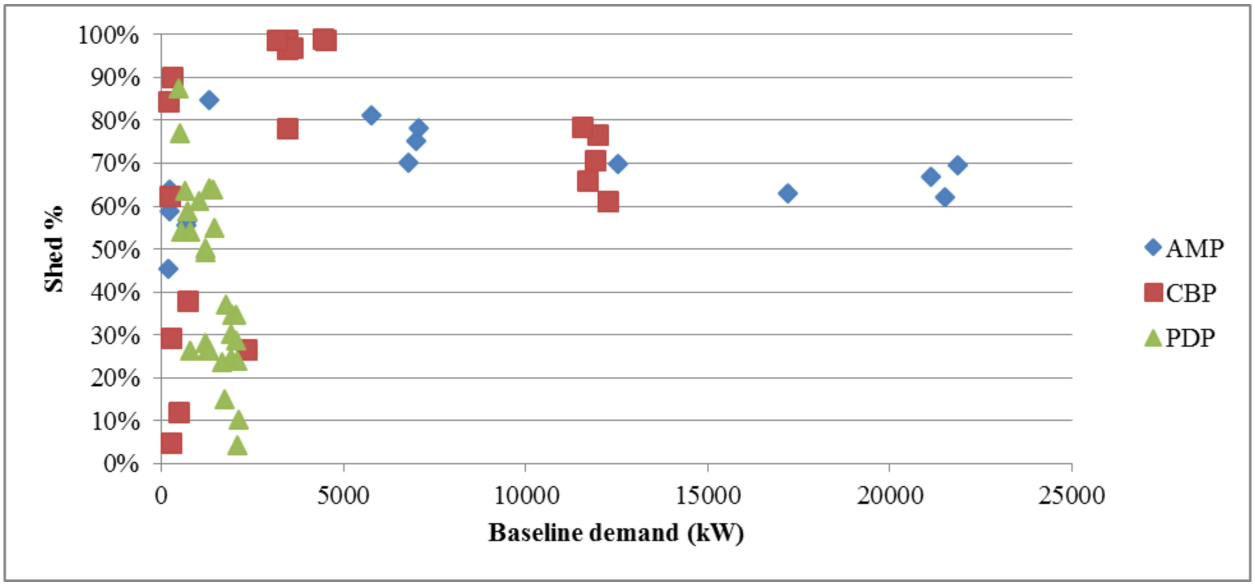


Figure 8: Participation rates, by program and baseline demand

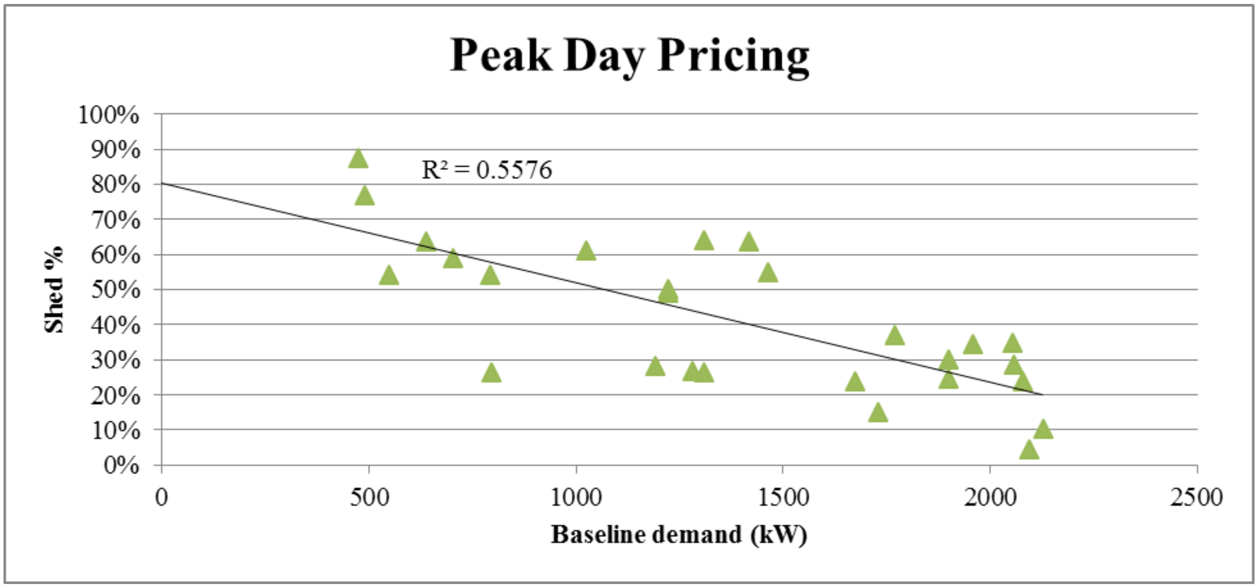


Figure 9: Peak Day Pricing (PDP) participation rates, by baseline demand

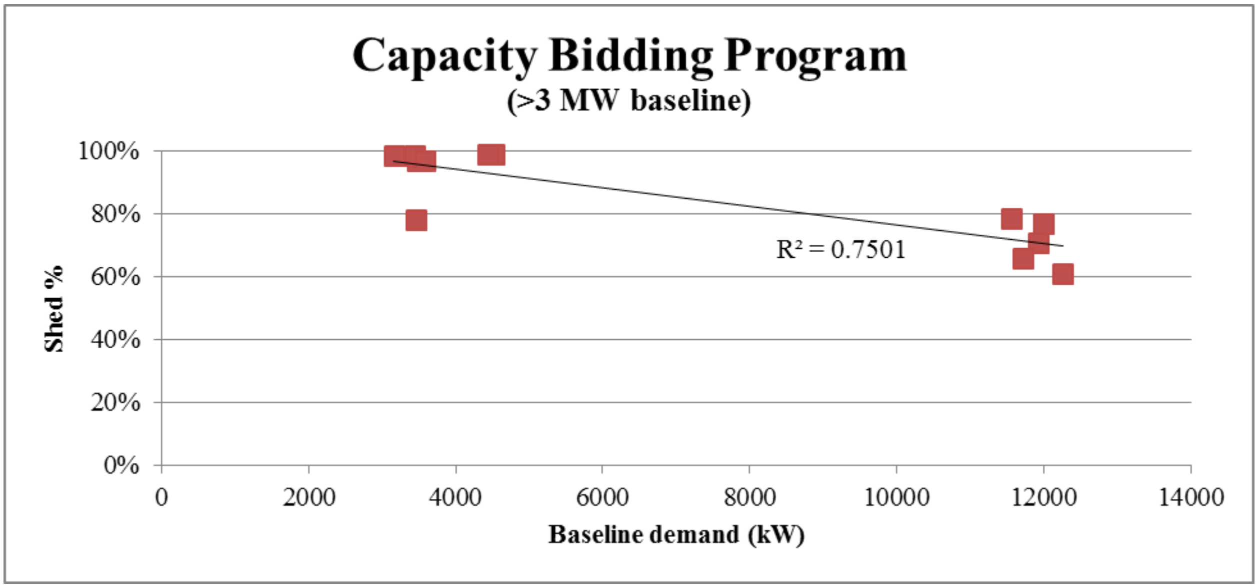


Figure 10: Capacity Bidding Program (CBP) participation rates, by baseline demand

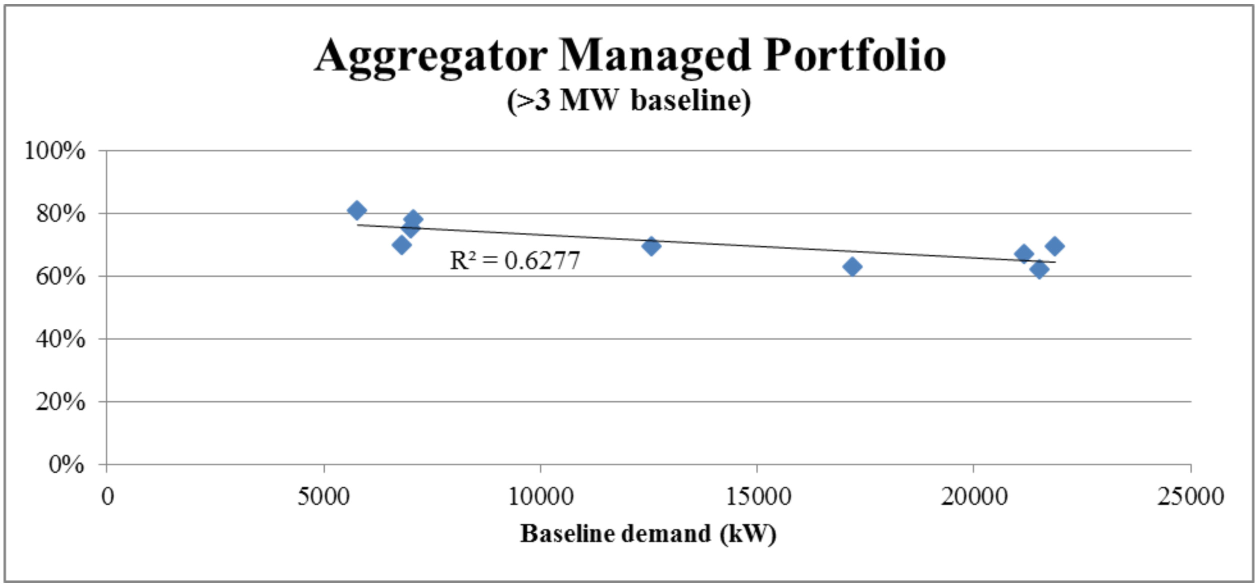


Figure 11: Aggregator Managed Program (AMP) participation rates, by baseline demand

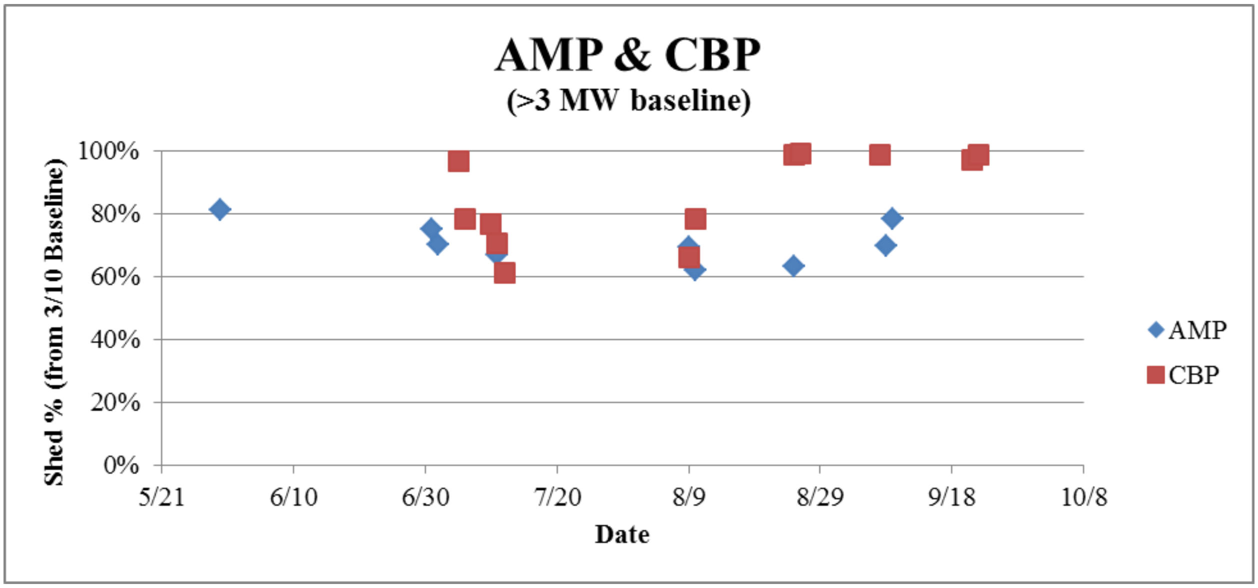


Figure 12: Participation rates by program and date, for AMP and CBP

5.3.2. Southern California Edison: Agricultural and Pumping Interruptible Program

The Southern California Edison (SCE) Agricultural and Pumping Interruptible (AP-I) Program is available for agricultural and pumping customers with at least 50 horsepower (hp) (37 kW) of load per service account. The program has operated since the 1970s, but was closed to new enrollment in 1998. In 2001, as a result of the 2000/2001 California electricity crisis, the program was re-opened for new enrollment. In 2006, marketing of the program was increased with the goal of increasing enrollment; as a result, enrollment more than tripled between the beginning of 2006 and the end of 2010, from 300 to 1,115 enrolled accounts (Southern California Edison 2013).

When an interruption is deemed necessary, SCE activates transmitters that communicate with load control devices installed at customer sites, automatically de-activating pumps for the duration of the event. After events, customers must manually re-activate their pumps. Customers can request notification of event start and end times via email, page, or text message. Interruptions are limited to a maximum of 1 per day, 4 per week, and 25 per year, with durations limited to 6 hours per event, 40 hours per month, and 150 hours per year. In practice, the events are much less frequent than their limits.

In return, customers on time-of-use (TOU) rates (greater than 95 percent of AP-I customers) are credited based on their demand profile: during summer months customers are credited based on their average on-peak demand and their average mid-peak demand, while in winter they are credited only based on their mid-peak demand. Customers not on TOU rates are credited at a constant rate per kilowatt-hour, year-round. Prior to 2009, all incentives were at a constant rate per kilowatt-hour.

A summary of recent event data is shown in Table 7. Switch success rates are based on the number of switches assumed to have shed load (>50% drop), divided by the total number of the customers assumed to be running pumps in the hour before the event (customers whose load in that hour was greater than 5 percent of their daily peak load). "Reference loads" for each hour are calculated based on a multivariate regression based on the following variables:

- A constant
- A binary variable for each hour of the day
- A binary variable for each month
- A binary variable for each day of the week, and for holidays
- The ratio of current energy cost to average daily energy cost
- The average daily energy cost
- The sum of cooling degree hours for the day (with a 65° base)
- The square of the sum of cooling degree hours for the day
- The sum of heating degree hours for the day (with a 65° base)
- The square of the sum of heating degree hours for the day
- A weighted average of the rainfall from the previous seven days
- A weighted average of the cooling degree days from the previous seven days
- Participation in other DR events
- A binary variable representing an AP-I event.

Not all variables were used to determine the reference loads for each year, but most were. In aggregate, the selected variables explained greater than 90 percent of the variation in energy use for each year, with yearly r^2 values ranging 0.93 to 0.99 for the years 2008, 2010, 2011, and 2012.

Table 7: Southern California Edison's recent AP-I events

Event Date	Event Time	Reference Load (MW)	Load Shed (MW)	Shed Rate (%)	Switch success rate (%)
11/7/2008	11:13am–11:51am	29.1	16.4	57%	78% (n = 311)
7/29/2010	6:57pm–7:28pm	52.8	39.7	75%	81% (n = 433)
9/27/2010	3:16pm–4:31pm	34.4	27.1	79%	85% (n = 342)
9/21/2011	1:48pm–3:01pm	41.5	33.4	80%	85% (n = 384)
8/14/2012	3:30pm–9:23pm	26.5	17.3	65%	N/A†
9/26/2012	2:50pm–4:00pm	28.1	24.0	85%	88% (n = 263)

† On August 14, as a result of a transmitter failure, not all switches received the shutoff signal

Source: Southern California Edison 2009, 2011, 2012, 2013

Southern California Edison had a target of 95 percent switch success rate across all local control areas by 2015.

5.3.3. Idaho Power's Irrigation Peak Rewards Program

Idaho Power's Irrigation Peak Rewards program began in 2004. Initially, it reduced load in peak hours using programmable timers integrated with the customers' pumping systems, which shut off pumps during pre-selected hours (weekday afternoons) and restarted them afterward. If pumps were already off, the controls prevented them from turning on. Incentives were given monthly, depending on the customer-nominated number of days of interruption per week and the baseline demand of the customer (monthly billing demand). For example, in 2005, incentive rates were $2.01 per kilowatt of demand for participating one day per week, $2.51 per kilowatt for two days per week, and $2.76 per kilowatt for three days per week. These incentive levels changed over the years. Table 8 shows details on program participation over the years.

In 2009, an option was added for automatic dispatch of pump stoppages, with day-ahead notice of events and reminders 30 minutes before the events began. This implementation was a form of direct load control (DLC), with communication to the pump controllers via cellular or satellite signals. Large customers were also able to participate in the dispatch option, controlling their pumps manually ("manual dispatch"). In addition, an energy credit was added, giving customers a set incentive per monthly billing kilowatt-hour. Customers were allowed to opt-out of events, but this incurred a penalty based on monthly billing kilowatt-hours or monthly billing kilowatts.

The program was evaluated using a "realization rate", a ratio of the amount of load shed during each event to the sum of the monthly billing demand for each participating customer. This value changed over the course of the season as demand rose and fell, but averaged around 50 percent.

Table 8: Details of implementation of Irrigation Peak Rewards Program

Year	Program options	Participation rate		Maximum load reduction (MW)
		Customer %	Meter %	
2005	Timer	23%	23%	40.3
2006	*No information available*			
2007	Timer	19%	20%	37.4
2008	Timer	19%	18%	34.5
2009	Timer, automated dispatch, manual dispatch	6%	9%	160
2010	Timer, automated dispatch, manual dispatch		11%	221
2011	Timer, automated dispatch, manual dispatch		12.5%	320*
2012	Timer, automated dispatch, manual dispatch		13%	340*

*Not called this year, estimations of load reductions

Sources: Idaho Power 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014.

In 2011 and in 2012, it was not necessary to call the dispatch option, so estimates were made of the potential load shifts that could have been achieved. The program was not foreseen to be necessary in 2013, and it was suspended. However, it was re-offered for the 2014 season: Monday-Saturday from June 15 through August 15, events could occur from 1 pm–8 pm (or 9 pm for extended option), up to 4 hours/day, up to 15 hours/week, and up to 60 hours/season. In addition, all timer participants were converted to automated dispatch.

5.3.4. Rocky Mountain Power's Irrigation Load Control Program

Rocky Mountain Power is an electric utility serving Utah, Wyoming, and southeastern Idaho. They have operated their Irrigation Load Control program since 2003 in Idaho and since 2005 in Utah (Rocky Mountain Power 2010a and 2010b). In each state, they offer a timed option (Schedules 72 and 96) and a day-ahead dispatchable option (Schedules 72A and 96A). Participants are allowed to opt-out of dispatched events by paying a penalty. Program implementation details are summarized in Table 9. Beginning in 2013, Rocky Mountain Power selected EnerNOC to manage the Irrigation Load Control program through a "pay for performance" structure (Rocky Mountain Power 2014a).

Several of Rocky Mountain Power's reports on the Idaho program noted that there was no indication by growers of adverse impacts to crop yield or quality, and that a local presence of irrigation specialists was key to program success. However, due to low load diversity and high program participation, several substations in Idaho have experienced over-voltage issues at the beginning of events when a large quantity of load disconnects, and under-voltage issues at the end of events when a large quantity of load reconnects. To combat this, Rocky Mountain Power began staggering the deactivation and reactivation of these loads to allow voltage stabilitization to occur (Rocky Mountain Power 2010a).

Table 9: Details of Rocky Mountain Power's Irrigation Load Control events

	Idaho			Utah		
Year	Number of events (total duration)	Load reductions (average)	Program cost	Number of events (total duration)	Load reductions (average)	Program cost
2009	6 events (24 hours)	247.1 MW	$11.1M	*Not available*	40.2 MW	$2.7M
2010	15 events (51 hours)	156 MW	$12.4M	*Not available*	49.1 MW	$2.5M
2011	3 events	164 MW	$9.3M	*Not available*	*Not available*	$2.5M
2012	*Not available*			12 events (46 hours)	25 MW	$2.1M
2013	10 events (40 hours)	150 MW	*Not available*	10 events (40 hours)	13 MW	*Not available*

Sources: Rocky Mountain Power 2010a, 2010b, 2011a, 2011b, 2012a, 2012b, 2013a, 2013b, 2014a, 2014b

PacifiCorp, which owns Rocky Mountain Power, has projected a market potential of 221.5 MW of irrigation DR in their territory by the year 2032: 172 MW in Idaho, 38.2 MW in Utah, 4.5 MW in California, 3.8 MW in Washington, 2.8 MW in Oregon, and 0.2 MW in Wyoming. Levelized costs are estimated to be $51–$64/kW-year, depending on the state, with Idaho and Utah representing the bottom of the range (Cadmus Group 2013).

5.3.5. Midwest Energy

Midwest Energy, serving northwestern Kansas, began an irrigation demand response program in 2010 as a pilot project. The program, Pump$mart (officially the Pump Curtailment Rider), runs from June 1 to August 31 annually, and can call events from 2pm-9pm, Monday-Saturday, with a maximum of 1 event per day, 4 hours per event, and 20 events per year. Incentives are $20/kW for the first year, $24/kW for the second year, and $28/kW for the third year and beyond, encouraging continued enrollment. There is also a "Plus" option, which awards a $32/kW incentive for being able to participate over a wider time range (12pm-9pm), longer events (up to 6 hours each), and more total hours (120 hours), compared to the standard option. The program controlled 1.8 MW in 2010 (pilot program) and 10.5 MW in 2011, and it had grown to 23 MW by 2013 (Midwest Energy 2012, 2014a, 2014b).

5.3.6. NV Energy

NV Energy, serving much of Nevada, including the Las Vegas and Reno areas, operates an Interruptible Irrigation Service (officially IS-2). Under this tariff, NV Energy can interrupt service to customers between March 1 and October 31 for the purpose of responding to reliability concerns (NV Energy 2013). As of 2015, the program had not been exercised, except for one test, as shown in Figure 13. In this test, 984 accounts shed a total of 20–25 MW for one hour.

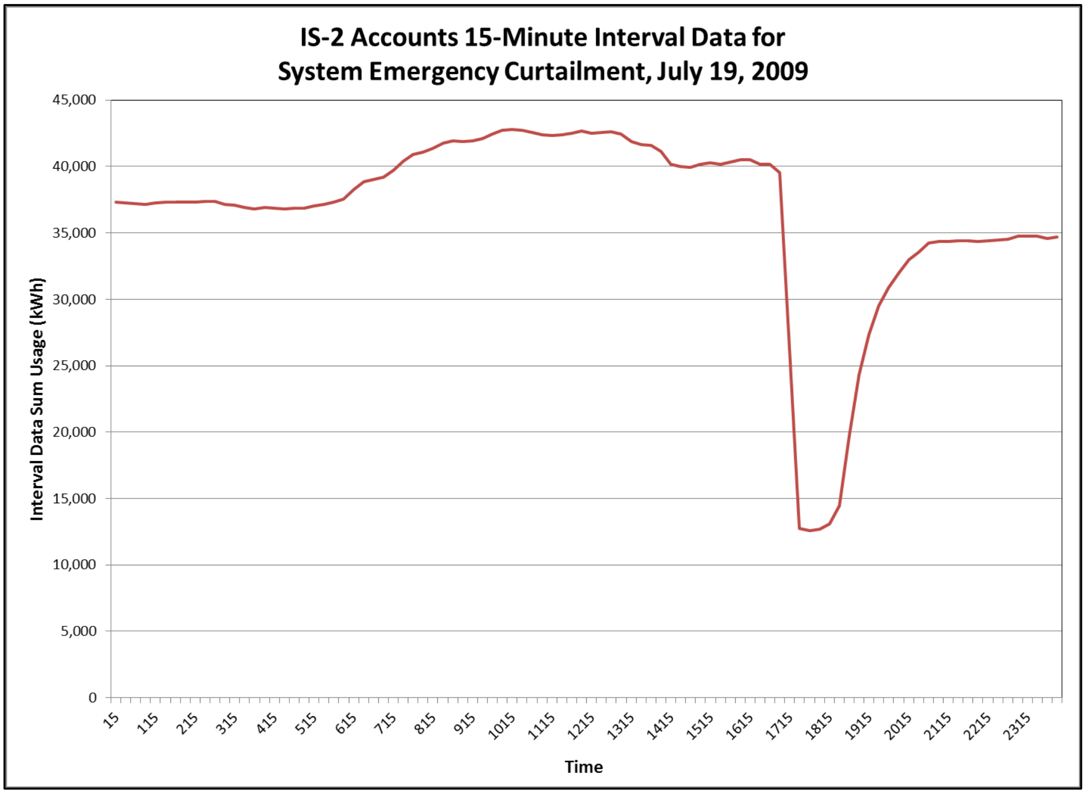


Figure 13: Load profile for Interruptible Irrigation Service customers on a test day
Source: Haixiao Huang, NV Energy. Personal communication.

5.3.7. Golden Spread Electric Cooperative

The Golden Spread Electricity Cooperative serves northwestern Texas and the Oklahoma panhandle. Of its 16 member cooperatives, 4 participate in an emergency load control program: Lamb County, Lighthouse, North Plains, and South Plains. As of 2015, the program has not been needed, but it has been called for three tests from 2009–2012.

- On August 7, 2009, a test was called and participants shed 34.2 MW out of a pool of 108,183 enrolled horsepower (80.7 MW) (42 percent), compared to a daily peak of 1,114 MW for the entire service area. Two members had not maintained their communications and control equipment, leading to lower participation than expected.
- On June 15, 2011, a test was called and participants shed 41.5 MW out of a pool of 130,047 enrolled horsepower (97.0 MW) (43 percent), compared to a daily peak of 1135 MW for the entire service area. One member had not maintained its communications and control equipment, leading to lower participation than expected.

- On July 6, 2012, a test was called and participants shed 57.8 MW out of a pool of 146,778 enrolled horsepower (109.5 MW) (53 percent), compared to daily peak of 1140 MW for the entire service area.

Golden Spread previously based its payments to growers on the assumption that 50 percent of the enrolled horsepower would curtail, so they were satisfied with the 53 percent achieved in the 2012 test. Currently, the program relies on the members offering the capacity they can shed (in MW). Total program enrollment in 2014 was 51 MW (Personal communications, Shane McMinn, GSEC).

5.3.8. Other Programs

In addition to the results from the case studies, many other utilities also offer demand response program for irrigation, but detailed information was not available:

- **Entergy Arkansas** runs the Agricultural Irrigation Load Control Program that operates weekdays June–August, for a maximum of three hours between 12pm and 9pm. The program offered $4.16/kW-month, and reported 7 events in 2013.[1]
- **Nebraska Public Power District**, which serves 25 public power districts in Nebraska, runs a program that operates from 10am–10pm, June-September.[2]
- **AEP Texas** runs the **Irrigation Load Management Program**, which operates weekdays June–September, from 1pm–7pm, with events ranging from 1–4 hours/event a maximum of 4 events/month, 60-minute advance notice, with direct load control.[3]
- **WIN Energy REMC** (Western Indiana Energy Rural Electric Membership Corporation) runs a program which operates weekdays 4 pm–6 pm central, with fixed rebates ($750/$1,000) per controlled pivot, a $27/kW demand charge if active during peak hour, and $100 checks every year.[4] WIN Energy REMC reports 10 MW of load shed.[5]

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[1] Entergy Agricultural Irrigation Load Control Program. http://www.entergy-arkansas.com/your_business/save_money/EE/agricultural-irrigation.aspx

[2] Nebraska Public Power District. Interruptible Irrigation Service Rate Schedule. http://www.nppd.com/assets/irrig3.pdf

[3] EnerNOC. FAQ – AEP Texas Irrigation Load Management Program. http://www.enernoc.com/our-resources/brochures-faq/faq-aep-texas-irrigation-load-management-program

[4] Win Energy. Take a Load off… the Peak. Irrigation Load Control Program. http://winenergyremc.coopwebbuilder.com/sites/winenergyremc.coopwebbuilder.com/files/program_flyer_2.pdf

- **Medina Electric Cooperative** in Texas offers reduced rates for irrigation load management participants.[6] Approximately 90% of irrigators participate in the program.
- **Cass County Electric Cooperative** appears to be participating in the same system as the Nebraska Public Power District.[7]

Many of these utilities (Nebraska public power districts, WIN Energy, Medina, and Cass County) are a part of Touchstone Energy, suggesting a coordination of efforts.

5.4. Estimated Potential in California

Based on the estimates of peak load, participation rate, and load shed rates, an estimate can be made of the DR potential of agricultural irrigation pumps in California, based on the methodology in Equations 1 and 2. The 2007 peak load is used because that is the most recent estimate of irrigation peak load (House 2007), and the load growth is assumed to be consistent with the energy growth as estimated by the Energy Commission (California Energy Commission 2014a & 2014b).

$$DR\ Technical\ Potential = 2007\ Load * Load\ Growth(2007-2015) * Shed\ Rate \quad (1)$$

$$DR\ Potential = 2007\ Load * Load\ Growth(2007-2015) * Shed\ Rate * Participation \quad (2)$$

If agricultural irrigation peak demand is assumed to have increased at the same rate as overall electricity consumption, peak demand is estimated to be 1,330 MW in 2015, and 1,450 MW by 2020. Assuming a shed rate of 80 percent (based on the PG&E and SCE case studies), the technical potential exists for over 1 GW of demand response from agricultural irrigation in 2015, and over 1.1 GW by 2020. With a participation rate of 15 percent (based on the case studies from Idaho Power), this represents approximately 160 MW of DR potential in 2015, and 175 MW of DR potential by 2020.

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[5] *EnergyLines*. February 2014. Vol. 37, No. 2. http://www.hepn.com/assets%5Cfiles%5Cenergylines%5CFebruary%202014.pdf

[6] Load Management | Medina Electric Cooperative. http://www.medinaec.org/loadmgmt

[7] Cass County Electric Cooperative. Load Control for Farms. http://www.kwh.com/content/load-control-farms

6.0 Conclusions and Future Research

6.1. Conclusions

Agricultural irrigation is a valuable resource for demand response, because of the large loads that are typically present and the inherent storage capabilities of wetted soil. Based on analysis of several DR programs in California and elsewhere in the United States, we estimate that there are 160 MW of achievable DR potential in California, and 1 GW of technical potential. By 2020, these values are expected to grow to approximately 175 MW of achievable DR potential, and 1.1 GW of technical potential. This technical potential is limited by several constraints common to farms in California: insufficient irrigation capacity, insufficient flexibility of water deliveries, labor, and irrigation methods, insufficient communications and controls, and insufficient financial incentives.

The gap between the technical and achievable potential can be narrowed by expanding the marketing of DR programs, increasing the incentives for participation, decreasing the costs of communication and control systems, increasing pump capacity to improve flexibility in irrigation scheduling, improving the efficiency of existing pumps to increase irrigation system capacity, increasing the presence of on-farm water storage, and increasing the flexibility of irrigation district surface water deliveries.

6.2. Future Research

Though we have been able to estimate the potential for DR in California agriculture and documented its constraints, there are still many gaps in the literature regarding how to accurately predict agricultural DR. Further research to improve the robustness of this topic could include:

- An updated study on the current electricity consumption related to agricultural water. The most detailed estimates of agricultural energy consumption and peak load are currently 12 and 8 years old, respectively, and the ongoing drought in California has surely influenced both of these.
- More detailed information on the population of California growers, e.g. crops grown, water sources, and irrigation methods. Since each of these factors influences the potential for demand response participation, more information would allow better estimation of grower flexibility.
- Surveys of large growers to determine their motivations (or lack thereof) for participating in demand response. This would allow agricultural demand response programs to be better tailored to the needs of growers.

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8.0 Glossary

Abbreviation	Definition
AMP	Aggregator Managed Program
AP-I	Agricultural and Pumping Interruptible tariff
Auto-DR	Automated Demand Response
CA DWR	California Department of Water Resources
CBP	Capacity Bidding Program
CEC	California Energy Commission
DLC	Direct Load Control
DR	Demand Response
ET	Evapotranspiration
ETo	Reference evapotranspiration
GW	Gigawatt
GWh	Gigawatt hour
ITRC	Irrigation Training and Research Center
kWh	Kilowatt hour
MW	Megawatt
NAICS	North American Industry Classification System
PDP	Peak Day Pricing
PG&E	Pacific Gas and Electric Company
SCE	Southern California Edison
TOU	Time-of-Use
TWh	Terawatt hour
USDA	United States Department of Agriculture