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OPPORTUNITIES FOR DEMAND RESPONSE IN CALIFORNIA AGRICULTURAL IRRIGATION: A SCOPING STUDY

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study is the final report for the Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study project (contract number 500-03-026) conducted by the Demand Response Research Center. The information from this project contributes to PIER's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

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ABSTRACT

California agricultural irrigation consumes more than ten billion kilowatt hours of electricity annually and has significant potential for contributing to a reduction of stress on the grid through demand response, permanent load shifting, and energy efficiency measures. To understand this potential, a scoping study was initiated for the purpose of determining the associated opportunities, potential, and adoption challenges in California agricultural irrigation.

The primary research for this study was conducted in two ways. First, data was gathered and parsed from published sources that shed light on where the best opportunities for load shifting and demand response lie within the agricultural irrigation sector. Secondly, a small limited survey was conducted as informal face-to-face interviews with several different California growers to get an idea of their ability and willingness to participate in permanent load shifting and/or demand response programs.

Analysis of the data obtained from published sources and the survey reveal demand response and permanent load shifting opportunities by growing region, irrigation source, irrigation method, grower size, and utility coverage. The study examines some solutions for demand response and permanent load shifting in agricultural irrigation, which include adequate irrigation system capacity, automatic controls, variable frequency drives, and the contribution from energy efficiency measures.

The study further examines the potential and challenges for grower acceptance of demand response and permanent load shifting in California agricultural irrigation. As part of the examination, the study considers to what extent permanent load shifting, which is already somewhat accepted within the agricultural sector, mitigates the need or benefit of demand response for agricultural irrigation. Recommendations for further study include studies on how to gain grower acceptance of demand response as well as other related studies such as conducting a more comprehensive survey of California growers.

Keywords: demand response, automated demand response, OpenADR, Time-of-Use, permanent load shifting, agricultural irrigation, irrigation controls, irrigation energy efficiency, agriculture variable frequency drives

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EXECUTIVE SUMMARY

Introduction

California agricultural irrigation consumes more than ten billion kilowatt hours of electricity annually. Furthermore, the electricity is consumed almost entirely between the months of May and October, which is during the period of greatest stress on the electricity grid. As many of the irrigation schedules are intrinsically flexible, significant potential exists for reducing stress on the grid through demand response (DR), permanent load shifting, and energy efficiency measures aimed at agricultural irrigation power use.

While permanent load shifting programs are fairly common among California growers, DR programs are much less common. Although in recent years, DR aggregators have successfully sold and administered some limited DR for California agriculture, the programs have mostly been operated as manual DR (for peak load reduction). With the energy intensity and intrinsic flexibility of irrigation, there is also tremendous potential for implementation of Automated Demand Response (AutoDR). Through AutoDR, irrigation can supplement California's quick response shed capacity, thereby contributing to the 4 gigawatts of ancillary services anticipated to be required to maintain grid stability in the context of the 2020 renewable portfolio standards (RPS) deployment goals (Masiello *et al.* 2010). Furthermore, as California's electricity markets move toward dynamic (real-time) pricing, growers may be significantly motivated to adopt AutoDR for their irrigation systems in response to price signals.

Some of the positive benefits of DR may potentially be accomplished effectively with permanent load shifting, which are often incentivized by way of Time-of-Use (TOU) programs[1]. However, it is expected that there would still be significant opportunity for peak-period DR, as not all irrigation would be shifted off-peak. At certain times of the year, some crops are irrigated nearly continuously because of the capacity of the irrigation system relative to the needs of the crops during highest evapotranspiration periods, or because of the nature of the crop itself. Furthermore, DR events are not restricted to peak times, so even when an irrigation system is run exclusively during off-peak times, there is still potential for DR participation.

Finally, irrigation systems on which energy efficiency and permanent load shifting measures have been implemented provide some of the best opportunities for AutoDR, as these measures may be adaptable for AutoDR participation. For example, Internet connectivity, which is required for AutoDR, may already be in place for crop environmental data monitoring and for remote irrigation scheduling. Also, the most demanding efficiency and permanent load shifting measures require sophisticated controllers that could also run AutoDR client software.

[1] Time-of-Use programs incentivize consumers to decrease electric usage during peak demand hours by imposing higher rates during peak hours in exchange for much lower rates during off-peak hours.

Purpose and Objectives

The purpose of this project was to conduct a scoping study of DR and permanent load shifting opportunities, and the adoption challenges in California agricultural irrigation. The specific objectives of the study were as follows:

- Parse the California irrigation load into categories using criteria such as growing regions, water sources, irrigation methods, and crop types. Then, examine the categories to determine how to focus efforts to gain the highest potential impact from DR and permanent load shifting programs.
- Determine where the best opportunities lie for DR and permanent load shifting programs in California agricultural irrigation.
- Suggest possible DR and energy efficiency solutions where applicable.
- Make initial limited determination for potential acceptance among California growers and what challenges and obstacles might exist for DR and permanent load shifting programs.
- Identify follow-up studies for the best opportunities for DR and energy efficiency including more extensive field studies and surveys of growers to assess potential acceptance.

Key Findings

Identified Data Skews and Trends from Published Sources and Survey

Data from published sources and a small limited survey was parsed into categories delimited by growing regions, water source, irrigation method, crop type, grower business size, and utilities servicing the California growing regions. Analysis of the categories yielded some interesting data on the concentration of energy use as well as some other significant trends:

- Most of the energy used for irrigation occurs in the Central Valley of California (Sacramento and San Joaquin Valleys combined), especially in the San Joaquin Valley.
- The greatest energy per unit of water applied occurs in the coastal growing regions.
- The greatest energy use by water source comes from the on-farm sources, and in particular, from ground water sources.
- There is a continuing trend toward converting from flood to drip/micro irrigation, which while reducing the amount of water applied, increases the amount of energy used.
- There is a strong Pareto Principle[2] correlation of grower size with regard to acres irrigated and therefore to irrigation energy use. About 14% of the growers, approximately 6,500, irrigate 84% of the irrigated acres in California agriculture, roughly 6.2 million acres.
- The growing regions' utility coverage is dominated by a few utilities, but especially by Pacific Gas and Electric (PG&E).

[2] The Pareto Principle (also known as the "80-20 rule" or the "law of the vital few") states that in many systems, roughly 80% of the effects come from 20% of the causes. Though the number 80% is not mathematically significant, this rule of thumb is a good approximation in many real-world examples.

Best Opportunities for Demand Response and Permanent Load Shifting Programs

Growing Region

The best regional opportunities for DR and permanent load shifting are in the Central Valley of California, especially in the San Joaquin Valley where the greatest amount of energy is consumed for agricultural irrigation.

Irrigation Source

The best irrigation source opportunities for DR and permanent load shifting come from on-farm sources, especially ground water sources, where over seventy percent of the total energy expended in California agricultural irrigation is consumed.

Irrigation Method

The best irrigation method opportunities for DR and permanent load shifting come from drip/micro sprinkler systems, the installation of which is a growing trend. Conversions to drip/micro frequently have compound effects on energy use by requiring the addition of both booster pumps and, in some cases, ground water pumps.

Irrigation System Capacity

The best opportunities for DR and permanent load shifting come from irrigation systems that can supply adequate water to a crop without running constantly (24/7) during peak evapotranspiration (ET) periods. Evapotranspiration refers to the transit of water from soil to air, via evaporation from the soil surface and transpiration through plant surfaces; the need to replace this water drives agricultural irrigation loads. At the bare minimum, all irrigation systems must have enough capacity to handle a crop's water requirements during peak ET periods. Consequently, all irrigation systems have excess capacity during non-peak ET periods, and can therefore contribute to load shifting and quick shed capacity for part of the growing season.

Variable Frequency Drives

The deployment of variable frequency drives (VFDs) for irrigation pump motors represents one of the greatest potentials for energy savings in agricultural irrigation. They can be used to match pressure requirements to an irrigation distribution network so that pressure doesn't have to be shed through valves. VFDs can also ease the stress on pumps and wells by allowing soft start/stop capability, which makes additional start/stops for DR less objectionable.

Grower Business Size

By working with the largest growers, the California utilities can address the majority of the potential load shifting and DR capacity of agricultural irrigation.

Utility Coverage

By working with the utilities that cover the majority of the dominant California growing regions (primarily PG&E and SCE), California can address the majority of the DR and permanent load shifting potential of agricultural irrigation.

Solutions (or Requirements) for Demand Response and Permanent Load Shifting Programs

Adequate Irrigation System Capacity

The most basic requirement for an irrigation system to accommodate either DR or permanent load shifting is the capacity to meet crops' needs without running 24/7. One way to increase irrigation system capacity is to increase system efficiency. Three energy efficiency approaches are considered:

- Improved Irrigation Pump Efficiency: Increasing the hydrological energy output vs. electrical energy input, generally referred to as overall pumping plant efficiency (OPPE).
- Reductions in Water Application: Reducing the amount of water applied while still meeting crops' irrigation requirements.
- Reductions in Pressure Losses: Identifying and eliminating unnecessary pressure losses in irrigation systems allowing water to be applied with less energy.

Automatic Controls

The best potential for executing DR and permanent load shifting in irrigation comes from pumps with automatic controls, which are uncommon with California growers. These controls have the potential to improve the reliability of permanent load shifting and manual DR.

Storage

In situations where irrigation cannot be interrupted during peak hours or for DR events, it may be possible to use gravity-fed stored water that's been accumulated during off-peak times. Even if booster pumps are required during peak hours or DR events, storage could shift the power used to draw from wells. Investing in water storage may not be practical for individual growers; however, it could be practical for irrigation districts.

Variable Frequency Drives

Variable frequency drives can be used to create a soft start/stop feature that reduces stress on the entire irrigation system, but especially on the well, which creates more flexibility for participation in DR and load shifting programs.

On-Site Solar Power Generation

On-site grid-tied solar power, which generates peak-power mid-day coincident with the grid's peak periods, would offset a part of the daytime pumping load and move a greater share of the agricultural pumping energy off-peak.

Potential Grower Acceptance of Demand Response and Permanent Load Shifting

Grower participation in permanent load shifting or Time-of-Use plans is already fairly common. Further, manually administered DR for peak load shifting has been gaining some acceptance among growers in the last few years primarily through the efforts of DR aggregators[3].

[3] The Energy Information Administration defines an aggregator as a marketer, broker, public agency, city, county, or special district that combines the loads of multiple end-use customers in facilitating the sale and purchase of electric energy, transmission, and other services on behalf of these customers (EIA n.d.).

However, it will be much more challenging to gain grower acceptance of AutoDR or "Real-time-DR", which will be required for response to dynamic pricing and real-time response to events. Grower acceptance of DR and permanent load shifting is also very dependent on financial incentives, which must at least offset the costs incurred by the growers' involvement.

Excess Irrigation Capacity

Growers with on-farm water supply that do not need to run their irrigation systems 24/7 in order to meet their crops' needs during peak ET periods have the greatest potential for participating in DR programs. Without this excess capacity, growers are restricted to participating during non-peak ET periods, when they do not need to run their irrigation systems continuously, or must upgrade their systems in order to participate. Both of these options reduce the value proposition of DR participation.

On-Farm Water Sources

Irrigation schedule control for growers that take water from irrigation districts varies somewhat with the irrigation district, but it is generally less flexible than it is for growers with on-farm sources of water. Growers with on-farm water sources are likely to be more accepting of DR, as they have greater flexibility to reschedule their pumping.

Permanent Load Shifting vs. Demand Response

If the bulk of the agricultural irrigation load can be permanently shifted to off-peak periods, then there is less need for DR. As TOU rate plans are already accepted and quite common among California growers, there may be an advantage to just encouraging more growers to adopt and conform to TOU plans. However, it should be considered that an irrigation system must have a greater capacity in order to accommodate permanent load shifting, as compared to DR, since a greater volume of water must be pumped off-peak.

Further, if the need for real-time response to DR events and dynamic pricing are significant enough, then it may warrant the efforts required to increase acceptance of DR programs, particularly AutoDR. There is little to no acceptance yet among growers for using automatic pump controls which would be required for AutoDR. Moving to automatic controls and AutoDR would require a fairly significant change in growers' irrigation habits, and significant system upgrades may be required. If these controls were able to improve energy efficiency or facilitate a reduction in demand charges, then upgrading equipment to participate in AutoDR would be more attractive.

Changing Attitudes toward Remote Pump Monitoring and Control

As a younger generation of growers takes over farming operations, there is a trend toward using more information technology to improve agricultural operations. Remote monitoring of irrigation systems may be easily extrapolated to automatic pump controls that could be capable of implementing AutoDR. The field of crop frost protection offers another potential incentive for having remote control of pumps, something that may become a greater concern in the wake of seemingly greater climate variations. The reaction time for using sprinklers to mitigate frost conditions may be improved with automatic pump controls.

Potential Challenges

Inadequate Irrigation Capacity

Many irrigation systems are designed with the bare minimum capacity to just cover crop needs during maximum ET periods by running 24/7. Systems designed this way are not able to participate in load shifting or DR programs during these periods. During non-peak ET periods, the challenge is to get enough load shifting and/or DR from these systems to be worthwhile. To incentivize upgrading irrigation system capacity to enable more frequent participation, financial incentives must be large enough to make participation practical.

District-Supplied Water

Growers that receive water from an irrigation district often have limited control over the scheduling of the water. Motivating the irrigation districts to make the necessary upgrades to give growers greater flexibility in water scheduling may require substantial financial incentives.

Lack of Automatic Controls

In order to have agricultural irrigation systems contribute to quick shed and/or dynamic pricing of electricity, the challenge will be to provide adequate financial incentives for growers to upgrade their irrigation systems with automatic controls, especially those capable of AutoDR.

Smart Meter Installation Schedule

AutoDR can only be implemented in areas where interval meters (*smart meters*) have been installed by the local utility. This is expected to be a minor issue because the smart meter installation schedule is likely to be completed before significant number of growers accept automatic controls for their irrigation pumps.

Lack of Variable Frequency Drives

Most irrigation pumps don't have VFDs. Without a soft start/stop capability that can be implemented with VFDs, growers may be hesitant to stop and then restart pumps for load shifting or DR. One challenge is to get growers to participate in load shifting and/or DR programs without VFDs. Alternatively, the challenge would be to provide adequate financial incentives for growers to upgrade their irrigation systems to using VFDs.

Recommendations

As the key findings of this scoping study reinforce the original premise that significant potential exists for reducing stress on California's electricity grid through permanent load shifting, DR, and energy efficiency measures aimed at agricultural irrigation power use, and that further, California's agricultural irrigation can contribute significantly to California's quick response shed capacity, further studies are recommended. These studies are recommended to include:

- Comprehensive studies on the current agricultural irrigation energy demand and estimates of DR potential
- Studies on how to gain grower acceptance for permanent load shifting, DR, and AutoDR
- Studies on the interaction between energy efficiency and DR in irrigation

Benefit to California

Irrigation schedules are intrinsically flexible, and significant potential exists for reducing stress on the grid through DR, permanent load shifting, and energy efficiency measures aimed at agricultural irrigation power use. This is especially significant for California, where agricultural irrigation consumes 10 billion kilowatt hours of electricity between the months of May and October each year, the period of greatest stress on the electricity grid. The findings from this report will contribute to the understanding of how DR, energy efficiency, and permanent load shifting measures in California agricultural irrigation may be implemented and what challenges exist for realizing their full potential.

CHAPTER 1:
Introduction and Background

California agricultural irrigation consumes more than ten billion kilowatt hours of electricity annually. The "on-farm" component, the primary subject of this scoping study, accounts for nearly three quarters of that total. Furthermore, the electricity is consumed almost entirely between the months of May and October, which is during the period of greatest stress on the electricity grid. Consequently, significant potential exists for reducing stress on the grid through demand response (DR), permanent load shifting, and energy efficiency measures aimed at agricultural irrigation power use. Demand response and permanent load shifting along with energy efficiency have been established by California's Energy Action Plan II as the state's preferred means of meeting the growth in future energy requirements. The Energy Action Plan II was produced as a joint effort by the California Public Utilities Commission (CPUC), the California Energy Commission (CEC), and the California Power Authority (CPA) in October of 2005 and updated in February of 2008.

Demand response includes scheduled peak-load shifting by the energy consumer (achievable via manual or automated DR), as well as reactive, or unscheduled load shifting based upon the current grid conditions (achievable via automated DR). Automated demand response (AutoDR) is a technology for reducing electricity demand by pre-programmed automatic reaction to DR events, which can be triggered in response to electricity pricing, monetary incentives, or utility directives. Manual DR reacts to the same types of DR events to which AutoDR reacts but is implemented by human operators instead of automatic controls. Generally, manual DR requires more advance notice of DR events than does AutoDR. Permanent load shift refers to the scenarios where electricity consumers have arranged consumption to be routinely during off-peak times. Permanent load shifting is usually accompanied by a type of utility rate plan called Time-of-Use (TOU) rates.

Reducing peak load in California agricultural irrigation has tremendous potential because, as mentioned previously, almost all pumping energy is consumed during the same time of year that the grid is already stressed, but also because many irrigation schedules are intrinsically flexible enough to be managed around TOU schedules. That is for irrigation systems that can apply the required amount of water without running 24/7, the irrigation schedules have planned gaps where water is not being applied, and furthermore, those gaps can, in principle, be scheduled to occur during times of peak load on the grid. A large percentage of growers have elected to use TOU rate schedules, representing 81% of the Pacific Gas and Electric Company (PG&E) agricultural revenue and 71% of the Southern California Edison (SCE) agricultural revenue (Klein, Krebs, Hall, O'Brian, & Blevins 2005). However, almost all agricultural pumps are manually operated and the personnel that operate them have many priorities that trump TOU electric rates. This suggests that use of automatic controls may have a significant impact on permanent (TOU) and scheduled load shifting (achieved by AutoDR). Further, although energy efficiency is not the primary target of this scoping study, the use of automatic controls and variable frequency drives (VFDs) for energy efficiency measures may

also positively impact adherence to TOU schemes and growers' ability to participate in DR programs.

While permanent load shifting programs are fairly common among California growers, DR programs are much less common. Although in recent years, DR aggregators have successfully sold and administered some limited DR for California agriculture, the programs have mostly been operated as manual DR for peak load shifting. With agricultural irrigation consuming over 10 billion kilowatt hours (kWh) annually, during the highest grid-stressed time of year, coupled with the intrinsic flexibility of the irrigation schedules, there is tremendous potential for agricultural irrigation to supplement California's quick response shed capacity through AutoDR. This potential can contribute to the 4 gigawatts (GW) of ancillary services identified as necessary to maintain grid stability in the 2020 renewable portfolio standards (RPS) deployment goals (Masiello *et al.* 2010); each percent of agricultural irrigation load participating represents an average of 23 megawatts (MW) of quick-shed capacity during summer months. Furthermore, California's electricity markets are moving toward dynamic (real-time) pricing, which could significantly impact growers' irrigation costs if they don't adopt AutoDR for their irrigation systems.

Some of the positive benefits of DR may potentially be accomplished effectively with permanent load shifting (achievable with TOU programs). If irrigation is already scheduled to occur only at times when there are no DR events, then there would be reduced benefit from DR. However, it is expected that there is still significant opportunity for DR as some irrigation would otherwise be scheduled during the time of a potential DR event. At certain times, some crops are irrigated nearly continuously because of the capacity of the irrigation system relative to the needs of the crops during highest evapotranspiration periods, or because of the nature of the crop itself. Rice is a prime example in that it is essentially irrigated continuously during peak evapotranspiration periods to maintain a layer of water above the soil. If there is advance notice of DR events, irrigation schedules may be moved up in time to store water on the field, avoiding the need to "catch up" after an event. It can be assumed that a DR event is most likely to occur during a time of greatest crop water requirements (hottest temperatures). Furthermore, DR events are not restricted to peak times so even when an irrigation system is run exclusively during off-peak times, the implementation of DR on the system can still contribute to load shedding during off-peak times.

Finally, irrigation systems on which energy efficiency and permanent load shifting measures have been implemented provide some of the best opportunities for DR. The technology installed for efficiency and permanent load shifting measures may be easily adapted to AutoDR. For example, Internet connectivity which is required for AutoDR may be in place for crop environmental data monitoring and for remote irrigation scheduling. Also, the most demanding efficiency and permanent load shifting measures require sophisticated controllers that can run AutoDR client software.

1.1 Purpose

The purpose of this project was to conduct a scoping study of DR and permanent load shifting opportunities, and the adoption challenges in California agricultural irrigation. The specific objectives of the study were as follows:

- Parse the California irrigation load into categories using criteria such as growing regions, water sources, irrigation methods, and crop types. Then examine the categories to determine how to focus efforts to gain the highest potential impact from DR and permanent load shifting programs.
- Determine where the best opportunities lie for DR and permanent load shifting programs in California agricultural irrigation.
- Suggest possible DR and energy efficiency solutions where applicable.
- Make initial limited determination for potential acceptance among California growers and what challenges and obstacles might exist for DR and permanent load shifting programs.
- Identify follow-up studies for the best opportunities for DR and energy efficiency including more extensive field studies and surveys of growers to assess potential acceptance.

1.2 Report Organization

The primary research conducted during the course of this study is represented in the first three sections of this report.

- The first section describes the background of the study, its purpose, and its organization
- The second section covers the gathering and parsing of data from published sources that may shed light on where the best opportunities for load shifting and DR lie within the agricultural irrigation sector. The goal was to look for concentrations of opportunities based on agricultural region, crop type, irrigation methods, and other possible parsing delimiters such as grower corporate size or utility company.
- The third section summaries the small limited survey that was conducted as part of this scoping study. The survey was conducted as informal face-to-face interviews with several different California growers to get an idea of their ability and willingness to participate in permanent load shifting and/or DR programs. The growers interviewed were located in the Sacramento Valley, the San Joaquin Valley, and the Sacramento-San Joaquin River Delta region.

The sections that follow draw a number of conclusions from the research. They include:

- *Best Opportunities for Demand Response and Permanent Load Shifting Programs*
- *Solutions (or Requirements) for Demand Response and Permanent Load Shifting Programs*
- *Potential Grower Acceptance of Demand Response and Permanent Load Shifting Programs*
- *Potential Challenges and Obstacles to Demand Response and Permanent Load Shifting Programs*

Finally the last two sections suggest future studies. The first of the two deals with how to gain grower acceptance for DR. The second covers all other suggested future studies including some for energy efficiency and its relationship to DR.

CHAPTER 2:
Parsing Data on Agricultural Irrigation

Data relevant to DR and permanent load shifting in California agricultural irrigation was gathered from published sources and parsed to identify characteristics of significance. The goal was to look for data that indicates how electricity load and energy consumption varies by growing region, irrigation method, and crop type. While not all of the data was directly available, enough of it was directly or indirectly available to observe some interesting data alignments. For example load data could not be found, but energy consumption varying by some of the targeted parameters was available. The assumption was reasonably made that load and energy consumption correlated strongly. Further, other strong Pareto Principle[4] arrangements emerged in data where such arrangements were not sought. The "law of the vital few" is very pronounced when looking at the data by grower business size and by utility coverage.

2.1 Data Sources

Data sources include the United States Department of Agriculture (USDA), the Irrigation Training and Research Center (ITRC) at the California State University in San Luis Obispo, the California Energy Commission, the Pacific Institute, the California Farm Bureau Federation, the River Network, and the Center for Irrigation Technology (CIT) at California State University, Fresno. Many of the published reports and papers trace their data on California agricultural irrigation water and energy use to the ITRC, which has developed an extensive database on irrigation in California. In addition, the USDA conducts a census report every five years that includes irrigation data, the last of which was conducted in 2008 for the 2007 growing season, and published as a report, the *2008 Farm and Ranch Irrigation Survey* (USDA 2008).

2.1.1 Discrepancy in Irrigation Water Use

There are a number of published reports and papers that quote California's agricultural irrigation water use as being in the range of thirty four to thirty six million acre-feet (AF) per year. The CEC and the Pacific Institute are among the organizations that cite those numbers in their respective documents. On the other hand, the USDA reports the annual use as approximately twenty two million acre-feet. The origin of the CEC and Pacific Institute cited data is the ITRC while the USDA data comes from the *2008 Farm and Ranch Irrigation Survey*.

The source of the USDA data comes from the growers themselves. Every five years, the USDA sends survey forms to all the growers in every state. The source of the mailing list comes from the National Agricultural Statistics Service (NASS), which maintains a list of farmers that produce and sell more than $1,000 of agricultural products per year. Although the NASS employs aggressive public relations and follow-up with the growers, not all growers participate

[4] The Pareto Principle (also known as the "80-20 rule" or the "law of the vital few") states that in many systems, roughly 80% of the effects come from 20% of the causes. Though the number 80% is not mathematically significant, this rule of thumb is a good approximation in many real-world examples.

in the survey. The response rate for the 2008 survey was determined to be about 85% (USDA 2008). Statistical sampling techniques were used by the NASS to fill in the gaps.

On the question of how much irrigation water is being applied, it should be noted that most growers don't have access to actual numbers. While some irrigation districts meter water, not all do. Further, on-farm sources are almost never metered. Therefore, the amount of water applied is usually estimated.

The ITRC used a different approach than the USDA to obtain its estimates on irrigation water applied. They started with data on evapotranspiration (ET), a combination of evaporation and plant transpiration[5]. Specifically, they used data on ETo zones as established by the California Department of Water Resources (DWR). ETo is "potential evapotranspiration" based on weather data. Actual evapotranspiration is dependent on both crop grown and ETo. They then applied data on crops in the dominant agricultural zones along with ITRC-derived calculations of ET by crop type and irrigation method as well as irrigation uniformity by method to estimate the amount of water applied in each of the zones. The ITRC also included water used for frost protection and for leaching salts from the root zone (Burt, Howes, & Wilson, 2003).

The numbers from the ITRC and the USDA are substantially different: thirty six million acre-feet versus twenty two million acre-feet for the total irrigation water applied annually in California. One possible explanation to consider is that there was a substantial decrease in water use between 2003 when the ITRC published its data and 2008 when the latest USDA *Farm and Ranch Irrigation Survey* was published. However, the *2003 Farm and Ranch Irrigation Survey* estimates the total water applied at twenty four million acre-feet, which isn't significantly different from what the subsequent 2008 survey reports. Therefore, the discrepancy seems to be due to differences in approach and in what data was included.

One difference in the approaches taken may be in which water-use categories are included. The ITRC data includes water used for frost protection and salt leaching, while it's not clear whether the USDA survey includes those categories of use. Another possibility is that growers may under estimate water use when there is no hard data (metered flow) of water applied. For example, consider Table 1 below that shows data from both the ITRC and the USDA for 2003, which compares the "off-farm" water consumed versus the "on-farm" water consumed for irrigation in in that year. While the USDA numbers are lower than the IRTC numbers in both categories, they are much further apart in the on-farm category. This may be due to the fact that on-farm water is almost never metered, while at least some district water is metered. It should be considered that growers, as a group, often feel like a scapegoat when it comes to California's water problems and, therefore, may be more inclined to under estimate their water use.

[5] Evapotranspiration refers to loss of moisture from soil due to evaporation from the soil itself and transpiration through crops. It varies continuously based on weather and crop(s) grown.

Table 1: 2003 Irrigation Water Use

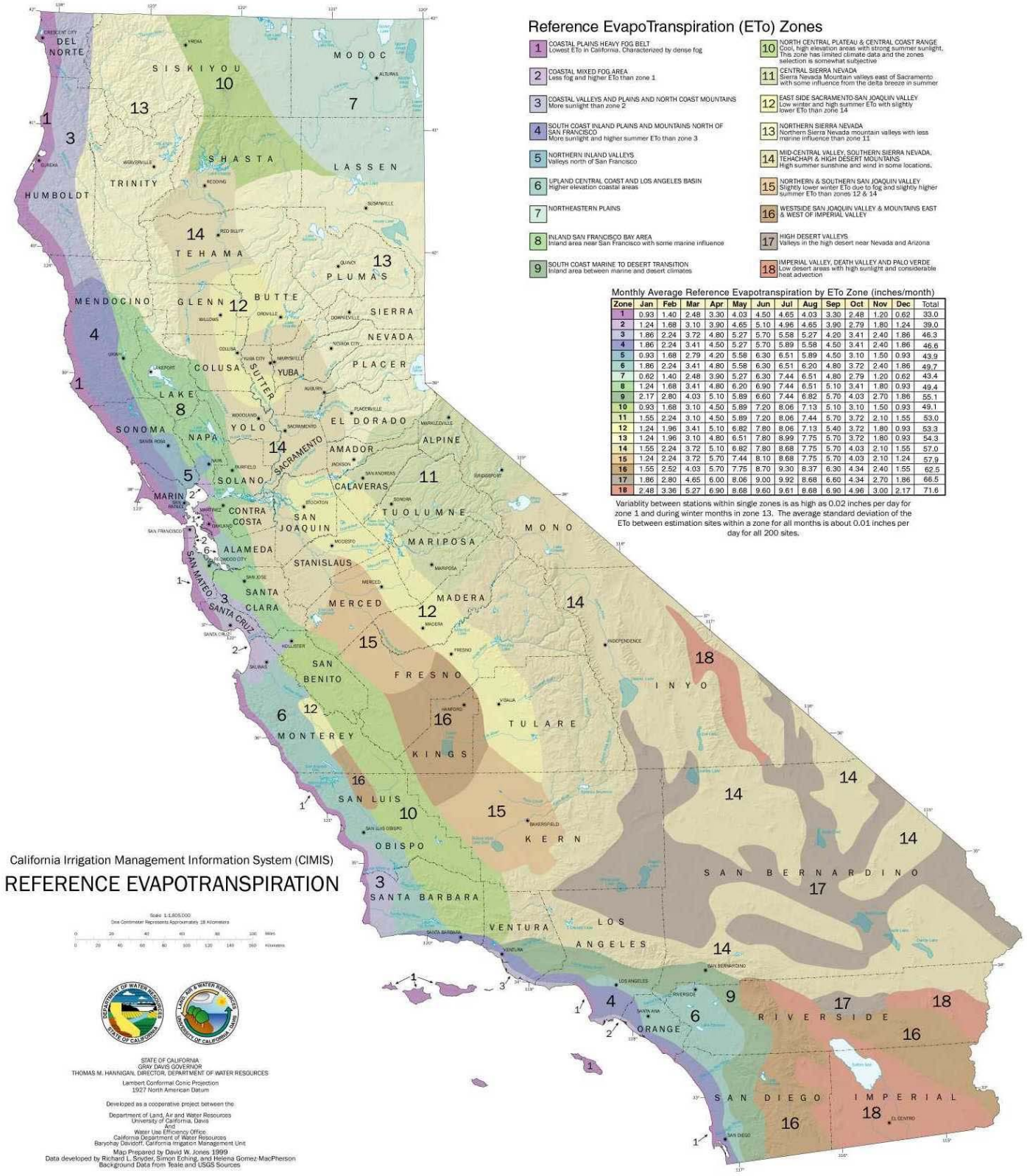
	ITRC 2003 report R 03-006	2003 USDA Survey
Off-farm water	24,144,900 AF per year	19,753,421 AF per year
On-farm water	12,085,400 AF per year	5,093,808 AF per year

Sources: Burt, *et al.* 2003, USDA 2003

2.2 Growing Regions

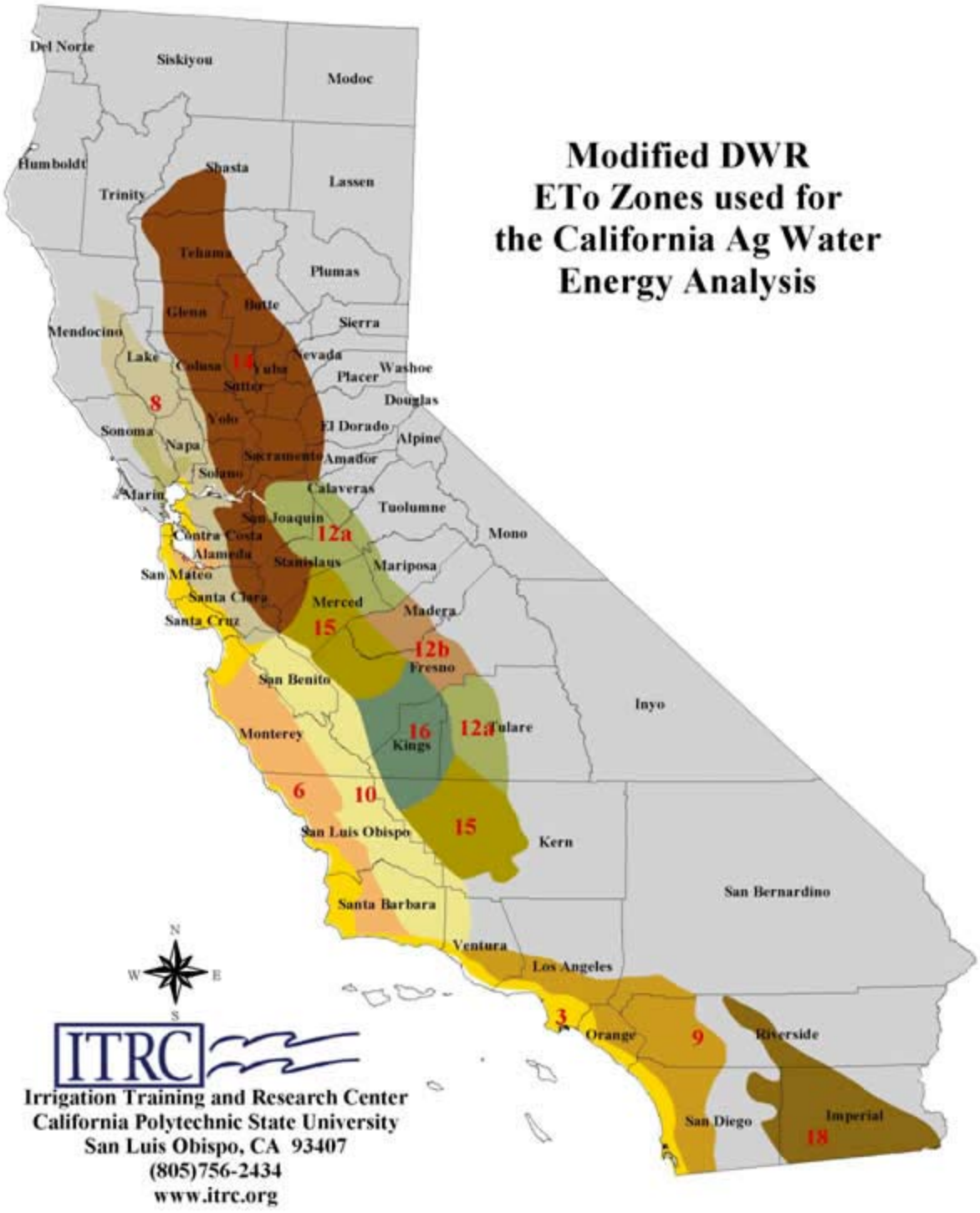
Data on annual water applied as well as electrical energy used by California agricultural regions was taken from an ITRC report by Burt *et al.* (2003), *California Agricultural Water Electrical Energy Requirements*. The report presents data on thirteen regions based on the California Department of Water Resources (DWR) map of ETo zones. The full map of ETo zones as provided by California Irrigation Management Information System (CIMIS) is shown in Figure 1 below. The thirteen zones chosen by the ITRC represent the dominant California agricultural regions. The ITRC zone map is shown in Figure 2. The map shows the DWR ETo zones 1, 3, and 4 condensed into zone 3 to reduce clutter. Also, zone 12 is divided into two zones, 12a and 12b.

Figure 1: California ETo Zones



Source: California Irrigation Management Information System

Figure 2: ITRC Modified ETo Zones



Source: Burt *et al.* 2003

2.2.1 Water

Based on the ITRC-modified ETo zones, the estimated total amount of water applied annually by zone for a typical year of precipitation is shown in Table 2 below. The numbers for each region were derived by using ITRC-developed evapotranspiration values of irrigation water for crop type by irrigation method as well as estimated irrigation distribution uniformity by irrigation method. They also factored in water used for frost protection and for leaching salts from the root zone.

Table 2: Water Applied by ETo Zone

ITRC-modified DWR ETo zone	Zone Description	Total Applied Water by Zone (AF/year)	Percentage of Total Applied Water by Zone
1	Coastal Plains, Heavy Fog	123,695	0.3%
3	Coastal Valleys and Plains	824,846	2.3%
4	South Coast Inland Plains	138,046	0.4%
6	Upland Central Coast	959,939	2.6%
8	Inland San Francisco Bay Area	173,209	0.5%
9	South Coast Marine-to-Desert Transition	880,841	2.4%
10	Central Coast Range	669,478	1.8%
12a	Northeast Sacramento-San Joaquin Valley	4,127,699	11.4%
12b	Southeast Sacramento-San Joaquin Valley	1,560,369	4.3%
14	Mid-Central Sacramento Valley	8,789,086	24.3%
15	North & South San Joaquin Valley	8,561,175	23.6%
16	West Side San Joaquin Valley	5,231,858	14.4%
18	Imperial Valley	4,190,200	11.6%
	Total	**36,230,300**	**100.0%**

Sources: Burt *et al.* 2003 and California Irrigation Management Information System

As seen in Table 2, nearly 80% of the irrigation water applied in California is applied in the Sacramento and San Joaquin valleys, totaling more than 28 million acre-feet per year. Of that 28 million acre-feet, 70% is applied in the San Joaquin valley alone, accounting for approximately 55% of the total irrigation water for the state.

2.2.2 Energy

The Burt *et. al* report (2003) provides estimates of electrical energy used for irrigation pumps by the same zones, with a confidence interval of ±10%. The data is shown below in Table 3.

Table 3: Electical 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	75,817	0.7%
3	Coastal Valleys and Plains	510,386	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	332,077	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%**

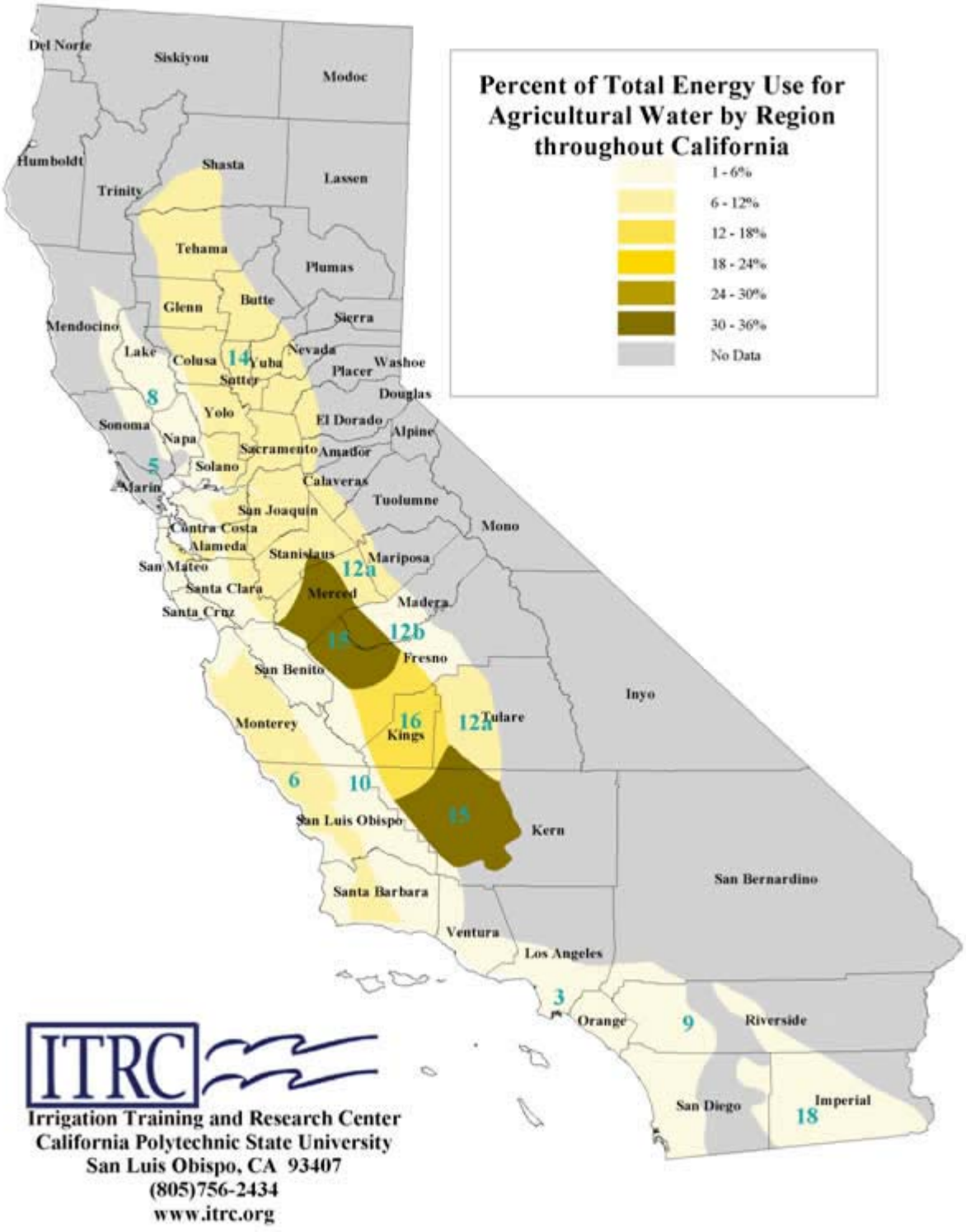
Sources: Burt *et al.* 2003 and California Irrigation Management Information System

From Table 3, it can be seen that approximately 77% of the energy is consumed in the Sacramento and San Joaquin valleys. However, 65% of the energy is consumed in the San Joaquin valley alone.

Figure 3 and Figure 4 below show some additional interesting energy distributions by region. Figure 3, depicting percent of total energy for agricultural water use by region, reinforces the conclusions made above from Table 3: there is a high concentration of agricultural irrigation energy use in the San Joaquin Valley. However, Figure 4, depicting average required energy required for agricultural water, shows that the highest energy requirement for a given amount of irrigation water is in the coastal regions. The reason for this is that all irrigation water in those regions comes from wells, as will be discussed further in following sections.

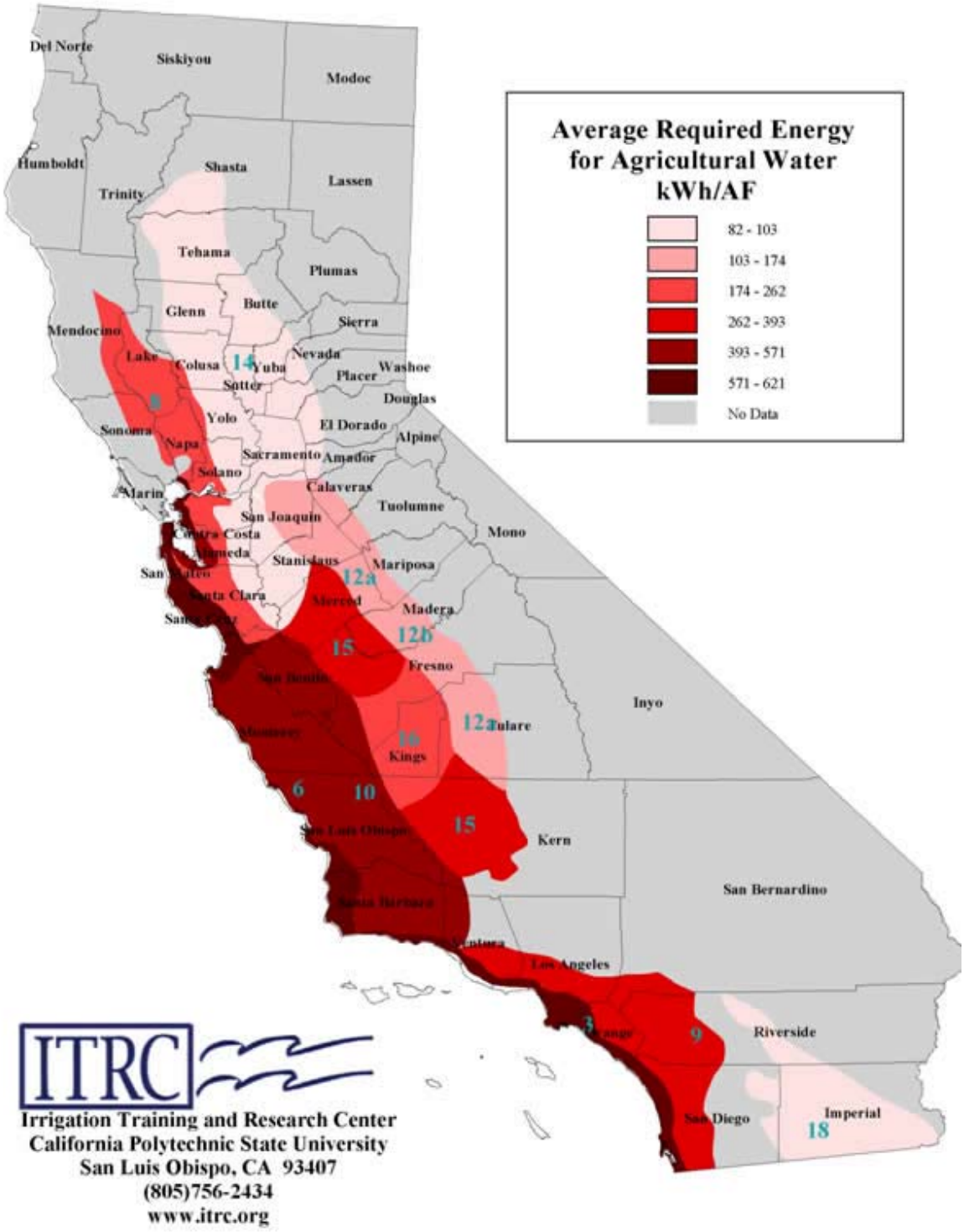
There are two Pareto Principle distributions for agricultural irrigation energy use, which is assumed to correlate closely with electrical load. The first indicates that the highest priority should be the Central Valley (Sacramento and San Joaquin), especially the San Joaquin Valley. The second suggests that there may be priority to the coastal regions where the energy required to acquire irrigation water is the greatest.

Figure 3: Percent of Total Energy Use by Region



Source: Burt *et al.* 2003

Figure 4: Energy per Arce-Foot of Water



Source: Burt *et al.* 2003

2.3 Water Source

Sources for irrigation water can be parsed several ways. The USDA census reports separate water source by wells (ground water), on-farm surface water, and off-farm surface water. They also report total off-farm sourced water. The ITRC separates the water source by irrigation district surface water, irrigation district ground water, and on-farm ground water. When looking at energy use, the ITRC also includes on-farm booster pumps and conveyance to irrigation districts, which are important energy-use categories, but do not represent separate sources of water.

2.3.1 Water

The USDA's Farm and Ranch Irrigation Surveys provide water-applied data by source in two ways: Ground water vs. surface water and off-farm water vs. on-farm water. Table 4 shows the data from the 2008 survey, which covers the 2007 growing season. Table 5 shows the same categories for the 2003 survey, which covers the 2002 growing season. Table 6 shows ITRC data from the 2003 report (Burt *et al.* 2003). The ITRC data from Table 2, which shows water applied by ETo zone, is expanded in another dimension to also show the water applied by source. Note that while the overall total water applied is greater than what is reported by the USDA survey of 2003, the irrigation district-supplied water vs. on-farm ground water ratio is fairly consistent with the 2003 USDA numbers.

Table 4: AF/year by Source (2007)

2008 USDA Survey		
Ground Water AF/year	Surface Water AF/year	Total AF/year
10,719,609	11,880,050	22,599,659
Off-Farm AF/year	On-Farm AF/year	Total AF/year
10,420,112	12,179,547	22,599,659

Source: USDA 2008

Table 5: AF/year by Source (2002)

2003 USDA Survey		
Ground Water AF/year	Surface Water AF/year	Total AF/year
9,659,305	15,187,923	24,847,228
Off-Farm AF/year	On-Farm AF/year	Total AF/year
19,753,421	5,093,808	24,847,229

Source: USDA 2003

Note the shift from surface water to ground water as well as the shift from off-farm water to on-farm water between the 2002 and 2007 growing seasons. This is most likely due to a significant number of irrigation systems converting to drip or micro-sprinkler irrigation. When converting to drip or micro-sprinkler irrigation, growers prefer to use on-farm wells even when irrigation surface water is available (Burt & Monte 2008).

Table 6: Water Applied by ETo Zone and Source

ITRC-modified DWR ETo zone	Irrigation District Surface Water Delivered (AF/ year)	Irrigation District Ground Water Pumping (AF/year)	On-Farm Ground Water Pumping (AF/year)	Total Applied Water by Zone (AF/year)
1	0	0	123,965	123,695
3	0	0	824,486	824,846
4	0	0	138,046	138,046
6	0	0	959,939	959,939
8	116,140	681	56,387	173,209
9	0	0	880,841	880,841
10	0	0	669,478	669,478
12a	3,025,343	129,393	972,963	4,127,699
12b	960,284	41,071	559,014	1,560,369
14	8,349,919	14,048	425,118	8,789,086
15	4,175,145	505,920	3,880,110	8,561,175
16	2,655,088	43,121	2,533,649	5,231,858
18	4,128,768	0	61,432	4,190,200
Total	**23,410,700**	**734,200**	**12,085,400**	**36,230,300**

Source: Burt *et al.* 2003

The conversion to ground water pumping with drip or micro-sprinkler conversions is often due to water scheduling and water quality issues. Drip or micro-sprinkler systems often necessitate more frequent irrigation cycles than the irrigation district rotation cycle allows. Even when the district rotation frequency would be adequate, growers often prefer the freedom of having water on-demand. Further, drip and micro-sprinkler systems require filtration of water entering the system. The quality of ground water is generally better than district-supplied surface water that may accumulate debris on its way to a grower's irrigation system.

This transition to drip and micro-sprinkler systems has implications to energy use and electrical load. While the transition generally saves water, it actually increases energy use and, most relevant to this study, the electrical load. This is discussed further in following sections.

2.3.2 Energy

Table 7 below shows the ITRC zone data from Table 2 expanded in a second dimension. Energy use for California agricultural irrigation is shown by water source as well as by the ETo zone. Two additional energy categories, on-farm booster pumping and conveyance to irrigation districts, are included, both of which account for energy required to deliver water to crops but are not associated with any additional water applied.

Note that over seventy percent of the total energy expended is from on-farm pumping and that on-farm ground water pumping represents sixty percent of all on-farm pumping energy use. This suggests that the best opportunities for DR and permanent load shifting is with the on-farm pumping, especially on-farm ground water pumping, assuming these irrigation uses can be shifted.

Another opportunity for DR can be found with the irrigation districts. Although they represent a smaller portion of the total energy used, they are much fewer in number and the energy used per district is greater than the energy used by the average grower. There have been projects to facilitate peak-load shifting for some larger districts. For example, the ITRC administered several projects under the Agricultural Peak Load Reduction Program (APLRP) for agricultural irrigation districts from 2001 through 2004 (Burt & Howes 2005; Burt, Amon, & Cordova 2002 & 2007). However, many districts still do not have DR or permanent load shifting programs in place.

Table 7: Energy Consumed by ETo Zone and Source

ITRC-modified DWR ETo zone	Irrig. District Surface Water Delivered (MWh / year)	Irrig. District Ground Water Pumping (MWh/year)	On-Farm Ground Water Pumping (MWh /year)	On-Farm Booster Pumping (MWh /year)	Conveyance to Irrig. Districts (MWh/year)	Total Electricity used by Zone (MWh/year)
1	0	0	54,964	20,852		75,817
3	0	0	365,562	145,076		510,386
4	0	0	61,207	18,132		79,339
6	0	0	401,843	148,034		549,877
8	3,896	137	14,573	21,350		39.957
9	0	0	255,199	87,567		342,767
10	0	0	273,277	58,730		332,077
12a	26,171	27,051	283,381	300,329		636,932
12b	8,307	8,586	159,637	101,075		277,606
14	131,125	2,032	108,394	488,733	450,526	1,180,809
15	514,605	199,386	1,659,804	688,121	1,269,062	4,330,978
16	137,662	8,840	846,938	380,371		1,373,811
18	0	0	14,236	415,152		429,388
Total	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**10,159,900**

Source: Burt *et al.* 2003

Finally, the *Conveyance to Irrigation Districts* numbers are based on the energy consumed by pumping from the California Aqueduct and the Delta-Mendota Canal into agricultural water districts. This category could be considered for DR; however, all the pump stations are already being operated only during off-peak times (Burt 2011c; Burt & Howes 2005).

2.4 Irrigation Method

Data on irrigation methods by acres irrigated is available from several sources including the USDA Farm and Ranch Irrigation Surveys, the ITRC, and Pacific institute. Table 8 and Figure 5 below show data taken from the 2008 and 2003 USDA Farm and Ranch Irrigation Surveys on

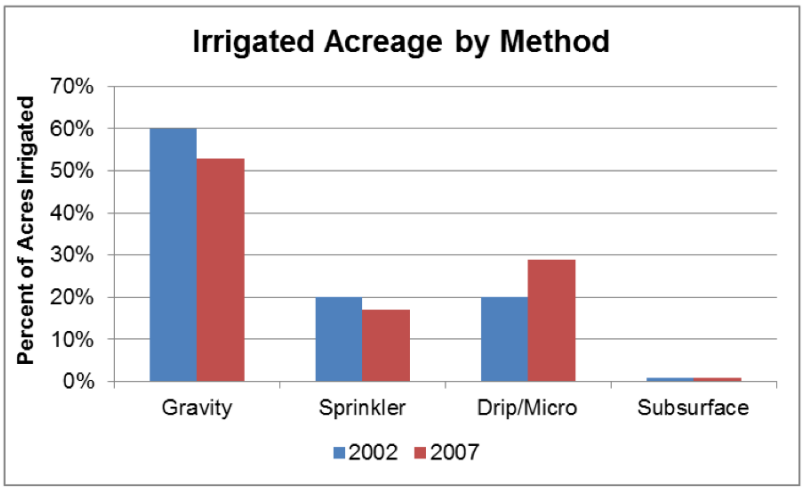
irrigation methods by acres irrigated. The term *Gravity* in those tables is interchangeable with the term *Flood*. The totals of the acres irrigated in those tables are slightly higher than the surveys' separately reported total irrigated acres. Presumably, some acres are irrigated by more than one method. The *Subsurface* irrigation method is accomplished with underground pipes or open ditches that are blocked to force water into a crop root zone.

Table 8: Acres Irrigated by Method, 2002 & 2007

	2003 USDA Survey (2002 growing season)		2008 USDA Survey (2007 growing season)	
Irrigation Method	Acres Irrigated		Acres Irrigated	
Gravity	5,261,073	60%	4,189,852	53%
Sprinkler	1,723,040	20%	1,367,179	17%
Drip/Micro	1,706,916	20%	2,336,130	29%
Subsurface	58,655	1%	66,282	1%
Total for All Methods	8,749,684		7,959,443	

Source: USDA 2003 & 2008

Figure 5: Acres Irrigated by Method, 2002 & 2007



Source: USDA 2003 & 2008

Table 9 shows data taken from an ITRC paper, *Evaporation Estimates for Irrigated Agriculture in California* (Burt, Howes, & Mutziger 2001). The first two categories are forms of *Gravity* or *Flood* irrigation. The third category is a combination of flood and sprinkler irrigation.

Table 9: Acres Irrigated by Method

ITRC 2001 evaporation		
	Acres	
All Furrow	2,380,226	26%
All Border Strip and Basin	2,656,321	29%
Combination Sprinkler and	494,778	5%

Furrow		
All Sprinkler	1,970,056	21%
All Drip/Micro	1,811,622	19%
Total for All Methods	9,313,003	

Source: Burt *et al.* 2001

Table 10 shows data from the 2009 Pacific Institute article, (Cooley, Christian-Smith, & Gleick 2009), which cited data on irrigation methods from a 2005 published article titled *Survey of Irrigation Methods in California in 2001* (Orang, Synder, & Matyac, 2005). While the Pacific Institute data doesn't show acres by irrigation method, the percentages of total irrigated acres are consistent with the other data from 2001 and 2002 (USDA 2003). The term *Other* in this table includes subsurface irrigation.

Table 10: Percentage of Irrigated Acres by Method

Pacific Institute 2001 Data	
	Percentage of Total Irrigated Acres
Flood	59%
Sprinkler	15%
Drip/Micro	24%
Other	2%

Source: Cooley *et al.* 2009; Orang *et al.* 2005

Of particular interest is the shift to drip/micro from other irrigation methods during the time from 2001 and 2003 to 2008. This is consistent with the shift from surface water sources to ground water during that same period as described earlier.

2.4.1 Water

While data directly available on irrigation methods is generally reported by acres irrigated, the water applied by irrigation method can be estimated using another part of the USDA Farm and Ranch Irrigation Surveys. The acres irrigated by irrigation method come from the surveys' section titled *Land Irrigated by Method of Water Distribution*, Section 4[6]. However, the surveys also contain a section titled *Estimated Quantity of Water Applied Using Only One Method*, Section 8, where there are separate subsections for each irrigation method. That section also reports acres irrigated by irrigation method but the totals are much less than the reported total irrigated acres in California or for that matter, much less than what's reported in Section 4 of the surveys. On the other hand, Section 8 of the surveys contains numbers for average acre-feet applied per acre for each of the four irrigation methods. Table 11 and Table 12 below combine data from the Farm and Ranch Irrigation Surveys' Sections 4 and 8 for the 2008 and 2003 survey years

[6] The USDA Ranch and Farm Survey "sections" are actually labeled as "Tables". The term "Sections" is substituted here in order to avoid confusion with the numbered Tables in this document.

respectively. The average acre-feet per acre numbers from Section 8 are multiplied by the acres irrigated numbers from Section 4 to create total acre-feet applied for each irrigation method.

Table 11: AF by Irrigation Method in 2007

2008 USDA Survey (combined sections 4 and 8)					
Irrigation Method	Acres Irrigated		Ave. AF/Acre	AF	
	(section 4)		(section 8)		
Gravity	4,189,852	53%	3.3	13,826,512	59%
Sprinkler	1,367,179	17%	2.5	3,417,948	15%
Drip/Micro	2,336,130	29%	2.6	6,073,938	26%
Subirrigation	66,282	1%	0.7	46,397	0%
Totals	7,959,443			23,364,795	

Source: USDA 2008

Table 12: AF by Irrigation Method in 2002

2003 USDA Survey (combined Sections 4 and 8)					
Irrigation Method	Acres Irrigated		Ave. AF/Acre	AF	
	(section 4)		(section 8)		
Gravity	5,261,073	60%	3.3	17,361,541	69%
Sprinkler	1,723,040	20%	2.3	3,962,992	16%
Drip/Micro	1,706,916	20%	2.3	3,925,907	16%
Subirrigation	58,655	1%		0	0%
Totals	8,749,684			25,250,440	

Source: USDA 2003

It is seen that the amount of water applied is even more dominant for gravity or flood irrigation than the acres irrigated by flood. Also the water applied for drip/micro is a smaller percentage of the total water applied than the acres irrigated for the same category. Irrigation water applied can be reduced when converting to drip/micro. However, ground water aquifers may actually be depleted faster with drip/micro conversions (Burt & Monte 2008). Furthermore, saving water is not generally the motivation for growers to convert to drip/micro. They convert because they can control water application uniformity better with drip/micro systems and also because the systems accommodate an efficient method of delivering fertilizers (Burt & Monte 2008).

2.4.2 Energy

It's difficult to find or calculate total energy used by irrigation method; however some relative data is available. The Pacific Institute, in its 2008 article, *More with Less: Agricultural Water Conservation and Efficiency in California* (Cooley, Christian-Smith, & Gleick 2008) cites some

relative numbers on energy intensity for lifting water 10 feet as well as booster pumping of drip/micro irrigation and standard sprinkler irrigation. The booster pumping numbers, which were derived by the Pacific Institute from data taken from the ITRC report by Burt *et al.* (2003), are the numbers of most interest. Lifting water is not specific to any one type of irrigation method other than, as pointed-out above in the section on Water Source, conversions to drip/micro are often accompanied by conversions to ground water sources from surface water sources. The amount of energy required to apply the water once it is at crop elevation, regardless of how it got there, is represented in Table 13.

Table 13: Energy Requirements by Irrigation Activity

Activity	Approximate Energy Requirements (kWh/AF)
Flood Irrigation without On-Farm Lift	0
Lifting Water 10 feet for Flood Irrigation	30
Booster Pumping for Drip/Micro Irrigation	206
Booster Pumping for Standard Sprinklers	284

Source: Cooley *et al.* 2008

If the acre-feet applied percentages are taken from Table 11 (USDA 2008), applied to an annual amount of total irrigation water applied in California of 30 million acre-feet, and multiplied by the numbers from Table 13, the state total relative energy required for the primary irrigation methods can be approximated. Table 14 shows the relative energy required for irrigation methods from the point where water is at the input to the irrigation system (the water has already been lifted or transported from a different location as necessary). The total applied water of 30 million acre-feet is simply chosen as a round number between the various cited numbers from the USDA and ITRC. However, notice that the total MWh/year in Table 14 closely matches the total "On-Farm Booster Pumping" from Table 7.

Table 14: Relative Energy by Method

Irrigation Method	AF	Relative kWh/AF	Relative MWh/year
Gravity	17,700,000	0	
Sprinkler	4,500,000	284	1,278,000
Drip/Micro	7,800,000	206	1,606,800
Total	30,000,000		2,884,000

Derived data from USDA 2008 and Cooley *et al.* 2008

Note that the greatest booster pump energy per unit of water results from the use of sprinklers, because they generally require greater pressure than drip or micro sprinklers. However because of the greater acreage of drip/micro irrigation, that category consumes more energy per year. Also the trend is toward even greater percentages of irrigated acres using drip/micro (Burt *et al.* 2003; Burt & Monte 2008). As previously mentioned, drip/micro conversions are frequently accompanied by a conversion from a surface water source to a ground water source

(Burt & Monte 2008). Therefore, the drip/micro irrigation method when used with groundwater pumps has much higher relative energy content than is shown in Table 14. The ITRC report by Burt *et al.* (2003) estimates that a doubling in drip/micro from their reported 2003 numbers would add an additional 1,917,200 MWh/year to the California agricultural irrigation energy use. Considering that drip/micro conversions are popular and a continuing trend, they may be considered for some focus with regard to DR and permanent load shifting.

2.5 Crop Type

Pacific Institute published data on water use by crop type in articles from 2008 and 2009, (Cooley *et al.*). Their data was based on 2003 estimates by the DWR. The crop categories used in their data are field crops, vegetables, and fruits and nuts. Field crops include all the grains, hay, and cotton. The fruits and nuts category primarily consist of orchard and vineyard crops.

2.5.1 Water

Table 15 shows the percentages of water applied for each type of crop as taken from the Pacific Institute articles and applies them to the total water applied number used in Table 14 above.

Table 15: Water Applied by Crop Type

Crop Type	Percentage of Water Applied	AF of Water Applied
Field Crops	63%	18,900,000
Vegetables	10%	3,000,000
Fruits and Nuts	27%	8,100,000
Total	100%	30,000,000

Source: Derived data from Table 14 and Pacific Institute 2008 and 2009 articles (Cooley *et al.* 2008 & 2009)

Field crops are mostly irrigated by flood (Cooley *et al.* 2009) and, as can be seen by comparing Table 14 on irrigation methods and Table 15 on crop type, the total amount of water applied for field crops is close to the total for the gravity irrigation method.

2.5.2 Energy

It's difficult to directly determine energy use by crop type other than to point out that field crops are more likely to use gravity for irrigation, which would leave other crop types as being more likely to use drip/micro or sprinkler irrigation methods. So while field crops use more than 60% of the applied irrigation water, it's probable that they account for a much smaller percentage of the total energy use. Crops that use drip/micro irrigation are more likely to have on-farm pumps for lifting ground water and booster pumps that are required to pressurize the distribution system.

2.6 Grower Business Size

The USDA Farm and Ranch Irrigation Surveys categorize farms by acres irrigated. Table 16 below shows the data from the 2008 survey, which shows a strong Pareto correspondence regarding the number of farms that dominate the acres irrigated. Approximately 14% of the farms irrigate 84% of the irrigated acres.

Table 16: Percentage of Acres Irrigated by Size of Farm

Acres	Farms	%	Acres irrigated	%
1-49	32,499	72.0	408,070	5.5
50-99	2,865	6.3	309,927	4.2
100-199	3,285	7.3	477,492	6.4
200-499	3,170	7.0	1,012,333	13.6
500-999	1,738	3.9	1,225,449	16.5
1,000 – 1,999	965	2.1	1,307,090	17.6
2,000+	614	1.4	2,706,646	36.3
Total	45,136	100	7,447,007	100

Source: USDA 2008

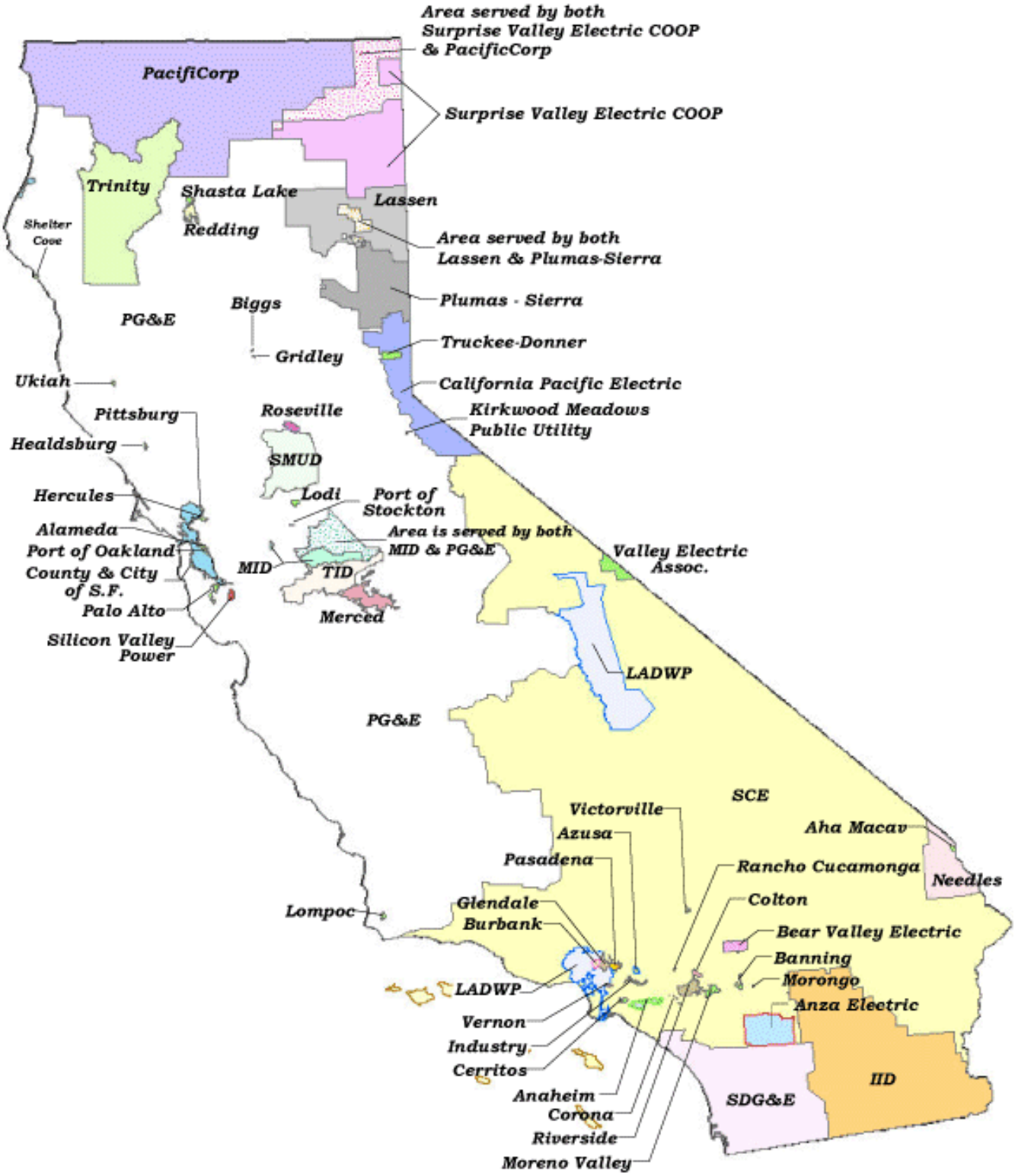
As there is some correlation of acres irrigated to energy use and, presumably, electrical load, it may pay to focus DR and permanent load shifting efforts on large growers. In fact it may be reasonable for electric utilities to deal directly with the very largest growers to manage DR programs. Currently, it's common for DR aggregators to handle agricultural DR.

For reference, *Appendix B: Top Growers in California* lists some of the top growers by acres irrigated within categories of crop type. It is not intended to be an authoritative ranking of California growers by acreage, nor does it even cover all categories. There are some large growers that aren't on any of the lists because of the categories covered. Also, the acreage for any specific grower within a category is not indicative of their total acreage for all crops. More research would be required to rank growers by total acreage irrigated. However, the growers listed are certainly among the largest in the state and as such may be candidates for direct DR negotiations with their respective utilities.

2.7 Utility Coverage

Figure 6 below is a CEC map of the California Electric Utility Service Areas. Table 17 shows Peak Load and Retail Sales by utility, in 2008 and 2010. PG&E is the largest in those two categories and, as can be seen by the map, it has the largest coverage area of all utilities in the state. However, if the coverage map in Figure 5 is compared to the ETo zone maps in Figure 1 through Figure 4, PG&E coverage in the primary California agricultural regions is even more dominant. It appears that agricultural irrigation load shifting and DR programs in the PG&E customer base alone could cover a significant majority of the agricultural irrigation load in the state. If the second largest utility, SCE, was included, then almost all of the agricultural irrigation load would be covered. Municipal irrigation districts supplying electricity (such as the Imperial Irrigation District and the Turlock Irrigation District) also merit some consideration, as agricultural pumping is a greater percentage of their loads compared to the more widespread utilities.

Figure 6: Utility Service Areas



Source: California Energy Commision

Table 17: Peak Load and Retail Sales by Utility

Peak Loads[1]			Retail Sales		Accounts
2010 MW	2008 MW	Utility	2010 GWh	2008 GWh	2010 # of Customers
18,229	19,431	Pacific Gas & Electric (PG&E)	77,582	81,935	5,212,605
18,515	18,776	Southern California Edison (SCE)	75,732	81,027	4,888,868
6,177	6,006	Los Angeles Department of Water & Power	22,944	24,695	1,449,174
4,687	3,764	San Diego Gas & Electric (SDG&E)	16,280	17,410	1,399,122
2,990	3,086	Sacramento Municipal Utility District (SMUD)	10,293	10,950	603,003
1,004	979	Imperial Irrigation District (IID)	3,218	3,332	146,717
470	490	Silicon Valley Power (SVP)	2,764	2,858	52,385
641	650	Modesto Irrigation District (MID)	2,429	2,598	115,053
580	581	Anaheim, City of	2,368	2,597	112,879
580	535	Riverside, City of	1,996	2,190	105,968
588	602	Turlock Irrigation District (TID)	1,915	2,023	99,608
331	338	Roseville Electric	1,177	1,307	54,596
316	289	Burbank Water and Power	1,174	1,197	50,100
293	310	Pasadena Water and Power	1,144	1,231	62,130
195	204	Vernon, City of	1,138	1,200	1,129
343	306	Glendale Water and Power	1,076	1,068	84,118
144	149	City & County of San Francisco (CCSF)	961	996	2,144
186	195	Palo Alto, City of	950	1,051	28,830
176	187	PacifiCorp	831	883	44,260
234	273	Redding Electric Utility	770	786	43,044
130	127	NV Energy (Liberty Energy in 2011)[2]	539	535	46,085
124	128	Lodi Electric Utility	444	454	25,166
92	88	Merced Irrigation District	426	429	7,746
68	76	Alameda Municipal Power	400	409	33,930
76	102	Power & Water Resources Pooling Authority	367	532	15
86	77	Colton Electric Utility Department	340	352	18,206
68	63	Azusa Light and Water	239	272	15,326
31	33	Shasta Lake, City of	160	183	4,424
28	32	Plumas-Sierra Rural Electric Cooperative	157	177	7,634
27	16	Corona, City of	150	81	771
38	35	Truckee Donner Public Utilities District	148	149	13,141
24	26	Lompoc, City of	133	143	14,810
45	43	Banning, City of	133	150	11,784
40	40	Bear Valley Electric Service	132	137	23,660
29	27	Lassen Municipal Utility District*	129	137	12,244
28	32	Ukiah, City of	107	125	7,500
29	19	Moreno Valley Electric Utility	95	74	5,779
34	29	Surprise Valley Electrification Corporation *	95	95	4,179
19	18	Trinity Public Utility District	87	87	7,095
20	21	Healdsburg, City of	75	81	5,596
16	17	Rancho Cucamonga Municipal Utility	65	63	490
12	7	Victorville, City of	57	31	22
16	17	Needles, City of	54	60	2,863
12	11	AEPCO (for Anza Electric Cooperative, Inc.)	47	47	4,458
15	15	Cerritos, City of	45	58	52
11	13	Port of Oakland	44	82	136
13	12	Eastside Power Authority	36	38	6
11	10	Gridley Electric Utility	35	37	2,795
6	7	City of Industry	32	33	106
4	4	Biggs Municipal Utilties	17	18	670
4	5	Pittsburg, City of (Island Energy)	15	18	344
3	3	Port of Stockton	9	14	55
3	4	Valley Electric Association	7	8	44
1	1	Shelter Cove Resort Improvement District	6	5	550
3	5	Mountain Utilities (Kirkwood Meadows PUD)[3]	6	6	760
1	3	Hercules Municipal Utility*	3	13	896
1,336	1,409	California Dept. of Water Resources (CDWR)	0	0	1
62,420	63,374	Statewide Totals	248,895	264,632	14,859,068
41,780	42,330	7 Investor-Owned Utilities (IOUs)	171,102	181,934	11,615,359
67%	67%	IOU share of Statewide Total	69%	69%	78%
17,400	17,398	45 Publicly Owned Utilities + 4 Coops & CDWR	60,472	64,535	3,219,709
28%	27%	POU share of Statewide Total	24%	24%	22%
3,240	3,647	18 Direct Access providers: 17 ESPs + 1 CCA #	17,322	18,164	24,000
5%	6%	Direct Acccess share of Statewide Total	7%	7%	0.20%

1 Peak Loads are actual non-coincident peak-hour loads and generally do not include transmission

2 Liberty Energy purchased the California retail service area and infrastructure from NV Energy on January 1, 2011.

3 Kirkwood Meadows PUD purchased Mountain Utilities (MU) in July 2011; data is for MU service.

* CEC estimate of 2010 Retail Sales; # Includes a CEC estimate of customer accounts for 12 smaller ESPs

Source: California Energy Commission, Electricity Analysis and Demand Analysis offices, September 9, 2011

CHAPTER 3:
Survey Summary

A small limited survey was conducted as part of this scoping study (a more through and substantial survey is outlined in the recommended *Additional Future Studies* section below). The survey was conducted as informal face-to-face interviews with seven different California growers. The growers were identified through the professional network of the authors of this study and chosen mostly on their willingness to be interviewed. Three of the surveyed growers are in the northern part of the Sacramento Valley, two are in the Sacramento-San Joaquin River Delta area, and two are in the San Joaquin Valley. The survey form shown in *Appendix A: Survey / Interview Questions* was used as a guide during the face-to-face interviews with the growers. The growers did not actually fill out any of the forms. The interviewer(s) informally filled in pages of the survey form as appropriate.

3.1 Crops

The crops produced by the surveyed growers include the following:

- Tomatoes
- Walnuts
- Almonds
- Alfalfa
- Beans
- Prunes
- Rice
- Cucumbers
- Wheat
- Pistachios
- Cotton
- Barley
- Melons
- Garbanzo Beans
- Garlic
- Onions
- Wine grapes

3.2 Source of Irrigation Water

Two growers got all water from irrigation districts and one other got some of their water from irrigation districts. One grower got all water from a tributary river of the San Joaquin Delta. All the other growers got irrigation water from on-farm wells. The grower that got a portion of the water from a district also has on-farm wells. Four of the growers got some or all of their water from surface sources while five got some or all of their water from the on-farm wells.

3.3 Irrigation Method

All the growers interviewed used drip and/or sprinklers. All sprinklers used by the surveyed group are micro-sprinklers except one case of low-pressure impact sprinklers.

3.4 Pumps

Three of the growers use well pumps only, in which case the pumps must perform both the task of lifting the water from the aquifer and pressurizing the drip/sprinkler distribution system. Three of the growers use booster pumps only as all their water comes from surface sources. One grower uses both well pumps and booster pumps.

3.5 Potential for Demand Response

Every grower surveyed expressed interest in participating in DR programs. More specifically, they expressed interest in potential financial incentives. In fact, the largest surveyed grower already participates in several DR programs run by aggregators. Specifically, the growers had participated in programs offered by Comverge, Pure Sense, and EnerNOC. Comverge provides only cash incentive to participate, whereas the other two provide a combination of cash and control systems. In all cases, specific well pumps are designated as "participating". EnerNOC and Pure Sense install automatic controls on the designated pumps as part of the incentive (there is no additional charge to the grower). The grower prefers the Comverge program because it's simpler and because the cash incentive is greater than the cash component of the other two. Further, they don't value or use the automatic controls supplied by the other two.

3.5.1 Limitations

Where irrigation districts supply water, the potential for participating is low due to the growers' lack of control over the water delivery schedule. For one of the surveyed growers, the capacity of the irrigation system would limit participation during the peak ET months.

3.5.2 Automatic Controls

Only one surveyed grower uses automatic controls for irrigation and then only on one crop. The grower uses automatic controls for rice irrigation; where they are used to minimize on-peak TOU energy and demand charges. They were installed as part of a larger energy efficiency project consisting of a grid-tied solar system. None of the other surveyed growers use automatic controls for their irrigation systems. Even the grower that participates in several aggregator-run DR programs does not use the controls that are given to the grower by the aggregators. The DR events, in that case, are handled entirely by human operators communicating to one another about scheduled events and employing the discipline to keep designated pumps off during those event periods.

CHAPTER 4:
Best Opportunities for Demand Response and Permanent Load Shifting Programs

4.1 Growing Region

As previously mentioned, seventy seven percent of California's agricultural irrigation energy is consumed in the Central Valley (Sacramento and San Joaquin valleys) with sixty five percent being consumed in the San Joaquin Valley alone. This suggests that the greatest regional focus should be the Central Valley with particular emphasis on the San Joaquin Valley. Further, a secondary focus might include the coastal regions where the energy needed to acquire a given volume of irrigation water is the greatest.

4.2 Irrigation Source

Over seventy percent of the total energy expended in California agricultural irrigation comes from on-farm pumping and that on-farm ground water pumping represents sixty percent of all the on-farm pumping energy use. This suggests that the best opportunities for DR and permanent load shifting will come from on-farm sources and especially from on-farm ground water sources.

4.2.1 On-farm Sources of Water vs. District-Supplied Water

Irrigation systems that draw water from on-farm sources have much greater potential for DR and permanent load shifting than irrigation systems that draw water from irrigation districts. Generally, irrigation scheduling for water that comes from irrigation districts has less flexibility than scheduling on-farm sources. Therefore, an irrigation system control for a district-supplied system has limited flexibility to respond to a demand event or schedule operation to any time other than when the district is supplying water.

Conversely, growers that pull water from on-farm sources are not bound by any schedule other than their crops' needs, which in-turn offers more flexibility for load shifting and DR. Also, in California, the total energy use of on-farm sourced irrigation is greater than the total energy consumed in district-supplied irrigation. This is primarily due to the fact that most on-farm sources are wells where water must be lifted in addition to pressurizing irrigation systems. As a result, the on-farm sources of irrigation systems present a bigger load to the grid and, therefore, greater potential for load shifting and DR.

Separate from the on-farm irrigation systems, some potential exists for DR and permanent load shifting within the irrigation districts. Note that the focus of this study is "on-farm" electrical load and that no irrigation districts were surveyed as part of this study. However, the ITRC at California State Polytechnic University in San Luis Obispo has done work with some of the larger irrigation districts on shifting their electricity consumption to off-peak periods as part of the CEC's Agriculture Peak Load Demand Program (Burt & Howes 2005). Upgrades to some of the districts allowed them to pump water into reservoirs during off-peak periods and then use

the water from the reservoirs during peak periods. The CEC provided incentive grants to the districts as part of the program. However, the interview with Charles Burt of the ITRC revealed that most of the irrigation districts in California still do not have reservoirs or other storage capacity and therefore do not currently have the capacity to participate in DR or load shifting programs (Burt 2011c). Therefore, significant potential still exists for upgrading irrigation districts in California to enable them to participate in DR and load shifting programs.

4.3 Irrigation Method

Section 2 points to drip/micro for some focus of DR and permanent load shifting programs. Conversions to drip/micro are popular and a continuing trend because of water application uniformity and the ability to deliver chemicals through the irrigation system. Additionally, conversions to drip/micro frequently have compound effects on energy use by adding both booster pumps and ground water pumps. This creates more potential load on average that could be shifted or shed during an event. Further, when on-farm ground water is the source, the grower has more schedule flexibility than with district supplied water (Burt & Monte 2008).

4.4 Irrigation Systems with Extra Capacity

Any irrigation system that can supply adequate water to a crop without running constantly (24/7) essentially has the capacity for DR and permanent load shifting. While, unfortunately, there are many irrigation systems that are designed to have just enough capacity to supply the amount of water required during peak evapotranspiration periods by running around the clock, there are definitely some that have the additional capacity that can accommodate DR or permanent load shifting.

Peak ET periods correlate closely with peak demand on the electrical grid, so any irrigation system that can accommodate load shifting and DR during those periods is a potentially valuable contributor to California's quick shed capacity. The percentage of California's irrigation load that meets this criterion is not known. However, based on the very limited survey sample of this study, the majority of the irrigation systems have the intrinsic ability to accommodate DR.

4.5 Non-Peak ET Irrigation Periods

At the bare minimum, all irrigation systems must have enough capacity to handle a crop's water requirements during peak ET periods. Consequently, all irrigation systems have excess capacity during non-peak ET periods. Irrigation in California varies some by region and crop type but generally starts around April and ends in October. Peak ET generally occurs around the months of June and July, leaving the other months available for DR and permanent load shifting.

While these systems are not as valuable to load shedding schemes as systems that can be off even at peak ET, they can still contribute to load shifting and quick shed capacity. Furthermore, this "non-peak ET" strategy applies to a much higher percentage of growers.

4.6 Large Growers

About 14% of the growers, approximately 6,500, irrigate 84% of the irrigated acres in California agriculture, roughly 6.2 million acres (USDA 2008), as can be seen in Table 16. It's not clear if the same 14% of the growers draw 84% of the irrigation electricity load, but certainly they represent a majority of the load. By working with a small percentage of the growers, the California utilities can address the majority of the potential load shifting and DR capacity of agricultural irrigation. Grower statistics can be found in *Appendix B*.

4.7 Utility Coverage

As previously mentioned, Pacific Gas and Electric covers the majority of the dominant California growing regions. By working with PG&E, California can address the majority of the DR and permanent load shifting potential of agricultural irrigation. If Southern California Edison, which has the second largest coverage of the growing regions, is added to the effort, then an even greater portion of DR and permanent load shifting can be addressed.

4.8 Irrigation Systems with Variable Frequency Drives

While it has already been mentioned how variable frequency drives may play a role in improving energy efficiency, and therefore possibly freeing up capacity for DR and load shifting, VFDs may also improve the potential for participation in DR and load shifting programs in another way. VFDs have been promoted as a way to ease the stress on pumps and wells by using them as soft start/stop controllers (Burt 2011). VFD use has not been widely adopted by growers even though it could increase the life of their pumps. If they draw from a well, it also can prevent deterioration of the well itself. In fact, one of the objections to DR is that growers don't want to stop and start a well pump more than absolutely necessary simply because they don't want to stress the well. Where VFDs are present, the well-stress objection to interrupting irrigation can be removed when it comes to DR or even permanent load shifting.

CHAPTER 5:
Solutions (or Requirements) for Demand Response and Permanent Load Shifting Programs

5.1 Adequate Irrigation System Capacity

The most basic requirement for an irrigation system to accommodate either DR or permanent load shifting is that it must have adequate capacity to meet crops' needs without running 24/7. As previously mentioned, the best opportunity for load shifting and DR occurs when an irrigation system has extra capacity even during periods of greatest evapotranspiration, which generally occur when electricity is already stressed. If the irrigation system must run 24/7 during periods of greatest ET, then it will still have some additional capacity during lower ET periods, which may allow it to participate in load shifting and DR programs during those periods.

5.1.1 Capacity Created by Improved Efficiency

One way to increase irrigation system capacity is to increase system efficiency. If the energy efficiency of an irrigation system can be increased, then in addition to lowering energy consumption and the cost of irrigation for the grower, extra capacity is also effectively generated. This extra capacity results in more flexibility for load shifting and DR.

5.1.1.1 Pump Efficiency

Increasing pump efficiency, generally referred to as overall pumping plant efficiency (OPPE), is one way to gain irrigation energy efficiency. OPPE is a measure of the efficiency of converting electrical energy into hydrological energy. There are currently existing efforts by the utilities working in cooperation with the Center for Irrigation Technology at California State University, Fresno as well as the ITRC in San Louis Obispo to identify inefficient irrigation pumps and then repair/upgrade them to run more efficiently. However, there is still significant potential for improving pump efficiency in California agricultural irrigation. For example, the CIT, which administers the Advanced Pumping Efficiency Program (APEP) for PG&E, performed only 13,660 pump tests and converted/retrofitted only 673 pumps during the 2002 through 2008 phase of the program (Center for Irrigation Technology). Based on the 2008 USDA survey, there are over 100,000 agricultural irrigation pumps in California (USDA 2008). Based on these numbers, APEP resulted in less than 14% of the pumps being tested and less than 0.7% retrofitted during the 2002-2008 phase. According to research conducted by the ITRC, 35% of well pumps and 51% of other irrigation pumps in California still have poor efficiency, less than 50% (Perez, Urrestarazu & Burt 2011; Burt 2011c).

5.1.1.2 Reductions in water applications

Another way to improve energy efficiency is by employing techniques that reduce the volume of irrigation water applied. There have been two primary approaches to reducing the amount of water applied: Improving the application uniformity and improving the irrigation scheduling (Burt 2011). Conversion from flood irrigation to drip/micro irrigation can improve

the application uniformity and reduce the overall application of water. However, it may actually increase the energy use (Burt & Monte, 2008).

There are numerous reports that claim improved irrigation scheduling practices will result in a net decrease in irrigation water applied (Cooley *et al.* 2008 & 2009; Marks 2010). Improved scheduling practices are based on use of irrigation feedback information such as soil moisture and weather data. However, the case has been made that use of such feedback data may be just as likely to induce an increase in water applied as it is to induce a reduction in water applied (Burt 2011).

5.1.1.3 Reduction in Pressure Losses

Some of the best opportunities for improving energy efficiency in irrigation lie in identifying and reducing unnecessary pressure losses. Some pressure losses are due to friction losses in and around the pump assembly or from irrigation system components (Burt 2011). To the extent that they can be reduced, there is potential for energy savings. If the dynamic head of the irrigation pump can be reduced to match reductions in friction losses, then water can be applied at the same rate but with less energy used.

Sometimes friction loss is introduced intentionally to compensate for too much pressure – although this approach is poor energy efficiency practice. Irrigation pump systems are usually over-designed to allow for some uncertainties in the pump curves, the irrigation distribution system, and variations in well water levels (Burt 2011). Often any excess pressure is simply shed through valves. Further, some irrigation systems employ a design that multiplexes one pump for two or more crops or for multiple fields of the same crop, each with different distribution systems. In these cases the pump systems must be designed to produce a discharge pressure and flow rate for the most demanding of the distribution systems. Often, pressure is simply shed through valves to match the requirements of the less demanding distribution systems.

A more energy efficient way to accommodate variations in pressure requirements is by using variable frequency drives. The deployment of VFDs for irrigation pump motors represents one of the greatest potentials for energy savings in agricultural irrigation (Burt 2011). VFDs are being adopted in California agricultural irrigation, but they're still the exception for irrigation pump drives.

Flood irrigation, which still accounts for over 50% of the irrigated acres in California (USDA 2008), may hold a particularly interesting potential for energy reduction. As there is no specific pressure requirement for flood irrigation as there is for sprinklers or drip systems, the discharge pressure of the irrigation pumps is used only to affect the flow rate. Some of those systems may have the potential to run at lower flow rates, which would in turn result in less friction loss.

5.2 Automatic Controls

The best potential for executing DR and permanent load shifting in irrigation comes from pumps with automatic controls. However, nearly all irrigation pumps used for agriculture in

California are manually started and most are manually stopped: A few have timers for shutting off pumps. While technically speaking, it's possible to conform to Time-of-Use or even DR programs with manual operation, it's difficult to maintain the discipline required. In spite of this, 81% of Pacific Gas & Electric's agricultural revenue and 71% of Southern California Edison's agricultural revenue comes from Kilowatt-hour sales on TOU rates (Klein *et al.* 2005). It is not known exactly how well the growers on TOU rates conform to the TOU schedules.

Although it's not clear how much peak-load reduction can be achieved by simply using automatic controls, given that it is hard enough when manually controlling an irrigation system to maintain accurate irrigation schedules according to crop needs, it is even harder to maintain TOU and DR discipline at the same time. Furthermore, there may be a "disconnect" between the irrigation operator and the person paying the utility bills: Most of the time, they are not the same person. Even when using automatic controls, crop irrigation requirements may trump TOU schedules and DR opportunities. However, automatic controls have a better chance of consistently maximizing the use of TOU schedules and rates as well as capturing DR opportunities.

Of course by definition, automatic controls are the only way to implement AutoDR: there must be at least some level of automatic controls with scheduling capability. Further, AutoDR requires that the controls have access to the Internet. A Demand Response Automation Server (DRAS) client must either run directly on the controller or it must run remotely on a server on behalf of the controller. A DRAS maintains DR event and price services data, which DRAS Clients can request and then use to carry out load reductions (Wikler *et al.*). Regardless of where the DRAS client resides, there must be some sort of remote communication channel (usually Internet-based) to the pump controller.

5.2.1 Minimal Controls with Remote DRAS Client

A pump may have a fairly simple controller that handles basic schedules and takes very simple commands over a remote wireless connection to a Network Operations Center (NOC). A proxy DRAS client running at the NOC would handle all DRAS interface issues on behalf of the pump controller. It could then communicate with the pump controller and rearrange its irrigation schedule according to DR events.

5.2.2 Robust Local Controls with Resident DRAS Client

A local pump controller that supports a full robust embedded operating system with an Internet connection can accommodate a DRAS client running directly on the controller. It can directly query a DRAS over its Internet connection and arrange irrigation schedules according to the events and criteria set by the grower.

5.2.3 OpenADR

One way to implement AutoDR is through the OpenADR Standard which has been developed by the LBNL Demand Response Research Center (DRRC). Further, Akuacom, an LBNL subcontractor, operates a program for interested developers that are creating OpenADR clients (Akuacom; LBNL). They provide documentation, DRAS accounts for client testing, and sample client code.

5.3 Storage

In situations where irrigation cannot be interrupted during peak demand or for DR events, it may be possible to use gravity-fed stored water that's been accumulated during off-peak times. Even if booster pumps are required during peak-demand or DR events, storage could shift the power used to draw from wells.

Investing in water storage may not be practical for individual growers; however, it could be practical for irrigation districts. In fact, several larger irrigation districts invested in storage in the 2001-2004 timeframe as part of the Agricultural Peak Load Reduction Program administered by the ITRC (Burt & Howes 2005). However, there is still significant potential for the remainder of the California irrigation districts (Burt 2011). It should be pointed out that the APLRP conversions were accompanied by grants from the CEC. Further grants by the CEC and/or specific utilities may be a required incentive for more water agencies to implement and/or upgrade storage capacity.

5.4 VFDs

Variable Frequency Drives are not common in agricultural irrigation, and where they are used, they're usually employed to adapt one pump station to two or more irrigation systems with different pressure/flow requirements. However, VFDs can also be used to create a soft start/stop feature that reduces stress on the entire system, and especially on the well. Stress on the well that would be caused by stopping a well pump and then restarting it is often cited as a primary reason for not being able to react to DR events. VFDs also have the potential to contribute to energy efficiency, which may free up capacity that increases an irrigation system's potential for participating in DR or load shifting programs.

There may also be a possibility of reducing the load as opposed to completely eliminating the load during an event if VFDs are used. In flood irrigation there are no specific direct pressure/flow requirements (indirectly, it must be sufficient to move water at some required rate). Widespread grower acceptance of this strategy is uncertain. However, at least one case (a rice farm in the Northern Sacramento Valley) can be cited where rice irrigation pumps are automatically slowed during peak-demand periods, as described in the *Survey Summary* section. As flood irrigation is still used to irrigation over 50% of California's irrigated acres (USDA 2008), this "reduced-speed during peak load periods" warrants further investigation.

5.5 On-Site Solar Power Generation

One solution to reduce agricultural pumping load during peak hours is the installation of on-site grid-tied solar power generation. As these panels typically generate peak power mid-day, coincident with the grid's peak periods, they will offset a part of the daytime pumping load and move a greater share of the agricultural pumping energy off-peak. Growers already on TOU plans will have a more favorable value proposition for solar installation, as their daytime electricity rates are higher than growers on fixed-rate plans.

CHAPTER 6:
Potential Grower Acceptance of Demand Response and Permanent Load Shifting Programs

Based on the limited number of grower interviews conducted as part of this scoping study, it seems that many growers, if not most, have some interest in participating in DR and permanent load shifting programs, especially if there are financial incentives involved. However there are some differences in their ability to participate. Also, any financial incentives must at least offset the costs incurred by the growers' involvement.

Participation in permanent load shifting or Time-of-Use plans is already fairly common. Further, manually administered DR has been gaining some acceptance among growers in the last few years primarily through the efforts of aggregators of DR. However, it will be much more challenging to gain grower acceptance of AutoDR or "Real-time-DR", which will be required for response to dynamic pricing and real-time response to events.

6.1 On-Farm Water Supply with Excess Capacity

Growers with on-farm water supply that do not need to run their irrigation systems 24/7 in order to meet their crops' needs during peak ET periods have the greatest potential for participating in DR programs. In fact, some growers who routinely irrigate during off-peak periods and are on TOU rate plans expressed interest in participating in DR programs. In other words, they do not want to miss out on potential financial incentives just because they were already helping to shift load from peak to off-peak periods. This is a very important consideration for the CEC, PUC, and the utilities when designing incentive plans for DR. The financial incentives for growers that irrigate strictly during off-peak times must be significant enough for them to stay on TOU plans and not be motivated to move to peak use just to benefit from DR incentives. Alternatively, DR incentives could be extended to cover off-peak periods.

6.2 On-Farm Water Supply without Excess Capacity (during peak ET)

Growers with on-farm water supply that need to run their irrigation systems 24/7 in order to meet their crops' needs during peak ET periods have less potential to participate in DR and permanent load shifting programs than the first category. However, they have the potential to participate during periods that are not at maximum ET when they do not need to run their irrigation systems 24/7. Otherwise, their system capacity would have to be upgraded in order to participate in DR and permanent load shifting programs during peak ET periods.

6.3 District-Supplied Water

Irrigation schedule control for growers that take water from irrigation districts varies somewhat with the irrigation district, but it certainly is not the same as it is for growers with on-farm sources of water (ITRC 2002). Some districts provide enough flexibility that growers, by exercising a great deal of scheduling discipline, could conform to TOU rates schedules or manual DR. However for AutoDR, the growers' pump control systems would have to have

direct control over their respective district turn-outs, which is a capability generally not facilitated by irrigation districts (not to mention that they would have to have pump controls that facilitate AutoDR). Also, it should be noted that some growers that take water from a district also have on-farm sources of water where they may have the ability to participate in DR and permanent load shifting programs as described above.

As previously mentioned, some potential exists for DR and permanent load shifting by the irrigation districts themselves. If the district's delivery schedules are based on the programs, then growers that receive the water will, by default, also be on the programs. However, if the district uses water storage to conform to DR and/or permanent load shifting while still being able to deliver water at any time, then depending on how the schedules are managed, each grower may have the opportunity to participate individually in DR and/or permanent load shifting programs.

6.4 Permanent Load Shifting vs. Demand Response

If the bulk of the agricultural irrigation load can be permanently shifted to off-peak periods, then there is less need for DR. Permanent load shifting in the form of Time-of-Use rate plans is already accepted and quite common among California growers. On the other hand, as DR is much less common (especially AutoDR), it would require a much greater effort in order to gain broad acceptance among California growers. There may be a Pareto Principle relationship of effort to benefit by pushing more growers to adopt and conform to TOU rate plans.

However, it should be considered that an irrigation system must have a greater capacity to accommodate a permanent load shift than would be required by DR. A permanent load shift would prevent irrigation from happening during peak periods every day instead of just during DR events. Therefore, if an irrigation system doesn't already have sufficient capacity, then there may be more up-front costs for upgrading it for permanent load shifting than for DR. The incentives to upgrade for permanent load shifting would have to be greater than for DR. As pointed out above in *On-Farm water supply with excess capacity*, the incentives must be high enough for growers with systems already on permanent load shifting plans to stay on them instead of shifting loads back to peak period just to take advantage of DR incentives.

It should also be considered that growers on TOU rate plans may not actually conform to the plans. The use of automatic controls may improve conformance. However, adoption of automatic controls is the greatest obstacle to growers adopting AutoDR. Therefore, ensuring permanent load shifting may be nearly as challenging for getting growers' acceptance as it would be to get their acceptance of AutoDR. Further, if the need for real-time response to DR events and dynamic pricing are significant enough, then it may warrant the efforts required to get California growers to accept DR, particularly AutoDR, programs.

6.5 Manual vs. Automated Demand Response

The potential for grower acceptance of DR depends significantly on the type of DR being considered. As mentioned above, there is already significant acceptance for Time-of-Use permanent load shifting. Also, manually administered DR through aggregators is starting to

gain acceptance. However, there is little to no acceptance yet among growers for using automatic pump controls which would be required for AutoDR and the addressing of real-time events and dynamic pricing.

Moving to automatic controls and AutoDR would require a fairly significant change in growers' irrigation habits. Often it's not just the pumps that are manually controlled but also valves that channel water to different delivery systems or different blocks of a given irrigation system. The standard practice is to always have human operators present for irrigation system operation. In order to accommodate AutoDR, significant system upgrades may be required. Even then, it would take some time for growers to accept and trust the technology. Growers in California do have a history of accepting new technology that benefits their operation but it usually takes some time (on the order of years) for it to be widely adopted and trusted.

6.6 Cost of System Upgrades vs. Financial Incentives

The potential for acceptance of DR and permanent load shifting programs in California agricultural irrigation will be greatly influenced by financial incentives to the growers. The incentives must be at least sufficient enough to warrant any capital expenditures required in order to participate in the programs.

As owners and managers of businesses, growers are motivated by financial gains and generally have a very good understanding of return-on-investment. The most straight forward way to motivate growers to participate in DR programs is by offering direct financial incentives or by offering savings on their electricity bills.

For growers to participate in TOU or manual DR programs, simple financial incentives work fairly well because many growers can participate without making major changes in their irrigation practices, provided they have adequate irrigation system capacity. If not, then financial incentives must by substantial enough to offset upgrading the irrigation system.

Participating in AutoDR or Real-Time DR programs is challenging for most growers. It requires the use of automatic pump controls, which most growers don't use, as well as changes in basic irrigation scheduling practices. Additionally, other parts of the system such as valves may need to be automated. The financial incentives will have to be more substantial or the growers will need other compelling reasons to install automatic pump and valve controls and change their irrigation scheduling practices. Of course as California's electricity markets move toward real-time pricing, the financial incentives for using AutoDR increase, that is the cost of not using it increases.

6.7 Other Possibly Compelling Motivations

6.7.1 Energy Efficiency and/or Demand Management

If a pump controller was able to improve energy efficiency or facilitate a reduction in demand charges, then there would be an incentive for a grower to use it above and beyond any incentives related to participating in AutoDR or Real-Time DR. Of course, the pump controller would also have to be capable of implementing an AutoDR client or, alternatively, it would

have to able to react to instructions from an off-site system running the AutoDR client as a proxy for the controller. In either case, it requires Internet connectivity for the controller. Once automatic pump controllers with intrinsic AutoDR capability are in place, then financial incentives for participation in Real-Time DR become viable.

6.7.2 Remote Pump Monitoring and Control

As a younger generation of growers takes over farming operations, there is a trend toward using more information technology to improve agricultural operations. For the most part, this has manifested itself in the form of environmental data sensor networks, which include some combination of soil moisture sensors, weather stations, or other types of sensors. However, there is also some increasing interest in monitoring irrigation systems including the pumps. If monitoring pumps on a network that ultimately routes data through the Internet is being done, then adding some level of control on the pumps is a relatively easy extrapolation.

The field of crop frost protection offers another potential incentive for having remote control of pumps. A common practice for reducing potential damage from frost conditions in certain types of orchards and vineyards involves running irrigation sprinklers when the ambient temperature is at the right point relative to the dew-point. The frost conditions that can be mitigated this way occur only during very early hours in the morning when there would not otherwise be anyone in the orchard or vineyard. As the timing of starting and stopping pumps can be fairly critical, the motivation for remote control may be high. Generally, growers would not use remote control as a reason not to travel to the crop location, but they might use it to start pumps before they arrive.

Again, if Internet-connected pump controllers are in place, then having direct or indirect AutoDR capability is not a great leap.

CHAPTER 7:
Potential Challenges and Obstacles to Demand Response and Permanent Load Shifting Programs

Most of the challenges and obstacles have been at least indirectly covered in previous sections of this study. What follows here is a summary of the obstacles to DR and permanent load shifting programs for California agricultural irrigation and the challenges associated with each obstacle.

7.1 Inadequate Irrigation Capacity

Many irrigation systems are designed with the bare minimum capacity to just cover crop needs during maximum evapotranspiration periods by running 24/7. Systems designed this way are not able to participate in load shifting or DR programs during maximum ET periods, which usually occur at the same time that the grid is already at maximum stress.

7.1.1 Load Shifting and Demand Response during Non-Peak ET Periods

If an irrigation system is designed to just meet crop requirements during peak ET periods by running 24/7, then it will have sufficient capacity to irrigate the crops without running 24/7 during non-peak ET periods. In other words, growers with these irrigation systems may be able to participate during the months when their crops are not experiencing peak ET. The challenge, in this case, is to get enough load shifting and/or DR from these systems during non-peak ET periods to be worthwhile.

7.1.2 Upgrade Irrigation System Capacity

Alternatively, an irrigation system that must run 24/7 during peak ET periods may be upgraded to have additional capacity so that participation in load shifting and DR becomes possible during peak ET periods, which is when the grid is at highest stress. The challenge, in this case, is to provide enough financial incentive to growers to upgrade their irrigation system capacity to the point where participation in DR and/or permanent load shifting programs becomes practical.

7.2 District-Supplied Water

Growers that receive water from an irrigation district have limited control over the scheduling of the water. Their pumps used to pull water out of the district canals must run when the water is available regardless of the time of day.

7.2.1 District Participation in Demand Response and/or Permanent Load Shifting

Some irrigation districts participate in load shifting and/or DR programs; however, many do not. The challenge, in these cases, is to motivate the irrigation districts to make the necessary upgrades that would be required in order to participate in load shifting and/or DR programs. This may require substantial financial incentives.

7.3 Lack of Automatic Controls

Most growers don't use automatic controls for their irrigation pumps. The ability for growers to participate in load shifting and/or DR programs would be limited without automatic controls. Specifically, only manual load shifting and DR programs can be implemented. Automatic controls are definitely required for the implementation of AutoDR.

7.3.1 Participation with Manual Controls

As previously mentioned, permanent load shifting (TOU) programs have significant acceptance among California growers and manual DR has gained some acceptance. If the vast majority of growers continue to use only manual irrigation controls, then one challenge is to get enough participation in the manual load shifting programs to adequately contribute to California's need to shift peak load to off peak periods. Another challenge is to get enough participation in manual DR programs, which depend on DR events that have advance notice, to adequately contribute to California's ability to shed load based on DR events.

7.3.2 Integrate Automatic Controls into Irrigation Systems

In order to have agricultural irrigation systems contribute to quick shed and/or dynamic pricing of electricity, the challenge will be to provide adequate financial incentives for growers to upgrade their irrigation systems to using automatic controls, especially those that can handle AutoDR. Also there is a basic challenge in getting growers to even accept (trust) the concept of using automatic controls, which would require fundamental change in the traditional way that they operate.

7.4 Smart Meter Installation Schedule

AutoDR can only be implemented in areas where interval meters (*smart meters*) have been installed by the local utility. This is expected to be a minor issue in that the smart meter installation schedule is likely to be completed before significant number of growers accept automatic controls for their irrigation pumps. For example, PG&E, which services the largest portion of California agriculture, is scheduled to finish smart meter installation in all their service areas by the end of 2012 (Pacific Gas and Electric). However, there is an "opt-out" option being considered by the California Public Utilities Commission, which could affect some users (California Public Utilities Commission).

7.5 Lack of Variable Frequency Drives

Most irrigation pumps don't have VFDs. Without a soft start/stop capability that can be implemented with VFDs, growers may be hesitant to stop and then restart pumps for load shifting or DR requirements. This is especially true for well pumps, as sudden stops and restarts stress the well.

7.5.1 Participation without VFDs

The challenge is to get growers to participate in load shifting and/or DR programs without VFDs. The best potential for this is on pumps that don't draw from wells and that have minimal potential for efficiency gains from VFDs.

7.5.2 Integrate VFDs into Irrigation Systems

The challenge is to provide adequate financial incentives for growers to upgrade their irrigation systems to using VFDs. Note there may also be efficiency incentives to using VFDs, which could leverage the benefits of load shifting and/or demand response.

CHAPTER 8:
Future Studies on How to Gain Grower Acceptance for Demand Response

Grower acceptance of DR depends to some extent on what type of DR is being considered. Permanent load shifting or Time-of-Use plans are already somewhat accepted by growers. Also, manually administered DR has gained some limited acceptance in the last few years, primarily through aggregators of DR. Much more challenging will be to gain acceptance among growers for AutoDR or "Real-time DR", which will be required to deal with dynamic pricing and real-time response to events. The following are proposed studies to increase understanding of how to gain grower acceptance of DR and improve the potential for success of agricultural irrigation DR programs.

8.1 Reasons for Compliance and Non-Compliance with Current TOU programs

Currently there are a high percentage of agricultural electric utility customers that are on TOU rate schedules, representing 81% of the PG&E agricultural revenue and 71% of the SCE agricultural revenue (Klein *et al*. 2005). However, there is a question of how well they actually conform to irrigation schedules where they benefit from the TOU rates. Almost all agricultural pumps are manually operated and the personnel that operate them have many priorities that trump TOU electric rate schedules. Also, in large operations, personnel that operate irrigation pumps are not usually the same personnel that pay the utility bill. Often close examination of utility bills reveal that TOU schedules are not being followed very closely even when top-level management believes that they are.

This study would first consist of a survey of agricultural utility customers to find those that have elected TOU rate schedules. Additionally or alternatively, the PG&E database could be queried for the customers (if that data is accessible). The next stage of the study would be to determine the level of compliance. This could be done through the survey or the database. There may be a need for the customers to give permission to the DRRC to access their utility billing data. The non-compliant customers will then be identified and surveyed for the reasons that they don't adhere to the schedules. Those reasons can then be ranked. The resultant list of obstacles to TOU is a starting point to what the objections might be to DR.

8.2 Survey and Rank Barriers to Real-Time Demand Response

Another future study could either create a separate survey or include survey questions on barriers to AutoDR/Real-Time DR in a larger survey. In the agricultural sector, there is currently significant participation in TOU programs and, to some extent, manually implemented DR programs. However, there is little to no AutoDR or any other type of Real-Time DR in California agricultural irrigation. The goal of this survey is to discover and rank the barriers to Real-Time DR.

8.3 Determine the Level of Financial Incentives Required for AutoDR

To participate in AutoDR for irrigations pumps, growers will have to adopt Internet-connected automatic pump controls and change irrigation scheduling practices to allow interruptions. They may even need to automate valves. To do so may require significant investments in irrigation system upgrades. Beyond the cost of automatic controls, VFDs may need to be added to ease irrigation system stress caused by stopping and restarting pumps. Also, the irrigation system capacity may need to be increased so that adequate quantities of water can be applied during the times when the irrigation system is not required by DR to be off.

The purpose of this study would be to determine what level of incentives will be required to justify the required growers' investments into their irrigation systems and changes in their irrigation management practices. As part of this study, the DRRC may develop tools for growers to determine the return on investment (ROI) or, alternatively, it may be a separate project.

8.4 ROI Tools

The development of ROI tools may be a separate project in itself as opposed to just being part of the previously described project. The tools may consist of an interactive application or simply spreadsheets with data input fields for a grower to fill in. The purpose of the tools will be to determine the amount of investment required to participate in DR programs with an emphasis on AutoDR and then what the return on that investment would be. Alternatively it could be used to determine the incentives required to attain a specified ROI.

8.5 Survey of Potential Incentives for Using Automatic Pump Controls

The purpose of this study would be to determine and rate potentially compelling motivations for using Internet-connected automatic controls on irrigation pumps beyond the incentives for real-time DR. This may be a separate study or it may be part of the financial incentives study mentioned earlier. Section 6.7 may be a starting point for this study.

Beyond listing potential motivations, this study should attempt to quantify the return from energy efficiency and/or demand management measures implemented through automatic pump controls as well as the return from remote pump monitoring and control. Additionally, the proposed DRRC-developed ROI tools may consider these returns on automatic pump controls.

8.6 How Irrigation Practices would have to Change in order to Accommodate Real-Time Demand Response

The purpose of this study would be to determine how growers would have to change their irrigation scheduling practices in order to accommodate real-time electricity pricing and real-time DR. It would address the questions of how much irrigation system capacity is required and how much tolerance is required for interruptions. It would also examine the potential for reducing pump speeds in flood applications as opposed to total pump interruptions.

8.7 Best Way to Structure Programs in order to Maximize Participation

This study would use the results of the studies listed above to create a proposal on how to structure agricultural irrigation DR programs in a way that maximizes grower participation.

CHAPTER 9:
Additional Future Studies

The following proposed studies target several topics on DR and energy efficiency not covered by the list of proposed studies on how to gain grower acceptance, found in the previous section.

9.1 Comprehensive Study on Opportunities for Demand Response in California Agricultural Irrigation

This study would be a direct extrapolation of *this* scoping study. First, the survey form in *Appendix C: Survey Questionnaire* would be used as a template for an on-line survey for California growers to complete. Secondly, if the DRRC could obtain data from utilities on their agricultural electricity load in a way that does not compromise any specific customer confidentiality, then that data would be used to refine, enhance, and corroborate data from the survey. Data from only PG&E may be sufficient, as it is the dominant utility for the primary growing regions of California.

The purpose of the study would be to generate more complete and detailed data for the questions that are addressed in this scoping study, namely, data for electrical demand (load) and potential for DR based on the following:

- Growing regions
- Water source
- Irrigation method
- Crop type
- Grower size
- Utility coverage

The DRRC may involve the ITRC in this study. The ITRC currently has the most extensive database on California agricultural irrigation. Also, they have a history of working for the CEC on energy efficiency and load shedding projects.

9.2 Update the ITRC Report on California Agricultural Water Electrical Energy Requirements

The most referenced source in this scoping study is the 2003 ITRC report on California agricultural water electrical energy requirements (Burt *et al.* 2003). The information in that report is extremely useful, but the data is becoming dated. If it hasn't already been started, a similar study should be initiated, which includes current updates on the data that was included in the 2003 report but it should include electrical load information in addition to the electrical energy information that was provided in the 2003 report.

9.3 Study of Permanent Load Shifting vs. Demand Response in California Agricultural Irrigation

This study would examine the benefits of maximizing the contribution of permanent load shifting vs. implementing DR programs in California's agricultural irrigation. As permanent load shifting is already widely accepted by California growers, there is a possibility that a Pareto Principle effect on load shifting may be realized by maximizing participation and adherence to permanent load shifting programs alone. However, if the need for real-time response to DR events and dynamic pricing are significant enough, then it may warrant the efforts required to get California growers to accept DR, particularly AutoDR, programs. The purpose of this study would be to examine the cost/benefit of pursuing either approach.

9.4 Study that Characterizes Growers' and/or Aggregators' Ability to Deliver Load Shedding

Currently, there is no method to verify aggregators' claims on their ability to shed load on demand. Though tests can verify that pumps can be shut off successfully, there is not a method to estimate the likelihood that they will be on or that growers will opt out of sheds. The purpose of this proposed study would be to create a model for the probability of being able to shed load based on various criteria such as crop type, irrigation method, and time of year. For example, the model could determine the ability of an aggregator to deliver based on the mix of crop types, the point in the growing season, and the installed capacity of the farm.

9.5 Studies on Potential Capacity Created by Energy Efficiency Measures and How They May Contribute to Demand Response Participation

DR and energy efficiency have been established by California's Energy Action Plan II as the state's preferred means of meeting the growth in future energy requirements. The best scenarios occur when efficiency measures, which save total electricity consumption, can also contribute to DR and permanent load shifting. This may be one or multiple studies.

As previously mentioned, some growers are limited in their ability to participate in DR and load shifting programs by their irrigation system's capacity. Therefore, any capacity added by energy efficiency measures can also increase the potential for participation in those DR and load shifting programs.

Another obstacle to participation comes from growers' unwillingness to start and stop their well pumps during an irrigation cycle because of the stress on the pump and well. However, the use of a VFD that may be used to improve efficiency could also eliminate the reluctance to start and stop a well pump because the VFD can be used to affect a "soft" start and stop. Also, in flood irrigation applications, a VFD may be used to *partially* lower the load. The purpose of this study would be to examine various efficiency measures and how they may contribute to DR potential. Further, the combined incentives and cost savings of energy efficiency and DR participation would be examined for total ROI that may be derived from the efficiency and DR upgrades.

9.6 Potential Benefits of Variable Flow Rates for Flood Irrigation

This study would examine the potential energy efficiency and DR benefits of variable flow rates for flood irrigation. While sprinkler or drip irrigation systems must maintain a specific pressure and flow rate, flood irrigation systems have some latitude to vary in pressure and flow rate. The pump discharge pressure only affects how fast the water is applied. There may be some potential for energy savings by slowing the flow rate, which in turn reduces friction losses in the distribution system, provided that water flows at least fast enough to meet the basic application requirements. Further the flow rate may vary with Time-of-Use or DR events.

There is one case identified by this scoping study's Survey Summary in which variable flow rates are used in rice irrigation. Flow rates are varied in response to a Time-of-Use schedule in order to save on electricity rates and, more importantly, demand charges. Utility demand charges vary significantly with the time of day.

9.7 Survey of Technology that May be Applied to Demand Response and Permanent Load Shifting in California Agricultural Irrigation

This study would present the technologies that can be applied and are being applied to irrigation DR and permanent load shifting. In particular, it will examine what technologies could be applied to automatic controls that include the ability to facilitate AutoDR.

9.8 Pilot Studies

Pilot studies may be used to test the various technologies and solutions that result from the other proposed future studies. They may apply to energy efficiency and/or DR. The pilot studies could involve multi-location installation and monitoring of the proposed solutions.

9.9 Determine ROI of Upgrading Water Agency Systems for Demand Response

While this scoping study has focused primarily on growers, it has also examined some potential benefits of DR for agricultural water districts. The purpose of this proposed study would be to examine further the potential for DR by California's agricultural water agencies, some of which already participate in permanent load shifting and/or DR programs. In particular, the ROI realized by the agencies and the state of California would be examined as a result of required system upgrades by the agencies that don't currently have the capacity to participate. For example, the cost of adding water storage capacity would be examined. Also, the impact of grants would be considered as part of this study.

9.10 Study of the Benefits of On-Site Solar Power Generation

As California's seasonal irrigation trends are coincident with its grid peak, there is value to reducing peak-hour irrigation energy use, with on-site solar generation having great applicability. This study could examine the benefits, both to the grid and to the growers, of widespread adoption of solar generation within the agriculture industry.

CHAPTER 10:
Conclusion

This scoping study was initiated on the premise that significant potential exists for reducing stress on California's electricity grid through permanent load shifting, demand response and energy efficiency measures aimed at agricultural irrigation power use, and that further, California's agricultural irrigation can contribute significantly to California's quick response shed capacity. The results of this scoping study reinforce that original premise.

First, available published data was parsed into categories delimited by growing regions, water source, irrigation method, crop type, grower business size, and utilities serving the California growing regions. Analysis of the categories yielded some interesting Pareto correspondence as well as some other significant trends:

- Most of the energy used for irrigation occurs in the Central Valley, in particular, the San Joaquin Valley.
- The greatest energy per unit of water applied occurs in the coastal growing regions.
- The greatest energy use by water source comes from the on-farm sources, and in particular, from ground water sources.
- There is a continuing trend toward converting from flood to drip/micro irrigation, which while reducing the amount of water applied, actually increases the amount of energy used per unit of water.
- There is a strong Pareto correspondence of grower size with regard to acres irrigated and therefore to irrigation energy use.
- The growing regions' utility coverage is dominated by a few utilities, but especially by PG&E.

The data was further enhanced with a small limited survey, which was conducted as informal face-to-face interviews with several California growers in various parts of the state including the Sacramento Valley, the San Joaquin Valley, and the Sacramento-San Joaquin River Delta area. The results of the survey and the analysis of the published data led to some preliminary conclusions about the best opportunities and solutions for demand response and permanent load shifting. It also led to a preliminary assessment of the potential challenges and the potential for grower acceptance of demand response and permanent load shifting programs. As part of examining grower acceptance, the trade-offs between demand response and permanent load shifting was considered. Finally, the study included recommendations for further studies on how to gain grower acceptance as well as other studies related to energy efficiency and demand response in California agricultural irrigation.

It is recommended that the future studies as outlined in both sections be pursued. However, even before further studies are conducted, there are some preliminary conclusions that can be drawn on how to focus efforts on demand response and permanent load shifting:

- Focus on the Central Valley (Sacramento and San Joaquin), but especially the San Joaquin Valley
- Focus first on the largest agricultural customers of PG&E (which are likely to be in the Central Valley)
- Promote VFD use on well pumps

However, it should be noted that simply adding VFDs to pump controls don't have any effect unless they're used in a way that improves energy efficiency or in a way that facilitates demand response. As outlined in the *Solutions* section, VFDs on well pumps can facilitate demand response simply by reducing the pump start and stop stress on the wells. VFDs can also contribute to energy efficiency where they can be used to eliminate unnecessary pressure shedding as described in the *Best Opportunities* section. Further, there is the possibility of VFDs being used in flood irrigation applications in a way that reduces energy consumption and also provide the potential for reducing peak demand by slowing flow rates during peak periods or during DR events.

Finally, in order for agricultural irrigation to contribute meaningfully to California's quick response shed capacity, automatic controls that are capable of handling AutoDR must be added to the irrigation pumps.

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Glossary

AF	Acre Foot
APEP	Advanced Pumping Efficiency Program
APLRP	Agricultural Peak Load Reduction Program
AutoDR	Automated Demand Response
CEC	California Energy Commission
CIMIS	California Irrigation Management Information System
CIT	Center for Irrigation Technology
CPA	California Power Authority
CPUC	California Public Utilities Commission
DR	Demand Response
DRAS	Demand Response Automation Server
DRRC	Demand Response Research Center
DWR	Department of Water Resources
ET	Evapotranspiration
ETo	Potential Evapotranspiration
GW	Gigawatt
ITRC	Irrigation Training and Research Center
KWh	Kilowatt Hour
LBNL	Lawrence Berkeley National Laboratory
MW	Megawatt
MWh	Megawatt Hour
NASS	National Agricultural Statistics Service
NOC	Network Operation Center
OpenADR	Open Automated Demand Response
OPPE	Overall Pumping Plant Efficiency

PG&E	Pacific Gas and Electric
ROI	Return on Investment
RPS	Renewable Portfolio Standard
SCE	Southern California Edison
TOU	Time-of-Use
USDA	United States Department of Agriculture
VFD	Variable Frequency Drive

Appendix A:
Survey / Interview Questions

The following list of questions was used in face-to-face or phone interviews.

Farm Information

Contact Information

All contact information will be confidential.

1. Business/Corporate Name of the Farm:_____
2. Business/Corporate Address:_____
3. Contact Name:_____
4. Email:_____
5. Phone:_____

Crop Types

List all crops produced by the business, regardless of location.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
- _____
- _____
- _____

n. _____

Crop Information (per crop)

1. Crop Type:_____
2. Location:_____
3. The number of acres:_____
4. Irrigation season:_____
5. Utility that provides power to the location:_____
6. Self-generation (solar, etc.) on site:_____
7. Total annual pumping costs for crop/location:_____

Irrigation System

1. Water distribution method (flood, drip, sprinkler, etc.):_____
2. Method used to determine when to irrigate and for how long:_____
3. Pump Scheme
    a. Total number of pumps:_____
    b. Number of wells:_____
    c. Number of booster pumps:_____
    d. Holding reservoirs/tanks:_____
4. Schematic (layout) of system:

Pump Information (per pump)

1. Pump Use (well, booster, etc.)_____
2. If Well Pump
    a. Well Depth:_____
    b. Standing Water Level:_____
    c. Pumping Water Level:_____
3. Pressure and Flow Rate:_____
4. Pump Station Power Rating:_____
5. Frequency of Use (how often):_____
6. Typical Run Time:_____
7. If VFD
    a. Why_____
    b. Speed settings (percent of full) used:_____
    c. What determines speed:_____
8. Control method (manual/automatic):_____
    a. If Automatic, type of control:_____
9. Number of hours (or percent of time) run during peak hours:_____
10. Frequency of efficiency audits by Utility/Other:_____
11. Last Audit:_____

Utility Information

1. Current and past participation with Utility rate saving options:_____
2. Quality of relationship with Utility account manager:_____

Demand Response

1. What impact would a 2/4/6 hour interruption have:_____
2. What is the flexibility for above interruptions with a 24hr advance notice:_____

AutoDR

(Insert explanation)

1. What would be of interest?
    a. Access to real-time pricing
    b. Incentives to add/up-grade controls
    c. Favorable electricity tariffs and credits for participation
    d. Increased reliability of service through automation
    e. Advanced agreement on DR black-out dates
    f. Other
2. What incentive would be required for participation_____

Appendix B:
Top Growers in California

This appendix lists some of the top growers of irrigated crops in California. The "Growing Produce" publications and web site cover some but not all irrigated crops. The following lists of top growers in California by category come from the Growing Produce web site (Growing Produce: Top 100 growers). Listed below are California's top five in grapes, nuts, stone fruit, and fruit and vegetable field crops. Actually, the Growing Produce organization lists the top twenty five in each of the categories for the entire United States.

The growers are ranked by acreage in the specific categories, which may not indicate their total irrigated acreage since many large growers have crops in multiple categories. Furthermore not all categories of irrigated California agriculture are covered by the Growing Produce web site and publications. For example, J. G. Boswell is listed in the category of "Fruits and Vegetables" as having 23,000 acres of tomatoes. However JG Boswell maintains large acreage in cotton among other crops and has total irrigated acres of approximately 150,000.

Grapes			
Farms	**acres**		**Location**
Bronco Wine Co	35,000		Ceres
Gallo Vineyards	15,000		Modesto
Vino Fiems	12,000		Lodi
Lange Twins Vineyards	6,500		Lodi
Monterey, Pacific	6,400		Soledad

Nuts			
Farms	**acres**		**Location**
Paramount	80,000		Lost Hills
Farmland mgt	26,500		Turlock
Braden Farms	14,000		Hughson
Agriland Farming Co	12,400		Chowchilla
South Valley Farms	11,000		Wasco

Fruit (stone)			
Farms	**acres**		**Location**
Gerawan Farming	7,000		Fresno
Wawona Packing	6,600		Cutler
Sunwest Fruit	4,900		Parlier
Fouler Packing Co	3,900		Fresno
Moonlight Packing Corp.	3,000		Reedley

Fruit and Vegetables (field crops)			
Farms	**acres**		**Location**
Grimmway Enterprises	54,300		Bakersfield
D'Arrigo Bros. Co.	33,600		Spreckels
Tanimura & Antle	30,000		Salinas
JG Boswell	23,000		Corcoran
Mission Ranchers	22,000		King City

Appendix C:
Survey Questionnaire

The following questionnaire design is meant to be implemented as an on-line survey to be completed by as many California growers as possible. It uses as many simple yes/no questions , multiple choice questions, and questions that take simple numeric answers as possible.

Business Information

Contact Information

All contact information will be confidential.

- ❑ Business/Corporate Name of the Farm:_____
- ❑ Business/Corporate Address:_____
- ❑ Contact Name:_____
- ❑ Email:_____
- ❑ Phone:_____

Crop Types

Check all crops produced by the business, regardless of location (as long as it's in California).

- ❑ Orchards and Vineyards
  - ❑ Nuts
    - ❑ Almonds
    - ❑ Walnuts
    - ❑ Pistachios
    - ❑ Pecans
    - ❑ Other _____ _____
  - ❑ Fruit Orchard Crops
    - ❑ Oranges
    - ❑ Other Citrus_____
    - ❑ Cherries
    - ❑ Prunes
    - ❑ Other Stone Fruit_____
    - ❑ Pome Fruit (Apples, Pears, etc.)
    - ❑ Other Fruit Orchard Crop_____
  - ❑ Olives
  - ❑ Vineyards
    - ❑ Wine Grapes
    - ❑ Table Grapes
    - ❑ Raisin Grapes
- ❑ Grains
  - ❑ Corn
  - ❑ Wheat

- ❑ Barley
- ❑ Rice
- ❑ Alfalfa
- ❑ Other_____

❑ Cotton

❑ Tomatoes
- ❑ Processing Tomatoes
- ❑ Fresh Tomatoes

❑ Field Crops
- ❑ Lettuce
- ❑ Potatoes
- ❑ Sweet Potatoes
- ❑ Onions
- ❑ Garlic
- ❑ Other Vegetables_____
- ❑ Strawberries
- ❑ Other Fruit Field Crops_____

❑ Flowers

❑ Nursery Products

❑ Other_____

Crop Information (per crop)

The on-line survey will lead the participant to a crop information questionnaire for every crop type checked in the previous "Crop Types" section above.

Number of Separate Locations (Farms) where this Crop is grown: _____

The on-line survey will lead the participant to a questionnaire for each crop location.

This is the beginning of the questionnaire for each location of a given crop.

Location of Crop

County

Pull-down list of California counties

Participant will select one of fifty six California counties

Sub-Basin (if known and applicable)

Pull-down list of DWR sub-basins

If applicable, the participant will select the Department of Water Resources (DWR) sub-basin where the crop is located. A map (shown on next page, Figure 7) can be shown for reference.

Number of Acres for this Crop (at this location)

- ❑ < 50 acres
- ❑ ≥ 50 acres and < 100 acres
- ❑ ≥ 100 acres and < 200 acres
- ❑ ≥ 200 acres and < 500 acres
- ❑ ≥ 500 acres and < 1,000 acres
- ❑ ≥ 1,000 acres and < 2,000 acres
- ❑ ≥ 2,000 acres and < 5,000 acres
- ❑ > 5,000 acres

Alternatively, this could be a simple number (participant fill-in) text field.

Are there irrigation pumps for this crop at this location?

- ❑ Yes
- ❑ No

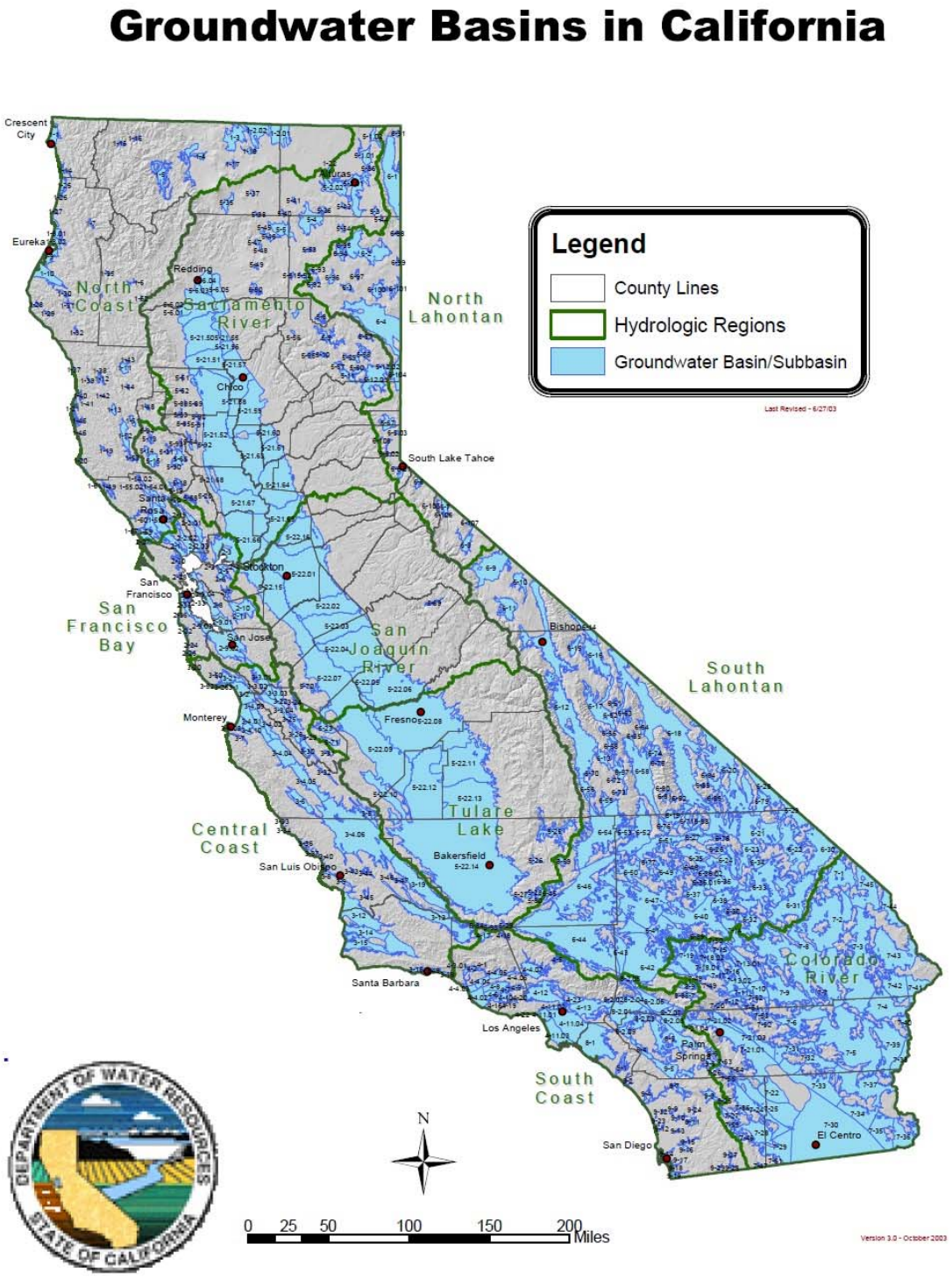
If "No" is checked, then the survey will exit this crop location and move on to the next crop location (if this participant has more crop locations that the survey has not yet visited).

What types of pumps (by power source) and how many of each are used at this location?

- ❑ Electrical Quantity:_____
- ❑ Diesel Quantity:_____
- ❑ Natural Gas Quantity:_____
- ❑ Propane Quantity:_____
- ❑ Other_____ Quantity:_____

If "Electrical" is not checked, then the survey will exit this crop location and move on to the next crop location (if this participant has more crop locations that the survey has not yet visited).

Figure 7: Groundwater Basins in California



Source: Department of Water Resources

What electric utility provides power to this location?

- ❑ PG&E
- ❑ SCE
- ❑ Other_____

Is there any self-generation on-site? Check all that apply.

- ❑ Solar
- ❑ Wind
- ❑ Other_____

Irrigation Method for this Crop

- ❑ Drip
- ❑ Sprinkler
- ❑ Flood
- ❑ Other_____

Method Used to determine when and for how long to irrigate (check all that apply)

- ❑ Condition of Crop
- ❑ Feel of Soil
- ❑ Soil Moisture Sensing Device
- ❑ Plant Moisture Sensing Device
- ❑ Commercial or Government scheduling Service
- ❑ Reports on Daily Crop Water/ET
- ❑ Scheduled by Water Delivery Organization
- ❑ Personal Schedule
- ❑ Computer Simulation Models
- ❑ Observation of Neighboring Farms' Irrigation Schedules
- ❑ Other_____

Irrigation Season

Start: Pull-down list of months ***Stop: Pull-down list of months***

Participant will select a starting month and ending month for the crop's irrigation season.

Frequency and Length of Time for Irrigation (by month)

Month n: *The following questions will be generated for each month of the irrigation season (from previous question).*

Number of Irrigation Cycles in this month _____

Length of Time for each Irrigation Cycle (in hours) _____

Source of Irrigation Water (check all that apply)

- ❑ On-farm wells Quantity: _____
- ❑ Irrigation District Cost($)/AF: _____
- ❑ Other _____

Total Quantity of Water Applied Annually (in AF): _____

Total Annual Costs of Irrigation Water

- ❑ Annual cost of purchased water, if applicable: $_____
- ❑ Annual electric utility bill for irrigation pumps: $_____

Electric Pumps by Category

- ❑ Well Pumps Quantity: _____
- ❑ Booster Pumps Quantity: _____
- ❑ Transfer Pumps Quantity: _____

Electric Pumps by Power Rating

- ❑ < 50 HP Quantity: _____
- ❑ ≥ 50 HP and < 100 HP Quantity: _____
- ❑ ≥ 100 HP and < 200 HP Quantity: _____
- ❑ ≥ 200 HP and < 500 HP Quantity: _____
- ❑ ≥ 500 HP Quantity: _____

Pump Efficiency Audits (by utility or other organization)

- ❑ Annually (or more frequently)
- ❑ Every two years
- ❑ Every five years
- ❑ Every ten years
- ❑ Less than every ten years or never

Pump Control Methods (check all that apply)

- ❑ Manual (manually stated and stopped)
- ❑ Semi-automatic (manually started – stopped by timer)
- ❑ Fully automatic (automatic scheduler for starting and stopping pumps)
- ❑ Controller that pulls information from Internet sources to adjust schedules
- ❑ Remote controllable over Internet
- ❑ Other _____

Do any of the pumps use Variable Frequency Drives (VFDs)?

- ❑ Yes Quantity: _____
- ❑ No

Flexibility in Irrigation Cycles

Flexibility in Irrigation Cycle Start Time:

How many hours can it be delayed or moved up without creating major problems?

- ❑ No flexibility
- ❑ 0 to 2 hours
- ❑ 2 to 4 hours
- ❑ 4 to 6 hours

- ❑ 6 to 8 hours
- ❑ 8 to 16 hours

Flexibility in Interrupting an Irrigation Cycle:

How many hours can it be suspended without creating major problems?

- ❑ No flexibility
- ❑ 0 to 2 hours
- ❑ 2 to 4 hours
- ❑ 4 to 6 hours
- ❑ 6 to 8 hours
- ❑ 8 to 16 hours

Answer the same questions based on getting a 24-hour notice.

Flexibility in Irrigation Cycle Start Time with 24-hour notice:

How many hours can it be delayed or moved up without creating major problems? Assume you have 24-hour notice.

- ❑ No flexibility
- ❑ 0 to 2 hours
- ❑ 2 to 4 hours
- ❑ 4 to 6 hours
- ❑ 6 to 8 hours
- ❑ 8 to 16 hours

Flexibility in Interrupting an Irrigation Cycle with 24-hour notice:

How many hours can it be suspended without creating major problems? Assume you have 24-hour notice.

- ❑ No flexibility
- ❑ 0 to 2 hours
- ❑ 2 to 4 hours
- ❑ 4 to 6 hours
- ❑ 6 to 8 hours
- ❑ 8 to 16 hours

Barriers to Shifting or Interrupting Irrigation Cycles

Rank the following barriers from 0 to 10 in significance with 10 being the most significant.

- ❑ Irrigation District sets the schedule _____
- ❑ Start/stop cycles are hard on pumps and wells _____
- ❑ Inflexibility of labor schedules _____
- ❑ Other _____

Incentives for Shifting or Interrupting Irrigation Cycles

Rank the following incentives from 0 to 10 in significance with 10 being the most significant

- ❑ Favorable electricity tariffs and credits for participation _____
- ❑ Advanced notice on utility black-out and/or expensive-rate periods _____
- ❑ Incentives to add/up-grade controls _____
- ❑ Other _____