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FINAL PROJECT REPORT

Barriers to Energy and Water Efficiency and Conservation Practices in Groundwater Pumping

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Barriers to Energy and Water Efficiency and Conservation Practices in Groundwater Pumping is a final report for a series of reports of the Clarifying and Quantifying Current and Near-Term Groundwater Pumping Energy Use and Costs in California to Improve Energy and Water Systems Reliability project (Contract Number EPC-15-035) conducted by Lawrence Berkeley National Laboratory. The other report for this project can be found in Blum and Ke, 2023, *Estimates of Groundwater Pumping Electricity Use and Costs in California*, California Energy Commission, Publication Number: CEC-500-2023-041. Accessible via: https://www.energy.ca.gov/publications/2023/estimates-groundwater-pumping-electricity-use-and-costs-california). The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

This project examined key knowledge gaps in energy-water interactions in California: the amount of electricity required to pump groundwater in the state and the opportunities and barriers for greater energy efficiency in groundwater pumping. The study results are presented in two reports. Because of a lack of historically accurate data on the amount of groundwater pumped in California and associated energy use, the first report, *Estimates of Groundwater Pumping Electricity Use and Costs in California* (CEC-500-2023-041) presents estimates of recent historic and future groundwater pumping and associated energy use.

This report presents the results of surveys of groundwater pumpers on their current groundwater pumping practices and assesses the barriers to and incentives for improving energy efficiency and water conservation associated with groundwater pumping. It further relies on previous findings to simulate how the estimated energy and cost could be reduced with enhanced pump energy efficiency and water conservation measures.

Results from the larger study enable stakeholders, such as state agencies, electric utilities, water planners, and large pumped water users to develop robust projections of energy use and costs associated with groundwater pumping, as well as strategies to reduce groundwater use and the corresponding pumping energy and energy costs in the state.

Keywords: irrigation, groundwater, incentive programs, pump efficiency, energy efficiency, lift, aquifer

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Background

California relies heavily on groundwater for its water needs. While its consumption varies year-to-year, on average, groundwater supplies 40 percent of the water used in California municipalities and agriculture. Approximately 85 percent — nearly all Californians — rely on groundwater as some part of their water supply. Considering total annual groundwater withdrawals, 76 percent of groundwater pumped statewide was for agricultural use, 22 percent for municipal use, and 2 percent for managed wetlands use.

Despite the essential role groundwater plays in fueling the state's economy, current pumping practices and their implications for energy demand are not well understood. This is particularly critical during drought periods, when heavy pumping and falling groundwater levels increase energy demand to continuously operate groundwater withdrawals. In addition, groundwater pumping is an energy-intensive activity; the state and electric utilities provide groundwater pumpers with assistance and incentives to reduce their energy use. However, because groundwater consumers have little understanding of existing available options to reduce their pumping energy use, energy planners can neither provide effective opportunities to improve efficiency in groundwater pumping nor accurately predict increases in pumping efficiency and its associated energy reductions.

Purpose

This project examined two key information gaps in California energy-water interactions: to determine the amount of electricity required to pump groundwater and to identify opportunities for greater energy efficiency in groundwater pumping. The study results are presented in two reports.

This report presents the surveys the team conducted with the three main populations of groundwater pumpers in the state, namely municipal and agricultural water suppliers and growers. The surveys sought to more fully understand groundwater pumping practices and efficiency actions from the perspective of each of these populations, as well as their perceived barriers to improving the energy efficiency of groundwater pumping and implementing on-farm water conservation measures. In addition, the surveys strove to understand the experience that these three groups of groundwater pumpers have with (and their interest in) programs designed to reduce groundwater pumping energy use (and in the case of growers, in on-farm water conservation programs). The report further provides both recommendations from the survey results and conversations the team held with experts, which may be useful for future initiatives that reduce the energy required to pump groundwater in California.

Approach and Results

The research team, led by members of Lawrence Berkeley National Laboratory, conducted the surveys during the fall and winter of 2018 and 2019. The three targeted populations were known to be hard to reach, specifically because they receive a multitude of survey requests from various entities. The team used several relevant third parties, which assisted with promoting the surveys and reaching out to the three targeted populations.

The municipal water suppliers that responded to the survey and were also large enough to be required to submit an Urban Water Management Plan (UWMP) to the California Department of Water Resources (DWR), served 22.1 percent of the 2015 population (approximately 30 million) of the UWMP submitting retail suppliers. These municipal water suppliers represented 13.6 percent of the reported groundwater that they pumped in 2015 (approximately 2.4 million acre-feet). Similarly, agricultural water suppliers that responded to the survey and were large enough to be required to submit an Aggregated Farm-Gate Delivery report to DWR, supplied water between the 2012 and 2018 water years (October to September) to 23.4 percent of the total irrigated land (approximately 34.8 million acres) served by all Aggregated Farm-Gate Delivery submitters. The volume of water they delivered during that period is about 22.3 percent of the amount of water delivered by all suppliers that submitted an Aggregated Farm-Gate Delivery for that period. Growers that responded to the survey operated in 27 of the 58 counties in the state irrigated, in the 2015 to 2017 period, an annual average of 44,600 acres of their combined annual average of 60,800 thousand acres. They further reported pumping an annual average of 94,600 acre-feet in the same period. One acre-foot of water equals about 326,000 gallons or enough to flood a football field 1-foot deep (a football field is roughly an acre). In California an acre-foot, or 326,000 gallons, typically meets the annual indoor and outdoor needs of about three average households.

Among the top five barriers to reduce groundwater energy use indicated by respondents from municipal and agricultural water suppliers, were: high initial capital investment costs, other more cost-effective operational improvements, and incentive programs that required too much time or other administrative burdens. Municipal water suppliers also reported that groundwater levels were not a concern, and that there was uncertainty about long-term energy-cost savings. Additional factors indicated by the agricultural water suppliers were that energy use reductions were not a major priority, and that the agency’s well pumps or improvements were not eligible for incentives.

In addition, when presented with a list of measures that could potentially help with reducing the energy to pump groundwater, municipal water suppliers indicated they are most interested in financial assistance for infrastructure upgrades that enhance pumping efficiency and establish efficient water-management practices. Municipal water suppliers also indicated they were interested in more collaboration with neighboring water agencies, as did respondents from agricultural water suppliers. Agricultural respondents further mentioned their interest in district-led managed aquifer recharge, including the use of recycled water for recharge and energy and flow metering of wells. Both groups of water suppliers indicated that their top preferences for the most desirable financial options are grant funding and rebates, while the least desirable mechanisms are carbon credits (from the California Cap-and-Trade program) and higher rates for customers.

The majority of growers responded that in the last 10 years they upgraded/retrofitted/repaired well pumps and conducted pump efficiency tests, mostly on their own (rather than as part of a utility or government program). These actions were driven both by energy-cost savings from reduced-pumping energy use and the knowledge/insights gained from pump-efficiency tests and other pump-monitoring technologies.

Large farm operations with sales of $1,000,000 or more, and medium farm operations, those with sales above $100,000, indicated that the administrative cost burdens associated with program requirements (for example, the application process, compliance or reporting requirements, other transaction costs), and the burden of paying costs up front (for example, rebate reimbursements or tax incentive programs) are among the main factors that hampered them from reducing the energy needed to pump groundwater on their respective farms. Large farms also mentioned the time burden of determining what programs or type of assistance they qualify for, and medium farms mentioned that improvements would not reduce operating costs enough to cover equipment and implementation costs.

In contrast, small-scale farmers, with sales below $100,000, identified their top barriers to reduce on-farm groundwater pumping energy as: not being aware of any options or programs to increase pump efficiency, investigating improvements were not a priority at the time, and improvements would not reduce operating costs enough to cover equipment and implementation costs.

The majority of growers, mostly on their own, have over the last 10 years created tail-water recovery or sediment-trapping ponds, boosted soil-moisture holding capacities, and reduced soil erosion with hedgerows, riparian habitat, or planting native trees or shrubs.

Conclusion

The team attributes the increased survey response rate to the efforts of third parties. The samples, however, despite all of the team and third-party recruitment efforts, are small and non-representative of the populations surveyed. The non-representativeness of the samples is also a consequence of the team's decision to adopt a nonprobability sampling approach, where respondents were specifically sought out through various channels in anticipation of the difficulty associated with reaching a large sample of respondents. Some survey results, such as the growers, are nevertheless consistent, with results from a previous survey conducted by the United States Department of Agriculture, which is representative of growers in the state. In addition, several results from the three surveys show consistency with the perspectives expressed by subject matter experts. However, characteristics from the samples to their corresponding general populations cannot be assumed, and caution should be taken when using the results presented in this report that support any decision associated with programs, incentives, and any other type of assistance to reduce the energy required to pump groundwater in the state.

Knowledge Transfer

The team has shared project results since the initial stages of the study with water, utility, and agency personnel. Another major avenue for disseminating information to stakeholders was through the members of the project's technical advisory committee with 15 representatives from federal, state, regional, and local agencies, Pacific Gas and Electric Company, and both academic and non-profit organization representatives. In addition, the surveys conducted as part of this research led to broad dissemination of information about the project.

The results of this project will additionally be disseminated through the posting of two final reports on the California Energy Commission’s website. These reports will also be distributed to all agencies and parties that participated in the study. The researchers also plan to summarize the results from this project in two Lawrence Berkeley National Laboratory technical reports. Finally, the team plans to prepare a paper to be submitted to a peer-reviewed journal summarizing the data and modeling approaches used to estimate the near-term total energy and grid-electricity use and costs for groundwater pumping.

Benefits to California Ratepayers

This research project quantified the energy used for pumping groundwater and identified efficiency measures for reducing its consumption. A major goal was to identify feasible energy-efficient technologies (for example, better pumps) and practices (for example, better irrigation and conservation) that users can adopt to reduce pump energy use.

Potential improvements in pump efficiency, irrigation efficiency, groundwater management, and urban water-efficiency programs offer total potential savings of between 600 and 750 gigawatt-hours of electricity and between 1.8 and 2.4 million acre-feet of water to both groundwater consumers and investor-owned utility ratepayers. These measures can also help prevent long-term groundwater depletion and the increased electricity needed to pump water from depleted aquifers. Improved disaggregated estimates of groundwater energy use, along with estimates of savings potential, will help California and utilities manage drought conditions, reduce customer utility bills, improve forecasting of future electric loads, and support electric sector resource planning.

CHAPTER 1: Introduction

The energy consumption of California's water sector has been estimated to make up 19 percent of the state's annual electricity demand (Copeland and Carter, 2017). It is largely unknown, however, what percentage of that energy is due specifically to groundwater pumping, although some efforts at assessment have been made. Pacific Gas and Electric Company's (PG&E) Advanced Pumping Efficiency Program (APEP), for example, estimates that of the 8 percent of statewide energy use consumed by agriculture, 70 percent can be attributed to groundwater pumping (PG&E, 2015). This estimate, however, excludes pumping for other purposes, such as municipal water use.

California relies on groundwater to meet a substantial share of its overall water needs. While it varies year-to-year, on average, groundwater supplies 40 percent of the water used in California municipalities and agriculture. Approximately 85 percent — nearly all Californians — rely on groundwater for some part of their water supply (Chappelle and Hanak, 2017). Despite the vital role groundwater plays in fueling the state's economy, current pumping practices and their implications for energy demand are not well understood.

The significant knowledge gaps in the extent and efficiency of groundwater pumping prevent accurate resource planning. In addition, the energy footprint of groundwater is greater than that of surface water and increases with dropping water tables during drought and times of heavy withdrawals. To add to the concern, electricity costs in California are well outpacing those of other states, having increased at a rate greater than five times the national average between 2011 and 2017 (Nelson and Shellenberger, 2018), and are projected by the United States Department of Energy's Energy Information Agency to grow, in the Pacific Region, by 42 percent by 2050. Increased groundwater use, coupled with higher electricity prices and falling groundwater levels means that the amount of money spent on groundwater pumping could rise considerably in the next 20 to 30 years.

Whereas several initiatives to reduce groundwater energy use — and consequently its cost — in the state have been available, the social barriers and incentives to participating in those programs are poorly understood, as are options for overcoming those barriers to enhance incentive programs.

This report documents the results of three surveys, each of which targeted a different segment of groundwater pumpers in California: municipal water suppliers, agricultural water suppliers, farmers, and ranchers. These surveys were an effort to better understand current groundwater pumping practices and efficiency actions, perceived barriers to improving the energy efficiency of groundwater pumping, and the experience and interest these pumpers have with programs designed to reduce energy use. The report further provides recommendations drawn from survey results, and from conversations the team held with subject-matter experts, which were useful in supporting future energy-efficiency policies and program designs in California.

The balance of this is report is organized into:

Chapter 2: Provides an overview of the relevant extant literature (with an emphasis on prior survey work) and of existing programs and incentives (directly or indirectly) related to energy use for groundwater pumping.

Chapter 3: Presents the survey methods, and the survey implementation, including details of the team's outreach to the three targeted populations.

Chapter 4 and Chapter 5: Present survey results.

Chapter 6: Provides insights the team obtained from experts that help evaluate the team's findings, and discusses survey results.

Chapter 7: Summarizes the report, presents limitations of this work, and offers suggestions for future survey efforts.

CHAPTER 2: Background

Concerns about groundwater pumping in California are not new. In the state's most current groundwater update, the California Department of Water Resources (DWR) estimated that on average, from 2005 to 2010, groundwater made up 38 percent of the state's average annual total water supply. Thirty nine percent of agricultural water use was met by extracted groundwater, compared with 41 percent of municipal needs (DWR, 2015a). Considering total annual groundwater extraction, 76 percent of groundwater pumped statewide was applied for agricultural use, 22 percent for municipal use, and 2 percent for managed wetlands use (DWR, 2015a). The annual average groundwater extraction over the years 2002 to 2010 was estimated at 16,613 thousand acre-feet (TAF) and fluctuated between a minimum of 12,019 TAF in 2005 and a maximum of 20,093 TAF in 2009 (DWR, 2015a).[1]

The large fluctuation observed in groundwater extraction is due to the highly variable hydrological conditions typically seen in the state, particularly when it comes to precipitation and subsequent surface-water availability. Figure 1 depicts DWR's Water Year Hydrological Classification Indices (water indices) from the Sacramento and San Joaquin valleys (DWR, 2017b). The water indices are derived from the current year's unimpaired runoff, representing the natural and unaltered water production of a particular river basin, while water years are defined as occurring from October 1 to September 30. These indices are broadly accepted as indicative of state hydrological conditions. The figure shows historical values for two different time periods: from 1906 to 2017, which is the full range of available data, and from 2008 to 2017, for a closer look at the past 10 water years. Each water index was normalized to the average of each time period. Compared with the averages estimated for each time period, the water indices can vary more than 100 percent, with values dipping below 50 percent of the average in dry years and above 200 percent in wet years.[2]

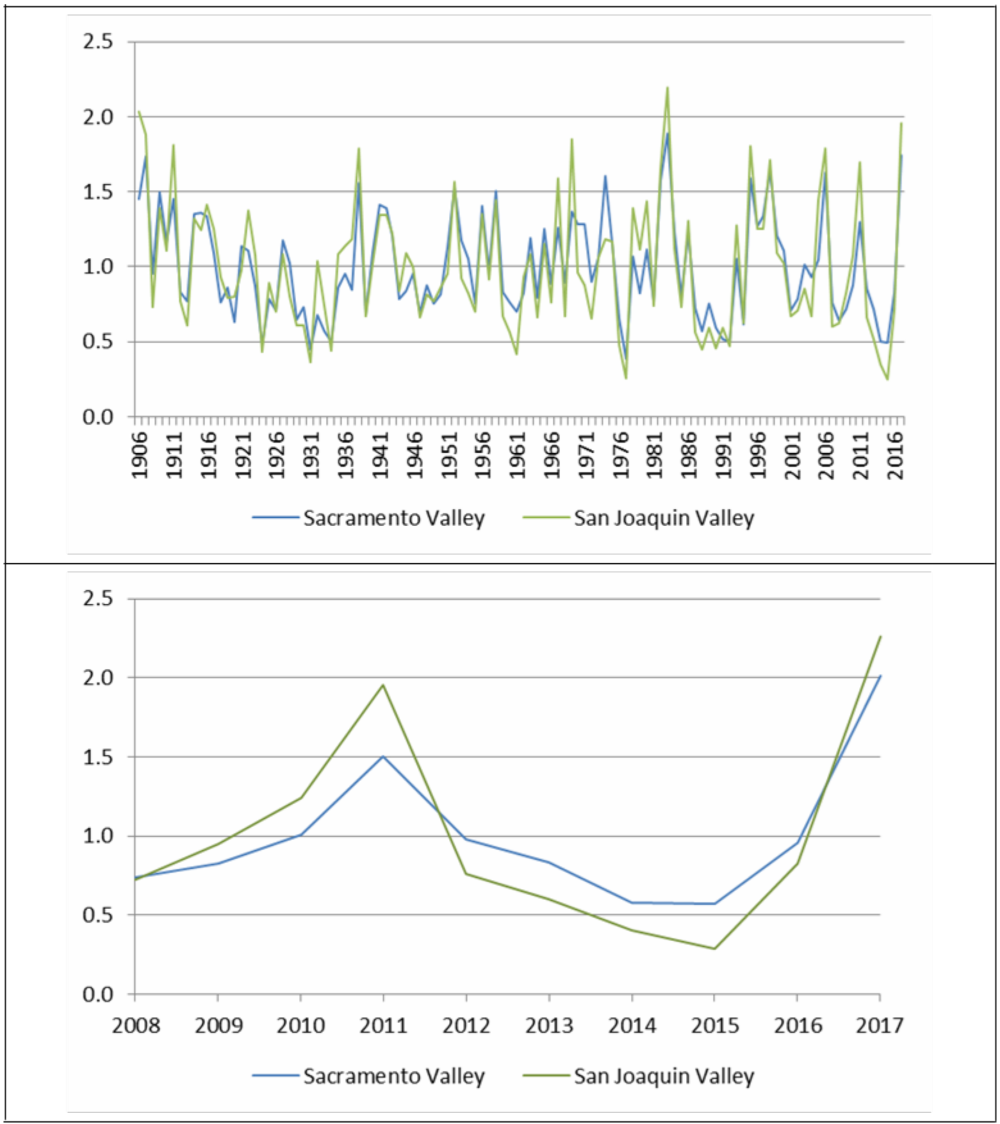
Coping with uncertain hydrological conditions (and the consequent changes in groundwater dependence over time) has proven challenging to water suppliers and private users of groundwater, particularly to agriculture. Previous research addressed those challenges from different perspectives and how they are experienced by different groups of groundwater pumpers. Results typically describe groundwater pumping behavior and practices in the state, and sometimes their energy implications, which are all relevant to this study. Other surveys of water suppliers and growers in California were conducted with different goals; their results are also relevant for this study since they characterize these populations and offer insights into response rates achieved. In addition, there were programs in the state that assisted groundwater pumpers in reducing the amount of groundwater pumped and improving pumping performance, both with implications for groundwater pumping energy requirements.

[1] In addition, the U.S. Geological Survey estimated an average withdrawal of 17,400 million gallons per day of groundwater in 2015, equating to about 19,500 TAF per year (98 percent of which was fresh, or non- saline water) (Dieter et al, 2018).

[2] When considering previous survey results and those presented in this report, these conditions should be borne in mind.

Those programs are described in the following sections, as are previous surveys that relate to this study.

Figure 1: Water Year Hydrologic Classification Indices



Source: Lawrence Berkeley National Laboratory

Water indices can fluctuate by up to a factor of two. The fluctuation in the more recent period is consistent with long-term historical data.

Survey of Water Suppliers

In their 1997 paper, Edinger-Marshall and Letey specified that California had more than 150 irrigation districts or other entities that deliver water to agricultural users. In surveying districts on irrigation methods, they contacted 127 districts via letter, because "knowing that district record keeping would be highly variable, we attempted to survey as many districts as possible, rather than sending requests to a random sample." Only 10 districts responded with irrigation methods data of sufficient quality to estimate trends within these districts; however, taken together, these 10 districts provided water to around 25 percent of the total irrigated acreage in the state (Edinger-Marshall and Letey, 1997). In general, surveyed districts showed less gravity (floor or furrow) irrigation in favor of more "combination" (specifically sprinklers to germinate, followed by surface methods) irrigation, as well as a minor rise in sprinkler and micro-irrigation methods.

Starting in 2005 and joined in 2007 by the California-Nevada section of the American Water Works Association (CA-NV AWWA), Raftelis Financial Consultants, Inc., (RFC) conducted a biennial online survey of water utilities in California regarding water rates and charges. In 2011, 216 agencies in California responded to the survey, compared to 217 in 2013; during these two years, only 113 agencies responded to both surveys (CA-NV AWWA and RFC, 2013). In 2015, 167 California agencies participated, compared to 352 in 2017, when the California Data Collaborative joined the effort (CA-NV AWWA and RFC, 2015; CA-NV AWAA et al., 2017). Across the 2013, 2015, and 2017 surveys, 65 to 68 percent of responding (self-selected) water utilities had tiered rate structures with increasing block rates, which encourage conservation because the unit price of water increases along with consumption. Interestingly, groundwater was mentioned for the first time in the 2017 report in connection with the Sustainable Groundwater Management Act (SGMA).[3] The concepts of "energy" and "energy efficiency" are not mentioned, while "efficiency" pertains in these reports only to "water efficiency."

In 2008 the Irrigation and Training Research Center (ITRC) at California Polytechnic State University surveyed irrigation districts with the goal of benchmarking the status of pumping systems used by these districts. The survey targeted districts with significant pumping loads, selected "based on energy use per acre of irrigated area, size, geographic location, and distribution infrastructure" (Burt and Howes, 2008). The 30 districts that participated in in-person interviews encompassed an approximate 1,896,000 irrigated acres. The authors defined three categories of pump facilities:

- **Deep Groundwater Well Pumps:** Any groundwater pumping for irrigation use by the district, excluding pumping to maintain groundwater levels.
- **Surface Supply Pumps:** Includes lift pumps and booster pumps within a district for irrigation water use, excluding pumping directly out of drains.
- **Surface Drain Pumps:** Typically pumps drain water out of drains into pipelines or canals; once the water enters the irrigation system, surface supply pumps do the pumping.

The energy intensity (energy requirement by volume water pumped, usually expressed in kilowatt-hours per acre-foot [kWh/af]) is generally much greater for deep well pumps than for other pump facility categories. Table 1 summarizes the most pertinent findings of the study; note that deep well pumps, with an average stated pumping plant efficiency of 57 percent,

[3] "Depending on basin conditions, agencies reliant on groundwater may experience localized effects including reductions in pumping, increases in management costs and purchases of more expensive water" (CA-NV AWAA et al., 2017).

were estimated to use 33 percent of electricity used by all pumps in an "average" water year.[4] In terms of pump age, 10 percent of deep well pumps were less than or equal to 5 years old, nearly 50 percent were 6 to 25 years old, and slightly more than 40 percent were more than 26 years old. The authors found that only 3 percent of deep well pumps were rebuilt each year.

Table 2 shows the prevalence of different technology characteristics of deep well pumps in the surveyed districts. They also found that outside of regular maintenance, most surveyed districts had undertaken few projects to reduce energy demands or shift peak loads since the California Energy Commission's (CEC) Agricultural Peak Load Reduction Program ended in 2004. Many at surveyed districts were aware of utility-funded pump testing and retrofitting repair programs, but most had not participated in such programs, with 21 out of 30 in favor of rebates designed with some consideration for irrigation district-specific concerns. Looking ahead, over the 5 to 10 years following the survey, nearly three quarters of respondents anticipated considerable growth in pump-connected load and electricity use.

Table 1: Characteristics of Pump Facilities in 30 Irrigation Districts

	Deep Well	Surface Supply	Surface Drain	Total
Number of pumps	646	1,199	200	2,045
Pump efficiencies checked per year	226	185	2	413
Total nominal connected horsepower (thousand)	149	296	11	457
Total average electricity use (GWh/year)	217	426	14	657
Average stated overall pumping plant efficiency	57%	60%	49%	55%
Percentage of pumps rebuilt per year	3%	12%	6%	9%

Source: Burt and Howes, 2008

Table 2: Technology of Irrigation District Deep Well Pumps

	Number	Percent of Total
Premium motors	70	11
Variable Frequency Drives	8	1.2
Automated Operations	59	9.1
Remote manual on/off	0	0
Diesel/natural gas engines	14	2.2
Remotely monitored pumps	17	2.6

Source: Burt and Howes, 2008

[4] "Depending on basin conditions, agencies reliant on groundwater may experience localized effects including reductions in pumping, increases in management costs and purchases of more expensive water" (CA-NV AWAA et al., 2017). The notion of an "average" year refers to a year that reflects average hydrological conditions (compared to historical conditions).

In 2009, the California State Water Resources Control Board (SWRCB) and the DWR partnered to conduct a survey online and via phone or email regarding municipal recycled water. It is unclear, however, how many respondents SWRCB and DWR reached, although they identified 210 water recycling systems through that survey effort. They found that most municipal recycling occurs in areas of the state with high population density, limited local water resources, and/or difficult wastewater disposal (Newton et al., 2011).

In 2011 and 2012, the DWR collaborated with the Association of California Water Agencies (ACWA) to survey ACWA's member agencies on groundwater management. Via an online survey, participating agencies relayed their level of confidence in the long-term sustainability of their current groundwater supply. Of 60 respondents, 72 percent stated that their groundwater resources were sustainable, with 28 percent holding the opposite to be true. In terms of hydrologic regions, those with the greatest levels of perceived unsustainability were in the San Joaquin River, Tulare Lake, and Central Coast Hydrologic Regions (DWR, 2015a). In the same survey, DWR and ACWA asked agencies to provide feedback on which components helped in making implementation of a groundwater management plan successful. Data from 58 respondents yielded the insight that the top components leading to success were data collection and sharing, sharing of ideas and information with other water resource managers, developing an understanding of common interest, outreach and education, broad stakeholder participation, and funding, with more than 80 percent of respondents agreeing each item was key (DWR, 2015a). Forty-nine participants identified challenges to effective groundwater management plan implementation, with limited funding for groundwater management projects and planning as the most significant barrier (DWR, 2015a).

Styles et al. (2013) at ITRC examined a Southern California Edison (SCE) database of pump tests performed from January 2006 to December 2011, with more than 34,000 individual pump tests averaging over 5,600 pump tests conducted per year.[5] In conjunction with reviewing these data, they conducted a survey of SCE's public and private pump test program participants. Public entities included counties, cities, community service districts, mutual water companies, and irrigation districts, while energy corporations, irrigation and agriculture management, and farm and ranch management, among others, were considered types of private customers. Of 100 contacted potential respondents, 38 program participants completed surveys, along with 17 pump dealers; ITRC noted that "it was unexpectedly difficult to get cooperation from the SCE customer base" due to survey fatigue, where respondents are too often asked to participate in questionnaires and surveys. The authors found that their survey respondents consider pump test results (pump flow rates, well water depths, and other pump performance data) valuable tools. However, the authors assert that among both program participants and pump dealers, there is no "industry standard" threshold for overall pumping plant efficiency (OPPE) value that triggers system repairs or upgrades to increase efficiency. In general, survey results demonstrated that larger organizations are more likely to use OPPE results in making decisions about pump-related actions, and more often address pump repairs as part of routine and preventative maintenance. In contrast, smaller entities regarded pump test results more as useful data, being more likely to wait on replacement until pump failure; a

[5] A pump test measures various aspects of the pump's operation, including flow rate, discharge pressure, well lift (if applicable) and power use.

majority of survey respondents took this more reactive, rather than proactive, approach to pump efficiency. Finally, in comparing their results to previous studies, the authors identified significant energy conservation potential.

- Targeting a small portion of the larger pumping systems in SCE's service territory, typically operated by public agencies.
- Incentivizing efficiency improvements for on-farm pumping systems, the average OPPE value for which Burt et al. (2003) found to be 48 percent, substantially lower than the 57 percent average OPPE for public water district pumps in SCE's territory (Styles et al., 2013).

In 2015, as part of an investigation into the effects of the fourth year of severe drought, a research team from the University of California (UC) at Davis surveyed district managers at more than 80 irrigation districts, predominantly via personal interviews (Howitt et al., 2015). They found that, overall, increased groundwater pumping, water transfers, surface storage, and water banking alleviated some of the worst effects of the drought. During a time when some domestic, municipal, and industrial wells ran dry, few agricultural wells ran dry given their greater depth. However, most surveyed respondents observed that growers in their districts had drilled many new, deeper wells at an accelerated pace during the drought, in large part due to smaller allotments of surface water. The authors also discuss some practices that remain relevant even in non-drought years. For example, they determined that many growers rely on standby wells on their land for greater scheduling flexibility, as well as for irrigation early and late in the season. Typically, in many areas of the state, district-supplied surface water is considerably less expensive for an individual grower than the energy costs incurred to pump groundwater for irrigation. This is an important economic cost, but most growers are willing to bear this cost if it allows them to avoid letting their land lie fallow.

In 2016, the DWR solicited input via an online survey to rank initial best management practices to facilitate the sustainable management of groundwater basins. Complete results do not appear to be available as of February 2019; however, a December 2017 presentation displayed the top five ranked best management practices as receiving between 32 and 42 responses each (DWR, 2017a).

More recently, in 2017 a research team from the Public Policy Institute of California conducted a survey regarding groundwater recharge in the San Joaquin Valley. Of the 202 agencies that deliver and manage water supply in the valley (151 agricultural and 51 urban water suppliers), 81 responded to the 19-question online survey, which also could be submitted via mail. Higher response rates from agricultural suppliers, larger urban suppliers, suppliers with greater access to surface water resources, and suppliers with dedicated recharge basins stated it probable that their respective samples over-represented districts engaging in active groundwater recharge (Hanak et al., 2018a).

Broadly, their survey found strong interest in groundwater recharge and highlighted a number of opportunities that would allow for expansion of the practice. Infrastructure limitations were the most critical barrier to recharge, from limited district basin capacity, district and system conveyance issues, and water flow availability lasting only a few months per year. Districts also recognized legal, regulatory, and technical barriers to both recharge programs and groundwater accounting, while on-farm recharge has been underused relative to its capacity, in part due to misaligned incentives for farmers (who currently would bear the costs of recharge to benefit the basin more widely).

Finally, it is important to note that agriculture and municipal water suppliers generally differ from each other on their customers' characteristics, water sources, and organizational structures, among other factors. Yet, some recent social science research looked at the two types of agencies together, from the institutional perspective of those agencies, with findings relevant to groundwater-related energy demand.

First, institutional structures should be considered when evaluating the capacity of water suppliers to reduce the energy needed to pump groundwater. The rational choice theory of decision-making holds that decision makers integrate all available information to make the best decisions they can. In contrast, Rayner et al. (2005) found that the water resource managers they interviewed were incentivized by the inherently conservative institutional structures in which they are embedded to instead rely on tested or conventional methods to avoid "political or public attention." They hold that water resource managers care most about high reliability, high quality, and cost, in that order, and that their motivations to avoid visibility means that water reliability and water quality are often maintained through redundant and economically inefficient means. Anand and Proctor (2013) similarly assert that institutional structures impede the collaborative management of a common pool resource like groundwater, because water planners and managers must contend with existing power structures at agencies that wish to maintain their authority and are often inflexible administratively. As water suppliers begin to shift from a traditional management approach to a more integrated water management approach, Ferguson et al. (2013) determined that a supportive institutional context is critical for required normative, cultural-cognitive, and regulatory changes.

California farmers and ranchers have pumped groundwater for decades. As the state has increasingly experienced extended drought periods in recent years, groundwater proved to be a resource critical for meeting agricultural watering needs (Garfield, 2017). During the recent 5-year drought, farmers and ranchers extracted more than 8-million acre-feet of water annually and drilled thousands of new wells (Kasler, 2018). Given the importance of groundwater to the agricultural sector in California, past efforts did assess irrigation tendencies and reliance on groundwater across pumpers in the state. Surveys conducted by the DWR and the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) was of particular relevance.[6]

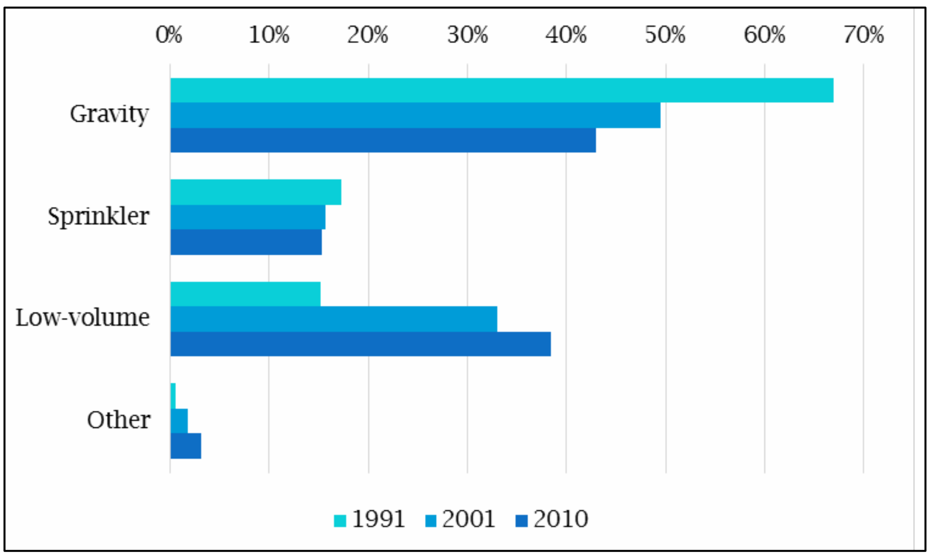
The DWR has long conducted surveys of growers to better understand irrigation methods across the state. The 1972 and 1980 surveys (published in 1975 and 1983, respectively) rested primarily on estimates from county farm advisors and UC Cooperative Extension specialists (Edinger-Marshall and Letey, 1997). For the years 1991, 2001, and 2010, the DWR partnered with the California Department of Food and Agriculture (CDFA) and NASS to mail a one-page

[6] Given California's extraordinarily varied cropping patterns, surveys of growers must be interpreted with response biases and sample size limits in mind.

questionnaire directly to growers. The single-page questionnaire asked growers to provide the area planted with certain crops — 13 crops in 1991 and 20 crops in 2001 and 2010 — requiring irrigation. In each case, 10,000 growers were randomly selected to receive the survey from a list of growers that NASS maintains, although non-irrigating growers, those who grew only rice, and those who only raised livestock were excluded. The share of questionnaires the DWR sent to each of the 58 counties in California corresponded to the proportion of the growers residing in each county (Tindula et al., 2013). For the 1991 survey, the usable response rate was 25 percent; in 2001, it was 35 percent; and in 2010, it was 51 percent (Edinger-Marshall and Letey, 1997; Orang et al., 2008; Tindula et al., 2013).

Given California's extraordinarily varied cropping patterns, surveys of growers must be interpreted with response biases and sample size limits in mind. Data provided by DWR's questionnaire allow for comparison over time of the share of acreage irrigated by survey respondents via a particular method, as seen in Figure 2 (DWR, n.d.).

Figure 2: Percentage of Acreage by Irrigation Method



Source: Data from California Department of Water Resources

The gravity (or surface) method category includes wild flood, basin, border, and furrow irrigation without sprinklers, hand-move or wheel-line sprinklers, followed by furrow irrigation, and land irrigated with furrows after being irrigated with sprinklers. Sprinkler methods refer to, among others, solid set, linear-move, hand-move, wheel-line, hose-pull, center pivot, and gun-type irrigation, while low-volume irrigation includes all low-volume systems such as drip irrigation (both surface and buried), mini-sprinklers, and micro-irrigation. The "other" category refers to subsurface irrigation, generally occurring only in the Sacramento-San Joaquin Delta, where open ditches or underground pipes are closed off to force water into crops' root zones. The notable shift away from gravity and toward low-volume irrigation between 1991 and 2010 demonstrated by survey respondents is indicative of strides growers have made toward greater water-use efficiency.[7]

[7] The transition may have energy implications: Whereas low-volume irrigation uses less water than surface irrigation, the former typically requires more energy for pressurizing the water than the latter.

Table 3 displays the 2010 reported acreage by irrigation method for the 20 crop types established by the DWR in its irrigation methods surveys, organized in descending order of total reported acreage, by crop type. Of the five crop types with the largest irrigated acreages, two rely mostly on low-volume irrigation, two on surface irrigation, and one on almost uniformly distributed shares across the main three irrigation methods. Overall, despite the significant variation of irrigation methods among crop types, some high-value crops like almonds, pistachios, vineyards, and subtropical trees, show the greatest shares of low-volume irrigation.[8]

Table 3: Acreage Distribution of Irrigation Methods by Crop Type (2010)

Crop Type	Gravity	Sprinkler	Low Volume	Other	Acreage
Almonds & Pistachios	13.4%	14.0%	71.2%	1.4%	180,061
Vineyard	20.3%	2.3%	75.4%	2.0%	179,382
Alfalfa	77.1%	17.8%	2.5%	2.6%	161,252
Grains	79.7%	13.2%	3.3%	3.8%	109,875
Other Deciduous	31.4%	27.1%	40.2%	1.3%	106,539
Corn	78.4%	1.0%	7.1%	13.5%	102,040
Other Truck Crops	24.3%	40.5%	35.1%	0.2%	92,661
Subtropical Trees	5.6%	14.8%	75.9%	3.6%	88,571
Tomatoes (process)	33.1%	3.7%	62.9%	0.3%	44,422
Pasture	68.5%	25.6%	-	5.9%	42,050
Other Field Crops	69.3%	15.0%	14.0%	1.6%	39,519
Cotton	73.0%	7.3%	15.4%	4.3%	37,155
Beans (dry)	66.5%	21.1%	12.4%	0.1%	10,452
Onions & Garlic	19.1%	39.1%	41.6%	0.3%	8,909
Cucurbit	50.5%	10.5%	39.0%	-	6,462
Tomatoes (fresh)	43.6%	11.0%	45.3%	0.1%	5,186
Turf Grass & Landscape	0.9%	78.7%	20.4%	0.0%	4,591
Potatoes	2.0%	81.1%	16.9%	-	4,089
Sugar beets	85.5%	3.0%	11.5%	-	2,433
Safflower	54.3%	44.4%	-	1.2%	1,601

Source: Lawrence Berkeley National Laboratory 2010

The transition to less water-intensive irrigation methods has energy implications. While better water-use efficiency has led to improved crop quality and yields as well as lower chemical applications, it has likely increased energy demand for groundwater pumping. Several factors are implicated in this claim. First, more efficient irrigation generally does not lead to more

[8] Note that as far as the research team can ascertain, results presented in Figure 2 and Table 3 are for the surveyed sample only.

water availability; in most of California, excess irrigation water either runs into streams for downstream reuse or seeps through soil to recharge underlying aquifers.[9] Second, groundwater is usually better suited to drip (low-volume) irrigation, given that it is available whenever the farmer needs to irrigate, sometimes multiple times per week, and it carries less emitter-clogging sediment than surface water, which often is delivered on an inflexible schedule. One drawback of more water-efficient irrigation is that "drip-irrigated farms may pump more groundwater — and they're not recharging the aquifer as much" (Pottinger, 2016). Moreover, the shift over time towards higher-value perennial crops such as nuts, vines, and fruits has hardened the year-to-year demand for water because fallowing these crops in dry years risks farmers' longer-term investments (Hanak et al., 2018b; Mount et al., 2015). In drought years, with limited surface water allocations, a larger proportion of that water demand is met with groundwater. Collectively, these drivers point to the need for greater groundwater recharge to counteract the negative consequences of improved agricultural water efficiency.

The USDA NASS conducts the (formerly the *Farm and Ranch Irrigation Survey [FRIS]*) every five years as a supplement to the Census of Agriculture. The most recent FRIS with data available occurred in 2013 (USDA NASS, 2014b). FRIS surveys a sample of farmers who indicated in the most recent Census of Agriculture that they rely to some extent on irrigation. NASS asserts that FRIS "provides the only comprehensive information on irrigation activities and water use across American farms, ranches, and horticultural operations" (USDA NASS, 2018). NASS used a stratified sampling design to yield a sample that reflects the FRIS population, as well as one with appropriate coefficients of variation levels at the state level. To do so, NASS employed a "certainty stratum" to ensure the sampling of major irrigators in each state, then sampled remaining strata systematically by acreage. NASS conducted the FRIS mainly via mailed questionnaires, 20 pages in length, with non-respondents contacted once via a follow-up mailing, and then via telephone or the Internet and in-person. In 2013, the national sample size target was 34,966 irrigated farm operators, with 2,078 in California. The overall response rate was 78 percent, indicating a relatively small potential for nonresponse bias, while 20,109 national respondents and 1,200 Californian respondents provided data that NASS was able to process and tabulate. NASS then weighted the sample data to provide statistical estimates for the nation and for each of the 50 states (USDA NASS, 2014b, Appendix A).

NASS estimated that in 2013, 44,347 farms in California irrigated around 7.5 million acres (USDA NASS, 2014b, Appendix A). The irrigated acreage represents approximately 50 percent of the total acreage of these farms. It also compares to the 2012 Census of Agriculture data showing 53,546 irrigated farms with 7.8 million irrigated acres (USDA NASS, 2012). This discrepancy likely arose because FRIS includes data exclusively for farm operations that irrigated in 2012 and 2013, compared to only one year (2012) in the Census of Agriculture; moreover, 9,522 operations nationwide reported to the FRIS process as being misclassified as irrigators in the Census of Agriculture (NASS 2014a, p. A3).

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[9] Similarly, irrigation districts' actions to curtail spills and seepage from canals also has lessened groundwater recharge and thus lowered water tables, especially in regions like the San Joaquin Valley (Hanak et al., 2018b; Mount et al., 2015).

The team obtained from NASS, FRIS 2013 descriptive statistics of farms in California that are relevant for this study.[10] Table 4 shows mean acreage and irrigated acreage at the individual farm level in California, as well as the 25th, 50th (median), and 75th percentiles. Larger farms pull up the mean acreage such that it exceeds twice the 75th percentile value for both parameters.

Table 4: Acres of Irrigated Farms in California

	Mean	25th Percentile	50th Percentile	75th Percentile
Acreage of irrigated farms	343	5	20	92
Irrigated acreage of irrigated farms	170	3	12	60

Source: Data from USDA National Agricultural Statistics Service

Table 5 presents the distribution of irrigated farms in the state according to their gross value of sales of agricultural products. More than one third of irrigated farms (38 percent) sold less than $10,000 of agricultural products, while more than another third (35 percent) saw sales of more than $100,000.[11]

Table 5: Gross Value of Agricultural Sales of Irrigated Farms in California

Value of Sale	Farms	Percent
$0 – $9,999	17,068	38
$10,000 - $24,999	4,254	10
$25,000 - $49,999	3,335	8
$50,000 - $99,999	4,220	10
$100,000 - $249,999	4,201	9
$250,000 - $499,999	3,252	7
$500,000 - $999,999	3,148	7
$1 Million and over	4,869	11

Source: Data from USDA National Agricultural Statistics Service

Table 6 displays the number of farms, the acres irrigated, and the acre-feet of irrigation water applied for three main water sources (off-farm water, groundwater from wells, and on-farm surface water) for acreage in the open.[12] Many farm operations irrigated in 2013 with water from more than one source. Yet, 16,164 irrigating farms, or 69 percent of all 23,363 farms applying groundwater from wells, with an acreage corresponding to 38 percent of the total

[10] Note that FRIS's sampling and weighting methodology supports providing estimates at the state level only, and does not allow for further disaggregation into smaller geographic areas (county).

[11] For irrigated farm operations in California, irrigated crops were highly important, making up an average of 93 percent of total farm sales, with the 25th, 50th [median], and 75th percentile values all 100 percent (based on special tabulation of FRIS data, provided by NASS Data Lab in September 2017).

[12] FRIS also reports some of these values for areas under protection such as poly-tunnels or greenhouses. However, because the water applied to these areas is several orders of magnitude smaller (i.e., the total amount of water applied to areas under protection was less than 0.1 percent of the amount applied to open acreage), Figure 4 excludes these values for simplicity.

irrigated area, relied on groundwater as their sole source of water. This discrepancy indicates that many smaller farms are reliant exclusively on groundwater or were in the survey year.

Table 7 shows summary statistics per farm operation by each type of water source. The table includes the irrigated acreage and quantity of water applied, as well as the cost of off-farm supplied water.[13] Mean values are influenced by large farms, and significantly exceed the 75th percentile value for each parameter except for the acreage of on-farm surface water. Also, while on-farm surface water and groundwater have no direct costs, excluding the energy costs of pumping and pressurization, the total cost of off-farm supplied water for farms in 2013 was $480 million.

Table 6: Water Applied to Irrigated Farms in California

Total Water from All Sources	Farms	Acres Irrigated (in thousands)	Acre-Feet Applied (in thousands)
Acreage in the open	44,437	7,544	23,489
Total water applied by source	-	-	-
Off-farm water	25,918	4,013	11,912
Groundwater from wells	23,363	3,852	9,753
On-farm surface water	-	-	-
Water applied from a single source only	-	-	-
Off-farm water	18,007	1,929	-
Groundwater from wells	16,164	1,449	-
On-farm surface water	914	256	-

Source: Data from USDA National Agricultural Statistics Survey

Table 7: Acreage and Water Applied by Water Source for Irrigated Farms in California

Source of Water	Unit	Mean	25th Percentile	50th Percentile	75th Percentile
Off-farm	acres	155	2	8	67
Off-farm	acre-feet	460	2	15	135
Off-farm	dollars	20,518	700	1,680	8,035
On-farm groundwater	acres	165	5	20	82
On-farm groundwater	acre-feet	418	2	30	150
On-farm surface water	acres	251	1	20	300
On-farm surface water	acre-feet	446	2	20	250

Source: Data from USDA National Agricultural Statistics Service

[13] The number of farms from which these statistics were derived stands in the "Farms" column under "Total water applied by source" in Figure 3.

Figure 3 and Table 8 provides statistics related to on-farm wells. An estimated 23,602 farm operations in California used 59,499 groundwater wells in 2013. The majority of farms, or 59 percent, used only one groundwater well. At the same time, 41 percent of farms pumped from at least two groundwater wells, 24 percent from at least three, and 15 percent from more than three wells. According to estimates from the Center for Irrigation Technology (CIT) at California State University, Fresno, 26 percent of groundwater wells used in 2013 had flow meters, and 36 percent of farm acres were irrigated by groundwater from wells with flow meters.[14]

Figure 3: Groundwater Wells in Irrigated Farms in California

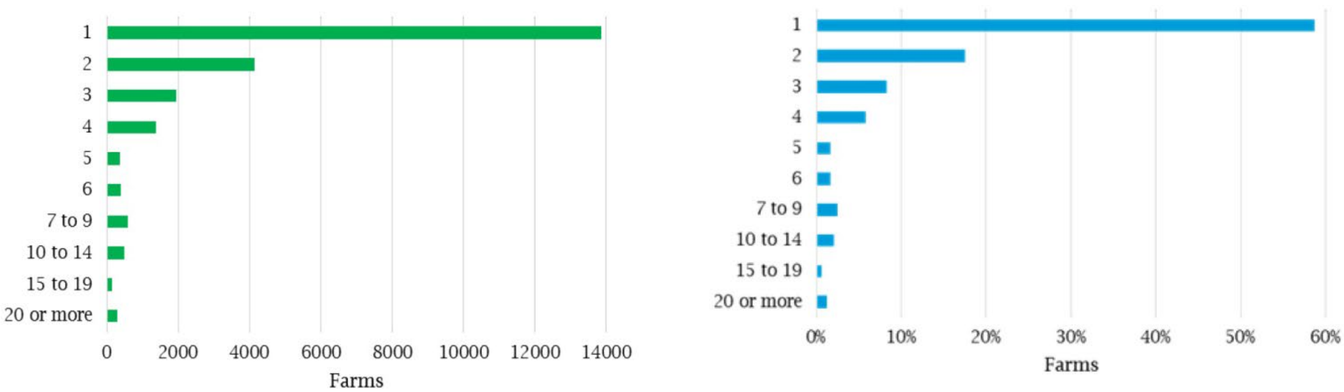

Table 8: Statistics Related to On-Farm Wells

Parameter	Farms	% Farms used wells in 2013	Wells	% of wells used	Acres irrigated in the open	% acres irrigated
Wells in use in 2013	23,602	-	59,499	-	3,852	-
Wells with flow meters	6,264	27	15,331	26	1,381	36
Primary well used	23,594	100	-	-	-	-
Secondary well used	9,738	41	-	-	-	-
Tertiary well used	5,591	24	-	-	-	-
Other wells beyond tertiary used	3,639	15	-	-	-	-

Source: Data from USDA National Agricultural Statistics Service

[14] CIT's director, David Zoldoske, stated in a 2015 interview that "only about a third of groundwater pumps [on California farms] have flow meters installed, so there's lots of room for wider adoption of this important technology." In the same interview, he emphasized the value of flow meters as follows: "[They] help growers see real-time changes in how much water they're using—if flow rates decrease, it could indicate a drop in groundwater levels, a worn pump, or perhaps a clogged filter. Without metering, it's like driving a car without a speedometer or odometer... Water meters can provide important information both on-farm (how efficiently is the irrigation system performing and how much water was applied), as well as measuring groundwater basin withdrawals" (Pottinger, 2015).

Table 9 provides statistics related to energy sources used for pumping. The upper section of the table refers to all pumps in irrigated farms; the lower section refers to well pumps only. Electric pumps dominate, followed by diesel-powered pumps. When compared to FRIS 2003 (USDA NASS, 2004), the overall number of powered irrigation pumps on California farms decreased. There has also been an increase in the number of these pumps powered by electricity and by liquefied petroleum gas, propane and butane, and a decrease in the share of these pumps powered by natural gas, gasoline and gasohol, and diesel (Blum and Ke, 2023). The decrease is likely associated with the California Air Resources Board's (CARB) initiative to reduce emissions 85 percent by 2020, by retrofitting, replacing and controlling the use of existing engines (CARB, 2000). Additional FRIS 2013 statistics related to well energy and other characteristics are presented in Appendix A.

Table 9: Pump Energy Source in Irrigated Farms in California

Wells and Other Irrigation Pump Types	Farms	#Pumps	% of All Pumps	Fuel Cost ($ millions)
Electric	24,124	70,370	84	544.8
Diesel & biodiesel	3,538	10,416	12	82.7
Solar & renewable	637	715	0.86	
Natural gas	578	810	1.0	2.8
Liquefied petroleum gas, propone & butane	498	1,105	1.3	1.2
Gasoline, ethanol and blends	24	24	0.03	0.004
Well Pump Types	**Farms**	**Acres irrigated (in thousands)**		
Electric	20,863	3,472	-	-
Diesel & biodiesel	2,937	539	-	-
Natural gas	502	26	-	-
Liquefied petroleum gas, propone & butane	476	7	-	-
Solar & renewable	155	11	-	-
Gasoline, ethanol and blends	16	Not available	-	-

Source: Data from USDA National Agricultural Statistics Service

In addition to describing farm operations, FRIS provides insights on farmers' behavior towards seeking technical and financial assistance, and information to reduce irrigation costs; ceasing irrigation during the survey year; and making improvements to reduce energy or conserve water or both. Table 10 displays the number of farms receiving overall assistance, as well as specifically technical or financial assistance, from a range of programs over the five years preceding 2013. Overall, California growers most often used USDA programs for water conservation and environmental improvements like Conservation Technical Assistance (CTA), Environmental Quality Incentives Program (EQIP), Agricultural Water Enhancement Program

(AWEP), Healthy Incentives Pilot (HIP), and Conservation Innovation Grants (CIG), with 55 percent of farms accepting assistance in some form and 72 percent receiving financial assistance via these programs. In contrast, private businesses lent the most technical assistance to California farms over this period.

Table 10: Assistance Received by Irrigated Farms in California

Assistance Received	Farms (%)	Farms Receiving Technical Assistance	Farms Receiving Financial Assistance
USDA programs for water conservation and environmental improvements (CTA, EQIP, AWEP, WHIP, CIG)	55	30	72
Private businesses (equipment dealers, bankers or water supply districts)	48	51	23
State programs (including CREP), local water management, or water supply districts	21	24	24
Other USDA programs for stewardship (CSP) or easements (CRP, WRP, GRP, FRPP)	8	3	9
Non-USDA federal programs (Bureau of Reclamation, U.S. EPA or other)	6	6	9
Total positive responses in California	**4,243**	**2,874**	**3,093**

AWEP=Agricultural Water Enhancement Program; CIG=Conservation Innovation Grants; CREP=Conservation Reserve Enhancement Program; CRP=Conservation Reserve Program; CSP=Conservation Stewardship Program; CTA=Conservation Technical Assistance; EQIP=Environmental Quality Incentives Program; FRPP=Farm and Ranch Lands Protection Program; GRP=Grassland Reserve Program; WHIP=Wildfire and Hurricane Indemnity Program; WRP=Wetland Reserve Program.
Source: Data from USDA National Agricultural Statistics Service

Table 11 displays the sources of irrigation information Californian farmers and ranchers relied on in 2013 to reduce irrigation costs or conserve irrigation water.[15] The top three sources for farms and acres irrigated are neighboring farmers, extension agents or university specialists, and private irrigation specialists and consultants; the figure also suggests that larger farms make more use of the latter two sources. Media reports and press information, as well as federal and state agencies, stand at the bottom of the list. It is unknown whether certain sources are preferable solely based on the frequency, content, or scale of information relevant to irrigation decisions, or whether this figure may also indicate the level of trust farmers place in certain sources above others. This should be borne in mind if state incentives to reduce groundwater pumping energy are offered in the future.

[15] Many respondents make use of multiple sources of information.

Table 11: Sources of Information for Irrigated Farms in California

Source of Irrigation Information	Farms (%)	Acres irrigated (%)
Neighboring farmers	40	38
Extension agents or university specialists	39	50
Private irrigations specialists or consultants	37	55
Electronic information services (DTN and other internet links)	26	28
Irrigation district or water supplier	24	31
Media reports or information in the press	21	21
Irrigation equipment dealers	21	36
NRCS, local conservation district, other federal, or state agencies	17	24
Total positive responses in California	**28,739**	**5,346,785**

Source: Data from USDA National Agricultural Statistics Service

Table 12 describes why some growers discontinued irrigation in 2013. Of the total number of irrigated farms surveyed in California, 3,874 reported ceasing irrigation during the survey year to an extent such that it affected crop yields, with 450 farms reporting this cessation to be permanent. The most often-cited reason was "other" or "unspecified," though 15 percent of farms and 33 percent of irrigated acres were affected by a shortage of groundwater, slightly less than attributed to surface water scarcity.

Table 12: Reasons for Discontinuing Irrigation in 2013 in Irrigated Farms in California

Reasons for Discontinuance	Farms (%)	Acres Irrigated in Previous Census
Other or unspecified	75	73
Shortage of surface water	17	36
Shortage of groundwater	15	33
Sold or leased irrigation land or irrigated area under protection	10	8
Restrictions on water use	9	6
Sufficient soil moisture	3	7
Irrigation is uneconomical	0.3	2
Converted to non-agricultural uses	0.2	0.01
Sold or leased water rights or annual water allocation	0.1	Not available
Loss of water rights	-	-
Converted to agricultural enterprise no longer requiring irrigation	-	-

Reasons for Discontinuance	Farms (%)	Acres Irrigated in Previous Census
Available water supply too salty	-	-
Total positive responses in California, discontinued irrigation since previous census	3,874	298,099
Total positive responses in California, farms reports discontinuances to be permanent	450	13,111

Source: Data from USDA National Agricultural Statistics Service

Finally, one of the most significant findings from FRIS with relevance to this study are the barriers California farmers faced in the five years prior to 2013 to improving their irrigation systems to lower energy use or save water. Table 13 exhibits these barriers in descending order for a number of farms. Note that the shares of acres irrigated, and acre-feet applied appear to be tightly correlated. The top three barriers by number of farms, which better represents smaller farms, are:

1. Investigating improvements was not a priority.
2. Farms cannot finance improvements.
3. Uncertainty regarding the future availability of water (which presumably makes a detailed or informal cost-benefit calculation challenging).

Table 13: Barriers to Energy-Water Use Improvements in Irrigated Farms in California

Barrier	Farms %	Acres Irrigated %	Acre-feet applied %
Investigating improvements not a priority	48	21	20
Cannot finance improvements	35	28	27
Uncertainty about future availability of water	31	44	45
Risk of reduced yield or poorer crop quality	25	20	20
Improvements will not reduce costs enough to cover installation costs	20	28	28
Will not be farming this operation long enough to justify improvements	17	11	12
Physical field/crop condition limit system improvements	17	20	23
Improvements will increase management time or cost	14	15	15
Landlord will not share in cost	7	22	23
Total positive responses in California	**26,371**	**3,496,710**	**10,940,118**

Source: Data from USDA National Agricultural Statistics Service

For acres irrigated and acre-feet applied, which better represent larger farms, the top three barriers are:

1. Uncertainty about future availability of water.
2. The sense that improvements will not reduce costs enough to offset their upfront costs.
3. The inability of the farm to finance improvements.

The large share of farmers who pointed to their inability to finance improvements as one of the barriers is consistent with the high percent (72 percent) of farms that rely on financial assistance for those improvements (Table 10). Concerning uncertainty about future groundwater availability: One expected effect of SGMA is more certainty about future groundwater availability. However, since by the time of the survey SGMA had not been issued, the barrier should be considered against a backdrop of inherent precipitation and surface water variability from year to year, as well as the uncertain regional effects of climate change on California's hydrology.

Programs and Incentives

Groundwater pumpers have access to a number of programs for water and energy efficiency in groundwater pumping. These programs run the gamut for the entities that sponsor and manage them — from federal to state, to utility, to local. However, the types of projects that qualify, application requirements, funding consistency, and information about these programs varies.

Environmental Quality Incentives Program

The USDA's EQIP identifies methods to reduce on-farm energy use through agricultural energy management plans, as well as energy audits. Several initiatives exist under the larger EQIP umbrella, each of which has its own specific objectives and requirements for participation. The Conservation Activity Plan initiative, for example, provides financial assistance to growers for either planning or practicing conservation improvements.

The funding available per project varies across states. EQIP maintains payment schedules for a variety of conservation practices eligible for financial assistance. Financial assistance ranges from a few hundred dollars to thousands of dollars (with nearly all under $10,000). Payment schedules are reviewed on an annual basis and updated to account for changes in material and labor costs. One example of an eligible conservation project relevant to this study is a written irrigation water management plan and pump test, which qualifies for an almost $4,000 subsidy (USDA, 2019).

Rural Energy for America Program

The USDA's Rural Energy for America Program (REAP) "provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses to purchase or install renewable energy systems or make energy efficiency improvements" (USDA, 2015). Applicants must receive at least half of their gross income from agricultural operations or be a small business in an eligible rural area to qualify.

Eligible projects include a fairly broad range of renewable energy and energy efficiency projects. Examples of eligible energy efficiency projects include replacement of energy-inefficient equipment, switching from diesel to electric motors, or solar or gravity pumps. Energy efficiency projects require an energy audit. Applicants requesting loan funding can apply for a minimum loan amount of $5,000, up to a maximum loan amount of $25 million. Loan participants must bear 25 percent of the total project costs themselves. Applicants requesting grant funding can apply for amounts between $1,500 and $250,000 but must bear 75 percent of the total project cost themselves (USDA, 2015).

State Water Efficiency and Enhancement Program

The CDFA's State Water Efficiency and Enhancement Program (SWEEP) provides "financial incentives for California agricultural operations to invest in irrigation systems that save water and reduce greenhouse gas (GHG) emissions" (CDFA, 2018). With the passage of Proposition 68, SWEEP received $20 million in funding to be allocated across two solicitation periods (2018 and 2019) (CDFA, 2019). In 2018, SWEEP had a total of $9.5 million to disperse to growers and ranchers across the state, with a maximum grant amount of $100,000 per project (CDFA, 2018). Project demand exceeds the available funds, with SWEEP reporting nearly $28 million requested by its 343 applicants in 2018 (CDFA, 2019).

SWEEP prioritizes applicants who qualify as either severely disadvantaged communities or socially disadvantaged farmers and ranchers; approximately 14 percent of all applicants meet this qualification (CDFA, 2019). Eligible projects must achieve GHG emission reductions in addition to water savings. SWEEP identifies a number of project types that meet the GHG reduction qualifications related to groundwater pumping. This includes improved energy efficiency of pumps (either through retrofit or replacement), pump fuel conversion replacing a diesel pump for an electric pump), installation of variable frequency drives (VFD) to better align pump flow and load requirements, and overall pumping reduction whether achieved through improved irrigation scheduling, installation of low-pressure irrigation systems, or other means. Pump efficiency tests are not eligible for program funds (CDFA, 2018).

The program employs stringent application requirements, complete with worksheet tools that must be completed. Applications are scored on the basis of merit and feasibility, water savings and calculation, GHG reductions and calculations, budget, and additional considerations. Among these additional considerations is reduced groundwater pumping in critically overdrafted groundwater basins, with projects that demonstrate reduced pumping in these regions (as determined by the DWR) receiving additional priority (CDFA, 2018). The program also includes a list of costs not covered by the program, with groundwater pump efficiency tests among them. Project funds are typically provided as reimbursement, rather than up-front project financing. Applicants that qualify as a disadvantaged community are eligible to receive up to 25 percent of project costs up front. Program participants must also work with CDFA during post-project outcome reporting to quantify project benefits (CDFA, 2018).

Renewable Energy for Agricultural Program

The CEC's Renewable Energy for Agriculture Program (REAP) was initiated in 2017. The goal of the program is to accelerate the adoption of onsite renewable energy technologies on agricultural operations, to reduce GHG emissions as well as demand for grid electricity, among other objectives. The program draws from funds made available through the Greenhouse Gas Reduction Fund, as it supports achieving the state's long term GHG emissions reduction goals. In 2018, REAP had available $5.7 million to disperse. Projects have a minimum eligible award amount of $50,000 and a maximum of $250,000.

Given that the focus of the program is on increasing the penetration of renewables in agriculture, projects must include a renewable component to be considered eligible. However, projects can entail other "non-renewable" components, so long as they are determined to advance California's GHG reduction goals. Equipment can be replaced for new equipment that also can be connected to the grid, as long as a renewable component is included. For example, removal or replacement of a diesel agricultural pump for an electrical pump would qualify if paired with the ability to be powered by solar, wind, or other onsite renewable technologies.

Applicants are scored on the basis of applicant and project eligibility, technical merit and need, technical approach (factors for success), the potential GHG impacts and benefits associated with GHG reduction, preference considerations, and priority populations (with 50 percent of total funds required to benefit disadvantaged communities and 10 percent required to benefit low-income communities) (Dodson and Neidich, 2018).

Advanced Pumping Efficiency Program

The Advanced Pumping Efficiency Program (APEP) is an educational and incentive program intended to improve overall pumping efficiency and encourage energy conservation. APEP is funded by the California Public Purpose Programs Charge (PPPC). All owners or users of non-residential PG&E electric or gas utility accounts that are primarily used for pumping water for production agriculture, landscape or turf irrigation, or municipal purposes (excluding industrial processes, raw sewage, or secondary-treated sewage), and who pay for the PPPC, are eligible to participate. The program assists with pump testing (for pumps greater than 25 horsepower only) and well retrofits. Between 2002 and 2015, APEP provided 2,167 pump retrofit and repair rebates, saving an annual average of 138.8 gigawatt-hours (GWh), subsidized 35,404 pump efficiency tests, and conducted 175 educational seminars (PG&E, 2015).

Agricultural Energy Efficiency Program

Southern California Edison previously offered an agriculture energy efficiency incentive program. The program, which was targeted for years 2006 to 2008, had a budget of $37 million and an almost exclusive focus on water pump improvements. Among other things, the program prioritized the repair or replacement of water pumps to improve water flow and reduce energy use, installation of pump system controls, improvements to water system design for more accurate pump testing, and installation of higher efficiency motors for water pumps. The program has since been integrated into SCE's larger agriculture efficiency offerings. However, SCE still provides pump testing services and some rebates for pump equipment such as installation of variable speed drives and upgrades to high-efficiency pumps. SCE also offers pumping and agricultural real-time pricing in its time-of-use (TOU) portfolio (SCE, n.d.).

Other Programs and Incentives

Other incentives to improve pumping efficiency in the state include an Agriculture Efficiency Program offered by San Diego Gas & Electric Company (SDG&E), which cites installation of pump VFDs as an eligible measure (SDG&E, n.d.). While the Southern California Gas Company (SoCalGas) does not have a program that specifically lists groundwater pump improvements as an eligible project, agricultural customers can apply for incentives that are not covered by existing rebates (SoCalGas, n.d.). Incentives to reduce pumping energy are also available from more locally run initiatives, such as the Turlock Irrigation District's Pump overhaul program, which offers rebates for pump replacements, installation of VFDs, and other retrofits (TID, n.d.).

CHAPTER 3: Method

The surveys described in this report rely on an interdisciplinary social science approach to investigate the barriers to and incentives for implementing energy- and water-related measures that contribute to reducing the energy needed to pump groundwater. The approach was inherently interdisciplinary in that the surveys spanned multiple disciplines (for example, engineering, sociology, policy, and finance), integrated the different domains of water and energy, and contained both qualitative and quantitative questions. Broadly, the research team examined the current state of groundwater pumping practices in California, as well as the rationale that underlies the adoption of (or failure to adopt) more energy-efficient groundwater practices. The research team developed three questionnaires to address these issues in the three most relevant populations of groundwater pumpers in the state: municipal water suppliers, agriculture water suppliers, and farmers and ranchers (also referred to as growers throughout this report). The questionnaires include questions about respondents' reliance on groundwater, past and planned well operation practices, and barriers to, and incentives for, lowering the energy needed to pump groundwater. The goal was to understand the conditions pumpers face on the ground, to accurately convey their experiences with pumping groundwater to inform future efforts to reduce the associated energy use and costs.

Target Populations

The following sections explore in greater detail relevant characteristics of the major populations of groundwater pumpers in California, namely municipal and agriculture water suppliers and growers.

Water Suppliers

The landscape of water suppliers in California is complex and heterogeneous, evolving as water resources were developed and contested in response to multifaceted and interlocking drivers: population and economic growth, agricultural needs, changes in federal and state water law, and water quality and supply reliability matters.

This survey targeted municipal water suppliers in California that pump at least some groundwater. This includes retailers and wholesalers that directly or indirectly supply water for municipal purposes (SWRCB, n.d.). The "Drinking Water - Public Water System Information" database maintained by the SWRCB uses the United States Environmental Protection Agency's (U.S. EPA) classification of water systems, which can be either public or non-public (U.S. EPA, n.d.a). A public water system "provides water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year" (U.S. EPA, n.d.b). The U.S. EPA classifies a public water system, which may be privately or publicly owned, as:

- Community (C): serves at least 15 service connections used by year-round residents or regularly serves 25 year-round residents.

- Non-Transient Non-Community (NTNC): serves at least the same 25 non-residential individuals during six months of the year.
- Transient Non-Community (NC): regularly serves at least 25 non-residential individuals (transient) during 60 or more days per year.

NTNC water systems might be office buildings, manufacturing plants, schools, or other institutions with their own drinking water systems, and NC water systems may be drinking water systems providing water in places such as campgrounds or highway rest stops. For the purpose of this study, community water systems are most relevant.

The Public Water System Information database contains information on 2,920 community water systems across California. Table 14 breaks the number of systems out and sums the non-transient population served by categories of population served and primary water source.[16] Note that the presence of surface water sources (for example reservoir, river, or intake) leads to a surface water classification for primary water source, even when groundwater dominates supplies relative to surface water. While very small and small water suppliers with groundwater as their primary source comprise nearly two- thirds of the community drinking water systems in California, large and very large water suppliers with surface water as their primary source together count 80 percent of the population served statewide by these systems.

California's 1983 Urban Water Management Planning Act obligates urban water suppliers that either provide more than 3,000 acre-feet of water per year, or serve more than 3,000 urban connections, to submit an UWMP to the DWR every five years (DWR, 2016). DWR lists 426 urban water suppliers meeting these thresholds, 11 suppliers under the reporting threshold, and 6 regional alliances that submitted 2015 UWMPs (DWR, 2015b). The research team was unable to determine whether, or how many, additional suppliers were required to submit UMWPs but were noncompliant. The DWR maintains an online public data portal for standardized data extracted from UWMPs (DWR, 2015b). Of 400 retail suppliers appearing in Table 6-1 "Retail: Groundwater Volume Pumped" on that website,[17] 7 suppliers (82 percent) pump groundwater; of 49 wholesale suppliers appearing in Table 6-1 "Wholesale: Groundwater Volume Pumped," 22 suppliers (45 percent) pump groundwater. For the 2011 to 2015 period, retail suppliers reported an average annual groundwater extraction of 8.3 TAF, while wholesale suppliers reported an average of 16.1 TAF.

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[16] The sum of non-transient population equals the sum of the estimated residential populations served (for example, residential area, mobile home park, or municipality) and the sum of the estimated non-transient populations served (for example, industrial/agricultural, medical facility, school). The research team did not attempt to validate either of these two parameters. Groundwater sources include: groundwater source not under the direct influence of surface water (for example, protected wells), purchased groundwater not under the direct influence of surface water, groundwater under the direct influence of surface water (e.g., unprotected well, springs), and purchased groundwater under the direct influence of surface water. Surface water sources include surface water directly available to the system, and purchased water originating from a surface source. For more information, see the Public Water Systems Data Dictionary at https://data.ca.gov/sites/default/files/PUBLIC%20WATER%20SYSTEMS%20DATA%20DICTIONARY_0.pdf.

[17] U.S. EPA sets these classifications; nationwide, small and very small public water systems together make up ~95 percent of all systems, but serve only 12 percent of all consumers (U.S. EPA, n.d.c)

Table 14: Characteristics of Community Water Systems in California

Population Served	Number of Ground Water Systems	Percent of Ground Water Systems	Sum of Non-transient Population (in thousands)	Percent of Non-transient Population	Number of Surface Water Systems	Percent of Surface Water Systems	Sum of Non-transient Population (in thousands)	Percent of Non-transient Population
Very small (≤500)	1,533	53.0%	220	0.6%	216	7.4%	422	0.1%
Small (501–3,300)	326	11.0%	415	1.1%	144	4.9%	231	0.6%
Medium (3,301–10,000)	118	4.0%	714	1.9%	107	3.7%	649	1.7%
Large (10,001–100,000)	140	4.8%	4,070	11.0%	217	7.4%	9,066	24.0%
Very large (>100,000)	17	0.6%	1,726	4.5%	102	3.5%	21,409	56.0%

Source: Data from State Water Resources Control Board Public Water System Information database

This survey also targeted all water suppliers in the state that primarily provide groundwater to customers for agricultural purposes, whether privately or publicly owned. These are commonly known as irrigation districts. Irrigation districts are special purpose districts that obtain and distribute water for the purpose of irrigating land within district boundaries.[18]

Part 2.8 of the Water Conservation Act of 2009 (Steinberg, Senate Bill X7-7, Chapter 4, Statutes of 2009) required agriculture water suppliers that provide water to more than 25,000 irrigated acres to submit an Agricultural Water Management Plan (AWMP) to DWR every five years. Completed AWMPs must include estimates of water use efficiency improvements since the last report, projections of improvements expected in 5 and 10 years, and a report on the implementation of 16 Efficient Water Management Practices (EWMPs) — the most critical two being measuring and pricing water deliveries volumetrically (DWR, 2017a). For those EWMPs that were not put into practice, each agriculture water supplier must document that implementation is either not cost effective or not technically feasible. In addition, Governor's Executive Order B-29-15 (April 1, 2015) required agriculture water suppliers that provide water to between 10,000 and 25,000 acres to submit AWMPs by July 1, 2016.

According to a DWR status report, by August 2017, 69 agriculture water suppliers had submitted AWMPs, each supplying water to more than 10,000 acres of land within their boundaries.[19] Together, the area of the submitting suppliers contained approximately 4 million acres, about 50 percent of California's 8.1 million acres of irrigated land, as determined in the California Water Plan Update 2013 (DWR, 2017a). The report listed 93 separate agriculture water suppliers that were required to submit 2015 AWMPs. Of those, 55 large suppliers (serving more than 25,000 irrigated acres) collectively represented about 4.3 million irrigated acres, while 38 mid-size suppliers (serving 10,000 to 25,000 irrigated acres) together made up approximately 580,000 irrigated acres (DWR, 2017a).

Agriculture water suppliers who deliver 2,000 or more acre-feet of water or supply 2,000 or more irrigated acres are also required to submit AFGD reports to DWR. The requirement was established by Assembly Bill 1404 (Laird, Chapter 675, Statutes of 2007), which in 2007 created the California Water Code Section 531.10. An AFGD report presents the total annual aggregated amount of surface water delivered by the supplier to their agricultural customers.

"Farm-gate" refers to the point where water is delivered from an agricultural water supplier's distribution system to each of its individual customers.[20] There were 151 agriculture water suppliers that submitted at least one AFGD report for the water years 2012 to 2018.

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[18] Not all agriculture water suppliers are called irrigation districts, however; other names used by these types of suppliers are reclamation districts, water districts, or water storage districts.

[19] Non-compliance has been high. The Sacramento Bee identifies 123 irrigation districts in California that report use of more than 10,000 acre-feet of water yearly. They also report that DWR does not have a comprehensive list identifying which agriculture water suppliers are subject to AWMP submittal requirements (Sabalow and Reese, 2017).

[20] Agricultural Water Measurement Regulation, Title 23, Division 2, Chapter 5.1, Article 2 of the California Code of Regulations

Farms and Ranches

This survey sought responses from growers across the state who pump groundwater. Many growers supplement surface water deliveries from irrigation districts by pumping groundwater from private wells on their own land. Some are also entirely dependent on the groundwater they pump from their wells. In general, there exists an inverse correlation between surface water deliveries and groundwater pumping. When surface deliveries are abundant — which depends on regulatory water allocations in any given water year — individual on-farm pumping lessens. But in drought years, with restrictions on surface deliveries, reduced local precipitation, and increased evapotranspiration, on- farm pumping ramps up sharply. For example, DWR cites a notable increase in groundwater pumping for agricultural purposes between 2007 and 2009 due to "dry conditions and substantial regulatory cutback of imported surface water" (DWR, 2015a). Moreover, groundwater is often preferred to surface water deliveries for several reasons. Pumping groundwater allows growers the flexibility to pump water whenever it is needed, in contrast to surface water deliveries, the schedules for which are often set days or weeks in advance. Also, groundwater is typically cleaner than surface water and thus preferred for use in drip irrigation systems, which can clog with too many impurities.

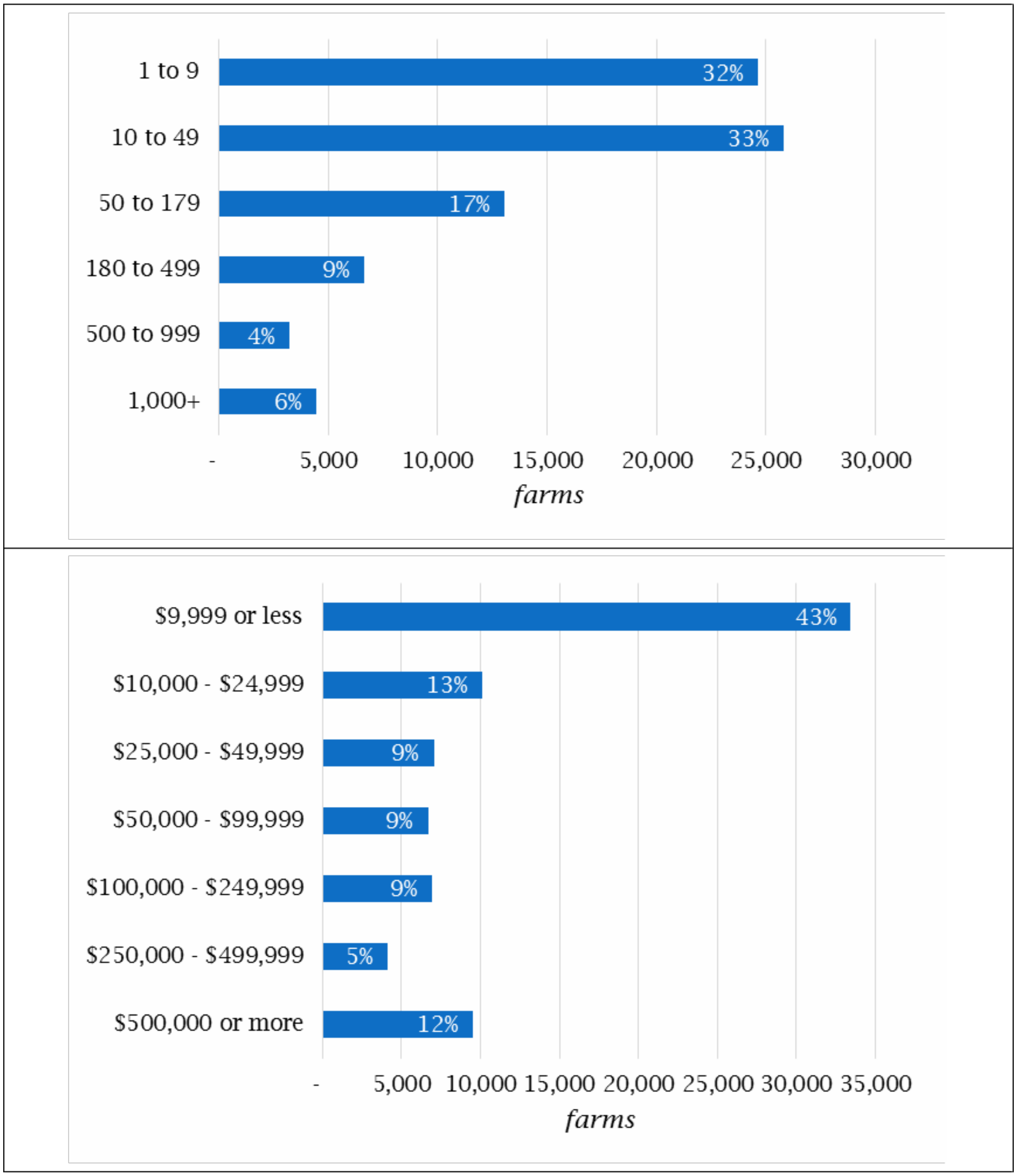
The CDFA reported, for 2017, 77,100 farm and ranch operations in California, covered 25.3 million acres, for an average of 328 acres per operation. As shown in Figure 4, the total sales value generated by agriculture in the state was $50 billion, with the top 10 commodities of value being dairy, grapes, almonds, strawberries, cattle and calves, lettuce, walnuts, tomatoes, pistachios, broiler chickens, and oranges (CDFA, 2018).

NASS last collected data on farm and ranch operator characteristics in the 2012 Census of Agriculture (CoA). According to the 2012 CoA, 55 percent of principal operators' primary occupation was farming, while 45 percent listed "other" as their primary occupation. Also, 82 percent of farm operators were male and 18 percent female, while average age was 60.1 years. For race and ethnicity, 91 percent of California farm operators were white, 6.1 percent Asian, 1.4 percent American Indian or Alaska Native, 0.84 percent more than one race, 0.43 percent Black or African American, and 0.37 percent Native Hawaiian or other Pacific Islander, while 12.4 percent were of Spanish, Hispanic, or Latino origin.

The CoA also showed that more than half of the farms in California encompassed fewer than 50 acres, and nearly three quarters of them saw gross sales of less than $100,000. Additionally, the CoA reported 7.9 million irrigated acres in California of the 25.6 total million acres in farms or ranches, or 31 percent of all farmland, was irrigated (USDA NASS, 2014a). At the same time, 53,546 farms in California — or 69 percent of farms in the state — irrigated land to some extent (USDA NASS, 2012). Table 15 presents irrigated acres by county for the top 10 counties by absolute area of irrigated land.

Also in 2012, there were 5,845 total farms with renewable energy producing systems on their land: 5,445 with solar panels, 324 with wind turbines, 190 with small hydro systems, 165 producing biodiesel, 113 leasing wind rights to others, 104 with geo- exchange systems, 56 producing ethanol, 41 with methane digesters, and 49 "other" (USDA NASS, 2012).

Figure 4: California Farms by Size and Value of Sales in 2012



Source: Data from USDA National Agricultural Statistics Service, Census of Agriculture

Table 15: Total Farm and Irrigated Land for Top 10 Counties in California

County	Land in Farms (thousand acres)	Irrigated Land (thousand acres)	Percent of Irrigated Land
Fresno	1,721	969	56%
Kern	2,330	730	31%
Tulare	1,239	557	45%
San Joaquin	787	485	62%

County	Land in Farms (thousand acres)	Irrigated Land (thousand acres)	Percent of Irrigated Land
Merced	979	468	48%
Imperial	516	455	88%
Kings	674	407	60%
Stanislaus	768	321	42%
Madera	654	292	45%
Monterey	1,268	264	21%

Counties are presented in descending order of absolute value of irrigated land.

Source: Data from USDA National Agricultural Statistics Service, Census of Agriculture

Survey Design

The research team conducted structured interviews or surveys of water utility managers and irrigators to ascertain institutional, economic, informational, and social barriers to reduce the energy intensity and use of groundwater pumping. Another goal was to identify the acceptability of various potential mitigation strategies that would reduce groundwater use and pumping energy. To guide its approach, the team investigated previous surveys related to energy efficiency in groundwater pumping and water efficiency in irrigation. The team also researched existing federal, state, and utility programs aimed at improving energy or water efficiency at water agencies or on farms.[21] At the same time, the team learned that there is no available comprehensive database of water agency contact information, nor one for growers in the state.[22]

In addition to potential respondents being difficult to locate, lessons from this exploratory period indicated that they were unlikely to be motivated to participate in a structured interview or survey. A review of the literature and informal discussions with this project's technical advisory committee (TAC) members revealed that target respondents are often asked to complete surveys by a variety of entities, far beyond their capacity to answer. Some TAC members and other subject matter experts asserted that because groundwater management in California is historically highly contentious, and neither Lawrence Berkeley National Laboratory (LBNL) nor the CEC were well-known entities among these populations, the level of

[21] Results from this investigation are described in Chapter 2.

[22] In 2000, the University of California, Berkeley Library submitted a successful proposal to create a comprehensive directory of California water agencies, citing "approximately 1,200 water and irrigation districts in California" (University of California Research Grants for Librarians Program, 2000. https://studylib.net/doc/7705679/survey-of-california-water-and-irrigation-districts) Librarians sent out a survey form to collect data on geographical location, population served, formation date, district type, water source, water delivery amounts, and predecessor agencies. These data were compiled into a searchable database at the Water Resources Center Archive, which has not been maintained in recent years. Web archives show that 314 water districts, including both municipal and agriculture water suppliers, were part of the database (web.archive.org/web/20120621063301/http:/web archives.cdlib.org:80/a/CAWaterDistricts/sites). Yet, the data is no longer available. Other existing alternative datasets and/or membership lists with water suppliers typically contain only agency names or websites in terms of contact. Concerning farmers and ranchers, USDA's NASS maintains the only extensive database of growers in the state, but the database is not publicly available.

trust potential respondents would place in the research team's efforts was likely to be minimal and lead to low response rates.

Given the lack of available contact information for potential respondents, as well as their likely reluctance to answer surveys, with input from TAC members the team reached a consensus to develop in-depth, structured survey questionnaires, to be administered primarily online (and also over the phone, if requested). Because respondents were foreseen to be difficult to reach, the research team found it necessary to employ nonprobability sampling, making every effort to engage potential respondents through a variety of channels. Chapter 4 further details these channels.

The main disadvantage of this sampling approach is that it is not advisable to infer characteristics from the sample to the general population, in statistical terms. This method is subject to unquantifiable response and self-selection biases, so the validity of the findings from these surveys cannot be established.

Prior to this research project, significant gaps remained in understanding groundwater pumping practices by municipalities and irrigators, as well as the associated barriers to curtailing pumping energy. As discussed in Chapter 2, previous research efforts touched on factors that prevent groundwater users from reducing pumping and energy use, yet past survey approaches regarding groundwater use have centered on irrigation districts or as in-depth case studies of a few water agencies. Combined with the probability of low response rates, the research team chose to develop in-depth, longer questionnaires to capture more information and nuance on this topic.

The team met with two growers on their property in Merced County to learn more about conjunctive use, the coordinated use of surface water and groundwater, as well as irrigation and groundwater pumping practices, which helped to inform the initial design of a questionnaire surveying farms and ranches. The general approach to developing questionnaires was to ask mainly closed questions rather than open-ended ones, both to lessen respondent burden and processing time, except where necessary (for example, leaving a blank for respondents to fill in if desired when an "Other" response option was selected, or where a predetermined set of responses might bias respondents or not adequately reflect reality).

The team developed questionnaires separately for municipal water suppliers, agriculture water suppliers, and for farmers and ranchers. Questionnaire development was a highly iterative process, with numerous revisions occurring for each questionnaire. It began with a review of existing surveys and programs, followed by successive research team brainstorming sessions. The whole process was informed via conversations with TAC members and other subject matter experts. These included representatives from water agencies, utilities, and state agencies, as well as several survey design and methodology experts.

TAC members connected the research team with small groups of individuals for field testing to improve the clarity and the acceptability of questions. The team met in person with six individual growers in Fresno and Kern counties to hear their opinions on the farmer and rancher questionnaire. Two of these growers provided their impressions on a one-on-one basis, while the other four growers met with the research team to proceed through the questionnaire in small segments (three related questions at a time) to deliver their observations. The team similarly sought opinions on water supplier questionnaires via a web-based field test from a small panel of three members of three irrigation districts located in Merced, Solano, and Kings counties, as well as a small panel of three members of three municipal water agencies located in Fresno, Riverside, and Orange counties. These field tests were designed to informally solicit opinions from participants, whose useful input the research team considered when revising the questionnaires. However, in all cases, the research team — guided by the TAC and survey methodology experts — made the final decision on the final content of questionnaires.

Broadly, the content of the survey questionnaires can be overviewed as follows:[23]

- All water suppliers (municipal and agriculture): groundwater supply, costs, well characteristics, energy sources, efficiency, efficiency actions taken and associated barriers or difficulties, attractive potential incentives, and good financial mechanisms.
- Agriculture water suppliers: (in addition to the content above) EWMPs and disincentives, groundwater costs to growers, factors affecting on-farm irrigation decisions, and role (if any) of the supplier in on-farm water or energy conservation.
- Farmers and ranchers: demographics, farm characteristics, groundwater use, well characteristics, operational changes affecting pumping energy, pump characteristics, energy sources, efficiency actions taken and associated barriers or difficulties, and attractive potential incentives.

Once the questionnaires were finalized, the team prepared a full research protocol for LBNL's institutional review board (IRB) entity, the Human Subjects Committee (HSC). The protocol required descriptions of: the overall protocol; key research personnel and their qualifications;[24] funding sources; potential conflicts of interest; the study population; recruitment methods, including a detailed Sequence of Experimental Events as experienced by each type of participant; data collection procedures; potential risks to participants, and associated precautions to minimize these risks; the informed consent process; data privacy and confidentiality; and an adverse event management plan. In addition, the team inputted the three questionnaires into the online survey platform,[25] and estimated durations for completing the online surveys.[26] Finally, the team built a website to host information about and links to each survey questionnaire (including language on informed consent), and thus support survey efforts.

Recruitment Plan

Given the anticipated difficulties in securing adequate responses for the surveys, the research team developed a multi-pronged recruitment approach, with individual recruitment plans for

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[23] The three questionnaires are presented in Appendix B.

[24] All required to have completed IRB training.

[25] Qualtrics® (www.qualtrics.com).

[26] Estimates were 25 minutes for municipal water suppliers, 30 minutes for agriculture water suppliers, and 20 minutes for farmers and ranchers.

each survey population: one for municipal water suppliers, one for agriculture water suppliers, and another for farmers and ranchers. The research team developed these recruitment plans in accordance with LBNL HSC requirements, and the HSC approved survey protocol.

The research team was the primary developers of the recruitment strategy, which ended up occurring in an iterative manner. Various partners, in particular TAC members, also participated in brainstorms for the best method of outreach. All three plans included methods to reach the target survey population through both contacting the target survey population directly, as well as through relevant third parties, such as industry associations. The recruitment plans explicitly outlined the following methods:

- Email solicitations (standalone and via listservs).
- Telephone solicitations.
- Media and advertising (such as advertisements in news outlets).
- Word of mouth (particularly with respect to capitalizing on pre-existing relationships with participants).
- Referral by independent source.
- Distribution of promotional materials (for example, flyers) in conferences and meetings.

Direct Outreach Recruitment Plan

The recruitment plan for efforts conducted directly by the research team followed a similar process for each of the target survey populations. Where email contact information was available, the plan prioritized recruitment emails; where no email contact information was available, the research team made telephone calls as an alternative, leaving voicemails when necessary. Initial contact (either phone or email) was conducted using pre-approved email text or a phone script. The plan outlined a waiting period of three weeks between initial recruitment and the commencement of follow-up contact. For those invited participants who do not respond to the questionnaire within three weeks, a first follow-up email or telephone call would emphasize to participants the importance of their responses. In the follow-up communication, participants would be given the opportunity to opt for responding to the questionnaire via a telephone call, to be scheduled at their discretion. The plan detailed up to two additional follow-up attempts similar to the one described above, both conducted at (at least) three-week intervals. Each communication also provided the target participants the opportunity to opt out and stop receiving any communication related to the surveys.

Third-Party Outreach

In developing the recruitment strategy, the research team acknowledged and anticipated the importance of the surveys reaching target respondents through industry-related organizations and entities with which they were more familiar and/or engaged. The research team independently investigated related industry organizations, as well as recommendations from TAC members and other organizations, to develop lists of potential strategic partners and organizations that had contact with the target population of a given survey. Some of these third-party organizations would directly email their contacts about the survey, while others would promote it in other ways (for example, by including it in a newsletter, announcing it in social media, or handing out flyers on behalf of the team). The recruitment plan included text drafted in advance for potential third-party outreach, though it acknowledged that third parties could modify this text as desired based on preferences or to better resonate with their contacts. The plan identified opportunities for multiple promotion efforts by the same third party, whether through multiple media (for example, recruitment emails and flyer distribution), or follow-up communications.

A particular third party with which the research team planned to partner for the survey of farmers and ranchers is the USDA's NASS. The team worked with their Pacific Regional Office to determine whether they could run the questionnaire as a mail survey to a statistically representative sample of farmers and ranchers in California. The team pursued this arrangement given its anticipated difficulties in reaching this target survey population, and growers' familiarity with the USDA as a surveying authority. NASS runs the Census of Agriculture, which surveys U.S. farmers and ranchers on land use and ownership, operator characteristics, production practices, income, and expenditures. However, time conflicts with other USDA survey activities prevented NASS from accommodating this request within the time frame of this study and ultimately prohibited the research team from delegating the farms and ranches survey recruitment and deployment to NASS Pacific Regional Office. As a result, the recruitment plan for farmers and ranchers included a (tentative) direct outreach approach and — given the team's lack of a directory of growers in the state with their emails — an outreach most likely conducted by other relevant third parties and means.[27] Examples of third-party organizations the research team sought to collaborate with included farm advisors and their networks, farm service providers, educational and vocational agricultural centers, and various media outlets popular with the target survey population community.

[27] Eventually, during survey implementation, the team was able to obtain a list with contacts of several hundreds of small farm operations in the state.

CHAPTER 4: Implementation

Once Lawrence Berkeley National Laboratory's Human Subjects Committee (HSC) approved the survey protocol, the research team began to implement the recruitment plan, targeting each respondent population in a unique effort during the 2018 to 2019 fall and winter periods. The research team reached out directly to potential respondents in all populations. The team sent initial and follow-up emails in accordance with the recruitment plan approved by the HSC. Appendix B shows the emails sent. All potential participants contacted had the opportunity to, for any reason, opt-out of participating in the survey. Some participants did exercise their right to opt out, sometimes simply because they don't engage in groundwater pumping, others provided no further explanation.

The team relied on contact lists they developed that included emails of 238 municipal water suppliers, 125 agriculture water suppliers, 10 suppliers that provide water for municipal and agriculture use,[28] and 470 growers. The list with emails of water suppliers extended the list the team developed to support its campaign of groundwater pumping data request (Blum and Ke, 2023). The one with emails of farmers and ranchers was developed upon contact information of growers listed in University of California Agricultural and Natural Resources (UCANR) *California Agricultural Tourism Directory* (UCANR, n.d.a). A total of 822 emails were sent to municipal water agencies, 394 to agriculture water agencies, 36 to those that supply water for both municipal and agricultural use, and 1398 to farmers and ranchers. Figure 5 summarizes the team's direct outreach efforts and the number of responses received.[29]

In addition to direct communication from the research team, trusted third parties and TAC members disseminated recruitment information to potential participants via their internal listservs, regular newsletters, personal contacts, or flyers produced by the research team or all the recruitment opportunities.[30]

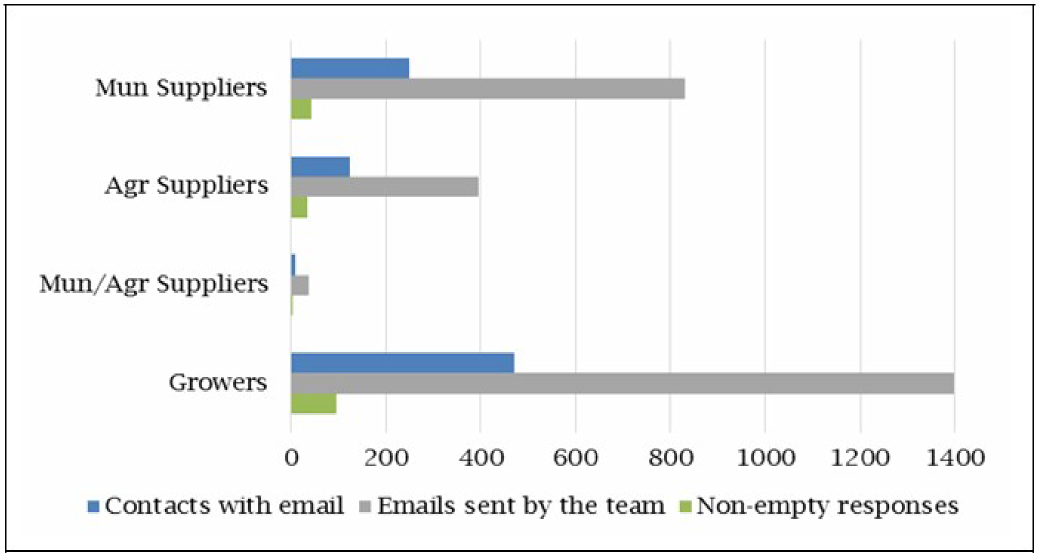
Table 16 summarizes the various recruitment opportunities that entailed partnerships or the involvement of third-party organizations. Unsuccessful recruitment efforts are not included in the table.

[28] Some water suppliers provide water for municipal and agricultural applications. Most of these organizations, however, deliver the majority of their services to either of these. In these cases, recruitment efforts contained information on the municipal and agriculture water supplier surveys, and asked recipients to take whichever survey they felt was most applicable

[29] Note that the number of responses cannot be directly attributed to the team's direct outreach, as the team also relied on third parties to recruit potential participants from the three targeted populations.

[30] When emailing their own contacts, third parties were encouraged to distribute the survey to those contacts who were the most appropriate, considering the content of the questionnaire.

Figure 5: Summary of Outreach



Source: Lawrence Berkeley National Laboratory

Table 16: Third-Party Outreach

Third Party	Media	Target Population		
		Municipal	Agriculture	F&R*
3rd Open Farm, UCANR Cooperative Extension	Event (Parlier)			x
2018 Fall Conference, ACWA	Event (San Diego)	x	x	
Pistachio Day, Pistachio Research Board	Event (Visalia)			x
57th Annual Conference, CA Irrigation Institute	Event (Sacramento)		x	x
Farm Journal	Email			x
CA Assoc of Resource Conservation Districts	Newsletter			x
UCANR Cooperative Extension	Email		x	x
CA Water Efficiency Partnership	Newsletter	x	x	
Almond Board of CA	Facebook			
Ag Alert, CA Farm Bureau Association	Advertisement Article			x
UCANR California Agritourism News	Newsletter			x
ACWA – Association of CA Water Agencies	Email	x	x	

Third Party	Media	Target Population		
		Municipal	Agriculture	F&R*
AWWA - American Water Works Assoc (CA-NV)	Newsletter	x	x	
Maven's Notebook	Article	x	x	
Groundwater Resources Association	Email	x	x	
East Merced Resource Conservation District USDA Natural Resource Conservation Services	Email			x
CA Climate & Agriculture Network	Newsletter		x	x
Center for Irrigation Technology, Fresno State	Tweet		x	x
California Agriculture, UCANR	Journal		x	x
Ag Net West	Article, broadcast		x	x

*Farmers and Ranchers
Source: Lawrence Berkeley National Laboratory

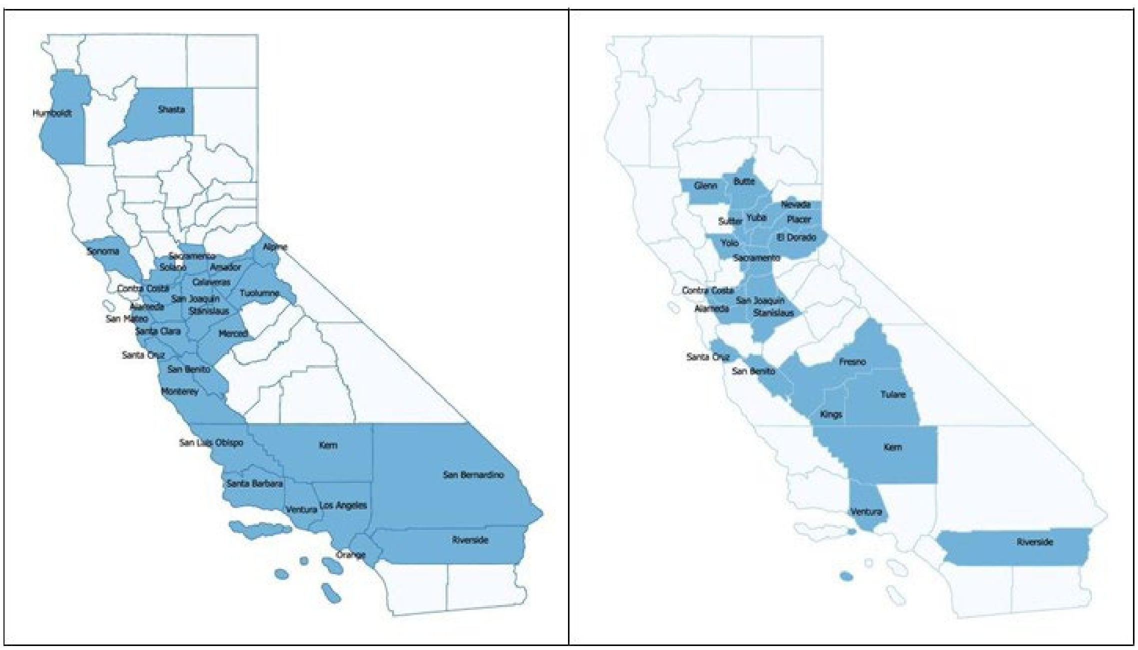
Survey recruitment fliers were distributed at the 3rd Open Farm, UC Kearney Agricultural Research and Extension Center, Parlier, in October 2018; ACWA 2018 Fall Conference, San Diego, in November 2018; Pistachio Research Board's Pistachio Day, Visalia, in January 2019; and in the California Irrigation Institute's 57th Annual Conference, Sacramento, in February 2019. Fliers were also distributed by a TAC member to municipal and irrigation districts that are members of the San Luis & Delta-Mendota Water Authority. The ACWA and the California Water Efficiency Partnership (CalWEP) emailed their members about the surveys.[31] So did the Groundwater Resources Association, the Natural Resource Conservation District, and the East Merced Resource Conservation District (along with the USDA Natural Resource Conservation Services). The Farm Journal emailed approximately 6,000 growers. The UCANR Cooperative Extension emailed around 200 farm specialists and advisors, as well as UC faculty to ask them to feature the survey with growers they work with. Additionally, the surveys were featured in newsletters from the California Association of Resources Conservation Districts and the California Climate and Agriculture Network; in the Maven's Notebook; in the California Farm Bureau Association's Ag Alert; and in the UCANR's peer-reviewed journal California Agriculture. Also, the survey of farmers and ranchers was posted on the Facebook page of the Almond Board of California, tweeted by the Fresno State's CIT, and featured in an article in Ag Net West and broadcast (radio) in its Farm City Newsday podcast. Finally, the survey of growers

[31] ACWA includes more than 450 municipal agencies, irrigation districts, contractors, groundwater sustainability agencies, regional authorities, and other types of water entities. Collectively, the ACWA agencies deliver more than 90 percent of the water to meet residential, commercial, and agricultural demand in the state (https://www.acwa.com/about/directory/). CalWEP, a chapter of the national Alliance for Water Efficiency that was formerly the California Urban Water Conservation Council, includes more than 200 members from a range of agency types (https://calwep.org/Members/Member-Directory).

was also advertised several times in the California Farm Bureau Association's Ag Alert newspaper.

Because the surveys captured statewide pumping among the three target groups of potential groundwater pumpers, the research team targeted (in its direct and indirect recruitment efforts) water suppliers and growers across the entire state as potential survey respondents. Participation did not require any particular quantity of groundwater pumped or, in the case of farmers and ranchers, crop type, acreage, or livestock headcount. As water supplier participants responded to the survey they were removed from the team's direct contact emailing list.[32] Overall, the team received 42 non-empty responses from municipal water suppliers, 34 from agriculture water suppliers, and 97 from growers.[33] The notion of a non-empty response refers to a questionnaire where a municipal or an agriculture water supplier identified themselves, sometimes consented to be acknowledged in this report, but did not respond to any of the questions in the questionnaire. For farmers and ranchers, since those questionnaires were not identified, the idea of a non-empty response refers to questionnaires where at least one question was answered. Figure 6 and Figure 7 show the counties for which the team received non-empty responses from each of the three populations surveyed. Table 17 lists the water suppliers that participated in the surveys and consented to be acknowledged in this report.

Figure 6: Distribution of Survey Responses from Water Suppliers by County



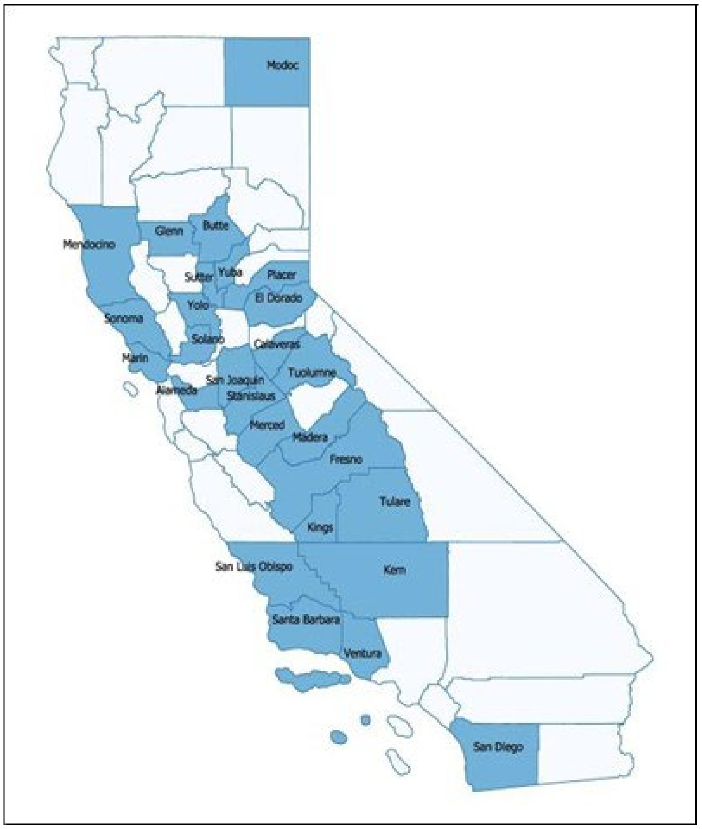
Left: Municipal water suppliers. Right: Agricultural water suppliers.

Source: Lawrence Berkeley National Laboratory

32 The same cannot be asserted for farmers and ranchers the team reached out directly, since their responses are anonymous, and concerning emails sent by third parties.

33 The team believes that, in case of growers, offering a nominal monetary incentive for participation (a $10-$20 prepaid gift card, or a random lottery for several higher-denomination gift cards) could have led to a higher response rate. While this is a common practice in survey research to decrease nonresponse (Singer and Ye, 2013; Adua and Sharp, 2010), CEC rules for research of this nature prevented the team from offering participants such incentive.

Figure 7: Distribution of Survey Responses from Growers by County



Source: Lawrence Berkeley National Laboratory

Table 17: Water Suppliers that Participated in the Survey

Alameda County Water District	Fresno Madera Kern Kings Tulare Counties
Alpaugh Irrigation District	Humboldt Bay Municipal Water District
Angiola Water District	Kings County Water District
Arvin Community Services District	Lindmore Irrigation District
Beaumont Cherry Valley Water District	Long Beach Water Department
Big Bear City Comm Services District	Los Angeles Dept of Water and Power
Biola Community Service District	Madera Irrigation District
Calaveras County Water District	Marina Coast Water District
Carmichael Water District	Mimbres Bolsum
City of Arroyo Grande	Modesto Irrigation District
City of Banning	North Kern Water Storage District
City of Brentwood	Orange Cove Irrigation District
City of Escalon	Orland Artois Water District
City of Fortuna	Pajaro Valley Water Management Agency
City of Lakewood	Pleasant Valley County Water District
City of Loma Linda	Reclamation District 1004

City of Los Banos	Richvale Irrigation District
City of Manteca	Rubidoux Community Services District
City of Newman	San Benito County Water District
City of Patterson	Santa Clara Valley Water District
City of San Bernardino Mun Water Dept	Santa Clarita Valley Water Agency
City of San Jacinto	Santa Nella County Water District
City of Santa Clara	Santa Rosa Water
City of Santa Cruz Water Department	Scotts Valley Water District
City of Santa Maria	Solano County Water Agency
City of Seal Beach	Sonoma County Water Agency
City of Shasta Lake	Stockton East Water District
City of Solvang	Sunnyslope County Water District
City of Turlock	Sutter Extension Water District
City of Vacaville	Town of Discovery Bay Comm Serv Dist
City of Vernon	Tudor Mutual Water Company
City of Yreka	Tulare Irrigation District
Compton Municipal Water	United Water Conservation District
Del Puerto Water District	Ventura River Water District
Desert Water Agency	West Kern Water District
Dudley Ridge Water District	Western Canal Water District
Eastside Water District	Westlands Water District
Elk Grove Water District	Wheeler Ridge Maricopa Water Stge Dist
Fair Oaks Water District	Yolo Cty Flood Ctrl & Wtr Conserv Dist

List includes organizations that provided blank questionnaires.

Source: Lawrence Berkeley National Laboratory

CHAPTER 5: Results and Analysis

Water Suppliers

As discussed in Chapter 3, urban water suppliers over certain thresholds must submit UWMPs to DWR. Comparing municipal water supplier respondents to the standardized data DWR provides on UWMPs reveals that 36 of 42 respondents submitted 2015 UWMPs. In aggregate, these 36 respondents supplied 22.1 percent of the (approximately 30 million) 2015 population served by the UWMP submitting retail suppliers. They also represented 13.6 percent of the (approximately 2.4 million acre-feet) reported groundwater these suppliers pumped in 2015. Six responding municipal suppliers were small enough to be under the submittal threshold for UWMPs.

Similarly, agricultural water suppliers over some thresholds are required to submit AFGD reports to DWR. Seventeen water suppliers that responded to the agriculture water supplier survey reported AFGDs. In aggregate, these respondents supplied water during the 2012 to 2018 water years to 23.4 percent of the total irrigated land (approximately 34.8 million acres) served by all AFGD submitters. The volume of water they supplied during that period corresponded to 22.3 percent of the amount of water delivered by all suppliers that submitted an AFGD for that period.

The two questionnaires used to survey water suppliers present great similarity, with the questionnaire applied to agriculture water suppliers, including additional questions regarding on-farm groundwater pumping within their respective service territories. Every reported result also indicates the number of respondents for that question (for example, n=77).

Reliance on Groundwater

Agriculture water suppliers were asked to indicate if their district owned and operated groundwater production wells. Out of 33 responses, 61 percent indicated they did own and operate groundwater production wells; 39 percent indicated they did not, but that groundwater is pumped in private wells within their service area.[34]

Next, municipal and agricultural water suppliers were asked to indicate their reliance on groundwater in numerical terms for the 2015, 2016, and 2017 water years, either by providing figures for total water supply and for the volume of groundwater pumped from suppliers' wells, or by entering the groundwater pumped as a share of total water supply in percentage terms. Table 17 contains summary statistics for municipal and agricultural respondents. Results are also presented in Figure 8. Given the small number of agricultural respondents to this question, caution is necessary in interpreting results. However, together Table 18 and

[34] The survey software was set up such that those respondents who indicated they did not own or operate any groundwater production wells skipped questions 2–16 concerning only the groundwater pumping by district-owned wells, to arrive at questions regarding groundwater pumping in the entire service area (including customers' private wells).

Figure 8 show that respondents relied less on groundwater in a wet water year like 2017, in contrast to a critically dry water year like 2015. Moreover, 15 of 41 municipal respondents, or 36.6 percent, relied only on groundwater (specifically, the share of total supply is 100 percent) for all three water years surveyed, so this change over time is somewhat attenuated for municipal respondents as a group, in contrast to agricultural respondents.

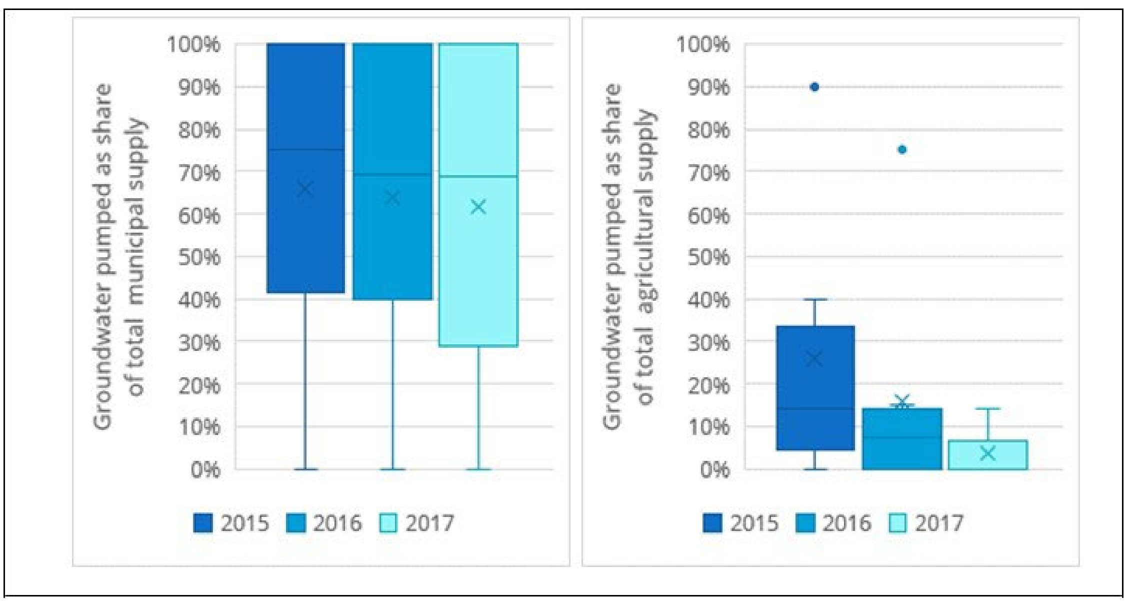
Table 18: Summary Statistics of Groundwater Pumped in Water Years 2015 to 2017

	Municipal (n=41)	Municipal (n=41)	Municipal (n=41)	Agricultural (n=7)	Agricultural (n=7)	Agricultural (n=7)
	2015	**2016**	**2017**	**2015**	**2016**	**2017**
Minimum	0%	0%	0%	0%	0%	0%
25th percentile	41.7%	39.8%	28.8%	4.7%	0%	0%
Average	66.1%	63.7%	61.9%	25.8%	15.9%	3.9%
Median	75.2%	69.2%	69.1%	14.3%	7.5%	0%
75th percentile	100%	100%	100%	33.5%	14.3%	6.5%
Maximum	100%	100%	100%	90.0%	75.0%	14.3%

Data represent volume of groundwater pumped as a share of total water supply.

Source: Lawrence Berkeley National Laboratory

Figure 8: Groundwater as Share of Total Supply in Water Years 2015 to 2017

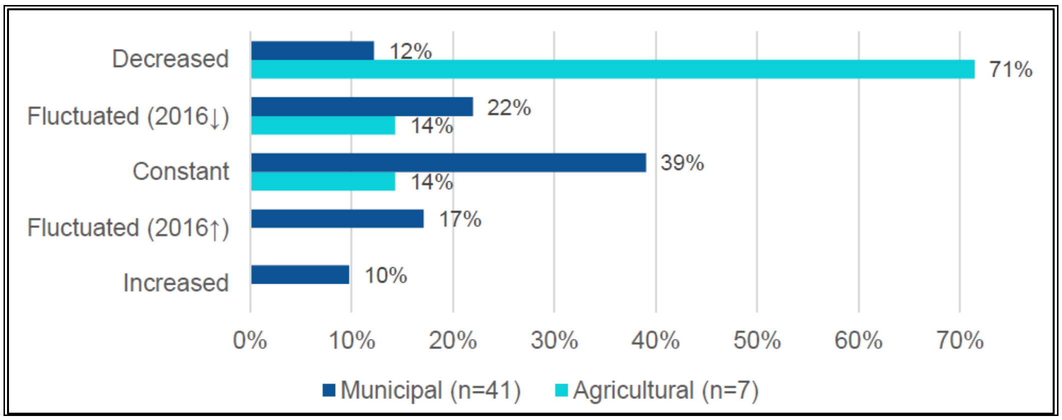


Left: Municipal respondents (n=41). Right: Agricultural respondents (n=7). The bottom of the boxplots marks the first quartile, the midline inside the boxes shows the median, markers denote mean values, and the top of the boxes represent the third quartile. Whiskers indicate the local minimum and maximum of the data, with dots beyond the end of each whisker, if present, displaying outlying data points that lie 1.5 times the interquartile range from either end of the box.

Source: Lawrence Berkeley National Laboratory

From these data, the research team determined whether this reliance on groundwater increased, fluctuated, stayed constant, or decreased from water years 2015 to 2017. For fluctuations, the team characterized them as either valleys (the share of groundwater pumped was lowest in water year 2016) or peaks (specifically the share pumped was highest in water year 2016). Figure 9 presents the share of municipal and agricultural respondents that fell into each category during this period. The plurality of municipal respondents saw their reliance on municipal water stay constant, although much of this fraction is due to municipal suppliers with 100 percent reliance on groundwater in all three water years. In contrast, most agricultural suppliers saw a decreasing trend in reliance on groundwater, which is reasonable considering that surface supplies are curtailed, sometimes drastically, in dry and critically dry years like those at the beginning of this period.

Figure 9: Trend of Groundwater Pumped as Share of Total Supply (2015 to 2017)



Source: Lawrence Berkeley National Laboratory

After acknowledging that groundwater pumping varies across years due to differing hydrological conditions, both questionnaires prompted respondents to ignore these hydrological variations in putting forward whether any changes in their agency over the past decade had yielded general trends in reliance on and depth to groundwater. More than 40 municipal respondents provided some type of response to this question. While responses were extremely varied by individual respondent, some common themes did emerge. Several respondents indicated that their groundwater pumping has remained virtually unchanged. Generally, these respondents did not provide much additional detail, simply noting that there were essentially no changes and that their groundwater use had remained steady. One respondent reported sole reliance on groundwater for the past 10 years and beyond, while another indicated stability in use with the exception of drought years. Another respondent indicated that despite the decline in their customer base (resulting in a decrease in water demand), groundwater pumping had remained relatively stable — indicating an overall increase in reliance in groundwater. Many respondents indicated a decrease in their groundwater use. This was attributed to a range of factors, including increased water use efficiency, household- level conservation efforts, greater reliance on recycled water, new surface water supplies, or chloride levels found in groundwater. One district reported that their groundwater pumping had declined by approximately 20 to 25 percent in the past ten years and attributed this decline to water use efficiency and use of recycled water. Two other respondents reported decreasing groundwater use as a result of strong conservation messaging received from the State and regulators throughout the recent drought. Another respondent attributed the decline to a decline in water use overall, specifically from some of their own efficiency and conservation programs. Trends and habits around the use of alternative water sources, including surface and imported water were mentioned as factors that led to decreased groundwater pumping.

Several respondents indicated that their groundwater use had decreased as a result of an increase in surface water availability, mentioning local governing bodies as active participants in this change. Fewer respondents indicated an increase in groundwater use. One respondent reported that their agency brought a new well online located in a deeper portion of their aquifer to improve supply resiliency in drought events. Others attributed pumping increases to the (presumably higher) cost of imported water and to goals of conjunctive use. One respondent reported that growth in their district had resulted in an increase of groundwater as a percentage of total supply from 15 percent to 30 percent. Another respondent reported that if groundwater use did increase, it was a result of the fact that the available surface water decreased. Two respondents indicated that their district solely relied on groundwater.

When discussing their agency's decision to rely on groundwater or increase or decrease reliance on groundwater as a key source, respondents often referenced other changes in their water supply that may have caused this. Some of these changes included the impacts of drought, ambitious water conservation goals, dropping groundwater levels, or declining groundwater quality. One respondent reported that the recent drought had caused groundwater levels to decrease to historic lows. As a result of state regulations, the drought, and strong conservation messaging, this agency had relied less on its groundwater basin in recent years. Another district indicated that system improvements had been made to allow them to maximize surface water use in place of groundwater.

Fewer agricultural respondents chose to answer this open-ended question. Several respondents indicated that there had been virtually no change in their groundwater pumping practices, reporting they pumped about the same as much as 10 years ago. Another reported that their groundwater basin is increasingly being relied upon as a result of the reductions in imported state and federal water supplies. Another respondent discussed the issues of dropping groundwater levels and the role that more efficient (micro and drip) irrigation systems play in reducing recharge. Additionally, they mentioned that growers in their district often avoid surface water as it requires better filtering.

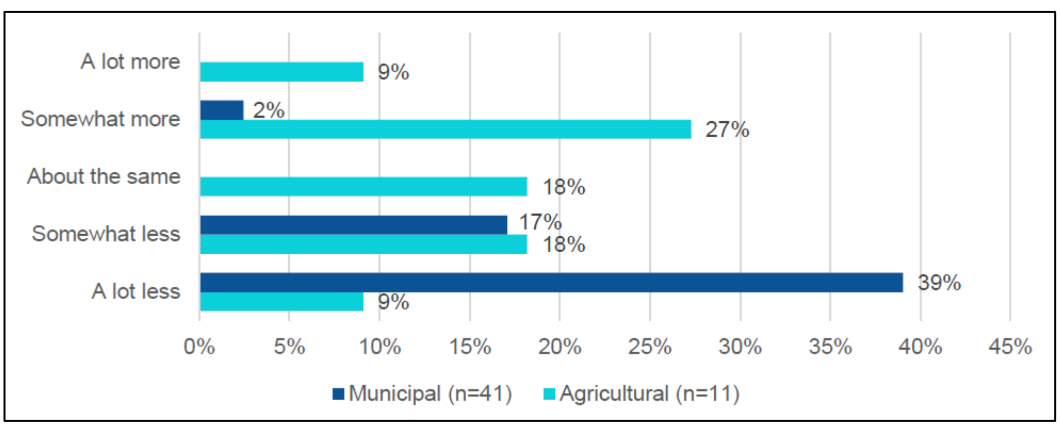
Turning to the relative costs of groundwater, which may have some bearing on its use, agricultural water suppliers and municipal water suppliers were asked how the cost of local groundwater generally compared to the cost of surface or imported water. Figure 10 shows a fairly even split for the agriculture water suppliers regarding whether local treated groundwater costs more or less than surface or imported water. Just over one third (36 percent) of respondents indicated that the cost was higher for local groundwater, 27 percent indicated that the cost was lower, and 18 percent indicated the cost was about the same. Note this does not add up to 100 percent as 18 percent of respondents were unable to generalize their responses, noting the following cost contributors.

- Expensive power costs to pump agriculture wells.
- Relevance of costs associated with turbine, pump, and water well repairs.
- Customers bear higher costs to use their own wells rather than purchase water from the agency.

Of the 41 municipal agencies that participated, over half (56 percent) indicated that groundwater typically costs less than treated surface or imported water, while 2 percent indicated that it costs somewhat more. This does not sum to 100 percent as 27 percent of the respondents indicated they do not have any water sources other than groundwater and 15 percent indicated they were unable to generalize their responses, providing the following summarized explanations in an open-ended response; dollar values are per acre-foot ($/af).

- Higher life cycle costs associated with purchasing surface water ($714/af) compared with groundwater ($150/af).
- Depending on surface water source, groundwater costs between $100-$670/af less than imported treated water.
- Primarily rely on groundwater; however, when surface water is occasionally available, it is about the same cost as groundwater.
- Maintain six independent water systems within three different source watersheds, where five use surface water and one uses groundwater.
- Reliance on a mix of several sources of water supply results in differing costs depending on supply source. In this case, the lowest was associated with treated, formally brackish groundwater from Source A, the second lowest cost was associated with treated surface water from Source B, the third lowest cost came from a blend of groundwater and purchased water, and the highest cost was associated with purchased water from Source D.

Figure 10: Costs of Local Groundwater Relative to Surface or Imported Water



Source: Lawrence Berkeley National Laboratory

To get a sense of the number of wells in participating agencies' service territories, respondents were asked for the number of groundwater wells in the 2015, 2016, and 2017 water years. Municipal suppliers were asked to submit these figures for active wells (that were ready to operate, given system demand) and for wells that were on standby (operated only if necessary). On the other hand, agricultural suppliers furnished figures for the total number of wells the district owned, as well as the total number the district operated. Table 19 contains summary statistics for both groups of respondents. In later (wetter) water years during this period, these data generally show that the number of active municipal wells decreased, with some of these wells on standby. Similarly, the number of agricultural respondents' wells in operation typically also diminished over this time frame.

In addition to the number of active and standby wells, municipal suppliers were asked in an open-ended question how many of their groundwater wells have wellhead treatment beyond disinfection (for example, chlorination, chloramination), indicating additional energy treatment needs. Thirty-four respondents gave a numeric response to this question. Of that, 56 percent indicated no wells had wellhead treatment. Fewer respondents indicated one to four treated wells. Fifteen percent of respondents reported treating five or more wells (Figure 11). Approximately 29 percent of respondents (including many that reported treating none of their wells) reported that a centralized treatment plant or facility treats all water from wells.

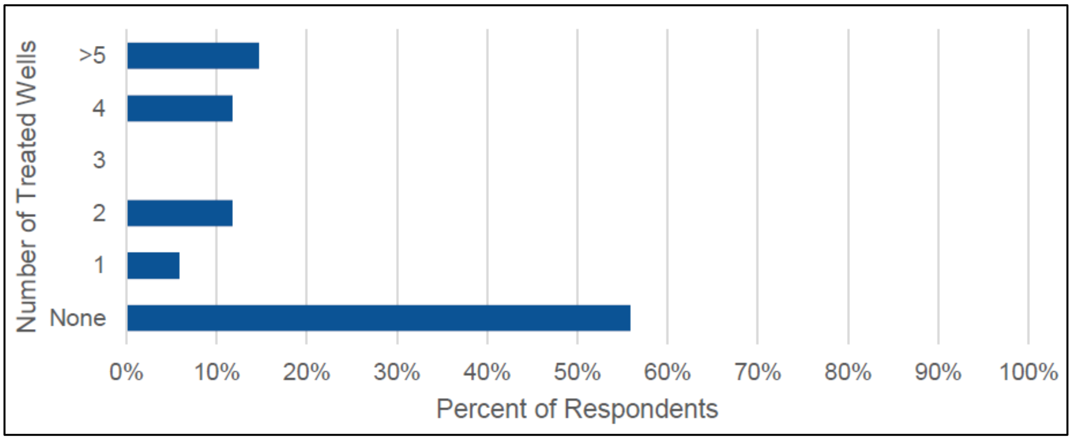
Table 19 contains summary statistics for both groups of respondents. In later (wetter) water years during this period, these data generally show that the number of active municipal wells decreased, with some of these wells being put on standby. Similarly, the number of agricultural respondents' wells in operation typically also diminished over this time frame.

Table 19: Summary Statistics of Groundwater Wells for Water Years 2015 to 2017

	Number of Active Municipal (n=39) Wells	Number of Active Municipal (n=39) Wells	Number of Active Municipal (n=39) Wells	Number of Municipal (n=39) Wells on Standby	Number of Municipal (n=39) Wells on Standby	Number of Municipal (n=39) Wells on Standby	Number of Active Agriculture (n=10) Wells	Number of Active Agriculture (n=10) Wells	Number of Active Agriculture (n=10) Wells	Number of Agriculture (n=10) Wells on Standby	Number of Agriculture (n=10) Wells on Standby	Number of Agriculture (n=10) Wells on Standby
	2015	**2016**	**2017**	**2015**	**2016**	**2017**	**2015**	**2016**	**2017**	**2015**	**2016**	**2017**
Minimum	0	0	0	0	0	0	0	0	1	0	0	0
25th percentile	3.8	3.8	3.8	0	0	0	2	2	2	2	0	0
Average	6	6	6.5	1	1	1	3.5	5	5	3.5	2	0
Median	10.2	10.3	10.1	1.6	2	2.1	23.1	25.4	25.6	21.7	22.2	10.4
75th percentile	13.5	13.5	13	2	2	2	13.5	15	15	11.8	12	3
Maximum	54	54	51	27	44	48	100	100	100	95	95	85

SharSource: Lawrence Berkeley National Laboratory

Figure 11: Municipal Groundwater Wells Treated Beyond Disinfection (n=34)



Source: Lawrence Berkeley National Laboratory

Groundwater Well Pumping Energy

Districts and agencies were asked to identify the percent of their groundwater pumps powered by non-electric means (for example, diesel or natural gas) or by off-grid electricity (for example, stand-alone solar power), excluding methods for generating power during a power outage. Almost all respondents for both municipal agencies and irrigation districts reported that none of their pumps were powered by those sources. Of the 41 municipal water suppliers that responded to this question, 95 percent stated that none of their agency's groundwater well pumps were powered by non-electric means or off-grid electricity. Four percent of agencies reported groundwater well pumps powered by non- electric means or off-grid electricity; of this share, two percent specified powering 6 to 10 percent of pumps with these alternative methods, and another two percent indicated 11 to 20 percent of their pumps. Of the 11 agricultural suppliers that responded to this question, 91 percent stated none of their district's groundwater well pumps were powered by non-electric means or off-grid electricity, while 9 percent responded that 1 to 5 percent of their well pumps were powered by such means.

Next, the questionnaire for agricultural suppliers prompted participants to disclose some general information about groundwater pump testing schedules and ranges for a common groundwater pumping efficiency metric. Table 20 summarizes how long it has been since the last time respondents tested the efficiency of their groundwater pumps, revealing that nearly all participating suppliers have conducted recent testing.

Regarding the results of these pumping tests, agricultural respondents reported the average, minimum, and maximum overall pumping plant efficiency (OPPE) of their groundwater well pumps. Only nine respondents answered this question. Table 21 summarizes these results. The two lowest ranges (1 to 40 percent and 41 to 50 percent) were reserved for minimum OPPEs only. Most respondents reported an average OPPE between 51 and 70 percent, with 44 percent of respondents indicating an average OPPE between 51 to 60 percent and one third of respondents reporting an average OPPE of 61 to 70 percent. More than half (56 percent) of respondents reported the maximum OPPE as 71 to 80 percent. One respondent, with only two district-owned groundwater pumps, reported the same OPPE range of 71 to 80 percent for minimum, maximum, and average. Results are consistent with Burt and Howes (2005), who reported that the irrigation district average OPPE for pumps ranged from about 34 percent to 67 percent, and the average irrigation district stated OPPE for well pumps was approximately 57 percent. Although it is possible for a pump to achieve an OPPE over 80 percent, the reported average 81 to 100 percent OPPE value from one respondent needs further investigation.

Table 20: Time Since Agricultural Suppliers Last Tested Well Pumps (n=11)

Time Elapsed	Number of Responses
Within the last 5 years	10
More than 5 years ago but less than 10 years ago	0
More than 10 years ago but less than 15 years ago	1
More than 15 years ago	0

Source: Lawrence Berkeley National Laboratory

Table 21: OPPE Range of Agricultural Suppliers' Well Pumps (n=9)

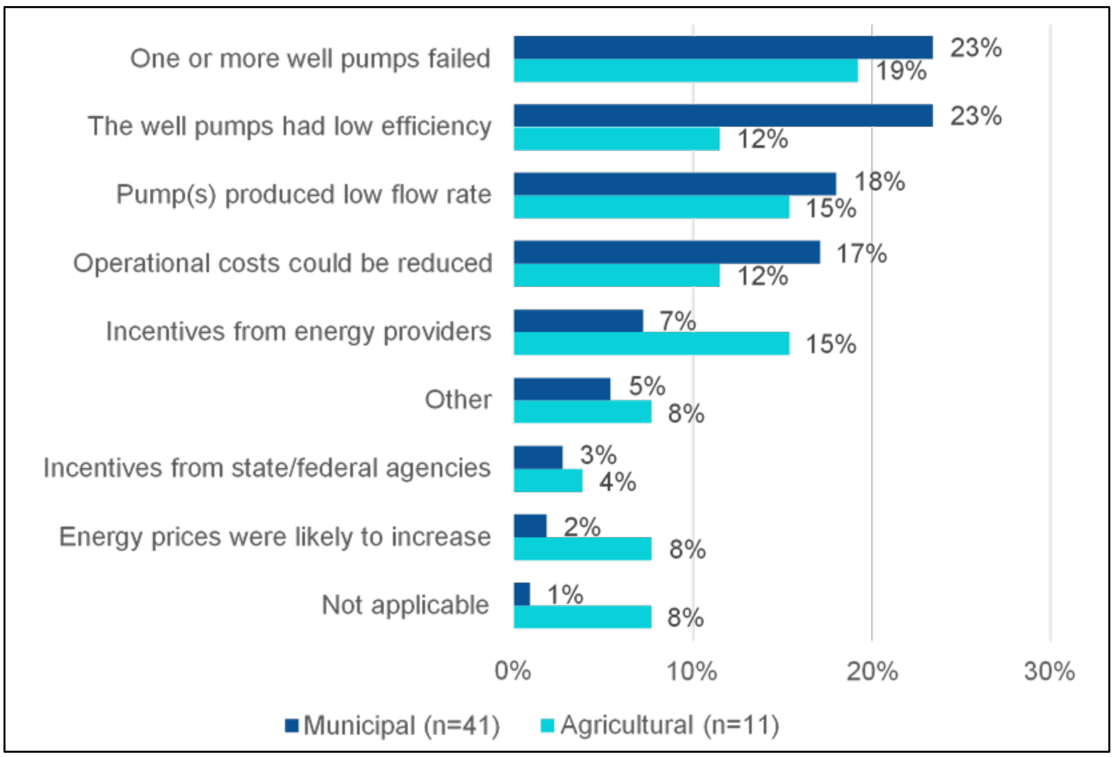
OPPE	Minimum	Average	Maximum
1% – 40%	2	0	0
41% - 50%	2	0	0
51% - 60%	3	4	0
61% - 70%	0	3	3
71% - 80%	2	1	5
81% - 100%	0	1	1

Source: Lawrence Berkeley National Laboratory

Turning to municipal respondents, an open-ended question asked them to describe what process, if any, they used to assess groundwater well pumps. The question prompted respondents to consider what type of assessments are performed, the frequency of assessments, and the share of pumps assessed at this frequency; 25 municipal respondents completed some part of this question. For pump assessment frequency, the largest share (six) of municipal respondents indicated that pumps are assessed or tested or both on a biannual basis. Four respondents reported annual testing. Many of the respondents reported some level of cooperation with their local utility (SCE and PG&E) either through a program or other support, while others worked with unidentified third parties or consultants. One respondent noted that while in the past they tested pumps on an annual basis, they were switching to biannual testing since SCE now charges a fee. One municipal respondent indicated that their pumps were tested every three years. Six municipal respondents noted that they have monthly accounting of groundwater volume pumped, power consumption, and cost for each of their well pumps. Only one of these six respondents reported some standardized frequency of pump assessments, suggesting that perhaps municipal suppliers that have metering and monitoring efforts in place are less likely to conduct pump testing. Two municipal respondents expressed that their organization had not taken up any pump assessments.

The research team wanted to better understand the main drivers of suppliers' decisions to replace, upgrade, or repair groundwater well pumps, or to rehabilitate wells. One question that was identical across both questionnaires gave several response options (in randomized order) and asked respondents to check all drivers that applied, as well as the "other" option. Figure 12 presents these results for municipal and agricultural participants. Because participants could check more than one answer option, 111 municipal and 26 agricultural total answer choices were selected. The four most common motivations for municipal respondents to take these actions — each representing more than 15 percent of responses and summed to be more than 80 percent of responses — were because well pumps failed, had low efficiency, were producing a low flow rate, or because operational costs could be cut. Six municipal respondents gave differing reasons in the "other" field, with two of these mentioning water quality concerns (stricter regulations for maximum contaminant levels).

Figure 12: Drivers for Decisions to Replace/Upgrade/Repair Well Pumps or Rehabilitate Wells



Source: Lawrence Berkeley National Laboratory

Another municipal representative stated taking these actions to increase the production of active wells and rehabilitate or replace aging infrastructure for standby wells, while yet another mentioned actively decreasing pumping capacity for two wells to more evenly balance system pressures and reduce pumping of sand. One city cited "a very proactive preventative and corrective maintenance program." For participating agricultural suppliers, shared drivers cumulatively representing half of responses were because well pumps either failed or produced low flow rates, or because they had received incentives from energy providers. Slightly less common impetuses were that well pumps exhibited low efficiency and that such actions could decrease operational costs. Two respondents chose the "other" option. One mentioned as a motivator the capability to participate in groundwater or conjunctive use water transfers. The other, which had not taken upgrade or rehabilitation actions, asserted that their wells were relatively new and have experienced low use.

Concerning energy costs to pump groundwater, respondents were asked to provide estimates of the share of their total energy costs relative to total operating costs, and the share of groundwater pumping energy costs relative to their total energy costs during the last five years (and at the end of the water year 2016).[35] Table 22 summarizes the results. For municipal suppliers, both shares do not present a significant change when the value at the end of water year 2016 is compared with the one regarding the last five years. As for agriculture suppliers, results show that while the share of energy costs relative to their total operating costs was, at the end of the 2016 water year, lower than the average of that share during the last five years, the share of groundwater energy costs relative to their total energy costs at the end of water year 2016 was greater than the share during the last five years. Caution should be taken with these results since, as informed by some respondents, the groundwater pumping energy reported could include energy used for booster pumps or other devices, or both.

In addition, to better understand the importance of energy consumption data for decision making, both agricultural and municipal suppliers indicated to what extent their groundwater energy consumption data are used in decision making (Figure 13). Half of agricultural suppliers responded that these data were important, while only 11 percent of municipal suppliers indicated that same option, 22 percent of municipal respondents indicated that these data were used, 43 percent indicated they were important, and 24 percent indicated they were a little important. Thirty percent of agricultural respondents indicated that these data were used to a great extent, 20 percent indicated they were somewhat relied upon, and zero percent indicated they were a little important. In general, these responses reveal that municipal suppliers value groundwater energy consumption data in decision making more than agricultural suppliers.

Table 22: Groundwater Energy Costs Relative to Other Costs

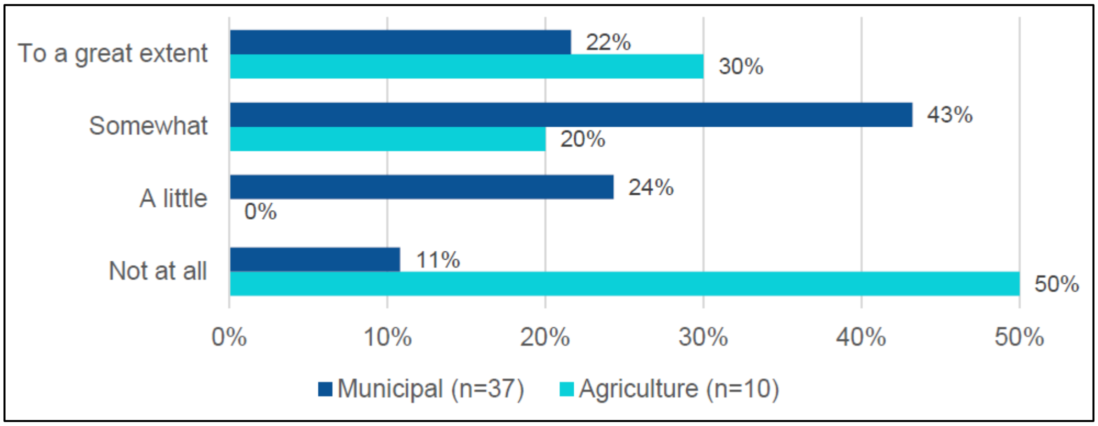
	Muni. (n=28) Minimum	Muni. (n=28) Mean	Muni. (n=28) Maximum	Ag. (n=6) Minimum	Ag. (n=6) Mean	Ag. (n=6) Maximum
Energy costs to operating costs						
Last 5 years	2.0%	14.1%	72.9%	15.7%	58.1%	90.0%
End of 2016 water year	1.5%	13.3%	70.2%	17.4%	48.5%	80.0%

[35] Alternatively, respondents were able to provide their total operating costs, all energy costs, and groundwater pumping energy costs for the same time periods. For those respondents that preferred to use the alternative format to provide this information, the team calculated the shares of their total energy costs relative to total operating costs, and the share of groundwater pumping energy costs relative to their total energy costs from their responses.

	Muni. (n=28) Minimum	Muni. (n=28) Mean	Muni. (n=28) Maximum	Ag. (n=6) Minimum	Ag. (n=6) Mean	Ag. (n=6) Maximum
Groundwater costs to energy costs						
Last 5 years	3.0%	44.7%	100%	3.0%	33.4%	95.0%
End of 2016 water year	0%	46.8%	100%	3.0%	44.8%	95.0%

Source: Lawrence Berkeley National Laboratory

Figure 13: Groundwater Energy Consumption Data Use in Decision Making



Source: Lawrence Berkeley National Laboratory

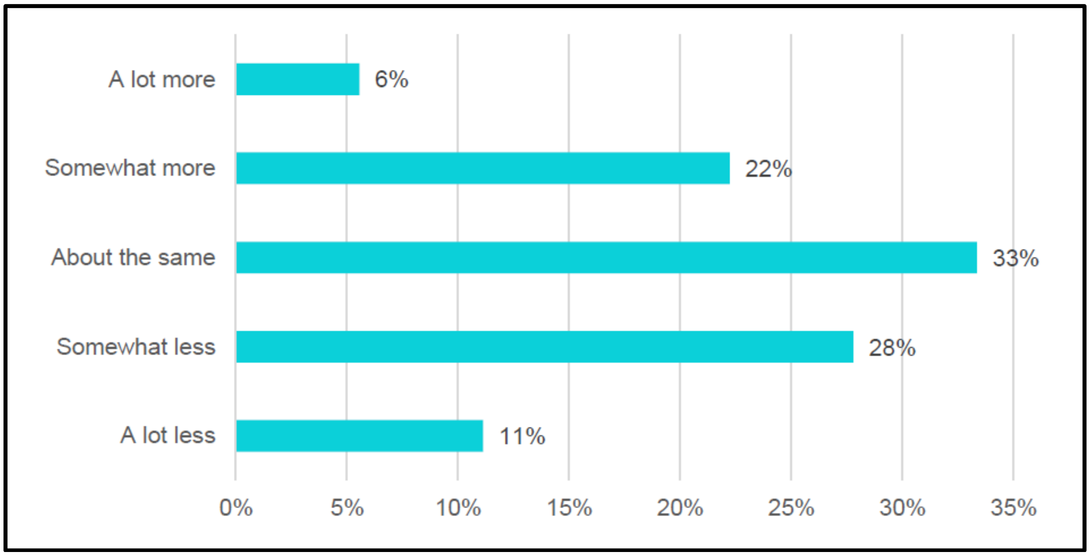
On-Farm Groundwater Pumping in Agricultural Supplier Service Area

This section of the agricultural supplier survey concerns factors that may affect the amount of pumping occurring by growers within the supplier service area. These questions were not asked of municipal suppliers.

First, agricultural respondents were asked how the costs of groundwater pumping on customers' farms compared to the cost of water supplied by the district. Participants also had the option to indicate that it was too difficult to generalize this answer, in which case they were then given an opportunity to provide more detail in an open-ended response. The share of respondents associated with each of the response options (except for those that could not generalize) are shown in Figure 14. Responses were fairly mixed with a slight tilt towards on-farm groundwater being a cheaper option than supplied water. Thirty-nine percent of respondents (excluding those that reported it was too difficult to generalize) indicated that on-farm groundwater cost less than what the district supplied, one third specified it cost about the same, and 28 percent signified that on-farm groundwater cost more than water provided by the district. Finally, 11 percent of respondents indicated on-farm groundwater cost "a lot less" compared with only 6 percent of respondents who indicated it cost "a lot more." Five percent of respondents indicated it was too difficult to generalize this issue of relative costs. Of these, two respondents stated that they were not aware of customer costs (for example, did or do not have power or pumping records available to sufficiently answer the question). Another reported that it depended on the growers' location, indicating that for growers located in a certain region of their service area, on-farm groundwater was significantly less costly, while it was significantly more costly to growers located in another region of their service area.

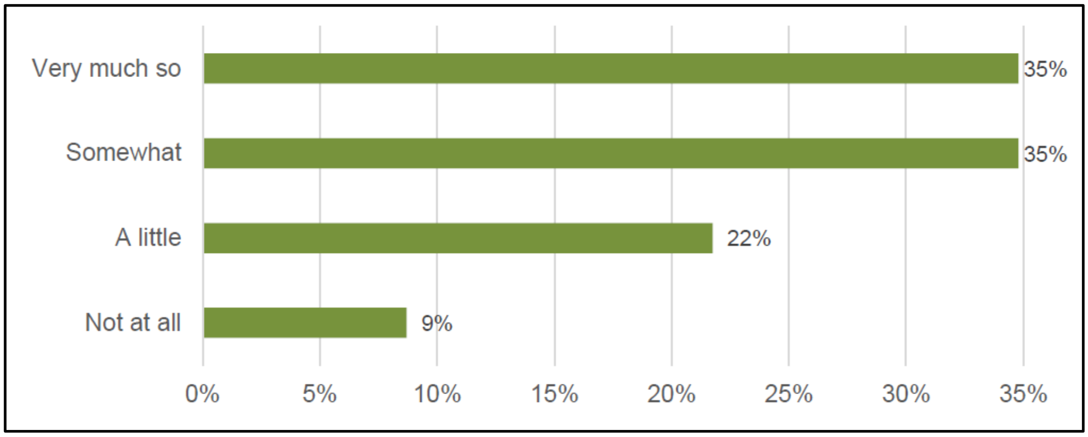
Next, agricultural suppliers were asked whether and to what degree their districts are concerned with on-farm groundwater usage. Of 23 respondents, 70 percent noted that they were at least somewhat or very much concerned with on-farm groundwater use, while less than one-tenth indicated they were not concerned at all (Figure 15). Note that there may be an unknown level of self-selection bias in these answers.

Figure 14: On-Farm Groundwater Costs Relative to Water From District (n=22)



Source: Lawrence Berkeley National Laboratory

Figure 15: Agricultural Suppliers Concern With On-Farm Groundwater (n=23)



Source: Lawrence Berkeley National Laboratory

Reducing the Energy Needed to Pump Groundwater

To better understand what types of actions related to groundwater pumping respondents have taken or would be interested in taking, municipal and agricultural respondents were asked to indicate actions they took in the last 10 years or felt it was likely they would take in the next five years.

Figure 16 shows the 14 actions municipal respondents had taken over the past decade or intend to take in the next five years. Rehabilitating or replacing well(s) and upgrading, retrofitting, or repairing wells were the two most common actions municipal respondents took: 89 percent of respondents in both cases. Also, in both cases, two-thirds of respondents had taken action in the past ten years and also intended to take action in the next five years. More than half of the respondents either took or anticipate taking nine of the remaining 12 actions.

The least popular action identified by municipal suppliers is participating in water trading markets or establishing pricing mechanisms resulting in less reliance on surface water relative to groundwater, with only 14 percent of respondents. Respondents were also given the opportunity to provide an open-ended response for other actions they previously implemented or intended to adopt in the future. Three municipal respondents identified other actions taken. All respondents selected that they had taken the action they described in both the past ten years and intend to in the next five years:

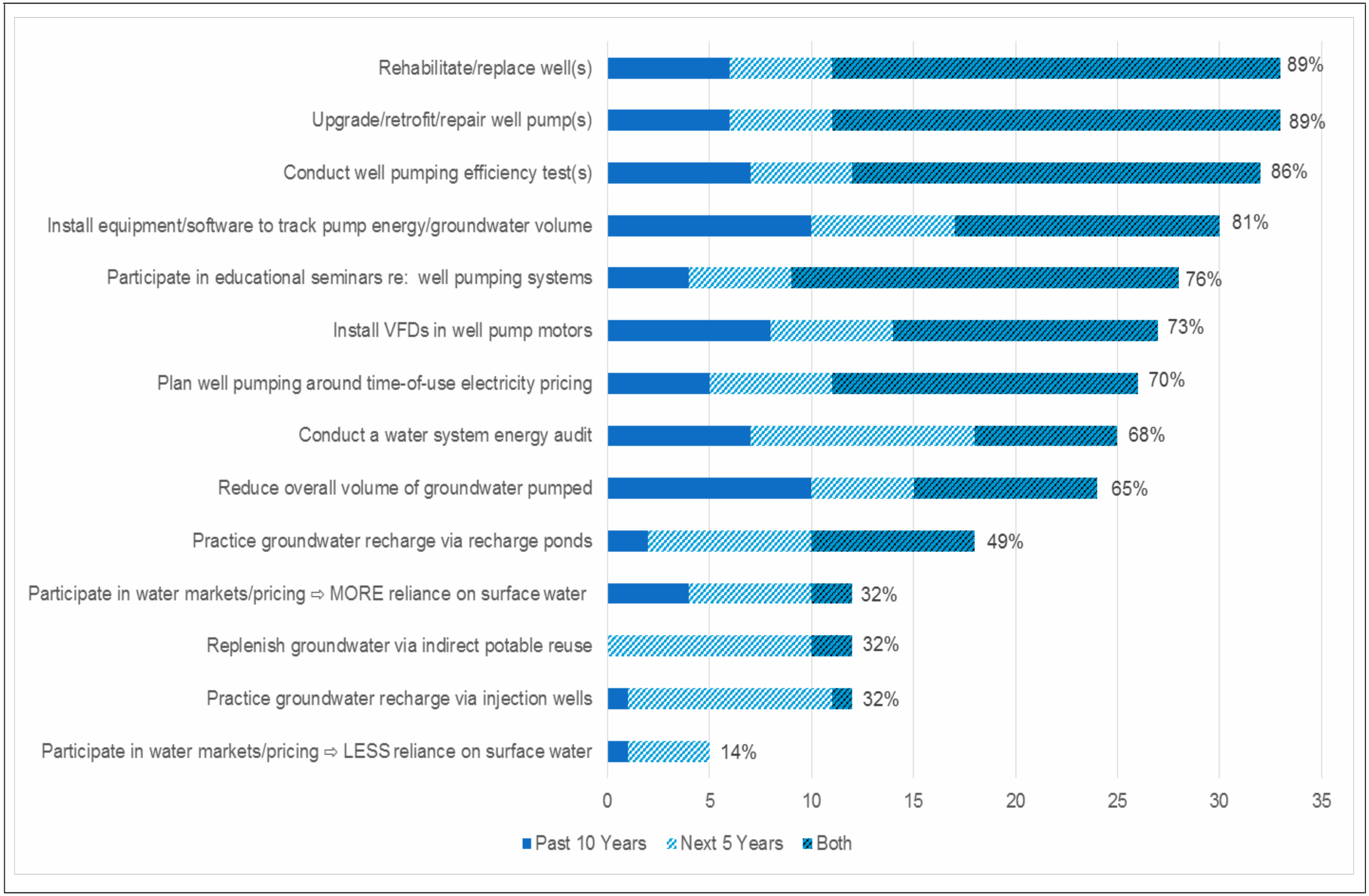
- "Exploring photovoltaic (PV) solar systems."
- "Robust water efficiency programs that reduce demand for all water supplies."
- "Landowner actions (all)."

Figure 17 shows the actions that agricultural suppliers took or intended to take. Eighty-nine percent of the respondents identified each of the following actions: installing equipment (sensors or controls) or software well monitoring tools or decision support systems) that track well pump energy use or groundwater volumes pumped, installing VFDs in well pump motors, and conducting well pumping efficiency test(s). In addition, over half of respondents specified each of the following practices: practicing groundwater recharge via recharge ponds; upgrading, retrofitting, or repairing well pump(s); rehabilitating or replacing well(s); replenishing groundwater via indirect potable reuse; and reducing overall volume of groundwater pumped (for example through conservation programs, increased reliance on surface or imported water). In contrast, no respondents expressed past or future action or interest in planning well pumping around time-of-use electricity pricing.

Two additional actions were noted by agricultural suppliers in an open-ended response option. The first additional action specified was "participating in less reliance on surface water and more on groundwater." The response noted that the district was not able to take that action because the district's groundwater supply typically has "a very high salt content, which is found to be detrimental to some of the crops that are grown in the district. It would therefore be difficult to implement more reliance on groundwater versus surface water." The second additional action described was based on only pumping wells when no other sources of water are available. The response noted that "in very short water years it fills out the amount of water we absolutely need."

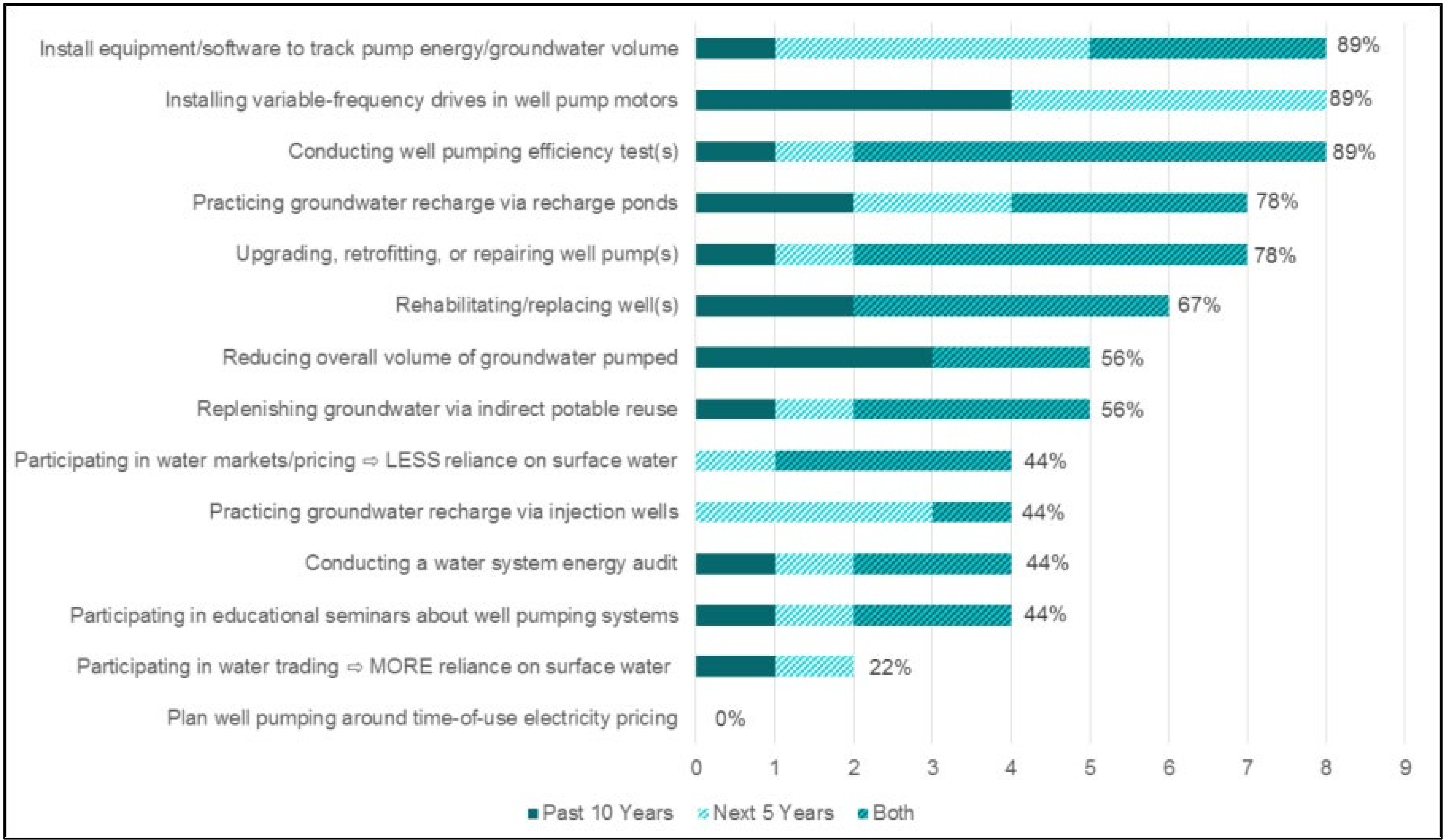
Both municipal and agricultural suppliers were given an open-ended opportunity to explain the difficulties, if any, they faced or anticipate facing in implementing any of the aforementioned actions. Additionally, they were asked to further explain barriers, if any, they faced that precluded or would preclude them from taking any of these actions. Twenty-one municipal suppliers responded to this question.

Figure 16: Municipal Suppliers' Actions Taken in the Past Ten Years or Intended to Be Taken in the Next Five Years (n=37)



Source: Lawrence Berkeley National Laboratory

Figure 17: Agricultural Suppliers' Actions Taken in the Past Ten Years or Intended to Be Taken in the Next Five Years (n=9)



Source: Lawrence Berkeley National Laboratory

Table 23 summarizes their responses and separates them into 11 different categories. The second column refers to the number of responses that addressed each topic; the sum of the numbers in this column exceeds the total number of respondents because some respondents addressed more than one topic in their comments. Only two agricultural respondents provided explanations regarding the difficulties or barriers (or both) for their agencies. One respondent stated that their agency only relies on pumping their wells if no other source is available, further noting that in very short water years this fills out the amount of water absolutely needed by the agency. A second respondent noted that their district's groundwater typically has a very high salt content, which is detrimental to some of their crops, which makes it difficult to decrease reliance on surface water and increase reliance on groundwater.

Table 23: Difficulties/Barriers Municipal Suppliers Face to Implement Efficiency Actions (n=21)

Topic	#	Summarized Comments
No difficulties/barriers	4	N/A
Regulations	1	Both state and environmental regulations
Recent California fires	1	Fire debris from recent CA fires has reduced percolation into the aquifer by 75%
Funding	4	Lack of funds has prevented upgrades to existing standby wells City water departments are often underfunded, civic leaders desire low rates for constituents (especially in lower-income cities), under-staffing, and reactive maintenance "Obtaining governing board buy-in, cost for infrastructure, funding"
Raising rates to account for cost	3	Need to raise rates to meet costs of upgrading and maintaining infrastructure Unable to raise rates in disadvantaged communities Only barrier to more surface water reliance is cost, and to address those costs, have had to raise rates
Storage/time-of-use	3	To better manage pumping times and operations, would need to develop more storage "The City cannot pump water around time-of-use electricity pricing because of demand for water during peak hours." Air Board restricts "running on back-up engines or generators to annual hour limits." "One issue of renewable energy is the change in "on peak" demand times. We do time of day use and don't pump 12pm-6pm in summer. We have adequate storage (1+ Maximum Day). This will shift in the next few years. We will

Topic	#	Summarized Comments
		have to look at our storage and demands to ensure adequate storage."
Recharge	2	Recharging via spreading grounds in urban area is limited by available land Injection well recharge is challenging with wells spread out and its dependence what the basin can handle related to: mounding effects, not spreading contamination, not affecting other users
Resource availability	2	"Cost, time, and expertise of in-house staff" Prioritize certain items, addressing additional items depends on resource availability
Relying more on groundwater	1	Goal is not to reduce groundwater pumping, goal is to increase local supply
Relying more on surface water	1	Would like to rely on more surface water and less groundwater, but face contracting limitations and issues with differing water qualities (potential added groundwater source fluoridates groundwater)
Other	3	Focus is on replacing, not retrofitting or upgrading Cheap electricity, so ROI on investments does not always make sense from a business perspective "Variable frequency drives are not currently installed but a future goal. Our operations staff would rather handle block flow, but we do see the need for VFDs to increase pumping in the future."

Source: Lawrence Berkeley National Laboratory

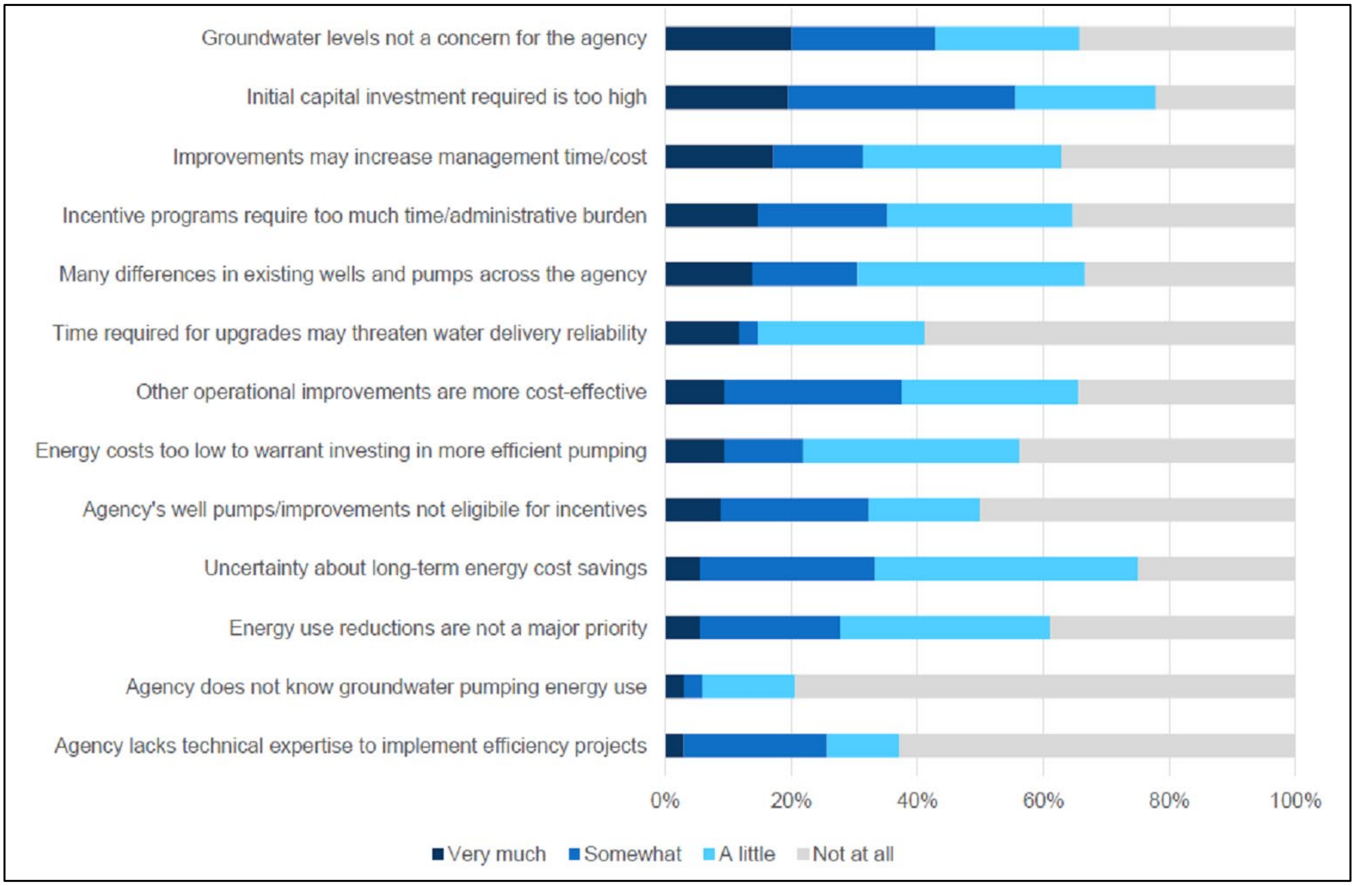
After soliciting respondents' unprompted perceptions of impediments to efficiency actions they face, and to yield more quantifiable results, respondents were asked to rate to what degree, if any, each listed potential barrier hampers their agency in reducing the energy needed to pump groundwater.[36] Figure 18 displays the full range of answers selected by municipal respondents, presented in descending order of the share of respondents who feel each option "very much" hampers their agency in curtailing groundwater pumping energy use. Almost no respondents chose the "other" answer choice; those who did provided very minor clarifications. The answer choices in the figure have been summarized; exact wording is found in Appendix B.1, Question 13.

[36] In the online survey, the order in which response options were displayed was randomized to minimize bias.

With this ordering, the five most common barriers to implementing energy- efficiency-related improvements at municipal suppliers follow.

1. Groundwater levels are not a concern for the agency.
2. The initial capital investment required is too high.
3. Improvements may increase management time or cost.
4. Incentive programs require too much time or administrative burden.
5. There are many differences in existing wells and pumps across the agency.

Figure 18: Barriers to Reducing Municipal Groundwater Pumping Energy (n=36)



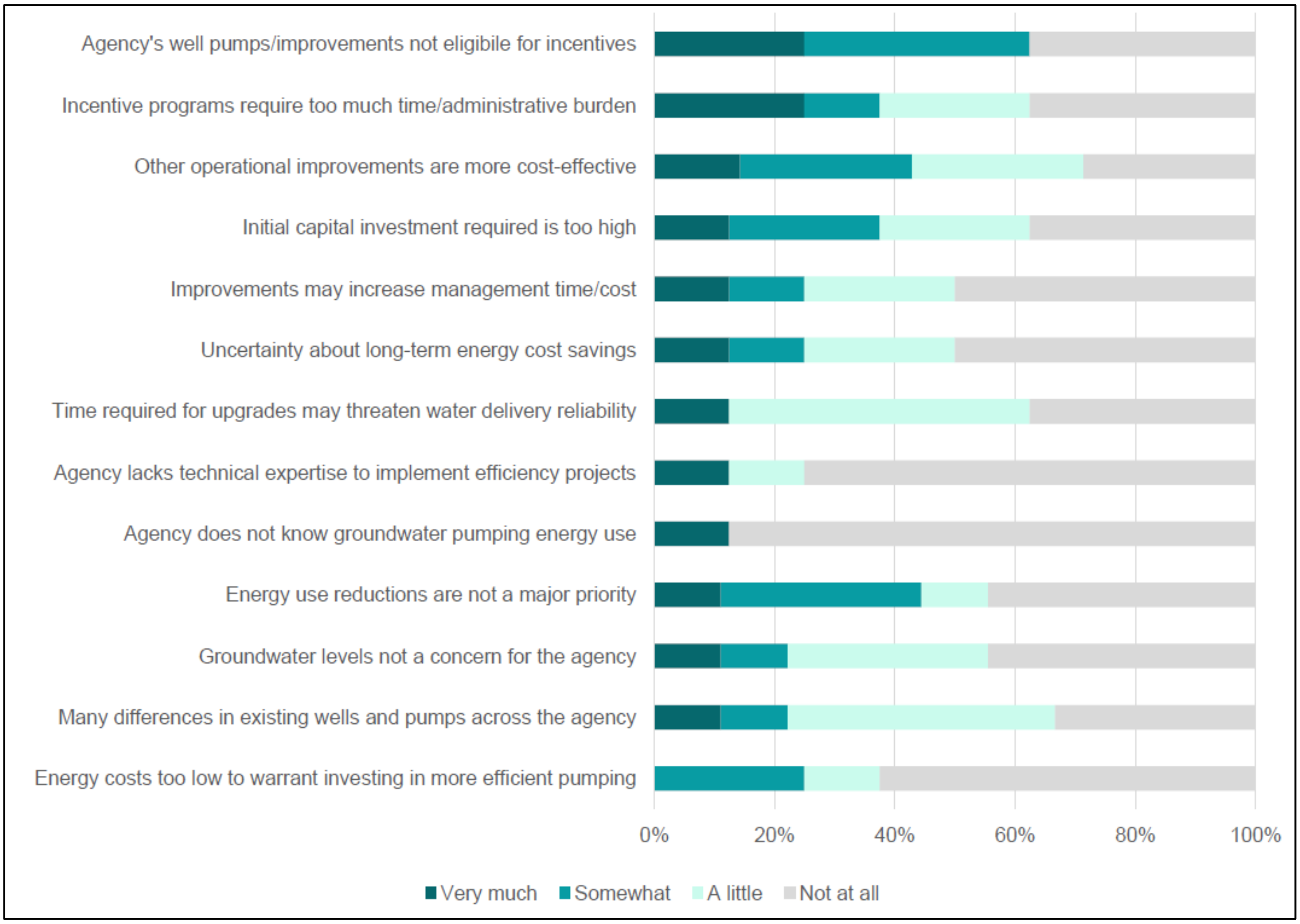
Source: Lawrence Berkeley National Laboratory

An identical question was asked of agricultural suppliers. Figure 19 displays the full range of answers selected by agricultural respondents, presented in descending order of the share of respondents who feel each option "very much" hampers their agency in curtailing groundwater pumping energy use. No respondent chose the "other" answer choice. The answer choices in the figure have been summarized; exact wording is found in Question 16 of Appendix B.2. With this ordering, the five most common barriers to implementing energy-efficiency-related improvements at municipal suppliers follow.

1. Agency's well pumps or improvements are not eligible for incentives.
2. Incentive programs require too much time or administrative burden.
3. Other operational improvements are more cost-effective.

4. The initial capital investment required is too high.
5. Improvements may increase management time or cost.

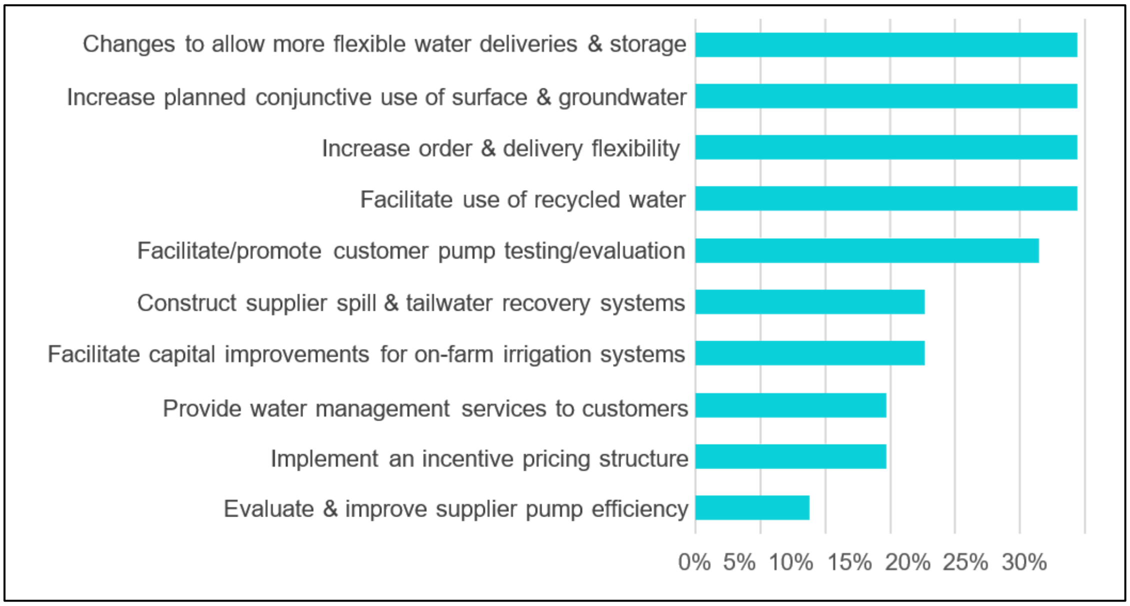
Figure 19: Barriers to Reducing Agricultural Groundwater Pumping Energy (n=9)



Source: Lawrence Berkeley National Laboratory

In addition, agricultural suppliers were asked if they had already implemented each of ten conditional EWMPs, previously discussed in Chapter 3. The research team wanted to learn which of these EWMPs were implemented, as well as the potential for each practice to reduce energy needs, which may vary notably depending on location, institutional context, and other factors. Figure 20 demonstrates the extent to which responding agricultural suppliers had already adopted each listed EWMP at the time they took the survey.

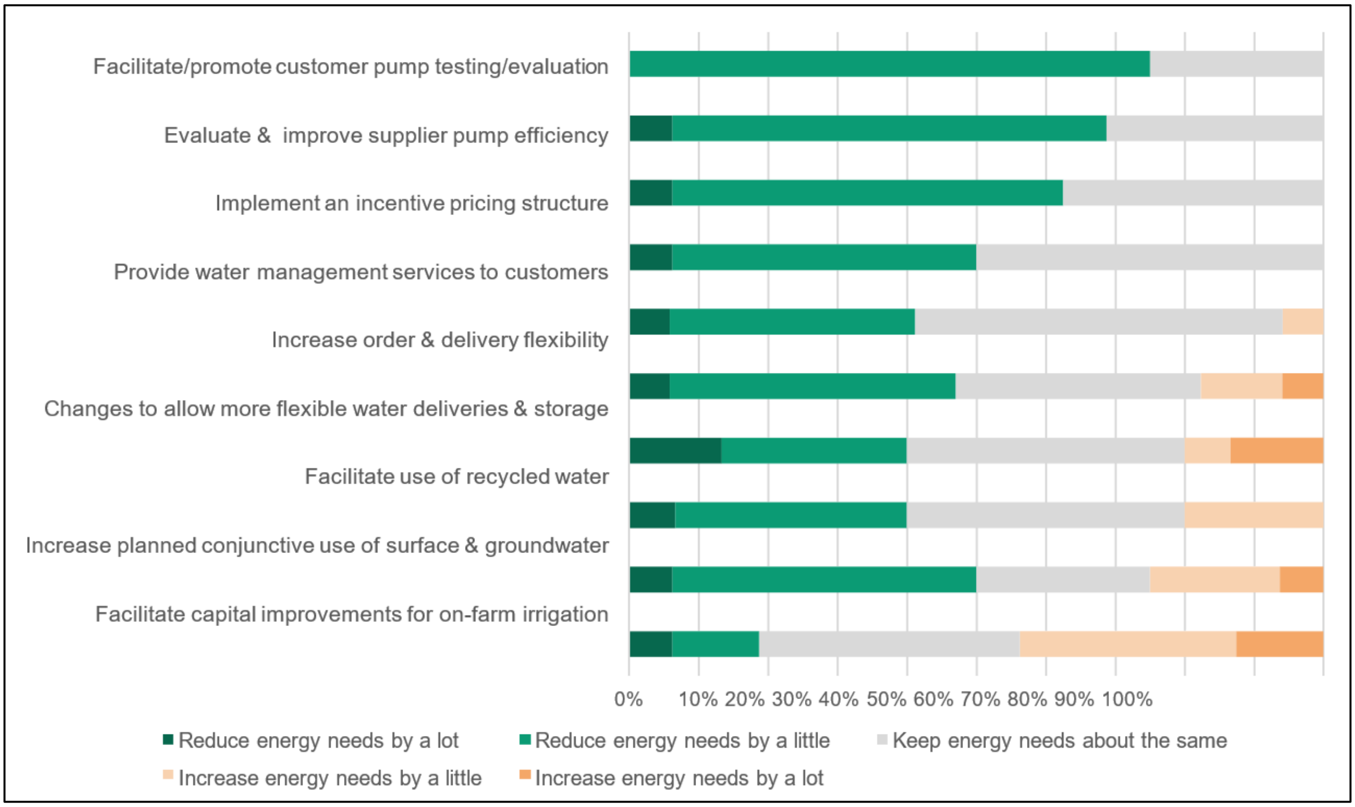
Figure 20: Implementation of Efficient Water Management Practices (EWMPs)



Source: Lawrence Berkeley National Laboratory

Nearly 30 percent of respondents had implemented four separate practices: identifying the potential for institutional changes to allow more flexible water deliveries and storage; increase planned conjunctive use of surface water and groundwater within the supplier service area; increase flexibility in water ordering by, and delivery to, water customers within operational limits; and facilitate the use of available recycled water that otherwise would not be used beneficially, meets health and safety criteria, and does not harm crops or soils. On the other hand, fewer than 15 percent of respondents had adopted the following practices: evaluate and improve the efficiencies of the supplier's pumps; provide for the availability of water management services to water users; and implement an incentive pricing structure that would promote either more efficient water use at the farm level, conjunctive use of groundwater, increased groundwater recharge, reduced problem drainage, improved management of environmental resources, and effective management of water sources throughout the year by adjusting seasonal pricing structures based on current conditions. Figure 20 should be interpreted in conjunction with Figure 21, which reveals for each measure whether responding agricultural suppliers anticipate that implementation will affect energy needs.

Figure 21: Potential of EWMP's to Affect Energy Needs (n = 18)



Source: Lawrence Berkeley National Laboratory

Another linked question involved asking agricultural water suppliers to identify the biggest barriers, disincentives, or difficulties they face with fully implementing the EWMPs with the greatest potential for reducing the energy required to pump groundwater in their district. Table 24 summarizes these results.

Table 24: Difficulties, Disincentives, or Barriers to Implement Efficient Water Management Practices

Topic	No. of Related Responses
Economic	5
Regulatory/Legal	5
Reliability/Environmental	2
Technical	1
Institutional	1
Political	1

Source: Lawrence Berkeley National Laboratory

Of the 18 respondents, half did not expect any barriers, disincentives, or difficulties in implementing those practices, while the other half did anticipate having problems. Of the responses that did anticipate difficulties, five responses touched on regulatory or legal issues;

five responses noted economic issues, some specifically highlighting higher costs for surface water hindering their ability to increase reliance on surface water; one response mentioned technical, political, and institutional issues; and two responses touched on reliability and environmental issues associated with surface water use. In addition, some respondents provided the following responses:

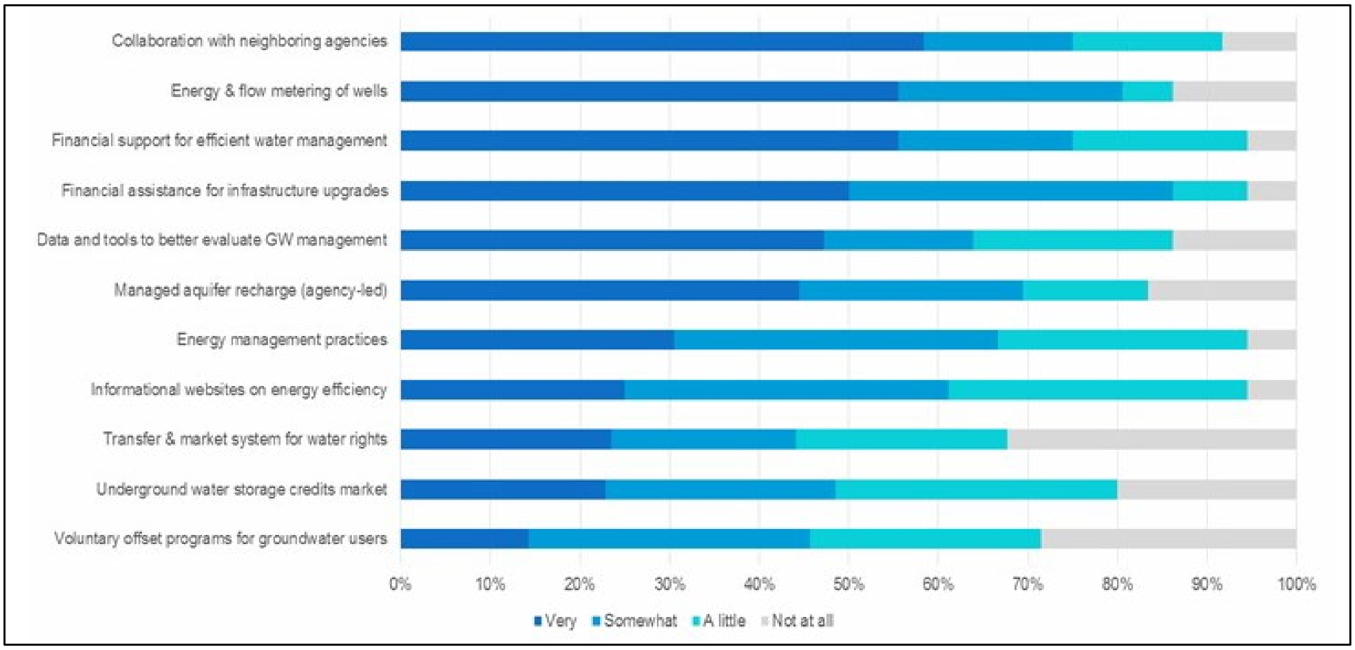
- Relying on surface water costs more than pumping groundwater. Environmental and regulatory restrictions limit available surface water at a reasonable rate. As a result, the district must acquire water at a higher rate through participation in transfer programs, which create an even greater disincentive to rely on surface water during drought years.
- Reduced reliability and increased cost associated with surface water make it difficult to increase use of surface water.
- Challenging to manage cost in California's changing regulatory framework. Oftentimes, irrigation districts have permitting processes or regulatory frameworks that do "not allow for maximum flexibility." Additionally, districts "are typically small operations trying to manage and operate large systems."
- California water law.
- "Incentive pricing structures - I don't think we have the legal authority to place pricing incentives on private well owners in our role as a water storage district. Pump taxes or meter taxes, however, could be used by our local groundwater sustainability agency if that is the desired course of action."
- "We have a healthy surface water supply and our landowners rarely augment with groundwater pumping. Early-in-the-season pumping to initially flood rice fields is the main reason. We do have some orchard conversions which are utilizing a dual system. Our district is completely gravity and there are lift pumps used and maintained by landowners, not by the district."

In addition, agricultural suppliers were asked if they had already implemented each of ten conditional EWMPs, previously discussed in Chapter 3. The research team wanted to learn which of these EWMPs have been implemented, as well as the potential for each practice to reduce energy needs, which may vary notably depending upon location, institutional context, and other factors. Figure 22 demonstrates the extent to which responding agricultural suppliers had already adopted each listed EWMP at the time they took the survey. Nearly 30 percent of respondents had implemented four separate practices: identifying the potential for institutional changes to allow more flexible water deliveries and storage; increase planned conjunctive use of surface water and groundwater within the supplier service area; increase flexibility in water ordering by, and delivery to, water customers within operational limits; and facilitate the use of available recycled water that otherwise would not be used beneficially, meets health and safety criteria, and does not harm crops or soils. On the other hand, fewer than 15 percent of respondents had adopted the following practices: evaluate and improve the efficiencies of the supplier's pumps; provide for the availability of water management services to water users; and implement an incentive pricing structure that would promote either more efficient water use at the farm level, conjunctive use of groundwater, increased groundwater recharge, reduced problem drainage, improved management of environmental resources, and effective management of water sources throughout the year by adjusting seasonal pricing structures based on current conditions. Figure 22 should be interpreted in conjunction with Figure 23, which reveals for each measure whether responding agricultural suppliers anticipate that implementation will affect energy needs.

Municipal and agricultural respondents were also asked to review a range of incentives and other offerings and indicate how interested they would be in each one by indicating a response of "Very," "Somewhat," "A little," or "Not at all" interested. The list of potential answer choices were identical between the two surveys, with the exception of two additional options provided only to agricultural respondents, as they were less relevant for municipal suppliers (holding educational programs on energy-efficient management of groundwater and managed aquifer recharge [landowner-led]). The full list of offerings for municipal respondents can be found in Question 14 of Appendix B.1**.** For agricultural respondents, see Question 21 of Appendix B.2. Abbreviated versions are provided in Figure 22 and Figure 23.

Figure 22 shows results from municipal respondents. Enhanced collaboration with neighboring districts and agencies received the highest number of responses for "Very" interested, with 58 percent of respondents so indicating. Closely following was energy and flow metering of wells and financial support for implementation of water management practices (through subsidy programs or funding matches), with 56 percent of respondents reporting the highest level of interest. Exactly half of all municipal respondents also indicated the highest level of interest in financial assistance for infrastructure upgrades to enhance pumping efficiency. Respondents were less interested in transfer and market systems for water rights, a long-term underground water storage credits market, and voluntary offset programs where groundwater users willing to reduce their usage are able to trade a credit for the unused water with users willing to purchase this credit. More than half of respondents indicated no or "a little" interest in these opportunities, although still slightly less than half of respondents indicated higher levels of interest.

Figure 22: Municipal Supplier Interest for Incentives and Other Offerings (n=36)

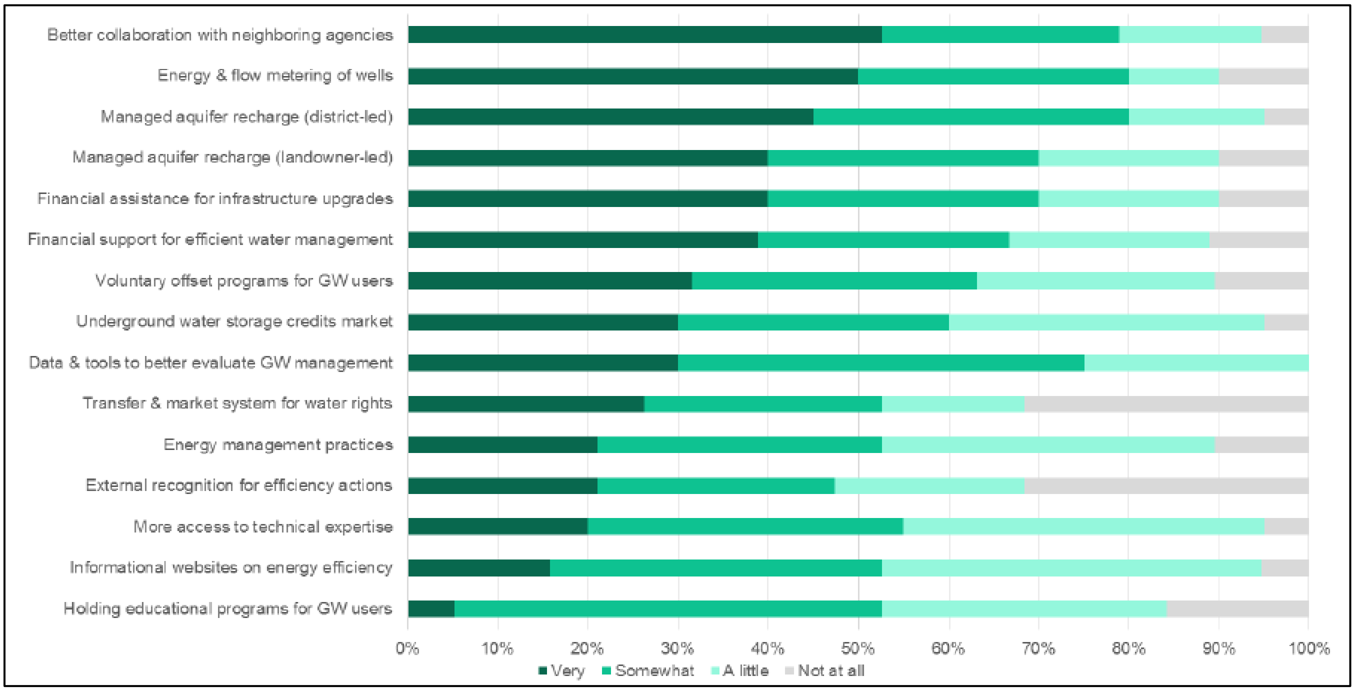


Source: Lawrence Berkeley National Laboratory

As shown in Figure 23, agricultural respondents, like municipal respondents, had the highest share of respondents indicate that they were "very" interested in "enhanced collaboration with neighboring water agencies/districts" (53 percent), followed by "energy and flow metering of wells" (50 percent). Also nearing top of agricultural respondents' interest was district-managed aquifer recharge, with 47 percent of respondents reporting they were "very" interested. Agricultural respondents were then interested in landowner-led managed aquifer recharge and then "financial assistance for infrastructure upgrades" (40 percent each). These districts were least interested in "holding educational programs on energy-efficient management of groundwater" (an option only provided for them), followed by "informational websites on the energy- efficient management of groundwater." Agricultural respondents were also less interested in technical expertise than their municipal counterparts, with only 21 percent expressing a high level of interest, compared to 31 percent of municipal respondents.

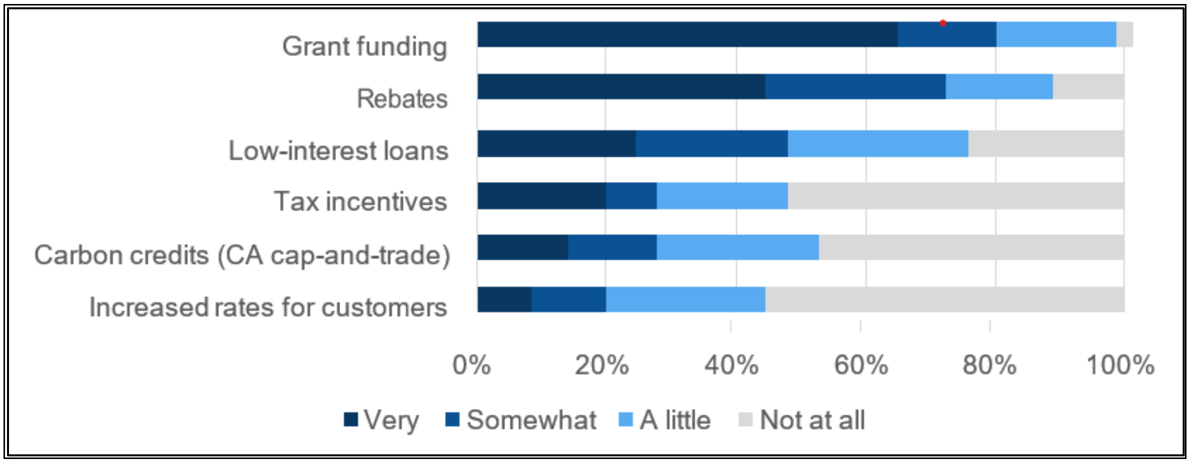
While the previous question assessed interest levels for various potential interventions or policy levers, the research team also wanted to examine the desirability of various financial mechanisms to curtail groundwater pumping energy. Figure 24 displays how desirable municipal respondents report each given financial mechanism to be, while Figure 25 displays analogous results for agricultural respondents.

Figure 23: Agricultural Supplier Interest for Incentives and Other Offerings (n=20)



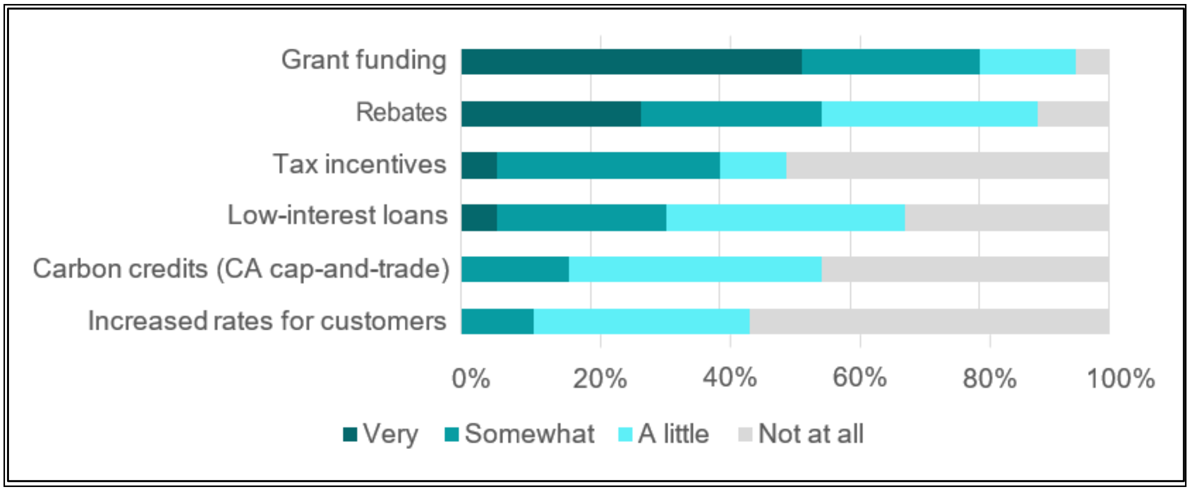
Source: Lawrence Berkeley National Laboratory

Figure 24: Desirability of Financial Mechanisms to Reduce Groundwater Pumping Energy, Municipal Respondents (n=37)



Source: Lawrence Berkeley National Laboratory

Figure 25: Desirability of Financial Mechanisms to Reduce Groundwater Pumping Energy, Agricultural Respondents (n=19)



Source: Lawrence Berkeley National Laboratory

Additional Comments

The conclusion of the online survey gave respondents from both agricultural and municipal suppliers the opportunity to provide additional information relevant to their groundwater pumping energy use in an open-ended format. Six respondents from agricultural districts and six respondents from municipal districts opted to elaborate further.

One agricultural respondent reported that in their part of the state, districts typically do not pump a lot of groundwater. However, if surface water is reduced (particularly in drought years), then pumping increases. They reported that their overall groundwater levels were fairly resilient, however, as their wells generally have recovered well after the irrigation season. Another agricultural respondent reported that their top priorities were water savings, delivery flexibility, and environmental use coordination. While energy is secondary to meeting these needs, they are inherently related and efficiency can often benefit them because of these priorities. Another respondent noted that given the hydrological conditions in their district, in-lieu recharge was critical to groundwater sustainability. One noted that it is very difficult to improve efficiency when reliant on gravity-fed sources. Another agricultural respondent recommended vertical turbine pump repairs, replacement of old electrical power sources to VFDs, and well rehabilitation as among the most effective efficiency improvements.

Two municipal respondents expressed interest in improved access to funding for solar PV systems. One explained that if grants were available and the payback time was subsequently reduced, agencies would "jump at the chance." According to these two respondents, increased solar would allow agencies to avoid high-peak power charges in the evening, but the long financial break-even point is currently a deterrent. Another municipal respondent reported no interest in many groundwater energy efficiency programs or opportunities because they already take many efficiency actions and are decreasing their reliance on groundwater, shifting to surface water. As a small district turning away from groundwater, these programs are simply not worth the time and energy to manage.

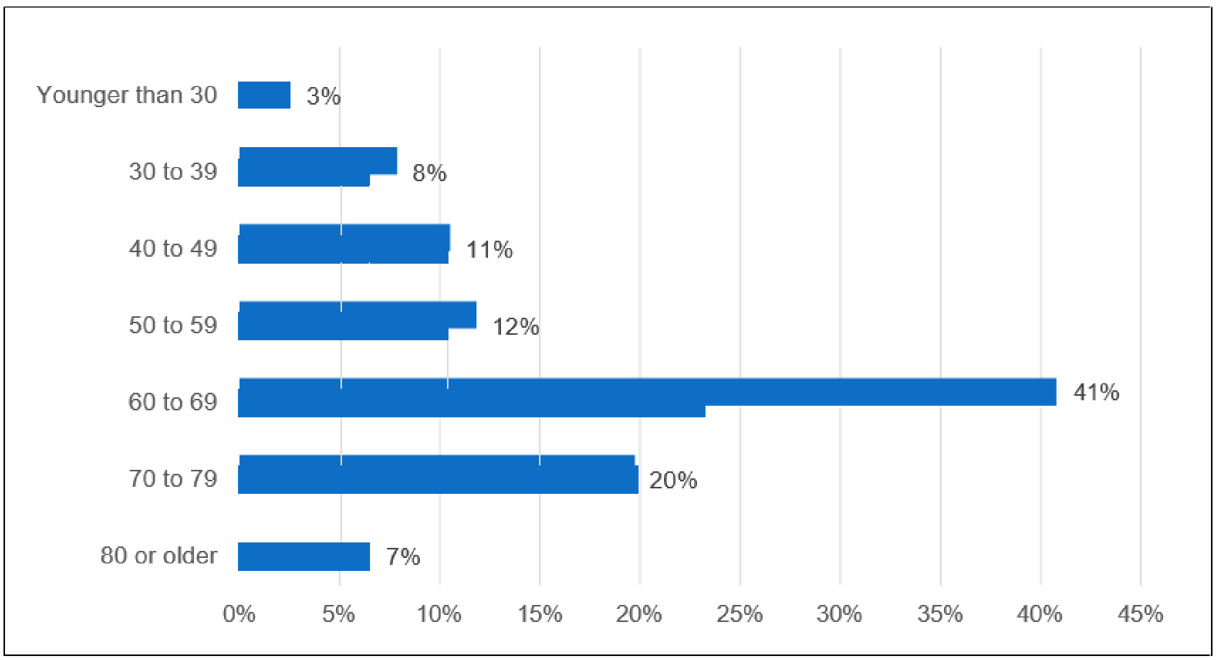
Farmers and Ranchers

The online survey for farmers and ranchers allowed respondents to skip any question they did not want to answer, except the first question about the county where their farm or ranch was located. The flexibility provided led to some respondents to drop out of the questionnaire without answering all the questions. The first section of the questionnaire, up to and inclusive of Question 8, encompassed demographic and farm characteristics. This section of the report displays responses only for those respondents who answered questions beyond Question 8, which pertain to groundwater and related energy. Every reported result also indicates the number of respondents for that question (for example n=77).

Respondent Demographics

The demographic characteristics of survey respondents may influence their responses to the questionnaire, so the research team designed the questionnaire to inquire about basic demographics, including respondent age, educational background, and whether farming or ranching is their primary occupation. Nearly two-thirds of all growers who took the survey were 60 years of age or older (Figure 26).

Figure 26: Respondents by Age Group (n=7)



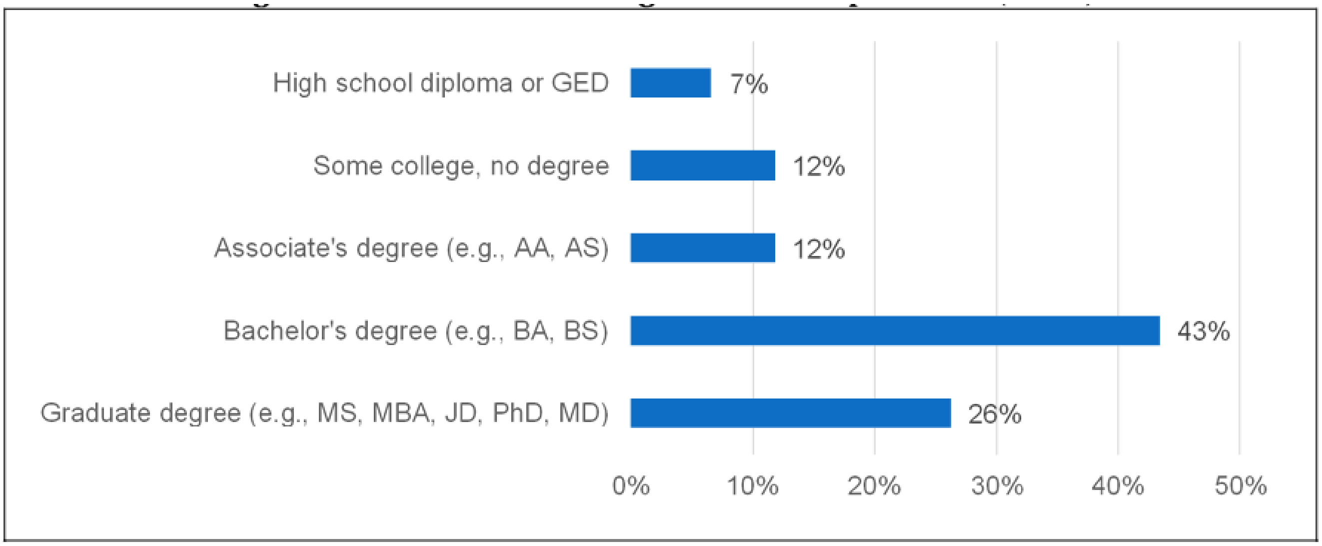
Source: Lawrence Berkeley National Laboratory

This is reasonably consistent with the average age of 60.1 years reported for principal farm operators in California in the 2012 Census of Agriculture (USDA NASS, 2014a). The highest level of education the respondents achieved, only seven percent reported not having pursued schooling past high school (Figure 27). More than two-thirds of respondents reported having a bachelor's or graduate degree, with 43 percent reporting a bachelor's degree, and approximately one-quarter reporting a graduate degree. Data on educational attainment exist neither in NASS's Census of Agriculture nor the *Farm and Range Irrigation Survey* nor in

CDFA's *California Agricultural Statistics Review* (2018). In contrast to the general population in California, with 17.5 percent of the population without a high school diploma and 32.6 percent having attained a bachelor's degree or higher, survey respondents were better educated (U.S. Census Bureau, 2017). In addition, farming or ranching is the primary occupation of more than three-quarters of respondents (Figure 28), substantially higher than the 55 percent of California principal operators who identified their primary occupation as farming in the *2012 Census of Agriculture* (USDA NASS, 2014a).

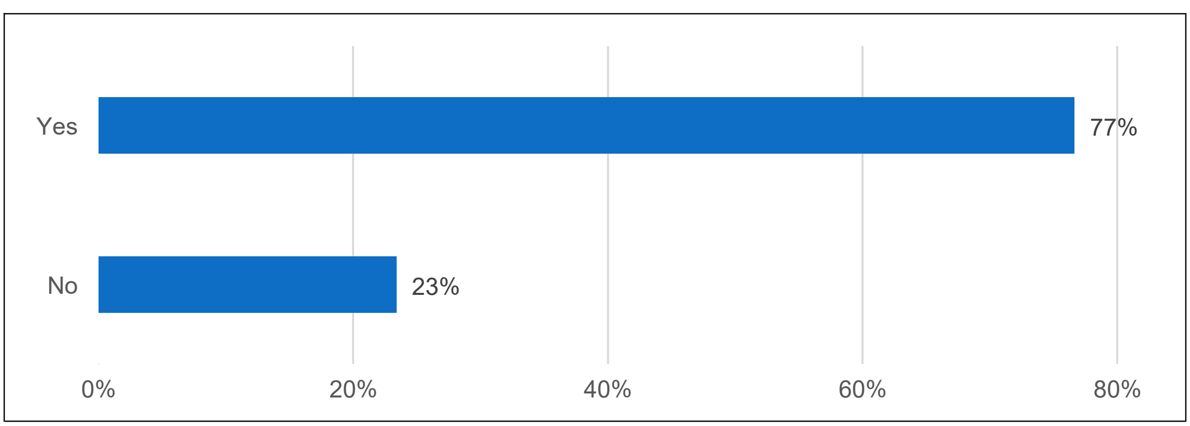
This higher share may be suggestive of self-selection bias; that is, those respondents most concerned with groundwater or groundwater energy use or both — perhaps because farming or ranching is their primary occupation — were more likely to complete the survey than the larger pool of potential respondents the research team targeted.

Figure 27: Educational Background of Respondents (n=76)



Source: Lawrence Berkeley National Laboratory

Figure 28: Farming or Ranching as Primary Occupations (n=77)

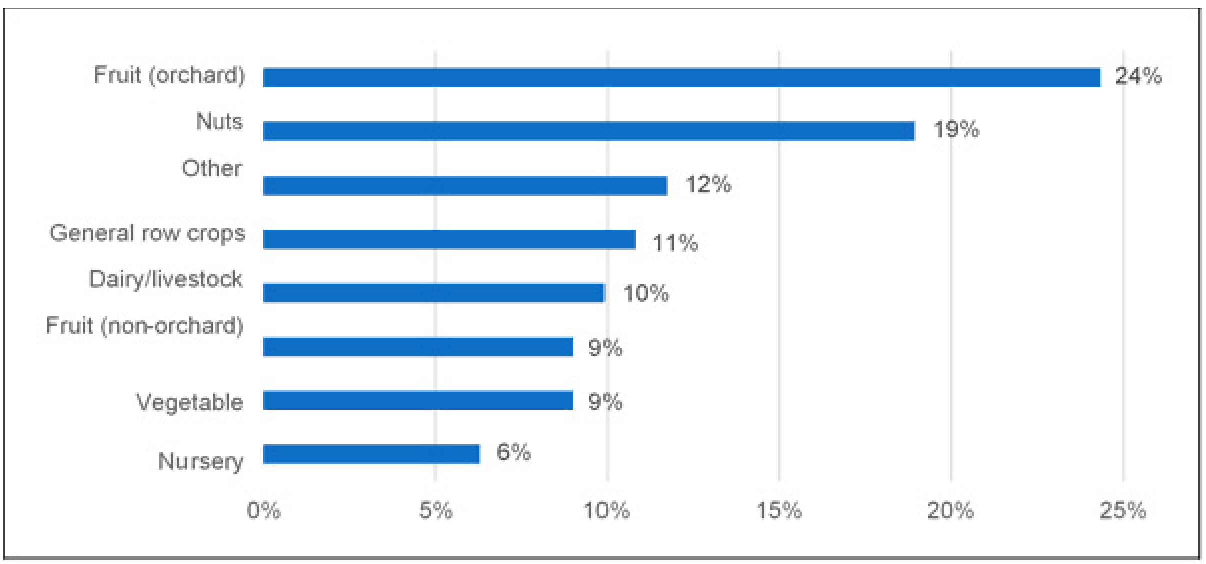


Source: Lawrence Berkeley National Laboratory

Farming Characteristics

Farm or ranch characteristics should be taken into account when interpreting responses to questions regarding groundwater and groundwater energy use. Survey respondents were asked to provide the county where their farm or ranch is located.[37] Figure 28 highlights in blue the 27 of 58 counties in California represented by the 77 farmers and ranchers who responded to the question. San Diego County (19 responses), Fresno County (11 responses), Tulare County (five responses), and Yolo County (five responses) represent the counties with the highest number of responses, alone accounting for more than half of total responses. Respondents also were asked to broadly categorize their farm or ranch. Orchard fruit was the predominant farm type among respondents (Figure 29), with nuts and "other" following in terms of prevalence. Each of the answer options from the questionnaire were chosen by some respondents, while 22 of 76 unique respondents, or 29 percent, chose more than one answer option; 111 categorizations were indicated in total. The DWR irrigation methods survey data cannot be directly compared given that these two sources used different categorizations, but almonds and pistachios, as well as "other deciduous" (which includes orchard fruits), are among the top five crops in descending order of reported acreage from DWR.

Figure 29: Respondents' Characterization of Their Farm or Ranch (n=76)

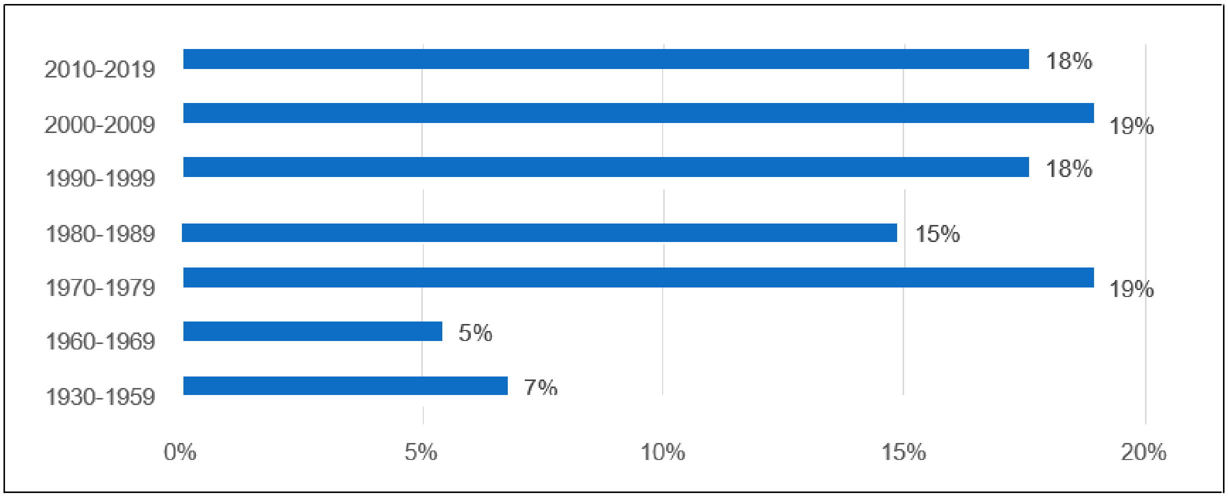


Source: Lawrence Berkeley National Laboratory

Growers also were asked to indicate the year when they began operating their farm or ranch. Figure 30 displays these results by decade with the exception of 1930–1959, which is grouped in reporting due to the relatively low response rate. More than half (55 percent) of respondents reported beginning their current operation in 1990 or later, although results were fairly even split across the last five decades since 1970, indicating that the questionnaire captures the experiences of growers with varied tenures on their farms and ranches.

[37] If the farm or ranch was located in multiple counties, the respondent was asked to indicate the county that encompasses the majority of the farm's land.

Figure 30: Year Farm or Ranch Began Operation (n=74)

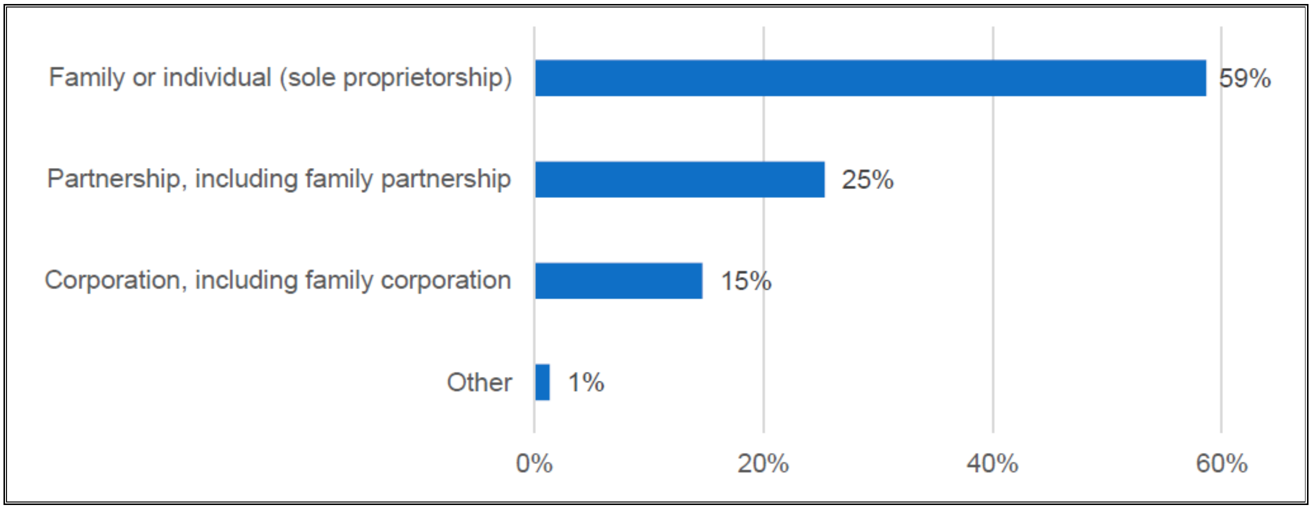


Source: Lawrence Berkeley National Laboratory

In addition, survey respondents were asked to classify their farms or ranches by ownership type. Figure 31 shows that more than half of the respondents (59 percent) classified their ownership as family or individual, or sole proprietorship. The second most common answer, one quarter of respondents, classified ownership as a partnership, including partnership with family. Only 15 percent of respondents classified their ownership as a corporation (including family corporation). While one respondent classified ownership as "other," no respondents indicated that their farm or ranch was a cooperative. In the open-ended portion of this survey, one respondent indicating partnership ownership mentioned that because they lease some of their land, as a tenant, their landlord has little incentive to improve the efficiency of their farm, as this improvement benefits the tenant and not the landlord.

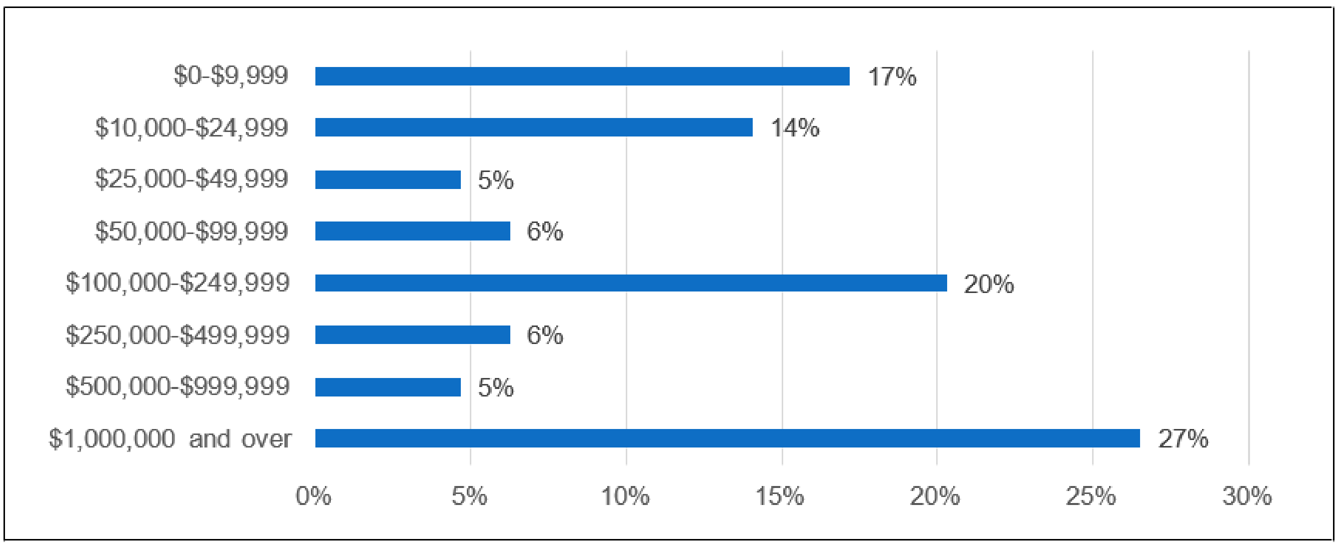
Other important farm and ranch characteristic is the value of their products. While most farms nationwide are smaller operations in terms of sales, it is not surprising that larger farms tend to be larger water users, representing 60 percent of applied irrigation water in 2013 (Schaible, 2017). Thus, respondents were asked to provide the gross value of all agricultural products sold from their operation in 2017 (Figure 32). For 17 percent of the survey respondents the gross value of agricultural products sold in 2017 was less than $10,000, while 37.5 percent of respondents reported a gross value of $250,000 or greater. Compared to FRIS (which is statistically representative of California growers), survey responses disproportionately represented more profitable operations. While 38 percent of FRIS respondents report $0 to $9,999 in gross value of products sold, only 17 percent of the respondents reported these sales. Similarly, "large" farming operations, defined by gross value of $1,000,000 or more, represented just over one quarter of survey responses, compared with only 11 percent for FRIS (USDA NASS, 2012).

Figure 31: Farm or Ranch Ownership Type (n=75)



Source: Lawrence Berkeley National Laboratory

Figure 32: Gross Value of All Agricultural Products from Operation in 2017 (n=64)



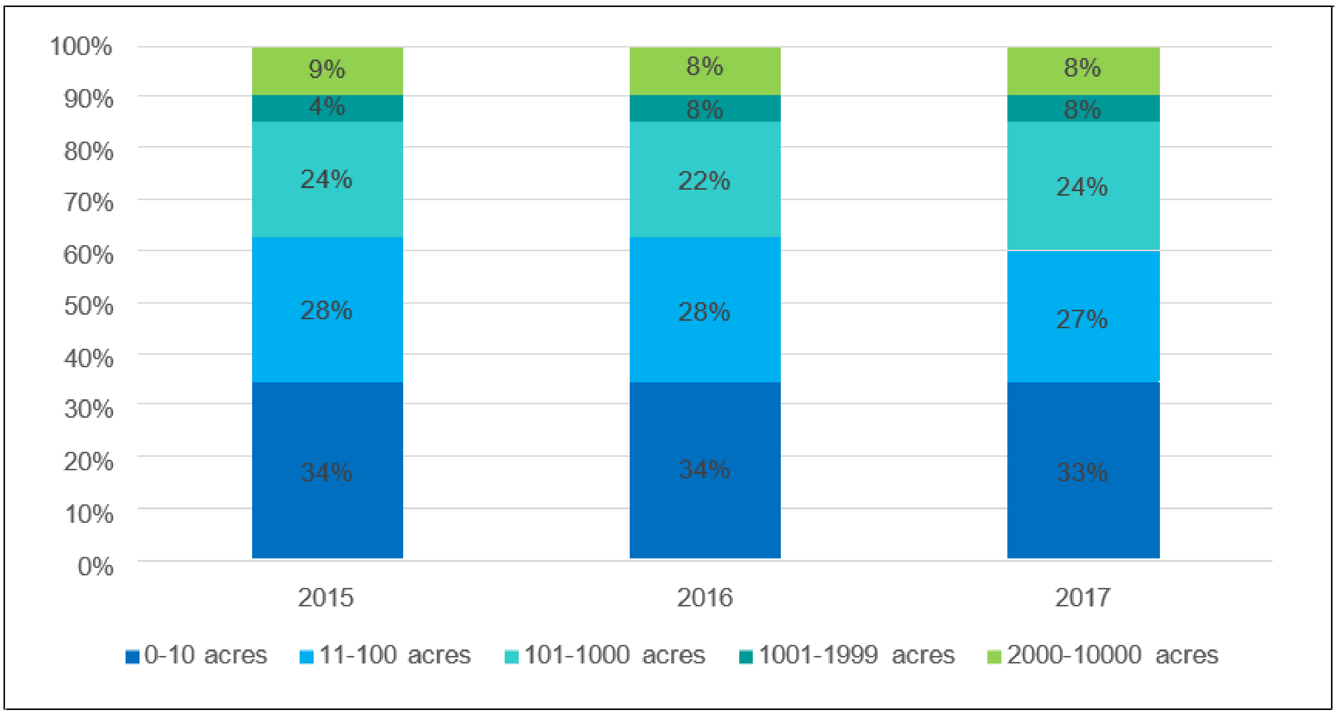
Source: Lawrence Berkeley National Laboratory

This discrepancy may be because larger operations may have had more resources available to respond to this survey, as well as smaller growers having historically been more difficult to reach (as corroborated by conversations with industry experts). This survey, however, represents larger operations on average, which should be kept in mind when reviewing results. This finding is interesting when compared to the findings about irrigated acreage (Figure 33 and Figure 34), which indicate that the sample contained a fairly substantial number of respondents with lower acreage. Other factors — such as crops with higher profit margins — may have resulted in high profits compared to relatively smaller irrigated acreage, although further investigation is outside the scope of this report.

Another relevant characteristic is the overall acreage of the farm. While respondents were asked to provide estimates of their overall as well as irrigated acreage between 2015 and

2017, irrigated acreage is more relevant for groundwater pumping energy consumption. Note that irrigation pumping costs per acre for large-scale farms in the West are usually about half those of smaller farms, because these costs can be spread over significantly larger acreage (Schaible, 2017). Figure 33 indicates the irrigated acreage (in ranges) reported by survey respondents for the calendar years of 2015, 2016, and 2017. The results remain fairly consistent across these three years. The USDA considers "very small" farms to be those containing fewer than 50 irrigated acres (Schaible, 2017), which represented approximately one third of overall survey respondents. Large-scale farms of more than 1,000 acres (colored in two different shades of green) represented approximately 16 percent of respondents. In comparison, the mean irrigated acreage of irrigated farms in California in 2013 was 170 acres (Table 4), with 25th, 50th (median), and 75th percentiles at 3, 12, and 60 acres, respectively (USDA NASS, 2012).

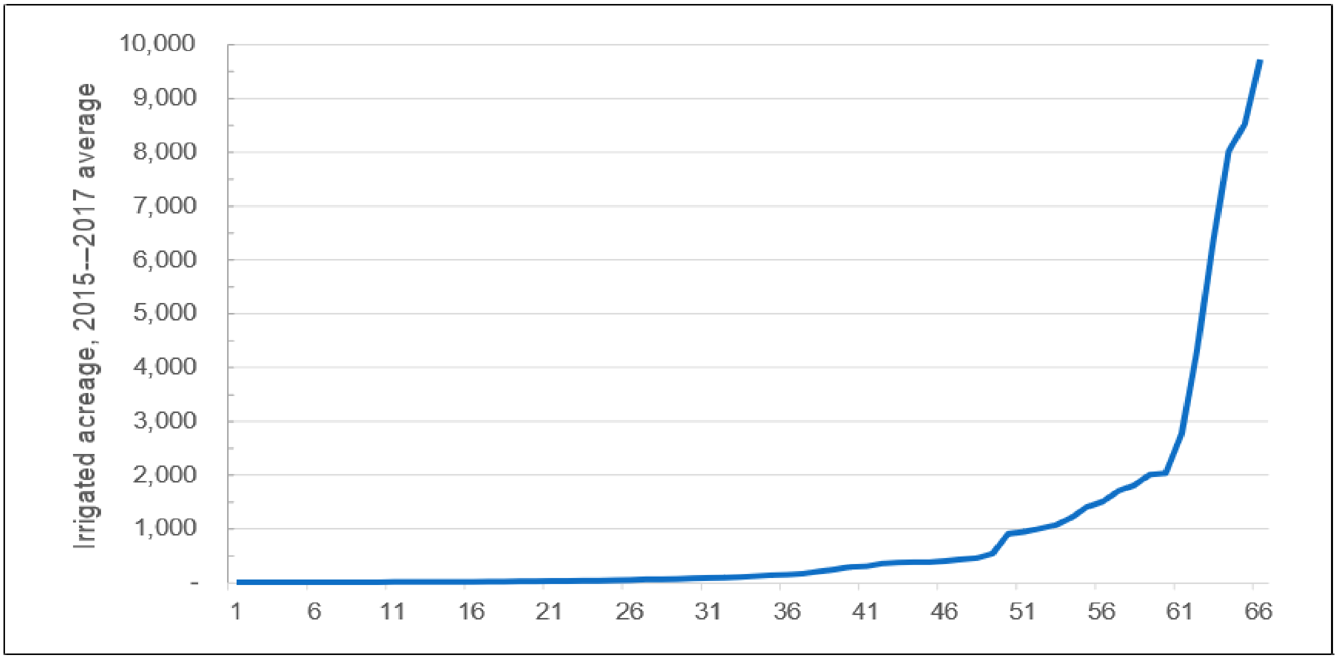
Figure 33: Irrigated Acreage 2015 to 2017 (n=66)



Source: Lawrence Berkeley National Laboratory

Figure 34 shows the distribution of the average irrigated acreage over this time period, with the number of respondents on the -axis.

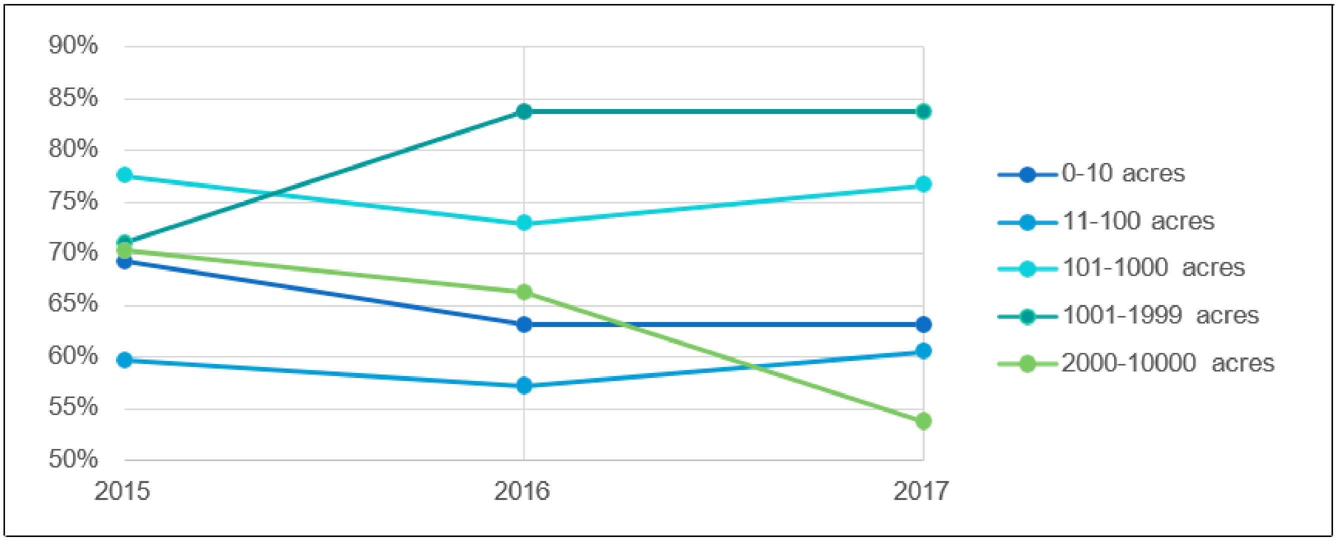
Figure 34: Distribution of Average Irrigated Acreage from 2015 to 2017 (n=66)



Source: Lawrence Berkeley National Laboratory

In addition, Figure 35 shows the percentage of irrigated acreage out of total acreage for survey respondents. This share varied between approximately 55 and 85 percent depending on farm size, although the sample size by farm size group may be too small to be meaningful. While irrigated acreage remained fairly consistent from year-to-year, there was some fluctuation — most notably the decline that occurred for very large farms, which may be a result of a comparably wet year in 2017.

Figure 35: Irrigated Acreage as a Share of Total Acreage (n=66)



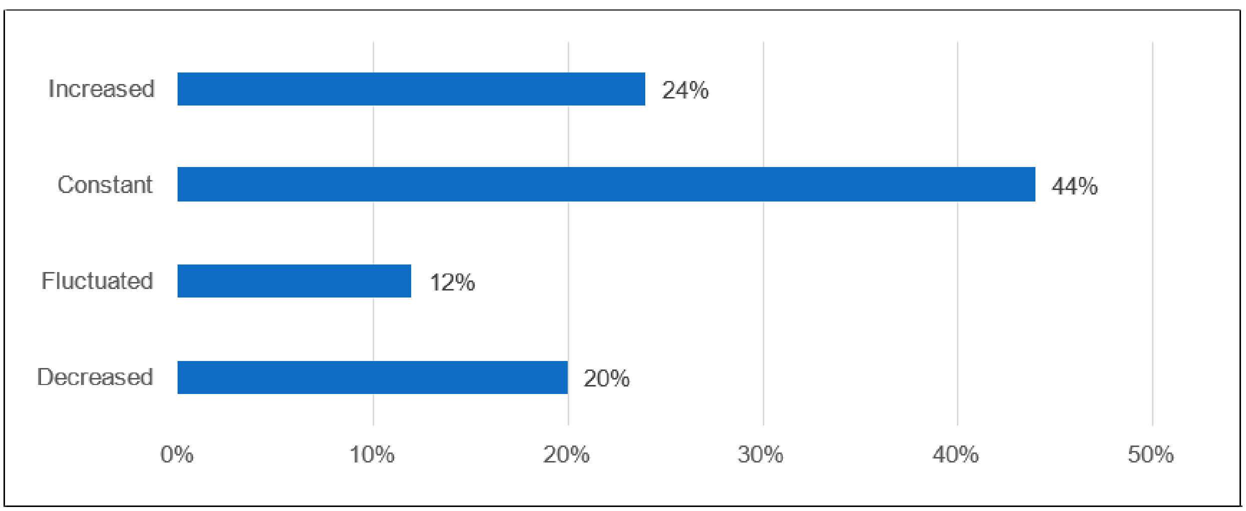
Source: Lawrence Berkeley National Laboratory

Reliance on Groundwater

The quantity of groundwater pumped on-farm can vary year-to-year, with important implications for policy planning. These changes in groundwater pumping can be driven by a number of factors, including climatic conditions and crop watering requirements. Respondents were asked to report the quantity of groundwater pumped in the calendar years 2015, 2016, and 2017. These three years were chosen given they are recent enough for respondents to recall and represent both drought and non-drought conditions. The California Drought Monitor classifies drought from least to most severe as "no drought," "abnormally dry," "moderate drought," "severe drought," "extreme drought," and "exceptional drought." In 2015, California entered its fourth year of severe drought. Throughout most of 2015, more than two-thirds of California fell into either the "exceptional drought" or "extreme drought" categories (the highest two ratings). Throughout 2016, that number remained high — but dropped to approximately half the state. In contrast, 2017 was a comparably wet year, with no area of the state reporting "exceptional drought" or "extreme drought." The California Drought Monitor reported that approximately 20 percent of the state was either in a "moderate drought" or "abnormally dry," with a very small part of the state reporting "severe drought" (Stevens and Chong, 2017).

Based on the values given by respondents, the research team then determined whether the quantity of on-farm groundwater pumped in 2015, 2016, and 2017 was consistent, increased, decreased, or fluctuated throughout those years. The results in Figure 36 indicate that less than half (44 percent) of respondents reported pumping a constant amount of groundwater throughout these three years, while it fluctuated for 12 percent. Interestingly, more respondents (24 percent) reported increasing their groundwater pumping throughout this period than decreasing (20 percent) pumping.

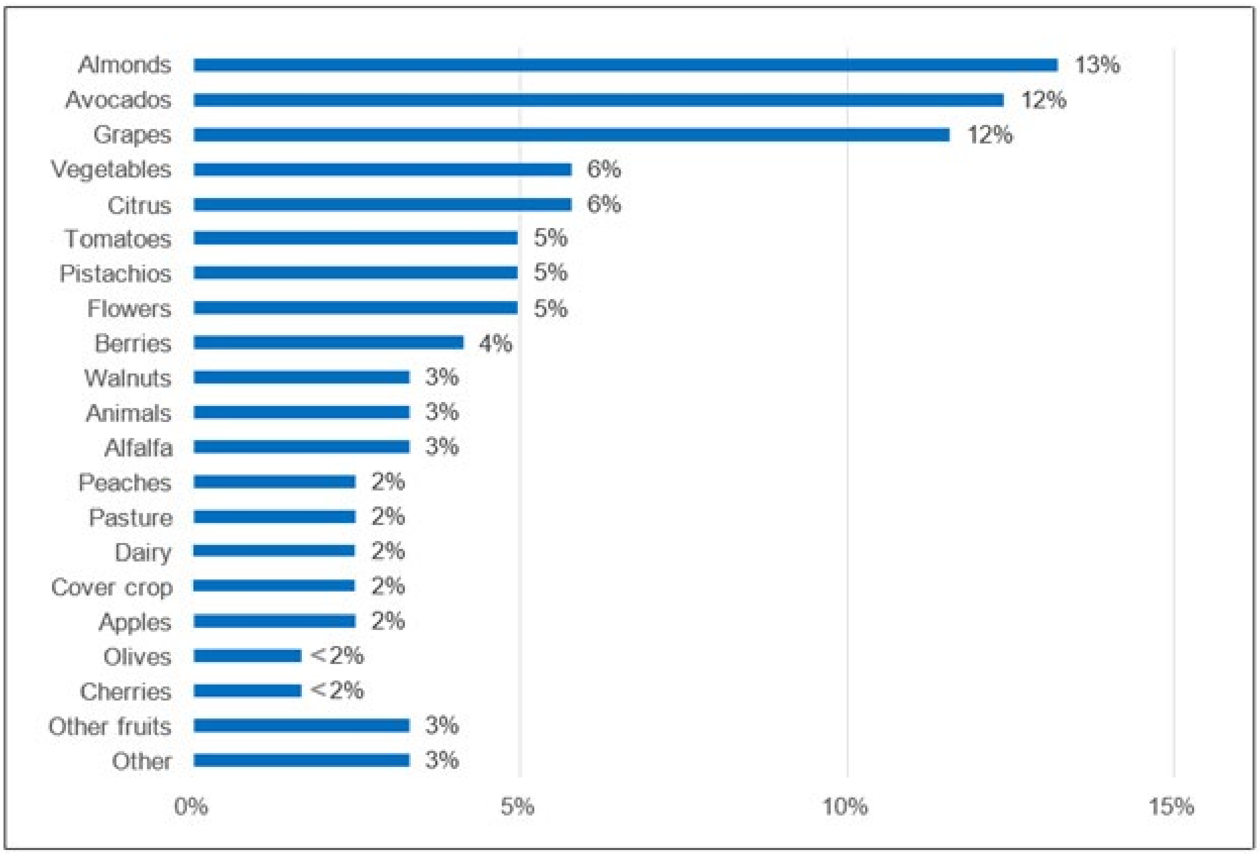
Figure 36: Trend in Groundwater Pumped From 2015 to 2017 (n=50)



Source: Lawrence Berkeley National Laboratory

Respondents were also asked to identify by water applied, the top three crops or agricultural products on their farms that were irrigated to any extent by on-farm pumped groundwater in 2017. The question allowed respondents to fill in up to three empty fields, instead of giving predetermined answer options. Twenty-seven percent of respondents identified having only one crop or agricultural product irrigated by on-farm pumped groundwater, 23 percent identified two, and 50 percent identified three. Given that respondents were able to identify up to three crops, 134 total responses were provided. Figure 37 provides a breakdown of the crop types identified by survey respondents, with crops binned into representative categories. Overall, almonds (13 percent), avocados (12 percent), and grapes (12 percent) made up the three most commonly mentioned crops. In total, fruits of any type represented 50 percent of the responses. These responses show broad farm or ranch categories. When compared with the CDFA's 2017 (CDFA, 2018) list of top 10 commodities by value (Chapter 3), which includes almonds and grapes, 45 percent of the crops identified by respondents fall onto the list,[38] indicating that a significant portion of survey respondents irrigate high-value crops with groundwater.

Figure 37: Top Three Crops or Agricultural Products in Terms of the Amount of Groundwater Applied in 2017 (n=60)



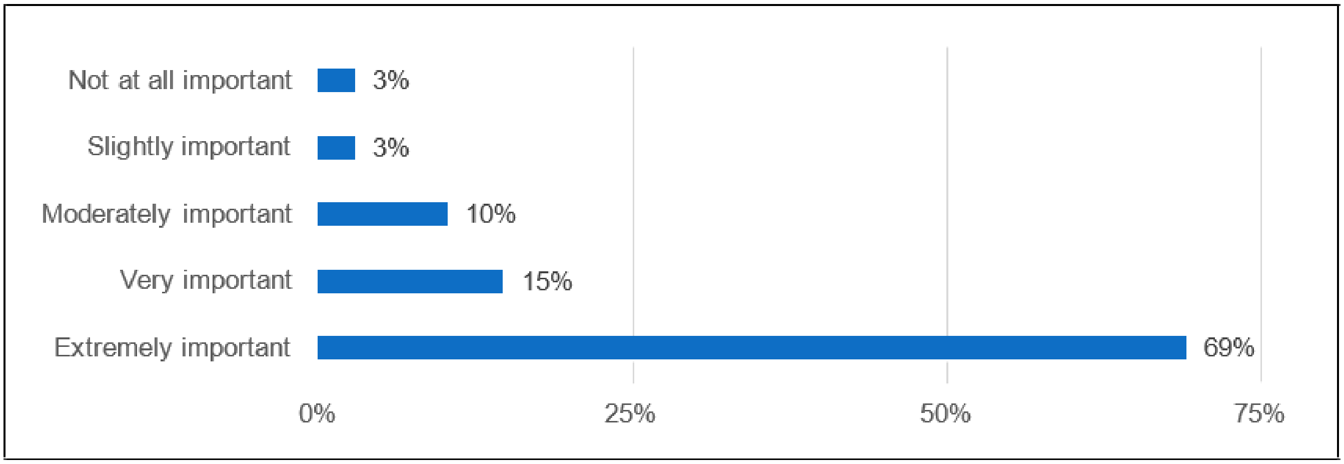
Source: Lawrence Berkeley National Laboratory

In addition, to better understand the relevance of groundwater to farming and ranching operations, respondents were asked to report how important groundwater is to sustain their business. Respondents selected one out of five possible options shown in Figure 38. More than

[38] For strawberries and oranges, both on the CDFA list of top 10 commodities, the research team only included responses in this percentage calculation if respondents specified strawberries or oranges, although a number of respondents also identified "citrus" or "berries" or both in the top three crops by amount of groundwater applied (CDFA, 2018).

two-thirds (69 percent) of respondents indicated that groundwater was extremely important, followed by 15 percent who reported it was very important. Ten percent reported it was moderately important, and only 6 percent of respondents indicated that groundwater was only slightly important or not at all important (Figure 38). These results suggest that access to groundwater is indeed a critical resource for the farmers and ranchers who responded to the survey. In addition, this may indicate some unknown level of self-selection bias, where growers who are more dependent on groundwater were more likely to participate in this survey, perhaps because they have concerns about future access to groundwater, or about how groundwater resources will be managed.

Figure 38: Importance of Groundwater of Sustained Business Viability (n=68)



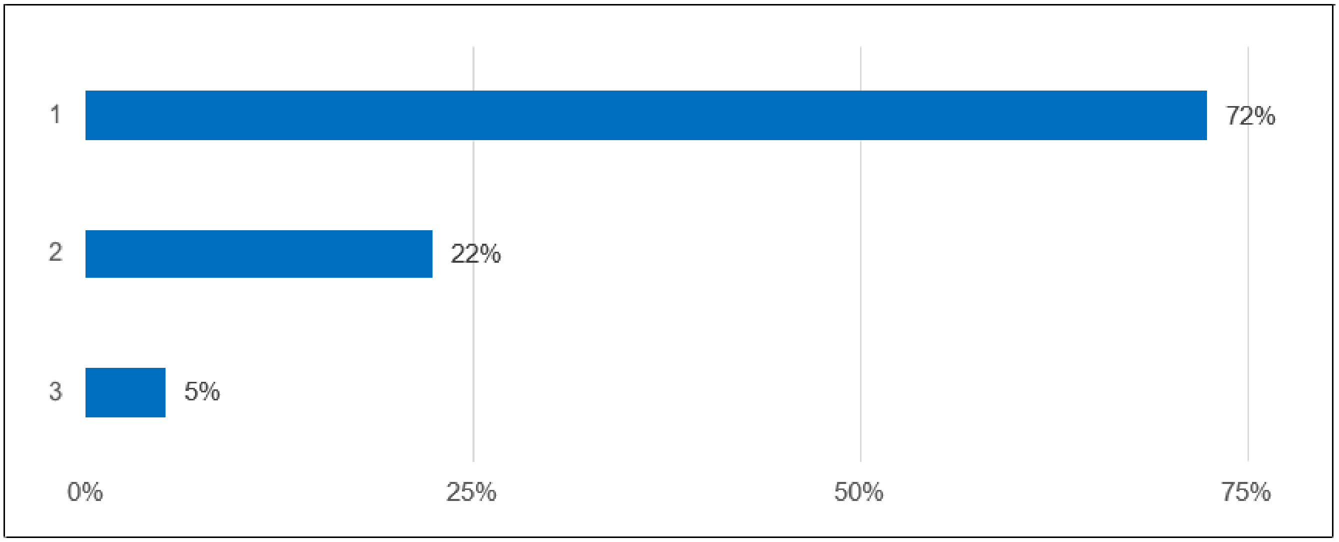
Source: Lawrence Berkeley National Laboratory

Results from the survey suggest that while it is important to ensure access to this important resource, the sustainable management of groundwater is also critical. In the open-ended portion of this survey, one small farm reported that they did not belong to any water irrigation project or system, with all water coming from wells on their property. Another, however, claimed less reliance on groundwater, noting they mostly used surface water and only supplemented with groundwater "as needed." Another respondent indicated that at least two sources of water "are required to protect our investment in permanent crops." This respondent reported that if a parcel doesn't have groundwater available, a well must be installed before permanent crops can be planted.

Groundwater Well Pump Power Sources

Growers were asked to provide the number of groundwater well pumps used on their farm based on the pumps' associated power source. Almost three quarters of respondents replied that all of their groundwater well pumps were powered by one energy source, while 22 percent indicated that their well pumps were powered by two energy sources, and 5 percent replied that their well pumps were powered by three energy sources (Figure 39). No respondents reported more than three different energy sources powering their well pumps. When it comes to specific power sources, the majority (60 percent) of 58 respondents indicated that their farm has at least one well pump powered by grid-only electricity, and 22 percent specified that their farm has at least one well pump powered by grid electricity combined with on-farm renewables (Figure 40). Smaller shares indicated other power sources: 10 percent of respondent farms power at least one well pump by liquid fuels (for example, diesel, biodiesel, gasoline, blends), 5 percent indicated having at least one pump powered by gas (for example, natural gas, LP gas, propane, butane), and 3 percent selected having at least one pump powered by on-farm stand-alone renewables (not connected to the grid). These results are consistent with the ones presented in Figure 6 in Chapter 4, when the shares of growers that rely on electric and non-electric well pumps are compared.

Figure 39: Number of Power Sources Relied Upon for Powering Cell Pumps (n=58)

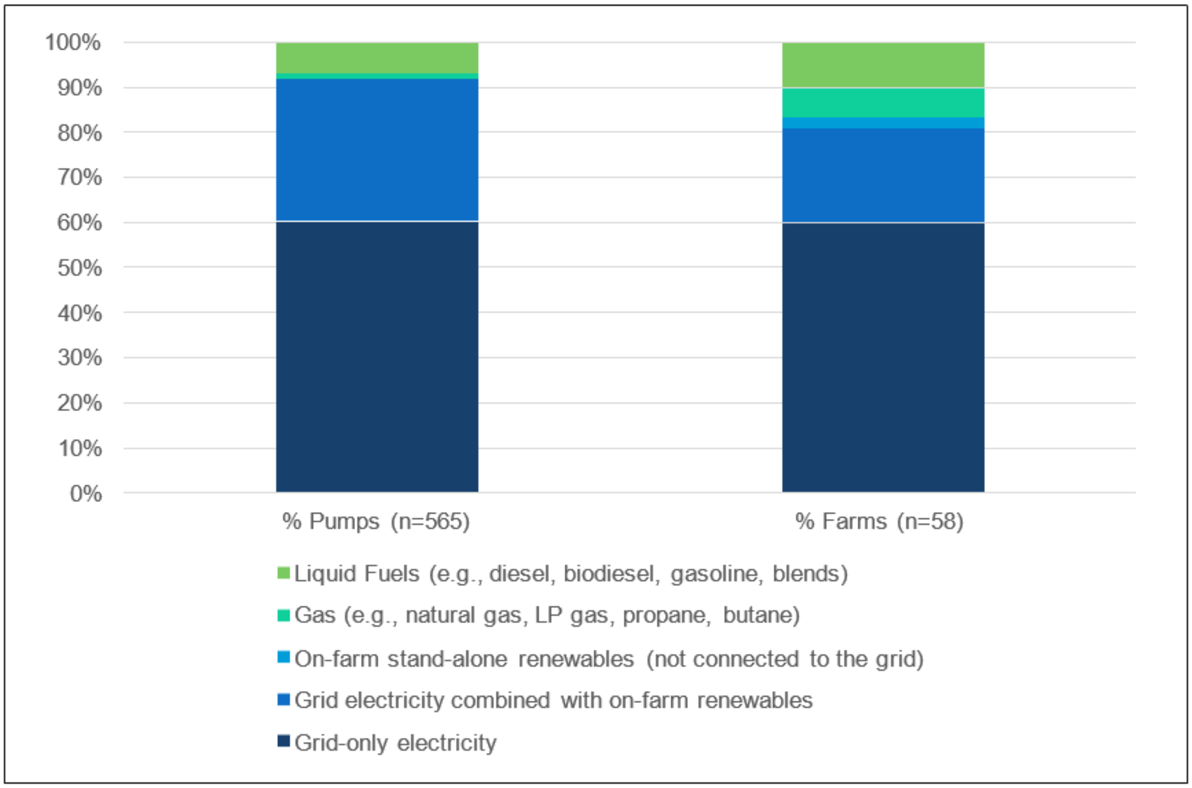


Source: Lawrence Berkeley National Laboratory

In total, the 58 farm operations accounted for 565 indicated groundwater well pumps. Sixty-one percent of those pumps rely on grid-only electricity, 32 percent on grid electricity combined with on-farm renewables, 7 percent on liquid fuels, 1 percent on gas, and less than 1 percent of pumps by on-farm stand-alone renewables. Moreover, while only 22 percent of farms reported having at least one well pump powered by grid- electricity combined with on-farm renewables, 32 percent of the total pumps were powered by grid electricity combined with on-farm renewables. This suggests that those farms that use grid electricity combined with on-farm renewables may be relying on that power source for a significant percentage of their pumps. Conversely, although 15 percent of farms have at least one pump fueled by gas or liquid fuels, only eight percent of the total pumps accounted for require gas or liquid fuels as their energy sources.

In the open-ended portion of this survey, one small farm indicated that while they are connected to the grid, their small solar system produces enough energy to cover all farm needs, including well water pumping. Another grower indicated strong interest in running pumps off-grid with the use of solar.

Figure 40: Share of On-Farm Groundwater Cell Pumps by Power Source, and of Farm With at Least One Cell Pump Relying on the Specified Power Source



Source: Lawrence Berkeley National Laboratory

Respondents were also asked whether in the next five years they expect to shift towards a different power source for their groundwater well pumps, considering retrofits and new installation pumps. If respondents planned to make multiple types of switches, the questionnaire asked them to indicate the switch that would affect the most pumps. Those not planning to switch any groundwater well pump power sources in the next five years were asked to leave the question blank. Twenty-two respondents answered affirmatively that they plan to switch power sources in the next five years, compared to 58 and 59 respondents to the questions on either side of this one, likely indicative that a majority of respondents are not currently planning to switch power sources.

Table 25 displays answer choices for those 22 respondents anticipating switching, with the power source to be switched away from in the left-most column. Of these respondents, two-thirds plan to switch from grid-only electricity to grid electricity combined with on-farm renewables connected to the grid, while nearly one quarter (combined) expect to switch to on-farm stand-alone renewables for retrofits or new installation pumps or both. However, these results must be viewed with caution, considering the small number of respondents.

Table 25: Intent to Shift Power Sources to Well Pumps in the Next Five Years (n=22)

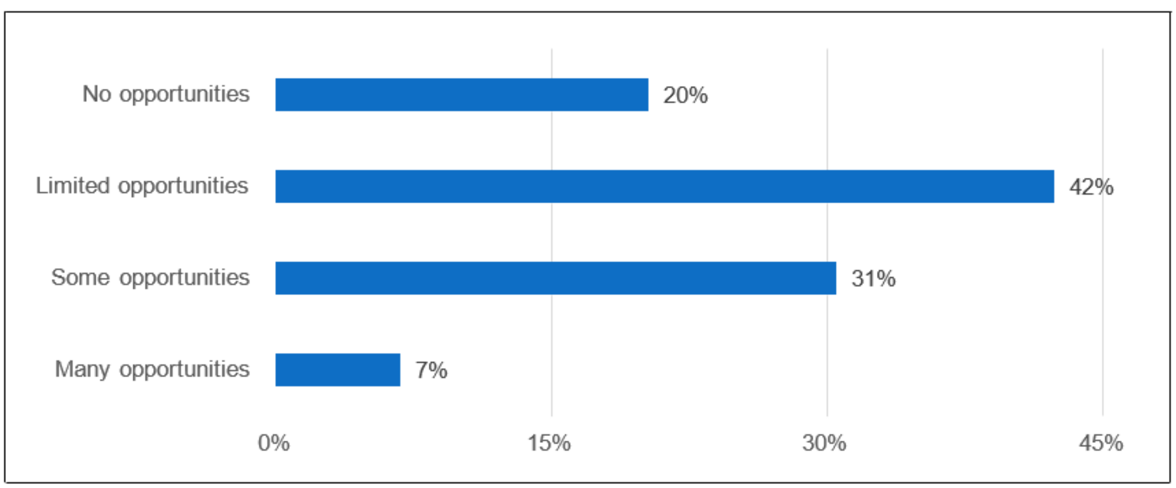
From...	To...		
	Grid electricity combined with on-farm renewables connected to the grid	On-farm stand-alone renewables	Gas or liquid fuels
Grid-only electricity	14	1	1
Grid electricity combined with on-farm renewables connected to the grid	-	3	
On-farm stand-alone renewables	-	-	-
Gas or liquid fuels	1	1	-

Source: Lawrence Berkeley National Laboratory

Reducing the Energy Needed to Pump On-Farm Groundwater

Respondents were asked whether and to what degree they felt opportunities exist to reduce the energy required to pump groundwater on their farm through increasing overall pump efficiency. Overall, respondents did not feel there were ample opportunities to curtail pumping energy use, with 20 percent reporting they felt there were "no opportunities" and 42 percent reporting "limited opportunities" (Figure 41). Slightly under one-third reported "some opportunities," while only 7 percent of respondents indicated there were "many opportunities" to pump groundwater.

Figure 41: Opportunities to Reduce Energy for Pumping Groundwater (n=59)

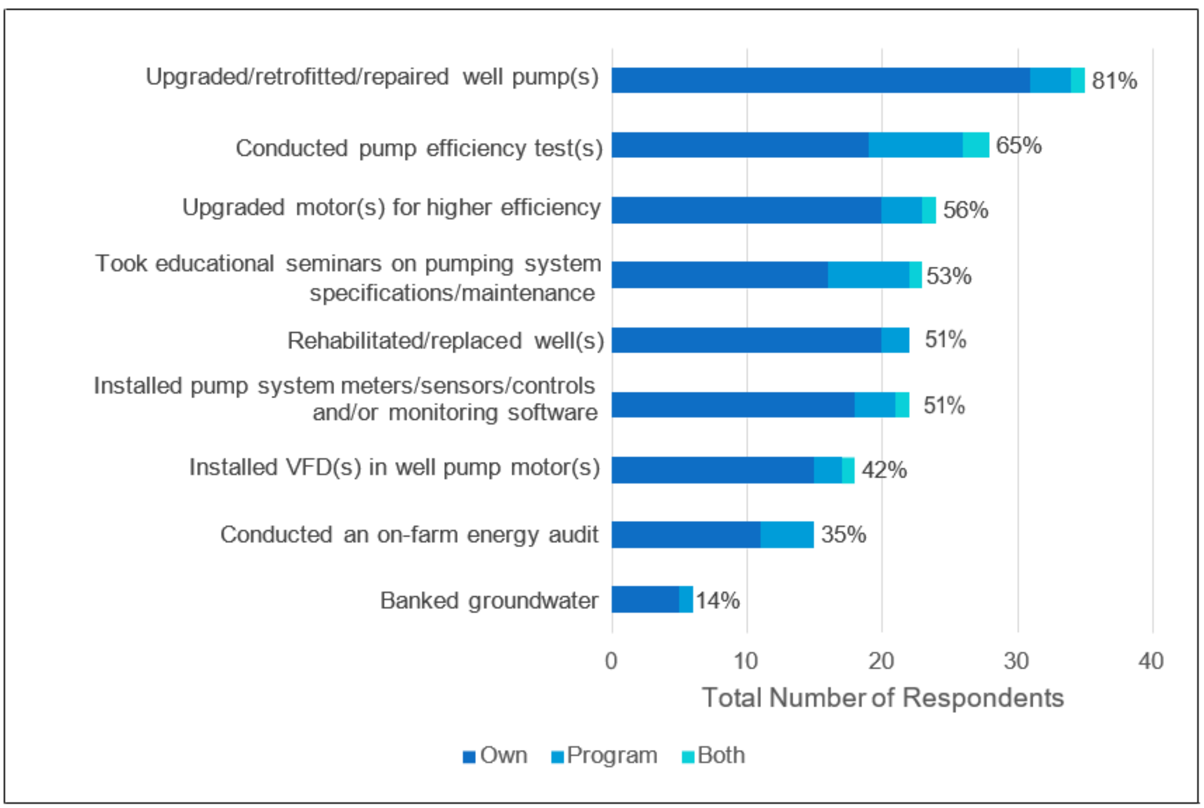


Source: Lawrence Berkeley National Laboratory

Although the previously mentioned unknown self-selection bias for this survey may apply (for example participants are more likely to be concerned with groundwater pumping energy consumption than the general population of growers in California; this finding suggests that further investigation is warranted to determine whether these limitations are products of operational constraints (for example, growers and ranchers already operating their pumps as efficiently as possible), financial barriers, educational or technical barrier awareness, and know-how).

To better understand what types of efficiency actions respondents have already taken, and if they have relied on available incentive programs to take these actions, respondents were asked to indicate which of the actions in Figure 42 were taken in the last 10 years and if they were taken on their own, as part of a utility or government program, or both on their own and as part of a program. Forty-three respondents indicated that they had taken at least one efficiency action over the past decade. Respondents' most common action — taken by 81 percent of those indicating having taken any action — was upgrading, retrofitting, or repairing well pumps. At the same time, many efficiency actions listed in the questionnaire were taken by more than half of respondents: conducting pump efficiency tests; upgrading motor(s) for higher efficiency; participating in educational seminars related to pumping system specifications and maintenance; rehabilitating or replacing wells; and installing pump system meters, sensors, controls and monitoring software. On the other hand, actions less commonly taken were installing VFDs in well pump motors; performing on-farm energy audits; and, by far the least common, banking groundwater.

Figure 42: Actions Taken Over the Last 10 Years That Could Affect Energy Use (n=43)



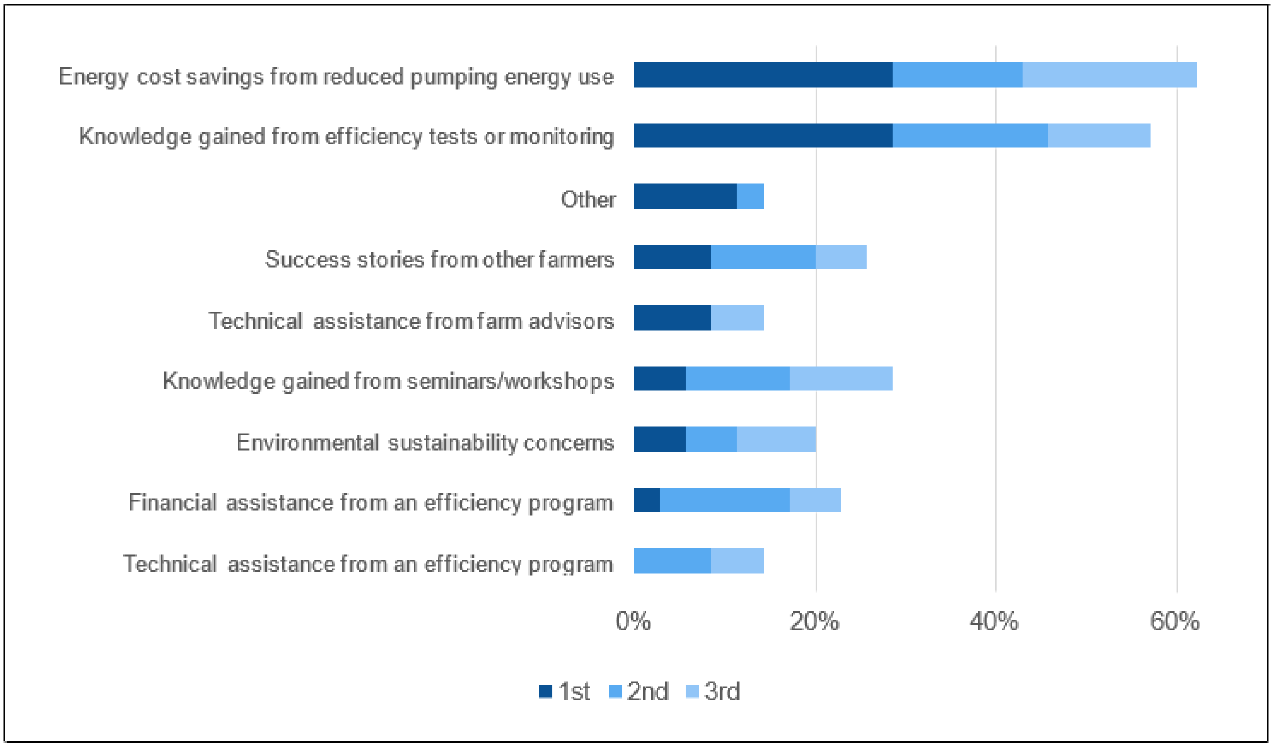
Source: Lawrence Berkeley National Laboratory

Also, the "other" response option for this question generated comments from growers noting the following additional actions: relying on surface water when available, installing soil moisture monitors, and installing solar. In the open-ended portion of the survey, one participant noted that the cooling system on variable speed drives was not reliable in the Central Valley heat. Another respondent commented that in their experience, new VFDs — even with financial incentives — do not provide adequate return on investment. This person noted that as a result, s/he is increasingly turning to the used or surplus marketplace to source VFDs, but has been unsuccessful in identifying any financial incentives or programs to assist with such purchasing. Still, this respondent reported that seeking out used VFDs (without financial assistance) is still "much better" than new VFDs (with financial assistance).

Respondents primarily took advantage of efficiency actions on their own, as opposed to as part of a program. However, more than a quarter of respondents took advantage of programs (this could include programs combined with taking actions on their own), for three efficiency measures: conducting pump efficiency tests (32 percent), participating in educational seminars on pumping system specifications and maintenance (30 percent), and conducting on-farm energy audits (27 percent). This implies that, while this group of respondents has taken numerous efficiency actions, significant room exists to increase the number of growers implementing these actions as part of an incentive or educational program.

Next, in an effort to better understand the rationale behind why respondents took efficiency actions as described, respondents were asked to rank a variety of factors that led to their decision to do so. Respondents were able to rank up to three options of incentives or influencing factors from the list provided. Figure 43 presents these results. Response options are sorted by the percentage of respondents that indicated each option as the most influential factor. It appears that "other" was a response option ranked as an important factor. This option yielded a "fill in the blank" response. Some of the responses given for "other" factors included: the pump failed and needed to be replaced, efficiency actions were required by a groundwater management agency, for efficiency and cleaner water, and after talking with pump, well repair, and sales experts.

Figure 43: Influential Factors in Taking Energy Efficiency Actions (n=35)

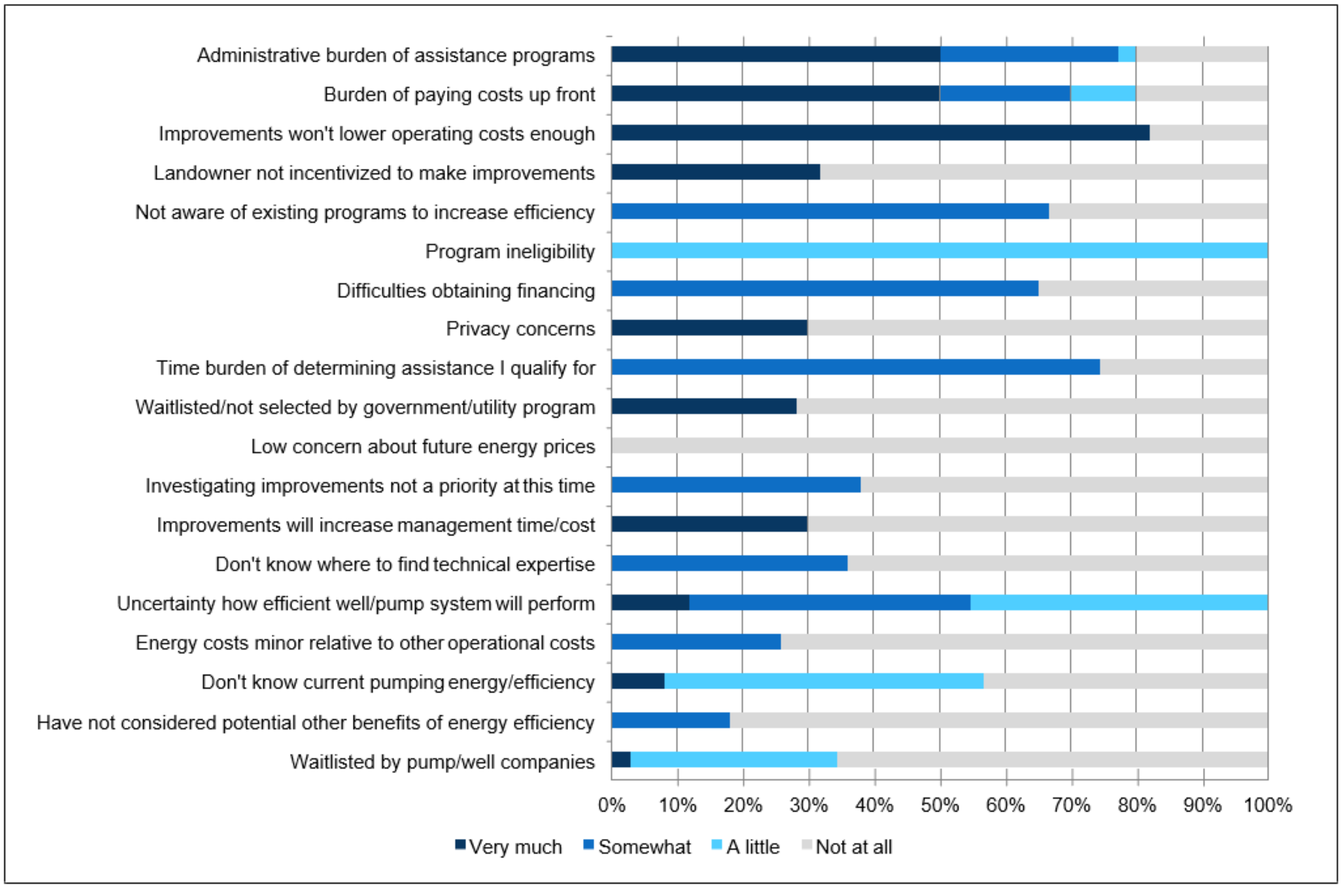


Source: Lawrence Berkeley National Laboratory

Respondents were also asked, to explore the barriers that farmers and ranchers face in curtailing groundwater pumping energy use more generally, "How much do each of the following hamper you in reducing the energy needed to pump groundwater on your farm?" Respondents were asked to rate each of 19 answer choices on a Likert scale of "not at all," "a little," "somewhat," and "very much."[39] Figure 44 displays the results in descending order of the share of respondents who indicated that a particular answer choice "very much" hampers them in lowering groundwater pumping energy. These answer choices are summarized; exact wording is found in Question 18 of Appendix B.3.

[39] In the online survey, the order in which response options were displayed was randomized to minimize bias.

Figure 44: Barriers to Reducing On-Farm Groundwater Pumping Energy (n=48)



Source: Lawrence Berkeley National Laboratory

With this ordering, the top five barriers to reducing on-farm groundwater pumping energy are:

- Administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs).
- Burden of paying costs upfront (such as programs) in rebate reimbursements or tax incentives.
- Improvements will not reduce operating costs enough to cover equipment and implementation costs.
- No incentive for landowners to invest in improvements that mainly benefit lessees.
- Not aware of any options or programs that exist to increase pump efficiency.

In addition, more than 80 percent of respondents felt that uncertainty about the actual performance of efficient well and pump systems hampered them at least a little, with the greatest share of responses for this answer choice indicating this is somewhat of a barrier. This finding suggests that more educational classes and demonstrations of efficient technologies at venues growers trust might be helpful in increasing adoption of these measures. Also, a few growers checked the provided “other” response option, and provided the responses presented (transcribed in their entirety) in Table 26 along with associated county and farm sizes.

Table 26: Individual Responses for "Other" Barriers

Comment	County	Farm Size (total acreage in 2017)
"There are no resources/workshops where I can learn more about well or pump efficiency."	Yolo	(not informed)
"…already invested in a new more efficient pump"	San Diego	2
"…shared well with other properties"	Santa Barbara	4.3
"No upfront money…"	Calaveras	40
"We've done everything we are aware of to increase well pump efficiency and have installed a solar energy system to run our farm."	Mendocino	375
"We receive no assistance whatsoever on any farm aspect."	Placer	420
"Difficulty in dealing with provider PG&E	Sutter	900

Source: Lawrence Berkeley National Laboratory

Finally, respondents were given a list of incentives that might motivate them to reduce the energy needed for on-farm groundwater pumping and asked to select up to three that they considered to be most important. Figure 44 presents the breakdown of 112 selected answer options from 48 respondents. Respondents most commonly selected tax incentives for pumping efficiency projects (26 percent) as a potentially motivating incentive, while they least commonly selected pumping efficiency projects (6 percent) and training and awareness program (5 percent). In general, between 9 and 14 percent of respondents felt the remaining six potential incentives would be motivating.

In addition, via the "other" response option, growers mentioned some other incentives that could be motivating: receiving an energy credit equal to the cost of a pump or system over two or three years; cost sharing or grants to pay for upgrades; and delivery of more surface water. Additional specific, relevant comments in their entirety are:

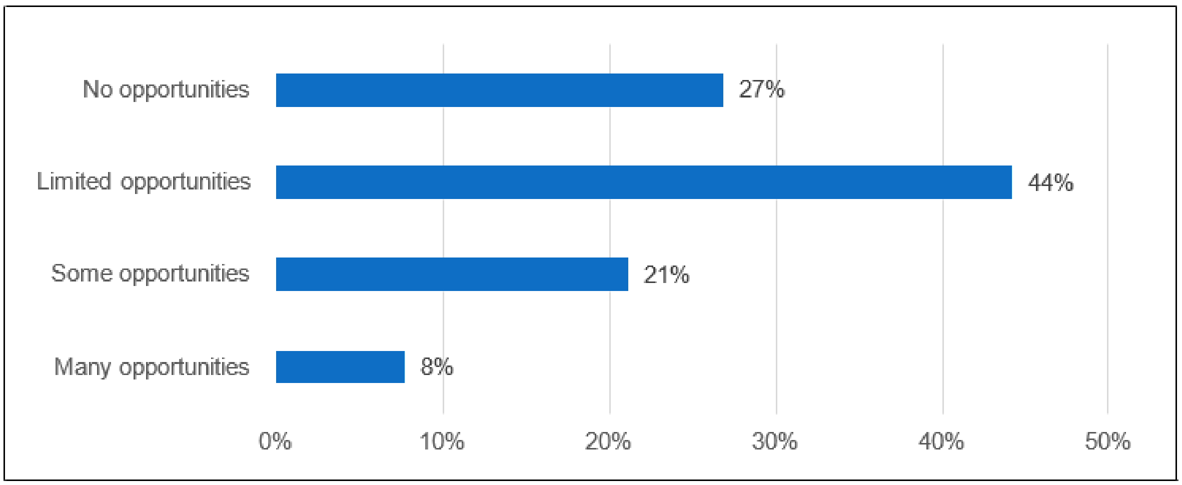
- "We need a special program that will get us carbon credits for our farm that can be applied to solar battery systems, and solar to run our pumps totally off grid. I would like to remove my 20 HP (horsepower) pump off grid that runs my drip system for the vineyard. Because my system is efficient and only uses 20 HP, I am not eligible for some Ag benefits. Counterproductive planning."
- "The cost of upgrading the efficiency of the 60+ wells on our farm is astronomical and unless I can get a significant ROI we keep kicking the can down the road. Most of our land is leased and the landowner has little incentive to improve the efficiency because it benefits the tenant and not the landowner. Most of the work on wells is done only when it reaches a crisis level. The efficiency on many of our wells is bad and we know that

something needs to be done but we are stuck in this quandary. I hate low interest loans because it takes too long to pay them off and landownership and leases are more fluid. Cost sharing or grants are the answer. Look at the participation level of the Carl Moyer Program[40] as a model. Great benefit to the participant and great participation."

Improving On-Farm Water Conservation

Respondents were asked to report whether and to what extent they felt there were opportunities to use less groundwater on their farms. The results are shown in Figure 45. Collectively, a substantial majority felt that there were no or limited opportunities (27 and 44 percent, respectively) to use less groundwater on farms. Approximately one-fifth (21 percent) reported that there were some opportunities, and only 8 percent reported they thought there were many opportunities.

Figure 45: Perceived Opportunities to Use Less Groundwater on Farm (n=52)



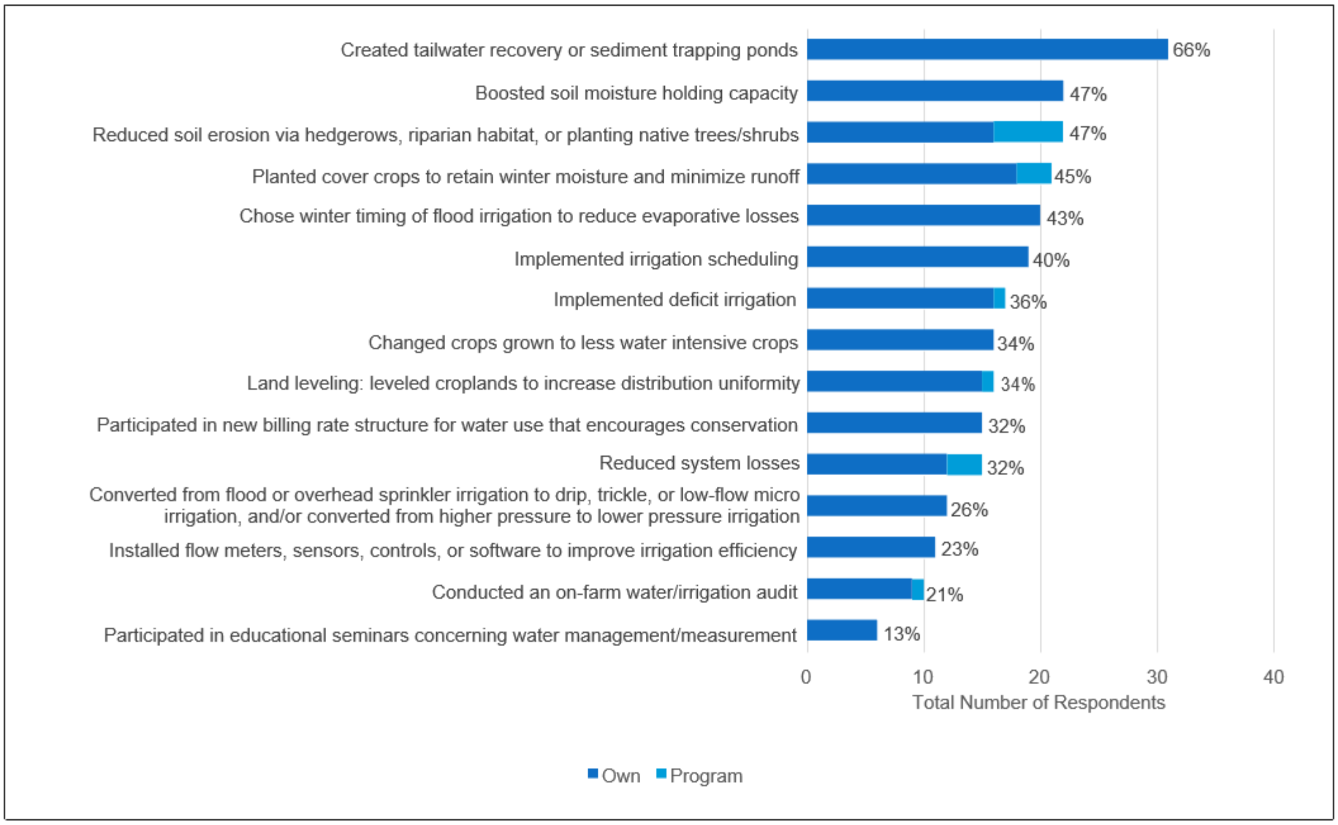
Source: Lawrence Berkeley National Laboratory

To better understand what types of actions respondents have taken that could affect the amount of groundwater pumped, and to better understand if those actions were taken on their own or as part of a program, respondents were provided the list of actions in Figure 46 and asked to indicate which of them they had taken in the last 10 years on their own, as part of a utility or government program, or both on their own and as part of a program; 47 respondents indicated that they had implemented at least one of the measures. The most common action was creating tail water recovery or sediment trapping ponds, reported by two thirds of those respondents who indicated taking any actions. Other actions taken by over 40 percent of respondents were boosting soil moisture capacity; reducing soil erosion via hedgerows, riparian habitat, or planting native trees/shrubs; planting cover crops to retain winter moisture and minimize runoff; choosing winter timing of floor irrigation to reduce evaporative losses; and implementing irrigation scheduling. Overall, very few actions were taken as part of a program, which may point to more opportunities to offer programs affecting the amount of

[40] This respondent is referencing the Carl Moyer Memorial Air Quality Standards Attainment Program administered by the California Air Resources Board, with more information available at https://www.arb.ca.gov/msprog/moyer/moyer.htm.

water pumped. In addition, open-ended comments from growers noted the following additional actions taken: installing automatic water control valves, mulching, and relying on dairy farming to create topsoil.

Figure 46: Actions Taken Over the Last 10 Years That Could Affect the Amount of Groundwater Pumped (n=47)



Source: Lawrence Berkeley National Laboratory

To investigate the barriers that farmers and ranchers face in implementing on-farm water conservation projects, respondents were asked to rate each of randomized 23 answer choices on a Likert scale of “not at all”, “a little”, “somewhat”, and “very much”. Figure 47 displays in descending order the share of respondents who indicated that a particular answer choice “very much” hampers them in implementing water conservation projects on their farm or ranch. The answer choices are summarized in the figure; exact wording is found in Question 22 of Appendix B.3. With this ordering, the top five barriers to implementing on-farm water conservation projects are:

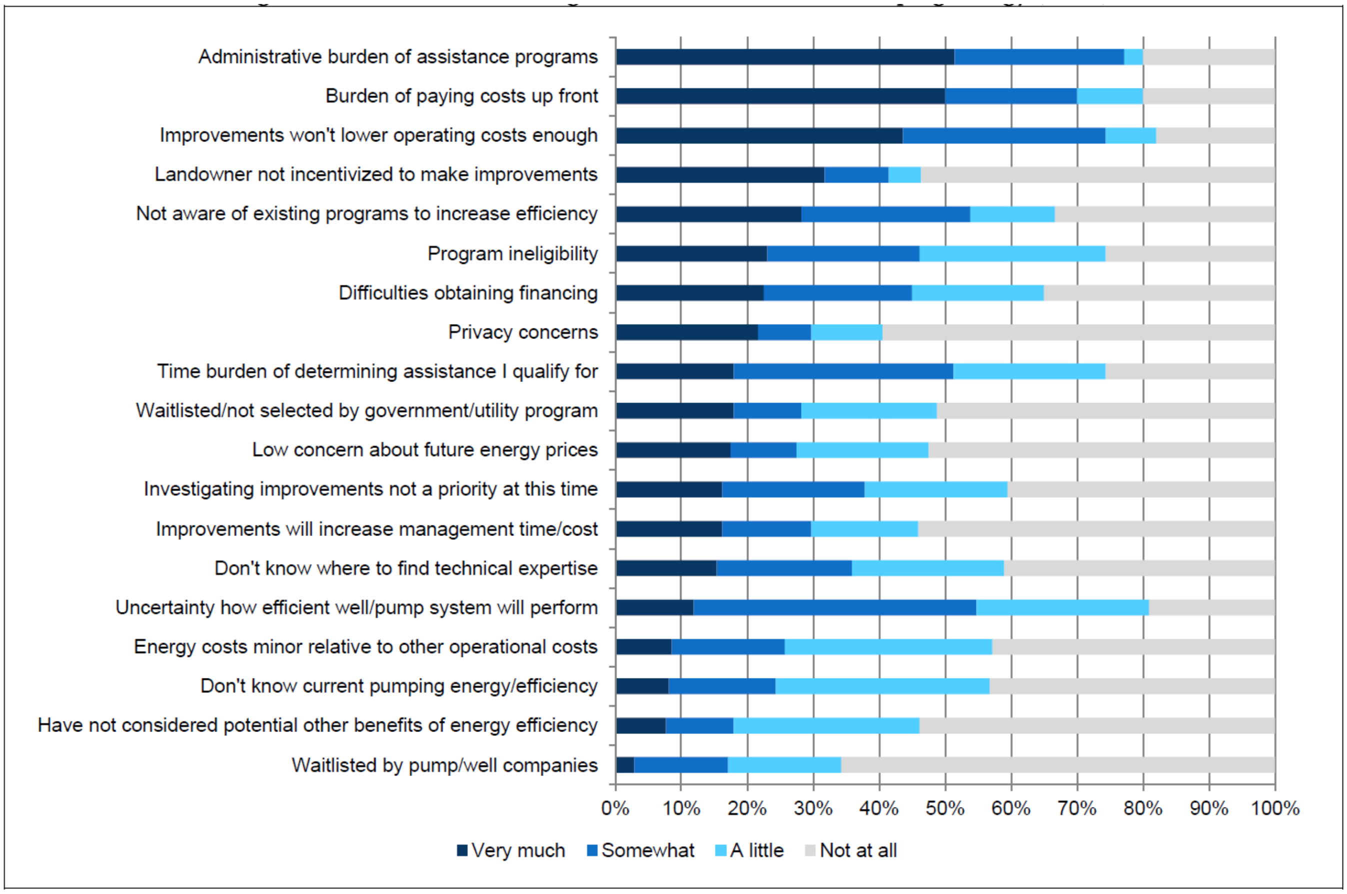
Burden of paying costs up front (for example, programs) in rebate reimbursement or tax incentives

- Improvements will not reduce operating costs enough to cover equipment and implementation costs.
- Administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs).

- Time burden of determining what programs or type of assistance for which growers qualify.
- Program ineligibility (for example due to income, landownership, or location issues).

In addition, more than 80 percent of respondents indicated that uncertainty about the actual performance of efficient irrigation systems deterred them at least a little — although overall, sentiment about this barrier was felt somewhat less strongly than its analog regarding lowering groundwater pumping energy use. Similarly, additional demonstrations of efficient irrigation technologies by trusted stakeholders could be helpful in increasing on-farm water conservation, especially in areas of the state with historically lower adoption of these measures.

Figure 47: Barriers to On-Farm Water Conservation (n=47)



Source: Lawrence Berkeley National Laboratory

Additional Comments

At the end of the survey respondents were given the opportunity to provide additional details they wished to provide to their groundwater pumping practices. Twenty-six respondents chose to provide additional information, which is summarized and excerpted below as appropriate. Comments represented a variety of the challenges and nuances of their individual groundwater pumping practices. Review of these responses revealed that there were two common themes discussed: the first was how actions undertaken by local energy utilities affected groundwater pumping practices, and the second was how broader changes in climate and expectations of sustainability have affected such practices.

Concerning utility-related comments, several respondents indicated frustration with the structure and other characteristics of their energy utility rates. For example, one grower noted that a less complex rate structure with PG&E would help them operate their pumps in an energy-efficient manner, citing that running wells for 24 hours is more efficient than starting and stopping, which occurs presumably to avoid peak rates. Two respondents indicated that changing TOU rates from their utilities (in these cases PG&E and SCE) presented issues. Specifically, one respondent indicated that they had installed a 320-kilowatt (kW) solar PV system on their net energy program, but that with the extension of the peak period from 12:00 p.m. to 6:00 p.m. to 12:00 p.m. to 8:00 p.m., shutting off pumps during the peak period won't work, because the solar PV does not generate as much power between 6 p.m. and 8 p.m.

Another respondent articulated similar concerns, citing that changes in TOU rates have affected their operations, as they "historically irrigated from 4:00 p.m. to 8:00 a.m. to save cost and water; but now the TOU peak rate is until 9:00 p.m. and we cannot start irrigation in the dark (workers must be able to check each sprinkler)." Another respondent noted that it is problematic that lower horsepower motors (defined by PG&E as a single motor with less than 35 HP or multiple loads less than 15 kW) that are operated less are charged higher rates than larger pumps that are used more. Table 27 indicates that larger pumps, as well as pumps with higher use (defined by 700 annual operating hours or more), are assessed lower average total rates.

Table 27: PG&E Average Total Rate per Kilowatt-Hour

Use	Small Pumps	Large Pumps
Low	$0.31604 (Ag4A)	$0.24867 (Ag4B) $0.23132 (Ag4C)
High	$0.24005 (Ag5A)	$0.18462 (Ag5B) $0.16205 (Ag5C)

Source: Lawrence Berkeley National Laboratory

CHAPTER 6: Discussion

Several interesting considerations can be drawn from the results presented in Chapter 5. However, to further inform this analysis, the research team held informal discussions with subject matter experts whose experience and perspectives on the barriers to improving the energy efficiency of groundwater pumping could help to shed light on critical considerations.

The team had an informal conversation with several staff members of The Energy Coalition (TEC), who have advised water agencies on improving the energy efficiency of groundwater pumping.[41] TEC is a not-for-profit consulting organization based in Southern California that manages, among other programs, the Southern California Regional Energy Network (SoCalREN) Public Agency Program. The County of Los Angeles administers SoCalREN to capture energy savings in the SoCalGas and SCE service territories, while the public agency program works with public agencies such as counties, cities, and water districts to implement energy-efficiency projects.

Considering the present situation in California, TEC identified several impediments to more energy-efficient groundwater pumping for municipal and agriculture water suppliers. They cautioned that barriers are related to a particular service area's geography, hydrology, and topography, and suggested that permitting issues and stringent water quality requirements may hinder agencies' implementation of new technologies. Some agencies also may have specific equipment needs that require reliance on a single source (for example groundwater). In general, TEC saw a lack of funding as a barrier particularly pertinent in the public sector, especially for municipal suppliers compared with agriculture water suppliers in the SCE and SoCalGas service areas. Municipal suppliers sometimes face roadblocks through the politics of city residents who live near groundwater pumping facilities. For agriculture water suppliers specifically, TEC pinpointed a shortage of technical staff and a more generally constrained capacity to consider energy efficiency when suppliers must already coordinate intensively with one another to meet upcoming SGMA requirements.

Concerning barriers to improve efficiency over the past five to ten years, TEC mentioned aversion to risk as the primary hindrance, calling to mind the Rayner et al. (2005) study on the inherent conservatism of water suppliers given their mandate to reliably deliver water. During the next five to ten years, TEC's expectations for obstacles to curtailing the energy needed for groundwater pumping touched on various issues. First, uncertainty exists around SGMA's effects on groundwater pumping volume and constrained surface water supplies given the changing climate and a shrinking snowpack. This scenario may lead to an increase in the value of recycled water or make direct potable reuse more favorable. At the same time, as groundwater recharge systems become more popular, more water will be pumped, requiring more energy. Next, as energy-efficient pumps become the industry's standard practice, available monetary incentives may be curtailed, and cuts in carbon-based energy consumption

[41] TEC consultants held a meeting with several project managers who have worked with water departments and districts in their network to further update this study.

will be achieved increasingly through renewable generation and energy storage. Finally, water suppliers will face the twin challenges of aging infrastructure and revenues based on the volume of water sold, the latter an incentive against water conservation.

Regarding existing incentive programs to improve pump efficiency, the water agencies TEC works with in SCE's service territory are aware of SCE's free pump-testing program, which provides thousands of tests annually (SCE, 2010). These agencies also know that pumping plant retrofits recommended through the test receive financial assistance, although TEC indicated that large accounts, in terms of energy consumption, receive more attention from investor-owned utilities (IOU) than smaller ones. However, some opacity about the application process exists, and certain energy-efficiency measures are not well known, such as VFDs or using a Supervisory Control and Data Acquisition (SCADA) system to automate (and optimize) pumping plant operations. TEC suggested that more information about the pump testing and implementation process should be made available to relevant stakeholders, and that trade groups are perhaps best suited to promoting awareness of pump efficiency. They further recommend more incentives for agency water conservation, and that energy agencies or IOUs work with multiple water suppliers simultaneously — for example, a group of agencies that has formed a groundwater sustainability agency (GSA) for SGMA purposes, or a water wholesaler.

The team also conversed with a technical specialist with the pump test and hydraulic services program offered by SCE. The program is funded by the California Public Purpose Program Charge and allows for one free test per pump per year.[42] If the pump test reveals a need for pump repair or improvements to achieve higher energy efficiency, various incentive programs exist to subsidize these upgrades, unless well rehabilitation is required.

According to the expert, the pump testing services program is well known within the SCE service territory. Outreach through email mailing lists, resource conservation districts, and Farm Bureau offices has spread awareness of the program, as well as regular classes on pump efficiency and VFDs offered at SCE education centers in Tulare and Irwindale. In the past, with 15 staff members, the program tested around 6,000 pumps — both well and booster pumps — per year; now, with only 10 staff members, the number of annual pump tests is closer to 3,500 to 4,000. A typical municipal customer will test half of their pumps one year, and then the other half the following year; there is no typical municipal customer in terms of supplier size. Similarly, large and small growers request pump tests, although pumps must be at least 25 HP to qualify for a free test.[43] In the expert's opinion, farmers can tolerate less energy efficiency compared to municipal agencies, considering that the annual run time of farmers' pumps is typically dwarfed by those of municipal pumps — which may run in excess of 4,000 hours per year — with a correspondingly longer payback period for any improvements that increase efficiency.

The expert mentioned that one overarching challenge to reducing the energy required to pump groundwater is the funding for pump testing programs like SCE's originates from one bucket earmarked for energy-efficiency improvements. The amount of funding available in this bucket

[42] Even though funding allows for one free test per pump per year, the program is turning away customers that request annual testing unless the pump runs in excess of 4,000 hours and steering them to 2 to 3-year intervals between tests.

[43] Smaller pumps can be tested for a $300 fee.

was decreasing over time as efficiency upgrades took place. However, the technical specialist categorized well-pump efficiency as a moving target that requires continual monitoring and intervention because, over time, pumps always wear, and water tables change.

For example, in a shallower groundwater basin, the water table can range from 50 to 150 feet from year to year, so the best efficiency point for pump position will also change. Another, smaller barrier for municipal and agricultural customers is the time required to make upgrades. Pump testing program staff complete most of the required documentation, but approval generally requires several months; staff must demonstrate that projects would not have occurred otherwise without the pump test or upgrade incentives, to demonstrate that these public funds are being wisely spent. After incentive approval, a well redesign project may require two months to be completed, because it requires two to three weeks for a pump contractor to furnish the design, a few weeks to a month for delivery, one week to pull the old pump, install the new, and ensure proper functioning, and, if necessary, another week for well rehabilitation. Ideally, this process would occur when the well in question can be out of commission with fewer negative effects, likely in the winter.

For municipal customers, one barrier to increased well pump efficiency is getting decision makers to understand and appreciate pump test results and efficiency upgrades. Technical staff members may recommend certain efficiency actions, but they generally must obtain budget approval from managers or, in some cases, city councils. Acceptable payback periods for municipal customers are three to four years to generally warrant investment. Some more proactive agencies act on set thresholds for payback periods or for pump efficiency, while other cities tend to be reactive. Whether cities are proactive or reactive depends on their culture, according to this subject matter expert.

When considering obstacles to energy efficiency for agricultural customers, the expert spoke at length about a common attitude of doubt and skepticism that growers have regarding new measures. In his view, while many growers prefer to run their farms the way they always have, younger generations are typically more open to new pumping technologies such as VFDs. In addition, for the population of growers his office serves, many of their operations are now far more water-efficient than in the past, given investments in their irrigation systems. The expert spoke of berry and citrus growers in Ventura County — who currently use 40 percent less water than they used to — and feel that growers in other parts of the state, like the Central Valley, should also pursue water efficiency. The expert also highlighted, considering the past five to ten years, the unfairness of expecting growers who were already water-efficient to further curtail their water use during the last drought. The expert also mentioned that bigger farms have more incentives to be energy-efficient, and that for farms of all types, the cost of capital for investing in energy efficiency can be an obstacle. The expert also mentioned that he anticipates greater irrigation efficiency over the next five to ten years. In his view, SGMA has made municipal and agricultural customers alike more aware of "wasted" water and increased leak detection efforts. The expert is hopeful that customers will continue to take advantage of incentive programs to increase the energy efficiency of groundwater pumping. The expert suggests that while the vast majority of his business is conducted over email, growers ultimately prefer to learn from one another regarding best practices and changing irrigation methods. His recommended venues for outreach and training include local resource conservation districts, large water conferences, and SWEEP.

In addition to the two experts, the team had a conversation with experts from Fresno State's CIT and PG&E's APEP to gain a more nuanced understanding of the difficulties in achieving a high level of participation from populations targeted by the surveys, and to learn more about APEP, the largest pump energy-efficiency program in the state.[44] The research team heard about the difficulties in reaching farmers and growers in California due to competing priorities, time constraints, and a cultural desire to protect information. In particular, smaller growers can be more difficult to reach. With respect to this study's surveys in particular, also discussed were the length of the surveys and the low likelihood of responses from blind recruitment emailing. The latter issue is one the research team acknowledged in developing the recruitment plan (Chapter 3), and a reason why they identified survey recruitment by trusted third parties as important components of the plan.

APEP provided more than $3 million in incentives for 495 retrofit projects involving municipal, water agency, and private water company pumping plants since 2006 (PG&E, 2015). Testing and retrofit requests tend to increase considerably in drought years. While APEP conducts 12 to 20 educational seminars per year (with high levels of attendance), program managers attribute the pump tests themselves to be the most effective marketing, creating awareness about the work that they do. However, reaching smaller growers continues to be a challenge.

APEP covers approximately $100 to $200 of the pump testing cost.[45] If a pump test reveals an OPPE of less than 50 percent, then APEP contacts the pumpers with a customized cost analysis of their pumping activities. According to the experts, pumping costs are non-trivial, particularly for big farmers, with annual operating costs for some of them reaching $70,000–$100,000 per well.[46] Despite this, however, growers have many competing priorities for capital improvements. A typical retrofit project may cost between $30,000 and $40,000, with the APEP program footing on average approximately 10 to 12.5 percent of the bill via a retroactive rebate. One exception is municipal agencies, which tend to recover closer to half of their project retrofit costs. In addition to cost concerns, TOU rates and SGMA have created some level of uncertainty, which may also play a role in some growers' deferring capital investments in efficiency. While growers acknowledge that demand management is going to only become more important over time, they may be employing a "wait and see" approach in terms of what investments to make. Some large growers routinely test their pumps every two years or so and may pursue retrofits that last between 10 and 12 years. Incentives, however, can only be offered every 6 years, and only 1 test is available per pump every 23 months.

The team also conferred with CDFA experts knowledgeable about SWEEP, to learn about the program and hear their perspectives about on-farm groundwater pumping energy. Concerning the main barriers that growers face in curtailing GHG emissions related to groundwater pumping, via water efficiency, energy efficiency, or switching to renewable energy sources or

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[44] APEP is described in Chapter 2, section 2.3.5.

[45] This corresponds to about 50 percent of the total cost of the test.

[46] Some of the larger growers may have multiple wells, which can add up to as much as a million dollars of groundwater pumping costs per year.

both, agency experts mentioned that water availability is paramount to growers in their decision-making, whether surface water or groundwater. Also, water efficiency and energy efficiency do not necessarily go hand in hand. For example, a grower looking to be more water-efficient might switch from flood irrigation and sprinklers to a drip irrigation system, which often requires more energy inputs due to required pressurizing. In addition, while VFDs are beneficial for energy efficiency, they are often quite expensive and not as often installed on crops that rely on surface water or groundwater with stable pumping levels. Regarding energy source, one primary barrier is the proximity to, and cost of, utility infrastructure. When considering the expense of having a power line taken out to a remote area to replace, for example, a diesel-powered pump, a grower will often maintain the status quo. Further, the cost of an interconnection enabling conversion from grid electricity to grid-connected on-farm generated solar photovoltaic (PV) may make such a project infeasible.

Over the past five to ten years, agency experts observed some general trends with a bearing on groundwater energy. First, there was a notable shift from lower-value and flood-irrigated crops like alfalfa toward tree crops, usually accompanied by drip irrigation, leading to increased water efficiency on a per-acre basis. Second, irrigation systems continue to become more advanced; for example, drip systems now often include pressure-regulating valves to achieve distribution uniformity. Next, many farmers are more interested in and reliant on technology and software for irrigation and energy efficiency. At the same time, the consistency, reliability, and integration of these tools has improved, with in-field weather station and short message service (SMS) data feeding into growers' smartphones. Lastly, agency experts indicated that historically farmers have not regarded VFDs as a good investment, seeing them as an unnecessary electronic component on what was seen as an on/off pump mechanism. However, as their neighbors and friends verify VFDs' efficacy in reducing energy and energy costs, this misinformation is increasingly overcome.

Considering groundwater energy use over the upcoming five to ten years, agency experts relayed their perspective that farmers will continue to be protective of their energy and water data, because they are apprehensive about future regulations. One agency expert reported hearing often from growers about their anxiety related to how their operations will fare in a water-restricted future, and that many are anticipating fallowing land. In their opinion, this protective stance may be related to how SGMA was legislated; however, regional and more localized efforts to meet SGMA mandates will likely be beneficial in enabling interested growers to become involved in making decisions.

The agency experts provided additional details on SWEEP relevant to this report. Common types of awarded projects are converting flood to drip irrigation; irrigation water management via flow meters or soil moisture sensors; pump conversions (diesel to electric) or upgrades (new components, VFDs, improved sand media filtration); and installing solar PV. In terms of regions, growers in the San Joaquin Valley have received the most funding from SWEEP. While larger farmers typically have more resources that allow them to write more competitive grants, the experts indicate that — due to the SWEEP application metric of savings on a per-acre basis — the program is distributing awards to farms of different sizes in proportion to their shares of the farm population. Unlike APEP, there is no threshold for minimum pump size.

As it first started operating in 2014, the program was undersubscribed and unable to allocate all its funding. Over time, submitted applications increased in volume to the point where there are currently roughly three to four times as many applicants as SWEEP is able to fund. Also, over time outreach to potential applicants has increased, which helped build momentum for the program. Outreach occurs formally via technical assistance providers, but also through county Farm Bureaus, UC Cooperative Extension, local resource conservation districts, and technology vendors, among others. Agency experts suspect though that word of mouth from growers' neighbors is the most effective recruitment method. In 2017, SWEEP held 23 technical assistance workshops that reached 157 potential applicants, some with bilingual capabilities in Spanish and Hmong (CDFA and NRCS, 2017). Workshops generally occur a few weeks prior to the start of the application window, which in the 2019 round spanned eight weeks (up from six weeks earlier). Technical assistance providers may not charge applicants for their services. The estimated time involved in preparing an application ranges widely, from a simple project involving a vendor quote for an irrigation water management system taking 4 hours to more complex projects requiring upwards of 20 hours to apply.

Agency experts also mentioned a few aspects of SWEEP that may pose hurdles for applicants. The application process is technical and can be quite challenging, particularly the GHG quantification methodology and the GHG calculator tool developed by CARB. A related challenge might involve lining up all needed application materials in a timely manner, such as getting a recent pump test (defined as occurring in the last two years), designing the proposed changes, and receiving quotes from vendors. CDFA being able to offer more technical assistance, both inside and outside workshops, would help alleviate this difficulty for applicants. Even if their funding were unlimited, experts opined that reaching out to all potential applicants would remain difficult. Some regional farming communities are more disconnected from state agencies, while some areas simply would not be well-suited to SWEEP assistance, such as being able to access surface water via senior water rights or using mobile diesel pumps, which pose the difficulty of attributing estimated savings to any one parcel of farmland. In terms of minority or disadvantaged groups, outreach has typically been successful in regions where those communities are more active, another example of farmers' trust in word of mouth and seeing their neighbors adopt new practices and technologies.

Finally, the team spoke with the UCANR Small Farms Advisor for Fresno and Tulare counties. The UCANR Small Farm Program, created in 1979 by an act of the California State Legislature, housed research and extension efforts "aimed at the needs of small- and moderate-scale farmers" who "are often not reached by traditional extension programs" (UCANR, n.d.b) While the Small Farm Program ceased to exist in 2017, four small farm advisors are still active on the county level.

The advisor works directly with small-scale growers, many of them immigrants, some of whom are refugees, predominantly Hmong and other Southeast Asians coming from refugee camps in Thailand. Educational backgrounds of the small farmers with whom the advisor works range from little formal education to those who have graduated from high school and college but could generally be characterized as mainly educated at a high-school level or less, with a smaller share of college-educated growers. English language skills are varied. Language barriers and immigration-related concerns mean that immigrant farmers are likely underrepresented in the Census of Agriculture. For most of the small farmers the advisor's program serves, farming is their primary occupation, selling farm products mostly to wholesalers and farmer's markets.

Individual farm acreage runs from 1 to 60 acres, although most are between 10 and 30 acres, with revenue typically between $10,000 and $50,000. An estimated 80 percent were leasing land; tenants are responsible for pump maintenance and paying the electric bills.

These farmers rely almost exclusively on groundwater and generally are not purchasing off-farm water from, for example, an irrigation district. This is partly because groundwater is better suited for vegetable production in terms of it being cleaner, and partly because some small growers may not know how to access supplied water.

According to the advisor, about half use drip irrigation, and half use flood irrigation in the furrows. Most of the pumps in use are small electric pumps under 25 HP in size (typically 10 to 15 HP). Free pump tests offered by Kings River Conservation District show that most of the groundwater pumps are very inefficient, with an estimated average of 30 to 40 percent OPPE, with some even more inefficient, and few more than 50 percent OPPE.

The advisor sees several current barriers to energy-efficient groundwater pumping among the small farmers in the advisor's program area. Some small farmers' acreage used to be orchards or vineyards, with old, inefficient irrigation systems set up with a shallower well. Absentee landlords can also be a problem because they are not interested in improving the property. The advisor mentioned that many of the small farmers, particularly those with limited technical backgrounds or English language skills, are unaware that they use inefficient pumps, are unlikely to understand the technical results of a pump test, or do not have time or the capacity to prioritize making them more efficient. The energy needed to pump generally only rises to awareness through peaking energy costs. Language barriers are also problematic when it comes to knowing which incentive programs exist and how to apply. Moreover, small farmers may not qualify for efficiency incentives,[47] but highlighted that small farmers do receive priority consideration for SWEEP in accordance with the Farmer Equity Act of 2017.

Considering how these barriers may have changed over the past five to ten years, the farm advisor spoke of the most recent multi-year drought. During this time, these farmers faced much higher energy bills than in previous years due to inefficient pumps, a dropping groundwater table, and, for flood irrigators, the need to leave the pump on longer to irrigate effectively when faced with low water flows. TOU rates imposed by the electric utility often meant that some small farmers were irrigating during hours with peak electricity tariffs, although the advisor and the advisor's staff were then able to help farmers switch to more appropriate rate structures. If a well were to dry up during a drought, landlords would sometimes split the costs of drilling a new well or might entirely cover the cost of drilling a new well, if they value the tenant.

Landlords could also decide not to drill a new well, and the tenant would leave the parcel of land and either find a new parcel or stop farming.

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[47] For example, to qualify for APEP pump testing and upgrade incentives, pumps must be at least 25 HP.

Concerning the advisor's expectations over the next five to ten years, the advisor mentioned that the effects of SGMA implementation, which starts in 2020, will be highly varied, depending on the characteristics of the local groundwater basin and how the GSA decides to manage groundwater. They indicated that some GSAs in the Central Valley are more open than others to involving marginalized groups in decision-making processes. In the short term, the advisor expects shallower wells to run dry during droughts, and that farmers leasing land may be vulnerable to groundwater markets, because landlords may sell the water to nearby farmers with higher-value crops or decide to use the water allocation from the rented land on their own, high-value crops. In the longer term, however, she expects SGMA to benefit small farms if it is successful in stabilizing groundwater levels.

The growers for whom the Small Farm Program was created are still underserved, with accompanying equity concerns. At the same time, given their vulnerable positions with respect to reliance on groundwater and older inefficient equipment, there is great potential to reduce the energy needed to pump groundwater on these farms. To this end, the advisor suggested several solutions. Incentive programs such as SWEEP and REAP could conduct more outreach in more languages to smaller-scale farmers.

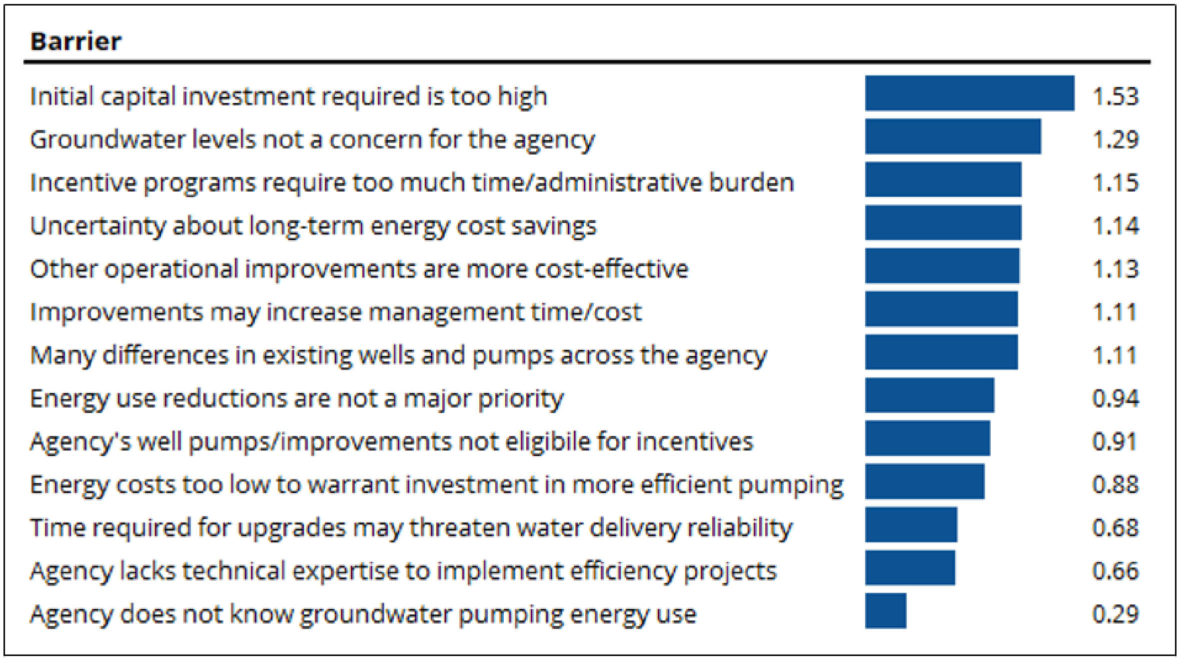
Similarly, while PG&E's programs like zero-interest loans and rebates for pump- efficiency repairs could benefit these farmers, the necessary paperwork is burdensome for small farmers, especially for those with educational or language limitations. In addition, the advisor sees small, diversified farms as particularly suited for the installation of VFDs and solar PV. Also, additional trainings on irrigation efficiency would be beneficial because most of the farmers rely on a trial-and-error approach instead of using moisture sensors and scheduling irrigation events. Also emphasized was the need for appropriate technology in this regard — which should be easy to understand and easy to fix — instead of expecting small farmers to use the California Irrigation Management Information System (CIMIS) or calculate expected evapotranspiration. Finally, there are only four small farm advisors statewide; the one the team spoke with is the only one in the San Joaquin Valley. Renewed support for the Small Farms Program, leading to more small-farm advisors and statewide support for small farms extension and research activities, would also allow small farmers to avail themselves of these opportunities to reduce groundwater pumping energy.

In addition, results from some questions discussed in Chapter 5, specifically the ones related to the barriers and incentives for increasing energy efficiency in groundwater pumping and conserving water, can be revisited with a more quantitative methodology. The team assigned weights to responses associated with a Likert scale, according to the position of the response relative to the scale. The weights are as follows: "not at all" = 0, "a little" = 1, "somewhat" = 2, and "very much" = 3. The team applied these weights to results displayed in Figure 18 and Figure 19, which present the barriers to reducing groundwater pumping energy respectively in municipal and agricultural water suppliers. Based on these weights, the team calculated an associated weighted average score, where the higher the score, the higher the barrier. Figure

48 displays the answer choices in descending order of these scores for all municipal respondents. With this ordering, the five top barriers faced by municipal suppliers follow.

- The initial capital investment required is too high.
- Groundwater levels are not a concern for the agency.
- Incentive programs require too much time or administrative burden.
- There is uncertainty about long-term energy cost savings.
- Other operational improvements are more cost-effective.

Figure 48: Weighted Scoring of Barriers to Reducing Municipal Groundwater Pumping Energy (n=36)



Source: Lawrence Berkeley National Laboratory

The new scoring approach brings to the top five barriers concerns with the uncertainty about long-term energy-cost savings and concerns that other operational improvements are more cost-effective in groundwater pumping. They replace, in the rank, concerns with the increased management time and costs of improvements and concerns with the differences in existing wells and pumps across the agency. Two of the five top hurdles in the scored rank are financial in nature (high initial costs, other improvements being more cost-effective), while another (burdens of incentive programs) touches on both financial and administrative concerns. These are consistent with the perspectives presented by TEC program managers, who mentioned lack of funding as a barrier, particularly pertinent to public municipal water suppliers. It is also in line with their view that risk aversion has been a hindrance to efficiency improvements in the last five to ten years. Combined, these two factors may explain why respondents consider the initial capital investments too high, even when these investments can prove cost-effective over the life of the improved pumping plant and under future energy cost uncertainties. Together, the three financial-related barriers indicated by respondents have the potential to be mitigated through some combination of better outreach and education, streamlining program requirements where possible, and financial assistance programs. The administrative-related barriers indicated by respondents (incentive programs require too much time or administrative burden, and improvements may increase management time and cost, the sixth barrier in Figure 47), are in line with the perspectives the team obtained from the specialist from SCE. The specialist mentioned that the time — and indirectly the cost — required to make upgrades prevent water agencies, especially municipal public agencies, (which sometimes need to obtain budget approval for improvements from city councils), from making efficiency improvements. The specialist also mentioned the timing of the upgrades, regarding continuity and reliability of the service, as a critical factor to decide on improvements. This too was indicated by respondents as a barrier to making pumping efficiency improvements, yet with a lower score than other barriers.

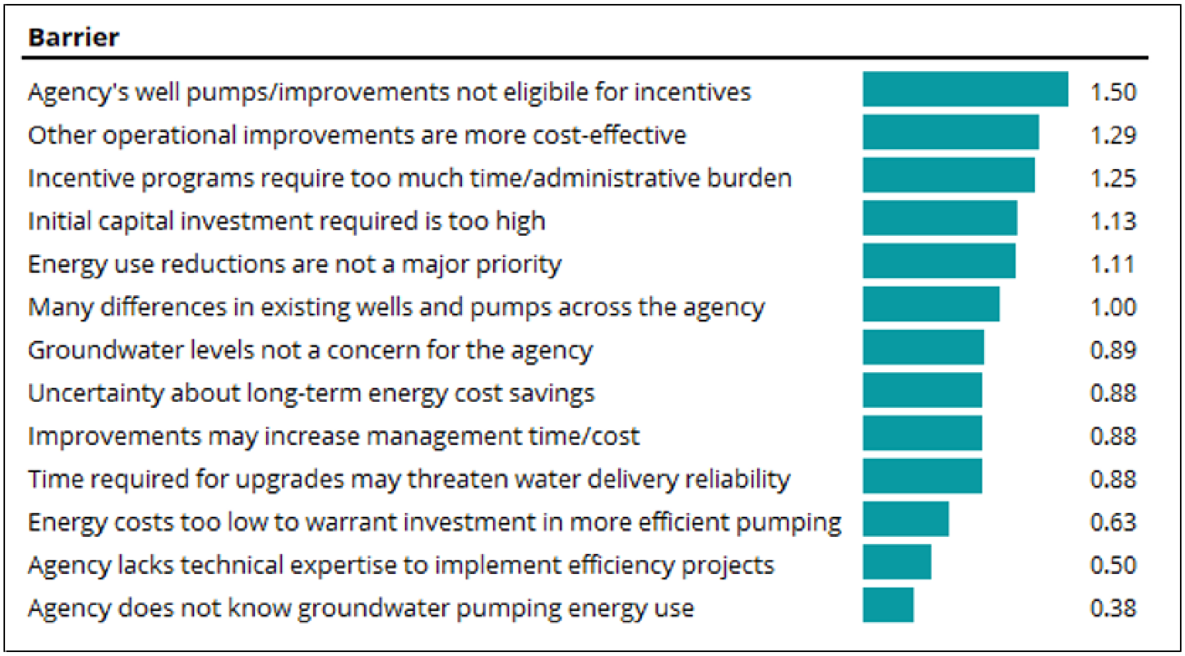
Groundwater levels not being a concern for a substantial share of municipal respondents may warrant further investigation, as its meaning may be multifaceted. For example, perhaps an agency feels the rate of groundwater withdrawals from the local aquifer is sustainable. In some cases, depending on hydrology, this may indicate a shallow water table, meaning that pumping requires relatively minimal energy. In other instances, this assumption may not be true. Finally, uncertainty about long-term energy cost savings might be addressed via better educational outreach or through the development of payback models that incorporate expected equipment lifetimes and projected future energy costs. However, uncertainty around SGMA — and whether groundwater levels will be required to be of concern for most agencies — and future energy costs may cloud the picture. Interestingly, most municipal suppliers appear to be familiar with how much energy they use to pump groundwater, and only about one quarter of respondents cite lacking technical expertise as "somewhat" or "very much" of a concern.

Concerning agricultural water suppliers, Figure 49 displays the same answer choices presented in Figure 19 (in Chapter 5) in descending order of the scores just described for all agricultural respondents. With this ordering, the five top barriers faced by agricultural suppliers follow.

- Agency's well pumps and improvements are not eligible for incentives.
- Other operational improvements are more cost-effective.
- Incentive programs require too much time or pose administrative burdens.
- The initial capital investment required is too high.
- Energy use reductions are not a major priority. Share of the "somewhat" response in the latter barrier when compared with the former. This is consistent with the notion that irrigation districts deal with customers that — in the short term — tend to be less flexible regarding their water needs and timing than the customers of their municipal counterparts; and that, as a consequence, reliability of water supply is their main business goal regardless of the amount of energy required to meet that goal. While the four EWMPs with the highest percent of implementation somehow relate to improving their ability to secure an appropriate level of service, the one with least percent of implementation relates to evaluating and improving their pumps' efficiency.

The fact that agricultural supplier well pumps and their improvements are not eligible for incentives was indicated as the top barrier for efficiency upgrades. This could be driven by a biased sample but deserves, nevertheless, further investigation. In addition, the three financial (and some administrative) barriers (the initial capital investment required is too high, other operational improvements are more cost-effective, and incentive programs require too much time or administrative burden), as discussed for municipal suppliers, are consistent with the perspectives presented by experts from TEC and SCE.

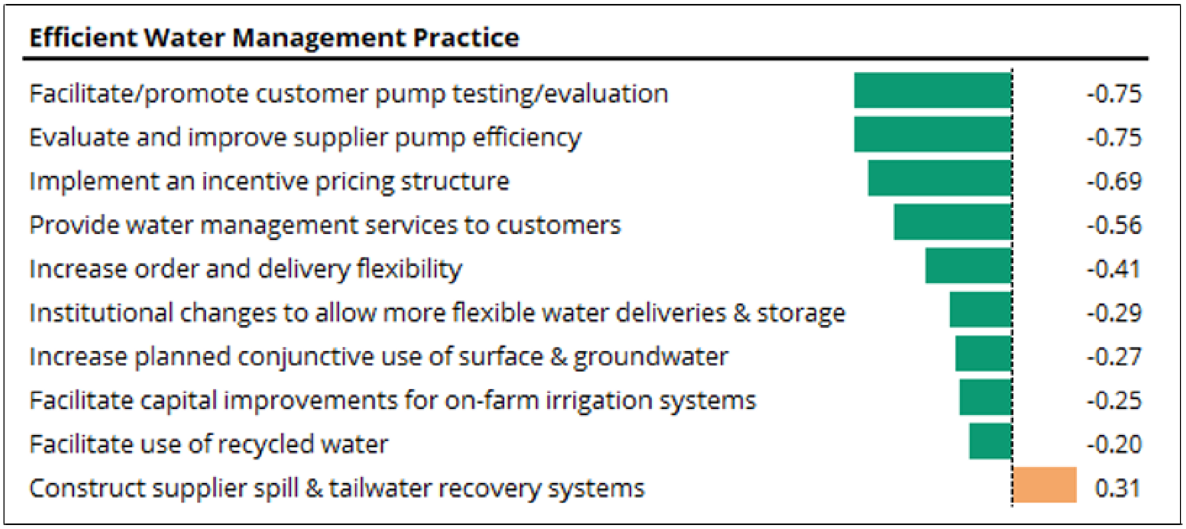
Figure 49: Weighted Scoring of Barriers to Reducing Agricultural Groundwater Pumping Energy (n=9)



Source: Lawrence Berkeley National Laboratory

The team also adopted a weighted approach to results presented in Figure 21 in Chapter 5 concerning the potential of EWMPs to affect energy needs. The weights, in this case, are as follows: "reduce energy needs by a lot" = -2, "reduce energy needs by a little" = -1, "keep energy needs about the same" = 0, "increase energy needs by a little" = 1, and "increase energy needs by a little" = 2. Figure 50 ranks EWMPs in descending order of respondents' perceptions of the ability of EWMPs to save energy. Interestingly, despite "energy use is not a major priority" appearing in the top five barriers to improve energy efficiency in groundwater pumping, respondents agree that nine of the ten EWMPs listed in the figure contribute to reduced energy use. A possible interpretation here is that these suppliers believe that some energy reduction is inherent to the EWMPs they implement. Also worth noting is that facilitating and promoting pump testing and evaluations to customers has a percent of implementation (approximately 27 percent) almost as high the implementation of the EWMPs, which contribute to improvements in their levels of water supply service (30 percent).

Figure 50: Weighted Potential of EWMP's to Affect Energy Needs (n=18)



Source: Lawrence Berkeley National Laboratory

The research team also conducted a weighted analysis to the responses presented in Figure 22 and Figure 23 (Chapter 5) that address, respectively, municipal and agricultural water suppliers' interest levels for incentives and other offerings. The sum of these weighted responses was then divided by the total number of respondents that answered that question. Table 28 presents the individual average weights for each response option.

This analysis reveals that municipal respondents were most interested in financial assistance for infrastructure upgrades to enhance pumping efficiency (scoring 2.31), followed by financial support for implementation of efficient water management practices (2.25), enhanced collaboration with neighboring water agencies/districts (2.25), and energy and flow metering of wells (2.22). This indicates that on average, respondents were somewhere between "somewhat" and "very" interested in these opportunities. The fact that financial assistance is the most desired type of incentive is consistent with the top barriers indicated by respondents and with experts' perspectives related to these barriers. Municipal respondents were least interested in external recognition for taking actions to improve pumping efficiency (scoring 1.29), followed by voluntary offset programs where groundwater users willing to reduce their usage are able to trade a credit for the unused water with users willing to purchase this credit (1.31), and followed by a long-term underground water-storage credits market (1.51).

Interest level for the top options was somewhat similar across the two groups.

Agricultural respondents were most interested in enhanced collaboration with neighboring water agencies/districts (scoring 2.26). This is consistent with the perspective presented by TEC experts, who mentioned agricultural water suppliers' lack of enough technical staff, which could explain agricultural respondents' interest in further collaboration with their peers. The second most indicated interests were managed aquifer recharge (district-led) and energy flow metering for wells both scoring 2.20. Agricultural respondents also indicated groundwater metering ground water management to be of high interest, with an average score of 2.05 (in contrast to the 1.75 reported by municipal respondents). The interest in metering well operations and in data and tools to improve groundwater management are somehow consistent with the perspective presented by SCE's specialist, who mentioned that well pump efficiency is a moving target that requires continual monitoring and intervention. While agricultural respondents indicated earlier in Question 9 that they did engage in some well metering and monitoring, this seems an area to be further expanded and likely the target of financial assistance. Agricultural respondents, like municipal respondents, were least interested in external recognition for efficiency actions (scoring 1.37), followed by holding educational programs for growers (1.42), and then a transfer and market system for water rights (1.47), which also scored low for municipal suppliers. The little interest in educational programs is in line with the perspective presented by several experts, who mentioned that utility pump efficiency programs are well known by agencies.

Table 28 indicates where responses diverged most between the two sample groups. The biggest differences in interest level were with agricultural respondents expressing more interest in and voluntary offset programs and district managed aquifer recharge than their municipal counterparts. Overall, respondents of both groups expressed similar levels of interest in the incentives and offerings, with an average weighted interest level of 1.81 for municipal respondents and a slightly higher interest level for agricultural respondents of 1.84.

Table 28: Weighted Analysis Scoring of Incentives and Offerings

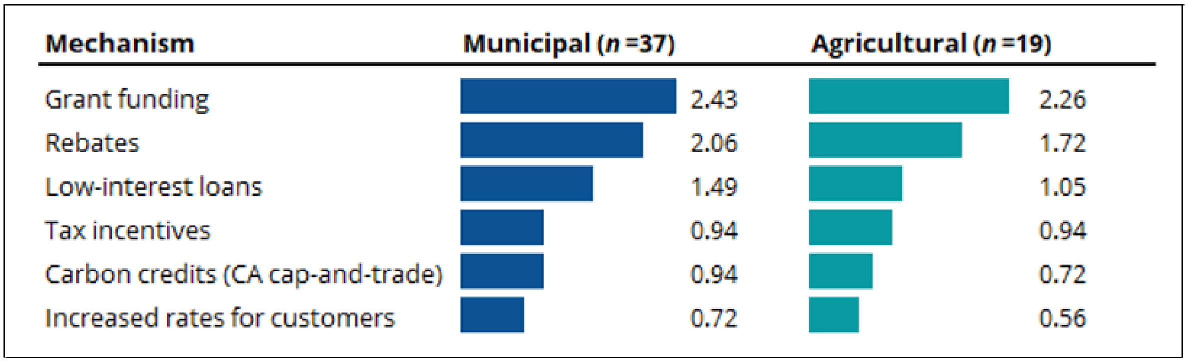
Municipal Incentive or Offering (n=36)	Score	Agricultural Incentive or Offering (n=20)	Score
Financial assistance for infrastructure upgrades to enhance pumping efficiency	2.31	Enhanced collaboration with neighboring water agencies	2.26
Financial support to implement efficient water management practices, e.g., subsidies, funding matches	2.25	Manage aquifer recharge (district led), including recycled water	2.20
Enhanced collaboration with neighboring water agencies	2.25	Energy and flow metering of wells	2.20
Energy and flow metering of wells	2.22	Data and tools to evaluate groundwater management	2.05
Energy management practices (i.e., demand response/load reduction)	1.92	Managed aquifer recharge (landowner led)	2.00
Managed aquifer recharge, including recycled water	1.83	Financial assistance for infrastructure upgrades to enhance pumping efficiency	2.0
Information websites on energy-efficient management of groundwater	1.81	Financial support to implement efficient water management practices, e.g., subsidies, funding matches	1.94

Municipal Incentive or Offering (n=36)	Score	Agricultural Incentive or Offering (n=20)	Score
More access to technical expertise to improve pumping efficiency	1.78	Long-term underground water storage credits market	1.85
Data and tools to evaluate groundwater management	1.75	Voluntary offset programs (groundwater users who lower trade credit for unused water with buyers who buy this credit)	1.84
Long-term underground water storage credits market	1.51	More access to technical expertise to improve pumping efficiency	1.70
Transfer and market system for water rights	1.35	Informational websites on energy-efficient management of groundwater	1.63
Voluntary offset programs (groundwater users who lower trade credit for unused water with buyers who buy this credit)	1.31	Energy management practices (i.e., demand response/load reduction)	1.63
External recognition for improving pumping efficiency	1.29	Transfer and market system for water rights	1.47
		Holding educational programs on energy-efficient groundwater management	1.42
		External recognition for improving pumping efficiency	1.37
Total weighted interest score = 1.81		**Total weighted interest score = 1.84**	

Source: Lawrence Berkeley National Laboratory

The team applied the same weighting approach to responses presented in Figure 24 and Figure 25, which address the desirability of various financial mechanisms to reduce groundwater pumping energy in municipal and agricultural water suppliers, respectively. Figure 51 presents the weighted results. After the scoring, the two preferred mechanisms for both groups of suppliers are still grant funding and rebates, and the two least desirable are still increased rates for customers and carbon credits. The only change in the rank after the scoring is that low-interest loans and tax incentives appear in reverse order of priority for agricultural suppliers.

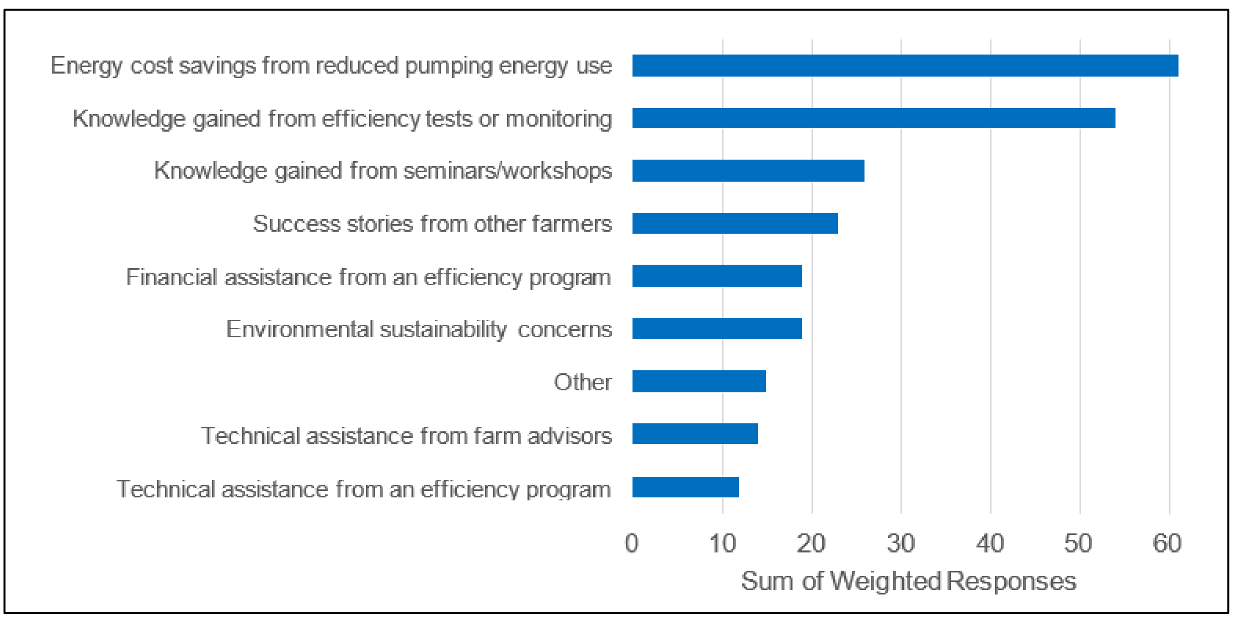
Figure 51: Weighted Scoring of Desirability of Financial Mechanisms to Reduce Groundwater Pumping Energy



Source: Lawrence Berkeley National Laboratory

Similarly, the team applied a weighting approach to responses from growers that ranked the factors that most influenced their decision to take actions they believe could affect their groundwater energy use. Figure 52 presents a weighted analysis of these factors. Responses were weighted as follows: a response of 1 (indicating most important) was assigned a weight of 3 points, a response of 2 (indicating second-most important) was assigned a weight of 2, and a rank of 3 (indicating third-most important) was assigned a weight of 1. Options that were not ranked were assigned a weight of zero, so were essentially not counted.

Figure 52: Influential Factors in Taking Energy Efficiency Actions, Weighted (n=35)



Source: Lawrence Berkeley National Laboratory

Respondents overwhelmingly signaled two factors that significantly motivated their actions: first, the energy cost savings from reduced pumping energy use knowledge or insights learned from pump efficiency tests or other pump monitoring technologies. These responses had a weight of 61 and 54, respectively. These response options also indicated as the "most important" factor most frequently, with 29 percent of respondents choosing the former as the "most important" influence, and another 29 percent of respondents choosing the latter as "most important." The second aspect, the one related to pump tests, is in line with perspectives presented by experts from PG&E and SCE. So is the following influential factor, which points to the knowledge that growers gain from informational and educational events, was also corroborated by SWEEP experts. The expert from SCE also mentioned that growers tend to be skeptical concerning new measures and prefer to learn from one another regarding best practices.[48]

This explains the fourth influential factor in the rank — that growers rely on success stories from other farmers to take energy-efficiency actions.

In this line, the experts from SWEEP mentioned the case of VFDs, which has not been historically regarded as a good investment by some farmers, until their neighbors and friends verify VFDs' efficacy in reducing energy and energy costs. Such farmers' behavior is also somehow supported by another experience shared by the SWEEP experts, who mentioned they suspect that word of mouth from growers' neighbors is the most effective recruitment method for the program. Assistance from programs (including technical and financial) did not appear to be as significant as an influencing factor.

for previously taken energy efficiency actions. However, that does not necessarily indicate a lack of interest in these programs — limited awareness or accessibility of these programs or accessibility could have precluded participation. In considering the responses motivating energy efficiency actions, it is unsurprising that growers specified energy cost savings as a primary driver. Additionally, the influence that pump tests and pump monitoring had on efficiency actions should not be overlooked since this suggests that improved understanding of current pump operations and performance often precedes energy-efficiency improvements.

Concerning the barriers to reducing on-farm groundwater pumping energy, the team adopted the same weighting approach used to rank barriers for water suppliers. Figure 53 displays the answer choices in descending order of the weighted scores for all respondents, as well as subgroups of respondents by farm size (based on total annual sales volume); the higher the score, the bigger the barrier perceived by each group of respondents. With this ordering, the five barriers for all respondents with the highest average weighting follow.

- Administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs).
- Improvements will not reduce operating costs enough to cover equipment and implementation costs.
- Burden of paying costs up front (programs) in rebate reimbursement or tax incentive.
- Not aware of any options or programs that exist to increase pump efficiency.
- Uncertainty about actual performance of efficient well and pump systems.

[48] Whereas this was noted by the specialist regarding irrigation methods, it should also apply when it comes to well pump improvements.

Figure 53: Barriers to Reducing On-Farm Groundwater Pumping Energy by Farm Size From Total Annual Value of Sales, With Calculated Weighted Averages of Likert Scale Scores (n=48)

Barrier to reducing on-farm groundwater pumping energy	All farms	Large farms	Medium farms	Small farms
Administrative burden of assistance programs	2.09	2.36	2.33	1.30
Improvements won't lower operating costs enough	2.00	1.64	2.21	1.91
Burden of paying costs up front	2.00	1.85	2.38	1.64
Not aware of existing programs to increase efficiency	1.49	0.50	1.62	2.25
Uncertainty how efficient well/pump system will perform	1.48	1.50	1.47	1.42
Time burden of determining assistance I qualify for	1.44	1.92	1.64	0.91
Program ineligibility	1.44	1.27	1.62	1.46
Difficulties obtaining financing	1.33	1.25	1.29	1.58
Landowner not incentivized to make improvements	1.20	0.83	1.25	1.21
Investigating improvements not a priority at this time	1.14	0.55	0.92	2.08
Don't know where to find technical expertise	1.10	0.92	1.17	1.00
Waitlisted/not selected by government/utility program	0.95	1.09	1.00	0.77
Low concern about future energy prices	0.93	0.83	0.73	1.08
Privacy concerns	0.92	1.17	1.00	0.30
Improvements will increase management time/cost	0.92	0.82	1.38	0.55
Energy costs minor relative to other operational costs	0.91	0.27	0.79	1.75
Don't know current pumping energy/efficiency	0.89	0.45	1.17	0.73
Have not considered potential other benefits of energy efficiency	0.72	0.69	0.62	0.82
Waitlisted by pump/well companies	0.54	0.73	0.50	0.20

Source: Lawrence Berkeley National Laboratory

Considering the average barrier score by farm size group may shed light on what types of farm operations perceive greater obstacles to groundwater pumping energy efficiency. The average barrier score for large farm operations, defined as those with $1,000,000 or more in gross value of all agricultural products sold in 2017, was 1.09. For medium farm operations, defined as those with a gross value of all agricultural products sold in 2017 of between $100,000 and $999,999, was 1.32. Finally, for small-scale farmers, defined as those with less than $100,000 gross value of all agricultural products sold in 2017, the average barrier score was 1.21.

For large farm operations, the top three barriers to lowering groundwater pumping energy use are: (1) administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs); (2) time burden of determining what programs or type of assistance they qualify for, and burden of paying costs up front (for example, in rebate reimbursement or tax incentive programs). The first two aspects are supported by the SWEEP experts, who recognize that — in the case of SWEEP — the application process is technical and can be challenging, posing hurdles to applicants. The third aspect above is consistent with the perspective of SCE's specialist, who mentioned that for farms of all types (sizes) the cost of capital for investing in energy efficiency can be an obstacle. The two barriers with the lowest average weighting for large growers are that energy costs are minor relative to other operational costs and that they do not know how much pumping energy is currently being used, or the efficiency of their well pumps. Because these were commonly cited as being "not at all" a barrier, one could infer that energy costs are not a minor component of operational costs on large operations, and that large-scale growers have good awareness of on-farm groundwater pump efficiency and associated energy use. This is also supported by the experts from APEP, who noted that groundwater pumping costs may sum up to a million dollars per year for some larger growers.

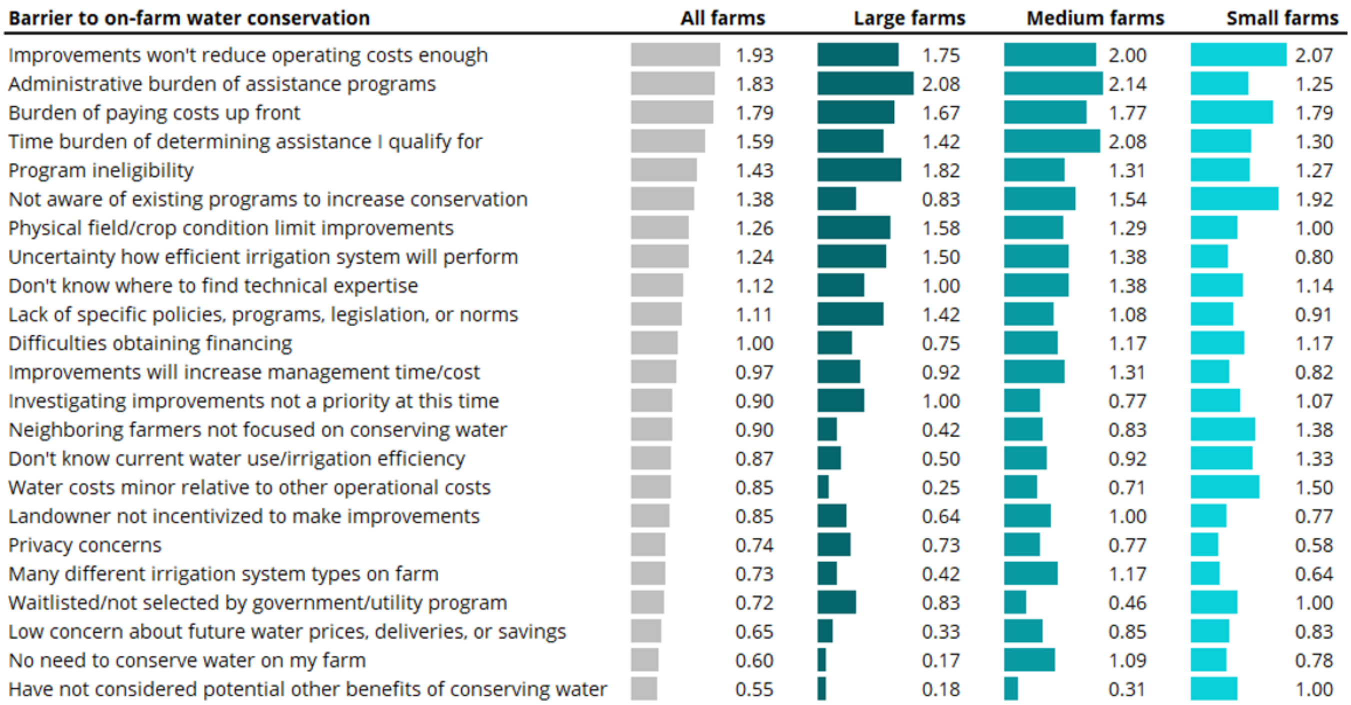
For medium farm operations, the top three barriers are: (1) burden of paying costs up front (such as in rebate reimbursement or tax incentive programs; (2) administrative burdens associated with program requirements (for example application process, compliance or reporting requirements, or other transaction costs); and that (3) improvements will not reduce operating costs enough to cover equipment and implementation costs. Similarly, to what is noted for large farm operations, the first two barriers are supported by the perspectives of experts from SCE and SWEEP. The least two commonly cited barriers are being waitlisted by pump testing or other well-related companies due to high demand and not having considered other potential benefits of energy efficiency (such as air quality, electric grid reliability).

In contrast, small-scale farmers identified the following top three barriers: (1) not aware of any options or programs that exist to increase pump efficiency, (2) investigating improvements not a priority at this time, and (3) improvements will not reduce operating costs enough to cover equipment and implementation costs. The first barrier is supported by the SWEEP experts, who mentioned that — even if funding were unlimited — it would be difficult to reach out to all potential applicants. The experts from PG&E and SCE reported that the pump test and efficiency programs these utilities operate are well known. However, as mentioned by the small farm advisor, the limited technical background of small growers, as well as language barriers, can be problematic when it comes to knowing which incentive or assistance programs exist and how to apply. The farm advisor also explained that small farmers are not aware they use inefficient pumps, are unlikely to understand the technical results from a pump test, and do not have time or the capacity to prioritize well pump improvements. In addition, if the landlord of the rented farm is not willing to pay for the well improvements, either in full or at least in part, investments required by the small farmer to improve pumping efficiency may be beyond their financial capacity or not prove cost-effective in the short term. The latter two aspects may explain why investigating improvements is not a priority for small farmers and why these improvements do not seem cost-effective, the two additional most important barriers indicated by small farmers. The two least common barriers are being waitlisted by pump testing or other well-related companies due to high demand and privacy concerns.

When considering barriers with the biggest discrepancy in Likert scale score across farm size, note that small-scale farmers or ranchers rated being unaware of any options or programs that exist to increase pump efficiency as a far more significant barrier (2.25, or between "somewhat" and "very much") than did large growers (0.50, between "not at all" and "a little"). This finding suggests that outreach to small farms may yield dividends, although many incentive programs as currently structured (such as PG&E's APEP and SCE's pump testing services) exclude pumps below 25 HP. In addition, small-scale growers were more far likely to mention as a barrier that investigating improvements was not a priority at this time than were large growers, who one expects would have more farm staff, budget, and capacity to consider implementing efficiency upgrades.

Concerning the barriers to on-farm water conservation, the team adopted the same weighting approach used to score growers' barriers to reduce on-farm groundwater energy described here. Figure 54 displays the answer choices in descending order of the weighted scores for all respondents, as well as subgroups of respondents by farm size (based on total annual sales volume); the higher the score, the bigger the barrier perceived by each group of respondents. With this ordering, the five barriers for all respondents with the highest average weighting are the same as those previously mentioned.

Figure 54: Barriers to On-Farm Water Conservation by Farm Size From Total Annual Value of Sales, With Calculated Weighted Averages of Likert Scores (n=48)



Source: Lawrence Berkeley National Laboratory

Considering the average barrier score by farm size group may shed light on what types of farm operations face higher barriers to on-farm water conservation projects. The average barrier score for large farm operations, those with $1,000,000 or more in gross value of all agricultural products sold in 2017, was 0.97. For medium farm operations, those with a gross value between $100,000 and $999,999, was 1.19. Finally, for small- scale farmers, those with less than $100,000 in gross value, the average barrier score was 1.14. In all cases, these scores were lower than those for lowering groundwater pumping energy.

For large farm operations, the three most significant hurdles to implementing on-farm water conservation efforts are: (1) administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs); (2) program ineligibility (such as income, landownership, or location issues), and (3) that improvements will not reduce operating costs enough to cover equipment and implementation costs. The first two barriers are consistent with the perspectives the team obtained from the experts from SWEEP, who recognized the application process can be quite challenging, and mentioned that some areas are not well-suited for program assistance. The two barriers with the lowest average weighting for large growers are that there is no need to conserve water on their farms, and that they have not considered potential other benefits of water conservation (for example minimizing groundwater overdraft, decreasing pumping energy). The low weighting implies that the converse is true: many respondents have taken into account co-benefits of water conservation, and most feel a need to conserve water in their operations.

For medium farm operations, the top three barriers to water conservation somewhat overlap with those identified by large operations: (1) administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs); (2) the time burden of determining what programs or type of assistance for which growers qualify; and (3) that improvements will not reduce operating costs enough to cover equipment and implementation costs. The first barrier is supported by the SWEEP experts, who mentioned the application process is technical, can be challenging, and poses hurdles to applicants. The two barriers least commonly cited are that respondents have not considered potential other benefits of conserving water (for example, minimizing groundwater overdraft, decreasing pumping energy) and having been waitlisted or not selected by government or utility programs (for example, project was considered low-priority or program had insufficient funds).

In contrast, small-scale farmers identified the following top three barriers: (1) improvements will not reduce operating costs enough to cover equipment and implementation costs, (2) not aware of any options or programs that exist to increase water conservation, and (3) the burden of paying costs up front (in rebate reimbursement or tax incentive programs). These are all consistent with the perspective the small farm advisor shared with the team. The limited technical background of small farmers, as well as language barriers, may prevent them from having a full understanding of the cost-effectiveness of on-farm water conservation measures, and from learning about available incentive and assistance programs, including financial assistance that could — at least partially — mitigate the burden of upfront costs. The two least common barriers are privacy concerns and having many different irrigation system types across farms; the latter suggests that small-scale farms may tend to rely upon only one irrigation system type.

Finally, small-scale farmers or ranches rated several impediments quite differently than large-scale growers. The barrier with the largest disparity in Likert score is that water costs were minor relative to operational costs; small growers rated this at 1.50, between "a little" and "somewhat," while large growers assessed this barrier at 0.25, very close to "not at all," with medium growers rating it at 0.71, close to "a little." Such a discrepancy may reflect why larger farms consider higher water costs as a share of operating costs and may be more motivated to irrigate efficiently. In addition, small-scale growers were more likely to state that they were unaware of existing programs that increase water conservation as a barrier — a similar finding to pump energy-efficiency programs.

CHAPTER 7: Conclusions

This report describes the surveys the team conducted with the three main populations of groundwater pumpers in the state — municipal and agricultural water suppliers, and growers — to understand groundwater pumping practices and efficiency actions, as well as perceived barriers to improving the energy efficiency of groundwater pumping and implementing on-farm water conservation measures. The surveys also sought to understand the experience and interest that these three groups of groundwater pumpers may have in programs designed to reduce groundwater pumping energy use. The report further provides recommendations drawn from survey results, and from conversations the team held with subject-matter experts, which may be useful to inform the design of future policies and programs that seek to reduce the energy required to pump groundwater in California.

Considering the characteristics of the three targeted populations, the team anticipated it would be challenging to incur high response rates for two notable reasons. First, potential respondents in these populations are regularly asked to participate in surveys, which has resulted in survey fatigue. Second, given that the topic of groundwater management in California is historically highly contentious, and neither LBNL nor the CEC were well-known entities among these populations, the level of trust potential respondents would place in the research team's efforts was likely to be minimal and lead to low response rates. Given the difficulty associated with reaching a large sample of respondents, the survey team used nonprobability sampling, which meant the survey team could not infer characteristics from the sample to the general population, in statistical terms.

The surveys were conducted during the late fall and the winter of 2018 to 2019. The team took many steps to address the limitations, including counting on several third parties which assisted with promoting the surveys and reaching out to the three targeted populations. However, as expected, the samples are small and non- representative of the populations surveyed. Nevertheless, in the case of the survey conducted with growers, some results are consistent with results from a previous survey conducted by the USDA, which can be considered representative of growers in the state. In addition, several results from the three surveys show consistency with the perspectives expressed by subject matter experts. Caution should be taken, though, when using the results presented in this report to support any decision-making related to groundwater pumping. For future, similar efforts, the team suggests employing additional outreach methods to increase the response rate, including snowball sampling, monetary incentives to encourage participation, and building partnerships with entities like USDA's NASS, which would be able to do outreach to a statistically representative sample. Additionally, the survey team suggests using a more concise survey questionnaire to minimize survey fatigue.

CHAPTER 8: Technology/Knowledge Transfer Activities

California relies significantly on groundwater to meet the state's water demand. The lack of a full, systematic recording of groundwater extractions poses challenges to understanding the drivers for groundwater pumping and subsequently estimating the energy needed to support the pumping. This is particularly critical during drought periods, when heavy pumping and the consequent deepening of groundwater tables increase the demand for energy to sustain groundwater extraction. In addition, the lack of understanding of programs to help reduce groundwater pumping energy prevents energy planners from accurately predicting increases in pumping efficiency and its associated energy reductions.

Project Background

This project offers a comprehensive look at how energy and groundwater interact in California and provides a basis for estimating energy demand for groundwater pumping in the near term, under alternative climate and policy scenarios. This report, the fourth part of the study, applies the relationships developed in the second part to estimate near-term groundwater pumping energy use and cost across the state under alternative climatic conditions. It further relies on findings from the third part of the study to simulate how the estimated energy and cost could be reduced with enhanced pump energy efficiency and water conservation.

Project Dissemination

This project has been disseminated since its initial stages. In May 2017, the project was introduced to participants of the Groundwater Workgroup of the Association of California Water Agencies (ACWA) during its 2017 Spring Conference in Monterey, California. The project has also been distributed to the following stakeholders by members of the project's TAC.

- California Department of Food and Agriculture
- California Department of Water Resources
- California Public Utilities Commission
- California State Water Resources Control Board
- City of Fresno
- City of Santa Rosa
- Irrigation Training and Research Center (California Polytechnic State University)
- Pacific Gas and Electric Company
- Powwow Energy
- Regional Water Authority
- San Luis & Delta-Mendota Water Authority
- UC Davis
- UC Kern Cooperative Extension
- UC Santa Barbara

- U.S. Department of Energy
- Westat

In addition, the survey conducted as part of this research led to the project becoming widely known among those who pump groundwater: municipal water agencies, irrigation districts, and growers, as well as the institutions that supported the team's outreach efforts. Survey recruitment fliers were distributed at the following events: the 3rd Open Farm, UC Kearney Agricultural Research and Extension Center, Parlier, in October 2018; ACWA 2018 Fall Conference, San Diego, in November 2018; Pistachio Research Board's Pistachio Day, Visalia, in January 2019; and the California Irrigation Institute's 57th Annual Conference, Sacramento, in February 2019. Fliers were also distributed by a TAC member to municipal water agencies and irrigation districts that are members of the San Luis & Delta-Mendota Water Authority. ACWA and CalWEP emailed their members about the surveys, as did the Groundwater Resources Association, the Natural Resource Conservation District, and the East Merced Resource Conservation District.

The Farm Journal emailed approximately 6,000 growers. The UCANR Cooperative Extension emailed around 200 farm specialists and advisors, as well as UC faculty to ask them to feature the survey with growers they work with. Additionally, the surveys were featured in newsletters from the California Association of Resources Conservation Districts and the California Climate and Agriculture Network; in the Maven's Notebook; in the California Farm Bureau Association's Ag Alert; and in the UCANR's peer-reviewed journal, California Agriculture. Also, the survey for farmers and ranchers was posted on the Facebook page of the Almond Board of California, tweeted by Fresno State's Center for Irrigation Technology, and featured in an article in Ag Net West and broadcast (radio) in its Farm City Newsday podcast. Finally, the survey for growers was also advertised several times in the California Farm Bureau Association's Ag Alert newspaper.

Knowledge Transfer

The team plans to share the results from this project with state agencies, academic researchers, electric utilities, and other relevant stakeholders through the project's TAC members and the third parties listed. The team will send the set of four technical reports produced during the project, and a summary of the relevant key findings. This information will also be sent to all municipal water agencies and irrigation districts that contributed groundwater data, and to those who indicated in their survey questionnaires they were interested in receiving the survey report.

The team also plans to summarize the results from this project in two LBNL technical reports. One report will include the data collection, organization, and analysis, as well as the estimates of groundwater electricity use and costs. The other report will summarize the survey efforts and results. In addition, the team plans to prepare a paper for a peer-reviewed journal. The paper will summarize the data and the methodological and modeling approaches used to estimate near-term total energy and grid-electricity use and costs for groundwater pumping in California and to present project results.

CHAPTER 9: Benefits to Ratepayers

Introduction

This research project quantified the energy used for pumping groundwater and identified efficiency measures for lowering energy use. A major goal of the project was to identify feasible energy efficient technologies (for example, better pumps) and practices (for example, better irrigation, conservation) that those users can adopt to reduce pump energy use. Better, more disaggregated estimates of groundwater energy use, along with estimates of savings potential, will help the state and utilities manage drought conditions, reduce customer utility bills, improve forecasting of future electric loads, and thus support electricity-sector resource planning.

An important outcome of this work is factors that allow user groups to overcome barriers to adopting conservation strategies. At this point, it is not known how this work will encourage users to adopt energy and water efficient technologies and practices. The team, nevertheless, estimates this project may reach total annual benefits of $100 million. Following are benefits the team estimated to user groups and ratepayers, assuming that they fully adopt the energy and water efficiency technologies and practices identified. IOU ratepayers may benefit from this work through effects, including:

- Lower energy costs from increased adoption of pump use efficiency measures.
- Environmental benefits, including air-quality and aquifer-quality benefits.
- Increased electrical system reliability from improved demand forecasts.
- Lower electricity rates from reducing both the electricity demand for groundwater pumping and the uncertainties of that demand.

Quantified Benefits

Conservation measures available to groundwater users in the state include:

- Improvements to pump efficiency.
- Improvements to farm irrigation efficiency.
- Groundwater management.
- Urban water-use efficiency.

The research team estimated reductions in groundwater pumping and energy use from these measures, evaluated reductions in air emissions related to those savings, and estimated the monetized values of those benefits.

Potential Pump Efficiency Energy Savings

A 2006 American Council for an Energy Efficient Economy (ACEEE) study indicated that average annual Central Valley groundwater electricity use is 2,250 GWh, and that average pump efficiency in the Central Valley is 70 percent (Wilkinson et al., 2006). Assuming the same electricity use today, a 10-percent increase in pump efficiency only in the Central Valley could save ratepayers about 250 GWh annually.

Potential Irrigation Efficiency Energy and Water Savings

The same 2006 ACEEE study suggests that improvements in agricultural irrigation efficiency could decrease agricultural pumping requirements between 0.2 and 0.8 million acre-feet of water annually. Given that it requires an average of about 200 kWh to pump an acre-foot of groundwater in much of California (Wilkinson et al., 2006), and assuming a similar decrease in pumping requirements today, irrigation efficiency measures have the potential to conserve between 40 and 160 GWh of electricity annually.

Potential Energy and Water Savings From Groundwater Management

Groundwater management and recharge programs could potentially reduce groundwater use about one million acre-feet annually — roughly 10 percent of annual average groundwater pumping in the Central Valley. Using groundwater management to raise groundwater pump depths by 10 percent could potentially conserve about 225 GWh of electricity annually.

Potential Energy and Water Savings From Urban Water Efficiency Measures

Urban water use efficiency measures have the potential to save about 2 million acre-feet of water annually. Urban areas, like agricultural areas, use groundwater to supply about 30 percent of their 9 million acre-feet of annual water demand (Wilkinson et al., 2006). Urban water use conservation could, at minimum, eliminate the need for 0.6 million acre-feet of groundwater pumping. Although the pumping depths to groundwater are not known precisely, 200 kWh per acre-foot provides a reasonable approximation of average pump electricity needs in urban California. This value suggests that urban water use efficiency programs have the potential to save 120 GWh of electricity annually.

These potential savings suggest that pump efficiency, irrigation efficiency, groundwater management, and urban water efficiency programs offer a total potential savings of 600-750 GWh of electricity and 1.8 to 2.4 million acre-feet of water to groundwater users and IOU ratepayers. The savings correspond to around 3.6 percent of the electricity used in agriculture and water pumping and 2.4 percent of the water used in California. They can help prevent long-term groundwater depletion and increased electricity needed to pump water from depleted aquifers. The savings will also avoid emissions of around 330 thousand tons of carbon dioxide and 450 thousand pounds mass (lbm) of nitrogen oxides, assuming emission factors of 0.49 ton of avoided carbon dioxide per megawatt-hour (MWh) and 0.67 lbm of avoided nitrogen oxides per MWh.

The potential benefits from full adoption of groundwater efficiency measures can be monetized. At an estimated retail price of electricity of $0.15/kWh, the potential energy savings would be worth $90 million to 115 million annually. In addition, at an estimated carbon value of $12 per ton, the potential carbon emissions benefits of the project are worth $4 million annually. Under those assumptions, the team estimates the total annual benefits of the project could reach $100 million.

Additional Benefits

This study further improves system reliability by helping utilities more accurately predict energy use associated with groundwater pumping. For example, current forecast methods appear to understate electricity demand for groundwater pumping, which is assumed to represent 5 percent of California electricity use; recent reports suggest the actual amount is closer to 7 percent. As for peak load reduction, it is difficult to evaluate the impacts of the potential mitigation measures on peak load, since currently much agricultural and almost all urban groundwater pumping is conducted at night, during lower-cost off-peak hours.

Impacted Market Segments in California

The most important affected market segments are those that rely on groundwater as a significant source of their water supply. Irrigated agriculture accounts for more than 70 percent of the total groundwater consumption in California and most attention should be focused on this user group. Public supply is the second most important segment of groundwater users in the state (estimated in 23 percent of total groundwater consumption). The surveys conducted during this research project focused on growers and public groundwater users, and factors that explain their groundwater use and conservation behavior.

Qualitative or Intangible Benefits to California Investor-Owned Utility Ratepayers

There are several benefits that might follow from this project in addition to the energy and water savings benefits described here, assuming water districts and users adopt conservation methods and high-efficiency strategies. These include:

- Benefits to water and air quality flowing from reduced groundwater pumping.
- System reliability benefits from improved methods to forecast electricity demand.
- Benefits to the quality and sustainability of aquifers that could result from decreasing groundwater pumping and groundwater overdraft.
- Benefits to crop yield of adopting water-efficient irrigation technologies.

The team also identified topics in this project that will assist water districts to design their mandated groundwater management plans to prevent groundwater overdraft, as required by the Sustainable Groundwater Management Act (SGMA), including:

- Available policies and technologies for preventing groundwater overdraft and decreasing electricity use.
- Barriers confronting households, farmers and districts that prevent the adoption of these policies and technologies.
- Factors that appear to increase the likelihood that households, farmers, and districts will adopt these policies and technologies.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
$/af	dollars per acre-foot
AFGD	aggregated farm-gate delivery
ACEEE	American Council for an Energy Efficient Economy
ACWE	Association of California Water Agencies
AFGD	Aggregated Farm-Gate Delivery
APEP	Advanced Pumping Efficiency Program
AWEP	Agricultural Water Enhancement Program
AWMP	Agricultural Water Management Plan
C	Community; the U.S. EPA classification for a public water system that serves at least 15 service connections used by year-round residents or regularly serves 25 year-round residents.
CA-NV AWWA	California-Nevada Section of the American Water Works Association
CalWEP	California Water Efficiency Partnership
CARB	California Air Resource Board
CDFA	California Department of Food and Agriculture
CEC	California Energy Commission
CIG	Conservation Innovation Grants
CIMIS	California Irrigation Management Information System
CIT	Center for Irrigation Technology (California State University, Fresno)
CoA	Census of Agriculture
Conjunctive use	The coordinated use of surface water and groundwater
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSP	Conservation Stewardship Program
CTA	Conservation Technical Assistance
DWR	California Department of Water Resources
EIA	Energy Information Agency
Energy-water nexus	Relationship between the water used for energy production, and the energy consumed for water use.
EPIC	Energy Program Investment Charge
EQIP	Environmental Quality Incentives Program
EWMP	Efficient Water Management Practices

Term	Definition
FRIS	Farm and Ranch Irrigation Survey
FRPP	Farm and Ranch Lands Protection Program
GHG	greenhouse gas
GRP	Grassland Reserve Program
GSA	Groundwater Sustainability Agency
GWh	gigawatt-hour
HIP	Healthy Incentives Pilot
HP	horsepower
HSC	Human Subjects Committee (Lawrence Berkeley National Laboratory)
IOU	investor-owned utilities
ITRC	Irrigation and Training Research Center
IRB	institutional review board
kW	kilowatt
kWh	kilowatt-hour
kWh/af	kilowatt-hours per acre-foot
lbm	thousand pounds mass
LBNL	Lawrence Berkeley National Laboratory
MWh	megawatt-hour
NASS	National Agricultural Statistics Service
NC	Transient Non-Community; the U.S. EPA classification for a public water system that regularly serves at least 25 non-residential individuals (transient) during 60 or more days per year.
NTNC	Non-Transient Non-Community; the U.S. EPA classification for a public water system that serves at least the same 25 non- residential individuals during six months of the year.
OPPE	overall pumping plant efficiency
PG&E	Pacific Gas and Electric Company
PPPC	California Public Purpose Program's Charge
PV	photovoltaic
REAP	Renewable Energy for Agriculture Program (CEC)
REAP	Rural Energy for America Program (USDA)
RFC	Raftelis Financial Consultants, Inc.
SCADA	Supervisory control and data acquisition

Term	Definition
SCE	Southern California Edison Company
SDG&E	San Diego Gas and Electric Company
SGMA	Sustainable Groundwater Management Act
SMS	short message service
SoCalREN	Southern California Regional Energy Network
SWEEP	State Water Efficiency and Enhancement Program
SWRCB	State Water Resources Control Board
TAC	technical advisory committee
TAF	thousand acre-feet
TEC	The Energy Coalition
TOU	time-of-use
UC	University of California
UCANR	University of California Agriculture & Natural Resources
U.S. EPA	Environmental Protection Agency
USDA	United States Department of Agriculture
UWMP	urban water management plan
VFD	variable frequency drives
WHIP	Wildfire and Hurricane Indemnity Program
WRP	Wetland Reserve Program

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: FRIS 2013 Statistical Results

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APPENDIX A: FRIS 2013 Statistical Results

NASS's FRIS 2013 describes relevant well characteristics at the farm operation level, such as numbers of wells used, wells with flow meters, pump capacity, operating pressure at well head, engine size for motors, and total hours operated in 2013, for primary, secondary, tertiary, and all other wells. Table A-1 provides summary statistics for those characteristics. Generally, except for operating pressure, tertiary and other wells have greater pump capacity, larger engine size, and are operated for more hours over the year in contrast to primary and secondary wells. At the same time, only 24 percent of farms in California that used wells in 2013 used more than two (also in Figure 5). These discrepancies may reflect that the larger farms, which may need to operate more wells to cover greater acreage, use bigger, more powerful well pumps more frequently.

Table A-1: Characteristics of Wells and Pumps in Irrigated Farms in California

Characteristics	Mean	Percentile		
		25th	50th	75th
Wells used in 2013				
Number of wells	3	1	1	2
Wells with flow meters	2	1	1	2
Pump Capacity (gallons per minute)				
Primary well	468	25	250	700
Secondary well	622	180	400	900
Tertiary well	716	118	647	1,000
All other wells, averaged	*768*	*300*	*600*	*1,100*
Operating Pressure at Well Head (pounds per square inch)				
Primary well	41	32	40	50
Secondary well	41	20	30	50
Tertiary well	34	20	40	45
All other wells, averaged	*34*	*20*	*26*	*40*
Engine Size for All Motors Including Electric (horsepower)				
Primary well	72	5	30	100
Secondary well	74	10	30	100
Tertiary well	86	10	40	107
All other wells, averaged	*103*	*35*	*70*	*130*
Total Hours Operated in 2013				
Primary well	772	185	500	1,000
Secondary well	1,024	235	649	1,500

Characteristics	Mean	Percentile		
		25th	50th	75th
Tertiary well	1,027	253	576	1,320
All other wells, averaged	*1,781*	*700*	*1,265*	*2,727*

Source (data): USDA National Agricultural Statistics Service

In addition to the well characteristics in Table A-1, FRIS 2013 provides information related to the energy sources used to run well pumps. Table A-2 presents summary statistics for that information.

Table A-2: Energy Related Characteristics of Wells in Irrigated Farms in California

Characteristics	Mean	Percentile		
		25th	50th	75th
Number of Pumps				
Electric	3	1	1	3
Diesel and biodiesel	3	1	2	3
Natural gas	1	1	1	1
LP gas, propane, and butane	2	2	2	2
Solar and renewable	1	1	1	1
Gasoline, ethanol, and blends	1	n/a	n/a	n/a
Area Irrigated with Water Pumped from Wells (acres)				
Electric	166	8	22	90
Diesel and biodiesel	183	14	35	150
Natural gas	51	4	4	4
LP gas, propane, and butane	56	n/a	n/a	n/a
Solar and renewable	70	1	34	40
Gasoline, ethanol, and blends	n/a	n/a	n/a	n/a
Energy Cost (dollars)				
Electric	$22,583	$900	$3,028	$8,922
Diesel and biodiesel	$23,377	$1,820	$3,600	$15,350
Natural gas	$4,877	$800	$800	$800
LP gas, propane, and butane	$2,420	$500	$500	$500
Solar and renewable	-	-	-	-
Gasoline, ethanol, and blends	$4,040	$168	n/a	n/a

Source (data): USDA National Agricultural Statistics Service

CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B: Survey Questionnaires

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APPENDIX B:
Survey Questionnaires

The three questionnaires developed by the research team targeting the three most relevant populations of groundwater pumpers in the state are presented in this appendix in the following order: municipal water suppliers, agriculture water suppliers, and farmers and ranchers.

B.1: Survey of Municipal Water Suppliers

BERKELEY LAB

Thank you for being willing to respond to this survey. To learn more about the project, visit gwenergy.lbl.gov.

We are interested in learning more about the energy associated with groundwater well pumping. If your organization also supplies water for agricultural purposes, please consider only municipal water use throughout this survey. Delivered groundwater from another supplier should not be counted here, as this would result in double-counting if that supplier also fills out this survey.

If at any point you need to leave the survey and come back to complete it, you may automatically return to where you left off by using the same browser and computer that you are using now.

Please provide the name of your water agency below. This information will not be publicly connected to your responses, but will allow us to reference any applicable Urban Water Management Plans, as well as consider geographic variables in our analysis.

While all individual results will remain confidential, in our public report we would like to acknowledge your agency in a list of agencies that we thank for their participation in this survey. Do you consent to this acknowledgment of your agency's participation? (If you do not consent, the name of your agency will not be acknowledged).

- ○ Yes, I consent
- ○ No, I do not consent

Throughout the remainder of the survey feel free to skip any questions, but please try to answer as many questions as you can.

Q1. Please fill out **ONE** of the two following options (whichever you prefer) for your agency's total water supply for the 2015, 2016, and 2017 water years.

Option 1:

	Unit of measurement		Water year		
	Acre-feet	Million gallons	2015	2016	2017
How much was the agency's total water supply?					
How much groundwater did the agency pump from its wells?					

Option 2:

	2015 water year	2016 water year	2017 water year
Groundwater pumped as share of total water supply (%)			

Q2. Because of different hydrological conditions, groundwater pumping may vary across years. Ignoring these hydrological variations, what changes in your agency over the past 10 years, if any, have yielded general trends in reliance on and depth to groundwater? For example, why is depth to groundwater generally increasing/decreasing, or why is your agency using less/more groundwater relative to total water supply today compared to 10 years ago?

Q3. How does the cost of treated local groundwater to your agency compare to the cost of treated surface or imported water? Treated local groundwater typically costs...

☐ A lot less ☐ Somewhat less ☐ About the same ☐ Somewhat more ☐ A lot more

☐ Unable to generalize; please explain ☐ We have no water sources other than groundwater

Q4. Please provide your best estimates below:

	2015 water year	2016 water year	2017 water year
In total, how many groundwater wells were active (ready to operate, given system demand)?			
In total, how many groundwater wells were on standby (operated only if necessary)?			

Q5. How many of your groundwater wells have wellhead treatment beyond disinfection (for example, chlorination, chloramination)? ___

Q6. What percent of your agency's groundwater well pumps are powered by non-electric means (*for example,* diesel or natural gas) or off-grid electricity (*for example,* stand-alone solar power)? Do not count methods for generating power during a power outage.

☐ 0% ☐ 6-10% ☐ 21-40% ☐ 61-100%

☐ 1-5% ☐ 11-20% ☐ 41-60%

Q7. What have been the primary drivers of your agency's decision(s) to replace, upgrade, or repair a groundwater well pump, or to rehabilitate a well? Check all that apply.

☐ One or more well pumps failed	☐ The well pumps had low efficiency	☐ One or more pumps produced low flow rate
☐ Operational costs could be reduced	☐ Energy prices were likely to increase	☐ The agency received incentives from energy providers
☐ The agency received incentives from state or federal agencies	☐ Other: ___ ___ ___	☐ Not applicable: the agency has never replaced, upgraded, or repaired a groundwater well pump, nor rehabilitated a well

Q8. Please fill out **ONE** of the following two options (whichever you prefer) to the best of your ability. If possible, please interpret total costs to be those pertaining only to water supply operations.

Option 1:

	On average (over last 5 years)	At the end of the 2016 water year
What share of the agency's total operating costs did the total energy costs represent? (%)		
What share of the agency's total energy costs did the energy cost from operating the agency's groundwater wells represent? (%)		

Option 2:

	On average (over last 5 years)	At the end of the 2016 water year
Total operating costs ($)		
Total energy costs ($)		
Groundwater pumping energy costs ($)		

If you feel it's necessary, please provide more context on what "total operating costs" and "total energy costs" represent in your answer above.

____

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Q9. If your agency assesses the energy consumption of its groundwater pumps, please describe these assessments (*for example,* what type of assessment, how often assessments occur, and what share of your district's wells are assessed at this frequency). _______________

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Q10. To what extent are groundwater energy consumption data used in decision making at your agency?

☐ Not at all ☐ A little ☐ Somewhat ☐ To a great extent

Q11. The following table contains a list of actions related to groundwater pumping that could affect energy use. For each one, indicate whether your agency has taken this action in the past 10 years and whether it is likely to take this action in the next 5 years.

	Action taken in past 10 years	Likely to take action in the next 5 years
Participating in educational seminars about well pumping systems	o	o
Conducting well pumping efficiency test(s)	o	o
Conducting a water system energy audit	o	o
Installing variable-frequency drives in well pump motors	o	o
Upgrading, retrofitting, or repairing well pump(s)	o	o
Rehabilitating/replacing well(s)	o	o
Installing equipment (for example, sensors or controls) or software (for example, well monitoring tools or decision support systems) that track well pump energy use or groundwater volumes pumped	o	o
Practicing groundwater recharge via recharge ponds	o	o
Practicing groundwater recharge via injection wells	o	o
Replenishing groundwater via indirect potable reuse	o	o
Participating in water trading/markets or establishing pricing mechanism resulting in MORE reliance on surface water relative to groundwater	o	o
Participating in water trading/markets or establishing pricing mechanism resulting in LESS reliance on surface water relative to groundwater	o	o

	Action taken in past 10 years	Likely to take action in the next 5 years
Reducing overall volume of groundwater pumped (for example, through conservation programs, increased reliance on surface/imported water)	o	o
Planning well pumping around time-of-use electricity pricing	o	o
Other:	o	o

Q12. Please explain the difficulties, if any, your agency has faced or anticipates having to face in implementing any of the actions listed in the question above (Q11), and/or the barriers, if any, that precluded or would preclude your agency from taking any of those actions.

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Q13. More generally, how much do each of the following hamper your agency in reducing the energy needed to pump groundwater?

	Not at all	A little	Somewhat	Very much
The agency does not know how much energy it uses for groundwater pumping	o	o	o	o
The agency does not have the technical expertise to implement projects to reduce groundwater pumping energy	o	o	o	o
The energy costs are too low to warrant investments in more efficient pumping equipment or well characteristics	o	o	o	o
The initial capital investment required is too high	o	o	o	o
There is uncertainty about long-term energy cost savings	o	o	o	o
Other operational improvements are more cost-effective	o	o	o	o
There are many differences in the existing wells and pumps across the agency	o	o	o	o
Energy use reductions are not a major priority	o	o	o	o
Groundwater levels are not a concern for the agency	o	o	o	o

	Not at all	A little	Somewhat	Very much
The time required to implement well pump upgrades might threaten reliability of water delivery	o	o	o	o
Improvements may increase management time or cost	o	o	o	o
Incentive programs require too much time or administrative burden	o	o	o	o
The agency's well pumps or well pump improvements are not eligible for incentive programs	o	o	o	o
Other	o	o	o	o

Q14. How interested is your agency in each of the following?

	Not at all	A little	Somewhat	Very
More access to technical expertise to improve pumping efficiency	o	o	o	o
Data and tools to better evaluate groundwater management	o	o	o	o
Informational websites on the energy-efficient management of groundwater	o	o	o	o
Financial assistance for infrastructure upgrades to enhance pumping efficiency	o	o	o	o
Managed aquifer recharge (agency lead), including recycled water	o	o	o	o
Voluntary offset programs where groundwater users willing to reduce their usage are able to trade a credit for the unused water with users willing to purchase this credit	o	o	o	o
External recognition for taking actions to improve pumping efficiency	o	o	o	o
Enhanced collaboration with neighboring water agencies/districts	o	o	o	o
Financial support for implementation of efficient water management practices (for example, through subsidy programs, funding matches)	o	o	o	o
Energy management practices (i.e., demand response/load reduction)	o	o	o	o

	Not at all	A little	Somewhat	Very
Energy and flow metering of wells	o	o	o	o
Transfer and market system for water rights	o	o	o	o
Long-term underground water storage credits market	o	o	o	o
Other	o	o	o	o
Other	o	o	o	o

Q15. Please rate how desirable for your agency each of the following financial mechanisms to decrease the energy needed for groundwater pumping would be.

	Not at all	A little	Somewhat	Very
Grant funding	o	o	o	o
Rebates	o	o	o	o
Tax incentives	o	o	o	o
Low-interest loans	o	o	o	o
Increased rates for customers	o	o	o	o
Carbon credits (from the state's cap-and-trade system)	o	o	o	o
Other	o	o	o	o
Other	o	o	o	o

Q16. If you have any final comments or matters you want to share with us regarding groundwater pumping energy, please use the space below.

____

____

____

Thank you very much for completing this questionnaire. Your responses are invaluable to our efforts to understand the difficulties that municipal water agencies face to reducing the energy required to pump groundwater.

Before you submit your questionnaire by clicking the submit button on the bottom right, we want to know if you are interested in any of the following optional benefits from your participation in this survey:

- ☐ I want to receive an electronic copy of the final public report resulting from this research.

☐ I want to receive a custom report that summarizes how my survey responses compare to aggregated results from other respondents.

Please send the report options selected above to me at:

Email address ______________________________

Name _____________________________________

If you have any questions, want to learn more about this research, or want to explore opportunities to further collaborate with us on this project, please feel free to contact us at: gwenergy@lbl.gov, (510) 486-6839 [Heidi Fuchs, Survey Lead], or (510) 495-2865 [Helcio Blum, Project Lead]. For issues related to your rights as a research participant in this study (LBNL HSC 382H001-31AU19), please contact LBNL's Human Subjects Committee at (510) 486-5399.

Thank you again for your time.

B.2: Survey of Agriculture Water Suppliers

Thank you for being willing to respond to this survey. To learn more about the project, visit gwenergy.lbl.gov.

We are interested in learning more about the energy needed to pump groundwater for irrigation purposes. If your organization also supplies water for municipal purposes, please consider only irrigation water throughout this survey. Delivered groundwater from another supplier should not be counted here, as this would result in double-counting if that supplier also fills out this survey.

If at any point you need to leave the survey and come back to complete it, you may automatically return to where you left off by using the same browser and computer that you are using now.

Please provide the name of your irrigation district below. This information will not be publicly connected to your responses, but will allow us to reference any applicable Agricultural Water Management Plans, as well as consider geographic variables in our analysis.

While all individual results will remain confidential, in our public report we would like to acknowledge your district in a list of districts that we thank for their participation in this survey. Do you consent to this acknowledgment of your district's participation? (If you do not consent, the name of your district will not be acknowledged).

☐ Yes, I consent

☐ No, I do not consent

Throughout the remainder of the survey feel free to skip any questions, but please try to answer as many questions as you can.

Q1. Does your district own and operate groundwater production wells?

☐ Yes

☐ No

If "No," Skip to Q17

GROUNDWATER PUMPING BY DISTRICT-OWNED WELLS ONLY

For Questions 2-16, please consider only your district's groundwater production wells, not other wells that are not operated by your district.

Q2. Please fill out **ONE** of the two following options (whichever you prefer) for your district's total water supply for the 2015, 2016, and 2017 water years.

Option1:

	2015 water year	2016 water year	2017 water year
How many acre-feet was the district's total water supply?			
How many acre-feet of groundwater did the district pump from its wells?			

Option2:

	2015 water year	2016 water year	2017 water year
Groundwater pumped as share of total water supply (%)			

Q3. Because of different hydrological conditions, groundwater pumping may vary across years. Ignoring these hydrological variations, what changes in your district over the past 10 years, if any, have yielded general trends in reliance on and depth to groundwater? For example, why is depth to groundwater generally increasing/decreasing, or why is your district using less/more groundwater relative to total water supply today compared to 10 years ago?

____

____

____

Q4. How does the cost of local groundwater to your district compare to the cost of surface or imported water? Local groundwater typically costs...

☐ A lot less ☐ Somewhat less ☐ About the same ☐ Somewhat more ☐ A lot more

☐ Unable to generalize; please explain____________ ☐ We have no water sources other than groundwater

Q5. Please provide your best estimates below:

	2015 water year	2016 water year	2017 water year
In total, how many wells did the district own?			
In total, how many wells did the district operate?			

Q6. What percent of your district's groundwater well pumps are powered by non-electric means (*for example,* diesel or natural gas) or off-grid electricity (*for example,* stand-alone solar power)? Do not count methods for generating power during a power outage.

☐ 0% ☐ 6-10% ☐ 21-40% ☐ 61-100%

☐ 1-5% ☐ 11-20% ☐ 41-60%

Q7. When was the last time your district tested the efficiency of its groundwater pumps?

☐ Within the last 5 years

☐ More than 5 years ago but less than 10 years ago

☐ More than 10 years ago but less than 15 years ago

☐ More than 15 years ago

Q8. What is the <u>average</u> overall pumping efficiency (OPE) of the groundwater well pumps your district operates? (Please select the range this number falls into).

☐ 1-40% ☐ 41-50% ☐ 51-60%

☐ 61-70% ☐ 71-80% ☐ 81-100%

Q9. What is the <u>minimum</u> OPE of the groundwater well pumps your district operates? (Please select the range this number falls into).

☐ 1-40% ☐ 41-50% ☐ 51-60%

☐ 61-70% ☐ 71-80% ☐ 81-100%

Q10. What is the <u>maximum</u> OPE of the groundwater well pumps your district operates? (Please select the range this number falls into).

☐ 1-40% ☐ 41-50% ☐ 51-60%

☐ 61-70% ☐ 71-80% ☐ 81-100%

Q11. What have been the primary drivers of your district's decision(s) to replace, upgrade, or repair a groundwater well pump, or to rehabilitate a well? Check all that apply.

- ☐ One or more well pumps failed
- ☐ The well pumps had low efficiency
- ☐ One or more pumps produced low flow rate
- ☐ Operational costs could be reduced
- ☐ Energy prices were likely to increase
- ☐ The district received incentives from energy providers
- ☐ The district received incentives from state or federal agencies
- ☐ Other:
- ☐ Not applicable: the district has never replaced, upgraded, or repaired a groundwater well pump, nor rehabilitated a well

Q12. Please fill out **ONE** of the following two options (whichever you prefer) to the best of your ability.

Option 1

	On average (over last 5 years)	At the end of the 2016 water year
What share of the district's total operating costs did the total energy costs represent? (%)		
What share of the district's total energy costs did the energy cost from operating the district's groundwater wells represent? (%)		

Option 2

	On average (over last 5 years)	At the end of the 2016 water year
Total operating costs ($)		
All energy costs ($)		
Groundwater pumping energy costs ($)		

Q13. To what extent are groundwater energy consumption data used in decision making at your district?

☐ Not at all ☐ A little ☐ Somewhat ☐ To a great extent

Q14. The following table contains a list of actions related to groundwater pumping that could affect energy use. For each one, indicate whether your district has taken this action in the past 10 years and whether it is likely to take this action in the next 5 years.

	Action taken in past 10 years	Likely to take action in the next 5 years
Participating in educational seminars about well pumping systems	o	o
Conducting well pumping efficiency test(s)	o	o
Conducting a water system energy audit	o	o
Installing variable-frequency drives in well pump motors	o	o
Upgrading, retrofitting, or repairing well pump(s)	o	o
Rehabilitating/replacing well(s)	o	o
Installing equipment (for example, sensors or controls) or software (for example, well monitoring tools or decision support systems) that track well pump energy use or groundwater volumes pumped	o	o
Taking the lead in implementing a managed groundwater recharge program	o	o
Encouraging landowners to implement a managed groundwater recharge program	o	o
Participating in water trading/markets or establishing pricing mechanism resulting in MORE reliance on surface water relative to groundwater	o	o
Participating in water trading/markets or establishing pricing mechanism resulting in LESS reliance on surface water relative to groundwater	o	o
Reducing overall volume of groundwater pumped (for example, through conservation programs, increased reliance on surface/imported water)	o	o
Planning well pumping around time-of-use electricity pricing	o	o
Other:	o	o

Q15. Please explain the difficulties, if any, your district has faced or anticipates having to face in implementing any of the actions listed in the question above (Q14), and/or the barriers, if any, that precluded or would preclude your district from taking any of those actions.

____

____

____

Q16. More generally, how much do each of the following hamper your district in reducing the energy needed to pump groundwater?

	Not at all	A little	Somewhat	Very much
The district does not know how much energy it uses for groundwater pumping	o	o	o	o
The district does not have the technical expertise to implement projects to reduce groundwater pumping energy	o	o	o	o
The energy costs are too low to warrant investments in more efficient pumping equipment or well characteristics	o	o	o	o
The initial capital investment required is too high	o	o	o	o
There is uncertainty about long-term energy cost savings	o	o	o	o
Other operational improvements are more cost-effective	o	o	o	o
There are many differences in the existing wells and well pumps across the district	o	o	o	o
Energy use reductions are not a major priority	o	o	o	o
Groundwater levels are not a concern for the district	o	o	o	o
The time required to implement well pump upgrades might threaten reliability of water delivery	o	o	o	o
Improvements may increase management time or cost	o	o	o	o
Incentive programs require too much time or administrative burden	o	o	o	o
The district's well pumps or well pump improvements are not eligible for incentive programs	o	o	o	o
Other	o	o	o	o

GROUNDWATER PUMPING IN ENTIRE SERVICE AREA

For Questions 17-22, we are interested in learning more about the energy use of groundwater pumping that occurs across your district, including customers' private groundwater wells.

	Check if your district has already implemented this practice	Please respond regardless of whether your district has or has not implemented this practice. This EWMP has the potential to...				
		Reduce energy needs by a lot	Reduce energy needs by a little	Keep energy needs about the same	Increase energy needs by a little	Increase energy needs by a lot
Facilitate use of recycled water	o	o	o	o	o	o

	Check if your district has already implemented this practice	Please respond regardless of whether your district has or has not implemented this practice. This EWMP has the potential to...				
		Reduce energy needs by a lot	Reduce energy needs by a little	Keep energy needs about the same	Increase energy needs by a little	Increase energy needs by a lot
Facilitate capital improvements for on-farm irrigation systems	o	o	o	o	o	o
Implement an incentive pricing structure	o	o	o	o	o	o
Increase order and delivery flexibility	o	o	o	o	o	o
Construct supplier spill and tailwater recovery systems	o	o	o	o	o	o
Increase planned conjunctive use of surface water and groundwater	o	o	o	o	o	o
Facilitate or promote customer pump testing/evaluation	o	o	o	o	o	o
Provide water management services to customers	o	o	o	o	o	o
Identify institutional changes to allow more flexible water deliveries and storage	o	o	o	o	o	o
Evaluate and improve supplier pump efficiency	o	o	o	o	o	o

Q17. How does the cost of groundwater pumped on customers' farms compare to the cost of the water supplied by your district? The on-farm groundwater typically costs...

☐ A lot less ☐ Somewhat less ☐ About the same ☐ Somewhat more

☐ A lot more ☐ Unable to generalize; please explain

Q18. To what extent is your district concerned with on-farm groundwater usage?

☐ Not at all ☐ A little ☐ Somewhat ☐ To a great extent

Q19. The next questions are about how certain practices, such as Efficient Water Management Practices (EWMPs), have affected or might affect the energy needed for groundwater pumping in your district. [Click here to learn more about EWMPs.]

Q20. Considering your answers to the previous question (Q19), in terms of EWMPs with the greatest potential to reduce the energy required to pump groundwater in your district, what are the biggest barriers, disincentives, or difficulties with fully implementing those EWMPs?

- ☐ We don't anticipate any barriers, disincentives or difficulties in implementing those practices
- ☐ We anticipate having the following issues (for example, regulatory, legal, economic, technical, institutional...) with implementing those practices:

____

Q21. How interested is your district in each of the following?

	Not at all	A little	Somewhat	Very much
More access to technical expertise to improve pumping efficiency	o	o	o	o
Holding educational programs on energy-efficient management of groundwater	o	o	o	o
Data and tools to better evaluate groundwater management	o	o	o	o
Informational websites on the energy-efficient management of groundwater	o	o	o	o
Financial assistance for infrastructure upgrades to enhance pumping efficiency	o	o	o	o
Managed aquifer recharge (landowner lead)	o	o	o	o
Managed aquifer recharge (district lead), including recycled water	o	o	o	o
Voluntary offset programs where groundwater users willing to reduce their usage are able to trade a credit for the unused water with users willing to purchase this credit	o	o	o	o
External recognition for taking actions to improve pumping efficiency	o	o	o	o
Enhanced collaboration with neighboring water agencies/districts	o	o	o	o
Financial support for implementation of Efficient Water Management Practices (for example, through subsidy programs, funding matches)	o	o	o	o
Energy management practices (i.e., demand response/load reduction)	o	o	o	o
Energy and flow metering of wells	o	o	o	o

	Not at all	A little	Somewhat	Very much
Transfer and market system for water rights	o	o	o	o
Long-term underground water storage credits market	o	o	o	o
Other	o	o	o	o

Q22. Please rate how desirable for your district each of the following financial mechanisms to decrease the energy needed for groundwater pumping would be.

	Not at all	A little	Somewhat	Very much
Grant funding	o	o	o	o
Rebates	o	o	o	o
Tax incentives	o	o	o	o
Low-interest loans	o	o	o	o
Increased rates for customers	o	o	o	o
Carbon credits (from the state's cap-and-trade system)	o	o	o	o
Other	o	o	o	o
Other	o	o	o	o

Q23. If you have any final comments or matters you want to share with us regarding groundwater pumping energy, please use the space below

____

____

____

Thank you very much for completing this questionnaire. Your responses are invaluable to our efforts to understand the difficulties that irrigation districts face to reducing the energy required to pump groundwater.

Before you submit your questionnaire by clicking the submit button on the bottom right, we want to know if you are interested in any of the following optional benefits from your participation in this survey:

- ☐ I want to receive an electronic copy of the final public report resulting from this research.
- ☐ I want to receive a custom report that summarizes how my survey responses compare to aggregated results from other respondents.

Please send the report options selected above to me at:

- ☐ Email address ______________________________
- ☐ Name _____________________________________

If you have any questions, want to learn more about this research, or want to explore opportunities to further collaborate with us on this project, please feel free to contact us at: gwenergy@lbl.gov, (510) 486-6839 [Heidi Fuchs, Survey Lead], or (510) 495-2865 [Helcio Blum, Project Lead}. For issues related to your rights as a research participant in this study (LBNL HSC 382H001-31AU19), please contact LBNL's Human Subject Committee at (510) 486-5399.

Thank you again for your time.

B.3: Farmers and Ranchers

BERKELEY LAB

Thank you for being willing to respond to this survey. To learn more about the project, visit gwenergy.lbl.gov.

We are interested in learning more about the energy needed to pump on-farm groundwater. Results from this survey may inform future efforts to reduce energy use and costs for growers.

As a reminder, your participation in this survey is completely anonymous. In publicly available reports, results will only be presented in aggregated form.

GENERAL INFORMATION

Q1. In what county is your farm or ranch located? (If it is in multiple counties, please indicate the county that encompasses the majority of land).

Alameda	Glenn	Marin	Placer	San Mateo	Stanislaus
Alpine	Humboldt	Mariposa	Plumas	Santa Barbara	Sutter
Amador	Imperial	Mendocino	Riverside	Santa Clara	Tehama
Butte	Inyo	Merced	Sacramento	Santa Cruz	Trinity
Calaveras	Kern	Modoc	San Benito	Shasta	Tulare
Colusa	Kings	Mono	San Bernardino	Sierra	Tuolumne
Contra Costa	Lake	Monterey	San Diego	Siskiyou	Ventura
Del Norte	Lassen	Napa	San Francisco	Solano	Yolo
El Dorado	Los Angeles	Nevada	San Joaquin	Sonoma	Yuba
Fresno	Madera	Orange	San Luis Obispo		

Throughout the remainder of the survey feel free to skip any questions, but please try to answer as many questions as you can.

Q2. What is your age?

☐ Younger than 30 ☐ 40 to 49 ☐ 60 to 69 ☐ 80 or older

☐ 30 to 39 ☐ 50 to 59 ☐ 70 to 79

Q3. What is the highest education level you have completed?

☐ No high school diploma or GED ☐ Some college, no degree ☐ Bachelor's degree (for example, BA, BS)

☐ High school diploma or GED ☐ Associate's degree (for example, AA, AS) ☐ Graduate degree (for example, MS, MBA, JD, PhD, MD)

Q4. Is your primary occupation farming or ranching?

☐ Yes ☐ No

Q5. How would you categorize your farm or ranch? [Check one or more]

☐ General row crops ☐ Fruit (non-orchard) ☐ Nursery

☐ Vegetable ☐ Nuts ☐ Other

☐ Fruit (orchard) ☐ Dairy/livestock

Q6. In what year did you begin operating your farm/ranch? __________

Q7. How would you classify the ownership type of your farm/ranch?

☐ Family or individual (sole proprietorship) ☐ Corporation, including family corporation ☐ Other

☐ Partnership, including family partnership ☐ Cooperative

Q8. Please provide your best estimates below regarding acreage on your farm in the calendar years (January-December) of 2015, 2016, and 2017.

	2015	2016	2017
How big was your farm (total acres)?			
How many irrigated acres were you farming?			

Q9. What is your best estimate of the quantity of on-farm pumped groundwater applied in the calendar years 2015, 2016, and 2017? Please indicate in total acre-feet, total gallons, or inches/acre, and check the corresponding unit.

	Quantity	Unit of measurement		
		Total acre-feet	Total gallons	Inches/acre
2015		o	o	o
2016		o	o	o
2017		o	o	o

Q10. Thinking about all the crops/agricultural products that were irrigated to any extent by on- farm pumped groundwater, what are the top 3 crops/agricultural products in terms of amount of groundwater applied in 2017?

1. _____
2. _____
3. _____

Q11. What was the gross value of all agricultural products sold from your operation in 2017, including landlord's share (if applicable)? [select one]

☐ $0-$9,999
☐ $10,000-$24,999
☐ $25,000-$49,999
☐ $50,000-$99,999
☐ $100,000-$249,999
☐ $250,000-$499,999
☐ $500,000-$999,999
☐ $1,000,000 and over

Q12. How important is groundwater to your sustained business viability? [select one]

☐ o Not at all important
☐ o Slightly important
☐ o Moderately important
☐ o Very important
☐ o Extremely important
☐

GROUNDWATER WELL PUMP POWER SOURCES

Q13. In the table below, please provide the number of groundwater well pumps used on your farm, by power source.

ELECTRICITY	# of on-farm well pumps that rely on the source
Grid-only electricity	
Grid electricity combined with on-farm renewables (for example, solar PV, wind) connected to the grid	
On-farm stand-alone renewables (not connected to the grid)	

ELECTRICITY	# of on-farm well pumps that rely on the source
Gas (for example, natural gas, LP gas, propane, butane)	
Liquid fuels (for example, diesel, biodiesel, gasoline, blends)	

Q14. In the next 5 years, do you expect to shift towards a different power source for your groundwater well pumps? Please consider both retrofits and new installation pumps. If you plan to make multiple types of switches, indicate the one that affects the most pumps. Please drag and drop your chosen power sources from the list on the left to the appropriate box on the right, with only one power source allowed per box. Leave blank if you don't plan to switch any groundwater well pump power sources in the next 5 years.

What fuel do you expect/plan to shift FROM?	What fuel do you expect/plan to shift TO?
Gas or liquid fuels	Gas or liquid fuels
Grid-only electricity	Grid-only electricity
Grid electricity combined with on-farm renewables connected to the grid	Grid electricity combined with on-farm renewables connected to the grid
On-farm stand-alone renewables	On-farm stand-alone renewables

ENERGY REQUIRED FOR GROUNDWATER PUMPING

This section covers past, present, and future actions taken to decrease the energy required to pump groundwater, first in terms of decreasing the energy use required for pumping, and second in terms of decreasing the amount of groundwater applied. Please consider only groundwater well pumps; do not consider booster and other secondary pumps.

Please focus only on actions that pertain directly to reducing energy in section A, and only on water conservation actions in section B.

SECTION A: REDUCING ENERGY

Q15. How many opportunities, if any, do you feel there are to reduce the energy required to pump groundwater on your farm through increasing overall pumping efficiency? [select one]

☐ No opportunities ☐ Limited opportunities ☐ Some opportunities ☐ Many opportunities

Q16. The table below contains a list of actions related to groundwater pumping that could affect energy use. Please check all actions you took in the past 10 years, either on your own, as part of a utility or government program, or both. [check all that apply]

	Taken on my own	Taken as part of a program
Participated in educational seminars re: pumping system specifications/maintenance	☐	☐

	Taken on my own	Taken as part of a program
Conducted pump efficiency test(s)	☐	☐
Conducted an on-farm energy audit	☐	☐
Upgraded motor(s) for higher efficiency	☐	☐
Installed variable-frequency drive(s) in well pump motor(s)	☐	☐
Upgraded, retrofitted, or repaired well pump(s)	☐	☐
Rehabilitated/replaced well(s)	☐	☐
Installed pump system meters, sensors, controls, and/or monitoring software to track pump energy use and/or water volumes pumped	☐	☐
Banked groundwater (for example, groundwater recharge via spreading basins)	☐	☐
Participated in water trading or water markets that reduced need to pump groundwater	☐	☐
Other ______________________________	☐	☐

Q17. If you have taken any actions listed in the previous question (Q16), which of the following factors influenced your decision to do so? Please rank up to three answer choices by typing the numbers 1 (most important), 2 (second most important), and 3 (third most important) in the corresponding boxes. [rank up to three]

— Knowledge/insights learned from pump efficiency tests or other pump monitoring technologies
— Knowledge/insights gained from seminars/workshops
— Success stories from other farmers
— Technical assistance available from an efficiency program
— Technical assistance from farm advisors (for example, from university extension)
— Energy cost savings from reduced pumping energy use
— Financial assistance available from an efficiency program
— Environmental sustainability concerns (for example, reducing pump energy contributes to better air quality)
— Other:____

Q18. How much do each of the following hamper you in reducing the energy needed to pump groundwater on your farm? [select one response per line]

	Not at all	A little	Some what	Very much
Investigating improvements is not a priority at this time	o	o	o	o
Privacy concerns	o	o	o	o
Time burden of determining what programs or type of assistance I qualify for	o	o	o	o
No incentive for landowner to invest in improvements that mainly benefit lessee	o	o	o	o
Improvements will increase management time or cost	o	o	o	o
Uncertainty about actual performance of efficient well and pump systems	o	o	o	o
I don't know how much pumping energy is currently being used, or the efficiency of my well pumps	o	o	o	o
I am not aware of any options or programs that exist to increase pump efficiency	o	o	o	o
I don't know where to find technical expertise to identify, evaluate, and/or implement projects	o	o	o	o
I have not considered potential benefits of energy efficiency (*for example*, air quality, a reliable electric grid)	o	o	o	o
Improvements won't reduce operating costs enough to cover equipment and implementation costs	o	o	o	o
Energy costs are minor relative to other operational costs	o	o	o	o
Low level of concern about future energy prices and how they will impact operational costs	o	o	o	o
Financing difficulties (*for example*, obtaining loans or other types of financing)	o	o	o	o
Burden of paying costs up front (*for example*, in rebate reimbursement or tax incentive programs)	o	o	o	o
Administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs)	o	o	o	o
Program ineligibility	o	o	o	o
Waitlisted by pump testing or other well-related companies due to high demand	o	o	o	o

	Not at all	A little	Some what	Very much
Waitlisted or not selected by government/utility program (*for example*, project was considered low priority or program had insufficient funds)	o	o	o	o
Other	o	o	o	o

Q19. Which of the following incentives would most likely motivate you to reduce the energy needed for on-farm groundwater pumping? Check up to three that you consider most important. [check up to three]

☐ Increased technical assistance

☐ Training and awareness programs

☐ Incentives for pump efficiency tests

☐ Improved access to financing for pumping efficiency projects

☐ Tax incentives for pumping efficiency projects

☐ Low-interest loans for pumping efficiency projects

☐ Carbon credits (from California's cap-and-trade program)

☐ Time-of-use electricity pricing (greater efficiency would lower pumping cost in peak pricing periods)

☐ Other

SECTION B: WATER CONSERVATION

Q20. How many opportunities, if any, do you feel there are to use less groundwater on your farm? [select one]

☐ No opportunities

☐ Limited opportunities

☐ Some opportunities

☐ Many opportunities

Q21. The table below contains a list of actions that could affect the amount of water pumped. Please check all actions you took in the past 10 years, either on your own, as part of a utility or government program, or both. [check all that apply]

	Taken on my own	Taken as part of a program
Participated in educational seminars concerning water management/measurement	o	o
Conducted an on-farm water/irrigation audit	o	o
Installed flow meters, sensors, controls, or software to improve irrigation efficiency	o	o

	Taken on my own	Taken as part of a program
Converted from flood or overhead sprinkler irrigation to drip, trickle, or low-flow micro irrigation, and/or converted from higher pressure to lower pressure irrigation	o	o
Reduced system losses (for example, lining or covering irrigation canals, irrigation system repairs)	o	o
Participated in new billing rate structure for water use that encourages conservation	o	o
Land leveling: leveled croplands to increase distribution uniformity	o	o
Changed crops grown to less water intensive crops	o	o
Implemented deficit irrigation	o	o
Implemented irrigation scheduling	o	o
Chose winter timing of flood irrigation to reduce evaporative losses	o	o
Planted cover crops to retain winter moisture and minimize runoff	o	o
Reduced soil erosion via hedgerows, riparian habitat, or planting native trees/shrubs	o	o
Boosted soil moisture holding capacity	o	o
Created tailwater recovery or sediment trapping ponds	o	o
Other	o	o

Q22. More generally, how much do each of the following hamper you in implementing water conservation projects on your farm? [select one response per line]

	Not at all	A little	Somewh at	Very much
Many different irrigation system types across farm	o	o	o	o
Physical field/crop condition limit improvements (for example, risk of reduced yield or poorer crop quality, don’t wish to disturb current cropping system)	o	o	o	o
Neighboring farmers are not focused on water conservation	o	o	o	o
I don’t need to conserve water on my farm (for example, receive enough surface water, have senior water rights)	o	o	o	o
Lack of specific policies, programs, legislation, or norms	o	o	o	o

	Not at all	A little	Somewhat	Very much
Investigating improvements is not a priority at this time	o	o	o	o
Privacy concerns	o	o	o	o
Time burden of determining what programs or type of assistance for which I qualify	o	o	o	o
Improvements won't reduce operating costs enough to cover equipment and implementation costs	o	o	o	o
No incentive for landowner to invest in improvements that mainly benefit lessee	o	o	o	o
Improvements will increase management time or cost	o	o	o	o
Uncertainty about actual performance of efficient irrigation systems	o	o	o	o
I don't know how much water is currently being used, or the efficiency of my irrigation system	o	o	o	o
I am not aware of any options or programs that exist to increase water conservation	o	o	o	o
I don't know where to find technical expertise to identify, evaluate, and/or implement projects	o	o	o	o
I have not considered potential benefits of water conservation (for example, minimizing groundwater overdraft, decreasing pumping energy)	o	o	o	o
Water costs are minor relative to other operational costs	o	o	o	o
Low level of concern about future water prices or deliveries, or long-term water (cost) savings	o	o	o	o
Financing difficulties (for example, obtaining loans or other types of financing)	o	o	o	o
Burden of paying costs up front (for example, in rebate reimbursement or tax incentive programs)	o	o	o	o
Administrative burdens associated with program requirements (for example, application process, compliance or reporting requirements, other transaction costs)	o	o	o	o
Program ineligibility (for example, due to income, landownership, or location issues)	o	o	o	o

	Not at all	A little	Somewhat	Very much
Waitlisted or not selected by government/utility program (for example, project was considered low priority or program had insufficient funds)	o	o	o	o
Other	o	o	o	o

If you have any final comments or matters you wish to share with us regarding groundwater pumping energy, please use the space below.

Thank you very much for completing this questionnaire by clicking the submit button on the bottom right. Your responses are invaluable to our efforts to understand the difficulties that California growers face to reducing the energy required to pump groundwater.

If you have any questions, want to learn more about this research, or explore opportunities to further collaborate with this project, please feel free to contact us at: gwenergy@lbl.gov, (510) 486-6839 [Heidi Fuchs, Survey Lead], or (510) 495-2865 [Helcio Blum, Project Lead]. For issues related to your rights as a research participant in this study (LBNL HSC 382H001-31AU19), please contact LBNL's Human Subjects Committee at (510) 486-5399.

Thank you again for your time.

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