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ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Programmable Irrigation and Fertigation to Increase Energy Efficiency and Grid Stability in Disadvantaged Agricultural Communities

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The work in disadvantaged communities was made possible thanks to West Hills College Coalinga and the Westside Family Services in Huron, California. The team also worked closely with farms on east side of San Joaquin Valley from AgMonitor's office at the Water Energy Technology center at California State University, Fresno. The deployments in Sacramento Valley built on AgMonitor's relationship with the University of California Agricultural and Natural Services and the AgStart incubator located near Davis, California. The deployment of AgMonitor's new basin-level analytical tool was adopted by the Ventura Resource Conservation District and made possible with AgMonitor's long-term relationship with the University of California, Santa Barbara.

The work that the team started with the project EPC-14-081 (water and energy) and extended with this project EPC-16-051 (nitrogen and labor) highlighted the need for public-private partnership to deal with the unprecedented transformation of farming in California. The team wants to thank the 12 organizations who co-founded OpenFarm:[1]

- Academic partners: California State University, Fresno; University of California Agricultural and Natural Services; West Hills College Coalinga.
- AgTech vendors: BlueRiver Technology; WiseConn Engineering, in addition to AgMonitor Inc. formerly known as PowWow Energy Inc. (name change in 2020).
- Economic development stakeholders: AgStart, Blue Valley Ventures, and the Center for Innovation Technology from the Western Growers Association.
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[1] OpenFarm: https://openfarm.ai/

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.

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

AgMonitor Inc. (AgMonitor), in collaboration with West Hills College Coalinga; University of California, Santa Barbara; Formation Environmental; and WiseConn Engineering, developed a programmable farm management system that integrates cutting-edge technologies to provide greater energy and water savings relative to existing energy efficiency programs. The new technologies were tested at two commercial farming sites in the California Central Valley: an almond orchard near Delano serviced by Southern California Edison, and a tomato field near Los Banos serviced by Pacific Gas and Electric Company. An additional test site at West Hills College Coalinga was used for education.

The programmable farm management system can optimize energy efficiency by 13 percent, water efficiency by up to 11 percent, and fertilizer efficiency by up to 14 percent from the pump to each plant through implementation of the following strategies: (1) continuous pump testing and remote pump control; (2) programmable irrigation or fertigation (precise application of fertilizers using a micro-irrigation system) for specific soil types and plant varieties within a field; and (3) integrated management of water and fertility management using a native mobile application. The new technologies are coordinated through AgMonitor's existing software-as-a-service platform to achieve water and energy savings larger than 20 percent compared to crop evapotranspiration.

Another application for programmable irrigation is load shifting, the reduction of power consumption during periods of peak demand on the utility grid. This became apparent as Southern California Edison and Pacific Gas and Electric Company released new utility rates. Peak demand hours changed from between noon and 6:00 p.m. to between 5:00 p.m. and 8:00 p.m. to allow more renewable energy resources to be integrated with the electrical grid. Cost savings up to 30 percent were demonstrated at technology transfer sites.

The project also developed new data fusion and visualization tools at a basin level to target agricultural energy efficiency programs where they are needed the most. New materials were also created for online classes in disadvantaged communities.

Keywords: Automation, Big Data, Disadvantaged Agricultural Communities, Agricultural Energy Efficiency, Energy Efficiency, Nitrogen, Software, Water, Irrigation, Fertigation, Farm, OpenFarm, On-Bill Financing

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Background

The storage, conveyance, and treatment of water account for nearly 20 percent of the total electricity consumption and 30 percent of non-power plant natural gas consumption in California, making consumers of electricity for water-related uses the largest electricity user group in the state. Agricultural water use consumes 10 terawatt-hours of electricity per year, which represents approximately one fifth of all water-related electricity consumption and 4 percent of total electricity consumption in California. Because the majority of electricity generation in the United States comes from power plants burning fossil fuels, it is critical to reduce electricity consumption associated with agricultural water usage in order to achieve the greenhouse gas (GHG) emission reductions mandated by California law. Such as, Senate Bill 100 that increased the targets of the California Renewables Portfolio Standard to require 60 percent of electricity retail sales to come from renewable resources by 2030 and 100 percent of the state's electricity resources by 2045.

Increasing the efficiency of energy usage for irrigation is the most immediate and effective means of reducing power consumption by the agricultural sector, as pumping water for irrigation accounts for 80 percent of agricultural electricity use. The energy efficiency of irrigated agriculture is governed by three factors: pump efficiency (the amount of energy expended by the pump to move a given amount of water), water pressure (lowering the discharge pressure by use of low-pressure spray nozzles, sprinkler heads, etc., reduces the amount of energy consumed), and water use efficiency (the amount of water used to grow a given quantity of food). Previous efforts have developed improved technology and methodology for all three of these areas affecting the efficiency of energy use for irrigation—for example, existing programs from the three California investor-owned utilities for pump testing and installation of variable frequency drives, etc. Deficit irrigation techniques have been developed for several permanent and annual crops that significantly improve water use efficiency by reducing water application during the growing season while maintaining or even improving crop yields. While these individual technologies have been proven separately to reduce energy use in agriculture, their overall impact is limited when they are not deployed in coordination with one another. An integrated solution is needed for implementing these water and energy efficiency measures in a coordinated fashion that will maximize their benefits and be easy and cost-effective for growers to implement.

In addition to contributing to GHG emissions, the large amount of power consumed for agricultural water use places strain on California's electric power grid during peak demand periods. Issues with grid stability become especially acute on hot summer days, when increased power demand for irrigation coincides with increased power demand for air-conditioning. In tandem with reducing power consumption associated with water pumping through increased energy efficiency, successful integration of more renewable energy resources is an important strategy for managing the grid to prevent instability and outages. This presents significant challenges due to the intermittent nature of solar power generation, which is the predominant source of renewable energy in many rural areas. When the net load ramps up as the sun sets and solar generation is lost, the grid can become unstable, leading to rolling blackouts and other power disruptions. These issues are amplified during extreme heat waves when wildfires can damage transmission infrastructure and necessitate public safety power shutoffs.

Load shifting has emerged as a primary strategy to address the challenges posed by incorporating large amounts of intermittent renewable generation resources into the power grid. Load shifting refers to the coordinated, targeted modification of the timing of power consumption by utility customers to better align with the daily cycles in power generation. This means providing customers with the means and incentive to use more power during periods of surplus renewable generation and reduce power use during periods of scarcity in renewable generation. In addition to relieving stress on the grid, this approach can lower power costs for customers and reduce GHG emissions by shifting power consumption to periods when more of the total power demand can be met by renewable generation resources. Altering consumption patterns on a large scale will require new automation tools in agriculture, which is under increasing labor and groundwater regulations. Both regulations are prime concerns for growers.

Project Purpose

AgMonitor Inc. (AgMonitor), in collaboration with West Hills College Coalinga (WHCC), University of California, Santa Barbara (UCSB), Formation Environmental, and WiseConn Engineering (WCE), have developed a programmable farm management system that integrates cutting-edge technologies to provide greater energy and water savings relative to existing energy efficiency programs or commercial irrigation offerings. A technical advisory committee was formed to keep a balance between farming conditions, new technology adoption, and managing the electrical grid: Members included: Don Cameron, grower and president of California Department of Food and Agriculture; Dr. Glenda Humiston, vice president of University of California Agricultural and Natural Resources; and Dr. Helcio Blum, Senior Researcher at Lawrence Berkeley National Laboratory.

This Electric Program Investment Charge project aimed to help growers optimize their operations to increase energy efficiency by 20 percent, water efficiency by 15 percent, and fertilizer efficiency by 15 percent through implementation of the following strategies: (1) continuous pump testing and remote pump control; (2) programmable irrigation or fertigation (precise application of fertilizers using a micro-irrigation system) for specific soil types and plant varieties within a field; (3) integrated management of water and fertility management using a native mobile application. In addition, the system offers growers a simple and straightforward method for scheduling irrigation outside of peak-power-demand periods to reduce strain on the electrical grid. The new technologies are coordinated through AgMonitor's existing software-as-a-service products (PumpMonitor and CropMonitor), which support both manually and automatically controlled irrigation systems. The objective of the project was to deploy the programmable farm management system at commercial scale under real-world conditions and document the resulting changes in energy, nitrogen, and water usage.

Project Approach

The programmable farm management system was tested at two commercial farming sites in the California Central Valley: an almond orchard near Delano serviced by Southern California Edison and a tomato field near Huron serviced by Pacific Gas and Electric Company (PG&E). An additional test site at WHCC was used for demonstration and education, and the team developed the continuous pump test with California State University, Fresno. Toward the end of the project, the team worked with eight additional farms to transfer the technology.

One site wanted to scale up programmable irrigation to thousands of acres and worked with AgMonitor to gather the necessary data to have access to on-bill financing, an option for property owners to pay for investments in clean energy upgrades through their utility. An irrigation automation system (hardware) was installed and used in concert with AgMonitor products (software) to improve energy and water efficiency at a 387-acre almond orchard selected as an experimental treatment site. The grower used the system to set an irrigation plan that implemented deficit irrigation, with the goal of irrigating below the crop evapotranspiration (ETc, a metric that estimates water demand of a crop) for the year while not over-stressing the trees.

One farm wanted to avoid peak-hour fees. AgMonitor and WCE worked with a grower at a 55-acre pistachio field technology transfer site near Los Banos to schedule irrigation operations outside of peak demand periods as much as possible. The farm had originally purchased the automation hardware (from WCE), and the software (AgMonitor) under a Statewide Water Efficiency and Enhancement Program. The grower requested help in 2020 with this in response to a new rate structure released by the utility, in which the definition of peak demand hours changed from between noon and 6:00 p.m. to between 5:00 p.m. and 8:00 p.m. to allow more renewable energy resources to be integrated with the utility power grid. Over two-month periods before and after implementing programmable irrigation, energy use data were collected and analyzed from a smart meter connected to irrigation pumps used for supplying water to the field section.

Using satellite data from a Department of Water Resources project and utility meter data from the California Public Utilities Commission, AgMonitor, UCSB, and Formation Environmental studied the impact of large-scale programmable irrigation on two disadvantaged communities near Delano and Huron. A new clustering algorithm was implemented to calculate the energy intensity of irrigation from 2016 to 2020 in groups of fields with the same crop, similar water table depth, and proximity. This new "big data" approach makes it possible to pinpoint areas more susceptible to groundwater overdraft and high energy intensity for pumping irrigation water.

Project Results

Water and Energy Savings

Water application in the experimental almond orchard in 2020 was 40.7 inches, which was 10.9 percent below the estimated water demand of the orchard. Crop yield was as high or higher and uniformity was improved relative to eight other orchards used for a baseline study.

The control orchards managed without programmable irrigation had a mean water application of 50.6 inches, which was 11.0 percent above the estimated water demand of the crop. The reduction of 9.9 inches of irrigation water at the trees resulting from the experimental treatment corresponds to a reduction of 339 acre-feet (ac-ft) of water at the pump, which represents savings of 19.6 percent.

The energy savings associated with the water savings at the almond orchard site were calculated based on pumping energy intensity (kilowatt-hours per acre-foot [kWh/ac-ft]) for the two wells that deliver water to the field. The pumping energy intensity was slightly improved by 1 percent thanks to continuous pump monitoring, and the total energy savings was larger than 20 percent. Total energy consumption data from utility smart meters in 2020 were compared to the total volume of pumped water recorded by flow meters at each pump. A weighted average pumping energy intensity of 312 kWh/ac-ft was calculated based on the proportion of water delivered by each pump during the growing season. Multiplying the pumping energy intensity by the total water savings of 339 ac-ft achieved in 2020 gives a corresponding energy savings of 106,071 kWh. An average power cost of $0.16/kWh was estimated based on analyses of the grower's monthly utility bills over an 18-month period. Applying this average cost to the calculated energy savings resulted in an estimated bill reduction of $17,183 in 2020.

The project also documented savings in fertilizer applications that have important GHG emission and energy saving implications. The results were documented as part of the overall project and done using life cycle assessment methods that were expanded by the Bren School at UCSB to cover the nitrogen cycle.

Peak Power Load Reduction

During a two-month baseline period preceding the change in utility rates, approximately 27 percent of a pistachio grower's power consumption at a farm near Los Banos occurred during the peak hours defined previously by the utility (noon to 6:00 p.m.). Over the two months following the rate change and implementation of programmable irrigation, average monthly power consumption during the newly defined peak hours (5:00 p.m. to 8:00 p.m.) was reduced to 0.2 percent, leading to a 33 percent cost reduction in the utility bill.

Solar Energy Integration

AgMonitor developed a cost module to calculate energy costs across pumps and buildings aggregated with a large solar generator. Net energy metering aggregation is possible up to 1 megawatt for the agricultural sector. A farm near Fresno used the solar alerts and the rate optimization tool under a new product by AgMonitor called RanchMonitor to increase the solar savings by 40 percent between 2018 and 2020. A couple of the challenges that farms face is that they do not receive reliable solar panel cleaning service by contractors in disadvantaged communities, and they do not know what the best rate is to select part of a net energy metering aggregation group.

Impact on Disadvantaged Communities

Agricultural communities are relatively underserved. The project decided to streamline measurement and verification from analysis of satellite and utility meter data. This streamline process can facilitate the adoption of water and energy saving projects and reduce the cost to implement programs in rural areas. For instance, a group of table-grape fields were identified near Delano that had changed their irrigation practices from 2017 to 2019. The project team was able to measure the energy savings and provide feedback on how to optimize irrigation to improve crop production.

The team led by AgMonitor and UCSB developed the protype of a new analytical tool at the basin level called SpaceMonitor. It also applied to farmlands near Huron, which showed that photovoltaic power generation was deployed so extensively that it exceeded total energy consumption in the area. This highlights a situation in which the intermittent nature of solar power generation will create significant challenges for areas where solar power generation is the predominant source of renewable energy. As an example, a farm in the study area reported that it lost two pumps that had their electrical engines damaged due to power spikes in the utility lines. The survey of the areas near Delano (west side of San Joaquin Valley) and near Huron (east side of San Joaquin Valley) are documented as part of the overall project, which was written with WHCC and UCSB. The team shared the findings with the California Energy Commission and the California Department of Food and Agriculture to provide information relevant to managing the power grid system crises during the extreme heat wave and wildfires in 2020.

Technology Transfer

Results from the project provided evidence to growers, investor-owned utility representatives, and policy makers that the technology provides an economically viable means of reducing the consumption of power and water for irrigation and achieving load shifting without reducing crop yields. Benefits of the project to California ratepayers include conservation of energy and water resources, reduced GHG emissions, lower operating costs for agricultural producers, and improvements to the stability and security of the state’s electrical grid.

The project had to adapt to the coronavirus pandemic. AgMonitor and WCE worked with WHCC to develop new educational materials online. This increased the access to new technology solutions. The materials were not only integrated into WHCC classes but also used in neighboring high schools to inspire new careers in agriculture, which is going through a digital transformation and offers new career opportunities.

Furthermore, WCE and AgMonitor developed new mobile applications both in English and Spanish. It is an important factor for new field workers who do not always have access to broadband and do not have the same levels of education. AgMonitor decided to develop a simple weekly report to integrate overall pump efficiency alerts and peak-hour alerts. It has the potential to become the new pump test report and bundle energy efficiency and demand response programs in a simple weekly report to farming staff who have time constraints. More work is required to study the potential of permanent load shifting to stabilize the grid in disadvantaged communities and integrate a larger amount of renewable energy.

The project team organized several technology events that culminated with the creation of the OpenFarm series of events. It was organized in the communities of Coalinga in 2017, Parlier in 2018, and Tulare in 2019. Due to COVID-19, the 2020 edition had to be online and was hosted by PG&E. PG&E awarded a contract to AgMonitor to bring a full energy and water management solution to the "food and ag" sector. More than 25 business energy service representatives presented the new platform to growers. Work remains to write a white paper to qualify programmable irrigation from a custom measure to a deemed measure (basis for utilities to claim savings for their energy efficiency portfolios). The California Technical Forum contacted the team to start working toward that goal.

Benefits to California

Benefits from deployment of the project technology were assessed from an analysis of the impact on the specialty crop segment of the agriculture industry, which represents more than 350 crops grown in California. Specialty crops are grown on approximately 4.25 million acres of farmlands and use 10.6 million ac-ft of irrigation water annually, which account for 31 percent of the total water for California.

Quantitative estimates of benefits are based on projections that market penetration of the technology will reach 20 percent of farmlands cultivated for specialty crops over the next 10 years (an average of 85,000 acres per year). For this scenario, the total amount of water savings over a 10-year timeframe will be 1.75 million ac-ft. The associated energy savings are calculated using an average value of 400 kWh/ac-ft as the energy of agricultural water consumption, which is a conservative estimate for fields irrigated from a well depth of 190 feet in the Central Valley. Corresponding reductions in energy costs and GHG emissions were calculated assuming $0.1175 per kWh in cost savings (based on average statewide industrial rates) and 0.000331 metric tons of carbon dioxide equivalent per kWh of electricity saved. Based on these assumptions, the proposed technology will save 700 million kWh of electricity over a 10-year timeframe, resulting in energy savings of $82.25 million to California investor-owned utility ratepayers and a reduction in GHG emissions of 231,700 metric tons of carbon dioxide equivalent.

The research performed with the SpaceMonitor tool requires more funding to scale data fusion and clustering at the state level. The field tests also set the groundwork for other studies on permanent load shifting to reduce the power load on the grid in summer.

According to a workshop organized in Modesto in 2020, farms must adapt or face bankruptcy. This illustrates the challenge to adapt to the new regulations. It also highlights the opportunity to create new and better jobs to help automate irrigation. The project focused on placing students at three farms to help create success stories to show that there are new careers in water management beyond the known careers in pest management (farming) or commercial driving (food distribution).

CHAPTER 1: Supporting Farming Communities

The Perfect Storm

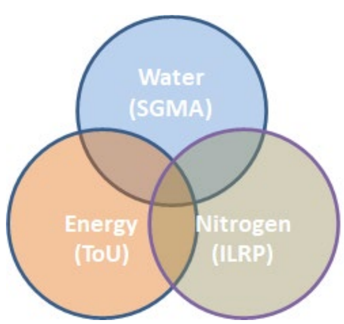
The storage, conveyance, and treatment of water account for nearly 20 percent of the total electricity consumption, and 30 percent of non-power plant natural gas consumption in California, making consumers of electricity for water-related uses the largest electricity user group in the state. Agricultural water use consumes 10 terawatt-hours of electricity per year, which represents approximately one fifth of all water-related electricity consumption and 4 percent of total electricity consumption in California.

Increasing the efficiency of energy usage for irrigation is the most immediate and effective means of reducing power consumption by the agricultural sector, because pumping water for irrigation accounts for 80 percent of agricultural electricity use. The energy efficiency of irrigated agriculture is governed by three factors: pump efficiency (the amount of energy expended by the pump to move a given amount of water), water pressure (lowering the discharge pressure by use of low-pressure spray nozzles, sprinkler heads, etc., reduces the amount of energy consumed), and water use efficiency (the amount of water used to grow a given quantity of food).

An integrated solution is needed for implementing these water and energy efficiency measures in a coordinated fashion that will maximize their benefits and be easy and cost-effective for growers to implement as new regulations on water and labor start.

At the outset of the project, the research team knew that the combination of new water regulations (Sustainable Groundwater Management Act, or SGMA), nitrate application reporting requirements (Irrigated Land Reporting Program), and the end of overtime exemption for irrigators would put an unprecedented amount of stress on farms by January 1, 2020 (see Figure 1). Therefore, the team decided to develop at the onset of this project a flexible platform to automate irrigation and fertigation scheduling that can reduce the pain in rural areas and accelerate the adoption of resource efficient strategies.

Figure 1: California Agriculture is Facing the “Perfect” Storm



Three new regulations are being implemented at the same across energy, nitrogen fertilizers, and water. It puts the farming industry in California at a crossroad. ToU stands for Time-of-Use.

Source: AgMonitor Inc.

This period is unprecedented because usually the agricultural sector deals with new agency regulations one at a time. Here, three major regulations under the Department of Water Resources, the United States Environmental Protection Agency (U.S. EPA), and the Department of Industrial Relations (DIR) happened at the same time between 2018 and 2022. The least known of the three—under the DIR—Assembly Bill 1066, directs farms with more than 25 employees to reduce the threshold for overtime from 60 hours in 2019 to 40 hours in 2022 to align with other sectors. This puts a lot of pressure on disadvantaged agricultural communities that already deal with intrinsic environmental and social issues. Farming communities lean on flexible resources from groundwater wells to seasonal workforce to adapt and provide a reliable supply of food.

What the team did not know is the extent of how climate change would push the California electricity system to its limit. Wildfires and automated power shutoffs accelerated the need to shave energy between 5:00 p.m. and 8:00 p.m. when the grid ramps up because solar generation slows down from its midday peak.

This report tells the story of a "perfect storm" and how disadvantaged communities can react to it with new integrated solutions, better technology adoption, necessary respect of the social fabric of rural communities, and better coordination among agencies.

Rollout of Sustainable Groundwater Management Act

The impact of SGMA and the role of the Groundwater Sustainability Agencies (GSA) were studied in detail in the previous EPIC project (EPC-14-081). The medium- and high-priority basins filed their Groundwater Sustainability Plan and have moved into an implementation mode since January 2020. The first curtailments are expected by 2025 or sooner, if there is another drought. Some sub-basins are already adjudicated meaning that the local stakeholders have already gone to court and agreed to a plan. The research team talked to some of them including Triangle-T near Chowchilla, California. They monitor the water table for the deep and shallow aquifers in addition to requiring monthly water records at every pump.

Integrated Land Irrigation Management requirements

In farming, a plan for maintaining soil fertility is critical for the health and productivity of crops. Over time, mineral nutrients such as nitrogen decline in soils because the plants use the nutrients to produce a crop or because overirrigation can leach the nutrients past the rootzone. Overtime, the amount of nitrogen in groundwater supplies can be significant. The goal of the Irrigated Land Reporting Program is for farms to account for that amount in their budget and avoid excess fertilizer application. The Water Coalitions in Salinas Valley and in Kern County are particularly active.

It is important to note that water quality is one of the undesirable effects that can trigger groundwater curtailments under SGMA. So, water and nitrogen application go hand-in-hand. The precise application of fertilizers using a micro-irrigation system is called fertigation. There is an opportunity to use software management tools and automated irrigation systems to control fertility as depicted in Figure 2 below.

Figure 2: Example of Fertigation Planning Tool

The prototype of the fertigation planning tool using the existing irrigation scheduling tool framework.

Source: AgMonitor Inc.

New Time-of-Use Electricity Rates and Labor Regulation

By coincidence, both the California Public Utilities Commission (CPUC) and DIR have made changes in 2019 on Time-of-Use (ToU) tariffs and labor regulations that impact profoundly the work and compensation of irrigators. Irrigators were previously "exempt" and could work as much as 60 hours to adapt to irrigation needs in the summer without receiving overtime pay. Assembly Bill 1066 now directs farms with more than 25 employees to reduce the threshold for overtime from 60 hours in 2019 to 40 hours in 2022. This led to changes in the schedule of irrigators to stay within 40 hours and hire another shift, which was not the intended goal.

At the same time Southern California Edison (SCE) changed its peak hours for the Agricultural sector from between noon and 6:00 p.m. to between 4:00 p.m. and 9:00 p.m. in 2019. Pacific Gas and Electric Company (PG&E) followed in 2020 with peak hours changing from between noon and 6:00 p.m. to between 5:00 p.m. and 8:00 p.m. (see Figure 3). Irrigating during the day is much more attractive to farms so they are seriously more inclined to make changes to their irrigation schedules.

Figure 3: Change in ToU Rates From PG&E

The peak summer hours were noon to 6:00 p.m. in the previous plan (left). In the new plan, peak hours for all seasons are from 4:00 p.m. to 9:00 p.m. for the Commercial sector (middle) and 5:00 p.m. to 9:00 p.m. for the Agricultural sector (right).

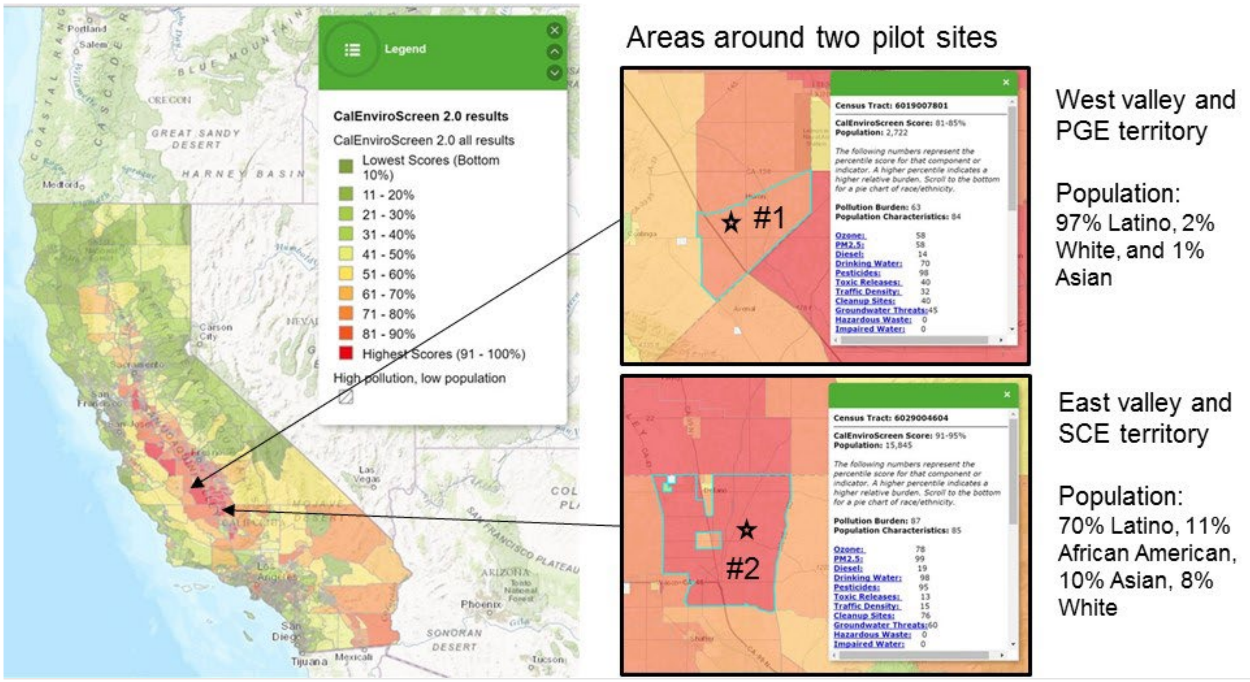
Source: Pacific Gas and Electric Company

This gradual but profound change also represents an opportunity for new technologies such as automation. It becomes too complicated to irrigate according to agronomic needs, labor constraints, and ToU rates. Farms need another degree of flexibility to turn pumps on and off and reconfigure irrigation valves. Automation is not new but became more mature recently with the advent of cheaper internet-of-things hardware and software systems. The combination of automated irrigation (for example, WiseConn Engineering [WCE]) and advanced monitoring and scheduling software based on artificial intelligence (for example, AgMonitor) is what is called "programmable irrigation."

Disadvantaged Communities in the Central Valley

The two disadvantaged agricultural communities were selected based on the CalEnviroScreen tool (Figure 4) developed by the Office of Environmental Health Hazard Assessment. The two disadvantaged communities have in common that agriculture is the main economy and that state prisons provide local jobs as well. However, there are some differences. The Delano area has a majority of smaller farms while the Huron area is composed mainly of larger operations that farm where oil rigs were common until recently.

Figure 4: Overview of the Two Disadvantaged Agricultural Communities



Huron census area (top right) and Delano census area (bottom right) were selected using an array of economic and environmental data collected by CalEnviroScreen (left)

Source: Office of Environmental Health Hazard Assessment, California Environmental Protection Agency

West Hills College Coalinga (WHCC) led the social survey using its local connections and a survey jointly developed with AgMonitor Inc. (AgMonitor). University California, Santa Barbara (UCSB) led the quantitative survey by fusing the data layers from several sources in collaboration with Formation Environmental and AgMonitor. The project team summarized the relevant information about the census area of Huron (west of San Joaquin Valley) and Delano area (east of San Joaquin Valley). The Ventura Resource Conservation District also adopted the tool developed by UCSB and AgMonitor after the Thomas fire.

West Side of San Joaquin Valley: Huron

Huron is a small city in Fresno County, California. As of the 2010 census, the population was 6,754. During the harvest season, the population swells to over 15,000 people due to the influx of migrant farm workers. Huron is located 15 miles east-northeast of Coalinga, at an elevation of 374 feet (114 meters). According to the 2000 United States Census, Huron was the city with the highest proportion of Hispanic or Latino people in the United States. The current Mayor is Rey Leon, and the State Senator is Anna Caballero. The local energy utilities are PG&E and Southern California Gas Company.

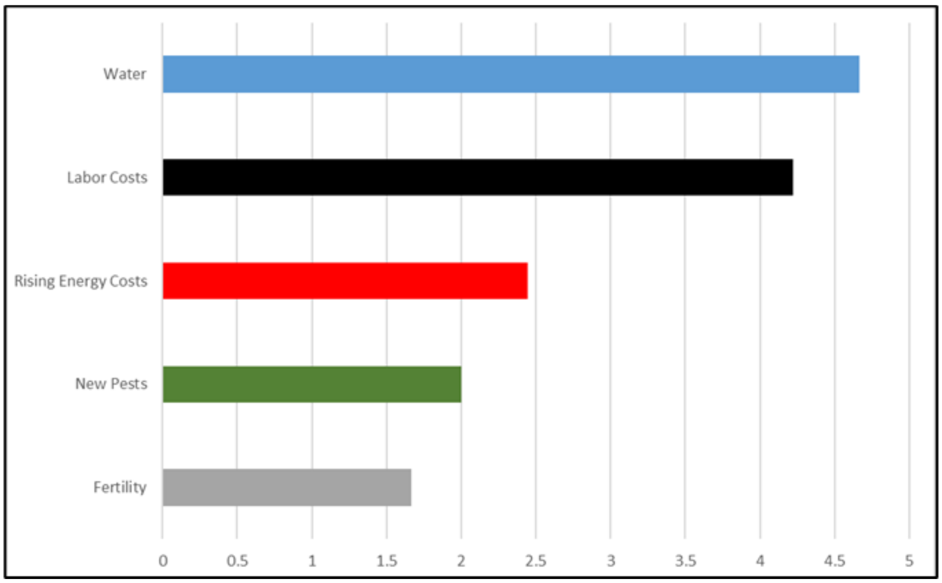
East Side of San Joaquin Valley: Delano Area

McFarland is a city in the San Joaquin Valley, in Kern County located 6.5 miles south of Delano and 25 miles north-northwest of Bakersfield, at an elevation of 354 feet (108 meters). The population of McFarland was 12,707 at the 2010 census. There is a majority of Hispanic people, but other minorities are well represented. The energy utilities are PG&E and SCE.

Ventura Area After the Thomas Fire

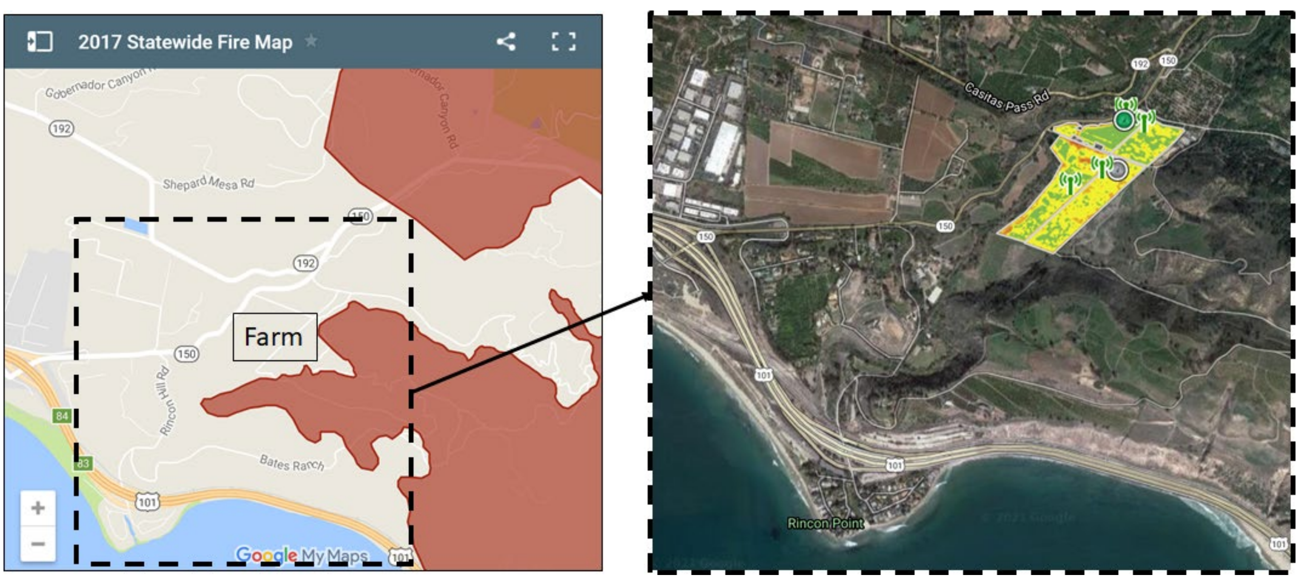
WHCC completed the survey with several farms along the Central Coast to get a sample of 30 farms and hear from growers about the main challenges they face. Water and labor were the leading concerns for both large and small farms (Figure 5). While large farms were concerned with rising energy costs, small farms were concerned with new pests due to the recent outbreak affecting the citrus industry. They also mentioned varying commodity prices as a financial challenge to keep a farming operation running. Maintained and well-irrigated land can stop fires. For instance, one of the farms involved with the project is where the Thomas fire stopped in 2019 (Figure 6).

Figure 5: Results of the Survey Across 30 Small, Medium, and Large Farms



Source: West Hills College Coalinga

Figure 6: Map of the Thomas Fire in Relation to an Avocado Farm



Sources: California Department of Forestry and Fire Protection and AgMonitor Inc.

CHAPTER 2: Overall Project Approach

The permanence in agricultural energy efficiency (AgEE) programs is less clear than for other sectors such as commercial buildings where changing light from incandescent light bulbs to light emitting diodes is predictable. It is due to two main factors. One has to do with the unpredictable use of well pumps year to year. It depends on rain and snow fall that drive annual surface water allocations. This can be resolved in the context of the new groundwater regulations by stabilizing the pumping water levels. GSAs are establishing a "safe yield" over five-year periods that will limit groundwater extractions in over drafted basins.

The other factor requires a completely different approach from "pump-to-nozzle" to ensure that energy savings occur. The last successful measure was for variable frequency drivers (VFD) to allow farms to run pumps at different operating conditions while maintaining high overall pumping efficiency (OPE). New measures based on a reduction of water use and energy use are more challenging. They must look at the complete irrigation system from end-to-end. An improvement in irrigation schedule or micro-irrigation system using automation does not necessarily translate into energy savings if the overall system is not set up or maintained correctly. One typical example is the relative failure of the "low-pressure nozzle" program that was terminated by PG&E. It aimed to reduce the overall head (the pump's ability to lift a given volume of fluid from its inlet valve to the outlet) at the pump. However, the change in the discharge pressure may require a pump retrofit to make sure that it continues to operate at the optimum efficiency level to achieve overall savings. This is why the CPUC has pushed back on investor-owned utilities (IOUs) to continue deemed pump retrofits. Today, new AgEE projects are "custom measures."

It is important to have an end-to-end approach and build in monitoring solutions to ensure that the energy savings and, in the case of this project, that the automated systems are simpler to operate to be widely adopted by farming staff. This chapter focuses on this very aspect. It can have multiple benefits: (1) to save water and energy, (2) to create some framework to support the adoption of off-peak irrigation, and (3) to look at the impact of solar integration across multiple pumps using net energy metering aggregation (NEMA). The goal is to create "win-win" situations where the farm makes the right farming decision and reduces its energy, water, and fertilizer use.

The interviews with farms in Chapter 1 led the project team to treat a farm as a business with different users who have different needs, also known as, "user personas." It is an important concept to provide an effective software platform to an enterprise. While small farm owners wear many hats, larger farming operations have experts for each role to scale up to tens of thousands of acres across California. To give an idea of the diversity of farms, the smallest farm that the team works with is a 50-acre vineyard, and the largest is a corporation that manages 50,000 acres. Keeping it simple must be part of the approach.

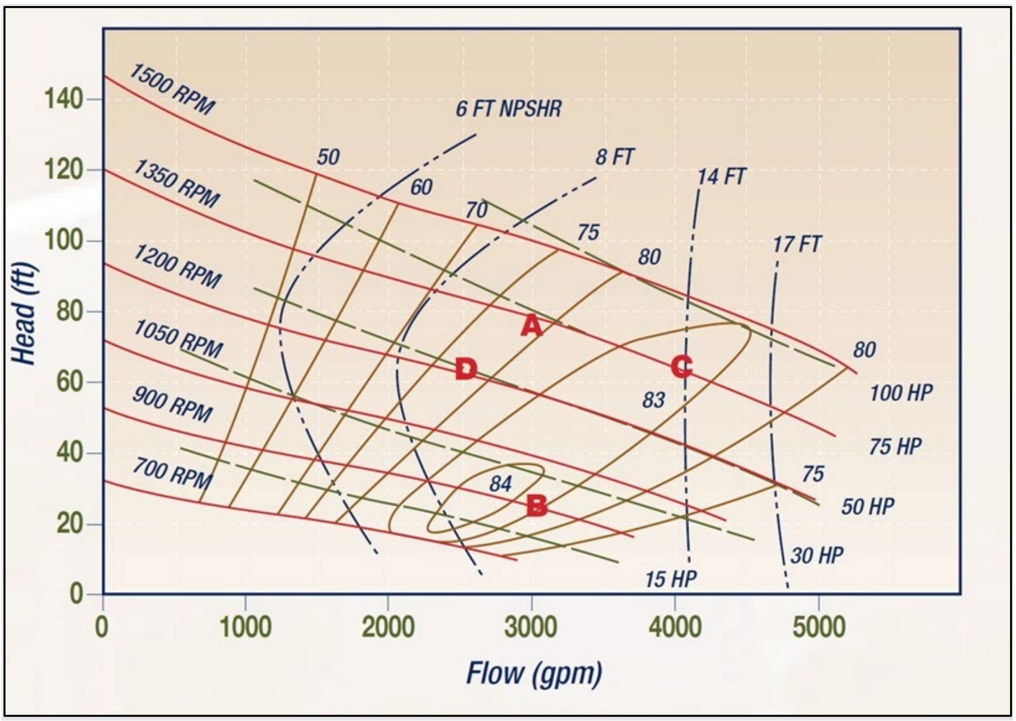
Continuous pump testing and control

The first critical activity to complete in the project was the integration of pump control and the creation of a continuous pump test with appropriate alerts. The basic concept is to offer a continuous OPE test. Continuous pump testing can also provide assurance that the different elements of the irrigation system are properly integrated after the installation of a VFD or an automation system. This section details the approach and its implementation at the pilot sites.

Algorithm to Estimate OPE from SmartMeter Data

An algorithm was built to estimate from power data based on the team's existing algorithm that estimates water flow from power data available from SmartMeters. The relationship between OPE and flow is typically quadratic and depends on the rotations per minute (RPM) and can be parametrized as a polynomial equation with power as an input (Figure 7).

Figure 7: Pump Curve for Different RPM Speeds



The pump curve is given for a specific RPM level and sets the OPE. The OPE varies with water flow for a SSP. A VFD motor can change the speed of the pump and will seek to maintain a high OPE for a given water flow.

Source: Pacific Gas and Electric Company, Advanced Pump Efficiency Program

Algorithm for Single Speed and Variable Speed Pumps

The OPE of a single speed pump (SSP) is set for each operating condition by the steady-state equation. The relationship between horsepower (HP), flow (Q), and total dynamic head (TDH) is known and one can develop a polynomial equation from the affinity equations. The polynomial equation for variable speed pumps (VSP) is different because the OPE is optimized for each RPM, but the OPE varies with the RPM. In both cases, the weighting factors are set by a three-point pump test.

The team's OPE algorithm was tested on several SSP and VSP stations and shared the results with the manager of PG&E's Advanced Pump Efficiency Program. Accuracy within 10 percent is acceptable because existing pump tests are not perfect either due to several conditions: turbulence in water affecting flow measurement accuracy, stability of the operating condition, and time constraints for the pump tester (Table 1).

Table 1: Typical Results of OPE Estimates from SmartMeters

Pump	TNI 10 S	TNI 8
Type	VSP	SSP
Date	7/2/2018	6/28/2018
Flow (gallons per minute)	656	613
Pressure (pounds per square inch)	27.5	28
Water level (feet)	236	254
Total Dynamic Head (feet)	299.5	318.7
Power (HP)	111.6	120.1
OPE measured (percent)	44.5 percent	40.8 percent
OPE estimate from SmartMeter (percent)	51.6 percent	45.5 percent
OPE difference (percent)	7.1 percent	4.7 percent

The error for SSP and VSP is below 10 percent.

TNI = total non-indicated
Source: AgMonitor Inc.

The team achieved typical accuracy of 5 percent but did not gather enough data to estimate the standard deviation. The team would need to partner with PG&E's Advanced Pump Efficiency Program with third-party testers and SCE's hydraulic team with their own pump testers to gather enough statistical data (30 tests for each type). Another approach is to work with telemetry vendors, which the team does, and qualify remote OPE tests to gather hundreds of data points.

Display of OPE Measurement Results

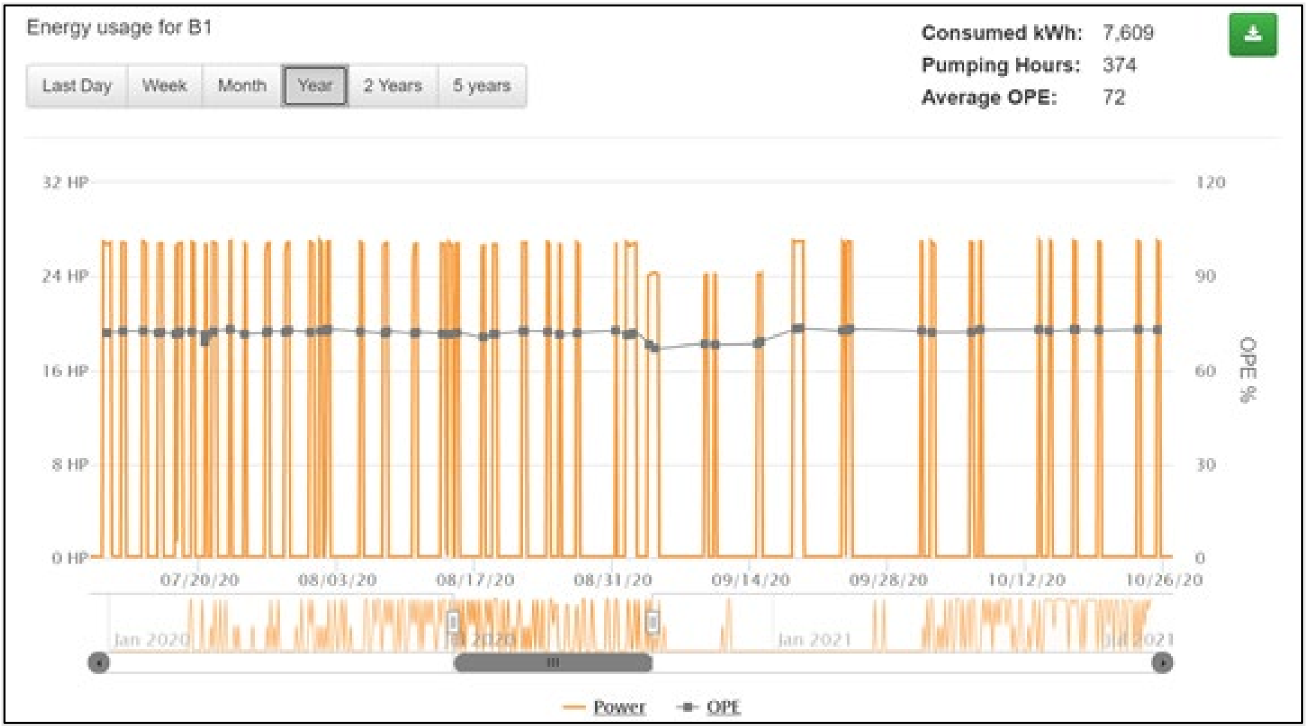
The team reviews below the two ways that IOUs are interested to sponsor pump tests (for example, $100 per year) and that farms are interested in looking at.

Continuous OPE Estimation from SmartMeter Data Only

The first way is to check how the pump is operating continuously along with the energy data with a 15-minute resolution. This is particularly useful to check changes in operating conditions.

In the first example, at a farm on the campus of California State University (CSU), Fresno, the OPE decreased after changing to irrigate only half the field. The average OPE is 72 percent for the whole field while the average OPE is 67 percent for half the field (Figure 8).

Figure 8: Display of Continuous OPE Testing for a Single Speed Pump

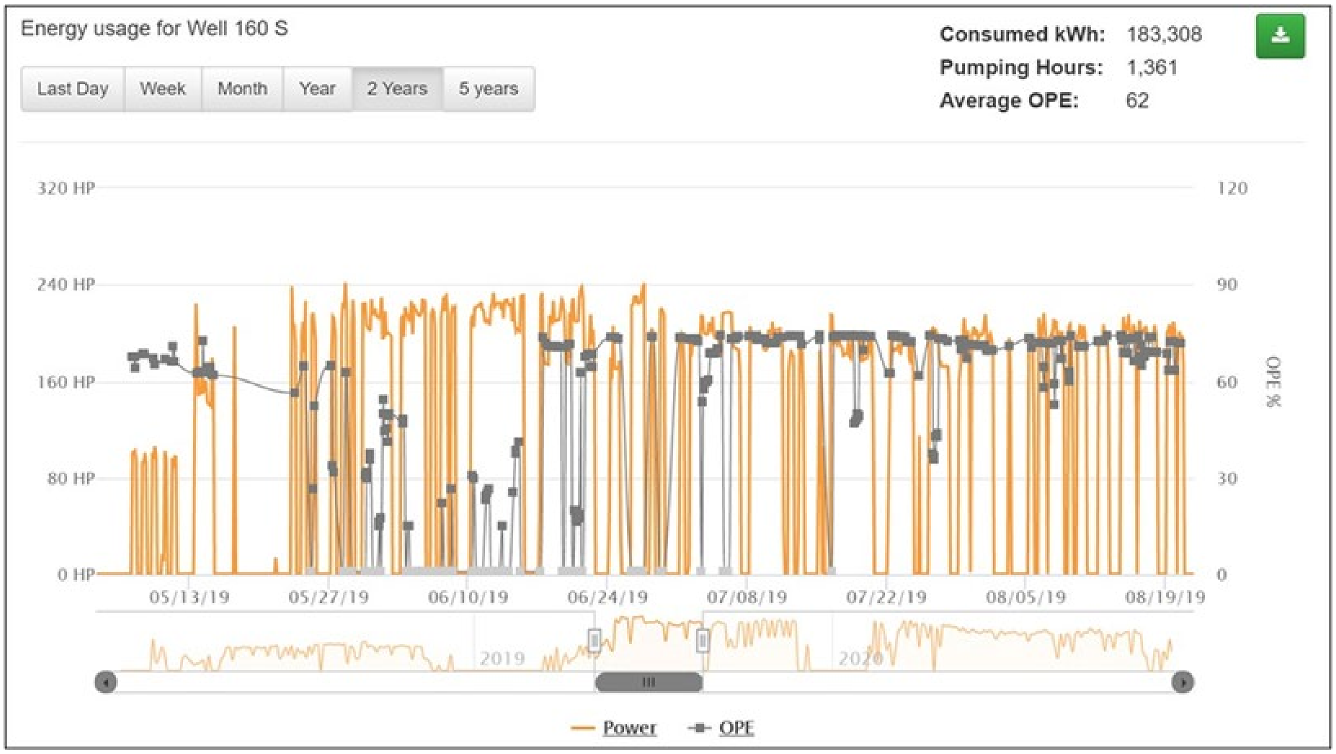


The OPE of a SSP at CSU Fresno goes down from 72 percent to 67 percent when only half the field is irrigated during the harvest of the almond orchard.

Source: AgMonitor Inc.

In the second example at a larger farming operation near Davis, in PG&E territory, the degradation in OPE after installation of an automation system to control the pump and the valves can be seen. The dealer's staff changed the VFD parameters, which led to the engine being overrun in June 2019.

Figure 9: Display of Continuous OPE Testing for a Variable Speed Pump



The OPE of a VSP used for programmable irrigation dropped significantly below 30 percent in June 2019 after the installation of the automation system. After the VFD parameters were corrected, and the pump was used in the proper range, the OPE increased back above 60 percent.

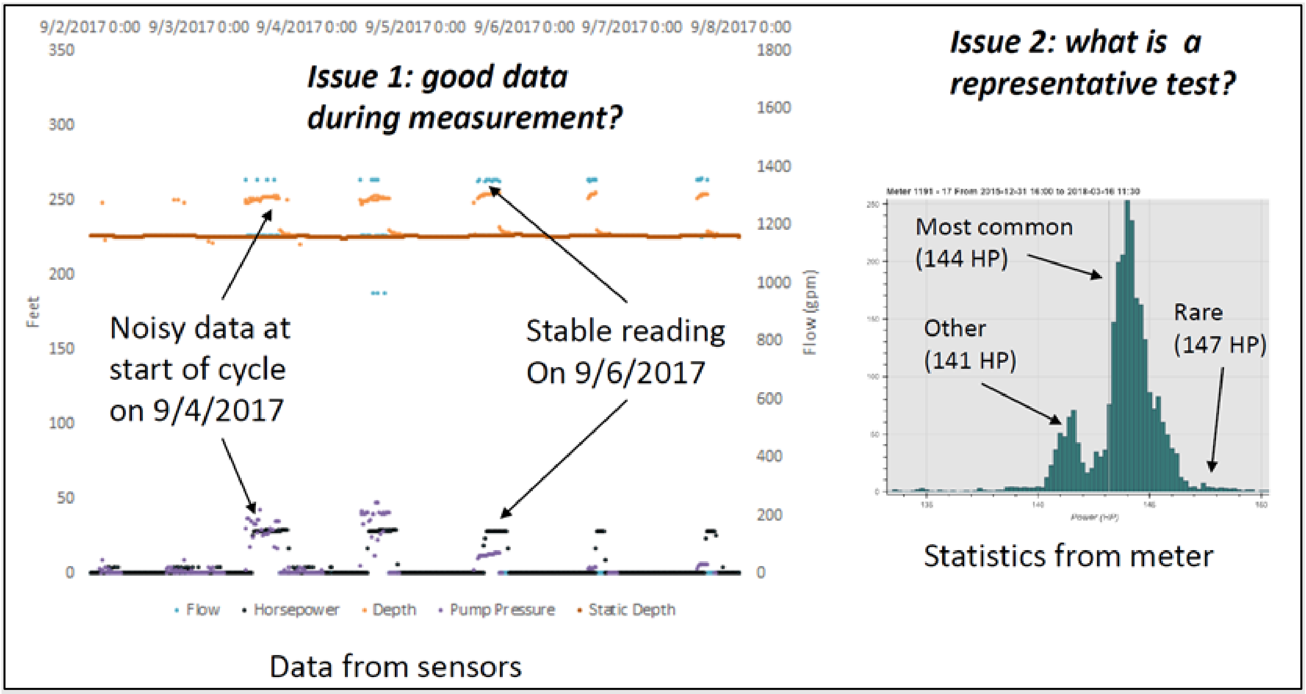
Source: AgMonitor Inc.

The farm decided to set some hydraulic rules to reduce wear and tear and run the various blocks of the orchard within some flow range. Despite irrigating for different parts of the orchard week-to-week, the pump achieved an average OPE of 65 percent in 2020 compared to 62 percent in 2019 and 64 percent in 2018 before the project started. The continuous monitoring of the pumping system is critical for programmable irrigation, and, in this case, the farm saw an improvement of 1 percent compared to manual operation.

Remote OPE Test Using Telemetry Station and SmartMeter Data

The second way to display OPE results is to provide an alternative to a pump test by gathering the data from a remote telemetry system at a pumping plant. The first step is identifying the three main operating conditions from historical SmartMeter data. It is not trivial because the team has to act as a pump tester: was the pump stable during the period under consideration? (Figure 10). One can also improve the relevance of the pump test by looking at the main operating conditions during a year based on number of hours.

Figure 10: Selection of Measurement Period for a Remote Pump Test



The visualization of the telemetry data (left) across pump flow, horsepower, pumping water level, pump pressure and static water depth from a pump are key to understanding the various operating conditions. A histogram of historical pump usage for various power levels can help choose the three main operating conditions and optimize the test dates for a season.

Source: AgMonitor Inc.

Once this is done, one can gather the data for specific irrigation events from the telemetry station with flow, discharge pressure, pump water level, and power data. The OPE results can be printed out as a replacement of an existing pump test result form. The only different is that it is done remotely. A prototype was done at a large farm near Fresno. The example below (Figure 11) shows that OPE varies greatly from 60 percent to 72 percent depending on what field is irrigated and what operating condition the pump is on.

Figure 11: Example of a Remote Pump Test Report

		Main – E1 (9/6/17)	E2 (8/14/17)	E3 (9/12/17)
1	**Pumping water level (ft)**	**233.8**	**248.8**	**248.7**
2	**Standing water level (ft)**	**223.6**	**228.6**	**223.3**
3	Draw down (ft)	10.2	20.2	15.4
4	Recovered water level (ft)	223	229	223
5	**Disch. pressure at gauge (PSI)**	**3.8**	**73.2**	**27.9**
6	**Total lift (ft)**	**262.6**	**418**	**313.5**
7	Flow velocity (ft/sec)			
8	**Measured flow rate (gpm)**	**1322.5**	**967.8**	**1193.5**
9	Customer flow rate (gpm)	1322.5	967.8	1193.5
10	Specific capacity (gp,/ft draw)			
11	Acre Feet per 24 hr			
12	Cubic Feet per Second (cfs)			
13	**Horsepower input to motor**	**144.9**	**141.5**	**149.0**
14	Percent of rated motor load (%)			
15	Kilowatt input to motor			
16	**Kilowatt hours per acre-foot**			
17	**Cost to pump per acre-foot**			
18	Energy cost ($/hout)			
19	Base Cost per KWh			
20	Nameplate (rpm)			
21	RPM at gearhead			
22	**Overall Pump Efficiency (%)**	**60.5**	**72.2**	**63.4**

The report has three OPE results for the three main operating conditions of the pumping plant. The report template uses the same format as PG&E's Agricultural Pumping Efficiency Program.

Source: AgMonitor Inc.

Weekly reporting including OPE Alerts

Although useful for troubleshooting, the previous examples are not that useful to a farming operation because most of the staff does not work in front of a computer. The staff needs a weekly report that they receive by email so they can look at it as part of a weekly staff meeting. Better yet, it can enable new conversations between the ranch manager who operates the pump and the accounting staff who pays the energy bill. This report addresses how the OPE alert is generated in that context.

Reporting Needs for Ranch Manager

A weekly pumping report was developed that is practical for ranch managers. It lists the OPE and provides an alert based on a threshold. It must provide operational information:

- How many hours was the pump used?
- Is there an alert (OPE or anomaly as currently supported)?
- Was the pump used during peak hours?
- What was the energy cost of pumping the water per acre-foot?

The last step is to connect to the accounting staff who pay the bill. They might see an increase in the next bill, but it is too late. The money is spent already, and the pump might already be out of service. Therefore, AgMonitor developed a cost module to estimate the cost of the pumping based on SmartMeter data to enable a conversation between the accounting staff and the ranch manager to make improvements (Figure 12). Ideally the report should be easy to review in a staff meeting.

Figure 12: Example of a Weekly Pumping Report With an OPE Alert From a Meter

Company: Farm — **Company Pumping Hours: 4174**

Ranch: Ranch 02 — **Ranch Pumping Hours: 0**

No pumping was recorded

New Alerts No new alerts during the week

Ranch: Ranch 03 — **Ranch Pumping Hours: 504**

Pump	Water Source	Meter SA ID	Pump Hours	Pump kWh	Est. Energy Cost ($)	Est. Water (ac-ft)	Cost per ac-ft ($)	Avg OPE (%)	Target OPE (%)	Peak Hours	Peak Charges ($)
R03 B02 250 HP Well	Well	2739879915	168	29416	$ 5,511.30					21	$ 3,995.94
R03 B02 5&50HP Lift, BS	Canal	2739879915	Unable to separate pump power data								
R03 B03 50HP WELL PUI	Well	6843690734	168	6659	$ 1,260.57	7.08	$ 178.05	40%	59%	21	$ 898.97
R03 B04 100HP WELL PU	Well	1321661748	168	15636	$ 2,930.45					21	$ 2,108.88
R3B4 100HP well 50HP b	Canal	1321661748	Unable to separate pump power data								

New Alerts

Asset	Status	Date	Message
R03 B03 50HP WELL PUI	WARN	2021-06-14	Warning: The water table at R03 B03 50HP WELL PUMP at Ranch 3 appears to be significantly declining. If this continues the pump may go down.

Ranch: Ranch 04 — **Ranch Pumping Hours: 337**

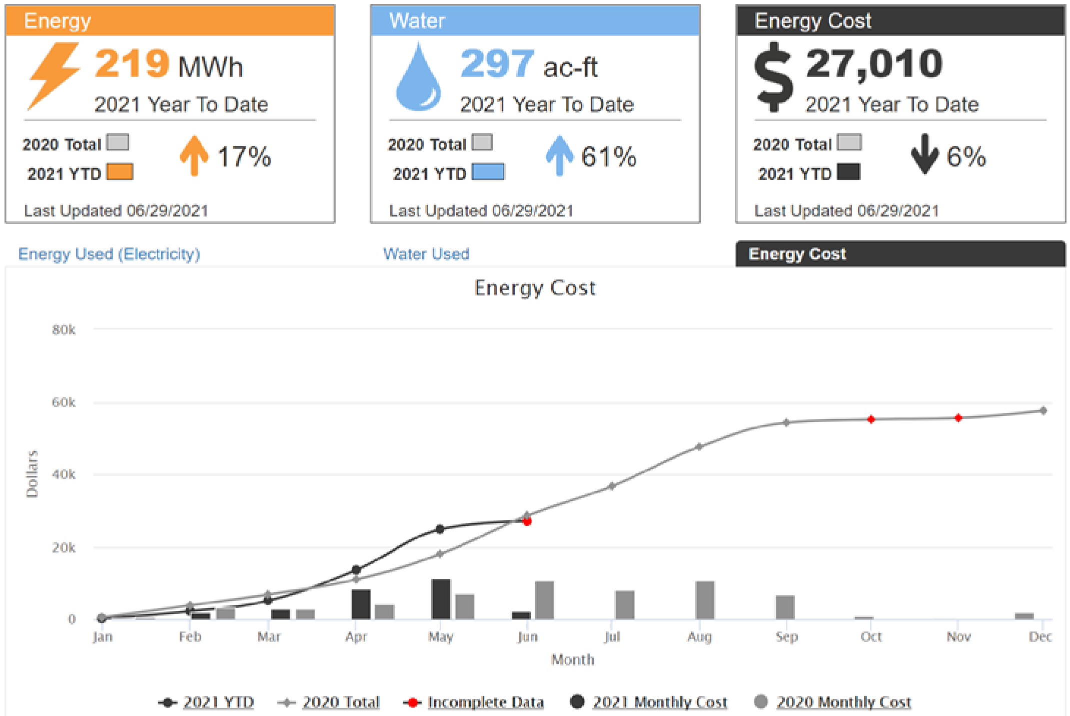
Source: AgMonitor Inc.

Reporting Needs for Accounting Staff

Accounting staff have other needs. They need to reconcile the energy bills every month and will discuss with ownership what larger projects need to be undertaken. This is where pump retrofits or other incentives such as VFDs have been useful. It is important to be able to measure the impact of an event, and the team gathers energy, water, and cost data.

AgMonitor developed a dashboard by project for the accounting staff to have all the billing details in one place (Figure 13). When AgMonitor received 95 percent of the bills, a notification is sent.

Figure 13: Example of a Dashboard With Monthly Update on Cost Data



Source: AgMonitor Inc.

Thresholds for OPE Alerts

When communicating the results of the model, the OPE estimation needs to be characterized as good, fair, or poor, so that growers know how to react to the data. These characterizations can be visualized simply using color such as green (good), yellow (fair), and red (poor). This aligns with the core value of AgMonitor to provide growers with answers, not more data.

The first step was to gather some expert advice on what thresholds to use for each characterization level. The team first spoke with Steve Villegas, from SCE. Steve is a certified energy specialist acting as a technical specialist for the pump test and hydraulic services team at SCE. Among other duties, Steve teaches classes to growers on how pumps operate and how the growers can save more energy. Steve provided an abbreviated version of Table 2 below as a resource for the project team but let the team know that it was likely a bit outdated.

Table 2: Characterization of OPE Levels for Various Pump Power Levels

Motor HP	Low (percent)	Fair (percent)	Good (percent)	Excellent (percent)	Booster (percent)
3 - 5	41.9 or less	42 - 49.9	50 - 54.9	55 or above	55
7.5 - 10	44.9 or less	45 - 52.9	53 - 57.9	58 or above	58/60
15 - 30	47.9 or less	48 - 55.9	56 - 60.9	61 or above	60/65
40 - 60	52.9 or less	53 - 59.9	60 - 64.9	65 or above	65/70
75 and above	55.9 or less	56 - 62.9	63 - 68.9	69 or above	70/72

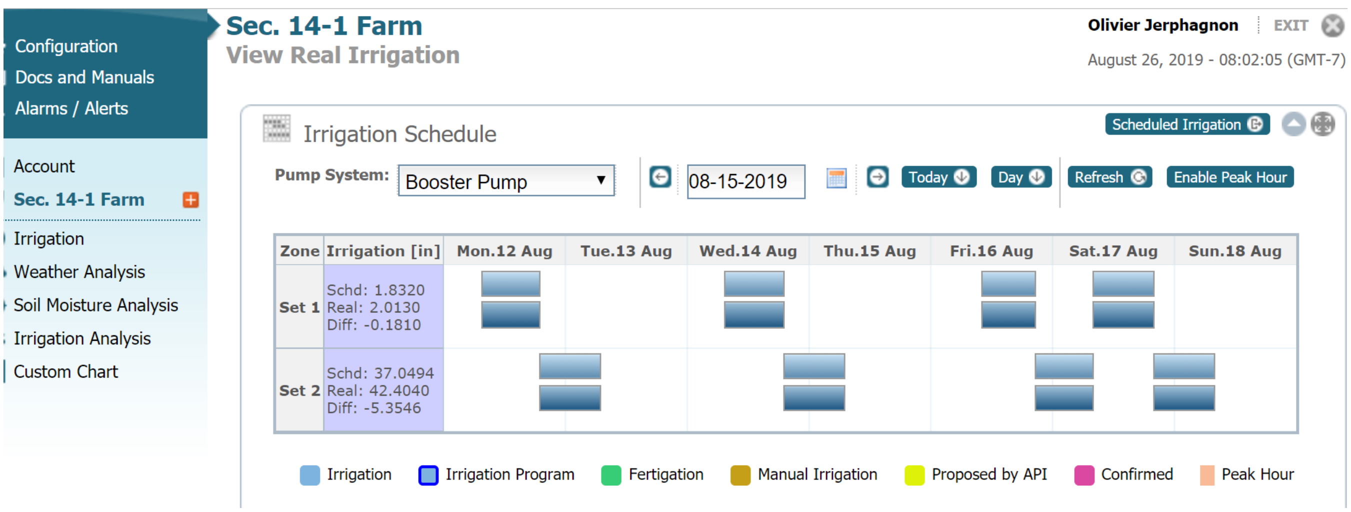
Source: Steve Villegas, Southern California Edison

The second person interviewed was John Weddington, the pump and irrigation specialist for Fresno State Center for Irrigation Technology. John explained there are numerous practical limitations for achieving high OPE seen in municipal pumps, meaning that agricultural pumps will rarely get close to max efficiency on the manufacturers pump curve. With this in mind, John said, "Regarding OPE standards, I believe this table [see Table 2] is still representative for agricultural pumps."

Integration with Automation System (DropControl)

Summarized in this section is the integration of the automation platform developed by WCE called DropControl (Figure 14).

Figure 14: DropControl User Interface for Scheduling Irrigation Events



Events scheduled from third-party platforms such as AgMonitor are highlighted in yellow and become pink when they are confirmed.

Source: WiseConn Engineering

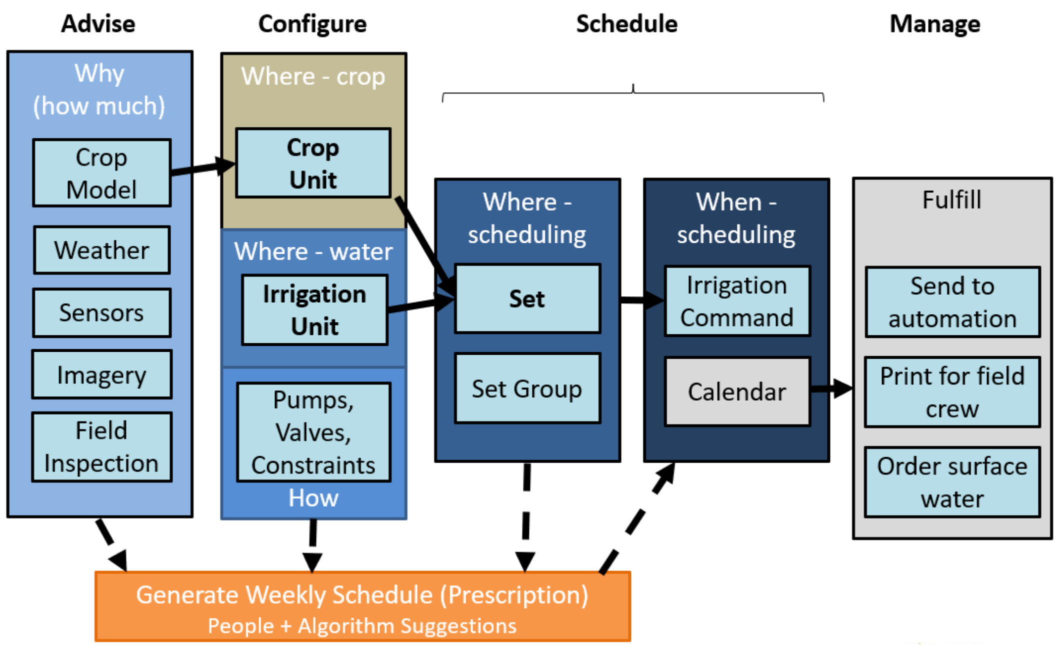
Communication with Third-Party System via Application Program Interface

The project team decided early to configure irrigation schedules for both manual and automated fields. In addition, some farms must order water from districts that will need to be pumped from a district's canal before being pumped out into a field. Therefore, three cases must be considered to fulfill all irrigation scheduling needs as depicted in Figure 15. The communication to an automated system such as DropControl is done via an application program interface (API) to load a schedule or receive alerts. WCE developed new features for the API.

Data Model to Select Irrigation Sets and Pump Sources

AgMonitor read the data exchange standard for precision irrigation developed under the supervision of American Society of Agricultural and Biological Engineers. AgMonitor has data models consisting of irrigation units (controlled by valves), crop units (management zones identified using soil types and crop varieties), and irrigation sets (group of irrigation units irrigated at the same time and shown as one in DropControl).

Figure 15: Diagram for Generating and Managing Irrigation Schedule



Source: AgMonitor Inc.

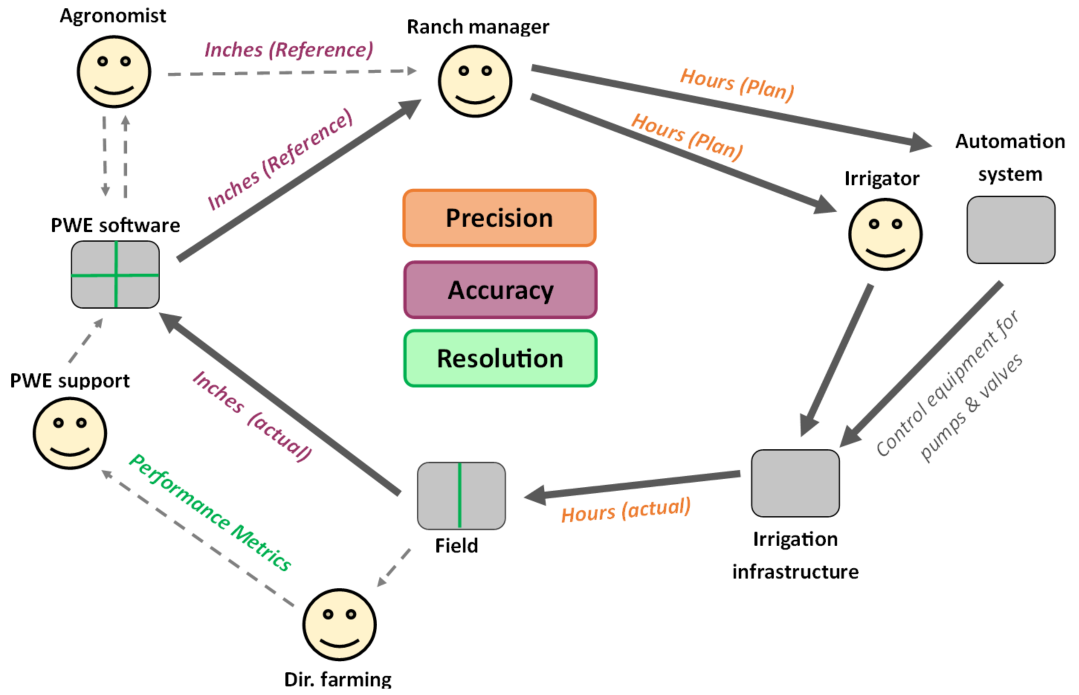
Improvements to DropControl's User Interface and Mobile Application

Because WCE was founded in Chile, and has an office in Fresno, they started early developing a mobile application in both English and Spanish to display sensory data and allow irrigators to interface with the automation system. They shared their experience working in Spanish with farm workers. This benefited the project because the new technologies could be adopted by more field workers. The data from WCE was also displayed onto AgMonitor's web-based dashboard and the calendar schedule of AgMonitor's mobile application. WCE also made improvements in their user interface to enable programs using templates.

Field Management with Mobile Application in English and Spanish

The second critical task to complete for this project was the development of a scheduling process (Task 3) and a mobile application (Task 4) that would work for the entire team. The team interviewed growers and identified five user personas for software development: agronomist, accounting staff, ranch manager, field crew, director of farming (Figure 16). This is in addition to farm owners and equipment dealers. It became clear that the field crew working in hours per irrigation set had different needs than the agronomist working in inches per management zone. Furthermore, the language barrier, with the field crew predominantly speaking Spanish, limited information to a calendar.

Figure 16: Diagram of Irrigation Workflow Paths



The workflow shows both paths for irrigation with an automation system or a field irrigator.

Source: AgMonitor Inc.

As a matter of fact, the data was not collected in a systematic manner to discuss if the plan was implemented. This leads to confusion: is a plant stressed because the agronomic plan is not correct or because the execution of the plan was not done properly? "Irrigation is like measuring with a micrometer and applying with a hammer," explained the Dean of Career Technical Education and Workforce Development at Hartnell College. The team focused on reducing that divide while making it easier for farms to scale from manually controlled irrigation to automatically controlled irrigation.

The last part of the project was to provide a mobile application in Spanish as well as in English to address the language barrier and improve communication among the team. The key people that the mobile application was developed for were the agronomist, the ranch manager, and the field crew as described in Figure 17.

Figure 17: View of Login Page of Mobile Application and List of Users

User persona	What they do
General Manager (GM)	Overall budget including water (SGMA) and profitability. Checks on the team every month.
Director of Farming (DF)	Team management and overall yield targets, along with contracts. Monitoring team at least weekly.
Ranch Manager (RM)	Farm and field operations, supervising field crew daily.
Accounting Staff (AS)	Reporting & tracking cost vs budget.
Agronomist (AG)	Overall crop health, including fertility & irrigation recommendations.
Field crew (FC)	Irrigation equipment and valve operation along with other field tasks.

Source: AgMonitor Inc.

The project team tested the mobile application at a commercial farm near CSU Fresno, with which the team has a relationship (Figure 18). The role of agronomist is split between the irrigation specialist (irrigation schedule) and the in-house prescriptions for fertility, but the same ranch team composed of the ranch manager and the irrigator use the information and make sure that things get done during a week.

Figure 18: Farm Staff Testing the Mobile Application

The farming staff that tested WCE and AgMonitor's mobile application included the field irrigator (left), irrigation specialist (center left), ranch manager (center right), and pest control advisor (right).

Source: AgMonitor Inc.

Weekly Agronomic Recommendation by Management Blocks

Farms usually consist of ranches that are located in different places. Ranches consist of parcels with different crops planted every year depending on soil factors, economic factors, and water availability. A programmable platform is useful for crop management because it can combine various irrigation units (controlled by valves) into management blocks grouped by soil and crop type (Figure 19).

Figure 19: Mobile Application Overview of Ranch Management Blocks and Soil Sensor Placements

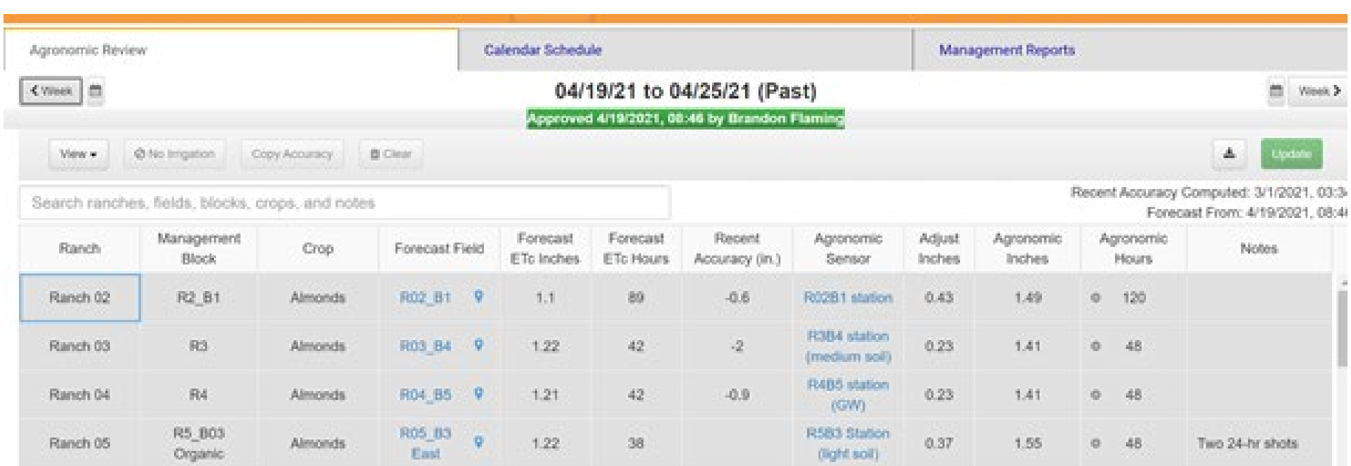
The mobile application overview of the ranch's management blocks shows three different soil types responding to irrigation, including light (orange), medium (yellow), and heavy (green) irrigation.

Source: AgMonitor Inc.

For instance, the farm used for the mobile application has 40 management blocks across 6,000 acres: almonds and olives, conventional and organic farming practices, lighter and heavier soil types. The team helped the farm place the soil sensor in each management block at a representative location using historical images.

AgMonitor integrated the forecasting tool from the previous EPIC project (EPC-14-081) and added the agronomic sensor of choice in the "Agronomic Review" page (Figure 20). The agronomist can check the evapotranspiration forecast in inches and make an adjustment. The recommendation in inches is converted into hours using the information about the ranch.

Figure 20: Mobile Application Overview of Ranch Management Blocks



Agronomic Review | Calendar Schedule | Management Reports

04/19/21 to 04/25/21 (Past)

Approved 4/19/2021, 08:46 by Brandon Flaming

View | No Irrigation | Copy Accuracy | Clear | Update

Search ranches, fields, blocks, crops, and notes

Recent Accuracy Computed: 3/1/2021, 03:3
Forecast From: 4/19/2021, 08:4

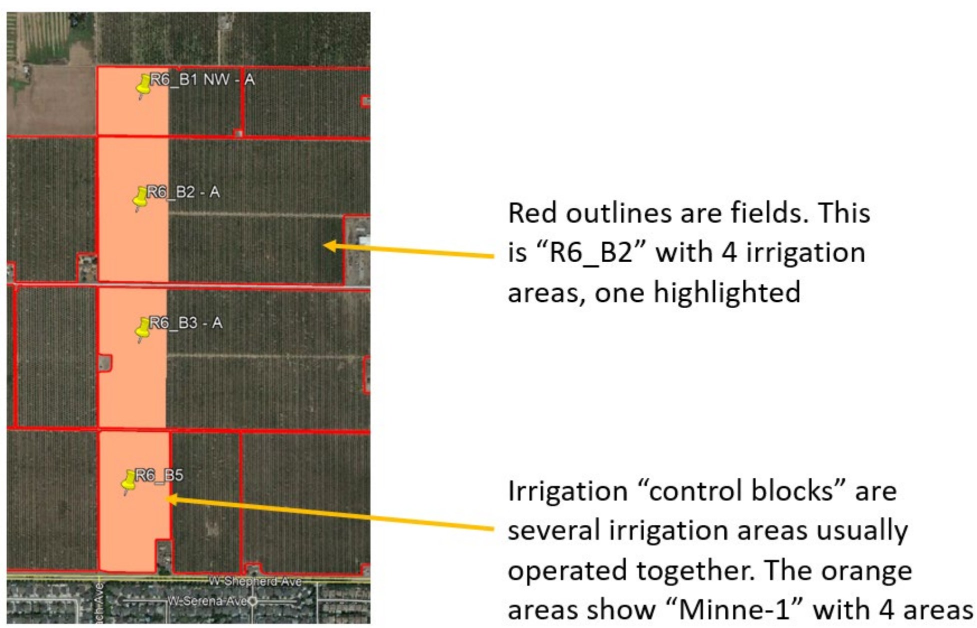
Ranch	Management Block	Crop	Forecast Field	Forecast ETc Inches	Forecast ETc Hours	Recent Accuracy (in.)	Agronomic Sensor	Adjust Inches	Agronomic Inches	Agronomic Hours	Notes
Ranch 02	R2_B1	Almonds	R02_B1	1.1	89	-0.6	R02B1 station	0.43	1.49	120	
Ranch 03	R3	Almonds	R03_B4	1.22	42	-2	R3B4 station (medium soil)	0.23	1.41	48	
Ranch 04	R4	Almonds	R04_B5	1.21	42	-0.9	R4B5 station (GW)	0.23	1.41	48	
Ranch 05	R5_B03 Organic	Almonds	R05_B3 East	1.22	38		R5B3 Station (light soil)	0.37	1.55	48	Two 24-hr shots

Calendar Schedule by Irrigation Sets

The second tab is performed on a tablet by the ranch manager to review the recommendation and make adjustments based on other field activities. For example, the ranch may have a schedule for a dry spray pesticide that conflicts with irrigation. It is particularly difficult for a ranch manager to deal with a new automation system on a field while continuing to provide printed irrigation schedules for other fields. AgMonitor integrated both cases in the second tab called "Calendar Schedule" (Figure 20).

The irrigation sets do not follow the same pattern as the management blocks. For example, the irrigation sets at the ranch in Figure 21 below are done vertically left to right, and the field crew gives them practical names. In contrast, the fields follow the parcels and have a number that the field crew does not know. Moreover, there are two management blocks (east and west) with a dedicated sensor station, but there are eight irrigation sets that irrigators name according to the local street names. AgMonitor translated the agronomic information in management blocks from the Agronomic Review tab to simple irrigation sets in the Calendar Schedule tab so the field crew knows exactly what to do.

Figure 21: Example of Irrigation Sets on a Management Block



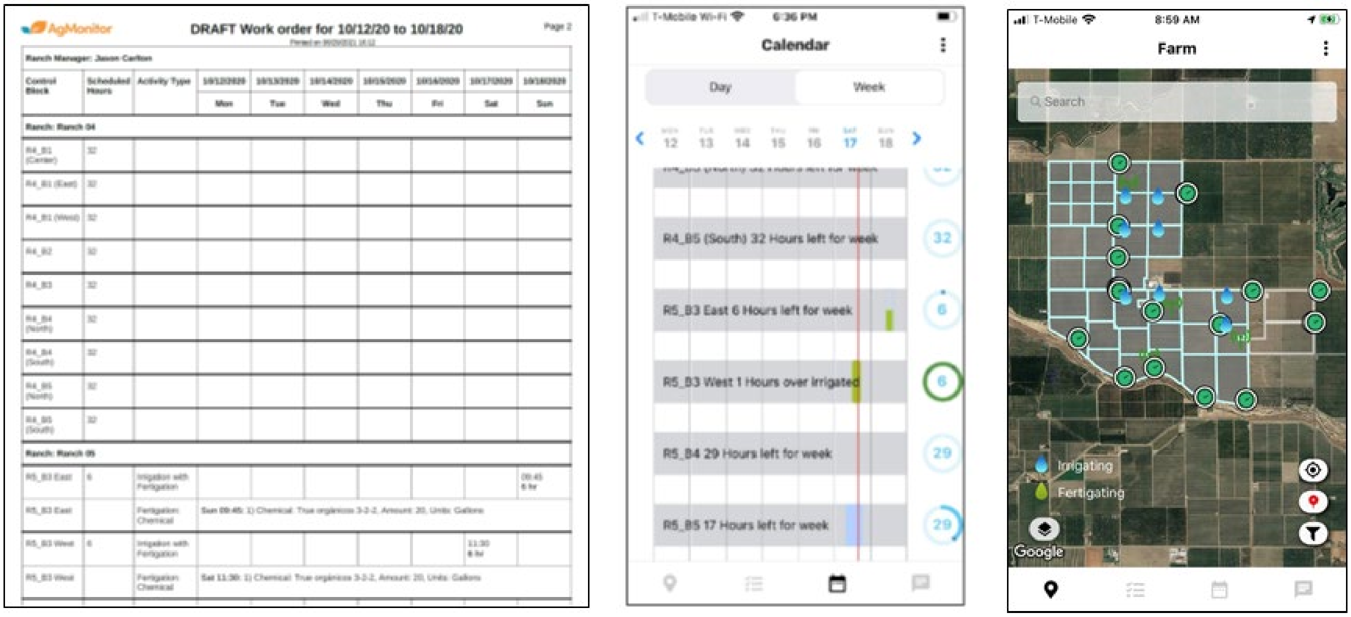
Source: AgMonitor Inc.

Work Orders for Both Automated and Manual Fields

It is very common for the ranch manager to print the irrigation schedule ("work order") because it represents a costly resource (water) from groundwater or surface allocation. During the mobile application trial, the field crew could have access to the work order from their smart phone or a tablet that was given to them.

The project team compared a printed work-order in English – the field crew can read the numbers – and the mobile application that is in Spanish (see Figure 22). The main difference is that the irrigator can be involved in the reporting by using the irrigation task (blue) or fertigation tasks (green). Alerts and new information can also be shared within the team on-the-go.

Figure 22: Mobile Application Schedule Viewing Options



The irrigation and fertigation schedule can be viewed three ways: Printout (left), Mobile Application with the Calendar View (center) and Map view (right)

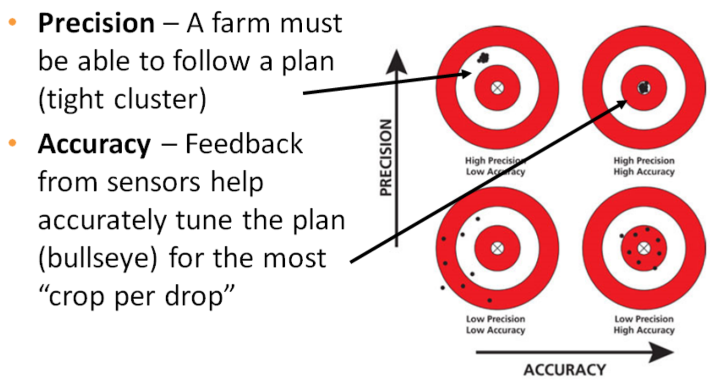
Source: AgMonitor Inc.

Both automated and manual fields are supported by the same application. AgMonitor will focus on that aspect in the management reports.

Measurement of Applied Water and Fertility Against Approved Weekly Plan

The team decided to develop weekly management reports to measure accuracy (water application in the root zone compared to a scientific reference) and precision (irrigation events in hours compared to the agreed schedule). This was not originally planned but became a critical task and a very useful feature for farms to create a plan and follow the plan to ensure the most "crop per drop" (see Figure 23).

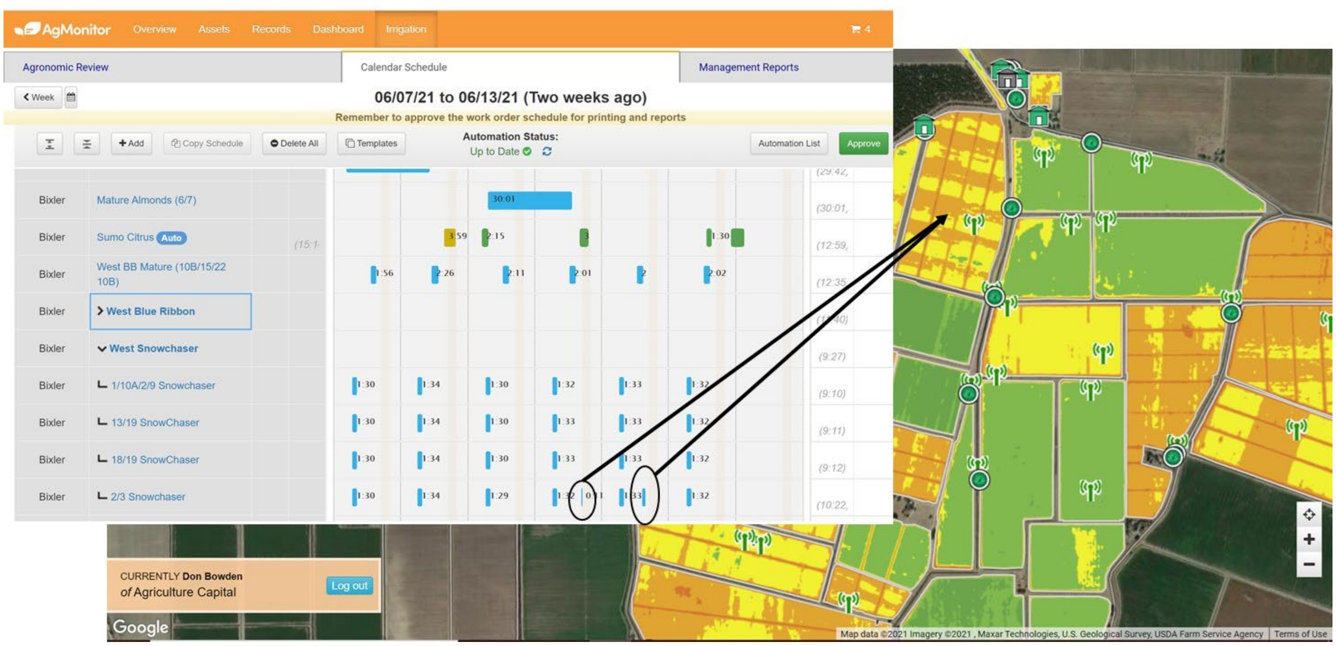
Figure 23: Accuracy and Precision Concepts Illustrated in a Series of Targets



Source: AgMonitor Inc.

The other metric to consider in a project that implements programmable irrigation is the temporal resolution (a minute or an hour) and the spatial resolution (an entire field or down to each irrigation unit controlled by a valve). The team takes an example of a farm near Tracy because it is a good illustration of both concepts. While the almond and citrus fields are planted in a regular pattern, the blueberry fields on the west side have six varieties planted across the fields in smaller areas controlled by a valve (Figure 24). This is a good example because the crops are laid out and irrigated based on soil type and variety.

Figure 24: Mobile Application Overview of Programmable Irrigation



The temporal and spatial resolution for programmable irrigation is shown for a farm with blueberry fields (west), almond fields (east), and a citrus fields (center east).

Source: AgMonitor Inc.

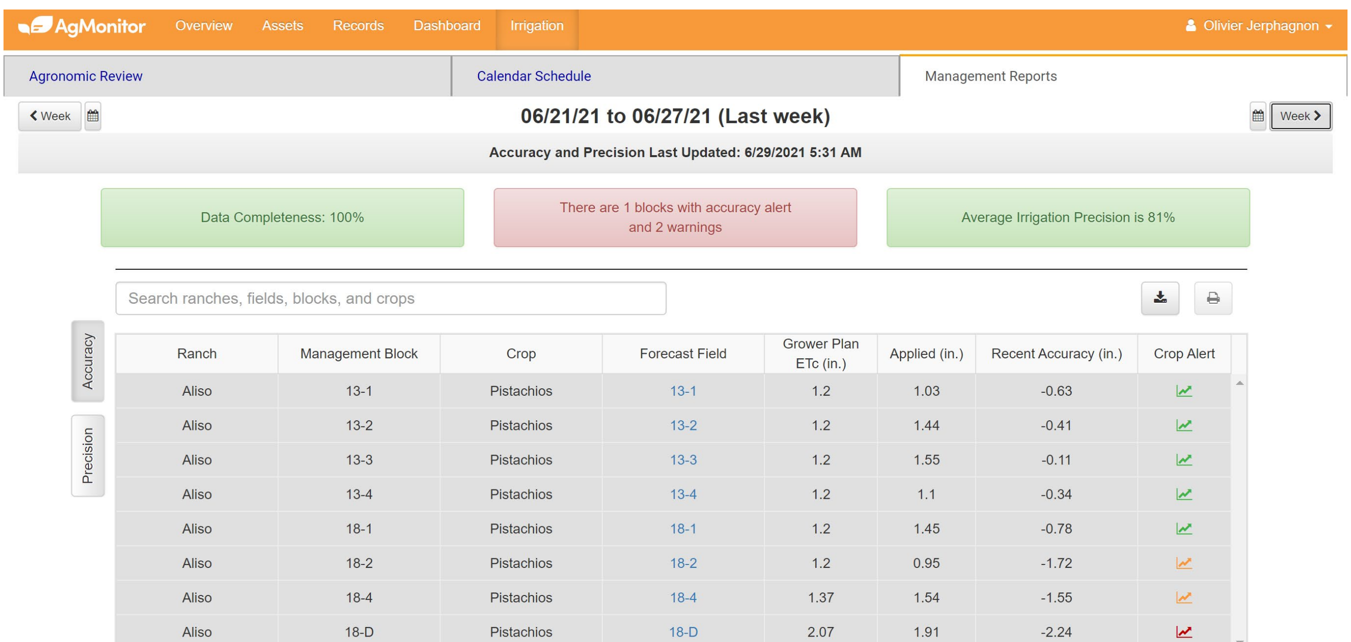
In this case, the spatial resolution for irrigation is to be able to irrigate individual valves by variety and soil type. The temporal resolution is in minutes as the irrigation manager irrigates multiples times a day to keep water and nutrients in the shallow root zone.

An illustration of the temporal resolution is the irrigation of the citrus fields located in the middle of the almond fields on the east side. The irrigator followed the advice of an agronomist and applied water in shots of 10 minutes each hour to keep water and nutrients in the root zone for the young trees. They carry an exclusive brand of oranges called "Sumo Citrus." This would not be possible without automation and the ability to enter a program via software. The irrigation events become longer as the trees age.

Accuracy Report to Improve Crop Management

The tab for the "Management Reports" shows the "Accuracy" report. It lists each management block and compares the actual irrigation to the agronomic plan in inches or water in the root zone. If the difference is larger than one inch over the past few weeks, AgMonitor set a warning (yellow). If the difference is larger than two inches, the team sets an alert (red) to help the operation correct the amount of irrigation the following weeks. The team provides an example for a ranch with multiple pistachio fields (Figure 25).

Figure 25: Accuracy Report for a Ranch With Pistachio Fields



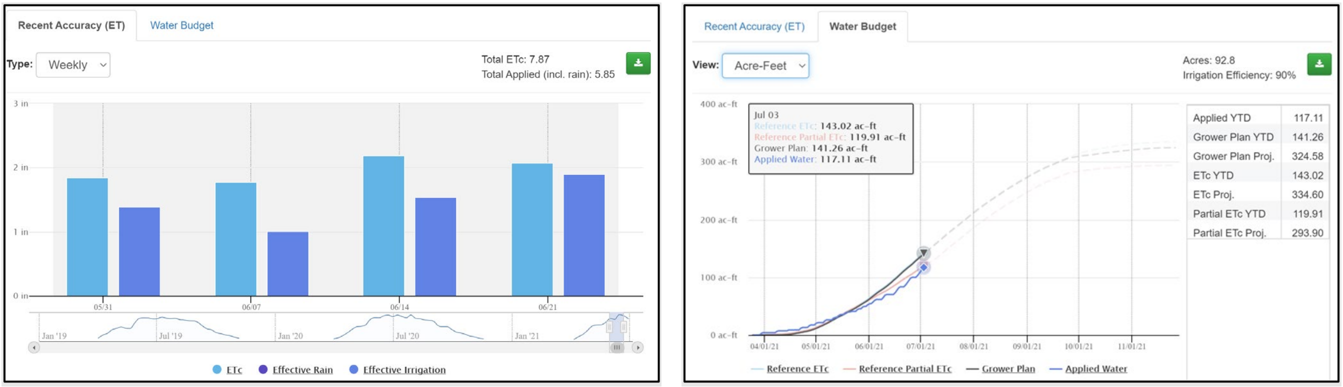
Ranch	Management Block	Crop	Forecast Field	Grower Plan ETc (in.)	Applied (in.)	Recent Accuracy (in.)	Crop Alert
Aliso	13-1	Pistachios	13-1	1.2	1.03	-0.63	
Aliso	13-2	Pistachios	13-2	1.2	1.44	-0.41	
Aliso	13-3	Pistachios	13-3	1.2	1.55	-0.11	
Aliso	13-4	Pistachios	13-4	1.2	1.1	-0.34	
Aliso	18-1	Pistachios	18-1	1.2	1.45	-0.78	
Aliso	18-2	Pistachios	18-2	1.2	0.95	-1.72	
Aliso	18-4	Pistachios	18-4	1.37	1.54	-1.55	
Aliso	18-D	Pistachios	18-D	2.07	1.91	-2.24	

Most of the fields are on target and have a "green" crop alert. Two fields are under irrigated by over an inch and have a "yellow" alert. One field is "red" as it is under irrigated by more than 2 inches.

Source: AgMonitor Inc.

The agronomist can check the graph and zoom in on the last four weeks (Figure 26, left) or look at the whole season (Figure 26, right). The graphs confirm that the field was under irrigated in the prior two weeks by more than two inches and that it needs an extra inch in the next two weeks to get back on plan.

Figure 26: Recent Accuracy and Water Budget Graphs



Recent Accuracy Graph (left) and Water Budget Graph (right) for a field that was recently under irrigated.

Source: AgMonitor Inc.

The most important information to get the farming team's attention and to trigger change is the simple alert. To that end, the team sends the list of management blocks with the crop alert and the accuracy number in inches as part of the weekly forecast. This allows the farming team to discuss, and the agronomist can make adjustment in the Agronomic Review page. That is the agronomic loop, and the goal is to get close to the "bull's eye" (Figure 23). For instance, the team at Farm Site #7 received a forecast on June 17 with four warnings and one alert (Figure 27). The team reacted and made a quick correction on fields 13-1 and 13-2 that no longer have a yellow warning on the following accuracy report (Figure 25). The severely stressed field 18-D is being addressed with irrigation following the plan Figure 26 (left), but it will take a few weeks to get back to normal and have a green status. Two fields 18-2 and 18-4 are getting worse with higher deviation from the plans with -1.72 inches compared to -1.24 inches, and -1.54 inches compared to -1.39 inches respectively. Fields need both constant and weekly attention.

Figure 27: Email Forecast With Crop Alert Status and Recent Accuracy

ET Forecast for Mon 06/21 to Sun 06/27/2021 at Woolf Farming

The ET_0 forecast is available online. We have used the crop coefficients (Kc) in your grower plan to create the forecast inches shown below. You need to click on the "Set irrigation recommendation" link below to adjust the hours for next week

Set irrigation recommendation (hours)

View management reports

Ranch: Aliso

Management Block	Crop and Type	Irrigation Strategy	Last Week (in.)	Next Week (In.)	Recent Accuracy (In.)
13-1	Pistachios, Drip	Grower Plan	1.17	1.28	-1.18
13-2	Pistachios, Drip	Grower Plan	1.17	1.28	-1.46
13-3	Pistachios, Drip	Grower Plan	1.17	1.28	-0.90
13-4	Pistachios, Drip	Grower Plan	1.17	1.28	-0.66
18-1	Pistachios, Drip	Grower Plan	1.17	1.28	-0.71
18-2	Pistachios, Drip	Grower Plan	1.17	1.28	-1.24
18-4	Pistachios, Drip	Grower Plan	1.33	1.45	-1.39
18-D	Pistachios, Drip	Grower Plan	1.84	2.20	-2.59

Last week's data is based on spatial CIMIS.
Next week's data combines the DTN ET_0 forecast with your crop model.

If you have any questions or suggestions, don't hesitate to contact us at support@agmonitor.com

The AgMonitor Team

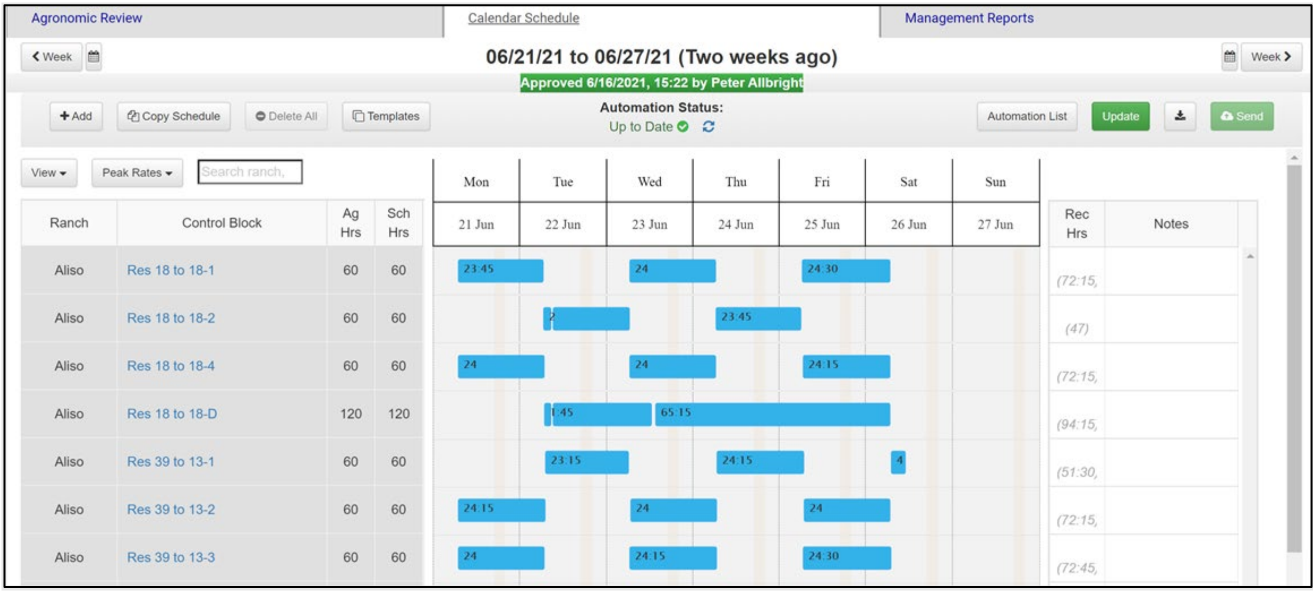
Source: AgMonitor Inc.

Precision Report to Track Operational Performance of Team

One of the issues made clearly visible in the calendar schedule for the example at a farm near Tracy is the ability for the field crew to follow the approved schedule. The fields at 13-1 and 13-2 are improved with proper irrigation (amounts close to 60 hours), but they are not close to being perfect: 54 hours compared to 60 hours for 13-1, and 72 hours compared to 60 hours for 13-2 (Figure 28).

This is why it is critical to measure precision and track the ability of a team to execute a plan regardless of the quality of the agronomic plan. In the case of the week of 6/21/2021 to 6/27/2021 at Farm Site #7, the overall precision is 81 percent.

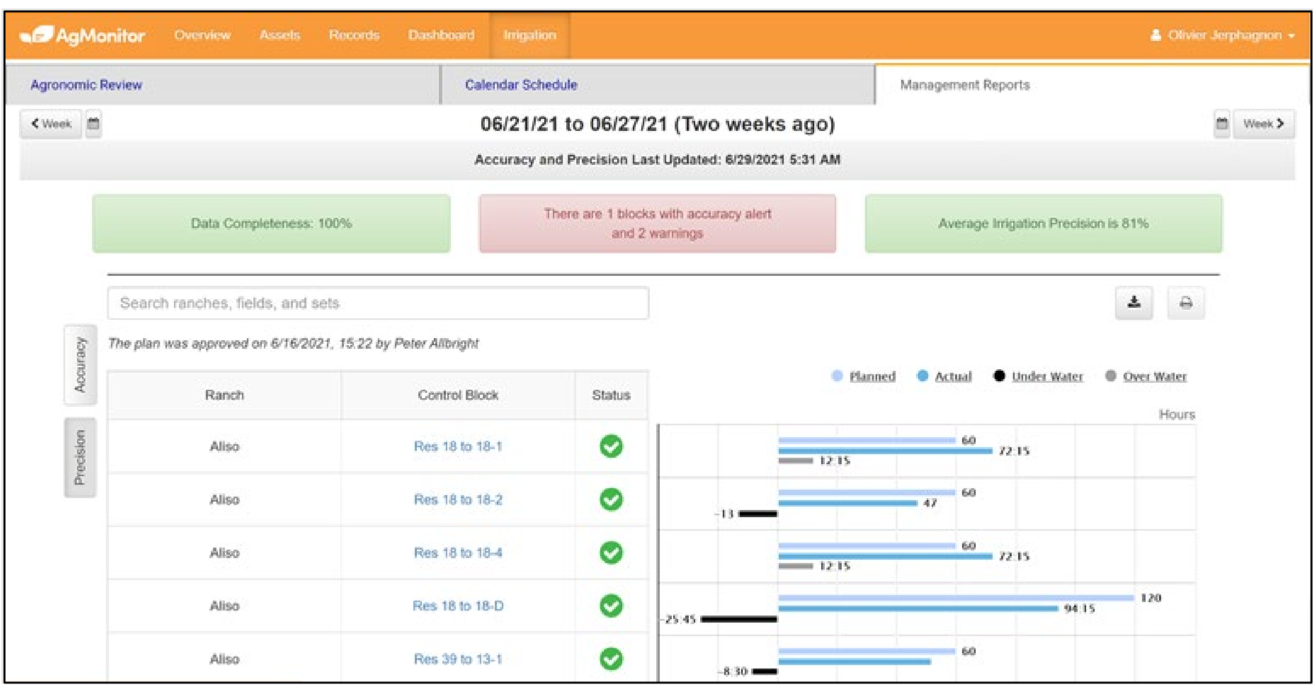
Figure 28: Comparison of Scheduled Hours and Recorded Hours for a Week



Source: AgMonitor Inc.

The team considers a precision above 80 percent "good" (green color, Figure 29) because there is enough water holding capacity in the soil to deal with errors week-to-week and avoid stress on the crop. Below that level, there is a risk to stress the crop (change from green to yellow color). Below a precision level of 50 percent (change from green to red color), there is a high risk of water stress because there is not enough water in the soil to compensate for the human errors.

Figure 29: Precision Report for Pistachio Fields



Source: AgMonitor Inc.

Data Coverage to Monitor Availability of Sensory Data

The third metric that is tracked is "Data Coverage," which is defined as the percentage of hours with correct data among a 168-hour week. If a farm is going to rely on sensory data to adjust farming practices, the data needs to be reliable. A director of farming at one of the testing farm sites mentioned that he was spending more time on trouble-shooting technology solutions in general than actually using data for farming. He was reluctant to test more cutting-edge technologies before they are vetted because time is his more precious resource at the farm.

Unfortunately, that is not always the case in the context of a disadvantaged community: poor broadband coverage, vandalism, animal bites, etc. Three of the farm sites had equipment stolen or stripped of copper.

This results in data availability much lower than the utilities have achieved with SmartMeters after 10 years managing 20 million connected devices. As shown in Figure 30, the project team frequently had ranches with some sensors below 85 percent of data available while meters are usually above 99 percent. Below is an example at Farm Site #7.

Figure 30: Data Coverage Report With Weekly Details by Day

AgMonitor

Data Coverage Report for Woolf Farming

For 06/07/2021 to 06/14/2021

Generated 06/17/2021 03:22

Sensor or Asset Identification						Last Week Average			Last Week						
Ranch	Asset Type	Asset Name	Utility or Data Provider	Sensor Name	Sensor Type	Average Coverage %	Average Availability %	Average Validity %	Mon 06/07	Tue 06/08	Wed 06/09	Thu 06/10	Fri 06/11	Sat 06/12	Sun 06/13
Aliso	Pump	18-8 North	PGE	Utility Power Meter		100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Pump	19 Filters	PGE	Utility Power Meter		100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Pump	19	PGE	Utility Power Meter		100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Pump	19 Reservoir Pump	PGE	Utility Power Meter		100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	East monitoring well	Pumpsight	Depth	Water Table	8.3	8.3	100.0	8	8	8	8	8	8	8
Aliso	Sensor Station	East monitoring well	Pumpsight	Static Depth	Standing Water Table	8.9	8.9	100.0	13	8	8	8	8	8	8
Aliso	Sensor Station	Aliso 13 Filters	Pumpsight	Flow	Water Flow	99.3	99.3	100.0	100	100	98	100	97	100	100
Aliso	Sensor Station	Aliso 13 Filters	Pumpsight	Total Volume	Total Volume	99.6	99.6	100.0	100	100	100	100	97	100	100
Aliso	Sensor Station	Aliso 13-1 Pres	Pumpsight	Pump Pressure	Pressure	99.9	99.9	100.0	100	100	100	100	99	100	100
Aliso	Sensor Station	Aliso 13-1 Pres	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	Aliso 13-2 Pres	Pumpsight	Pump Pressure	Pressure	99.9	99.9	100.0	100	100	100	99	100	100	100
Aliso	Sensor Station	Aliso 13-2 Pres	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	13-3 Pressure	Pumpsight	Pump Pressure	Pressure	99.4	99.4	100.0	100	100	99	100	97	100	100
Aliso	Sensor Station	13-3 Pressure	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	Aliso 13-4 Pressure	Pumpsight	Pump Pressure	Pressure	99.7	99.7	100.0	100	99	100	100	99	100	100
Aliso	Sensor Station	Aliso 13-4 Pressure	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	Aliso 18 Filter	Pumpsight	Flow	Water Flow	99.4	99.4	100.0	100	100	100	100	96	100	100
Aliso	Sensor Station	Aliso 18 Filter	Pumpsight	Total Volume	Total Volume	99.4	99.4	100.0	100	100	100	100	96	100	100
Aliso	Sensor Station	18-1 Pressure	Pumpsight	Pump Pressure	Pressure	99.1	99.1	100.0	99	100	98	100	97	100	100
Aliso	Sensor Station	18-1 Pressure	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	18-2 Pressure	Pumpsight	Pump Pressure	Pressure	99.4	99.4	100.0	100	100	100	99	98	100	99
Aliso	Sensor Station	18-2 Pressure	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100
Aliso	Sensor Station	18-4 Pressure	Pumpsight	Pump Pressure	Pressure	99.6	99.6	100.0	100	99	100	100	99	100	99
Aliso	Sensor Station	18-4 Pressure	Pumpsight	Pump Pressure (as switc	irrigation_switch_virtual	100.0	100.0	100.0	100	100	100	100	100	100	100

Data Coverage

The green color is set for 98 percent or better, yellow for 85 percent or better, and red for less than 85 percent.

Source: AgMonitor Inc.

Eighty-five percent, which represents better than 2-sigma in a gaussian distribution, was chosen as the first threshold for alert. Below 85 percent is a "red" alert: the equipment needs immediate assistance from the vendor or repair from the local dealer. Above 85 percent is a "yellow" warning: the equipment needs maintenance, or the missing data may come a day later. Above the 98 percent threshold, which represents better than 3-sigma on a gaussian distribution, is considered a "green" status: there is enough data to make a decision because the missing data will not affect the results by more than one digit.

Large Scale Data Analysis to Identify Projects and Streamline the Assessment of Energy Savings

One of the key aspects of streamlining measurement and verification was to leverage new water data from satellite images to create a baseline and identify saving opportunities. The set of actual evapotranspiration (ETa) data was developed in the last 10 years by a series of government projects including the purchase of 2010 to 2020 data from Formation Environmental by the Department of Water Resources.

The research team decided to also integrate SmartMeters at the scale of the two census areas (Huron and Delano). AgMonitor's partner UCSB had to apply for all the data from PG&E and SCE using the CPUC proceeding 14-05-016 that provides access to energy data while protecting privacy. UCSB set up a secure server and provided the team anonymized data by area or by crop to facilitate the integration of data layers that have different resolutions:

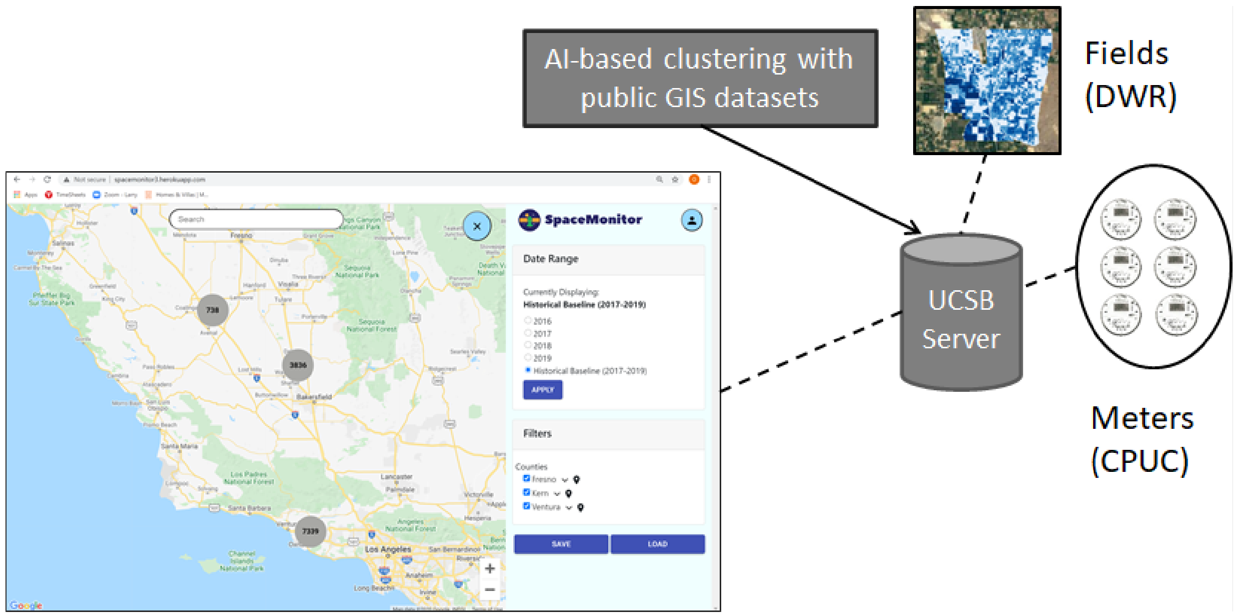
- Energy data came at 15-minute or one-hour data intervals by meter. It cannot be associated with a field (customer) per privacy rules. Therefore, the team needed to collect many meters in an area by crop type to gather weekly energy use.
- Water demand came as daily data per pixel and listed per field from the latest crop census. The team had to do some filtering to avoid errors at the border of a field to provide useful data. The team aggregated the water demand data by week so it could be compared to weekly energy use.

It was a major innovation because the team had to use advanced clustering algorithms. AgMonitor developed an online tool called SpaceMonitor (Figure 31). The team verified the data fusion technique at a few "ground truth" locations among the experimental sites (Site #1 and Site #2) and the technology transfer sites (Site #4 to Site #10). AgMonitor summarizes below the findings in the context of identifying and verifying saving opportunities in disadvantaged communities.

New Water Demand Dataset from Satellite Images

The key data source used in analysis was evapotranspiration (ET) data. Actual evapotranspiration data (ETa) quantifies the amount of water evaporating from the ground combined with the water lost through transpiration of a plant at a given time. It uses a surface energy balance system (SEBS) model to measure the residual energy due to ET after subtracting reflection from solar radiation. In simpler words, ETa can be thought of as a representation of the water consumption of a crop.

Figure 31: Architecture of the Data Exploration Tool

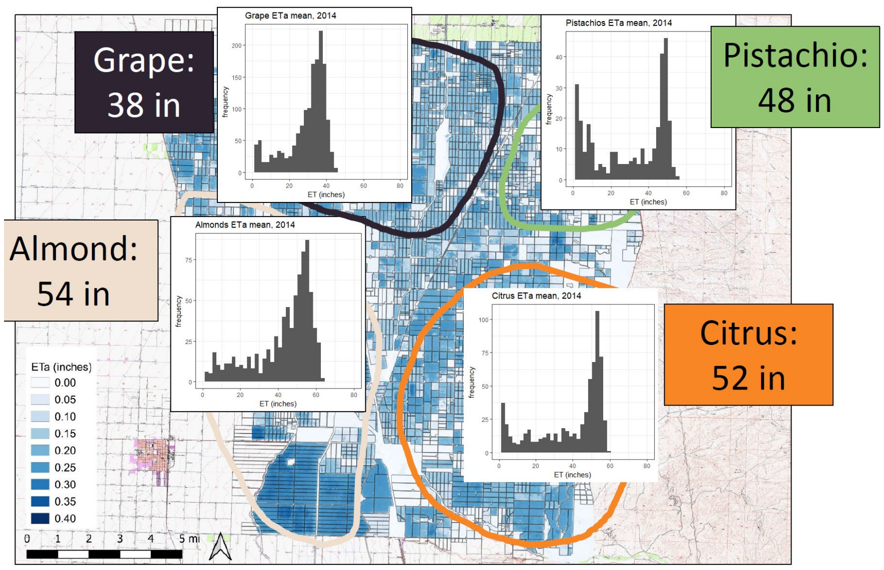


The meter-level data is stored by a secure UCSB server and made available cluster-by-cluster to protect the privacy of California ratepayers. The satellite data is processed according to the field shapes from the most recent crop census and stored also on UCSB server. The key to the project is identifying useful clusters to compare the energy use and water demand in the farming communities. Maps down to each field are created to engage the farmers and discuss impactful projects.

Source: AgMonitor Inc.

The ETa data was then qualified by comparing it to a crop's potential evapotranspiration (ETc). ETc refers to the maximum amount of water that would evaporate or transpire from a crop if it had unlimited access to water. ETc is thought of as the potential crop "water demand" while ETa can be thought of as the actual "water consumption." For this experiment, the research team focused on the Delano and Huron census tracts as shown in Figures 32 and 33. The crops were based on the 2016 crop census.

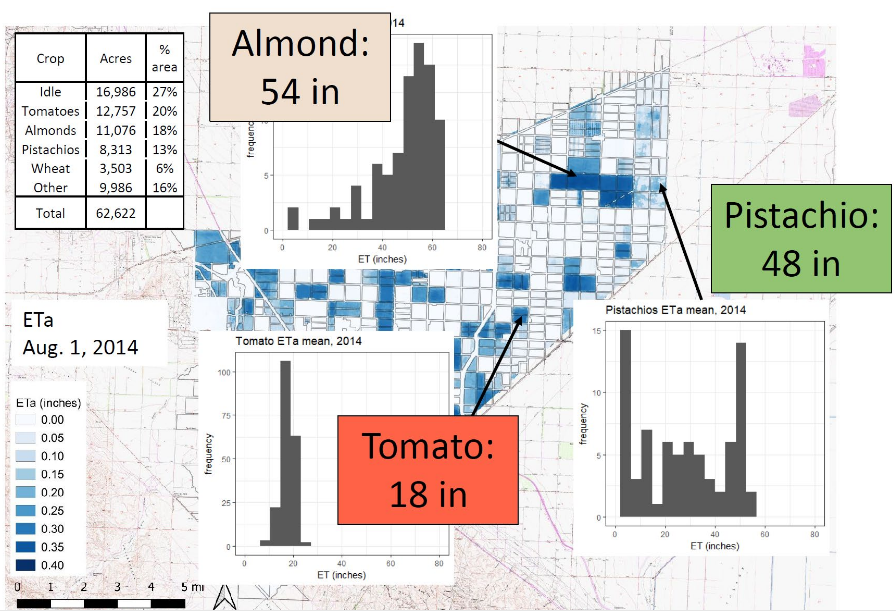
Figure 32: Mean ETa for Four Main Crops in the Delano Area From 2010 to 2018



The ETa data per pixel on the map is represented by a blue color scale. ETa distributions are also displayed by crop across the Census Tract.

Source: AgMonitor Inc.

Figure 33: Mean ETa for Three Main Crops in Huron Area From 2010 to 2018



Almonds and pistachios have about 2.5 times the amount of ETa when compared with tomatoes.

Source: AgMonitor Inc.

Historical Baseline of Water Use for Several Crops

The ETa satellite data from Formation Environmental was analyzed for the primary crops in the Huron and Delano census tracts to understand if ETa was a good estimation of actual water application. The team selected almond as it was in the top three crops in both Huron and Delano. The team selected the grape for Delano and tomato for Huron. Finally, the team selected citrus because it was common in Delano and on the coast (for example, Ventura).

The overarching result found was that on a specific field basis, the ETa data is not a reliable way to estimate water application to the field during a season. However, if the ETa is averaged over a larger area (per ranch, or per farm) the ETa for some crops accurately reflected if crops were over- or under-watered when comparing to averages.

A summary of each crop is below:

- Tomato: Individual field estimations of ETa were the most accurate here with only about a 10 percent difference from reality. However, the distribution of tomato ETa for years other than 2016 is skewed due to the fact that row crops are on rotation.
- Almond: On a per field basis, the ETa estimation did a poor job at reflecting actual water application. At the pilot in Delano, the single field had an error of about 40 percent across the three years. However, at the 2020 tech transfer site in Williams, the team saw an average of only 3 percent error across eight orchards that were quite spaced out. The results show that ETa may reflect water application for almonds if averaged over several fields and a larger area.
- Citrus: The results for citrus showed that the ETa was different from the actual water application on a citrus ranch. However, it did accurately reflect the average application being lower than other crops in the area. The Citrus Research Board is working with University of California (UC) Davis and Formation Environmental to improve their model for citrus trees.
- Grape: The ETa estimations for 23 grape fields were significantly higher than the actual water applied. The grower here was irrigating significantly below ET. However, the ETa data captured that the fields were overly stressed, and the plants stopped transpiring for a couple of months.

The results are consistent with a recent publication from UC Davis that compared the SEBS model from Formation Environmental and other algorithms processing satellite images and weather data to estimate ETa (Xue et al., 2020). This research shows good correlation of the ETa data from SEBS with on-the-ground measurement stations for almond and tomato. It is still too early to estimate water extraction from pumps using only ETa because other factors are important: water holding capacity from soil and frequency of irrigation, etc.

Parametric Data Model to Evaluate Energy Efficiency Projects

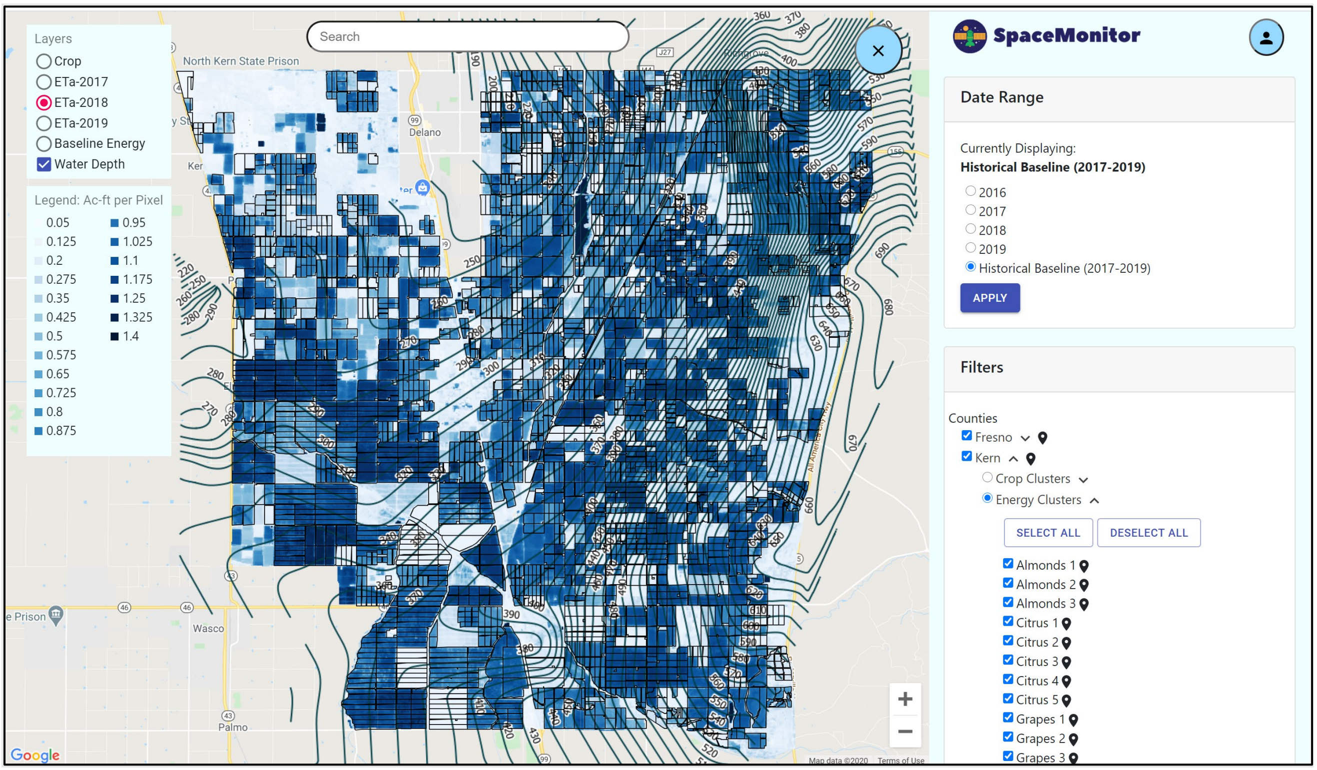
Increase in the energy footprint of irrigation is due to a variety of factors. Using the pump to nozzle system approach, they are:

1. Drop in water table that leads to a higher lift in fit (Head in feet)
2. Change in overall pump efficiency (OPE in percent)
3. Change in water demand due to changes in crop mix or irrigation practices (Water in inches or acre-feet).

The first two factors are by changes in water table and the team decided to integrate the data layer representing the water table across a census tract as shown in Figure 34 for the Delano area. Based on the parametric model developed under Task 6 to predict energy footprint from water demand, the team was able to define a clear clustering strategy.

AgMonitor wanted to group fields that had similar challenges in an area that could be serviced by a program implementer of energy efficiency (EE) measures. The results of the clustering process are shown in Figure 35.

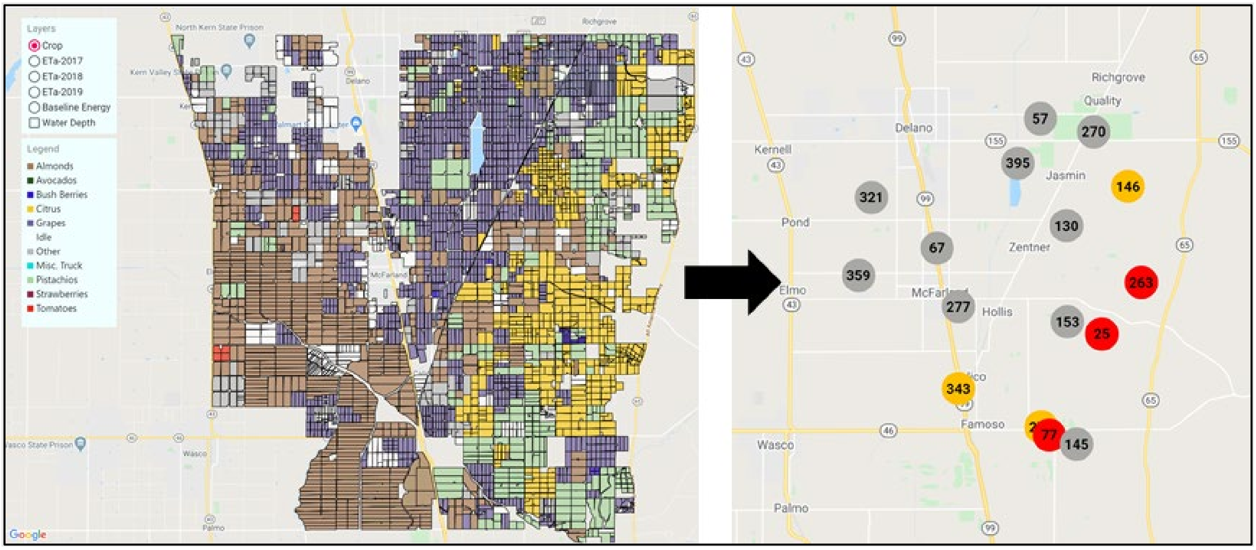
Figure 34: Overlay of Water Depth Contours and Water Demand From Crops



The water demand is calculated per pixel from satellite images by Formation Environmental. The shade of blue is proportional to the amount of ETa in acre-feet across a season (for example, 2017) with the legend on the left of the picture. The depth of the water table is represented by water contours of constant increment; the labels indicate the depth of water in feet.

Source: AgMonitor Inc.

Figure 35: The Main Crops in Delano Grouped by Location and Water Depth

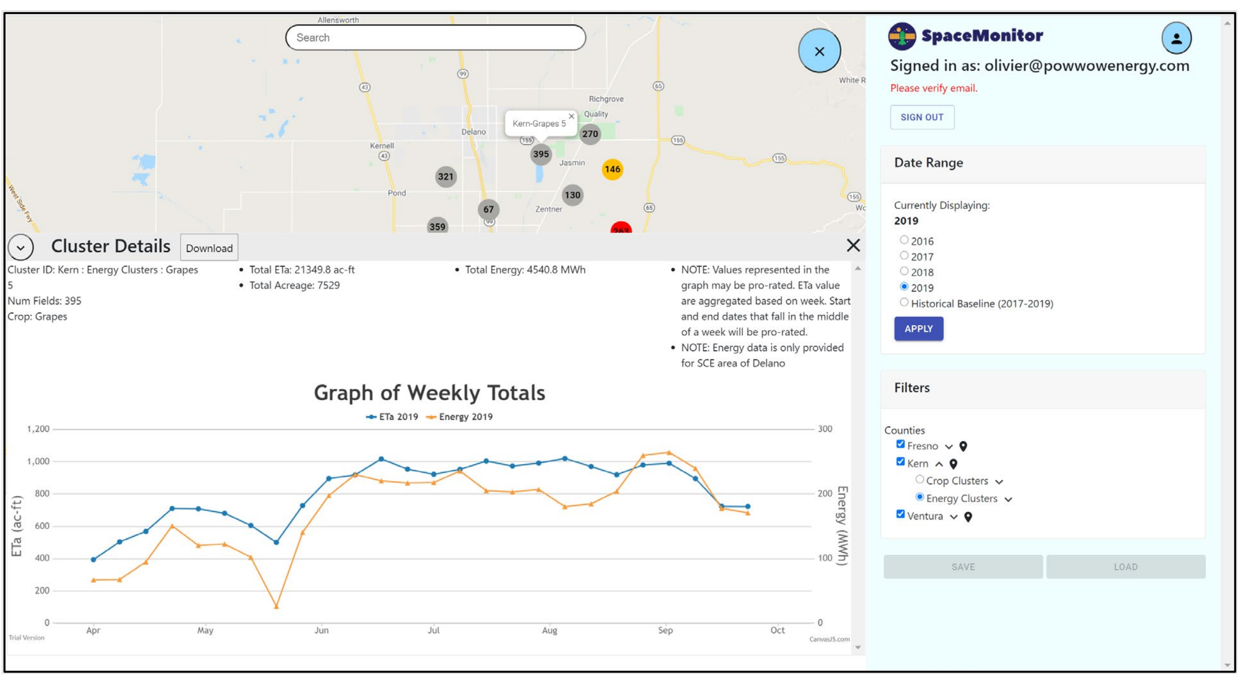


Each circle on the right picture represents a cluster of fields that have the same crop, are close and have a similar water table.

Source: AgMonitor Inc.

One can now use the clusters to compare the energy data from the actual meters against the energy predictions from the parametric model. The example below is for a grape cluster. The team found that the energy intensity in terms of kilowatt-hours per acre-foot (kWh/ac-ft) matched the reality on the ground (compared with private pump test results at several farms). The project team used the energy intensity to classify clusters as no risk (grey), warning (yellow), and alert (red) as shown in Figure 35 and Figure 36.

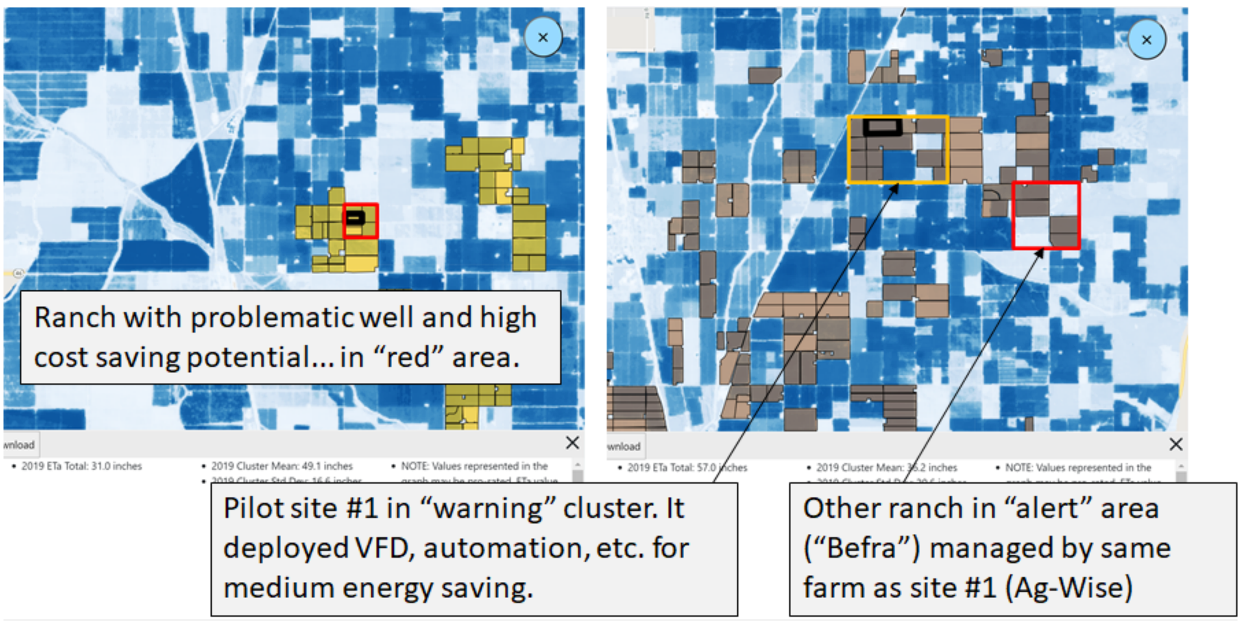
Figure 36: Comparison of Actual Water Demand and Energy Use for a Cluster



Source: AgMonitor Inc.

The research team compared two clusters of almonds, one red and one yellow. The classification seems to work well when the team compared two ranches close-by with two different situations. As depicted in Figure 37, one of the pilot sites was in the yellow cluster and they used a VFD controller and automation to reduce fertigation and improve EE. Five miles east, the same farm manages another ranch, and the situation is quite different because of the water table. They could not use the deep well long because the pumping level was too close to pump intake level. They would have benefited from a targeted pump test program and discussing a retrofit before the start of 2020 season.

Figure 37: Comparison of Two Well Pumps in Two Different Clusters

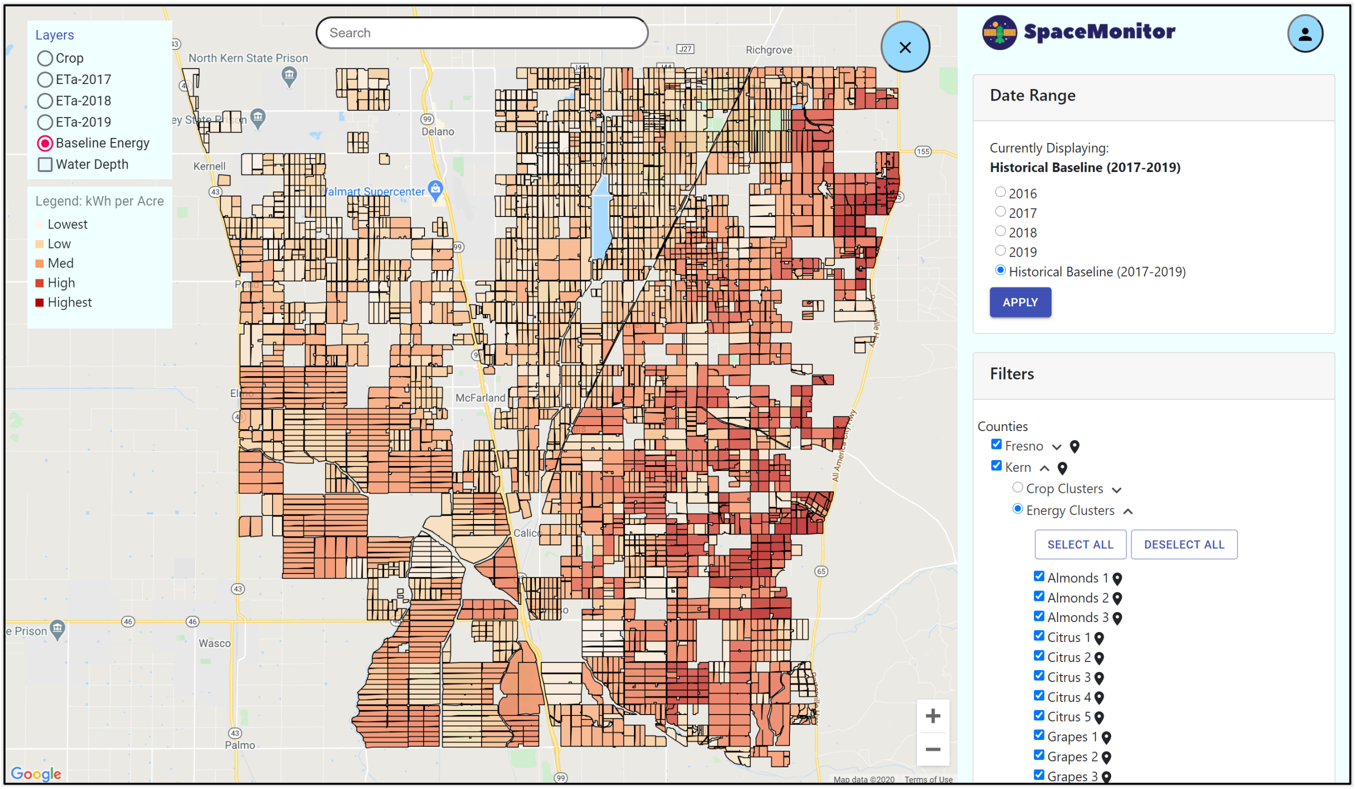


Source: AgMonitor Inc.

The almond field identified here was operated by the same farm that operated Site #1 in the project. The research team decided to create an energy map for the whole Delano area by allocating the same relationship between energy and water at the cluster level. It does provide some site-specific information, but it does not violate the privacy of each site because the energy intensity was calculated using public data at a cluster level. This stresses the importance of a community dealing with the same situation, in this case the chronic drop in water table that puts farming at risk in the long term.

It is not possible to know when a drought will hit but one can predict generally how high the energy consumption will be then. Figure 38 shows the energy intensity in terms of kWh per acre assuming 0 percent surface water allocation as it happened in 2015.

Figure 38: Energy Intensity of the Fields in Terms of kWh Per Acre



Source: AgMonitor Inc.

This model shows clusters of a crop that would be great targets for EE measures can be located and existing methods of targeting AgEE which are not informed by data can be improved upon. However, the accuracy of this model depends on the ETa dataset, which was discussed in the previous section to have limitations on a per field basis.

The next chapter will demonstrate how to use ETa data to help streamline the process for a specific farm to get on-bill financing (OBF) when they do not have historical water records.

CHAPTER 3: Project Results

AgMonitor carried out the experiments from 2017 to 2019 primarily from the two hosts in Huron and in Delano area and the experimental site at WHCC (four pilot test sites). However, the team reached out to several other commercial farms (eight farms) to cover enough crops. Some others stemmed out from the survey that was carried out with WHCC. The team summarizes the list of experimental sites (#1 to #3) and farms where the team carried deployments with the team's technology for technology transfer (#4 to #12) (Table 3).

Table 3: Description of Each Farm Site that Hosted Experiments

Farm	Location	Crop	Experiment goals
Site #1	Delano (east)	Almond	Irrigation and fertigation by zone (2) and 2 by variety (2)
Site #2	Huron (west)	Tomato	Soil mapping and irrigation deficit with 4 treatments on 16 random blocks
Site #3	Coalinga (west)	Pistachio	Education in disadvantaged communities and Field Day in 2018
Site #4	Fresno (east)	Almond	Continuous pump test and Field Day in 2020
Farm #5	Los Banos (west)	Pistachio and tomato	Soil mapping to identify 2 zones and later off-peak irrigation
Farm #6	Winters (north)	Almond	Weekly OPE report with VFD and OBF project. Different irrigation across 3 zones to compensate for soil variability in spring and 2 sets for variety in summer
Farm #7	Fresno (east)	Olive and almond	Precise irrigation to improve olive oil quality and almond yield, and mobile app testing
Farm #8	Tracy (north)	Blueberry and citrus	Various management constraints based on soil and variety (6 pumps and 200 valves).
Farm #9	Los Banos (west)	Almond	Weekly tracking of water per zone and weekly accuracy report
Farm #10	Delano (east)	Table grape	Comparison of satellite water data with field water data for different stress levels
Farm #11	Ventura (coast)	Avocado	Weekly OPE report in SCE area
Farm #12	Helm (west)	12 crops	Solar optimization and pump test integration

The project sites cover eight crops across Sacramento Valley and San Joaquin Valley.

Source: AgMonitor Inc.

The overall results that were developed in Task 7 are summarized below (see Table 4). They were verified by Dr. Geyer and the team at the Institute for Energy Efficiency at UCSB.

Table 4: Summary of the Project Results Against the Project Goals.

Category	Baseline	Result	Project Goal
Water application	11.0 percent above ETc	-10.9 percent below ETc	-15 percent
Energy consumption	11.0 percent above ETc	-12.0 percent below ETc	-20 percent
Energy bill savings	$0.0	$ (17,100.00)	
Peak operation	27.0 percent	0.2 percent	
Fertilizer application	0.0 percent	-14.0 percent	-15 percent

Source: AgMonitor Inc.

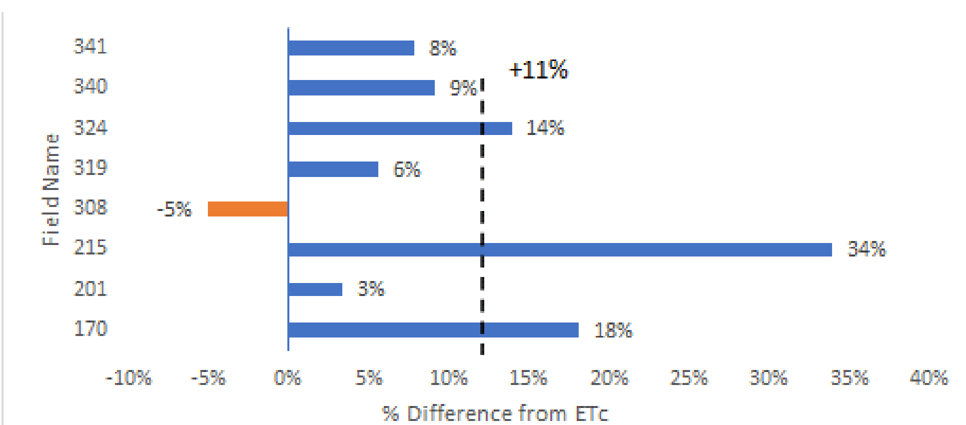
Increased Water and Energy Efficiency

The main goal of the project was to achieve the optimum water savings using a programmable irrigation platform. The team knew from the previous project EPC-14-081 that significant savings could be achieved, but they were limited by the practical constraints. By using the new programmable platform to irrigate per soil zone or per crop variety, the team wanted to demonstrate further water savings of 15 percent and energy savings of 20 percent compared to existing solutions using crop ETc or soil moisture monitoring.

Additional Water Savings

The best illustration of water savings using all AgMonitor's cutting-edge technologies was demonstrated at Farm #6. The team first created a baseline of irrigation practices (Figure 39). The average water application in 2019 before the deployment of the technology was 11 percent above crop ETc. A reduction of water application of 11 percent would represent the current state of the art because the field has different soil types and cannot be optimized for each zone (irrigated for the average or the weakest part of the field).

Figure 39: Baseline of Irrigation Practices Across Eight Fields

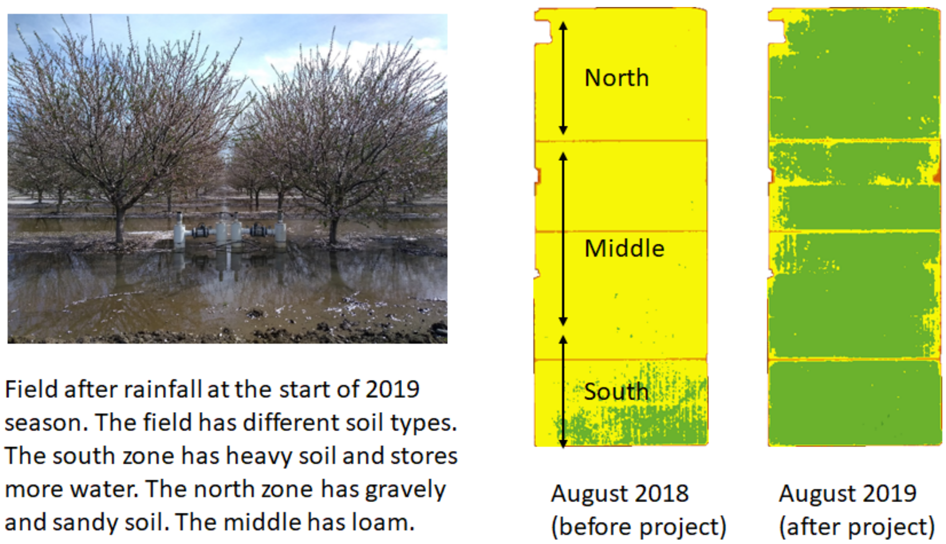


Water application is measured from March 1, 2019 to October 30, 2019 and compared to crop ETc.

Source: AgMonitor Inc.

The team developed a plan with the grower for each of the three zones and used the automation platform to avoid stress for each variety in the summer before harvest. A series of NDVI (Normalized Difference Vegetation Index) images in Figure 40 shows how crop uniformity was improved. Figure 40 also shows the south section storing more water after rainfall due to heavier soil mixture.

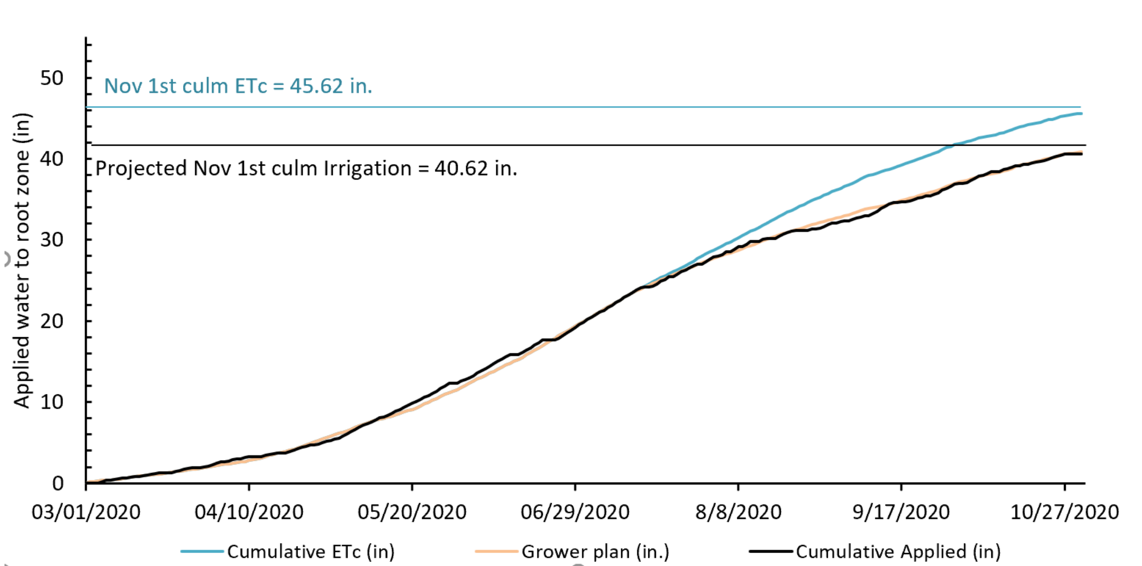
Figure 40: Vigor Uniformity From NDVI Images at Farm #6



Source: AgMonitor Inc.

Figure 41 below illustrates the accurate implementation of the grower plan in cumulative inches for the middle zone. The team leveraged the 20 automated valves to create a program for each zone and that is how different savings were obtained for each zone.

Figure 41: Water Application in Inches Compared to the Grower Plan and ETc



The black curve describes the applied water in inches while the blue curve is the ETc reference in inches and the orange curve is the grower plan that implements a level of water deficit.

Source: AgMonitor Inc.

The results of the 2020 season are summarized in the Table 5 below. By using cutting-edge technologies from pump to nozzle the project achieved another 10.9 percent in water savings below ETc for a total of 19.74 percent. This was done without affecting the quality of the crop. The orchard achieved a record crop in 2020 thanks to improved uniformity.

Table 5: Summary of Water Saving Results in 2020 at Farm #6

Variable	Field 160
Baseline application (inch)	50.6
2020 ETc (inch)	45.6
2020 irrigation (inch)	40.7
Irrigation savings at trees (inch)	9.9
Irrigation savings at pump (ac-ft)	339
Irrigation savings (percent)	19.74 percent

Source: AgMonitor Inc.

The project achieved additional water savings on one part of the field. Listed below in Table 6 is the water savings for each of the zone. The maximum savings was 24.6 percent and the average 19.7 percent.

Table 6: Results From the Trial at Farm #6 With the Breakdown by Zone

Variable	North Block	Middle Block	South Block	Field Average
Baseline (inch)	50.6	50.6	50.6	50.6
Season Cumulative ETc (inch)	45.6	45.6	45.6	45.6
Season Cumulative Irrigation (inch)	43.1	40.6	38.2	40.7
Savings compared to ETc (percent)	5.5 percent	11.0 percent	16.2 percent	10.7 percent
Weight for full field (percent)	20 percent	60 percent	20 percent	100 percent
Irrigation savings (inch)	7.5	10.0	12.4	9.99
Water savings (percent)	14.8 percent	19.8 percent	24.6 percent	19.74 percent

Source: AgMonitor Inc.

The irrigation manager particularly enjoyed optimizing the duration of irrigation events. He went from irrigating in 10-to-16-hour shots into shorter shots. He found that the field responded the best to shots of 4 hours followed by two shots of 2 hours each. This was easy to implement using a programmable platform. Continuous pump testing was also useful to identify pump issues, and it provided an additional 1 percent in pump efficiency, thus pushing the overall energy savings from 19.7 percent to over 20 percent.

Providing Weekly Management Reports is Critical

One of the key results of the project at Site #1 (almond) and Site #2 (tomato) is that the team needed to collect water measurements weekly and provide management reports back to the farm. The experiment results in 2018 for Site #1 and Site #2 were particularly disappointing because the project team thought that the water cuts were occurring, but they were not for two reasons: equipment shortfalls leading to measurement errors and deviations from the plan during the season.

The team sat down at Harris Ranch near Huron with the farm manager of Site #2 who led the implementation of the experiment (Figure 42). He explained that the lack of visibility in what actually happened on the field was the most useful. Many platforms provide data, but few provide useful reports. He thought that the project should focus on that aspect.

Figure 42: Description of Site #2 Near Huron

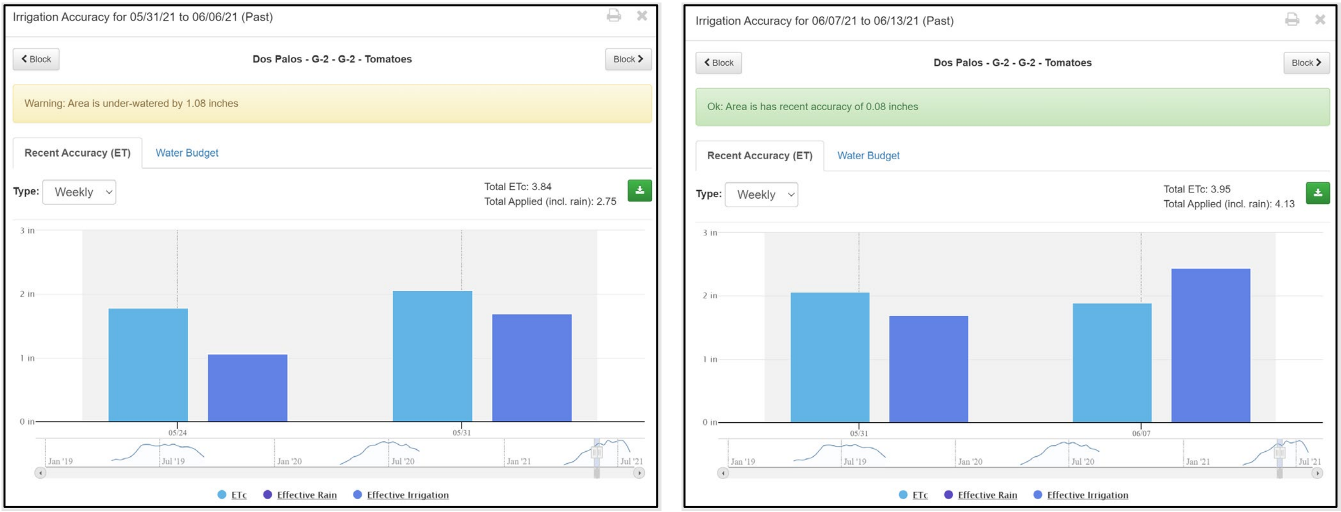
The telemetry icons in green indicate the location of the valves that are automated with the pump.

Source: AgMonitor Inc.

This is why AgMonitor decided to shift focus for the 2019 experiments at both sites. The team used the software platform and the automated irrigation system to assess how accurately a farming operation could follow a plan in inches (water in root zone) and implement a recommended irrigation schedule in hours (pump operation). It is critical to provide feedback on how the team communicates and to catch hardware issues early.

Below are examples of irrigation accuracy for a tomato field irrigated with an automated system. The field was underirrigated, and the grower made a correction (Figure 43).

Figure 43: Accuracy of Irrigation of a Tomato Field During Two Consecutive Weeks



Water application deviated by 1.08 inch from the plan during the first week, and a warning was generated. The grower applied more water the next week and the accuracy improved to 0.08 inch.

Source: AgMonitor Inc.

The feedback loop is necessary to stay on budget and achieve the savings. Figure 44 shows a cumulative view of the same field, and the grower is on track to achieve the 20 percent savings below ET (plan of 21.3 inches compared to crop ET of 27.4 inches). Although he had to make two adjustments during the season: under irrigation in May and over irrigation in June when a heat wave occurred.

Figure 44: Water Budget Graph With Cumulative Water Application

Applied YTD	21.90
Grower Plan YTD	21.48
Grower Plan Proj.	27.18
ETc YTD	23.11
ETc Proj.	30.86
Partial ETc YTD	21.48
Partial ETc Proj.	27.29

The light blue curve represents the ETc reference, the black line the grower plan, and the dark blue curve what has been applied in inches. Year-to-date data and projections for the end of the season are summarized in the table on the right side of the graph for ease of planning.

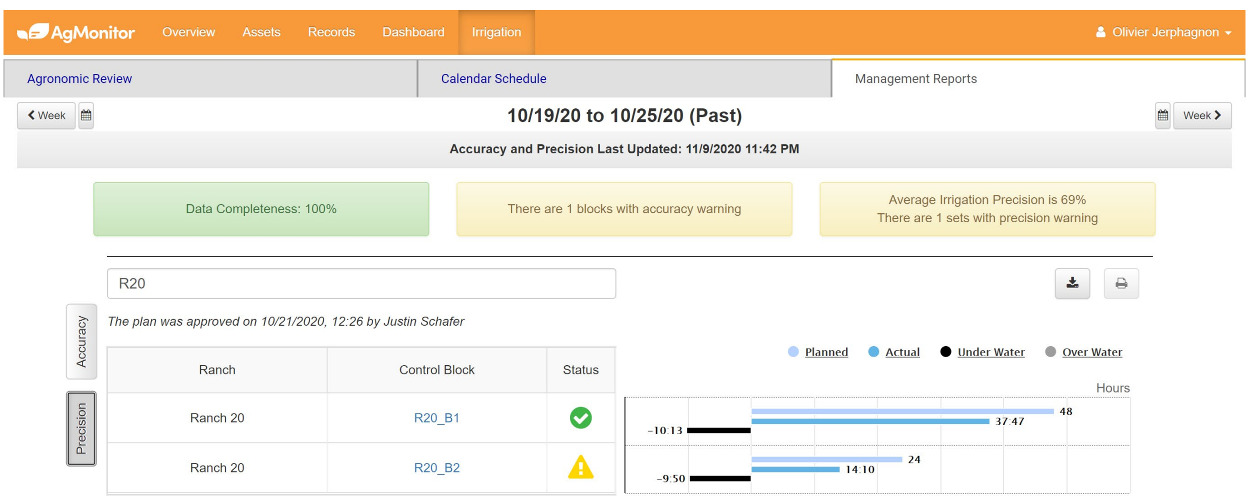
Source: AgMonitor Inc.

Throughout the project the team learned that there are many other field activities (spray of pesticide, pump equipment repairs, preparation of ground before harvest, etc.) that have to be managed at the same time as irrigation, but there are only 168 hours in a week. This forces a ranch manager to make difficult trade-offs, and the irrigators can rarely meet the plan exactly. The team decided to develop a weekly report to compare on precision. It compares the actual hours of irrigation and the planned hours for the fields.

The team surveyed the issue across the 11 sites and found that precision varies from 50 percent to 90 percent in manually irrigated fields with an average of 70 percent. That is an eye-opener: if an irrigator is given a schedule of 100 hours, actual irrigation will be 70 hours some weeks and 130 hours some other weeks. This is an illustration as the reality varies each week.

For instance, the precision at the olive fields at Farm #6 near Fresno varied a lot. The team provided precision data back to the director of operations, and he worked with the ranch manager to implement a tighter implementation as the team got closer to harvest. The ranch manager went from one long shot a week to two shorter shots per week as olive trees have a shallow root zone of two feet. He gained more control on the total hours of irrigation with a precision improving from 50 percent to 70 percent on average, and he kept the water and nutrients in the root zone. Figure 45 shows the green status for block 1 and yellow warning for block 2 with the average precision at 69 percent.

Figure 45: Precision Report for Olive Fields at Farm #7



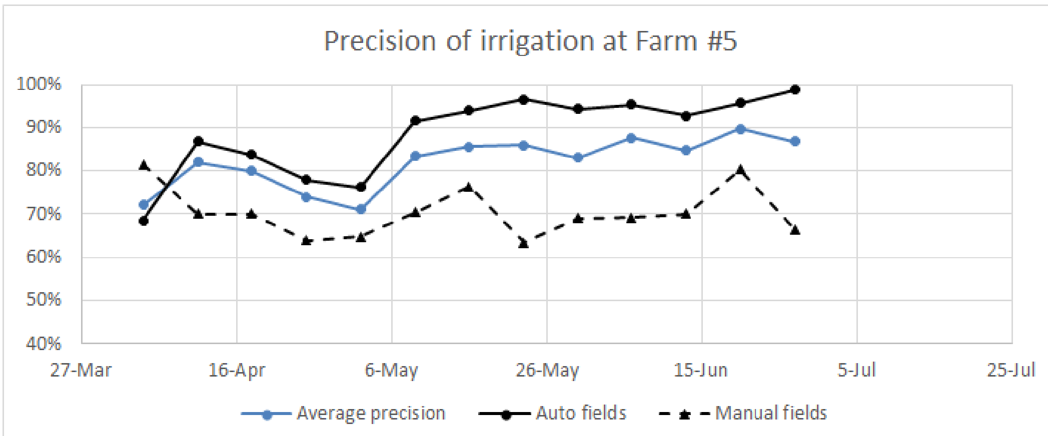
Source: AgMonitor Inc.

On the other side of the spectrum, the team worked with an almond processor that contracts out the agronomic work and the farm management. The agronomist and the field crew work closely by sharing a two-week schedule. The team measured the precision and found that the average precision was 90 percent the first week and only 75 percent the following week. The field crew made a concerted effort to follow exactly the schedule the first week but tended to focus on other field activities (for example, pest spray) the following week.

One of the questions that the project team decided to explore was the difference that an automation system made on precision. There is a learning curve because the agronomist or the ranch manager has to enter the exact start and end times for the irrigation events of the week. That requires more planning, and the farms that the team worked with found that they needed to update the plan a couple of times a week.

Figure 46 shows a comparison between several ranches manually irrigated and several ranches irrigated automatically for a total of 5,000 acres. Despite a poor start, the automated fields display a precision of 90 percent on average while the manual fields remain at 70 percent.

Figure 46: Comparison of Precision for Manually and Automatically Irrigated Fields



Source: AgMonitor Inc.

Example of Water and Energy Savings at Large Scale

The team had the chance to work with a large table grape grower in the Delano area (Farm #10). They shared their water application treatments in 2018, and they changed their irrigation schedule in 2019. They historically irrigated based on ET but decided to save water and improve fruit quality by testing deficit irrigation.

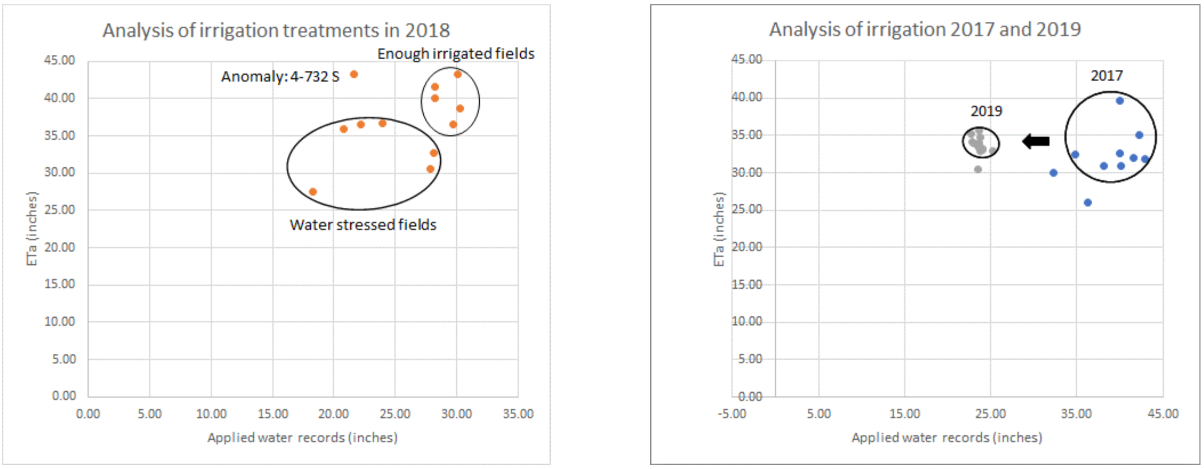
The team used the SpaceMonitor tool to compare their water application records (not taken by AgMonitor) with the ETa data from Formation Environmental. As shown in Figure 47, one cluster of grape fields exhibited too much stress and the others continue to transpire as expected. This was verified with the grower.

The comparison turned out to be very useful:

- The team identified an incorrect water record at the farm (one out of 12).
- The team analyzed statistically that the optimum water application was 27 inches, which was higher than 24 inches that they chose for 2019.

The new water application target of 25 to 27 inches compared to crop ET of 38 to 40 inches depending on weather each year is a high level of deficit (over 30 percent). The measurement and verification team composed of UCSB and AgMonitor decided to look at the impact on energy use in the area. Most of the 4,000-acre table grape operation was in one of the clusters East of Delano. The amount of water savings is in hundreds of acre-feet and the amount of expected energy savings in hundreds of megawatt-hours (MWh).

Figure 47: Comparison of Water Records and ETa for 12 fields in 2017, 2018 and 2019

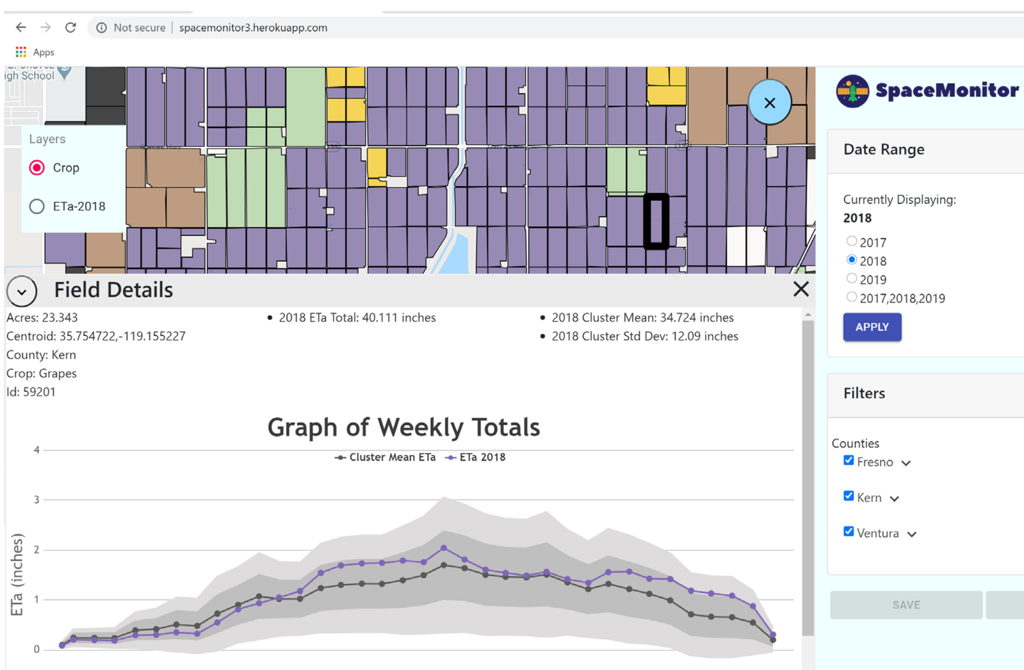


The left graph shows the results for 2018 for different levels of water application from 18 to 32 inches. The right graph shows the result with a tight water application around 24 inches.

Source: AgMonitor Inc.

The comparison of the weekly ETa and energy data are shown in Figure 48 and 49. It is quite remarkable to see in 2019 that the change in irrigation in the summer of 2019 created a significant drop in energy use for the entire cluster during July and August compared to its baseline (June and September). That demonstrates the impact of precise irrigation and the importance of the agriculture and water sector on the energy use of the grid.

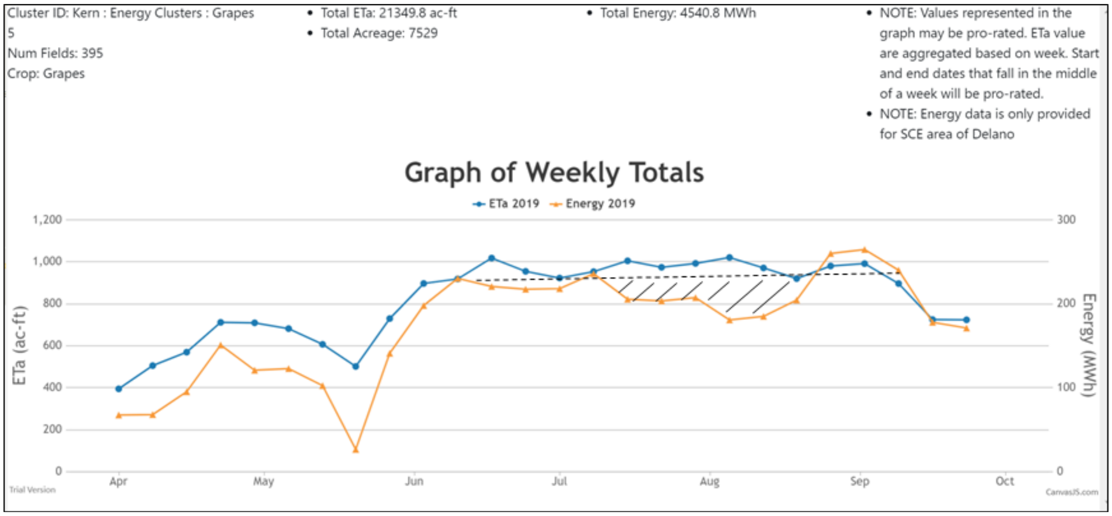
Figure 48: ETa Data for One Field in Table Grape Cluster Near Delano



The field selected (purple curve) exhibits moderate reduction in ETa during summer compared to the mean (dark grey curve) in the cluster.

Source: AgMonitor Inc.

Figure 49: Comparison of ETa and Energy in One Cluster



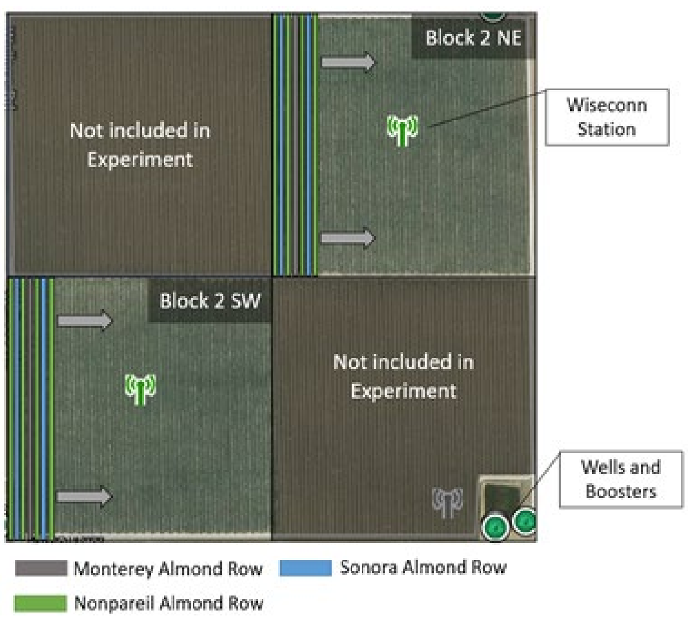
The blue curve shows the mean weekly evapotranspiration (ac-ft) while the orange curve shows the weekly energy consumption (MWh). The drop in energy in the cluster during summer from July to September is due to the deficit irrigation at Farm #10. The shaded area in black represents the total energy saved in summer 2019. The drop in energy in May 2019 was due to heavy rainfall.

Source: AgMonitor Inc.

Reduced Nitrogen Application

Fertilizer is commonly overapplied. The use of micro-irrigation coupled with valve and pump control gives an opportunity to apply different levels of nitrogen per crop variety. For example, Site #1 decided to apply a lean fertigation schedule in 2018 and continue in 2019 (Figure 50). Those were the two "treatment" years and the team used 2017 as the "control" year.

Figure 50: Set of Fertigation Experiments at Site #1 Near Delano



The lines of three different highlight the three varieties of almond varieties planted on the field.

Source: Institute for Energy Efficiency, University of California, Santa Barbara

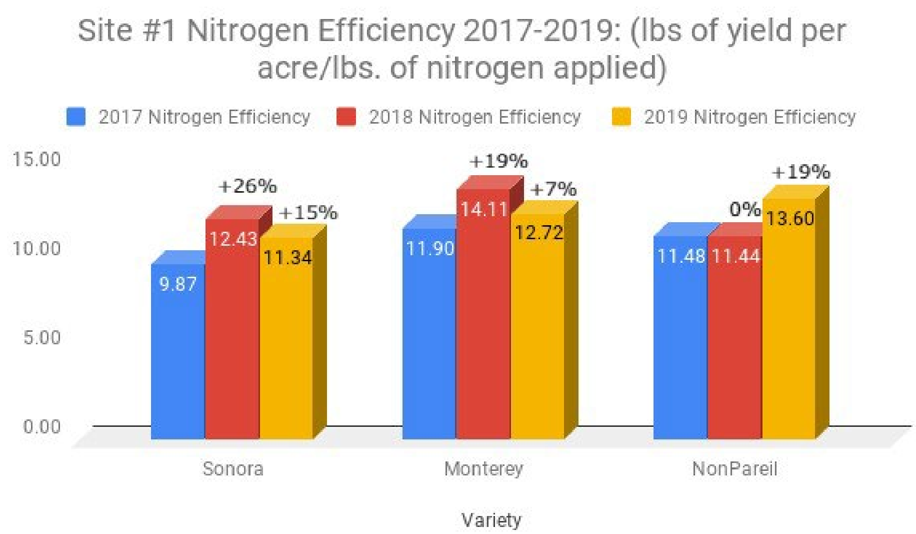
The farm carried out the experiment near Delano by utilizing pre-season vigor projection such as nut counts to predict a projected yield. Based on predicted yield, a grower can apply the necessary level of nitrogen to replenish the soil that provides nutrients to the trees. AgMonitor tracked the amount of water (irrigation) and nitrogen (fertigation) by monitoring the pump and valves thanks to the DropControl platform. The figure below explains the configuration of the field with 3 varieties (Sonora, Monterey, and Nonpareil) and the telemetry system across the two fields by one booster pump.

At Site 1, fertilizer use was tracked across all years and assessed against crop yield to calculate the nitrogen use intensity. The season 2018 provided the team with a particular example of high nitrogen saving. Due to changing weather early in the season, the pollination did not work well for one variety. The nut count was significantly lower, and the farm decided to apply significantly less nitrogen on that part of the field.

Nitrogen Savings of 14 Percent from Reduced Fertilizer Use

As shown in Figure 51 the gain in nitrogen efficiency for the Sonora variety was particularly high at 26 percent in 2018. It was smaller in 2019 with 15 percent. The results for the two other varieties are shown as well. The average savings in nitrogen per amount of crop yield was 14 percent. The range was large from 7 percent to 26 percent indicating that expected yield is a major factor and more precision in fertigation is needed.

Figure 51: Summary of the Fertigation Experiment at Site #1 Near Delano



The three colors represent each year from 2017 to 2019 and the nitrogen efficiency in pounds of yield per pounds of nitrogen applied is shown with bars for each variety.

Source: Institute for Energy Efficiency, University of California, Santa Barbara

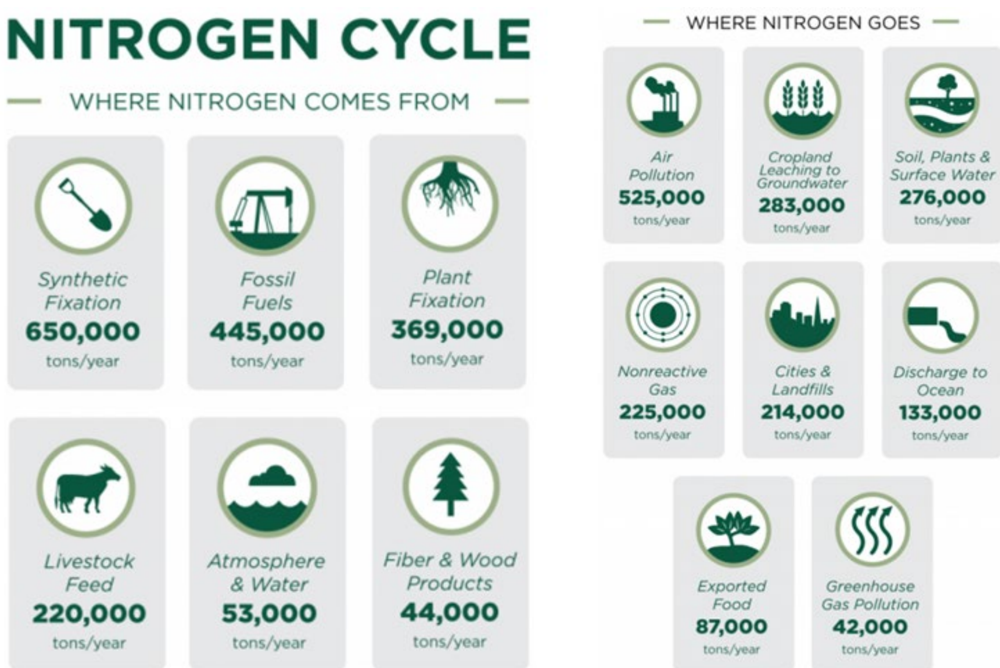
Discussion of Energy Savings from Reduced Fertilizer Use

The project team invested in developing a lifecycle assessment model for fertilizers to understand the potential for energy savings from reduction in nitrogen application. To AgMonitor's knowledge, it is the first such lifecycle assessment model developed for the

California Energy Commission (CEC). It is important because the United States fertilizer industry spends nearly half a billion dollars on energy each year according to the Environmental Protection Agency (U.S. EPA, 2020).

Most of this energy consumption is associated with the production of synthetic nitrogen fertilizers using natural gas. The cycle of nitrogen with its inputs and outputs is represented in the figure below (Figure 52). While fertilizer is essential for modern food production, studies from across the world have found that farmers who use these products are vastly over-applying them. Various assessments have pointed out a range of factors from farmers not accounting for nitrogen already existing in the soil to excess irrigation of cropland. Estimates for the exact amount of fertilizer lost during this over application range from 27 to nearly 70 percent depending on the study.

Figure 52: Summary of the Nitrogen Cycle

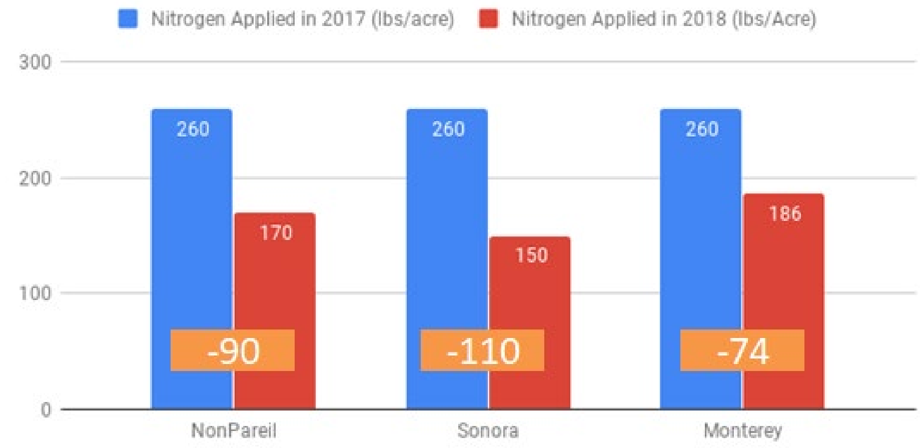


Source: Dr. Tom Watts, University of California, Davis

While this range is largely dependent on agricultural technology and farming practices, there are significant benefits in even small improvements in on-farm fertilizer application optimization (Roy and Misra, 2002). Therefore, the results of the project experiments are relevant.

Taking a close look at the first nitrogen application experiments that the team carried out at Site #1 in 2018, it led to a significant decrease in nitrogen application across three varieties (Figure 53) compared to 2017. The grower was comfortable to apply less nitrogen because bud set and pollination earlier in the season led to a lower nut count. Site #1 adjusted fertilizer application based on expected yield. This was an encouraging result.

Figure 53: Summary of Amount Nitrogen Per Acre Saved in 2018 at Site #1



Source: Institute for Energy Efficiency, University of California, Santa Barbara

Reduction in nitrate should be measured in context of food production. The crop yield varies year to year due to several factors. Therefore, the team decided to look at the reduction in nitrate application per output of production for the subsequent experiment in 2019. Figure 51 summarizes the nitrogen efficiency at Site #1 in 2018 and 2019.

The improvement from 7 percent to 26 percent with an average of 14 percent was achieved by applying water and nitrogen precisely with the automated systems. For instance, the precision of irrigation in 2019 was 98 percent at Site #1 (almond) compared to 94 percent at Site #2 (tomato). Row crops have a shallower root zone and irrigation is adjusted almost daily as opposed to weekly for tree crops such as almond. Precision is more challenging for row crops such as tomato. However, the team found that it can force growers to be more accurate. The accuracy in water application at Site #2 was 96 percent compared to 91 percent at Site #1.

As displayed in Table 7, nitrogen intensity improved in both 2018 and 2019. Despite yields being much lower in 2018, the field's use of nitrogen consistently improved. The farmer was able to apply only the needed amount of fertilizer on a per-variety basis. This was one of the project's largest energy efficiency gains and plays a key part in calculating the total energy input of crop production.

Table 7: Summary of Nitrogen Intensity at Site #1

Water Year	Total CAN-17 Fertilizer Used (Tons)	Total Yield (Tons)	Nitrogen Intensity (Ton of Fertilizer Used Per Ton of Harvest)
2017	10.00	111.90	0.089
2018	6.50	80.61	0.081
2019	9.43	120.13	0.079

Source: Institute for Energy Efficiency, University of California, Santa Barbara

By considering the embodied energy of nitrogen production, the team at UCSB calculated the energy savings from reducing nitrate application. The table below (Table 8) summarizes the results in 2018. The savings should be put in context. For that reason, the team converted the amount of calcium ammonium nitrate saved into kWh (Table 8). In 2018, the embedded energy savings from Nitrogen reduction at Site #1 (68,300 kWh) is comparable to the total energy used for pumping (88,400 kWh) during one season.

Table 8: Summary of Embodied Energy Savings at Site #1

Almond Variety	Total CAN-17 Fertilizer Saved (Tons)	Embodied Energy Saved (kWh)	Avoided Emissions (Ton CO_2e*)
Monterey	1.71	33,800	11.69
Nonpareil	1.04	20,502	7.09
Sonora	0.71	13,998	4.84
Total	3.46	68,300	23.62

*CO_2e = carbon dioxide equivalent
Source: Institute for Energy Efficiency, University of California, Santa Barbara

If this practice can be expanded upon to the wide variety of niche crops that dominate California's agricultural landscape, the state can expect significant improvements in environmental quality and embodied energy consumption for future generations. In summary, nitrogen intensity can be reduced by 14 percent (weighted average of the almond varieties by acre from 2017 to 2019), and the actual amounts of nitrate application should be adjusted every year according to expected yields to avoid excess nitrate entering the groundwater. UC Davis also recommends taking into account the amount of nitrogen in the groundwater extracted for irrigation (Harter et al., 2012). This was not a factor at Site #1, but it can be in areas such as Monterey and Tulare counties.

The projected benefits for California were calculated by the team at UCSB, assuming the 14 percent reduction from this study's field trials could be implemented on all fields across the state. The results were: 1,1234.000 metric tons of CO_2 equivalent avoided; 796,685 megajoules (MJ) of energy saved; 70,244 metric tons of nitrogen diverted from entering groundwater.

In summary, there are significant benefits to reducing fertilizer consumption and managing irrigation to avoid leaching of excess fertilizer into the aquifer. This research is important to California because the state has a long history as America's top producing agricultural entity. However, most of the factories producing nitrogen are not in California so public agencies need to decide if it makes sense to provide energy efficiency incentives for reducing nitrogen application.

Energy Savings and Better Solar Integration

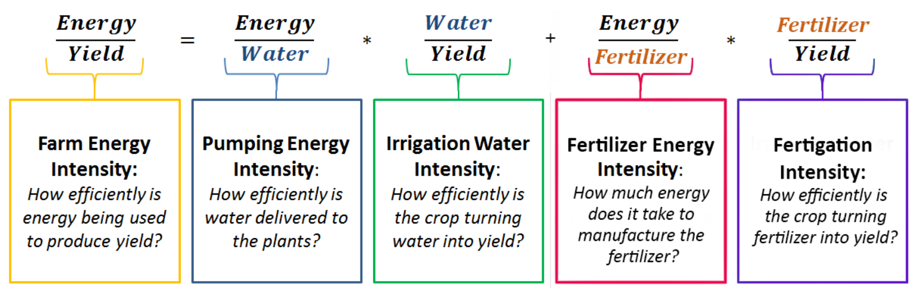
The team reviewed the mechanisms of energy savings by reducing water and nitrogen use thanks to programmable irrigation and fertigation. The following subsection summarizes the total energy savings and also explores other energy cost saving opportunities.

Total Savings of 13 Percent from Water and Nitrogen Reduction

A programmable irrigation platform by soil zone or crop variety allows the reduction of both water and nitrogen application. Full automation of the nutrient application requires the control of the injection pump, which WCE can do. It is, however, more difficult because nitrogen can load an irrigation system if a mistake is made, which can hurt the plants. Most of the farms that the team worked with, still controlled the injection point manually.

The convergence of the precise application of water and nitrogen using micro-irrigation systems remains an important trend. The question is "what is the combined energy savings?" Most of the energy consumption for water is at the pump while most of energy footprint of nitrogen is in the production phase. The complete lifecycle assessment system of the farm energy intensity is described below in Figure 54. Two fertilizer components were inserted, in addition to the two water components, from AgMonitor's previous research.

Figure 54: Visualization of the Components of Farm Energy Intensity



Source: Institute for Energy Efficiency, University of California, Santa Barbara

AgMonitor decided to use the equation for an ideal farm, for example Site #1, with both water and nitrogen savings the same year: 14 percent reduction in fertilizer application (MJ to kWh) and 11 percent in water application (ac-ft to kWh). Table 9 below summarizes the calculations. The weighted average of energy savings is 13 percent, which was reported for the project.

Table 9: Summary of Nitrogen and Water Embodied Energy Savings at Site #1

Saving Mechanism	Reduction	Energy Footprint (kWh)	Energy Savings (kWh)	Percentage to Total Energy Footprint
Water	1.71 ac-ft	47,200	5,192	11 percent
Nitrogen	1.04 MJ	204,920	28,688	14 percent
Total		252,120	33,880	13 percent

This demonstrates the potential impact of including nitrogen management in energy efficiency. One company at the Water and Energy Technology started during the team's project trials to produce nitrogen at farm sites using solar systems. This would make it easier to claim incentives since the production is done within California.

Reduction of Utility Cost by 10 to 30 Percent from Off-Peak Irrigation Cost

The general manager of the farm managing Site #1 was the first one to mention to AgMonitor that programmable operation could be leveraged to reduce the rising cost of pumping. The farm implemented a comprehensive plan to avoid peak-hour penalties across 7,000 acres: automation at two ranches including Site #1 (Figure 55), timers at other ranches where automation was not available, and changes in irrigator schedules to manually turn pumps on and off where pumps require attention. In part of San Joaquin Valley, there is a lot of sand in the water, and the pump must be turned on carefully.

Figure 55: Interval Data from SmartMeter for a Pump Station Used to Irrigate Outside Peak Hours

The automated irrigation system is programmed avoid irrigation between the peak hours of 4:00 p.m. to 9:00 p.m. in SCE territory. For instance, the pump is turned on at 9:15 p.m. on July 25, 2021.

Source: AgMonitor Inc.

The results for Site #1 are summarized in Figure 56 by using the weekly report format.

Figure 56: Summary of Energy Cost Spending During Peak Hours

Ranch: Site #1 in 2018 — Ranch Pumping Hours: 21842

Pump	Water Source	Meter SA ID	Pump Hours	Pump kWh	Est. Energy Cost ($)	Est. Water (ac-ft)	Cost per ac-ft ($)	Avg OPE (%)	Target OPE (%)	Peak Hours	Lost ToU ($)
AO 1 DW	Well	3-014-2260-54	174	2587	$ 1,288.66	10.08	$ 127.84				$ 3.26
AO 1 Field Booster	Reservoir	3-042-9333-96	1349	58572	$ 15,081.08	328.02	$ 45.98	58%	59%	231	$ 3,412.03
AO 1 Transfer Booster	Reservoir	3-042-9333-96	39	817	$ 3,137.37					1	$ 16.43
AO 12A Booster	Reservoir	3-014-2260-51	2197	69356	$ 11,438.45	763.77	$ 14.98			289	$ 804.41
AO 12B-C Booster	Reservoir	3-014-2260-51	3524	169101	$ 22,869.99	660.02	$ 34.65	65%	59%	435	$ 1,401.44
AO 2 Field Booster	Reservoir	3-014-2260-50	2042	86380	$ 15,196.32	483.13	$ 31.45	71%	59%	288	$ 1,569.20
AO 2 New DW	Well	3-040-5587-46	76	19857	$ 6,830.10	21.16	$ 322.78				$ 95.92
AO 3 Field Booster	Reservoir	3-014-2260-53	1371	58479	$ 16,383.68					312	$ 1,365.19
AO 3 Transfer Booster	Reservoir	3-001-1997-93	1372	59063	$ 16,388.37	373.17	$ 43.92			312	$ 1,377.69

Ranch: Site #1 in 2019 — Ranch Pumping Hours: 23766

Pump	Water Source	Meter SA ID	Pump Hours	Pump kWh	Est. Energy Cost ($)	Est. Water (ac-ft)	Cost per ac-ft ($)	Avg OPE (%)	Target OPE (%)	Peak Hours	Lost ToU ($)
AO 1 DW	Well	3-014-2260-54		0	$ 484.22						
AO 1 Field Booster	Reservoir	3-042-9333-96	1678	67613	$ 10,769.69	488.74	$ 22.04	38%	59%	84.7	$ 898.73
AO 1 Transfer Booster	Reservoir	3-042-9333-96	22	432	$ 2,297.33					4.2	$ 18.06
AO 12A Booster	Reservoir	3-014-2260-51	1883	59508	$ 9,273.34	653.82	$ 14.18			152.8	$ 131.82
AO 12B-C Booster	Reservoir	3-014-2260-51	3157	150696	$ 19,247.98	594.89	$ 32.36	65%	59%	343.0	$ 413.30
AO 2 Field Booster	Reservoir	3-014-2260-50	1918	81795	$ 12,343.93	446.99	$ 27.62	71%	59%	110.6	$ 225.69
AO 2 New DW	Well	3-040-5587-46		0	$ 2,069.55						
AO 3 Field Booster	Reservoir	3-014-2260-53	1772	78703	$ 11,792.59					148.4	$ 213.29
AO 3 Transfer Booster	Reservoir	3-001-1997-93	1774	79464	$ 11,861.13	502.79	$ 23.59			148.5	$ 215.37

The comparison of the annual ranch report for 2018 (top) and 2019 (bottom) shows a large reduction in ToU charges during peak hours. Peak hours are from 4:00 p.m. to 9:00 p.m. in SCE territory.

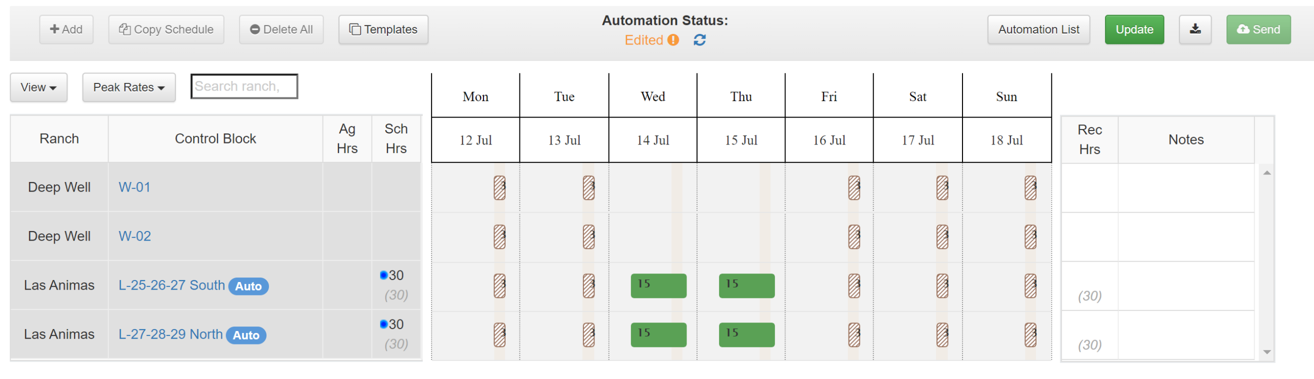
Source: AgMonitor Inc.

The team added two columns to identify if the pumps were used during peak hours or not: one column counts the number of peak hours of operation and one column calculates the additional energy cost due to ToU. The farm was able to reduce peak-hour penalties on energy charges (charge per kWh) by over 80 percent at that ranch. Across all ranches the farming operation reduced the proportion of peak-hour charges on the bill from 13 percent to 3 percent and saved more than $100,000.

ToU was established by the CPUC and implemented by the California Independent System Operator (California ISO) to even the grid: the cost of a kWh, or the cost of a kilowatt (kW), is higher during periods when there is a lot of demand and lower where there is less demand. The peak hours used to be between noon and 6:00 p.m. at PG&E and SCE. They moved to 4:00 p.m. to 9:00 p.m. at SCE, and 5:00 p.m. to 8:00 p.m. at PG&E. The underlying reason is the high level of solar penetration in California that changed the overall consumption curve of California ISO. The period of high demand is now from 4:00 p.m. to 9:00 p.m. with a steep ramp from 5:00 p.m. to 8:00 p.m. when the sun sets and people go home and use appliances.

The team did a more detailed analysis at a technology transfer site in PG&E territory (Farm #5) by monitoring the reduction in both energy charges (per kWh) and the demand charges (per kW). By choosing the optimum rate and avoiding peak hours entirely, the utility bill was reduced by over 30 percent. It showed the importance of building a software module to optimize the selection of a utility rate based on historical SmartMeter data. In this case, the farming staff used CropMonitor to load the schedule into the automated system. All the irrigation events can clearly be seen against other field activities (Figure 57).

Figure 57: Example of Automated Irrigation Outside Peak Hours at Farm #5



The irrigation schedule avoiding peak hours is loaded into the automation system to achieve 100 percent of irrigation and fertigation during off-peak hours and avoid peak demand charges.

Source: AgMonitor Inc.

Optimization of Solar Savings by Up to 40 percent

The large penetration of solar is creating new challenges for farms that must consider not only incorporating new utility rate structures into their operations but also maintaining a new type of assets. Not maintaining solar assets affects the cost of pumping water.

Several farms asked for help including Site #2, Site #3, and Farm #4. The team developed a tool to optimize the selection of rates across a NEMA group and a new algorithm to send a text alert when solar panels need to be cleaned. Figure 58 is an example at Farm #12.

Figure 58: Production of Solar Energy at Farm #12 With and Without Cleaning

The red arrow marks the period of time of lost generation capacity due to dust on the panels that were not washed until rain fell in October 2018. The subsequent two years the farms reacted to an alert from the team's cost module and cleaned the panels in August to increase the savings from solar.

Source: AgMonitor Inc.

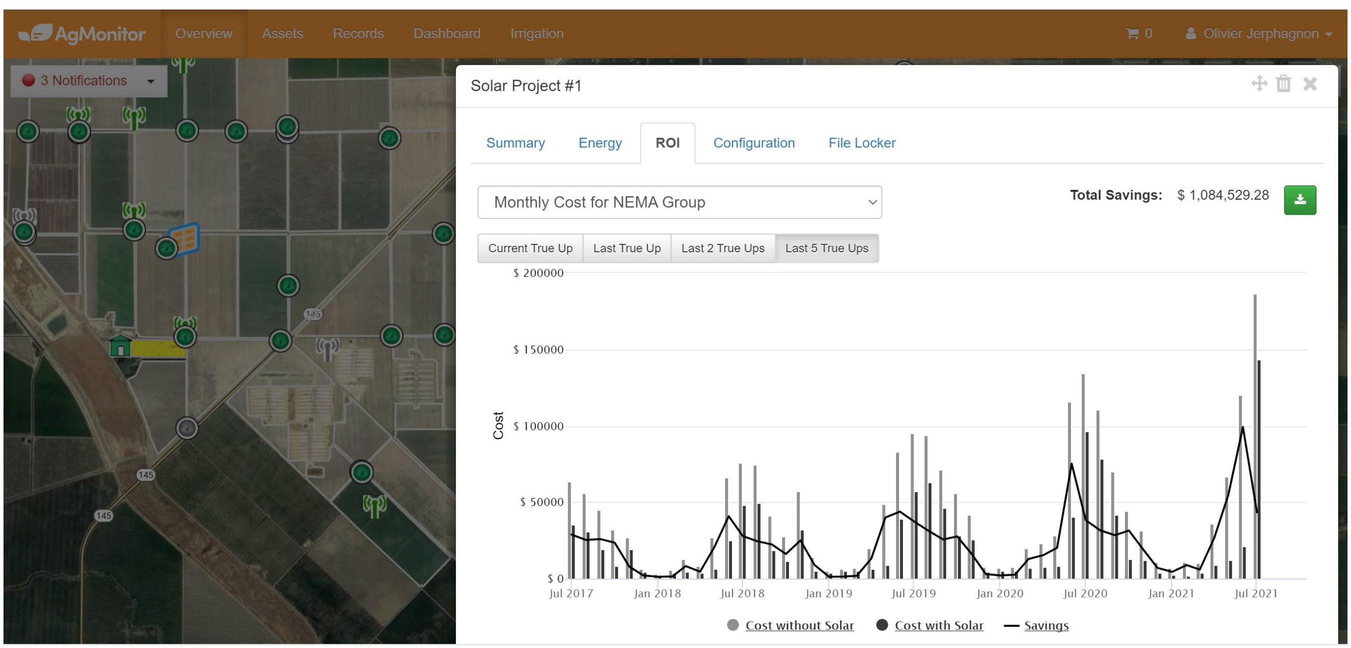
One illustration how disadvantaged communities are underserved is that farms sometimes must wait weeks to get a cleaning service. Most cleaning contractors work with utility-scale solar generators in California, and a 500-kW deployment at a farm is a low priority.

In one case the cleaning contractor never came but charged the farm, and the grower used the AgMonitor's system to check if the work was done. This led to a conversation among farms who bought the equipment to clean the equipment themselves. The key was to maintain the quality of the water (purifiers) and make sure that the temperature difference between the water used and the panels is not greater than 20 degrees Fahrenheit to avoid cracking the glass protecting the photovoltaic arrays.

The cost to buy a cleaning system is about $5,000, and the cost of a cleaning service is more than $5,000, so it pays off quickly when a farm has more than one array and cleans two or three times over the summer. The payback period is less than two years.

Return on investment (ROI) is an important criterion for farms to adopt new technologies at scale. This is why the team used the cost module to create an ROI calculator by calculating what the utility bill would have been without solar (Figure 59) and what the utility bill is with solar. The calculation of a bill across multiple meters using energy credits is too complicated for one person and requires software to automate the process across multiple scenarios to optimize the best rate and measure impact of cleaning.

Figure 59: History of Savings From Solar Across NEMA Group at Farm #12



The light grey bars represent the estimated bill without solar and the dark grey bars represent the actual bill from the utility. The difference is plotted as a black curve. The savings have been increasing every year since 2018 by cleaning the solar panels and optimizing the rates.

Source: AgMonitor Inc.

By cleaning solar panels in 2019 and optimizing the rate selection for the meters, the farm was able to increase the solar savings significantly year-over-year compared to 2018. The savings from solar increased by 21 percent in 2019 despite being a wet year (heavy rainfalls in May) and by 42 percent in 2020 (similar to 2018). The savings are summarized in Table 10 below.

Table 10: Increased Cost Savings by Better Integrating Solar at Farm #12

Calendar year	PG&E bills with solar	Estimated bills without solar	Annual Savings ($)	Increase in savings (percent)
2018	$ 214,153	$ 415,458	$ 201,305	Baseline
2019	$ 294,165	$ 537,587	$ 243,422	21 percent
2020	$ 317,429	$ 603,592	$ 286,163	42 percent

Source: AgMonitor Inc.

The results of Farm #12 were particularly encouraging. AgMonitor decided to do a larger study across 10 farms and dairies in San Joaquin Valley over five years from 2017 to 2021. The results were shared during a webinar hosted in October 2021 by PG&E. The average increase in solar savings was 29 percent, and it recovered hundreds of thousands of dollars in cash flow for farming operations as they dealt with increases in input costs (fertilizer, energy, and water).

The study identified other interesting trends:

- The size of the solar arrays varies significantly with NEMA group from 3 to 22 meters. Dairies as other food processors have a large load that takes most of the 1 megawatt (MW) limit. Irrigation takes more meters to reach that limit, and farms will typically include a shop in the NEMA group.
- Solar deployment across pumps and buildings reduced the cost of electricity by half. This led to a cost per kWh of about 11 cents, which is lower than natural gas.
- Solar reduced the cost of water but had a different impact on wet years and dry years. Because dry years force farming operations to pump more water from the ground, the solar savings are higher. This led to an average cost of 12 cents per kWh in wet years compared to 10 cents per kWh in dry years. Solar has a profound impact in farming as it helps mitigate the higher cost of pumping during drought years.
- The change from legacy to new rates was in general beneficial to farms. Although solar generators connected to the grid before January 2017 could stay on the legacy rates until 2027, the team found that 60 percent of the meters benefited from the new rate structure. This was due to lower demand charges in general while energy charges are mostly offset by the on-farm solar generation.

CHAPTER 4: Technology Transfer Activities

The team decided to organize its technology and transfer plan around three goals:

1. To continue to engage stakeholders at the food-energy-water nexus via workshops with farms, power utilities, and water agencies. This included the development of new education tools with the team's local community partners led by WHCC and the further development of field days.
2. To bridge the digital divide in disadvantaged communities by designing the mobile application for the staff in the field (English and Spanish) and deploying the new technologies at commercial farms beyond the team's pilot sites.
3. To prepare the transition of most of energy efficiency incentives to third-party program implementers. The team responded to the request for abstract (RFA) and shared the team's EPIC project findings with program implementers bidding on the request for proposals (RFP).

Technology Adoption in Rural Communities

During the survey in disadvantaged communities, the project team led by AgMonitor realized that rural farming communities have specific needs to adopt cutting-edge technologies across the operation from field workers to the director of farming.

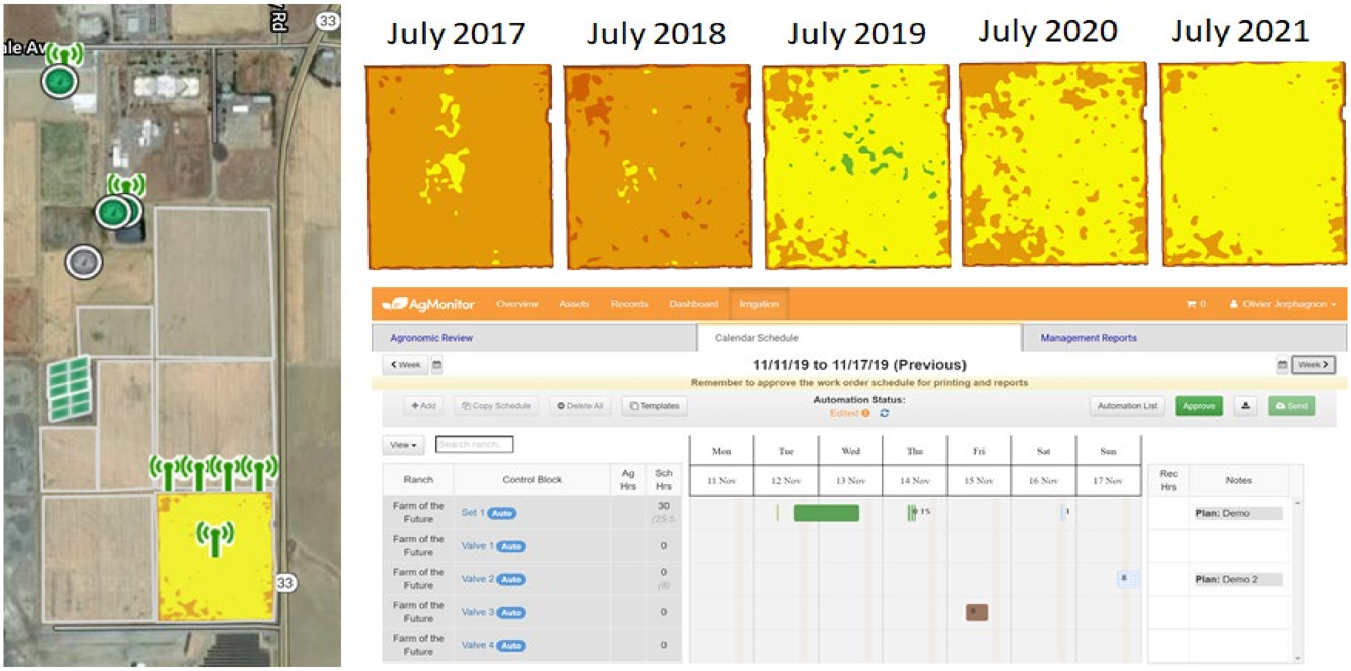
The System at West Hills College Coalinga and OpenFarm Events

The team started with a complete automated system at the "Farm of the Future" at WHCC. WCE and AgMonitor deployed the hardware and software to program the pistachio field.

The automation hardware and software were integrated into the Irrigation Management and Control Systems classes. Figure 60 shows the improvement across the field over the years by using the programmable irrigation platform. The whole field can be irrigated at once to save time, or by valves, to add additional water or nutrient in each of the four zones. WHCC sells the pistachio crop every year to fund its experimental activities and/or maintain the equipment. The classes are funded by student fees and government subsidies.

The team also hosted a Field Day in 2017 at Farm of the Future to display the cutting-edge technologies to growers. It consisted of three activities: field demonstrations, technical presentations, and an industry panel. The staff at WHCC presented how to use an electro-magnetic or electro-conductance machine to create soil or salinity maps that can be included in the definition of management zones (see Figures 61 and 62).

Figure 60: Description of Programmable Irrigation System at Site #3 in Coalinga



The layout of the Farm of the Future is represented on the Google map on the left. The series of NDVI images on the right summarizes the improvement of the field from 2017 to 2021 (orange to yellow to green as crop health improves over time with the automate system).

Source: AgMonitor Inc.

Figure 61: Field Demonstration on Soil Related Data Acquisition and Processing

Terry Brase from Farm of the Future at WHCC reviews how to use an electro-conductance machine from Veris Technologies. It is attached to a tractor to map a field.

Source: West Hills College Coalinga

Figure 62: Industry Panel at the Second OpenFarm Workshop Hosted by WHCC

From left to right: Curtis Garner from Bowles Farming, Ryan Nelson from City of Clovis, Britton Wilson, Stuart Woolf from Woolf Farming, and Dr. Tulinda Larsen from Women and Drones.

Source: West Hills College Coalinga

The growers at the workshop expressed the concern of increasing farming data that is not easy for them to manage to ensure proper control over their farming data. They asked for integration tools based on standards and collaboration among vendors.

This led to the creation of the OpenFarm event (Figure 63), hosted on the east side of San Joaquin Valley in Parlier by UC Agricultural and Natural Resources (ANR) Kearney Agricultural Research and Extension (KARE) Center in 2017, followed by an event in Parlier in 2018.

Figure 63: Farm Executives, Presenters, and the Keynote Speaker at the OpenFarm Event in 2017

Attendees of the OpenFarm event in 2017 discussed the need and business case for new technology adoption. From left to right: Dr. Khaled Bali (UC ANR), Morgan Halpenny (Pumpsight), Dr Jeffery Dahlberg (UC ANR KARE Center), Curtis Garner (Bowles Farming), Michael Toms (Fowler Packing), Keegan Witte (Maricopa Orchards), Glena Humiston (UC ANR), Nick Trujillo (WHCC), Dr. Burke Greer (AgMonitor), Gabriel Youtsey (The Vine and UC ANR), and Olivier Jerphagnon (AgMonitor).

Source: Kearney Agricultural Research and Extension Center, University of California Agricultural and Natural Resources

The event in Parlier in 2018 focused on technology innovation and big data analysis. There was a series of posters at the event that presented new technology solutions ready to manage water and nitrogen. Photos from the Third Annual OpenFarm event are presented in Figure 64.

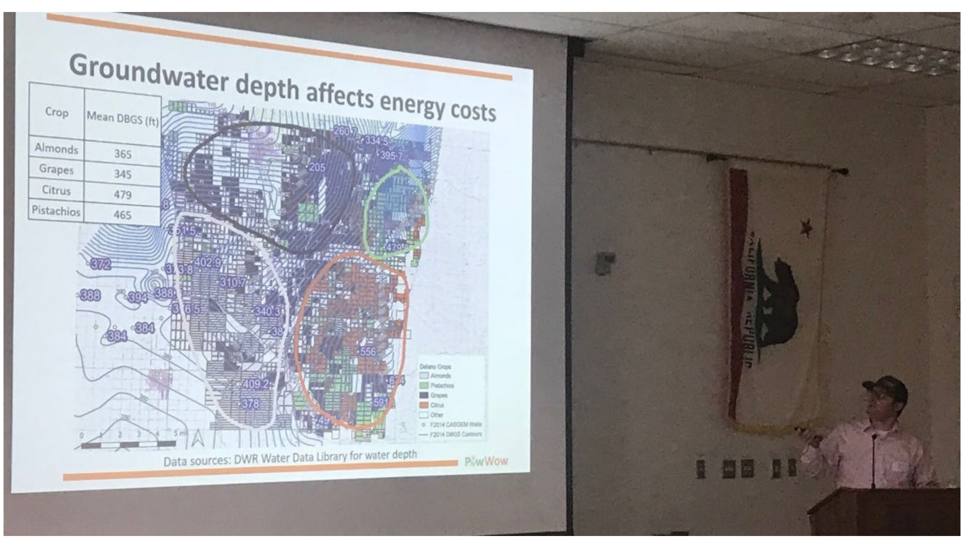
Figure 64: Field Presentation at the Third OpenFarm Event

Guillermo Valenzuela from WCE (left) and Olivier Jerphagnon from AgMonitor (right) explain how to precisely apply nutrients and water in micro-irrigation systems at the Third Annual OpenFarm event.

Source: Kearney Agricultural Research and Extension Center, University of California Agricultural and Natural Resources

AgMonitor also presented in the oral session on the use of large data sets to analyze a whole basin (Figure 65). Collaborators from UCSB and Formation Environmental came to the event, and the team connected with another EPIC project led by Lawrence Berkeley National Laboratory.

Figure 65: Oral Presentation on Census Areas of Huron and Delano



Dr. Burke Greer from AgMonitor explains the results of the big data analysis for Delano area.

Source: AgMonitor Inc.

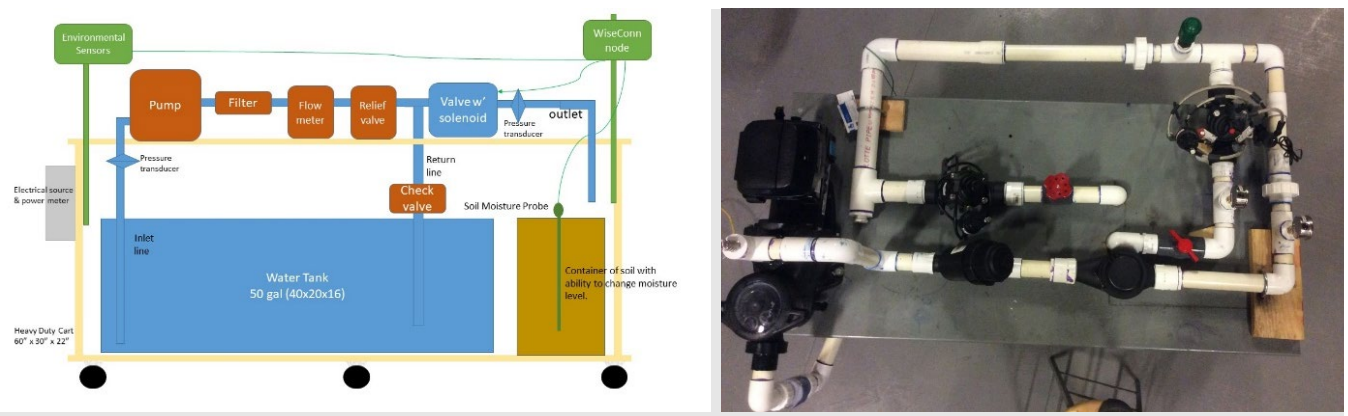
Emulators to Inspire New Agricultural Careers in High Schools

It was challenging for WHCC to perform experiments during this project because they have limited staff and are focused on teaching six-week classes that are mostly online with one lab class. Actually, the research assistant who was hired using the team's EPIC funds was the first dedicated non-teaching staff member. He was able to stay at the end of the project by securing employment in the grant office.

Most career tracks in the food and agricultural sector are for pest control advisor or commercial driver that require state licenses. Students study for these licenses during a two-year certificate program. Welding or water management are careers that need more qualified labor. According to the President of the California Department of Food and Agricultural who was on the team's Technical Advisory Committee, there are hundreds of new jobs in Central Valley. Using technology is a new skill.

Our co-Principal Investigator, Terry Brase, leveraged the automation system at the Farm of the Future to provide hands-on experience to develop troubleshooting and, more generally, critical thinking skills, for students who have limited education (for example, high school). Here lies the challenge to inspire new careers: most people considering agriculture as a career make their decision while in high school. Therefore, WHCC educators decided to create an automation system emulator for high schools that contains a pump, power and flow meter, a valve, and a controller from WCE (Figure 66).

Figure 66: Emulator of an Automated Irrigation System Including Active Parts



The design (left) includes active elements in orange, sensors in green, and a water system in blue consisting of a tank of water, two valves connected to the tank and a soil container. A picture (right) provides an overview of the emulator.

Source: West Hills College Coalinga

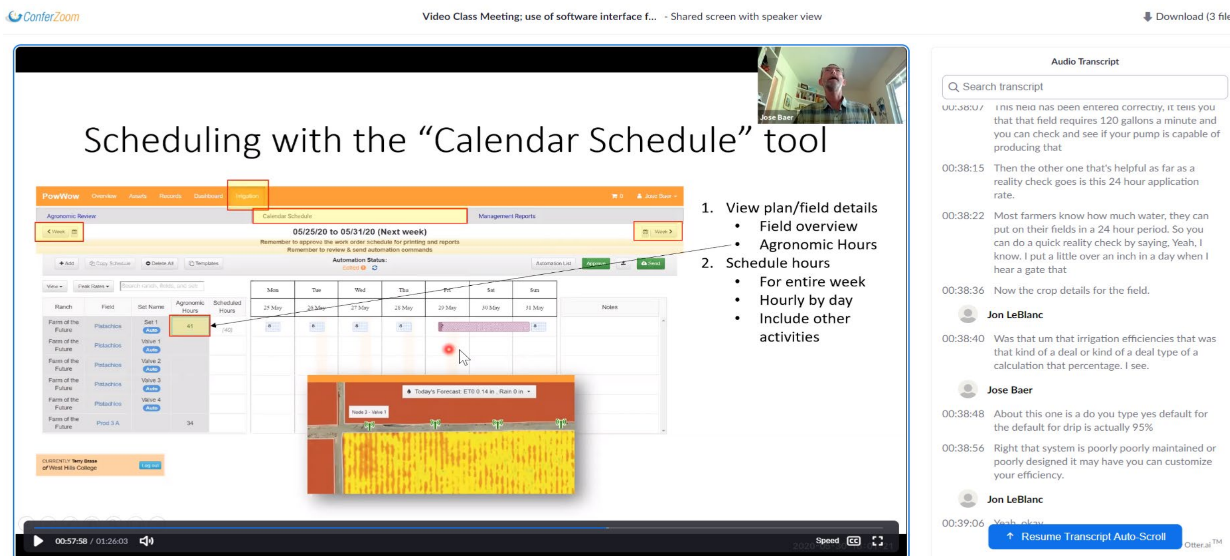
One the software side, AgMonitor created an online class with WHCC about the "digital transformation" of farming to help improve resource efficiency and reduce the tension on labor. The assets covered are pumps, solar generators, telemetry stations to control valves (for example, WCE) or collect data from an agronomic sensor (Tule Technologies). The software platform makes it easy to create multiple user accounts for students to explore the digital copy of the assets and develop an irrigation schedule. The class was not only taught by Terry Brase at

WHCC but also taken to local high schools in disadvantaged communities (for example, Mendota). Figure 67 is a screenshot of a class tool.

Move to Online Classes in English and Spanish

The class developed by WHCC and AgMonitor in 2019 was already carried out online (Figure 67). When the COVID-19 pandemic hit, the co-Principal Investigator decided to develop more content online to continue the program. He also sent kits to students to use at home.

Figure 67: Screenshot of the Online Class on Programmable Irrigation and the Management of the Different Farm Assets



The figure describes the calendar schedule interface of the programmable irrigation platform. It includes a video feed from the speaker teaching the online class hosted by WHCC. A transcript of the recorded class is provided on the right for ease of use by the students who can select a section using their computer.

Source: West Hills College Coalinga and AgMonitor Inc.

However, the community college was hit harder financially than other higher education institutions such as University of California campuses because most of their funding comes from subsidies based on the number of students attending classes on campus. During the project the team also learned that some farm workers wanting to take classes could not attend the lab sessions due to transportation. They also work long hours.

Therefore, the team developed a non-credit class about mobile applications to teach students how to use an application on a smartphone or a tablet. The three applications developed by WCE, by AgMonitor, and by the farm managing Site #2 were used as examples. The non-credit class was recorded both in English and Spanish. Over time, the materials developed can evolve into a non-credit class or a for-credit class. Non-credit classes are also useful to attract farm workers who are not in the education system yet. WHCC hired a Spanish-speaking staff member who can help prospects with registration online.

Technology Transfer with Key Farms

California farming is at a crossroad: while regulatory compliance is growing, the number of crops and the average size of a farming operation are dropping. Thanks to the team's annual OpenFarm events, the project team was able to understand three hurdles to provide the right tool for California farming, and the team attempted to address them:

1. **Lack of standards to integrate various vendors into a cohesive solution.** The vendors with a technology background are more aware of the situation and have educated leading farms about the subject. A few large farming operations have attended events such as AgGateway but have failed to unite and send a representative. The team focused on the integration of three vendors at Farm #6 (AgMonitor, Ceres Imaging, and WCE) and recorded a video. The ease of integration will enable the farm to scale programmable irrigation from 300 acres to 3,000 acres using OBF.
2. **A clearer business case from vendors.** Farms have expressed clearly that too many technology solutions do not solve a real problem. The simple weekly report that the team developed under Task 2 is in response to the clear request of growers. The team took the time to develop more complete and complex solutions under Task 3 and Task 4. Farms need to see a positive impact on their bottom line (reduced cost or increased yield) before scaling a solution by reducing water and energy costs. The team developed clear business cases at Site #1, Farm #6, Farm #8, and Farm #9.
3. **An industry that needs to value more education than on-the-job training.** It is difficult for the team's academic partners to work with older growers who value more on-the-job training while new technology solutions require staff with more education than a high school degree. AgMonitor's partner WHCC was able to get into high schools but still has difficulty filling more seats for a number of reasons: bureaucracy to sign up in a Community College when a farming staff wants to try a first class; the busy schedule of a farm worker who needs to help his or her family may have conflicts when classes are online during the week after dinner, and the labs on Saturday; and basic educational background to learn concepts in control systems, geospatial information systems, or agronomy. OpenFarm will advertise the available classes for at UC, CSU, and community college campuses.

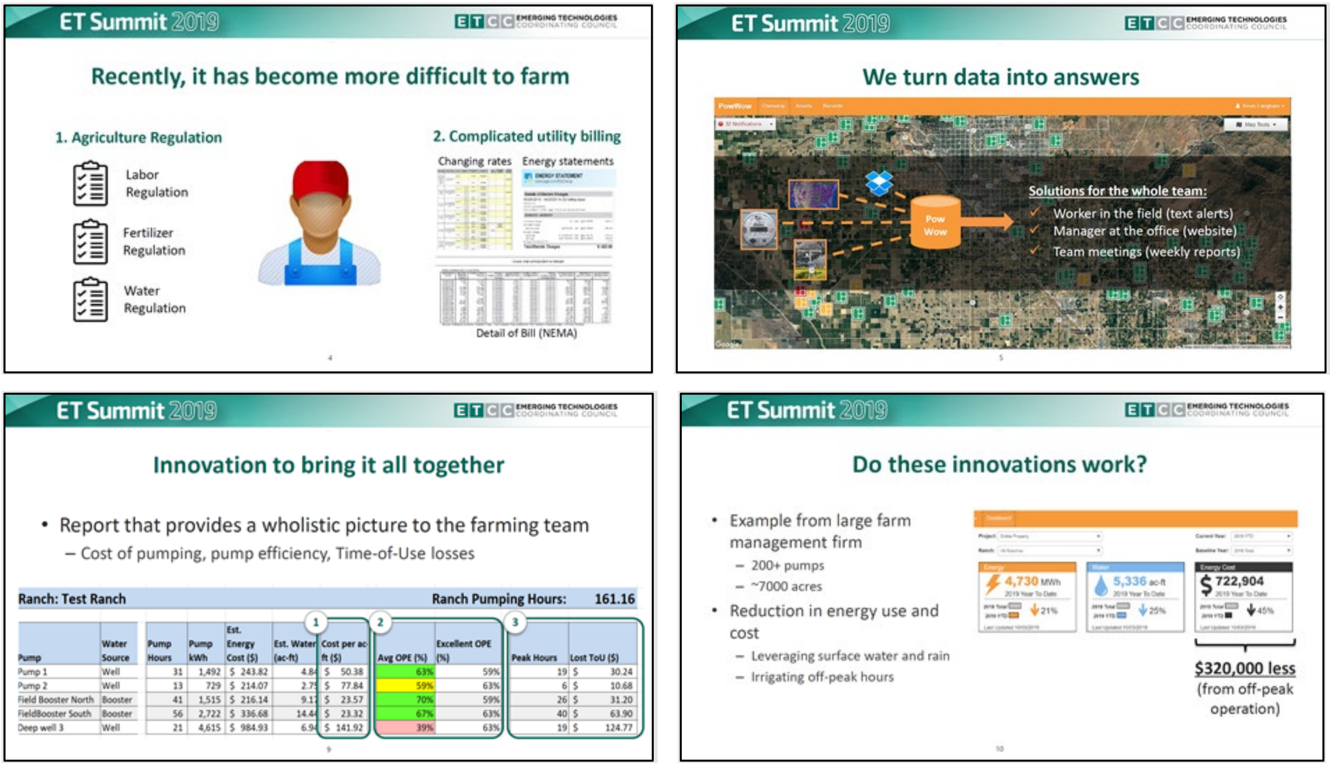
The remainder of this subsection describes the business cases at Site #1, Farm #6, Farm #8, and Farm #9.

Site #1 near Delano (East of San Joaquin Valley)

The farm management firm that hosted the experiment at Site #1 learned that it is easier to deploy automation for a new planting because the valves are installed, and the pump station is designed to match the irrigation layout. They have since deployed automation from WCE and software from AgMonitor at multiple ranches.

The two farm managers review every week the weekly ranch report to track the efficiency of the pumps and to make sure that they pumps are operated off-peak during summer. AgMonitor calculated the cost savings and also interviewed one of the farm managers, a woman who recently graduated from an agricultural school. She put emphasis on getting the buy-in from the field crew and the need for simplicity. The findings were shared during the Agriculture and Water session at the Emerging Technology Transfer Conference in 2019 (see Figure 68).

Figure 68: Presentation at Emerging Technology Summit in 2019 Summarizing the Findings of the EPIC Project



Series of screenshots of the slides presented at Emerging Technology Summit 2019 including the challenge for farming to adapt to new regulations (top left), AgMonitor's solution across multiple users with different educational background (top right) innovation developed during AgMonitor's project (bottom left) and the cost savings at farm scaling adoption (bottom right).

Source: Emerging Technology Transfer Council

The presenter, Kevin Langham, insisted that the programmable irrigation platform must provide simple management reports every week and cover both manual and automated fields to provide farms a transition path in the next 5 to 10 years.

In terms of a business case, the cost savings at 7,000 acres are more than three times the cost of the software. AgMonitor has found this level of savings ($3 saved for $1 invested) consistently across projects that better manage their farm assets with the new solution.

Farm #6 near Davis (Sacramento Valley)

The owner of the vertically integrated operation manages a farming staff but also a huller and sheller and a processing facility to provide high-quality almonds sold worldwide. He explained it was important to have a financing mechanism because the equipment for automation is relatively expensive ($300 to $500 per acre depending on the vendor, while the irrigation system typically costs $1,000 per acre).

Many farms try automation using grants from Natural Resources Conservation Services or California Department of Food and Agriculture. The team developed the idea to use OBF with PG&E and checked the process. It is possible for data needs to be gathered first because OBF is typically used for lighting in school buildings. The team talked to the farm owner and decided in 2020 to gather all the data necessary at Farm #5.The farm has the flexibility to choose the level of energy savings (Table 11) as long as the payback period is between 1 and 10 years. The sweet spot is 3 to 7 years. The team summarized the cost savings in the table for different levels of energy savings and the payback period. The process for OBF is described in the diagram below (Figure 69).

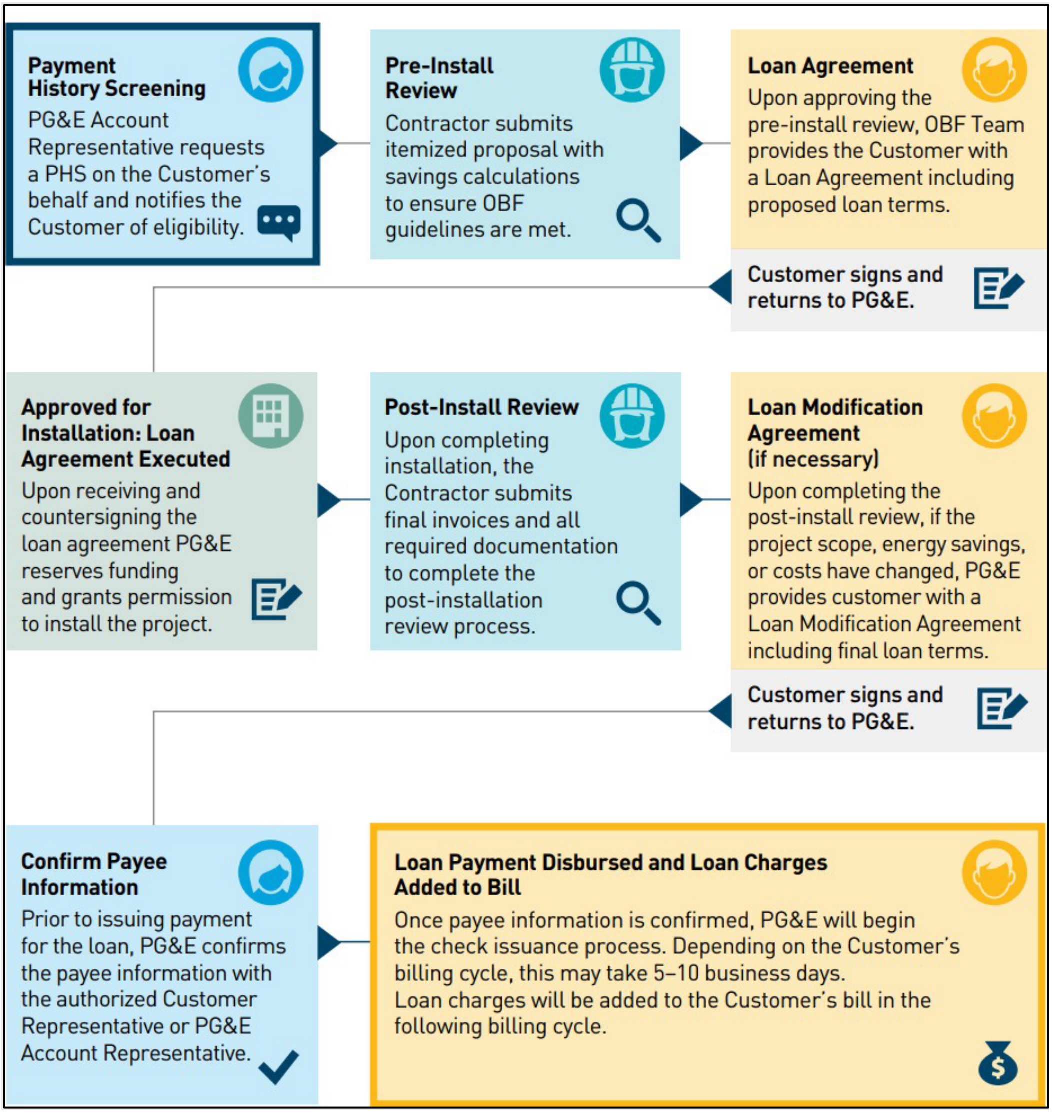
Table 11: Summary of Energy Cost Savings at Farm #6 for Different Levels of Water Savings

Variable	10 Percent	15 Percent	20 Percent	25 Percent
Baseline (ac-ft)	1,722	1,722	1,722	1,722
Projected application (ac-ft)	1,549	1,463	1,382	1,291
Savings (ac-ft)	172	258	339	430
Energy intensity (kWh/ac-ft)	313	313	313	313
Savings (kWh)	53,819	80,729	106,071	134,549
Cost ($/kWh)	$0.16	$0.16	$0.16	$0.16
Annual savings ($)	$8,719	$13,078	$17,184	$21,797
Payback period	5.5 years	3.6 years	2.8 years	2.1 years

Source: AgMonitor Inc.

The process to receive the OBF loan takes three months. The team started the process for the owner of Farm #6 who wants to leverage the data to fund future projects including a remote site in a disadvantaged community.

Figure 69: Overview of Flow Process to Qualify for On-Bill Financing



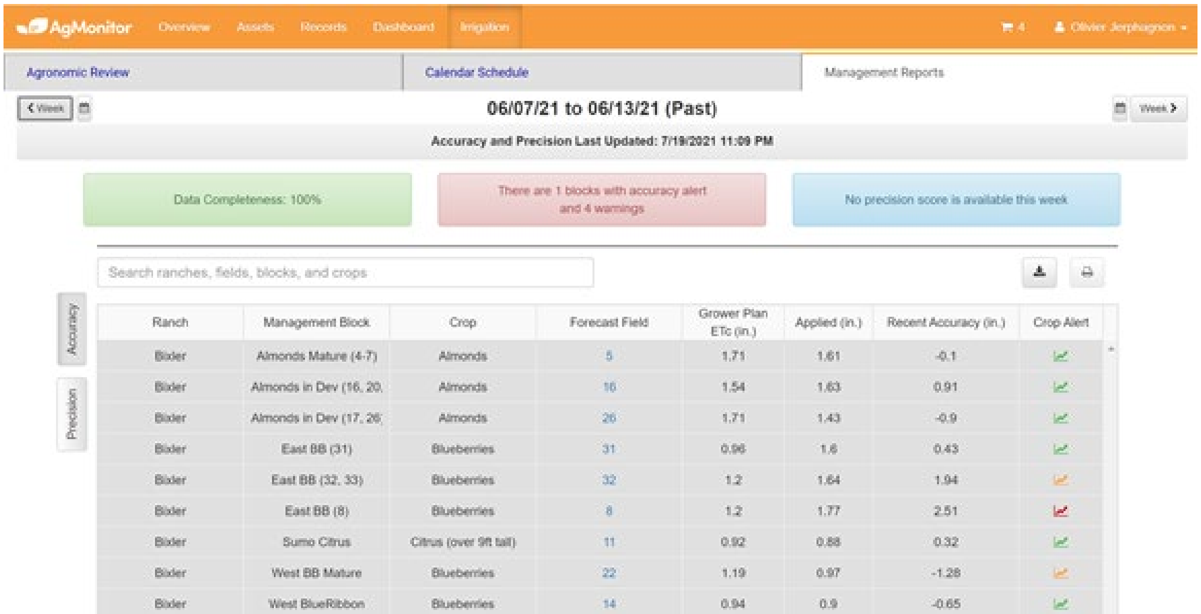
The OBF process application and lending program consists of 8 steps whether the project receives energy efficiency incentives or not.

Source: PG&E

Farm #8 near Tracy (Delta region)

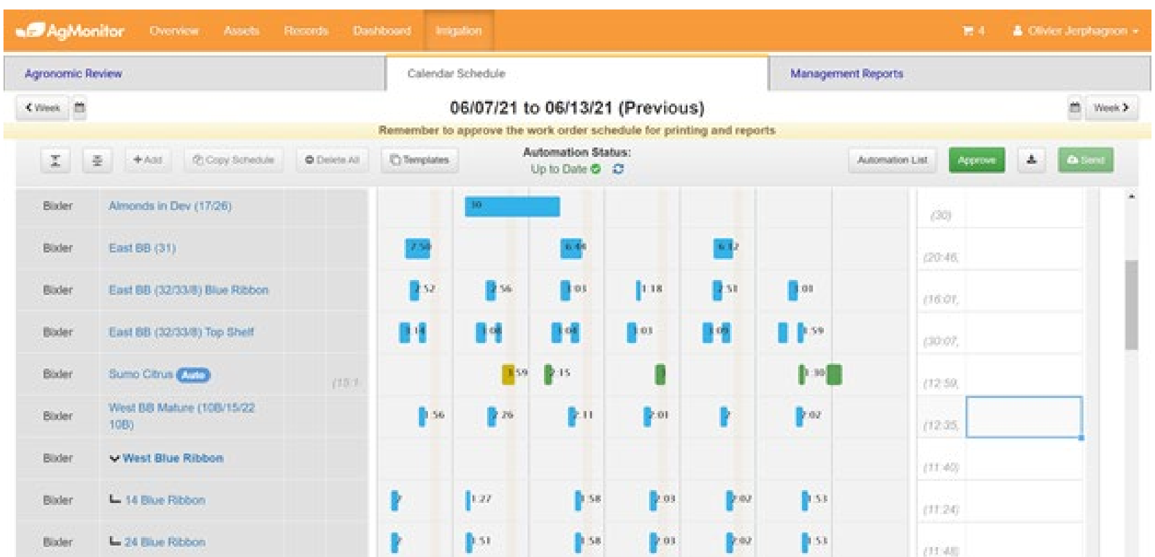
It is sometimes challenging to engage with the farming staff because they have limited time while the ownership can see the overall business case. At Farm #8 the team started with water reporting (PumpMonitor) and rate optimization (RanchMonitor), and the director of farming decided to deploy CropMonitor to close the loop in 2020 to both improve crop yield (farming practices) and avoid peak hours (utility rates). In exchange, the team had to promise to integrate AgMonitor and WCE information into weekly management reports that he could read in less than 30 minutes. The agronomic loop is summarized in (Figure 70) and the operational loop is shown in (Figure 71). It is particularly interesting because there are different crops and different varieties for each crop managed by over 200 valves.

Figure 70: Screenshot of Accuracy Report at Farm #8 Across Management Blocks



Source: AgMonitor Inc.

Figure 71: Screenshot of Calendar Schedule at Farm #8 Across Irrigation Sets



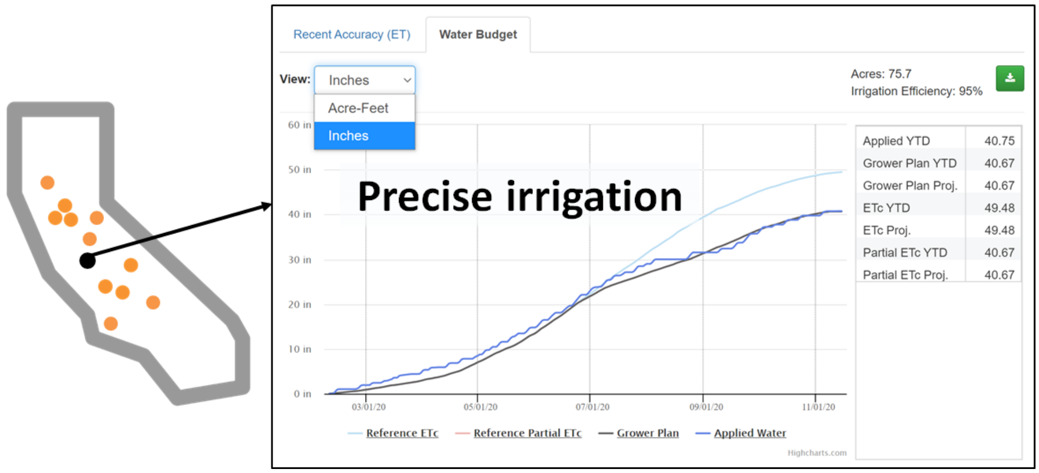
Source: AgMonitor Inc.

The rate selection and the avoidance of peak hours ($40,000 saved) alone paid for the software ($13,000) with an ROI over 300 percent. The impact of crop optimization is more difficult to assess because it requires yield data that Farm #8 did not give (due to privacy reasons).

Farm #9 near Los Banos (West of San Joaquin Valley)

One of AgMonitor's technology transfer farms had three different soils and different yields historically (before 2019) so it provided an opportunity to measure the impact of using closed-loop irrigation. The farm was already harvesting per field and per crop, which would be more difficult within a field like Farm #6 that has three zones but is harvested at the same time per variety. The deployment provided a high degree of visibility on how the programmable platform can reduce variability (see Figure 72 and 73).

Figure 72: Irrigation Record of a Technology Transfer Farm Near Los Banos



Source: AgMonitor Inc.

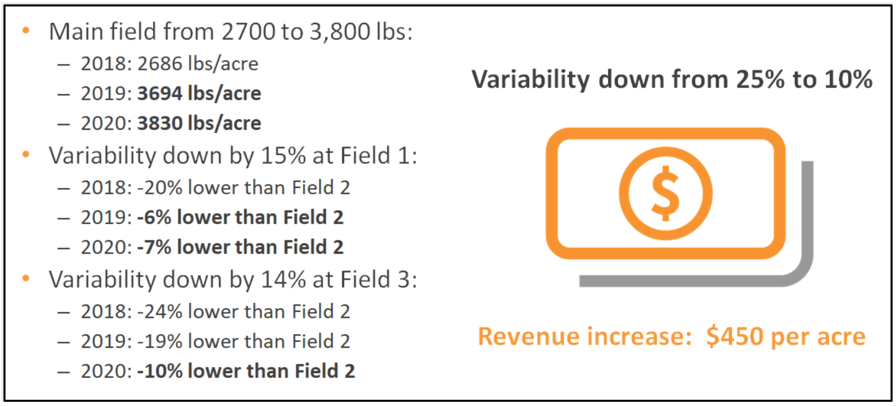
Rather than claiming yield improvements, which is not credible at commercial farm without treatment and control plots (there are over a dozen factors affecting yield), the team focused on improving uniformity (aerial images, Figure 73) and reducing yield variability.

Figure 73: Comparison of the Vigor of the Almond Fields in 2018 and 2020

Source: AgMonitor Inc.

The team decided to develop a business case based on the reduction of variability from 25 percent to 10 percent because (i) it is easier to be accepted by growers and (ii) it is similar to other optimization processes in other sectors such as six-sigma (a set of techniques and tools for process improvement) in manufacturing or food processing. One could claim that the solution helped improve the absolute yield of the reference field (Field 2). But the 2020 season had an unusually large crop across California. The team focused on the improved yield at the overirrigated field (Field 1) and the underirrigated field (Field 3). The increased profits represent $450 per acre (Figure 74).

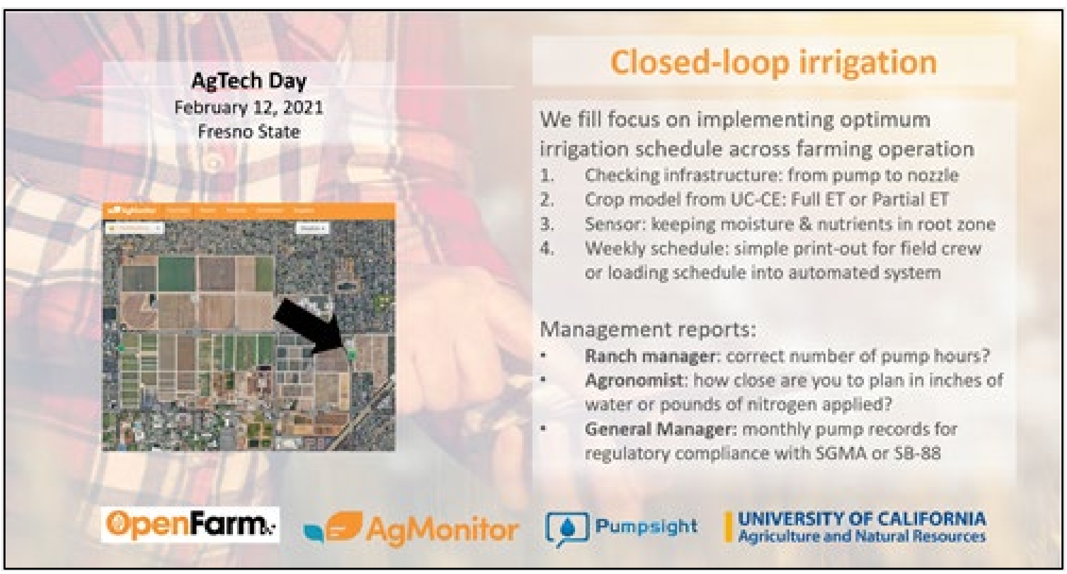
Figure 74: Evolution of Crop Yield Across Three Almond Fields from 2018 to 2020



Source: AgMonitor Inc.

The business case was used during AgMonitor's AgTech Day with Fresno State in 2021. A picture of the first slide of the live event (which was online due COVID-19) is illustrated in Figure 75.

Figure 75: First Slide of Field Demonstration at CSU Fresno Experimental Farm



Source: AgMonitor Inc.

Agricultural Energy Efficiency Programs

Southern California Edison

The team worked with SCE in the context of new water regulation and the introduction of the new utility rates. The first event that the team organized with at the Energy Education Center (see Figure 76) in Tulare focused on balancing water demand and supply to meet new water regulations (SGMA). The team had participation from irrigation districts and farms. One district manager warned that the energy demand will level out as SGMA is implemented because farms will not be able to pump as much during dry years. One GSA director explained that it would be good to capture stormwater during wet years; he actually deployed a 150 cubic feet per second pump in McMullin Area GSA to do just that in 2017.

Figure 76: Water Panel at Energy Education Center in Tulare in 2017

From left to right: Olivier Jerphagnon, Sarge Green, Aaron Fukuda, and Don Cameron discuss balancing water demand and supply ahead of the new groundwater regulation.

Source: Southern California Edison

AgMonitor joined the Western Growers Association in 2018 and organized a second event in 2019 (see Figure 77) at the Energy Education Center. WCE and AgMonitor displayed off-peak irrigation capabilities and AgMonitor displayed the solar alert with a local cleaning service. Both companies took part in the industry panel that stressed that there is an opportunity to create local jobs in the valley to manage water and integrate renewable energy better. The interaction of labor regulations and water regulations create new challenges, though. All panelists noted that there were opportunities to adopt new technology solutions in the field, but one farm manager on the panel stressed the importance of getting buy-in from the irrigators and field staff when deploying a new program.

Figure 77: Technology Adoption Panel at Energy Education Center in 2019

Dennis Donahue from West Growers Association leads a panel on farming operation that includes small and large farms.

Source: Southern California Edison

Pacific Gas and Electric Company

AgMonitor signed a contract with the new Revenue Development Department of PG&E, and PG&E invited the team to be part of agricultural energy events in 2020. AgMonitor's focus was to talk about off-peak irrigation and solar ROI optimization in the context of new agricultural tariffs (ToU) and optimizing solar integration (NEMA). The variation year-to-year in surface allocation makes it challenging to plan weekly irrigation and optimize solar projects.

The outbreak of COVID-19 led to the cancellation of the two in-person workshops but led to discussions about online seminars. The team had to adapt and focused on helping farms go through a "digital transformation" using the software tool. AgMonitor started to organize demonstrations via Zoom and AgMonitor sold a contract without meeting the grower in April 2020. The relationship culminated with PG&E hosting the fifth OpenFarm event online on January 20, 2021, which was well attended (Figure 78).

Figure 78: Fifth OpenFarm Event that was Hosted Online by PG&E

Source: Pacific Gas and Electric Company

Third Party Programs

Pacific Gas and Electric Company

PG&E was the first IOU to release its AgEE RFP. After being selected in the RFA round (see Technology and Knowledge Transfer Plan), the AgMonitor team shared its approach and capabilities with multiple program implementers: ICF, Lincus, and Franklin Energy. Only ICF was selected after the RFP round.

PG&E decided to award the AgEE RFP to TRC Solutions based in Bakersfield California as part of its public advice letter (PG&E, 2020). The organization is part of the TRC Companies that acquired the Energy Services division of Lockheed Martin in 2019. The team managed several food processing projects for PG&E.

The PG&E sourcing team offered to debrief with AgMonitor, which is unusual as the team only applied to the RFA. They mentioned that AgMonitor scored high on seven criteria (Figure 79) and low on none. They asked why AgMonitor did not apply to the RFP, and the team responded that AgMonitor was advised within the Emerging Technology Transfer Council community not to respond directly as the legal and financial terms are not appropriate for small companies. The team learned from other contacts at PG&E that it was limited to a first wave of awards after coming out of bankruptcy. PG&E is slowly outsourcing EE programs and will have 40 people checking EE saving claims.

Figure 79: List of Outsourcing Selection Criteria From PG&E

FIGURE 3 – PG&E Multi-Sector RFA Evaluation Criteria	
RFA Scoring Criteria	**Sub-Criteria**
Program Concept	Portfolio Alignment Assessment of Program Benefits Program Feasibility
Program Benefits	Team Composition & Qualifications Prior Program Implementation Experience
Program Innovation	Innovative Program Design Features

Source: Pacific Gas and Electric Company

PG&E decided to extend the contract with AgMonitor and renewed the pump test program with Fresno. The pump test program is no longer funded by EE funds, and it is covered by marketing for education and outreach purposes. The PG&E team in Fresno asked AgMonitor to work with TRC Solutions since they will need help to meet EE goals and that the small team in Bakersfield plans to rely on sub-contractors. As a result, in November 2020, AgMonitor signed a nondisclosure agreement with TRC Solutions. They are working on a "deemed measure" for closed-loop irrigation that will be deployed first as a "custom measure."

Southern California Edison

SCE is the second largest IOU and recently released its RFA for the agricultural sector. The team already works with SCE (previous pilot project), and the team offered a pilot extension to complete the integration of pump tests (automatic upload), to look at EE projects at farms, and to study how to streamline EE saving calculations.

The team saw the same trend at SCE as PG&E, although pump testing is done internally by the hydraulic team composed of nine testers, a few engineers, and two managers out of Riverside and Tulare. In terms of funding, SCE plans to move out of EE and move to operations and maintenance. The team interviewed one of the pump testers (see Figure 80) at one of the SCE pilot sites near Santa Barbara.

The pump testing team views the future AgEE program implementer as a customer that they can work with. Similar to PG&E, AgMonitor can play an important role in reaching out to farms and implementing sound EE saving projects.

Figure 80: SCE Pump Tester at Farms Near Ventura and SmartMeter Data Showing Improved Pump Efficiency After a Pump Retrofit

AgMonitor worked with a pump tester from SCE hydraulics team (left) to check a few pumps near Ventura after the pilot program and the recent fires. One farm re-sized its pump and gained 5 percent in pump efficiency between 2019 and 2020 (right).

Source: AgMonitor Inc.

The team informed SCE that it shared AgMonitor's RFA information with program implementers. As for PG&E, the team will not bid directly, and the team can sub-contract with the program implementer that is selected.

In the meantime, the team are streamlining the electronic upload of the pump tests into AgMonitor's platform and talking to the two managers about how to serve farms more efficiently post-COVID with more targeted tests and working with local agencies on SGMA.

CHAPTER 5: Conclusions

AgMonitor, in collaboration with WHCC, UCSB, Formation Environmental, and WCE, developed a programmable farm management system that integrates cutting-edge technologies to provide greater energy and water savings relative to existing energy efficiency programs or commercial irrigation offerings.

The new technologies were further deployed at eight commercial sites covering eight crop types to accelerate technology transfer. The team shares below the conclusions from the project.

Next Generation EE program in Agriculture and Water

Energy savings from water and nitrogen reduction are better understood thanks to this EPIC project. While energy savings from closed loop irrigation and continuous pump tests are ready to be deployed, incentives from nitrogen require more discussion.

From Custom to Deemed Measure: Programmable Irrigation

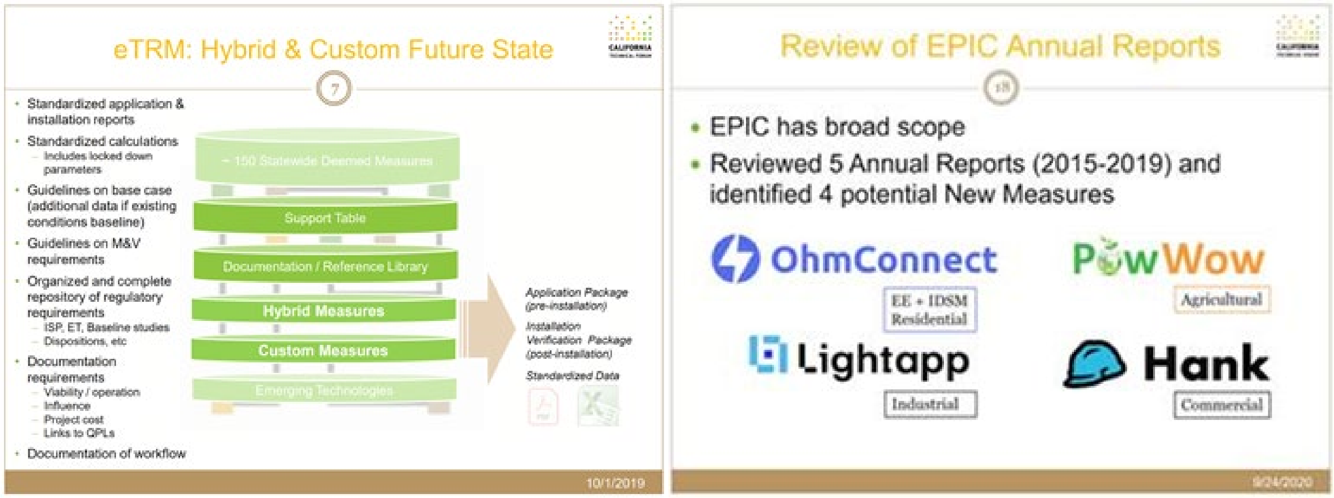
Energy savings from programmable irrigation have been both mentioned in the roadmap of SCE ("irrigation scheduling") and PG&E ("closed loop irrigation"). The integration from pump-to-nozzle generates energy savings exceeding 20 percent, thanks to a baselining process and weekly reports to make sure that the goals are met. In addition, farmers are more comfortable with setting their savings targets from 15 percent to 30 percent and knowing that risks are mitigated by end-to-end integration.

Receiving incentives requires going through the custom measure process with the IOU and CPUC until enough data is gathered to make it a deemed measure (Figure 81 left). That was the process that the VFD program went through in its early years. AgMonitor (formerly known as PowWow) is working with the winners of the PG&E and SCE RFPs to develop a white paper. AgMonitor's work was noticed by the California Technical Forum as one of four potential measures coming out of EPIC and the only one for agriculture and water (Figure 81 right).

Discussion on Nitrogen-Related Savings

The energy savings related to nitrogen are important if considering the energy footprint of production and transportation. However, most of the production of nitrogen is done outside California. Reduction of fertilizer applications also has many environmental benefits. The team recommends that the CEC and CPUC consider fertilizer application as a potential source of energy savings for AgEE programs by integrating fertigation with irrigation. In the meantime, the CEC can support emerging technologies to produce nitrogen on farms using renewable energy. This would alleviate the need to build a large new factory to produce nitrates in California.

Figure 81: Slides from the California Technical Forum Summarizing the Process from Emerging Technology to Deemed Measure

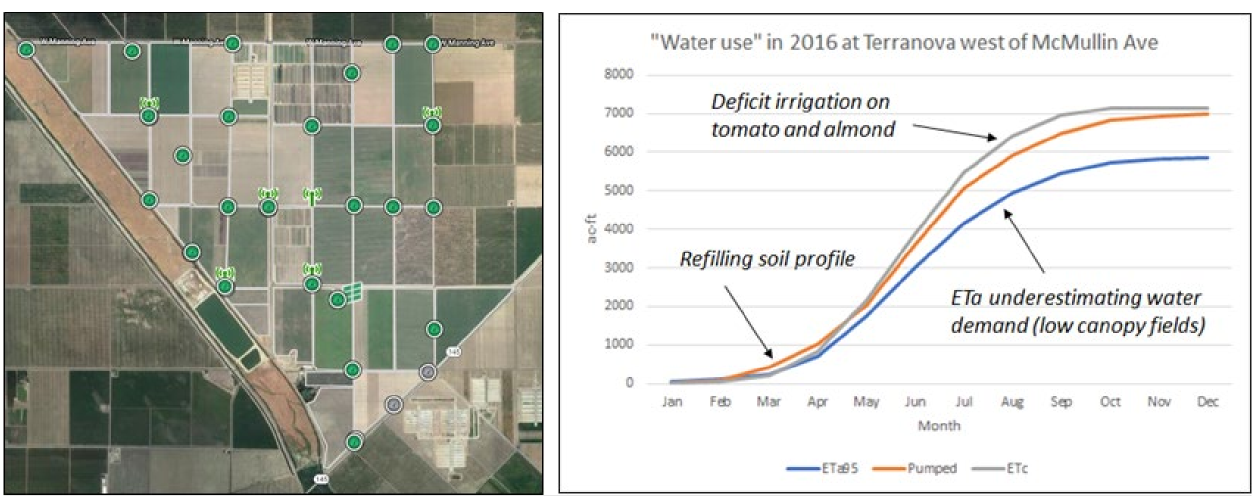


Source: AgMonitor Inc.

Large Projects at a Sub-Basin Level

AgMonitor presented to several irrigation districts and GSAs in 2020. Most of them have purchased a version of processed satellite data to estimate water demand in a basin. They all appreciated the comparison with actual water measurements at the pump (Figure 82). Many farmers are concerned that their groundwater consumption will be over-estimated. AgMonitor can help ensure proper accounting of groundwater consumption by using actual evapotranspiration data and by integrating into irrigation scheduling at the field level to develop region-specific farming practices.

Figure 82: Comparison of Water Demand and Water Use Data in Sub-Basin



Three different water measurement methods were compared in a sub-basin (left). The grey curve represents the crop ETc measured using a network of weather stations, the blue curve the ETa measured from satellite images, and the orange curve the water pumped (right).

Source: California Irrigation Management Information System, Formation Environmental, and AgMonitor Inc.

However, irrigation districts and GSAs need turn-key solutions to cover a number of water assets such as monitoring wells (depth sensors), pumps (Smart Meters and flow meters), groundwater recharge ponds or fields, etc. That is why PG&E extended its contract with AgMonitor to integrate hardware vendors with farms and districts to provide a full energy and water management to the food and agriculture sector.

Impact on Disadvantaged Communities

Disadvantaged communities are underserved, and the team made a point on focusing on their needs in this project. The project team learned quickly that disadvantaged communities have challenges that other communities do not have. Realistic goals must be set due to difficult living conditions: lack of broadband access, safety issues, and transportation. The team had to adjust the project scope by working with WHCC to develop new materials and getting additional help for the development of the mobile application.

The survey of the two disadvantaged agricultural communities showed that the needs of growers in California are misunderstood and new technologies must adapt. In summary:

- Technologies must solve a clear problem and be packaged as solutions that are ready to be used. The challenge is that the staff is diverse with very different educational backgrounds across the team and sometimes multiple languages.
- There is a need for new educational programs (both in Spanish and English) to help the new generation of workers develop the necessary skills in an industry facing many regulatory challenges led by water and labor. The goal of this EPIC project was in sync with farm needs. Workers need accessible classes.
- Water is undervalued for several reasons and success stories are critical for the development of new water management careers in an industry where the chemical supply chain is well established. AgMonitor's project placed several WHCC students at the tech transfer farms, and some of tech transfer farms used the new materials from WHCC.

Grid Stability in Context of Solar Integration

The penetration of renewable energy near Huron was one of the surprises of the project. The team shared AgMonitor's results with the California Department of Food Agriculture (State Water Efficiency and Enhancement Program) and the CEC (EPIC program) using AgMonitor's SpaceMonitor portal to illustrate the issue of quality of electricity service in disadvantaged communities producing more renewable energy than they are consuming. The grid becomes unstable. The project integrated solar generators in AgMonitor's energy and water management platform because IOU bills are particularly difficult to understand in the context of NEMA since they can include a dozen pump assets, a few buildings, and a 1 MW array. Farms should be able to understand its energy costs.

The project team strongly recommended funding additional work on the integration of programmable irrigation to shift energy from periods of low energy production (4:00 p.m. to 9:00 p.m.) to periods of high renewable energy production (night for wind and midday for solar).

CHAPTER 6:
Benefits to Ratepayers

This project underscored several benefits to ratepayers. This section covers both cost savings and improvement in air quality including the reduction in GHG emissions. In the context of agricultural communities, it is worth mentioning the economic opportunity to create hundreds of jobs to manage water and nutrients to deal with new regulations and maintain the vitality of the food sector in California. Challenges remain including a more resilient grid affected by the high penetration of solar and the automated shutoffs due to the risk of wildfires. Programmable irrigation can be part of the solution by shifting irrigation energy load from on-peak to off-peak periods.

Reducing Costs and Improving Air Quality

The cost savings from more precise irrigation were expected, and new measures have been strengthened to support incentives despite the difficulty to estimate baseline energy in the agricultural and water sector compared to the commercial sector. The reduction in undesirable emissions from reduced fertilizer application is a clear result from the study carried out by UCSB, and the reduction was not expected to be as high.

Cost Savings from Energy and Water Savings

The experiments demonstrated that programmable irrigation can reduce water and energy use by applying the right amount of water at the right time using science-based planning and simpler reporting tools. Based on the technology transfer trials of CropMonitor with automation, the team quantified the following benefits in Table 12.

Table 12: Energy Cost Savings Per Acre from Programmable Irrigation

Benefit	Amount
Water use reduction	-19 percent
Energy use reduction	-20 percent
Power bill reduction	-$41 per acre

Source: AgMonitor Inc.

To estimate the monetary benefits of AgMonitor's platform, the team assumed that market penetration would increase from less than 0.1 percent today to over 5 percent in 5 years (Table 13). The assumption is conservative. Higher penetration may be achievable through additional incentives and educational outreach, as discussed in other sections of this report.

Table 13: Potential Benefit to California Rate Payers

Year	2021	2022	2023	2024	2025
Acres deployed (California)	6,000	10,000	40,000	85,000	300,000
Annual energy savings	$246,000	$410,000	$1,640,000	$ 3,485,000	$12,300,000

Source: AgMonitor Inc.

Improvement in Air and Water Quality from Nitrogen Savings

The relationship between the reduction of energy consumption on the grid and the reduction of GHG emissions is well understood. This subsection focuses on the application of fertilizer, for which reporting is led by the U.S. EPA under the Irrigated Land Reporting Program to reduce groundwater infiltration. Programmable fertigation can play an important role. The GHG reduction is summarized below (Table 14). It is an important factor for disadvantaged communities. According to the 2019 "State of the Air" report, Fresno-Madera-Hanford ranked the highest in the nation for year-round particle pollution, while Bakersfield maintained its rank as the city with the highest particle pollution (American Lung Association, 2019).

Table 14: Annual Improvements in Air and Water Quality from a 14 percent Reduction in Fertilizer Applications in California Using Programmable Fertigation

Benefit	Amount (metric tons)
Total CO_2 equivalent emissions avoided from a farm nitrogen fertilizer use	889.333
Total amount of nitrogen diverted from entering California groundwater	46,829

Source: University of California, Santa Barbara

The numbers calculated by UCSB show the high potential impact on managing fertilizer applications more precisely. The numbers are for all of California because UCSB did not take into account market penetration. The numbers can be easily adjusted by a factor for various levels of adoption: 1 percent, 10 percent, 20 percent, etc.

Better Targeting of AgEE Projects

In recent years, the cost effectiveness of AgEE programs has been questioned by the CPUC. For instance, not every pump test results into a pump retrofit. Also, the difference between a necessary repair ("pump is broken") and an improved EE measure is not always easy to track. That is why EE incentives for pumps in 2020 were limited to OPE levels from 30 percent to 50 percent according to Advanced Pumping Efficiency Program run by CSU Fresno.

The project has demonstrated how clustering and data fusion across energy use, water demand, groundwater levels, and crop census data layers can identify at-risk areas to reduce the cost of bringing new AgEE measures to market. The right information can help increase the number of conversions from a meeting to an actual project. This is a major milestone, and more funding would be needed to host all the data sets for California and provide a portal for AgEE programs while protecting the privacy of ratepayers. This project has the potential to improve the cost effectiveness of the new third-party program implementers who have a limited presence or name recognition in the Central Valley.

Access to local service providers is essential in disadvantaged communities. For this reason, the project recommends integrating the existing pump test program (Advanced Pump Efficiency Program for PG&E, and Hydraulic Team for SCE) with continuous pump tests. Weekly reports can help farms measure the benefit of identifying the financial benefits of new AgEE projects. The president of the California Department of Food and Agricultural, who was on AgMonitor's technical advisory committee, mentioned that AgEE measures boil down to managing the cost of water per acre-foot for a grower. Both AgEE and solar savings are beneficial to farms.

Need to Improve Grid Stability

Adaptation to New Off-Peak Hours and Rates

The project initially did not include the reduction of power load during peak hours and the associated savings in power costs (Table 15). The feasibility of shifting 15 hours of irrigation pump operation each week from peak demand hours to non-peak demand hours should be further studied in the context of new ToU rates. At the pilot site #1 load shifting of 15 hours per week from peak demand hours resulted in significant savings.

Table 15: Potential Benefit to California Ratepayers

Benefit	Average	Minimum	Maximum
Bill reduction across 10 ranches covering 3,000 acres ($/ac)	-$30/ac	-$15/ac	-$67/ac

Source: AgMonitor Inc.

To estimate the potential impact in California, the team made the same assumptions in market penetration for PumpMonitor and CropMonitor. That is, that market penetration would increase from less than 0.1 percent today to over 5 percent in 5 years (Table 16).

Table 16: Potential Annual Savings to California Ratepayers

Year	2021	2022	2023	2024	2025
Acres deployed	6,000	10,000	40,000	85,000	300,000
Annual savings from load shifting	$150,000	$250,000	$1,000,000	$2,125,000	$7,500,000

Source: AgMonitor Inc.

Tables 13 and 16, taken together, would yield total cost savings to California ratepayers over five years of $29,106,000, which is roughly 10 times the grant amount of the EPC-16-051 project.

Identifying Areas where Solar Penetration is High

The use of SpaceMonitor demonstrated that it is possible to identify areas with high solar penetration that can put the grid at risk. This is another use case for the development of big data tools in the future for the energy and water sector. The project team strongly recommends private-public partnerships such as the prototype developed by UCSB, Formation Environmental, and AgMonitor.

The integration of energy storage at IOU substations or electric vehicle fleets at farms (farm management) of food processing facilities (food distribution) is the next frontier to meet the state mandate for 100 percent renewable energy by 2045. This is an important topic to shape the remaining load during periods of steep ramps (4:00 p.m. to 9:00 p.m.).

The team developed RanchMonitor to manage the interaction of buildings, pumps, and solar generators under a NEMA group. The product could be extended to include more assets on a ranch: electric vehicle fleets and energy storage systems.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
$/ac	dollars per acre
ac-ft	acre-feet or acre-foot
AgEE	agricultural energy efficiency
AgMonitor	AgMonitor Inc.
ANR	Agricultural and Natural Resources (University of California)
API	application program interface
CEC	California Energy Commission
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPUC	California Public Utilities Commission
CSU	California State University
DIR	Department of Industrial Relations
EE	energy efficiency
U.S. EPA	United States Environmental Protection Agency
EPIC	Electric Program Investment Charge
ET	evapotranspiration
ETa	evapotranspiration, actual
ETc	evapotranspiration, calculated
GHG	greenhouse gas
gpm	gallons per minute
GSA	Groundwater Sustainability Agency
HP	horsepower
IOU	investor-owned utility
KARE	Kearney Agricultural Research and Extension (Center)
kW	kilowatt
kWh	kilowatt-hour
kWh/ac	kilowatt-hours per acre
kWh/ac-ft	kilowatt-hours per acre-foot
MJ	megajoules
MW	megawatt
MWh	megawatt-hour

Term	Definition
NDVI	Normalized Difference Vegetation Index
NEMA	Net Energy Metering Aggregation
OBF	on-bill financing
OPE	overall pump efficiency
PG&E	Pacific Gas and Electric Company
Q	flow
RFA	request for abstract
RFP	request for proposal
RMP	rotations per minute
ROI	return on investment
SCE	Southern California Edison
SEBS	surface energy balance system
SGMA	Sustainable Groundwater Management Act
SSP	single speed pump
TDH	total dynamic head
ToU	Time-of-Use
UC	University of California
UCSB	University of California, Santa Barbara
VFD	variable frequency driver
VSD	variable speed drive
VSP	variable speed pump
WHCC	West Hills College Coalinga
WCE	WiseConn Engineering

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