Precision Irrigation

A Method to Save Water and Energy While Increasing Crop Yield,

A Targeted Approach for California Agriculture

By Gary Marks, March 2010

Introduction

Crop irrigation requirements vary in time with weather and soil conditions. Precision irrigation provides a means for evaluating a crop's water requirements and a means for applying the right amount at the right time. Often in the literature, precision irrigation is referred to as irrigation scheduling[1, 3]: That is scheduling based on environmental data, whether that data comes from local field sensors or from more global sources such as regional meteorological information.

Applying precision irrigation practices offers significant potential for saving water, energy, and money. Further, it has the potential to increases crop yield. There is an additional positive environmental impact from precision irrigation in that farm runoff, a major source of water pollution, can be reduced.

While precision irrigation has value for all types of irrigation in any region of the world, this paper focuses on the irrigation of California agriculture, which uses nearly 80% of the state's water and more than ten billion Kilowatt hours of electricity annually. That is enough electricity to power one million typical American households each year[13]. The approximate power plant capacity required to power California irrigation through the months of May through October is 2500 MW, which is equivalent to 250 Min-Nuke power plants running at an average of 10MW each[14]. The carbon footprint associated with the power is approximately six million metric tons of CO_2 per year[5].

This paper will first describe precision irrigation technology. Many studies cite the benefits of using crops' environmental data for planning and scheduling irrigation. The benefits of automatic pump and valve controls are also presented, a part of precision irrigation that has not been addressed by previous studies.

An analysis of water, energy and money savings follows the description of precision irrigation technology. Studies are cited on water savings realized from precision irrigation practices. Further data is cited on the water-energy nexus: The strong link between water and energy use. The cited studies on water savings deal only with savings that are based on using environmental data. This paper goes further to claim that the use of sophisticated automatic controls can save even more water, energy, and money and also reduce peak electricity demand. Also, the case is made for using a different metric for water savings: That is water saving should be measured against changes in crop yield as opposed to just changes from past water use for a given crop.

Finally, a strong case is made for potential water, energy and money savings that can be realized by applying precision irrigation to California agriculture. Approximately 6.8 million acre-feet can be saved and more than 2 billion Kilowatt hours of electricity can be removed from the grid annually along with an additional 1 billion Kilowatt hours of peak-load reduction.

Precision Irrigation Technology

The technology for precision irrigation falls into two categories: That used for gathering environmental data and that used for automatically controlling the irrigation system. Environmental data, used to determine crop water requirements, may come from locally installed sensors or from regional weather data. There may also be supporting technology in the form of wireless communication networks, Internet connections, and other networking infrastructure such as switching hubs, routers, and gateways.

Weather Data

Weather data can be obtained from a locally installed weather station in the crop's field or from a weather data service. In the former case, the weather station may be integrated with other environmental sensors as described below. Examples of weather services include the California Irrigation Management Information System (CIMIS) and AgriMet. CIMIS is a network of fully automated weather stations operating throughout the state of California (125 stations as of July 2009[1]). AgriMet is another meteorological data collection system that is operated by United States Bureau of Reclamation.

Field Environmental Sensors

Soil moisture sensors are the most common type of environmental sensor employed for determining a crop's water requirements. However, sensors for ambient temperature and humidity in the crop's field are also common. As stated above, full weather stations may even be included in local sensors. Sensors are strategically located at a number of points within a crop's field in a way that covers variations in soil type and climate.

Pressure transducers may also be employed in the field for monitoring the water pressure of irrigation zones. For crops that require continuous flood conditions, such as rice, water level sensors at various points in the field may be used. They may be used as direct real-time feedback for automatic controls (discussed below) and/or data collection and logging.

Sensor Data Collection

Sensors may be queried manually or automatically by a data collection system. Automatic data collection systems will query at regular intervals (generally every 15 minutes or so) and then log the data into a database for subsequent reference.

Also, automatic data collection systems generally require a wireless communications network of very low power data collection nodes with solar cells and rechargeable batteries. Refer to figure 1 below for an example of a node. Any node within the network may have one to several sensors attached. Some nodes may be used only as a communication relay within the wireless network.

In addition to the wireless nodes, the network may also include switching hubs, routers, and gateways. Viewing of real-time data as well as data in the database archive may be limited to a local network on the farm or may be accessible from the Internet.

The greatest challenge in deploying nodes is getting a relatively clear line-of-site between nodes. While the networks are generally based on a mesh protocol that is self healing, they still need a clear path back to a base point (usually at the pump site) where there is a local network or Internet connection. The wireless spectrum is usually in the unlicensed low-power range that cannot penetrate hills or dense vegetation. Common frequencies include 900 Mhz, 2.4 Ghz, and 5.8 Ghz. Fortunately, in most agricultural environments the terrain is flat; however, nodes and antenna placement must be done in a way that prevents the crop from absorbing the signals. This can be a challenge with orchards that have tall trees such as walnut orchards.

Figure 1, Saturn Node from Iris Connection, Inc.

Automatic Controls

Once environmental data has been obtained for the purpose of determining the desired schedule for applying water to a crop, the task of carrying out that schedule falls to either human operators or automatic controls. Of course, automatic controls provide a more precise and reliable scheduler than does a human operator.

Manual operation is generally performed by farm laborers that have the task of setting valves and starting, switching, and stopping irrigation systems as only a portion of the many chores that they are expected to perform. Those chores may be spread out over many different locations. Alternatively, an irrigation operator may be dedicated to irrigation chores, but generally deals with more than one property. Often the actual irrigation schedule is dictated more by where the operator happens to be at any given time during the “tour of chores”, than by the crop’s irrigation requirements.

In principle the amount of time that an irrigation system runs is based on the amount of water the crop needs for a particular application. The time is then either formally calculated based on known or estimated water application rates or estimated based on experience. However, the more sophisticated automatic control systems can control directly the amount of water applied. This requires the use of a flow total sensor at the pump discharge (one of the control site sensors listed below).

Sensors at Control Sites

There may be sensors, other than the environmental sensors described above, at the pump and/or valve control points of an irrigation system. Actually, some sensors are required for automatic controls. For example, pressure transducers are used to detect overpressure conditions at a pump’s discharge or across filters. Other sensors that may be included are flow rate, flow total and well water level. Another sensor that may be used for control but isn't at the control site is a water level sensor used for continuously flooded crops like rice. The sensor provides a feedback control for starting and stopping a pump based on maintaining a desired water level in the field. The data from all these sensors may also be logged into the same database used for the environmental sensor data.

Remote Control

If the automatic control system has a local area network connection or, even better, an Internet connection, then some level of remote control may be available. A network connection can allow remote pump and/or valve on/off functions. It also allows the creation and editing of irrigation schedules. At minimum, control site sensor data may be viewable just as the environmental sensor data is viewable as described above (Sensor Data Collection).

Time-of-Use (TOU) Rate Control

A high percentage of California agricultural electricity consumption comes from customers that are on TOU rate plans. According to the California Energy Commission's report, "California's Water - Energy Relationship", by Klein et al, 81% of Pacific Gas & Electric's agricultural revenue and 71% of Southern California Edison's agricultural revenue comes from Kilowatt-hour sales on TOU rates[4]. Yet many farmers are forced to irrigate during peak rate periods due to crop requirements and labor's working hours.

Automatic controls have the potential of minimizing peak electricity use while insuring that crop needs are still met. The more sophisticated automatic controls track TOU rate periods and merge them with crop irrigation schedule requirements to produce an optimum schedule that irrigates at the lowest cost, which also helps California's electric grid with peak load reduction.

Automated Demand Response

Automated Demand Response (AutoDR) is a relatively new technology for reducing "…electricity demand in response to price, monetary incentives, or utility directives so as to maintain reliable electric service or avoid high electricity prices"[10]. AutoDR is designed to implement demand response with no human intervention.

A Demand Response Automation Server (DRAS) maintains DR event and price services data, which DRAS Clients can request and then use to carry out load reduction.[11]. A sophisticated automatic control system for precision irrigation could take on the role of a DRAS Client, which would result in even greater financial incentives to the rate payer (farmer) and further promote California's electric grid peak-load reduction.

Both Pacific Gas & Electric and Southern California Edison are promoting AutoDR programs[12]. However, so far there have been no programs focused on California agricultural irrigation. There may be significant potential for the application of AutoDR to California agricultural irrigation. This possibility warrants further study.

Using the Internet

Internet connectivity can be a significant advantage in precision irrigation. The Internet and related technologies can be leveraged in ways that are only indirectly referenced in the sections above. Environment sensors and automatic controls include:

- Real-time sensor data can be viewed from any location
- Logged data can be automatically moved to database storage on remote servers enabling subsequent browsing of historical trends
- Pumps can be started and stopped remotely
- Irrigation scheduling can be programmed remotely
- AutoDR is a possibility with an Internet connection

Figure 2 shows an example of control panels and real-time data trend charts from an Internet client application that is connected to an irrigation management system.

Figure 2, Control Panels and Data Trend Charts from the Saturn System of Iris Connection, Inc.

Alert Distribution

Possibly the greatest advantage to a system's Internet connection comes from the potential of distributing alerts through the Internet. Using email protocols (SMTP), messages can be delivered as standard email or text messages to cell phones. Alternately, SMS (Short Message Service) can be used to delivery text messages. SMS message delivery time is generally more deterministic than SMTP.

Connection Challenge

The challenge of Internet availability is in providing connection to a system located at a rural pump site. There are rarely telephone lines with DSL capability or cable service near-by. However, in many cases wireless Internet Service is available. Fortunately, much of California's agriculture is situated in the Great Valley (a combination of the Sacramento Valley and the San Joaquin Valley), which is large and flat and where good clear line of sight enables wireless Internet services to cover large areas. Other Internet connection options include cellular and satellite, both of which can be costly, especially if significant quantities of data are transferred.

Local Area Network

An alternative to bringing the Internet directly to the pump site is making a wireless network connection to a farm house or office where Internet is available. For example, this can be done with a wireless Ethernet bridge. In fact, multiple sites can be networked to a single Internet connection by using a gateway/router and multiple Ethernet bridges or, alternatively, a multipoint Ethernet bridge.

Generally, a wireless Ethernet bridge uses a low-powered unlicensed spectrum similar to that used by the wireless sensor nodes described above and, therefore, have similar line-of-site challenges. However, they may have more transmission power (within the FCC rules) simply because they may be located at pump sites or at office sites where line power is available instead of a small solar array and rechargeable battery. Figure 3 shows an example of an Ethernet bridge end-point at a pump site.

Figure 3, 5.8 Ghz Ethernet bridge end-point at pump site

Savings in Water, Energy and Money

Agriculture consumes approximately eighty percent of California's fourteen trillion gallons of yearly water use[4]. The state has eight million irrigated acres spread over fifty four thousand farms[7]. Thirty four million acre-feet of water is used and more than ten billion Kilowatt hours of electricity is consumed annually to irrigate those acres [4].

Precision irrigation can result in a large percentage reduction in both water and energy consumption, even though, since such large quantities of water and energy are consumed by irrigation, a small change in percentage would be significant. A study by the Pacific Institute[1], which considered three technology and management scenarios for improving the efficiency of water use in California agriculture, concluded that "Improved Irrigation Scheduling" (precision irrigation) yielded the greatest water savings. Refer to figure 4 below, which was taken from the Pacific Institute July 2009 report, "Sustaining California Agriculture in an Uncertain Future".

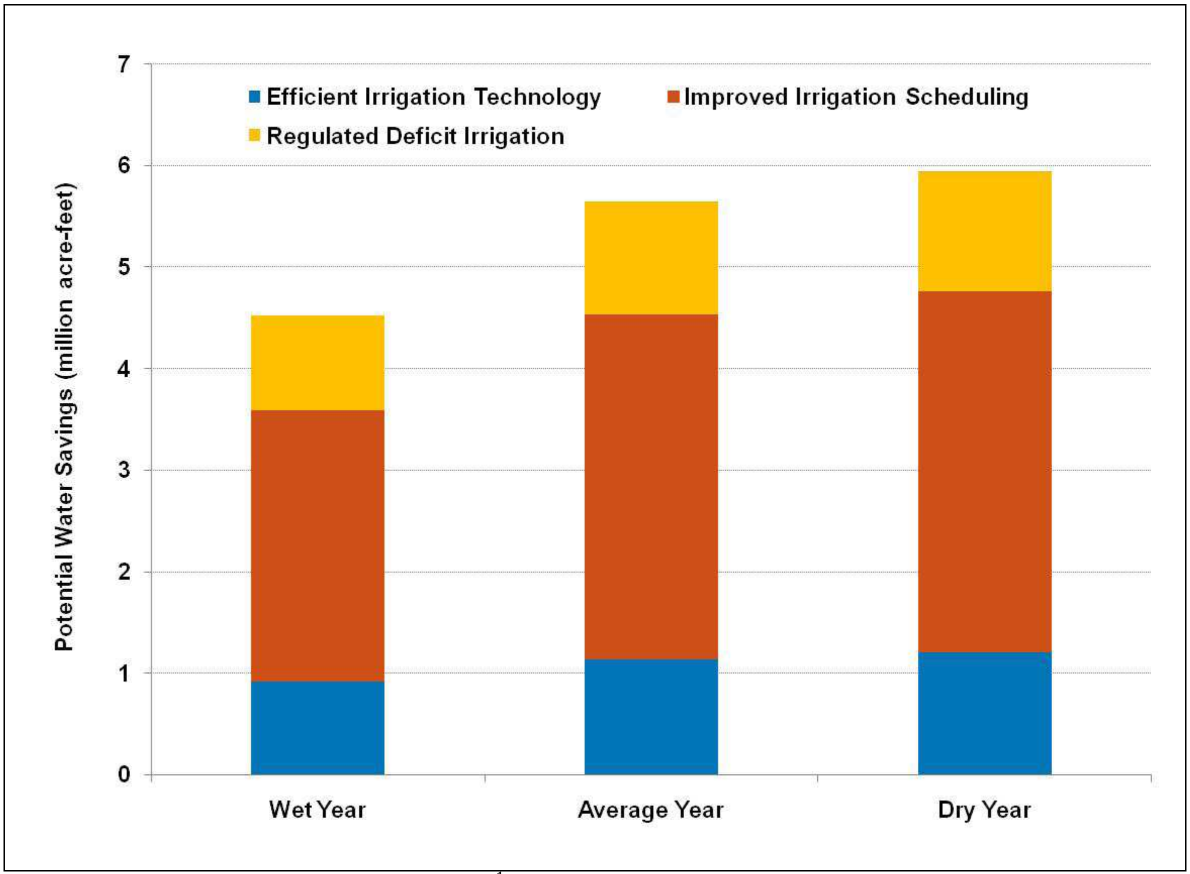

Figure 4, Pacific Institute July 2009 report[1], "Sustaining California Agriculture in an Uncertain Future"

The other two technology and management scenarios, are "Efficient Irrigation Technology", and "Regulated Deficit Irrigation" (RDI). The efficient irrigation technology scenario is based on shifting a fraction of the crops irrigated from flood irrigation to sprinkler or drip irrigation. Regulated Deficit Irrigation (RDI) means applying less water to crops during draught-tolerant growth states.

This last category, RDI, is also included in precision irrigation as it is also a strategic part of irrigation scheduling. In addition to saving water and energy, RDI can be used to improve crop quality and/or yield.

Water Savings

Precision irrigation may or may not lead to a reduction of water for all application cycles. In fact, there are times when environmental data could lead an operator to increase the amount of water applied at a given time. However, as precision irrigation provides the means to optimize the water required by a given crop, it can still lead to net water savings in those situations of greater water use if that water use is viewed as being normalized by crop production. Further, even if the data pushes more water on one cycle, it may reduce water on other cycles. On average, the studies cited below have determined that water is saved when precision irrigation methods are used.

There have been various studies on the impact of precision irrigation, or "irrigation scheduling" as it is called in some cases. Some studies have looked at just the impact of using weather data, while some have looked at the impact of local (in the crop) environmental sensors. Still others have looked at the impact of both. There are no known studies that consider the additional impact on water savings of automatic pump and valve controls. However, the Pacific Institute's report does indirectly endorse the positive impact of automatic controls. Their "vision of the future" (2050) includes "computer-controlled irrigation systems" [1].

Savings from Scheduling Based on Environmental Data

According to the Pacific Institute's "Sustaining California Agriculture in an Uncertain Future", a survey by the Department of Agriculture and Resource Economics at UC Berkeley determined that use of CIMIS reduces water use by an average of 13%[1]. The Pacific Institute's report also cites a Kansas study that found that irrigation scheduling reduced water use by 20%[1]. The same report references a consulting firm in Washington, using AgriMet to provide irrigation scheduling and soil moisture monitoring services to farmers, had found that some reduced their water and energy use by as much as 50%[1]. An October, 2008 Maariv Business report on Israeli agricultural irrigation determined that use of field sensors reduces water use by 20% or more[6].

Two more studies cited by the Pacific Institute report claimed water savings from "irrigation scheduling"[1]. The first, Kranz et al. (1992), found that irrigation scheduling reduced the applied water by 11%. The second comes from a consulting firm in eastern Oregon that incorporates AgriMet weather data into local crop models. They found that users of the service reduced their water and energy use by about 15% (Dokter 1996)[1].

Collectively the studies cite savings from 11% to as high as 50% with more than one claiming water savings of 20%. Furthermore, the studies consider only the availability of data without the additional impact of automatic pump and valve controls. Finally, the value on which the Pacific Institute settled for further analysis is 13% (refer to figure 4). They cited the fact that some percentages of the farmers are already using some form of precision irrigation so that additional savings can only be applied to those that are not using any type of precision irrigation. For example, based on data from Eching (2002) and updated United States Department of Agriculture data (USDA 2007a), about 20% of California growers are using CIMIS[1].

Savings from Regulated Deficit Irrigation (RDI)

RDI has been cultivated as a technique for improving the quality and/or yield of certain crops. It does not work well on all crop types. RDI has been found to be more effective with vineyard and orchard crops than with field crops[1]. According to Fereres and

Soriano (2006), "…the yield-determining processes in many trees and vines are not as sensitive to water stress during particular growth stages as many field crops"[1].

On crops for which RDI is appropriate, this can be an effective means for saving water. By applying RDI to just almonds, pistachios, and wine grapes, an estimated 1.0 to 1.5 million acre-feet of water can be saved in California annually, according to Goldhamer and Fereres (2005)[1]. That represents approximately 3% to 4% of the total water used for agricultural irrigation in the state. Further, there is reason to believe that RDI will benefit other tree and vine crops as well as possibly certain vegetable crops, such as tomatoes[1]. If RDI is applied on all California crops for which it's beneficial, then 5% of the total California agricultural irrigation water can easily be saved.

Savings from Scheduling with Automatic Controls

As noted above, there have been no studies on the impact that automatic controls would have on saving water. However, it is not unreasonable to assert that an additional 5% to 10% saving can be achieved from automatic scheduling controls.

When pumps and valves are set manually, irrigation schedules are subject to labor schedules as much as the crop's irrigation requirements. The question is whether or not manual operation is likely to lead to over-watering or under-watering. Considering that some crops can be damaged by over-watering and that some irrigation methods could lead to excess pooling of water, an irrigation operator in those circumstances is at least as likely to error on the side of under-watering as he is on the side of over-watering.

However, if we were to only consider irrigation methods and crops that are not affected by over-watering, it is reasonable to assume that watering errors are more likely to be on the side of over-watering. A good crop example is rice, where there is essentially no such thing as over watering, as the crop sits in several inches of water throughout most of the crop cycle. Water levels are maintained by allowing water to overflow adjustable-height barriers at the rice field's outlet point. A simple level-sensor feedback to an automatic control, like that mentioned in the "Sensors at Control Site" section above, could keep a rice field at an ideal level without any run-off.

In flood irrigated fields that slope (border strips, furrows, etc.), water flows from the top of the field to the bottom of the field where the water then runs off. The runoff will last at least as long as it takes to saturate the root zone at the bottom of the field. Then when the water source is shut off at the top of the field, the remaining water on the field will run off so no pooling of water is allowed. In flood irrigated fields that don't slope, water must still run long enough to reach all points in the field and remain on long enough to saturate the last point reached. These fields generally host crops that are tolerant to over watering as there may be pooling in various points of the field.

Generally all flood irrigation systems allow some water to run off to either regulate water level, as in the case of rice, or just as a way to prevent pooling of excess water that could damage the crop. Even when the system is not specifically designed for runoff, as in the case of flood irrigated fields that don't slope, manually operated irrigation application is more likely to result in over-watering than under-watering. For scheduled flood irrigation, an automatic control with the ability to measure the water dose or time the water application would minimize the amount of water that runs off the field.

Fifty four percent of California's irrigated acreage is irrigated by the flood method. Furthermore, flood irrigation uses more water per acre for a given crop than alternative irrigation methods, so the percentage of irrigation water used is higher than 54%. If we were to consider the nearly constant run-off of rice fields with the run-off of other flood irrigated crops, a 10% savings of water over all the flood irrigated acreage is a conservative estimate. If we only apply the saving to half of the irrigation water used for all of California agriculture, we can conservatively claim a 5% savings above and beyond the methods described above. Additionally, there is an environmental gain from the reduction of runoff that may, in some cases, be a source of water pollution.

The 5 to 10% savings, claimed above from the use of automated controls, is based upon a number of conservative assumptions. A more complete study is warranted, and is likely to demonstrate even larger savings.

The Case for Twenty Percent

Based upon the various studies of the impact of irrigation scheduling, a case for 20% water savings can be made just from implementing irrigation based on environmental sensor data. However, if the more conservative number of 13% used by the Pacific Institute is simply added to potential savings from RDI and use of automatic controls, it is reasonable, and perhaps even conservative, to estimate that an average water savings over all regions and crop types in California could be 20% by implementing the precision irrigation methods outlined above in "Precision Irrigation Technology". Twenty percent water savings equates to approximately seven million acre feet annually, which also has associated energy savings as developed below.

Energy Savings

Saving Energy by Saving Water

With very few exceptions, transportation and application of irrigation water requires energy consumption. Some of the energy is consumed to transport water to a farm and some of the energy is consumed on the farm to lift, transport, and apply water to the crops. Saving water has the potential of saving energy and, therefore, costs for both off-farm and on-farm energy.

The electrical energy content of water used for California agricultural irrigation is approximately 10.5 billion Kilowatt hours per year[4]. An additional 1.3 billion Kilowatt hours-equivalent energy is consumed by diesel and natural gas water pumping for irrigation[4]. Of course the energy content for a specific application varies with the crop type, the geographic location, and the irrigation method used (flood, sprinkler, drip, etc.).

In another way of considering the energy content of irrigation, the California Energy Commission's (CEC) "California's Water - Energy Relationship" report by Gary Klein, et al, points out that generally, due to energy costs, lower energy content water will be used before any higher energy content water[4]. In other words, if a farmer has more than one source of water where one has higher energy content than the other, he will use the lower energy content water before he resorts to using the higher energy content water, which has a higher cost. Conversely, when the farmer is able to reduce water application, he will focus first on the higher energy content water.

It should be noted that energy costs may not be the only costs. Some irrigation water comes from irrigation districts that charge for water allocations. This could be a mitigating factor to energy costs. For example, taking water from an irrigation canal may have lower energy costs than pumping ground water from a well, but may still cost more than the ground water due to the allocation charge.

Still the CEC concludes, on average, that energy savings resulting from water savings are greater on a percentage basis than the actual water savings. Therefore, a case can be made for the potential to save a significant percentage of the 10.5 billion Kilowatt hours of electricity consumed by agricultural irrigation in California. While the case for 20% water savings made above is reasonable, the lower percentage of 13% water savings used by the Pacific Institute could still result in a 20% energy savings. Twenty percent applied to the 10.5 billion Kilowatt hours could remove more than two billion Kilowatt hours of electricity from the grid. An additional 260 million Kilowatt hours can be removed from the Kilowatt hour-equivalent energy consumed by diesel and natural gas powered irrigation pumps.

Reducing Peak Load with Automatic Controls

It is not known how much peak-load reduction can be achieved by simply using automatic controls; however, given that it is hard enough when manually controlling an irrigation system to maintain accurate irrigation schedules according to crop needs, it is even harder to maintain TOU discipline at the same time. Even when using automatic controls, crop irrigation requirements may trump TOU schedules. However, automatic controls will have a better chance of consistently maximizing the use of TOU schedules and rates. It is reasonable to claim that an additional 10% of total energy used can be shifted from peak to off-peak periods simply by migrating manually controlled irrigation systems to automatically controlled irrigation systems that employ controls sophisticated enough to optimize TOU schedules while adhering to crop irrigation requirements. This hypothetical 10% would result in one billion Kilowatt hours in peak-load reduction. Actual peak-load reduction may be even more, which suggests that the impact of this type of automatic control on peak-load reduction is worthy of further study.

Peak-load reduction may be further reduced with the use of AutoDR. Maximizing the benefit of AutoDR demands even more from the automatic controls, which will run a DRAS client application (refer to AutoDR in the “Irrigation Technology” section above). Instead of just adhering to preset schedules, the DRAS client will be able to make decisions on when and how to operate at any given time based on price services and utility load-reduction directives from the DRAS. As stated above, even though there is significant potential for AutoDR in California agricultural irrigation, there are currently no AutoDR programs that address this area. This is another area that warrants further study.

Cost Savings

Savings of water, energy, and money are closely coupled: When water is saved, the energy to transport and apply the water is saved, and the money that would be spent on that water and energy is saved. Globally, the state benefits from all three savings. However, the end user, the farmer, benefits primarily from the relationship of money savings to the water and energy savings. While some farmers may be concerned with the environment, all are concerned with running their business, which means that among other things, they will want to minimize costs whenever possible.

Direct Water Costs

Some farmers pay directly for water allocations from irrigation districts, which may account for some or all of the irrigation water they use. They may also get a portion or all of their water from sources for which they don't have direct payments. That is they only have to pay for the energy and infrastructure (pumps, pipes, etc.) to lift, transport, and apply the water to their crops. The costs of allocations vary quite a bit from region to region within the state. The allocation costs range from less than $100 to over $600 per acre-foot. Therefore, the direct cost of water varies from $0 to over $600 per acre-foot. Any water savings on high direct-cost water resulting from precision irrigation techniques can, therefore, result in substantial money savings to the farmer.

Energy Costs

As pointed out above in "Saving Energy by Saving Water", there is energy consumption associated with transporting and applying irrigation water and, of course, there is cost associated with that energy. Some of those costs are incurred by irrigation water districts to transport water to farms. Other costs are incurred by the farmer for on-farm energy used to lift, transport, and apply water to the crops.

On-farm energy is likely to be higher for water that has no direct costs because that water usually is pumped from ground water sources. As water is very heavy, lifting water from aquifers requires a lot of energy, especially in parts of the state where the aquifers may be more than a thousand feet below ground level. Another source of on-farm energy use comes from pressurizing irrigation systems that use sprinklers, micro-sprinklers, and drip irrigation. These systems use more energy per unit of water delivered. However, they may save enough water over flood irrigation techniques that the total energy used may actually be lower.

The precise correlation between energy and cost savings are difficult to determine. While nearly 90% of irrigation energy comes from the grid, it's difficult to establish an average rate charged by utilities for that energy. The costs that the agricultural rate payers incur can vary quite a bit with rate plan[8]. Most plans have substantial differences in rates based on time of year and time of day. Although the plans typically offer lower rates in the winter, most irrigation is performed from May through September.

One specific reference for irrigation electricity rates comes from the Agricultural Pumping Efficiency Program (APEP) conducted by the Center for Irrigation Technology (CIT) that uses an average rate of 16 cents per Kilowatt hour for their estimated returns on improving pump efficiency[9]. Using that reference and the PG&E Agricultural Rate Schedules, 15 cents per Kilowatt hour average is a reasonable assumption.

Using the 15 cent average and the estimated potential of two billion Kilowatt hours that could be removed from the grid per year (based on 20% water savings), the combined energy savings of all the irrigation rate payers in a given year would be 300 million dollars. Regardless of how irrigation water is lifted, transported, and applied, saving water will save energy, which will in turn save on energy costs. Furthermore, the cost savings on high energy-content water such as water lifted from ground water and/or water delivered through pressurized irrigation systems can be particularly significant for the farm rate payer.

Also, the farm rate payer has the potential for even more financial incentives with TOU and AutoDR programs. The differences between peak and off-peak rates for agricultural TOU plans vary from as low as 9 cents per Kilowatt hour to as high as 30 cents per Kilowatt hour. Using the estimate of a 10% peak-load reduction from "Reducing Peak Load with Automatic Controls" above, and a conservative rate difference of 10 cents per Kilowatt hour between peak and off-peak rates, then an additional 100 million dollars of savings can be achieved simply by adopting TOU rate plans and employing sophisticated automatic controls to maximize the benefits.

As there are no AutoDR programs yet available to agriculture, it is unknown what additional financial incentives may be gained by rate payers for adopting AutoDR. However, the California Public Utilities Commission (CPUC), the California Energy Commission (CEC), and at least two major California utilities, PG&E and Southern California Edison, are promoting the adoption of AutoDR; therefore, it is anticipated that there will be future incentives for agricultural rate payers.

Crop Yield Improvements

There is a third way for a farmer to save or, more precisely, gain money as a result of precision irrigation practices. As stated above, precision irrigation provides a means for evaluating a crop's water requirements and a means for applying the right amount at the right time. Optimizing water application to a crop's requirements has the potential of increasing its yield. Consistent with the statement on water savings above, increasing yield as a result of precision irrigation actually saves water when viewed as being connected directly to crop production even in a case where total water per acre increases.

The Pacific Institute's "Sustaining California Agriculture in an Uncertain Future" report cited an average of 8% increase in yield from the Department of Agriculture and Resource Economics at UC Berkeley survey on use of CIMIS[1]. The Pacific Institute's report also cites that the Kranz et al study found that the use of "irrigation scheduling" resulted in a yield increase of 3.5%. Of course the financial impact of yield improvement depends not only on the percentage of yield increase but also on the value of the crop. Those values range from hundreds of dollars per acre to as high as $4000 per acre.

Most farmers are skeptical about claims of increased yields, primarily because of the difficulty in measuring the impact of any one variable. Farming, by its nature, is subject to a large number of variables at all times, many of which are out of the control of the farmer. However, farmers will generally agree that any improvement in the irrigation process based on better information about a crop's requirements will, in fact, have a positive impact on yield even if it can't be precisely measured. Further, as pointed out in "Savings from Regulated Deficit Irrigation" above, one of the most common irrigation methods used for improving yield involves a decrease in water application.

Labor Savings

The precision irrigation technology described above offers labor savings in several areas. First, if environmental sensors are not used, then soil moisture must be determined some other way. The most common is the labor intensive method of using a shovel to dig down into the soil to determine the moisture at various levels below the surface. This must generally be done in multiple locations in the field. If sensors are used but not connected to wireless nodes that move data through a network, and preferably the Internet, to a workstation, then the sensors must be manually read. This requires that someone walk from sensor to sensor and manually record data. If the sensors are spread over several properties then there is even more travel involved.

Automatic controls eliminate the requirement of an irrigation operator traveling to the pump site to manually start and stop the pump. If there are multiple irrigation zones and automatic valve control is employed, then there is even more labor savings. Setting and resetting valves can be very labor intensive.

Conclusion

The application of precision irrigation to California agriculture has the potential of saving significant amounts of water, energy and money. While savings to the entire state and its infrastructure are substantial, individual farmers have the potential of saving substantial money on water, energy, and labor as well as possibly increasing the yield of their crops. Farm electric rate payers can acquire even more financial gain from TOU and AutoDR incentives.

Studies have been cited on potential water savings from CIMIS and AgriMet, using local crop and environmental sensor data, and the benefits of Regulated Deficit Irrigation and its potential for crop yield and quality improvements. In fact, in cases where there is yield improvement, net water savings as measured against yield increases may result, even in cases where total water applied increases. Finally a case is made for the additional benefits of having automatic pump and valve controls, including the optimization of TOU rate use and AutoDR.

California agriculture uses 34 million acre feet of water annually, which is approximately eighty percent of California's consumption of fourteen trillion gallons of water per year. A case has been made that 6.8 million acre-feet can be saved by applying precision irrigation technology to the entire state's irrigated acreage. Additionally, 2 billion Kilowatt hours of electricity can be removed from the grid and another 260 million Kilowatt hour-equivalent can be saved on energy consumed by diesel and natural gas powered irrigation pumps.

Additionally, peak-load can be reduced by 1 billion Kilowatt hours with the use of TOU rate plans and sophisticated automatic controls that maximize TOU rate benefits.

Additional benefits can be realized with agricultural AutoDR programs and automatic controls that can exploit it.

The energy savings alone can power 200,000 average American households and reduce CO_2 emissions by 1.2 million metric tons annually. The energy savings combined with the peak-load reduction can reduce power plant capacity by as many as 75 average-size (10 Megawatt) power plants.

The need for further studies has been identified: The potential benefit of employing AutoDR on California agricultural pumps; water and energy savings that can be realized from sophisticated automatic pump and valve control; and finally, the potential for automatic irrigation controls to optimize TOU rates and increase peak-load reduction.

References

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