Manage Irrigation for Energy Conservation & Load Shifting

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Abstract. This paper deals with development of a decision support system (DSS) for conjunctive management of energy and water use efficiency in irrigated agriculture. The primary goal of this work is to motivate and facilitate energy demand management (energy load shifting) to improve grid stability, reduce costs and facilitate use of more sustainable sources of energy. Energy and water conservation *per se* are secondary goals. The project is funded by the California Energy Commission under the EPIC program.

Keywords. Irrigation Management, Load Shifting, Deficit Irrigation, Proportional Deficit, Demand Response Programs

Introduction

Irrigated agriculture in parts of California is an energy intensive industry. One farm we are working with provides a rather startling example. Irrigating 360 acres of cotton with ground water from deep wells, the farm must lift approximately 500,000 tons of water more than 1,000 feet annually. That energy intensity attracts the attention of utilities for potential energy load shifting to mitigate problems associated with the highly variable demands on the electrical grid.

Utilities have devised incentive programs for energy load shifting in irrigated agriculture. The project reported here, funded by the California Energy Commission, is designed to motivate and facilitate farms' participation in those programs. Initially this project focused on two general strategies, *Time of Use* (TOU), for which utilities charge higher rates for electrical energy used at times when energy demands on the grid are high, and *Demand Response* (DR), which offers incentive payments for temporarily curtailing pumping if and when requested by the providing utility at times of peak demand. As this project has evolved we have found increasing interest in a third strategy, participation in a *Transactive Energy* market through which the farm decides when to buy pumping energy based on a rate schedule that varies with grid demand.

To take advantage of these incentive programs it is necessary to align irrigation schedules as closely as possible with anticipated intervals of lesser energy demands on the grid. That makes irrigation scheduling a more challenging, two dimensional problem, managing both water and energy use conjunctively. Rather than simply tracking soil moisture and irrigating at management allowed depletion, the irrigator must schedule irrigations ahead of time, sometimes well into the future, in anticipation of times when irrigation is likely to be curtailed. A more comprehensive understanding of crop water availability in spatially variable fields will be needed to ascertain whether to accept or decline a curtailment request. And the irrigation schedule will need to be updated quickly when curtailments occur.

The project is built upon an existing Decision Support System (DSS) developed originally with USDA, BPA and Oregon State funds that is used to design optimal, farm-specific water use strategies, translate those general strategies into detailed seasonal irrigation schedules and track and update those schedules to adhere to the chosen strategy as circumstances change during the season. That DSS is being augmented with new software elements to more easily align irrigation schedules with grid energy availability and cost.

Eighteen months into the project the DSS is near completion. Preliminary use of the software has revealed useful insights into the merits of the different energy load shifting strategies mentioned above.

The original decision support system (IMO)

A panel of nationally recognized experts in agricultural irrigation, commissioned by a consortium of utilities to prepare a 'Road Map' to advance efficiency in irrigated agriculture, stated that "Irrigation efficiency is ultimately determined by management, and good management depends on soft technologies (software, modeling)" (English and Evans, 2013). This project, promises to be a major contribution to development of such soft technologies.

IMO was specifically designed to provide the following capabilities:

- *Crafting optimal irrigation strategies in advance of the season*: IMO is used to first guide advance development of research-based water use strategies to target optimal soil moisture levels for the different stages of crop development, specifically including regulated deficit irrigation (RDI) strategies. It then generates detailed irrigation schedules to implement those strategies based on historic local weather and subject to the specific circumstances and operational constraints of individual farms. For purposes of the present project the schedule to be developed can be adjusted to minimize energy costs and/or capitalize on incentive payments for energy load shifting.
- *Tracking and projecting crop water availability as a season progresses*. IMO tracks variable soil moisture patterns in heterogeneous fields and projects field-wide crop water availability weeks into the future enabling farm managers to determine whether and when crop water availability is sufficient to tolerate pumping curtailment while still ensuring that the irrigation schedule will achieve targeted soil moisture levels.
- *Automatically generating revised irrigation schedules.* IMO enables rapid updating of the seasonal irrigation strategy to accommodate changing circumstances; in this application that capability facilitates revising the scheduling strategy to accommodate DR curtailments that have occurred or in anticipation of events that may occur in the near future while still maintaining the intended water use strategy.

Proportional Deficit

Implementing deficit irrigation in the context of energy management programs requires an irrigation strategy that applies a minimum yet still economically viable amount of water. Additionally, the strategy must be flexible enough to accommodate the uncertainty inherent in load shifting programs. The IMO system implements a deficit irrigation strategy proposed by University of California Cooperative Extension researchers. The strategy is based on the concept of Proportional Deficit wherein the amount of water applied is a fraction (or percentage) of the crop evapotranspiration (ETc) that occurred since the last irrigation. Typical irrigation practice in micro-irrigated almond orchards in California is to irrigate every day (or ever few days). The Proportional Deficit strategy is easy to implement because the grower only needs to track ETc for a day or two and application depths are simply a percentage of the ETc.

Use of the IMO system provides two default strategies for Almonds. The first strategy, proposed by David Doll of UCCE, has five distinct stages. This strategy uses a gradual drawdown to 50% of plant available water so that mild stress begins at onset of hull split (approximately the first week of July). This moisture level is maintained with 100% ETc replacement until 75% of hull split, followed by greater than 100% ETc replacement in anticipation of harvest. A brief dry down period occurs prior to harvest and is followed by 100% ETc replacement for the remainder of the season. The advantage of this strategy is that it provides precise control of stress during hull split however, the manager must have some means to measure stress (e.g. stem water potential) during the critical periods. The target level of stress might be based on stem water potential or some other measure of crop water status or crop stress. Because of the uncertainties involved in carefully managing mild stress there would be some advantage to applying lighter, more frequent irrigations. That would make it easier for the farm to respond quickly if/when stress reaches some allowable limit. It could also increase flexibility to respond to DR/ADR energy load shifting incentives.

The second strategy is more prescriptive and is derived from FAO66 and David Goldhammer's recommendations for RDI of almonds (Goldhammer, 2012). The strategy is expressed as a series of dates and percentages. Two sets of values, targeting either 30 or 35 inches of application, is shown in the following table.

Table 1 Second Proportional Deficit strategy

30 inches			35 inches	
70%	until May 1		**75%**	until July 1
50%	until July 1		"	"
25%	until July 15		**50%**	until July 15
100%	until Aug 15		**100%**	until Aug 15
60%	until October		**75%**	until October

The figure below illustrates a target pattern of optimal soil moisture prescribed by the UCANR advisor, the first of the above general strategies. The general pattern can be adjusted to higher or lower total water use, maintaining the same seasonal pattern but with different levels of total seasonal water use.

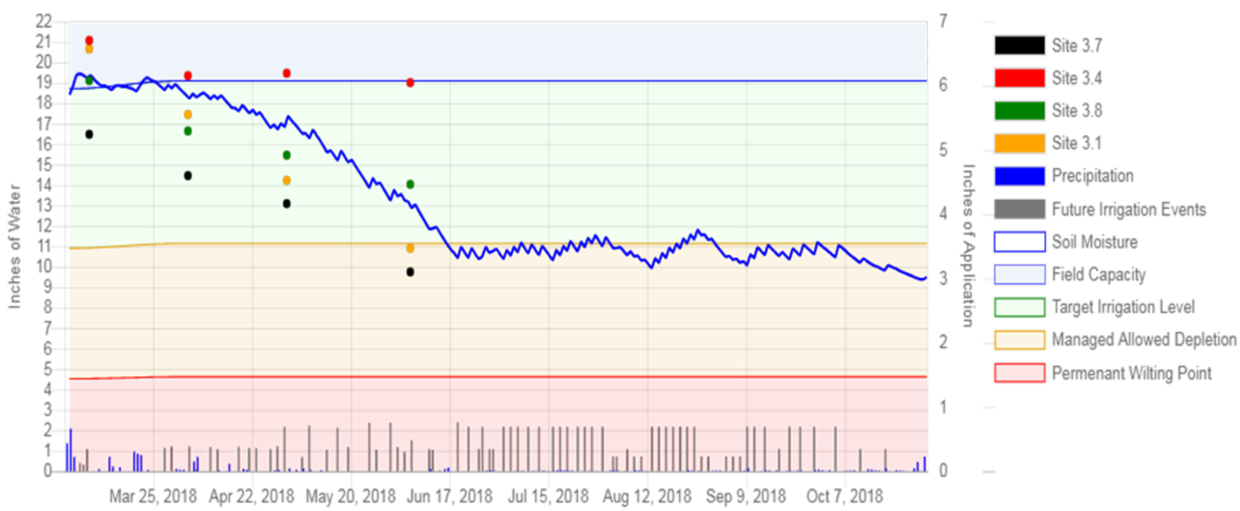

Figure 1 Proportional Deficit strategy

Planning for Proportional Deficit irrigation is more complicated than implementing it. IMO supports the strategy by providing a special interface that allows the user to interactively change the percentage of ETc replacement at various stages during the season. Figure 2 shows a screen shot of the prototype interface. The upper chart is a graph of soil moisture produced by the IMO simulation system. The lower chart is the sequence of % ETc replacement values. The user can click & drag on the point to adjust the values. After each adjustment, the simulation results are updated. The planning process involves interactively adjusting the ETc values until reaching an acceptable soil moisture pattern. During the season (e.g. after a DR event), the user can repeat the planning process using actual weather and irrigation data collected during the season.

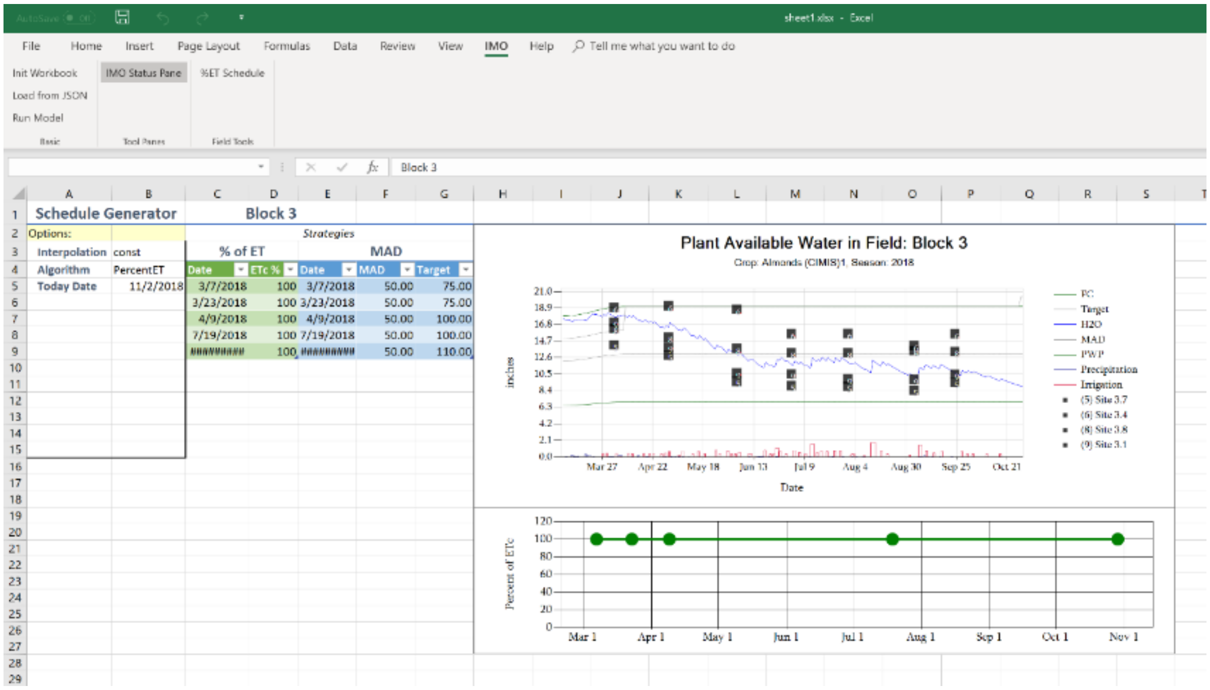

Figure 2 Screenshot of the prototype planning tool

Demand schedules: the water demand pattern

The following sections outline characteristic patterns of irrigation water use and energy costs which the decision support system is designed to accommodate.

Seasonal water use patterns are illustrated below for almonds in the southern San Joaquin Valley of California. A generic seasonal pattern for full irrigation of almonds is shown in Figure 3. However this pattern is not immutable. Some degree of reduced water use, an RDI strategy, may also increase net income by reducing operational costs and increasing water use efficiency. Figure 4shows an alternative pattern recommended when a farm water supply is limited to 60% of the nominal water requirement (from Goldhammer, 2012).

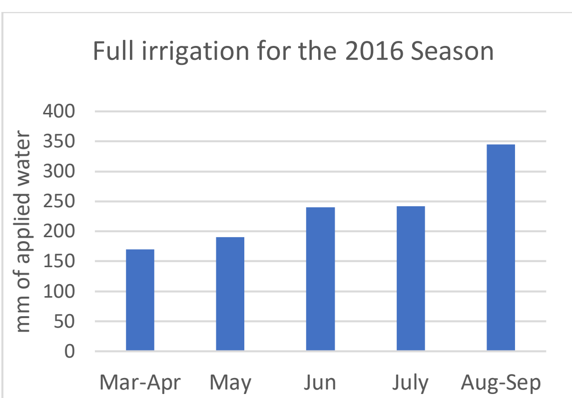

Figure 3 pattern for full irrigation of almonds

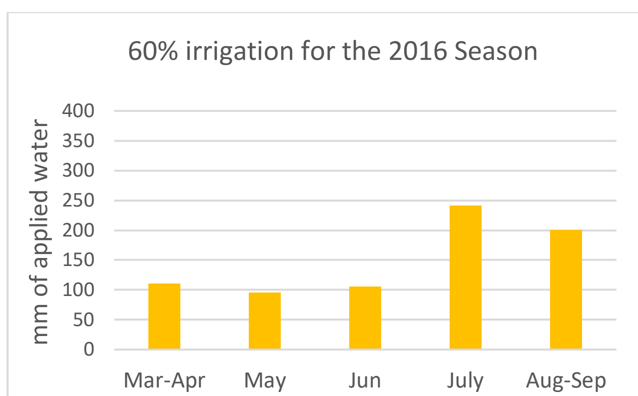

Figure 4 pattern for 60% irrigation of almonds

The energy demand pattern

Three temporal patterns of grid energy demand are of interest here; the seasonal pattern of energy demand, the diurnal pattern of a typical day during the irrigation season, and the emerging pattern of renewable energy generation.

The complex dynamics of grid energy demand and supply cannot be adequately presented within this paper. We will use daily and seasonal patterns of the dollar value assigned to energy conservation to illustrate the patterns of grid energy demand that are relevant to agricultural users.

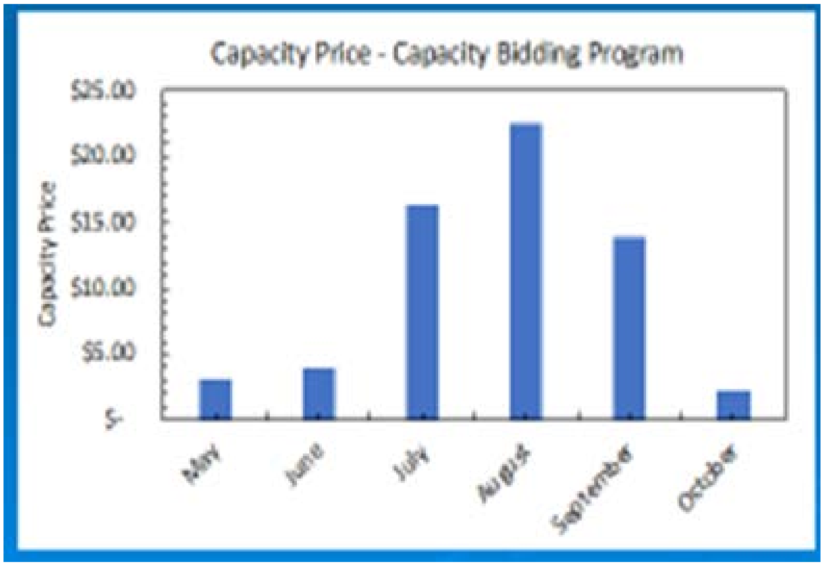

Figure 5 Monthly capacity price incentive factor

Seasonal patterns of grid energy costs:

These can be illustrated by a proxy variable, the monthly capacity payments offered for curtailments of pumping energy use by PG&E. The DR incentive program offered by PG&E computes a 'capacity' payment based on the product of the kilowatts of power to be curtailed (the capacity) multiplied by a 'capacity factor' that varies monthly depending on the relative demands on the grid for each month. The capacity factors range from $3.00 per kWh in May to $22.00 in August. As indicated, decisions to irrigate in July through September may need to account for these prices.

Diurnal patterns of grid energy costs:

One type of diurnal rate schedule is a two-tiered schedule. PG&E offers $0.19 /kWh for off peak hours and $0.45/kWh for peak periods for peak demand times (noon to 6:00 PM). Another typre of rate schedule proffered by Southern California Edison (SCE) varies with time of day and, equally significantly, with daily high temperatures (Figure 5). The various lines indicate rates for day when temperatures range between 81 and 84 degrees, 85 to 90 degrees and so on. The TOU rate offered by PG&E is shown as well for comparison. So, for example, at 3:00 PM (15:00) on a day when temperatures exceed 95 degrees the energy use rate will be $2.50 /kWh under the real time pricing schedule, whereas with the PG&E summer rates the price would be $0.45 /kWh.

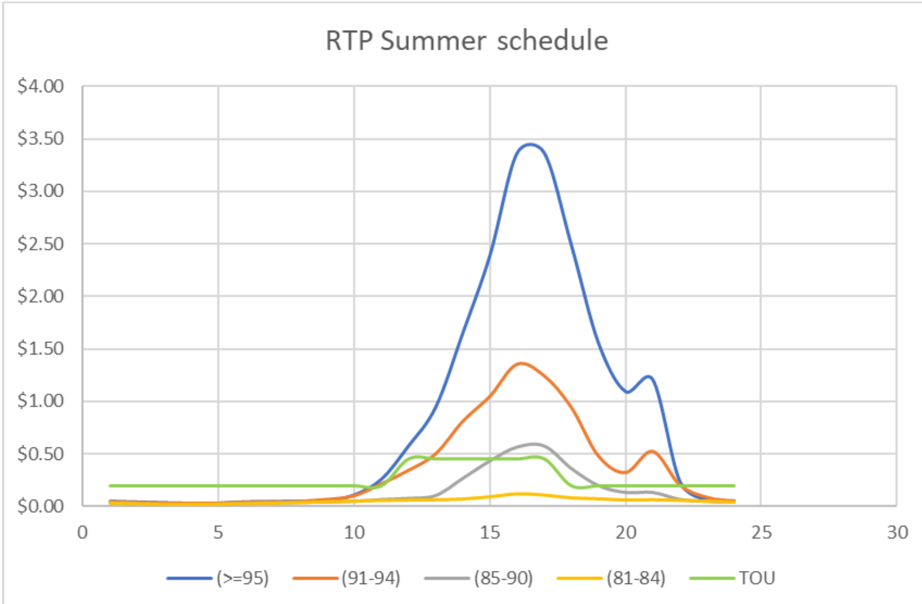

Figure 6 hourly rates for Real Time Pricing for Southern California Edison in 2018

Illustrations

We will illustrate conjunctive management of energy and water use with a case study from work with a cooperating farm in the southern San Joaquin Valley. The farm in question had limited access to water, so the seasonal water use could only provide 60% of full irrigation for almonds. The IMO system was therefore used to develop the deficit irrigation strategy proposed by University of California Cooperative Extension which was shown earlier. The farm stipulated that they prefer to irrigate weekly and prefer 24 hours set times in a three-set rotation.

IMO was used with to derive a detailed irrigation schedule to produce the target soil moisture pattern following the farm operational preferences as closely as possible. That schedule can then serve as a baseline for comparing alternative irrigation strategies, particularly including DR/ADR based strategies for a pumping head (TDH) of 200 feet and a field size of 160 acres. The bar chart below illustrates the

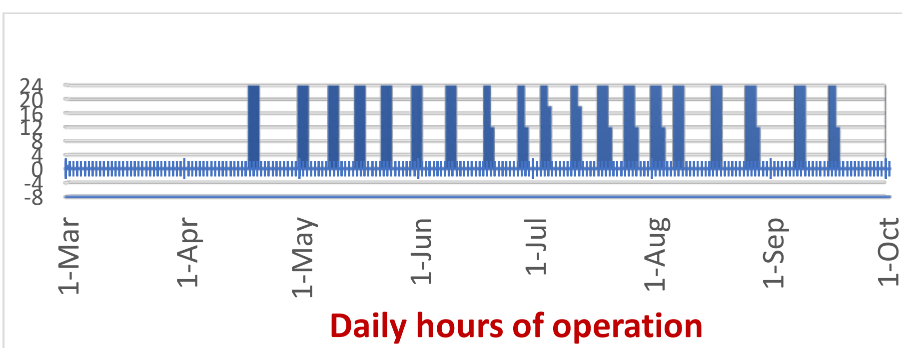

Figure 6 Baseline irrigation schedule for sample analysis

schedule as a bar chart showing the prescribed dates and number of hours for each irrigation during the season. As indicated, the pumping energy cost in this baseline case would be $36,910.

The system was then run again but with the irrigation schedule modified to follow a TOU schedule based on the two tier PG&E rate schedule ($ 0.45 per kWh for peak rate pumping and $ 0.19 /kWh for off-peak pumping). The pumping costs would be reduced by $9,900, a 27% saving.

The resulting irrigation schedule, illustrated in Figure 7, would involve more prolonged irrigation events, but the applied water would still be sufficient to maintain the intended pattern of crop water availability. However, a fundamental issue with TOU scheduling is that the delivery system capacity is generally reduced by the number of hours curtailed each day. In this case

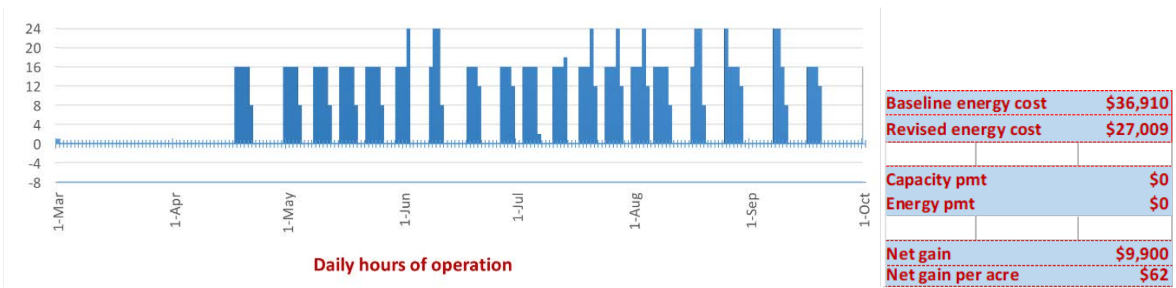

Figure 7 TOU irrigation schedule for sample analysis

The analysis was then repeated a third time for a DR strategy, superimposing the DR schedule actually called in that region in 2017 as a test case, assuming the farm accommodated every DR request and using the capacity incentive payments illustrated in Figure 4. An additional component of the incentive payment called the *Energy payment* added to the total incentive. The DR events are shown as negative hours (inverted red bars) in Figure 8. The effect on pumping costs would be unchanged since the pumping would be delayed but not eliminated. However the incentive payments would provide an offsetting payment of $2817.

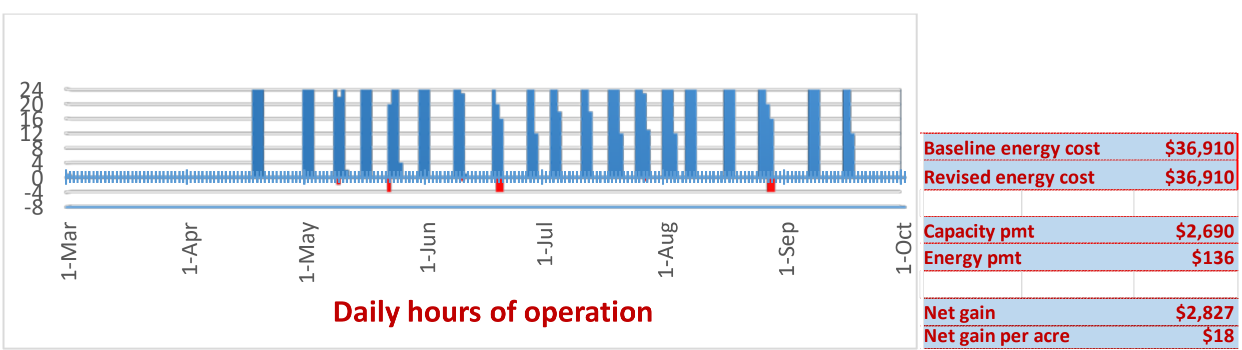

Figure 8 DR irrigation schedule for sample analysis

Transactive energy

Finally, we will compare TOU and DR incentives with a transactive energy strategy involving a different farm, another almond orchard in Merced County. The comparison is for a single irrigation event, a three day rotation of 28 hour sets. The TOU and DR strategies were based on the hours of curtailment and incentive payment rates outlined in the previous example. However, in this case, pumping costs were based on 360 kW pumping capacity for a 312 acre orchard. The cost of a single irrigation cycle using those rates and hours were:

Baseline, no load shifting	$6420
TOU based on PG&E rates	$4790

The analysis was then repeated using the RTP price schedule from SCE shown earlier (Figure 5). The farm was assumed to curtail pumping during the schedule to shut down during the six or eight highest cost hours from the RTP schedule. The cost of a single irrigation cycle for three different temperature days using SCE summer RTP rates (optimized for time of day) were:

Moderate temperature day (<80)	$1189
High temperature day (85 90)	$1847
Very high temp day (>95)	$3063

Though the transactive rate schedule offers the lowest cost strategy in all three cases, it should be noted that if, for any reason, the farm should elect to irrigate during peak price periods that advantage would be lost, and in fact the cost for a very high temperature day would be:

$9,948

Conclusion

This project described in this paper is still ongoing. Eighteen months into the project the DSS is near completion. Preliminary use of the software has revealed useful insights into the merits of the different energy load shifting strategies mentioned above. Complete results from the 2018 growing season will be presented at the 2018 Irrigation Association Education Conference.

Transactive energy strategies offer the greatest savings, but if for any reason a farm is forced to depart from the TE strategy the penalty may outweigh the potential incentives.

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