AN ON-LINE ADVISORY PROGRAM FOR OPTIMUM IRRIGATION MANAGEMENT

Charles Hillyer[1]
Marshall English[1]
John Busch[2]
Carole Abourached[1]
Chadi Sayde[1]

ABSTRACT

Conventional irrigation practices are predicated on maximizing crop yield – a biological objective. As worldwide competition for water intensifies a fundamentally new paradigm for irrigation management is emerging predicated on maximizing net returns to water – an economic objective. Maximizing returns to water generally involves some degree of deficit irrigation, particularly when water supplies or system constraints limit the availability of water, but few farmers are well equipped to deal with the analytical challenges associated with managing water deficits. This paper presents a web based advisory service for irrigation management now in use in a pilot program in Oregon. While the system can be used for conventional irrigation scheduling it is designed explicitly to assist irrigation managers with planning and implementing optimum irrigation strategies when water supplies are limited or expensive. Though originally developed for use in Oregon, discussions with other states have been initiated to make the system available nationally. This paper provides an overview of the analytical framework and demonstrates primary features of the user interface.

INTRODUCTION

A web-based irrigation advisory program, funded by NRCS and managed by Oregon State University, has been developed to assist irrigators with maximizing net economic returns to water. Economic optimization will frequently involve some degree of deficit irrigation, and that presents challenging management problems, including: (i) irrigation efficiency cannot be determined *a priori*. Since efficiency is linked to irrigation intensity it must be derived from the management strategy chosen; (ii) where water supplies or system delivery capacities are limited irrigation of all fields must be scheduled conjunctively to allocate water most effectively; (iii) conjunctive irrigation scheduling of multiple fields requires that farm water delivery constraints be taken into account; and (iv) since deficit

[1] Biological and Ecological Engineering Dept., Oregon State Univ., Corvallis OR 97331; hillyer@engr.orst.edu, englishm@engr.orst.edu, abouracc@onid.orst.edu, saydec@onid.orst.edu
[2] USDA-Natural Resource Conservation Service, Baker City, OR; John.Busch@or.usda.gov

irrigation implies yield loss it is necessary to estimate the yield impacts of management strategies.

Few commercial farms are equipped to deal with these questions. The program discussed in this paper will assist farmers in meeting these management challenges, and as such it represents a significant departure from earlier scheduling programs. The general plan for the system was developed in 2004 and refined during user-group meetings in seven locations around Oregon. The design philosophy was to account for specific farm circumstances and bring the irrigation manager's experience and preferences into the analysis. Since different managers have different objectives and tolerance for risk and face different local circumstances their preferred irrigation strategies will differ. The procedure for determining optimal allocation of limited water will therefore be based on an iterative, directed search that utilizes several program features designed to meet the analytical challenges of optimum irrigation management:

- The program provides for simultaneous scheduling of multiple fields in order to analyze strategies for apportioning limited water;
- It explicitly accounts for delivery system capacities, water supply constraints and intervals when irrigation is precluded by other farm operations;
- It provides full-season forecasting of irrigation requirements based on historical weather (high, low and average water demand years), enabling the manager to develop seasonal water use plans and/or anticipate water shortages as the season progresses;
- It allows the user to consider alternative, unconventional scheduling strategies such as reduced irrigation adequacy, partial season irrigation and user-stipulated irrigation dates;
- It analyzes the application efficiency that will derive from stipulated management strategy by modeling determinants of water losses (spatial variability of soils, irrigation uniformity, irrigation timing and adequacy, surface runoff and redistribution).

The system will eventually include three primary elements, two of which are now operational. The first is a general model of irrigation efficiency (IEM) that analyzes the disposition of applied water as spray losses, surface retention, runoff and redistribution, infiltration, percolation, evaporation and transpiration. The second is a robust, user-friendly, web-based 'expert' user interface (OISO). The interface obtains Penman estimates of reference ET from a regional weather station network, uses IEM to analyze irrigation requirements, then communicates advisory information to client farms and obtains operational data from them. These first two elements have been in beta testing with cooperating farms and are to be installed on the NRCS web farm in Fort Collins this fall. The third primary element, which is still in development will provide estimates of yields reductions when irrigation intensity is reduced.

The irrigation efficiency model (IEM)

The Irrigation Efficiency Model is designed to model the relationship between irrigation intensity, water losses and crop water use. IEM was originally developed by Oregon State University and the New Zealand Ministry of Agriculture and Fisheries (English 1992), then further developed and refined with funding from a USDA National Research Initiative grant (Isbell 2005). The model is implemented in C# and uses a variant of the MODCOM simulation framework (Hillyer 2003). The implementation is modular and was designed with the anticipation of future extensions and modifications.

IEM functions as a soil water balance model, tracking irrigation and precipitation inputs, estimating potential crop ET, adjusting the potential ET to account for low soil moisture or wet surface conditions, and partitioning ET into its component parts of evaporation and transpiration using the algorithms outlined in FAO 56 (Allen 1998). When soil moisture reaches a user specified level of allowable depletion the model calculates the gross irrigation requirement, expressed as the duration of irrigation required to bring soil moisture up to a user specified refill level. Calculations of gross irrigation requirements are based on net irrigation requirement and an *assumed* application efficiency provided by the user. Subsequently, when an irrigation takes place, IEM simulates *actual* application efficiencies by modeling the principal determinants of irrigation losses, including spatial variability of soil characteristics, irrigation timing and adequacy, patterns of applied water, wind effects on spray losses, wind distortions of sprinkler patterns, variability of surface infiltration rates, and surface water accumulations and redistribution. By simulating these factors the model analyzes the disposition of applied water in terms of evaporative losses, percolation, and runoff.

Simulation of the variability of soil moisture in a heterogeneous field with non-uniform water applications is a particularly important aspect of IEM. Such spatial variability has important implications for irrigation scheduling, and can be an important factor in yield modeling. These points are illustrated by Figures 1, 2, 3 and 4. Figure 1 shows a histogram of measured ‘field capacities’ in a small area (one acre) of a silt loam soil that illustrates the innate variability of soil water holding characteristics. That variability has two important implications. First, since net irrigation requirements are commonly based in part on field capacity, the variability indicated by Figure 1 implies that net irrigation requirements depend upon which part of a heterogeneous field is considered the ‘control’ sector for scheduling purposes. Secondly, since it is common practice to rely on soil moisture measurements to determine ‘true’ soil moisture, the variability shown in Figure 1 implies that such soil moisture measurements must be treated as highly uncertain. These two conclusions will not be news to experienced irrigation managers, but they illustrate the rationale for simulating spatial variability.

The variability in Figure 1 is less useful as an indication of crop water availability. Given the integrating effect of root distributions and lateral flow of soil water the true variability of crop available water is likely to be less than this histogram would suggest. On the other hand larger scale variations commonly seen in field soils may cause much greater variations than suggested by Figure 1. Figure 2, taken from the NRCS soil survey for Oregon, shows a field comprised of two distinctly different soils, one with an available water capacity of 2.3 in/ft to a depth of more than 5.0 feet, the other an AWC of 1.7 in/ft to 2.0 ft. These imply much greater field-wide variation than that suggested by Figure 1.

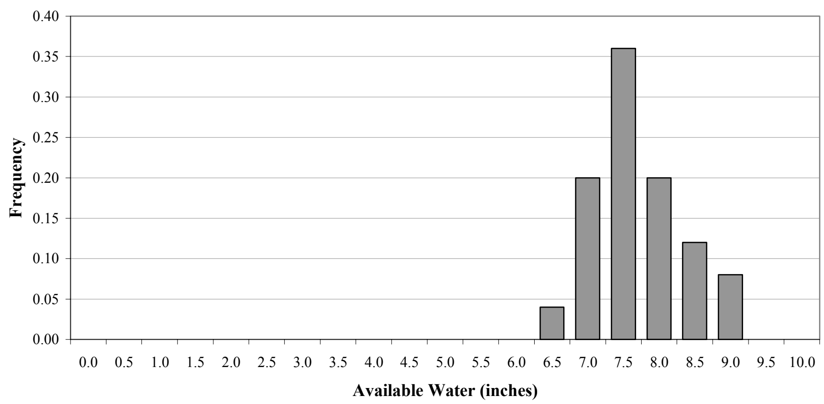


Figure 1. Variability of field capacity in a homogeneous silt loam soil

Variations in crop available water imply corresponding variations in crop yield. Figure 3 shows an IEM simulation of the spatial variability of T in a relatively homogeneous field irrigated at 90% of cumulative ET. Histograms of transpiration in Figure 4 show the changing spatial pattern of T in a relatively uniform field irrigated at intensities of 60%, 80% and 100% of potential ET (Isbell 2005). The variance of T at 100% irrigation is small, but as irrigation is reduced the variance of T increases and the shape of the probability density function changes. If crop yields are assumed to be more or less linearly related to ET or T these spatial patterns of ET imply corresponding patterns of crop yield. The importance of such patterns, if any, is being analyzed at this time.

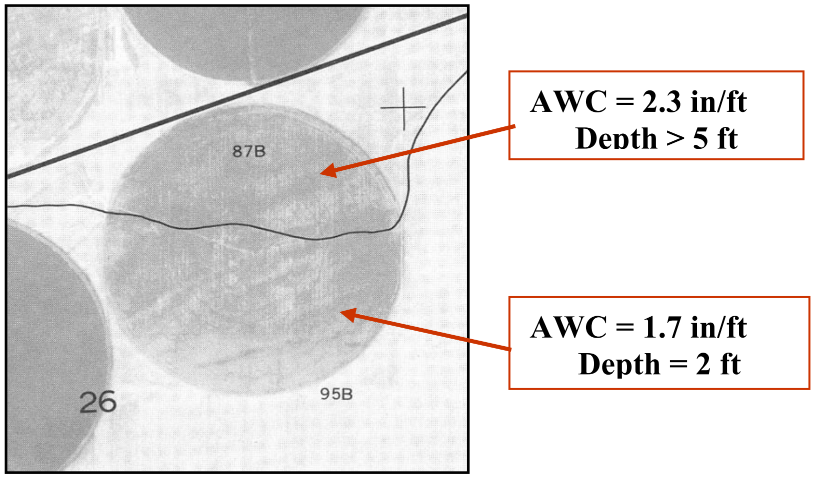


Figure 2. Two soil types in a single field

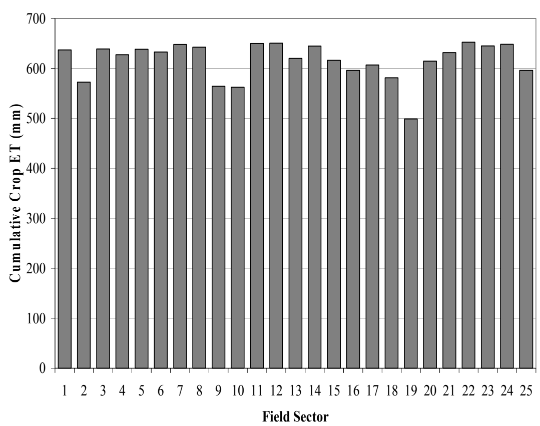


Figure 3. Distribution of Cumulative Crop ET

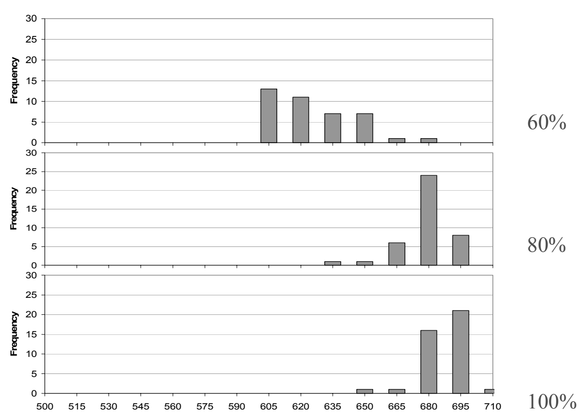


Figure 4. Simulated Distributions of Crop ET

Simulating the variability of soil water and crop available water provides a mechanism for explicitly accounting for these issues when formulating optimum irrigation strategies. That begs the question of how to determine the appropriate scale of variability for simulation purposes. At present that is left to the user's judgment, though default values are provided by the system.

Web based interface (OISO)

OISO analyzes operations for a single water source (called a water management unit, or WMU) and multiple fields that share that water source. The program is initialized by first entering the WMU command area, delivery rates and volumes. The following inputs then define the fields and irrigation systems that share that water supply:

(i) descriptions of each field include area, crop type and development dates, soil depths, infiltration rates, water holding characteristics and antecedent moisture;
(ii) irrigation systems are described by system type (e.g. pivots), application rates, nominal rotation times, estimated uniformity coefficients and sprinkler head configurations.
(iii) irrigation management strategies are described in terms of MAD, refill level, application efficiency to be assumed for calculating gross irrigation requirements, and the field sector (defined by the total water holding capacity) to be used for scheduling purposes.

As noted earlier, a weather station network provides daily Penman reference ET[3]. OISO downloads recent weather data, then calls IEM to calculate soil moisture (including spatial variations in moisture) on a daily basis, determine when irrigations are required and calculate the depths of water that need to be applied. When an irrigation event occurs IEM analyzes the disposition of the applied water as previously outlined. Outputs to the user indicate soil moisture status on a daily basis and recommendations for timing and duration of upcoming irrigations. The program forecasts crop water demand from the current date to the projected season end date. A typical graphical output for a single field is shown in Figure 5, with irrigation events (red) and precipitation (green) shown along the horizontal axis.

[3] At present the system is linked to the USBR Agrimet network.

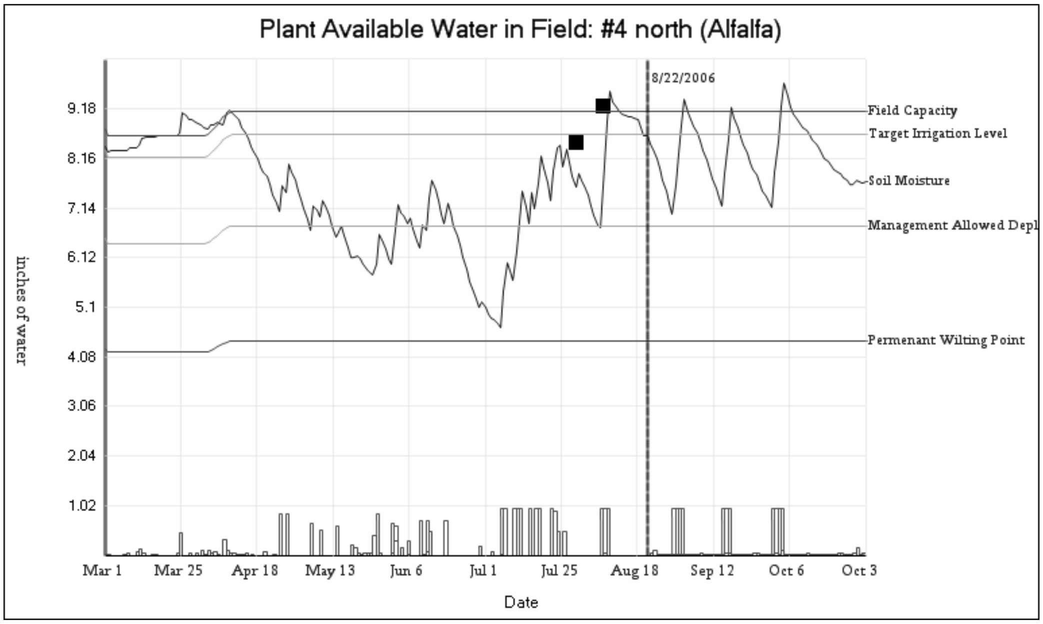
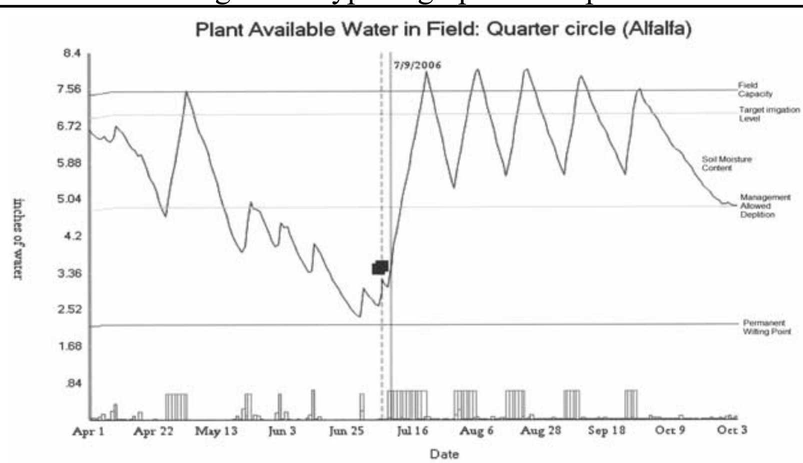


Figure 5. Typical graphical output



Field Name	**Aug/ 20**	**Aug/ 21**	**Aug/ 22**	**Aug/ 23**	**Aug/ 24**	**Aug/ 25**	**Aug/ 26**	**Aug/ 27**	**Aug/ 28**	**Aug/ 29**	**Aug/ 30**	**Aug/ 31**	**Sep/ 1**	**Sep/ 2**
#4 north					900	900	900	900						
#4 Southeast														
#4 southwest	900	900	900	900								900	900	900
Total	900	900	900	900	900	900	900	900				900	900	900

Dear Mr. …..
The above OISO analysis is a summary for July 8th. The last irrigation date entered was June 28th. The last cutting of alfalfa was June 10th and the next assumed alfalfa cutting date is July 15th. If there have been more recent irrigations, or soil moisture measurements please let us know by *reply email* or call 541-602 6845. For more complete details you can go directly to the web site:
http://bre-rose.bioe.orst.edu/Realtimeirrigationschedule/index.htm

Figure 6. Sample daily output to client

The graph shows recent history of soil water up to the current date (left of the vertical line), then a forecast of required irrigation dates and soil moisture to the end of the season. The black squares represent measurements of soil moisture. A two week calendar of upcoming irrigation events is also presented. The system provides a 'push-pull' communication link in which daily email messages are sent to individual clients presenting the current status of the individual fields and inquiring about the previous day's farm operations. By simply picking the *reply email* hot button the client can easily send back current operational information such as recent irrigation events, soil moisture measurements or alfalfa cuttings. Clients wishing to see more complete analyses can access their individual web pages by picking the URL. Figure 6 is a prototype message currently being generated manually by project personnel. Ultimately such messages will be generated automatically. The website will also generate a calendar of irrigation dates and rates (Table 1), detailed tables of irrigation dates and amounts (Figure 7), detailed plots of soil moisture, evapotranspiration, and cumulative application for multiple weather regimes.

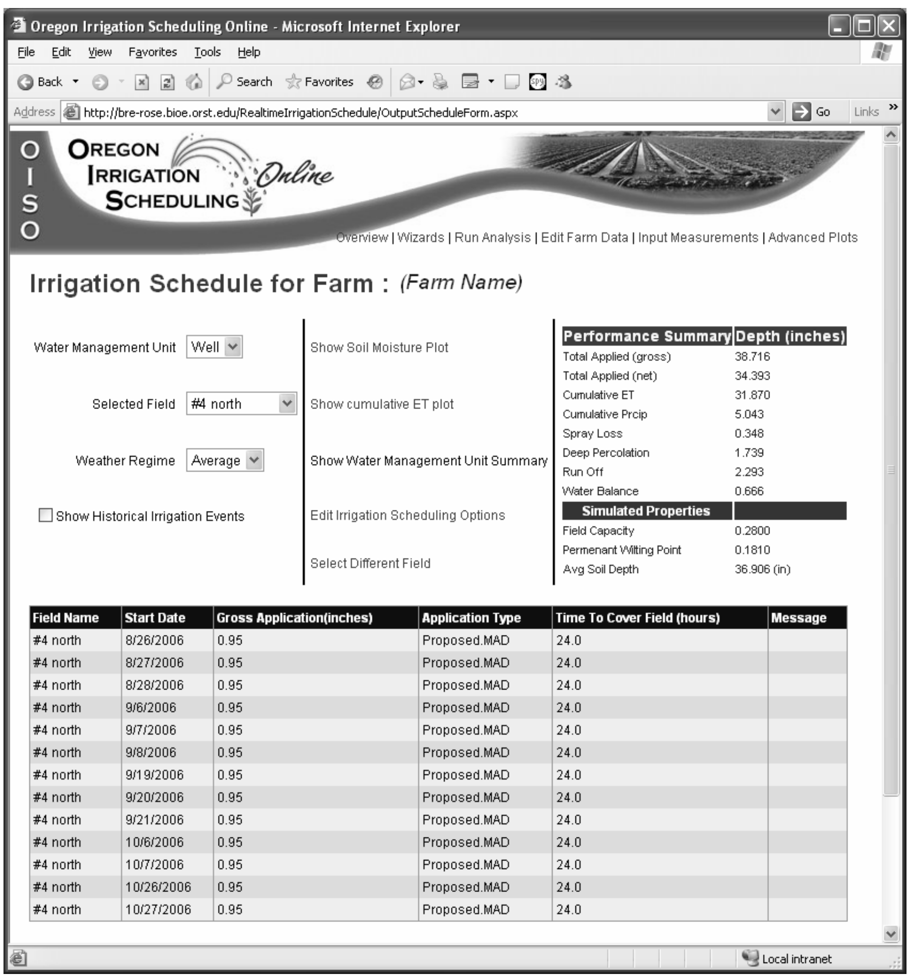


Figure 7. Sample web site output screen

The full potential of this system becomes clearer when planning water use for multiple fields with limited water. That problem, for which this system was originally designed, is illustrated by
Figure 8 which shows monthly crop water demand for each of four crops on six fields during the 2002 crop year and aggregate demand for all fields on a cooperating farm in eastern Oregon. The horizontal line indicates the farm water supply. At peak of season the water demand for full irrigation is about 80% greater than the supply. Clearly it is not possible to fully irrigate all six fields, but strategic timing and deficit irrigation strategies have enabled this farm to manage these fields profitably in water short years. The present program is designed to deal with the unconventional strategies that farms such as this have developed use over the years.

Since different managers have different objectives and tolerance for risk and face different local circumstances their irrigation strategies will differ. Consequently, determining the allocation of a given water supply among several fields is based on an iterative, directed search that accounts for specific farm circumstances and brings the manager's local experience and preferences into the analysis.

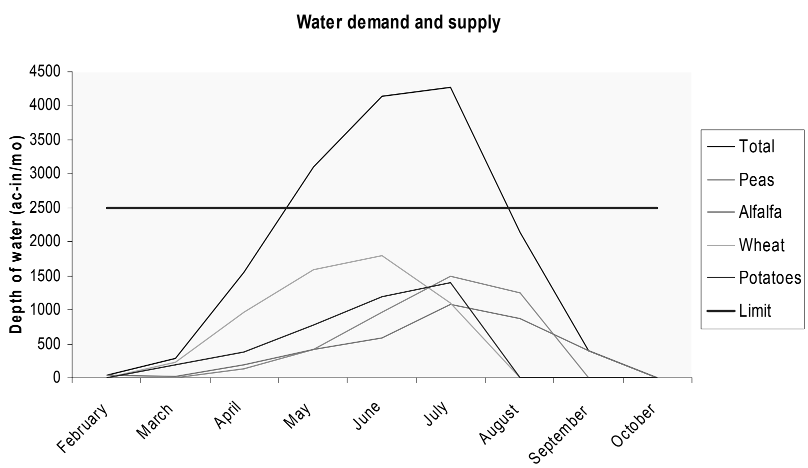


Figure 8. Nominal Crop Water Demand for four crops on Seven Fields

The procedure consists of these steps:

(i) propose a water management plan, consisting of a cropping pattern, irrigation system configuration and irrigation management strategies for each field
(ii) estimate daily water demand and resulting crop yields for each field for weather years of low, average and high water demand.
(iii) compare total demand with available water supply and delivery system capacity
(iv) if the water demand exceeds available supply or system capacity, adjust the cropping pattern and/or irrigation plan and repeat the analysis until a

> feasible strategy is found such that the total demand is in-line with available water.

An example seasonal water use plan form the same cooperating farm[4] is shown in Figure 9 showing color coded graphs of projected irrigation dates and delivery rates (gallons per minute) for irrigation of five crops on seven fields of various sizes with a variety of irrigation systems. The resulting aggregate farm water demand, summed for all fields, is also shown (black line). Total farm water delivery capacity, about 2400 gpm, is shown as a horizontal line. As in the earlier example, the water demand would exceed supply for much of the season, particularly in May and June, so the initial water use plan shown here is not feasible. Several changes might then be proposed to deal with this water shortage; (i) a small field of alfalfa in its last year of production could be fallowed, (ii) a second field of alfalfa could be deficit irrigated, (iii) alfalfa cutting dates could be shifted slightly, and (iv) a circle of winter wheat could be deficit irrigated.

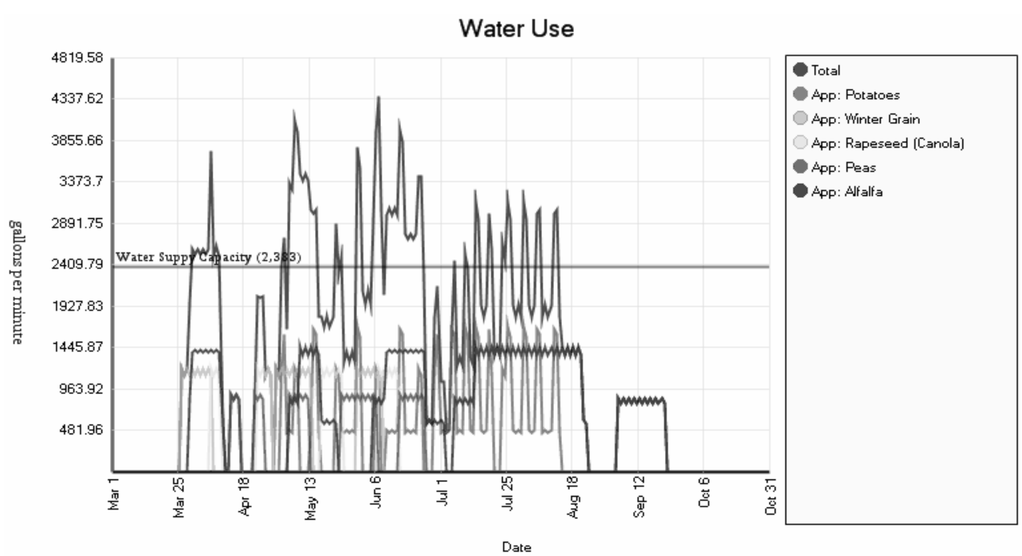


Figure 9. Seasonal Water Demand on a Cooperating Eastern Oregon Farm

[4] This plan is for a different crop mix than was in place in 2002.

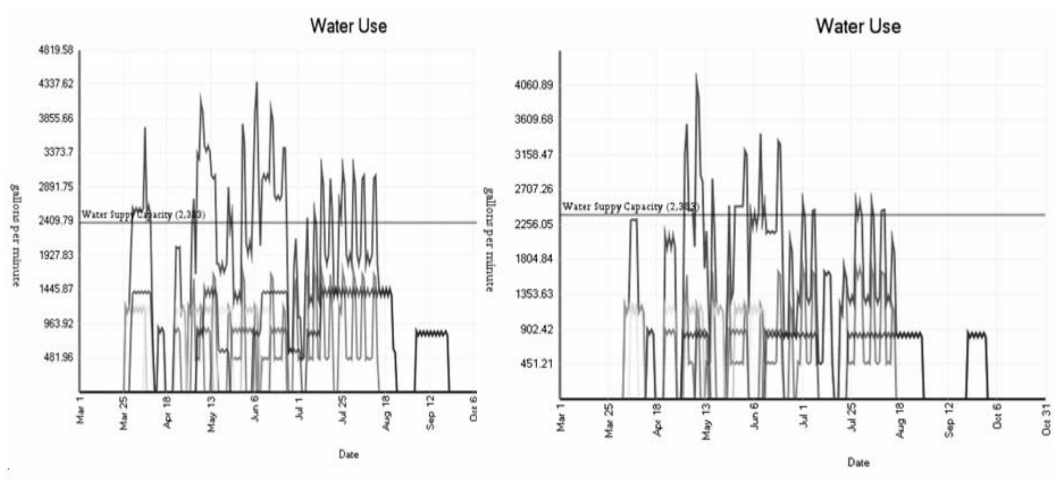


Figure 10. Original & Revised Water Demand Plots

Figure 10 compares the first water demand graph (left) with the resulting revised graph (right). The proposed changes would substantially reduce overall demand, and shorten most periods of excess demand which would make the water shortages more manageable. The next step would be to further refine the irrigation schedules on a day-by-day basis, shifting irrigations from specific high demand days to days when capacity is under-utilized. Table 1. shows the two-week calendar of irrigation dates and rates (gpm) for the period beginning June 4 for all seven fields, with daily totals along the bottom line. On days when demand exceeds capacity the aggregate is shown in red.

During the coming winter the program will be modified to allow direct editing of the scheduling calendar, deleting or adding entries for specific dates, or clicking and dragging strings of entries, until the total demand for each date is brought in line with supply. The concept is illustrated in Table 2, which shows two minor changes in the recommended schedule. By starting canola irrigation one day earlier and eliminating the last day of a scheduled irrigation of wheat the two days of excess demand could be avoided.

Table 1. Calendar of Irrigation Dates & Rates

	Jun/4	Jun/5	Jun/6	Jun/7	Jun/8	Jun/9	Jun/10	Jun/11	Jun/12	Jun/13	Jun/14	Jun/15	Jun/16
43 potatoes									480	480	480	480	480
44 alfalfa										850	850	850	850
45 peas									900	900	900	900	900
46 alfalfa													
47 wheat	1200	1200	1200	1200	1200	1200	1200						
48A potatoes							1200	1200					
48B canola		1200	1200	1200	1200	1200	1200	1200	1200				
Total	1200	2400	2400	2400	2400	2400	3600	2400	2580	2230	2230	2230	2230

Table 2. Editing Irrigation Dates

	Jun/4	Jun/5	Jun/6	Jun/7	Jun/8	Jun/9	Jun/10	Jun/11	Jun/12	Jun/13	Jun/14	Jun/15	Jun/16
43 potatoes									480	480	480	480	480
44 alfalfa										850	850	850	850
45 peas									900	900	900	900	900
46 alfalfa													
47 wheat	1200	1200	1200	1200	1200	1200	1200 X						
48A potatoes							1200	1200					
48B canola		1200	1200	1200	1200	1200	1200	1200	1200				
Total	1200	2400	2400	2400	2400	2400	3600	2400	2580	2230	2230	2230	2230

Additional plans for modifying or expanding the system this year include linking the farm setup wizards to NRCS on-line, GIS-based soils data and expanding the system options to include micro-irrigation and surface irrigation methods.

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