Final Report:
Oregon State University Subcontract to WyEast Water and Economic Optimization Project
2005-2008

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Executive Summary

Though nominally funded for the 2005 growing season the project was not initiated until mid-July of that season due to delays in concluding the contract. Subsequently, the project plans laid out in the original WEOP proposal, though sound in principle, were confounded by a host of problems that required adaptation and modification of the plans as the project evolved. In the end the implementation of the project was quite different in detail from the original plan. As originally planned, the irrigation advisory service was to employ the WISE irrigation scheduling program from WSU, using weather data from the WEOP stations, TDR soil moisture measurements and in-line flow measurements, with all field data collected and transmitted to OSU automatically. In the end, irrigation scheduling required development of a new, web-based advisory program (OISO) using Agrimet weather data, in conjunction with in-field measurements of applied water and neutron probe measurements of soil moisture taken manually by OSU personnel commuting from Corvallis.

Correcting the problems with the original instrumentation, then designing and implementing altogether new field operations, installing and calibrating new instrumentation, and conducting these efforts from Corvallis was a significant drain on project resources. Those problems and the late start of project operations delayed the project to the point that we were not able to complete the ultimate objectives by the end of the project. However most of the essential supporting tasks were successfully completed, and most of the original project objectives were completed, and the project is being continued as an OSU Extension program.

The engineering component of the project included completion of the field surveys of irrigation systems, development of a smoothly functioning irrigation scheduling advisory service, updating of field soil surveys, installation and calibration of viable instrumentation and implementation of crop yield models for use in this project; these have all been completed. Economic data pertaining to the cooperating farms is complete. An automatic link between the web-based advisory program and a general enterprise budget (an Excel spreadsheet designed to analyze the economic implications or irrigation

practices) now makes it possible for the cooperating farmers to do the kinds of economic analysis of irrigation strategies that were the original intent of the project.

With regard to the ultimate objectives, the project did provide the cooperating farms with the analytical tools needed for precise irrigation management, including the capacity to analyze alternative irrigation strategies for maximizing net returns to water. The cooperators did utilize these advisory services in varying degrees, including some cases where they configured the advisory program to develop water conserving strategies rather than conventional irrigation strategies. Observations of their irrigation scheduling practices indicated that in general the farms were not over-irrigating, and in most cases they were under-irrigating. However their irrigation timing was often off.

What was not accomplished in this project was detailed investigations of optimum irrigation strategies for the individual cooperating farms. By the end of the project all analytical tools were in place and available to the farms to do that, and OSU has advised the cooperating farms that we will assist them with such analyses as an ongoing Extension effort if they are interested in cooperating.

While development of farm-specific optimization strategies for individual farms were not completed, a general optimization analysis was done to establish preliminary estimates of the potential value of conserved water. The potential economic benefit to be realized by capitalizing on water markets was analyzed based on a general enterprise budget and water market prices that prevailed in the region in 2006. However, that analysis revealed that significant reductions in water use would not be justified by current water market prices. Coupled with the fact that the cooperating farms were generally under-irrigating to some extent, it appeared that there may be little incentive for their participation in water markets at the present time. However, if impediments to water markets are removed in the future (one of the original objectives of this project) it is probable that the cooperating farms may then benefit from reduced water use.

Advisory services for the cooperating farms are now continuing as an unfunded effort by Oregon State University and we anticipate completing the last of the original objectives during the 2009 irrigation season.

One supporting task that is still in progress and is unlikely to be fully completed during the coming year is implementation of a new crop yield model. Modeling of crop yields was of central importance to the economic analysis, and the original plan called for use of the FAO 33 general yield model (see section on Yield modeling). That model has in fact been installed as part of the irrigation advisory service. Early in the project it was learned that FAO was developing a substantially improved replacement model for FAO 33, and an attempt was made to adapt that model for use in the WEOP program. However that effort has fallen behind because of delays at FAO in delivering a final version of the model for forage crops (alfalfa in the cases we have been working with).

A project review meeting was held on Feb. 21 2007 with NRCS program oversight personnel, participating farmers, OSU, WyEast participants. The meeting focused on two items that were of particular relevance to the OSU part of the project: (i) a critical review of the format and content of the web based irrigation management advisory program, and (ii) comments from the participating farmers regarding the value and ease of use of the program The participants suggested several changes in the system but also indicated general satisfaction with the prototype service. They also suggested the program be reformatted to provide additional information in a easier to access format..

Subsequently a major program review of the entire irrigation management program in the BEE Department at OSU was held on March 2-4, 2007. Participants included 10 professionals in the fields of irrigation engineering, agronomy, economics and extension who are serving in the capacity of advisors to the program. Though the scope of that meeting was much broader than this project alone, the meeting encompassed critical review of this project and of the irrigation efficiency model and the web based advisory service that are central features of this project. Outcomes of the meeting included suggestions for immediate modifications of the models and general suggestions for a second generation model to be initiated late in 2007.

Introduction

This project was a subcontract to WyEast for the primary tasks outlined below:

1. Collect baseline data on irrigation system performance on cooperating farms
2. Monitor the existing irrigation practices of the cooperating farm managers
3. Develop a water optimization model for use in developing economically optimum irrigation strategies
4. Provide on-farm irrigation advisory services, both for planning of optimum strategies and for implementing (scheduling) irrigation operations

Activities relating to these four basic tasks are summarized in the following paragraphs.

Collect baseline data and monitor existing irrigation practices on the cooperating farms

At the time of project inception it was anticipated that WyEast and OSU personnel would recruit three cooperating farms to participate in the project. Initially three cooperating farms were recruited in the Ochocco Irrigation District for participation in this effort; Wade Flegel, Brad Santucci and Bonny Craig. At the end of the first year of the project the Craig farm dropped out of the program because he had elected to stop farming the field selected for the project. However another cooperator was recruited, Rex Barber. During the second season the Santucci farm dropped out because of conflict with field technicians. At that point another farmer, John McElheren of Maupin, asked to participate at his own expense, and that farm was added to the project and provided the same services as the original farms. Additionally, at the start of the third year another farm (Bob Miller) in the Lone Pine Irrigation District asked to participate and was added to the study. However that farm's participation began late in the third year and there was insufficient time to fully evaluate management practices on that farm or to fully implement the field instrumentation or scheduling activities. During the fourth season that farm shifted equipment and changed cropping patterns and was therefore not included in the operation.

Consequently, at the end of the third year there were three participating farm operator; Wade Flegel, Rex Barber and John McElheren. System performance data Uniformity, pressures, nozzle wear, leaks, etc.) were collected for each of the fields involved in the project at least once, and in most cases twice. Additionally, system surveys were done on other fields of each farm where the field technicians noted potential problems. The intention was to provide a more complete perspective on ways to improve irrigation system performance; these additional surveys were done as a service to the cooperating farms.

Monitoring existing irrigation scheduling practices was done in conjunction with the use of a web-based irrigation advisory service through which operational data (timing and duration of irrigation events and soil moisture measurements) were analyzed and the results communicated to the cooperating farm. The web-based service provided a medium through which baseline data on the timing and amount of irrigation events scheduled by the farm managers in the first year of the program were recorded and compared with calculated irrigation needs and observed soil moisture conditions.

Each farm received a detailed, written report on the performance of their irrigation systems and recommended changes in system configuration or scheduling practices. Subsequently they received continuous feedback on their irrigation management practices along with real-time irrigation scheduling recommendations, during the irrigation seasons.

Develop Water Optimization Model.

An analytical program was to be developed for use in optimizing irrigation water use. The analysis was to consider a long run scenario reflecting year to year variations in water supplies. The intention was that the analytical model would indicate changes in profit as a result of potential water markets, quantities of water saved for in-stream use, changes in cropping patterns and irrigation technologies, and identify barriers to broader application of optimized water use. It was anticipated that conventional irrigation water needs would be met and still have “excess” water to take to market via lease or other mechanism that generates revenue.

This task was anticipated to require several years to complete. In the first year effort was to be focused on identification of key variables and development of the basic model. Ultimately this task was combined with development of the on-farm advisory service as discussed below.

The economic components of this work involved development of enterprise budgets for each of the cooperating farms and assessment of the potential opportunity costs of conserved water as derived from regional water markets. Enterprise budgets were developed as planned. This project had no responsibility for development of water markets, but an effort was made to identify existing regional markets and assess the potential price paid for conserved water. Current water market prices were found to be quite low, possibly too low to warrant the cooperating farms participation in sale or leasing of water. The low prices offered in the water market are probably a reflection of the legal impediments to such transactions and not truly representative of the value of the water.

Another important component of this effort was development of crop models that would be used to estimate yield losses associated with any instances of under-irrigation. The intention was to establish a way of analyzing the economic merits of deficit irrigation, should any participating farms be interested in that strategy. Yield modeling was therefore to be included in the analytical system, focusing initially on wheat, alfalfa and pasture. Eventually the yield modeling was to encompass other crops common to the area which the farm managers might consider as candidates for partial irrigation. The general yield model used for this project, based on FAO Irrigation and Drainage Paper #33, was built into the analytical system at the start of the program. However, outputs of this model were not displayed in the program interface because the FAO 33 model is generally regarded as a poor predictor of yields[1] and a more accurate replacement model was expected to be available during the third year of the project. However, at the time of this writing that replacement model had still not been made available by the model developers, so provisions were made to display outputs of the original FAO 33 yield model during the last season of the project. These will be used on an interim basis for ongoing work with the cooperators.

The availability of weather data, soil moisture measurements and measured water deliveries were of central importance for analysis of alternative irrigation strategies. These data were to be gathered by instrumentation installed in the subject fields of

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[1] Though generally seen as a poor predictor of yields, the FAO 33 model was selected for this project because it is the only viable general yield model available at the time the project was initiated.

cooperating farms and relayed by telemetry through a WyEast computer to the OSU staff. However, field instrumentation and telemetry systems did not function well during the first two years of the project, and OSU was compelled to utilize Agrimet weather station network and in-field neutron probe measurements to obtain the required data.

While the WEOP stations were not used for irrigation management in the course of the project the data collected by those stations was still of real value. Those data are now being used to derive functional relationships between Agrimet station ET values and ET at the cooperating farms. These relationships will provide a basis for improved estimation of ET at the locations of the cooperating farms based on Agrimet data, rather than having to maintain stations in the field in the future.

On-Farm Advisory Service

Another key component of this work was to provide an irrigation advisory service for both conventional irrigation scheduling and implementation of optimal irrigation scheduling. The economic analyses were to indicate the potential benefits of different strategies in terms of reduced water use and increased farm profits. Preferred strategies were then to be translated into detailed irrigation management plans and communicated to the cooperating farms through the on-farm advisory service. Management planning tools were to include algorithms for pre-season estimation of seasonal irrigation schedules, and analysis of alternative scheduling strategies which would enable the farm manager to plan water use in advance.

Initially the alternatives considered were to be limited to conventional irrigation management (i.e. near-full irrigation). The decision algorithms were to be used to generate recommendations for conventional scheduling strategies, including detailed criteria for real-time irrigation scheduling i.e., at what stages of crop development and what levels of soil moisture depletion irrigations should commence, what application efficiencies should be assumed in calculations of gross water requirements (efficiencies will depend upon management strategies), and how the irrigation system should be operated to be consistent with the farm manager’s preferred set times or rotation rates. However the analytical system was to be structured for analysis of economically optimum management.

A computer-based irrigation scheduling program developed originally at Washington State University, known by the acronym WISE (Washington Irrigation Scheduling Expert) was intended to be the vehicle for analyzing irrigation schedules and communicating recommendations to the cooperating farms. The OSU staff were to adapt the WISE program for installation and use on computers of the cooperating farms. The WISE program was designed for downloading to personal computers of the cooperating farms. However, at project inception the WISE program was found to be incompatible with the personal computers and/or operating systems in use by the cooperating farms and was therefore abandoned. In its place, OSU developed a web-based program that served the same basic purposes as the WISE program was to do, and in addition provided for record keeping, long-term planning and analysis of alternative (deficit) irrigation strategies. This program, known by the acronym OISO (for Oregon Irrigation Scheduling Online) was developed with supplemental funding from NRCS under a separate grant. WEOP project planning was revised such that the WEOP project would serve as a pilot program to field test, evaluate and refine the OISO system. OSU requested additional funding from the WEOP program for that purpose, and in response WEOP management modified the OSU subcontract to shift additional funds to support OSU efforts.

Methods, problems, actions taken

This section presents a history of project activities and outcomes. The organization of this section of the report follows the outline of tasks originally detailed in the subcontract Scope of Work, as amended in 2007, which are enumerated below. Note, however, that some sub-tasks of Task 7 are discussed in conjunction with earlier tasks.

- Task 3: Collect irrigator baseline irrigation data
- Task 4: Evaluate existing irrigation systems
- Task 6: Develop Water Optimization Model.
- Task 7: On-Farm Advisory Service -- Apply Water Optimization Model on-farm.

Task 3: Collect irrigator baseline irrigation data

Field instrumentation and a telemetry system were to be installed to record the irrigation system baseline data in order to evaluate the timing and efficiency of irrigation applications.

During 2005 it was expected that the cooperating irrigators would follow their customary irrigation schedules. Irrigation schedules were to be monitored. Weather stations, soil moisture measurement probes (TDR) and flow meters were to be installed, and telemetry was to be set up to collect required field data to calculate crop water demands, to record the irrigation system baseline timing and amount of water use, and to evaluate system performance. Pump flows and amounts of available moisture in the soil profile were to be monitored, and system water use efficiency was to be calculated. However, system problems with the in-field instrumentation and telemetry systems were encountered that forced a change of plans and delayed completion of this task until the 2006 season. The following discussion relating to Task 3 is in three parts. The first part details the problems associated with field instrumentation and corrective actions taken. The second part deals with the step taken to circumvent the instrumentation problems using other sources of data. The third part outlines the results achieved under Task 3

Instrumentation problems and corrective actions:

The original project called for installation of weather stations on each of the participating farms, installation of flow meters to measure deliveries to the individual fields, installation of TDR probes to monitor soil moisture at several locations and depths in the fields, and a telemetry system to transmit all of the above data to WyEast via Automata. Complications arose with the instrumentation and telemetry, including: (i) problems with use of TDR probes for measuring soil moisture; (ii) weather station instrumentation problems; (iii) telemetry of field data, and; (iv) the algorithm originally used to calculate reference ET from the weather station data.

The TDR soil moisture measurements were not adequate for characterizing soil moisture content during the season. OSU originally recommended that the TDR probes be inserted vertically to get a better measure of soil water uptake in the full soil profile. However the very rocky soils of the cooperating farms precluded simply inserting the probes by force, and would have precluded adequate contact with the soil for accurate measurement of soil moisture content. . OSU elected to install neutron probes in parallel with the TDR to provide a larger zone of measurement, but the [probe tubes could not be inserted to the full depth of the root zone, and probe measurements were therefore somewhat inconclusive.

Initially the weather station installations did not go well for a variety of reasons. Some of the field instruments originally installed for this work needed to be replaced, including the net radiometer at the Barber farm and several of the TDR probes. Because of the station problems and the late program initiation we began water use analyses and scheduling operations utilizing Agrimet weather data and ET estimates from the Madras and Powell Butte Agrimet stations.

Early in the project OSU downloaded the WEOP weather stations manually for input to the the OISO web-based irrigation scheduling software. However, differences between ET estimates derived from the WEOP weather stations on the cooperating farms and the ET estimates generated by the Agrimet stations at Madras and Powell Butte were too large to be explained by local microclimate variations (the WEOP station ET estimates were less than the Agrimet station estimates by almost half at times). While Agrimet weather data were not as representative of the study area farms, they were nevertheless deemed more reliable than the estimates derived from the on-farm stations.

Initially it was found that the new weather instruments were not working properly; the problems with individual instruments were resolved satisfactorily during the second season. By the end of the second season individual instruments were reporting results that agreed well with Agrimet instruments. However estimates of ET still disagreed with Agrimet valuies by a wide margin. The OSU system programmer met with WEOP contract programmers to analyze the problems with the seemingly incorrect ET estimates. After substantial investigation they found that the time tag that accompanies the data when transmitted to the satellite is influenced by the position of the satellite. Weather stations store data until connection with a satellite. But when the data were stored it appears that some data were losing the time tags and were transmitted as if they been read recently when in fact it may have been hours earlier. Other data retained its time tag. The net effect explained low estimates of ET. This problem was fixed by rewriting of the software used to process satellite data.

At the start of the second year of the project it was found that the problem with Automata estimates of ET persisted. The conclusion was that the differences derived from the coding of the ET model used by WEOP. The OSU system programmer therefore developed detailed algorithms and program code to build a new model for reference ET. The software fix was implemented during the 2007 season. In order to establish confidence in the computed ET values WyEast arranged with an independent contractor (Jac LeRoux) to verify that the ET estimates derived from the WEOP stations were then correct. However it was then late in the 2007 season and no attempt was made to begin using the WEOP stations. All analyses for the first three seasons of the project were therefore based on Agrimet station data.

Implementation of Task 3 using alternative data sources

Though the original project plan was to be monitor soil moisture automatically via the telemetered TDR readings, problems with TDR installations and the limited accuracy of those instruments prompted OSU to assign field technicians to measure soil moisture directly using neutron probes. OSU arranged for use of a neutron probe as well as training and licensing of field technicians. Given the complex, rocky and shallow soils of the study fields in the Ochocco District and the Barber and McElheren farms it was necessary to remap the soils in some detail and to calibrate the neutron probes explicitly for those soils. NRCS personnel visited the subject fields during the 2006 season and did extensive additional mapping of soil characteristics. Calibration was done by OSU based on simultaneous *in-situ* gravimetric sampling and probe readings during probe tube installations for three sites in each field participating in the project. The characteristics of the gravimetric soil samples were also analyzed in a soils lab at OSU.

Linking the weather stations to OISO

The work plan for this project included a sub-task to link the WEOP weather stations to OISO. While originally listed as Sub-task 7(d) it is appropriate to discuss that sub-task here as part of Task 3. Early in the project a procedure for downloading WEOP weather station estimates of ET was established, but the weather station data problems discussed above precluded using those data until late in the project. Consequently the

OISO system was automatically linked to the AGRIMET weather station network and the system was adapted to the Agrimet data protocols (i.e. the format, data intervals, reference ET models and units defined for ET, wind run, temperatures, humidity and solar radiation. By the time the validity of WEOP ET estimates was verified at the end of the 2007 season the project was fully invested in the AGRIMET system and we elected not take the time at that point to adapt to the WEOP data. However, OSU has continued with analysis of the relationships between the WEOP station estimates of ET (as corrected) and the Agrimet station estimates. ET estimates derived using data from all stations as input to a single (common) model of reference ET were sufficiently consistent to justify using the WEOP data for future work. A comparison of all such ET estimates is shown in Appendix C. A follow-on analysis has been undertaken by OSU to serve two purposes: (i) to better understand regional microclimate variations and the potential value of in-field weather stations, and (ii) to develop functional relationships for use in adjusting Agrimet station estimates of ET to more accurately represent actual ET at the cooperating farms in the future.

Accomplishment of Task 3

Partial season data collection and analyses were done during the 2005 season for the Flegel, Barber and Santucci farms, but the 2005 analyses are regarded as preliminary because of the problems with soil surveys and instrument calibration that were still being resolved during that season. Due to the problems outlined above and the changing participation of cooperating farms, a complete season of irrigation management data were not collected and analysis of irrigation management for the three cooperating farms (Flegel, Barber and McElheren) were not completed until the 2006 season.

The analysis that began with the 2006 season these included irrigation timing and amounts and measured soil moistures. The soil moisture measurements did not begin until July due to the problems encountered with field instrumentation. Results of the analyses for that year were embedded in the outputs of the OISO program. The individual farms were instructed in how to access those analyses, and the results were reviewed with the farm managers. The analyses of these three farms are shown in Appendix A.

Additional data collection and analysis from the Santucci farm are not shown because that farm elected to discontinue cooperation with this project.

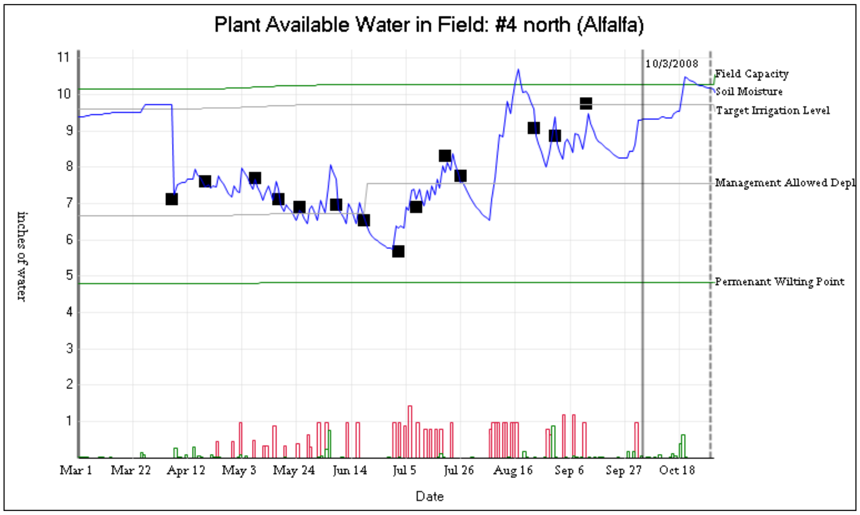
Task 3 calls for feedback to the cooperating farm regarding their irrigation management and application efficiency. That information was presented in both graphical and tabular format to all three cooperating farms. The graphical analyses, as displayed by the OISO interface, included two graphs. The first, a history of crop water availability throughout the season, shows a trace of estimated soil moisture derived from pre-season moisture, cumulative estimated ET and periodic soil moisture measurements, and the timing and amount of each irrigation event and precipitation. The second shows cumulative ET, both potential and actual ET. Examples are shown below (Figure 1).

In addition to the graphical history, a seasonal summary of water use information is presented to the cooperating farmers; this information includes totals of gross applied water, net applied, cumulative ET, cumulative precipitation, estimated spray losses, percolation and runoff. Note that runoff refers to the amount of water accumulation and redistribution of surface water takes place. It is not necessarily off-field runoff. A summary of water use for the example shown is presented in Table 1.

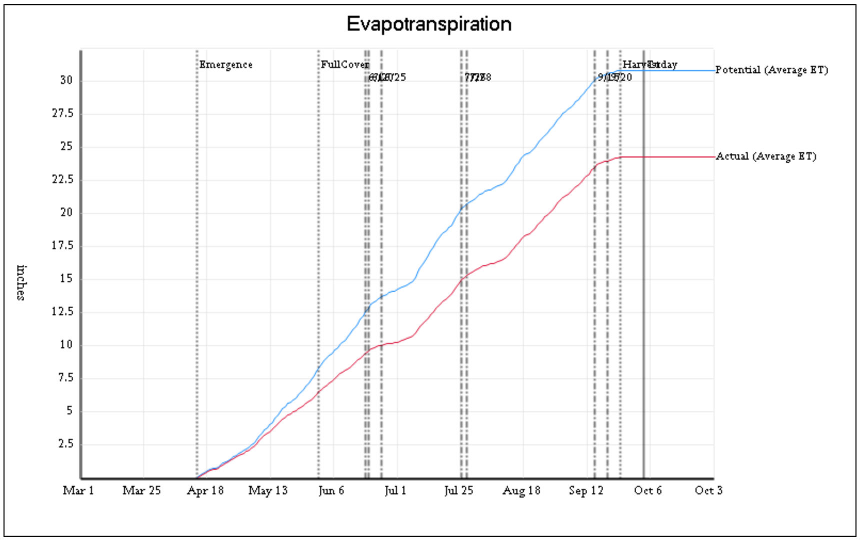
Taken together, the graphical and tabular data provide a comprehensive picture of irrigation management and efficiency. For example the tabular data show that application efficiencies were high (since percolation and spray losses were quite low). Thus the ratio of net applied water to gross applied implies an application efficiency of 83%. However the graphical data indicate that the field was under-irrigated through the first two thirds of the season, indicating some degree of ET deficit that would have eventuated in some yield loss. The graphical data can be used to point out errors in timing of water use.

Figure 1; Graphical Representation of Seasonal History

Farm 1; 2007 Season



Plant Available Water in Field: #4 north (Alfalfa)



Evapotranspiration

Table 1; Seasonal Water Use Summary; Farm 1; 2007 season

Depth applied (gross)	21.9 inches
Net applied	18.2 inches
Cumulative ET	22.4 inches
Cumulative precip	4.2 inches
Spray losses	0.3 inches
Deep percolation	0.15 inches
Runoff	2.15 inches

Task 4: Evaluate existing irrigation system

Task 4(a) provide one-on-one technical assistance to evaluate existing irrigation system operation and management; including: system design efficiency considering hours of set *time and return period in days, pump flow and energy use, pump and sprinkler pressure, application rate, average time to refill root zone, average set time, leaks and other system problems.*

Task 4(b) make recommendations for system operation, maintenance or upgrade to a more efficient irrigation system based on costs and benefits were to be provided to the cooperating farm managers

On-farm, one-on-one technical assistance was provided for four farms (the Flegel, Santucci, Craig and Barber farms) during 2005. The evaluations were initiated in mid-July of the first season but could not be completed because of the late start. Additional field evaluations were completed in 2006 for the Santucci, Flegel and Barber farms, as well as the McElheren farm which joined the project that year. The evaluation of uniformity of sprinkler systems involved two tasks; (i) checking of the pressures, discharge rates and nozzle diameters of individual sprinkler nozzles; and (ii) catch can measurements of application uniformity. These measurements allowed us to assess uniformity and revealed causes of poor uniformity.

Additionally, field technicians walked the distribution system lines to find system leaks or breaks, and assessed the power used for pumping. Photos of serious leaks or breaks were taken and passed on to the farm managers.

A complete example of a system survey is shown in Appendix B. The study field in this case was a center pivot. However the field survey was extended to adjacent fields irrigated with hand lines and wheel lines as an assist to the farmer.

Figures 2(a,b) illustrates the results of the uniformity study done beneath the pivot. The uniformity surveys were represented in two ways, first as a progression of catch can data along the length of the pivot arm (Figure 2(a)) from which the uniformity coefficient was calculated. These data were then used to generate a histogram of catch can depths observed (Figure 2(b)). The variation in depth was then used in conjunction with a simple yield model to estimate the approximate yield reductions associated with the various levels of either under-irrigation or over-irrigation throughout the field. The result was an estimate of the yield decrement that would result from the non-uniformity of applied water if the field average depth of application was 100% of nominal crop water requirement. In the case illustrated here it was estimated that yields would be reduced by 6% due to the non-uniformity of applied water the pivot.

Figure 2(a)

Discharge Variation; Farm 1 Center pivot

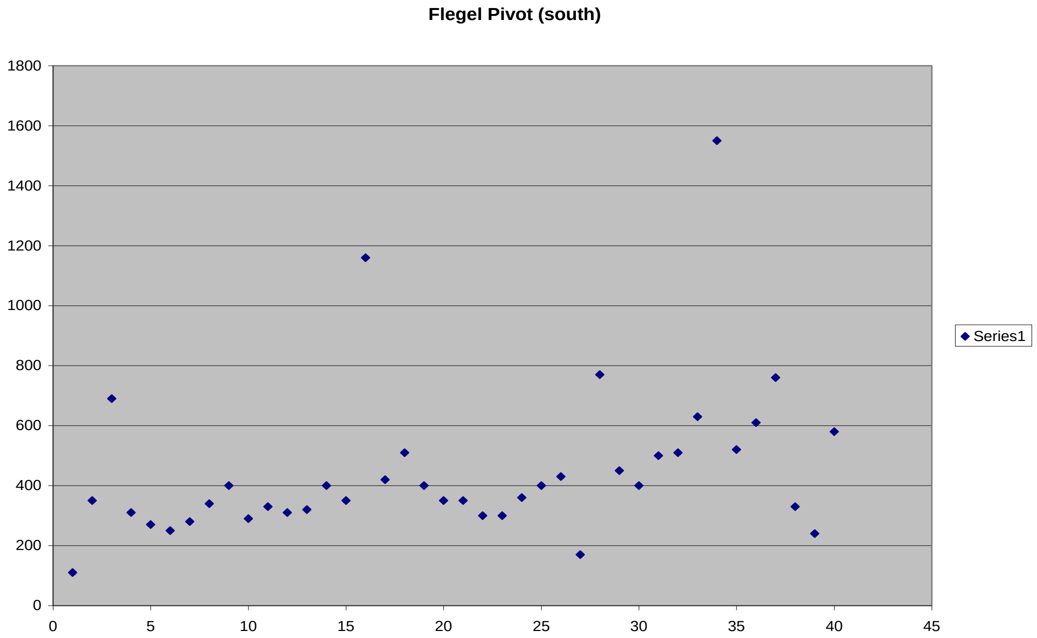
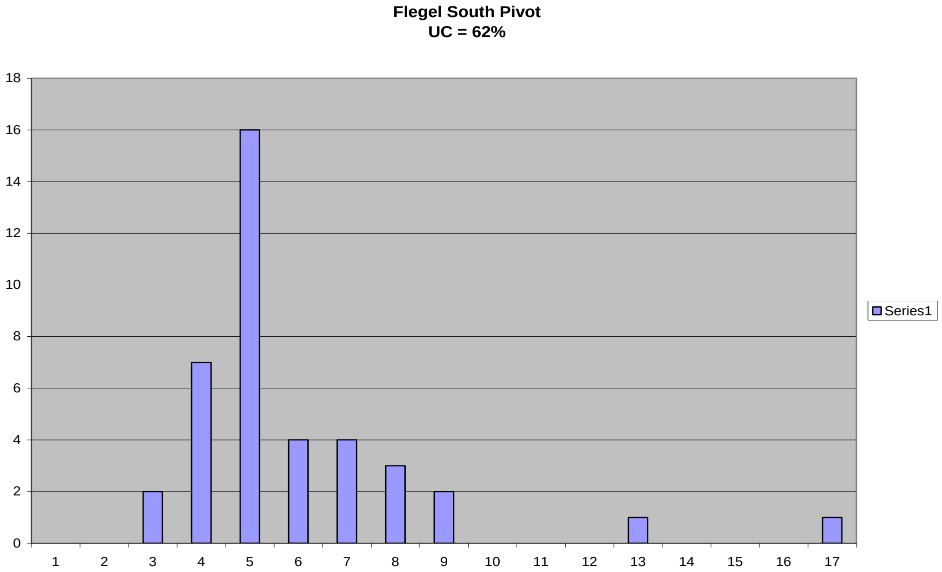


Figure 2(b)

Histogram of catch can readings; Farm 1 pivot



Irrigation systems in the fields surveyed in 2005 included both wheel lines and center pivots. However none of the wheel lines surveyed were on project fields except on the two farms that subsequently dropped out of the project (Craig and Santucci). Detailed problems observed with specific sprinkler heads were noted and repairs recommended. Noteworthy problems in the distribution systems (mainlines, laterals, hydrants, couplings, etc.) observed by the field technicians were also pointed out to the farm manager and repairs recommended.

The three farms that remained with the project all were using pivots on the fields involved in the study. There were no recommendations for system upgrades on those pivots other than the recommendation that the entire nozzle package for the quarter circle on the Flegel farm should be replaced to improve uniformity; the project purchased a new nozzle package which was installed by the OSU technicians.

Task 6: Develop Water Optimization Model.

Task 6(a) Develop deficit irrigation scheduling strategies

Task 6(b) Develop algorithm for optimization of individual fields

Task 6I Adapt strategies/procedures for cooperating farms

Task 6(d) Develop whole-farm optimization procedures

Task 6(e) Explore alternative strategies for whole farm optimization

This part of the project was to be done in parallel with the NRI project for development of analytical tools for irrigation optimization. The intention was to adapt the optimization algorithms developed by the NRI project to optimize irrigation water use on (i.e. maximize net economic returns to water) on the cooperating farms. Task 6 was anticipated to require several years to complete.

The efforts undertaken for Task 6 involved: (i) implementation of models of crop response to applied water (yield models)[2]; (ii) economic analyses of operations costs and revenues for the cooperating farms, and (iii) development of search algorithms for identifying optimal irrigation strategies. These three broad activities are discussed below under their respective headings.

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[2] Note: this activity is identified as part of Task 7 in the original plan of work.

Yield modeling

The yield modeling work has involved three different approaches. The first approach was to estimate potential yield reductions associated with poor uniformity of applied water, as was discussed above under Task 4. This first model was based on general equations derived by Dr. Kenneth Solomon to account for both deficit irrigation and excess irrigation. The Second model, which was designed to account more explicitly for the effects of deficit irrigation, was based on a UN(FAO) General Yield Model published in FAO Irrigation and Drainage Paper #33 ("*Yield Response to Water*"). The FAO #33 model uses a linear relationship between crop yield losses and the ratio of actual crop ET to potential crop ET. This model, which was originally proposed for this project and was incorporated into the web-based advisory program (OISO) is now linked to an enterprise budget spreadsheet (as discussed below); thus the yield consequences of a given irrigation strategy can now be estimated by OISO and the resulting estimate entered automatically into an enterprise budgets constructed by the individual farm managers.

While the FAO#33 model is widely used, and is in fact the only general yield model to gain wide acceptance (FAO#33 is the most widely circulated of all FAO Irrigation and Drainage papers), it has long been recognized that the model is not particularly reliable. But at the time this project was designed there were no other appropriate general yield models available. However, early in the project we became aware of a new model being developed by FAO to replace the FAO #33 model. At a March, 2007 meeting of the Project leadership OSU made a presentation and led discussions of a significant revision in the yield modeling component of the work. A decision was made to adopt a more rigorous and robust approach based on a new general yield model (*AquaCrop*) that was being developed by an FAO task committee, under the direction of Pasquale Steduto, to replace FAO#33. At that time FAO had just released an initial version of the model. The project decision was to continue use of FAO 33 while Aquacrop was being incorporated into the program and field tested with alfalfa and wheat, the principal crops grown on the test fields of participating farms. One graduate student (Carole Abourashed) was assigned to act as liason with FAO to become familiar with the new model and adapt the OISO yield model to utilize Aquacrop. Abourashed was invited to participate in a pre-release workshop at FAO headquarters for calibrating, testing and using the new general yield model. (Abourashed was also asked by FAO to take the lead in calibration of the new model specifically for alfalfa. That task is being funded by the RMA grant.)

Carole was not able to attend the workshop on the short notice we were given. Subsequently she contacted one of the four principal developers of that model, Theodore Hsiao of the University of California and arranged to spend four days with him in July, 2007, during which he instructed her on the details of the model and assisted her with planning field experiments to calibrate and test the model with regional crops in the western US.Since then, however, progress at FAO with calibration and validation of Aquacrop has progressed only slowly. Late in 2007 FAO began revision of the version of the model that deals with forage crops. That revision has now been completed and at this writing the model is in the final validation stage, but the new yield model is not yet operational; the older FAO 33 model is still being used for this project.

Being able to predict how various deficit irrigation strategies will impact yields is a vitally important part of this project since yield predictions can translate into economic consequences of reduced water use. Economic optimization of irrigation strategies was delayed by the efforts to improve upon the yield model. It is still our intention to incorporate the AquaCrop model into the system during the coming winter (2008-09), but the delays with FAO release of that model have forced us to return to the older FAO #33 model. During the last year of this project (2008) OSU returned to the task of implementing the original FAO #33 model as part of the OISO system, linking OISO outputs directly to the enterprise budgets and automatically downloading both yield estimates and input requirements (energy, labor, etc.) associated with selected irrigation strategies, as discussed in the following section.

Economic analysis

Development of crop production enterprise budgets was done initially by extension personnel in Crook County. An Agricultural Economics graduate student utilized this information to formulate a general budget spreadsheet which provided a preliminary basis for calculating production costs on the participating farms.

The economic analysis then proceeded to development of farm-specific enterprise budgets tailored to the individual cooperating farms. An AREC graduate student met with each of the participating farmers involved in the project during the 2006 season (Flegel, Barber, Santucci and McElheren) to adapt the general budget to the specifics of their individual farms. Ultimately she focused the enterprise budgets on the fields involved in our initial modeling work (these are attached to this report as electronic files). She is also moving forward with representative budgets for alfalfa, alfalfa establishment and wheat to be published by the Extension Service.

The economic analysis effort then focused on creating a general template that could serve as an OISO interface between the farm operator and the crop yield model for simulating water use and consequent yields. This template was presented to the advisory panel in March, 2007 to solicit suggestions for improvement. Full capability for individualized economic analysis of alternative irrigation strategies was ultimately added to the web-based advisory service in July 2008. A general enterprise budget spread sheet was designed using an Excel platform. The web-based advisory program (OISO) was then configured to interface with the Excel spread sheet to transfer information relevant to irrigation costs and crop yields. The irrigation cost factors output to the spread sheet include the number of irrigation events, hours of operation, hours of pumping and flow rates. Crop yields estimated by OISO are automatically downloaded to the spreadsheet as well. The enterprise budget is also configured to evaluate yield-dependent factors (fertilizer needs, harvest costs). The resulting system is capable of rapid analysis of total costs and revenues for alternative irrigation strategies when and as a given irrigation strategy is evaluated by the program.

Another critical driver has been an estimation of opportunity costs of water. While costs savings may justify some reduction in irrigation water use, the ability of an irrigator to capitalize on water savings has always been seen as the primary motivation for participation in the water conservation program envisioned by this project. That would be particularly true for the farms participating in this project which we found, by and large, to not be using excess water and, in fact, to be significantly under-irrigating at time. For that reason one of the original WEOP project tasks to remove impediments to water markets was clearly a critical part of the project.

Early in this project, OSU met with the Deschutes Water Conservancy, which has been managing the only water marketing we were aware of in the study area. Our objective in that meeting was to ‘inform the water markets’ about the direction of our work and to determine a market value that we might use for the economic analyses that were to be part of the OSU work. The prices that were discussed at the meeting were on the order of $7.00 per acre-ft., possibly too low to be relevant to farms that were already under-irrigating. This market price was used in conjunction with the general enterprise budget for alfalfa production to estimate the potential value of water saved. The resulting analysis, which is illustrated in Figure 3 below, indicated that optimum water use, taking market prices for saved water into account and assuming a crop price of $125 per ton, would be attained at 90% of full irrigation.

The conclusion was that the maximum on-farm economic benefits of water conservation strategies will not be realized until market values are allowed to rise to their full potential levels. For that reason the planned removal of impediments to water marketing in the area remains a critical component of this project. It is important to note, however, that if current water law allowed using the saved water to increase irrigated acreage it would have justified a greater reduction in water use. The point is that clearing legal obstacles to water markets remains an important objective if the full potential of this approach to irrigation management is to be realized.

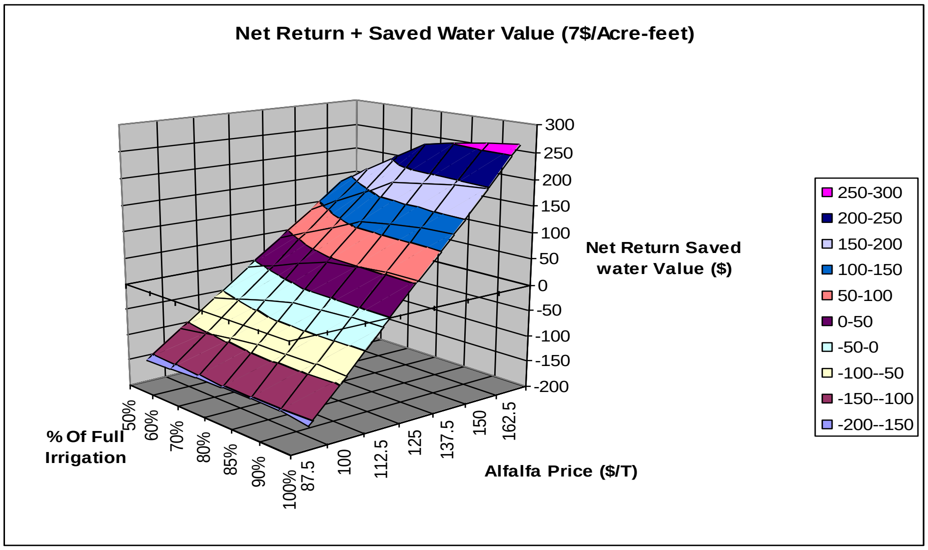


Figure 3

Net returns to water with partial irrigation of alfalfa

(assumes $7 per ac-ft market price for conserved water)

One additional activity relating to economic analyses deserves mention. During the second year of the project the AREC graduate student consulted with Jim Peterson, an agronomist who oversees the OSU wheat breeding programs. He suggested that the traditional soft white wheats grown in the Pacific Northwest may not be suitable for production under deficit irrigation situations because it lowers yield and hurts grain protein levels. He recommended that we look at switching to a hard red winter or hard white winter wheat. Under deficit irrigation conditions, these varieties drop in yield but increase in protein content and, therefore, gain a price premium in the marketplace. The AREC graduate student undertook a literature review of that theory and found some support for that argument. However, a large producer in the Hermiston area has had long experience with deficit irrigation of the Stevens variety (soft white winter wheat) has indicated that deficit irrigation of that variety is profitable. The results of this preliminary analysis were therefore inconclusive. It may be worth investigating that option with field trials at one of the experiment stations.

At this writing we are now in a position to realize the project goal of identifying optimal deficit irrigation strategies.

Optimization algorithm

As originally conceived, the water optimization model was expected to utilize a general algorithm for systematic search for optimal water use strategies. That general algorithm was to be developed by the NRI project. As the NRI work progressed, however, it was concluded that a general optimization algorithm that could realistically account for all the factors impinging on a farm manager’s optimizing strategy was not practical. Accordingly an alternative approach was adopted for this project; the new approach was to facilitate an iterative, user-directed search for optimal strategies in which the farm manager chooses the strategy to consider and the system then does a rapid assessment of the stipulated strategy. One element of this approach was establishment of the automated link between the irrigation and crop yield models (IEM and the FAO#33 model) and the enterprise budget; that automated link was discussed above. The other key element was an adaptation of the OISO interface to allow user editing of recommended irrigation schedules. As originally configured the OISO interface presented graphical and tabular displays of recommended irrigation dates and total water demand for all fields for any given two week interval in the season. A rapid editing feature was developed during the summer of 2008 and deployed in October, 2008. This feature allows the irrigator to directly edit the table of recommended irrigation events, deleting, inserting or shifting irrigation dates to accommodate the water supply. The system then uses the edited irrigation schedule as a user-defined irrigation strategy, reevaluates the full season consequences of the strategy and outputs revised calculations of water, energy, labor and other input demand, crop yields gross revenues. (Note: much of the effort to implement the rapid editing feature was developed with additional funding provided by an RMA grant rather than the original NRI grant.) The rapid editing feature was being tested at the time of this writing (October, 2008).

Task 7: On-Farm Advisory Service – Apply Water Optimization Model on-farm.

Task 7(a) algorithms for pre-season planning

Task 7(b) Proposed rules for conventional irrigation scheduling

Task 7I Development of crop yield models

Task 7(d) link weather stations to OISO

Two of the above sub-tasks have been addressed earlier in this report. Task 7I was fundamentally part of Task 6, and discussion of yield modeling has been presented above as part of the report on Task 6. Task 7(d) was implemented in conjunction with Tasks 3 and 4; it is discussed specifically in the section dealing with Task 3.

The following sections deal with development of the analytical capabilities required for Tasks 7(a, b). These capabilities were designed into the web-based system in conjunction with the parallel NRCS funded project for development of the web-based irrigation advisory service (OISO). Implementation of these capabilities for the WEOP project was accomplished by adapting the web-based system specifically for use by each of the individual cooperating farms, as discussed in detail below.

algorithms for pre-season planning

Original WEOP plans called for installation of the Washington State University Irrigation Scheduling Expert (WISE) program on personal computers on the participating farms. The WISE program was intended to serve as a vehicle for pre-season planning and for presenting irrigation scheduling advice to the individual farms. Task 7(a,b) were to involve determination of appropriate soil parameter values, irrigation system characteristics and crop parameters. Additionally, OSU was to adapt the WISE program to utilize the weather data derived from the WEOP stations, and to instruct the cooperating farms in use of the software and interpretation of the outputs. However, it was discovered that the WISE program was no longer compatible with many computers due to evolution of computer architecture and operating systems since the WISE program was released. It was therefore proposed by WyEast and OSU that OSU develop a program similar to the WISE program that could be used for the WEOP project. OSU applied for and received a separate grant from NRCS (Oregon) to adapt an existing model of irrigation system performance (Irrigation Efficiency Model, or IEM) for this application and to support the systems programming and development of the web interface. Originally, in discussions between OSU and WEOP management, OSU proposed that WEOP provide additional funding to support in-field testing, evaluation and implementation of the new system. A memorandum of understanding, prepared in 2005, articulated a tentative agreement to that effect, but was never signed off by WEOP. Instead, the original agreement between OSU and WEOP was revised and the budget increased to account for the field work associated with field testing and pilot application of the new system.

The algorithms for pre-season planning and delivery of advice on conventional irrigation scheduling services were initiated for the cooperating farms beginning in 2006. Initial analyses were done by hand using Agrimet weather stations data because of the problems with the WEOP weather data collected in the participating fields discussed earlier. The time required for development of the web-based scheduling software delayed full implementation of the irrigation management advisory program until the middle of the season. Prior to that time OSU began providing direct advice to irrigators in frequent, face to face meeting. . Beginning about midway through the second year of the WEOP program irrigation scheduling advice has been delivered to the cooperating farms by means of the web-based system. All cooperating farms were ‘installed’ on the web-based OISO system and by going on-line they were able to access daily analyses of soil water status and recommended dates of upcoming irrigations. After the web-based system was fully implemented the client farms began receiving daily email summaries of the current status of each field and forecasts of necessary irrigation dates for a two week horizon.

Principal WEOP activities for testing and pilot application of the OISO advisory service operations were validation of the irrigation efficiency model, testing whether the model realistically represented the spatial variability of soil moisture and crop yields when water use is restricted, and verifying model analyses of the disposition of applied water by determining depths of application and changes in soil water content to calculate water balances in the test fields. Additionally, OSU was responsible for assessing the suitability of the web based user interface (i.e. determining whether client farms are comfortable with the information content and format of the web pages and adapting the interface in response to their feedback).

The primary advisory services being provided to the participating farms included: (i) recommendations for conventional irrigation scheduling strategies, (ii) pre-season estimation of seasonal irrigation schedules, (iii) analysis of alternative scheduling strategies to enable the farm manager to plan water use in advance, and (iv) detailed record-keeping.

Proposed rules for conventional irrigation scheduling

The irrigation advisory services provided by this program have included both conventional irrigation scheduling (i.e. near-full irrigation) and alternative, water conserving strategies. Graduate students working with the cooperating farms have consulted with the farm managers regarding the strategies they wish to pursue during each season. Though advice on conventional irrigation strategies has been made available to them from the beginning, some have chosen water conserving strategies on their own. Scheduling advice to implement such water-saving strategies has been provided by the system. As noted earlier, the analyses provided to the farms have not provided yield estimates or economic analyses (other than for the analysis of yield impacts of nonuniform systems as noted earlier). However the algorithms for those elements of the analysis have now been built into the program and the OSU intention is to continue this advisory service for the cooperating farms as applied research under the OSU extension program for the indefinite future.

Accomplishments

Four major accomplishments of this project are summarized below:

(i) The project served as a pilot program for a new, web-based irrigation advisory service (OISO); although software development for OISO was funded by NRCS as a parallel project, the WEOP project defined the need and provided the impetus for the service, project staff developed the initial design specifications, and the three year pilot program of implementation, field testing, client feedback from the cooperating farms and redesign of the OISO system have been of critical importance in moving the OISO program from the prototype stage to a functioning version for general use.

(ii) An advanced advisory program for optimum irrigation management was established in central Oregon; this region, where competition for water is expected to intensify in coming years will benefit from the experience gained in implementing the program on cooperating farms over a wide geographic area (Maupin, Prineville and Terrebonne), and will continue to benefit from OSU Extension support of this program during the coming years. OSU extension staff intend to expand the program in that region.

(iii) The project provided a wealth of practical experience for OSU Extension staff regarding the real-world issues and challenges associated with optimum irrigation management; this experience has been of great value as OSU has begun implementing advisory services in other regions of the state and in partnership with other states. That experience has also highlighted research questions that are now being addressed by OSU, in cooperation with other institutions, to make such programs more successful.

(iv) Implementation of the program yielded data that will be useful for extending this program to a wider range of farms in the region.

- a. Collection of data from the WEOP stations provides a basis for improved understanding of spatial variability of ET within the regional microclimates of central Oregon, and the functional relationships derived from those data will provide for more accurate estimation of ET in areas not now supported by Agrimet stations.
- b. intensive investigations of soil profiles, and associated calibration of instruments for soil moisture measurement has provided a much clearer understanding of soils in the central Oregon area, and a better understanding of the value and limitations of local soil surveys.

Conclusions and Recommendations

Though the original project did not fully complete the objectives originally intended, the work undertaken in this project did produce important results and useful conclusions:

1. Water use on the cooperating farms was not excessive, and in fact total water use was often less than total crop water demands. However there was some room for improvement in the timing of irrigations. In some cases they were found to be under-irrigating and in other cases over-irrigating. The scheduling information we provided showed that fairly clearly, and we have the subjective impression that they appreciated and profited from the feedback they received regarding soil moisture conditions in their fields.
2. Irrigation system maintenance problems, resulting in low irrigation uniformities, were a problem in many fields. Such non-uniformities result not only in poor application efficiencies, but potentially reduced yields as well. Yield losses associated with low uniformities under wheel line systems was typically on the order of 5%.
3. Preliminary economic analysis of current water markets suggested that prices currently paid for conserved water are not sufficient incentive to motivate adoption of water conservation strategies.
4. An important aspect of irrigation advisory services in general is the periodic measurement of soil moisture to update estimates of soil moisture. However, three

years of field experience with the cooperating farms in Central Oregon have led to two important conclusions with respect to such measurements:

   a. The TDR probes originally proposed for use in this project proved inadequate for purposes of optimal irrigation scheduling. Though such probes are capable of detecting a wetting front and indicating trends in soil moisture depletion they cannot indicate volumetric water content with any degree of accuracy. However optimal irrigation management requires knowing the actual volume of available water in the root zone and water uptake between irrigations. It was largely for that reason that we were compelled to utilize neutron probe measurements.
   b. Neither soil moisture measurements nor calculated ET provide clearly superior estimates of field-wide soil moisture conditions, but both embody useful information. New analytical methods are needed to use both sources of data in combination to achieve more reliable estimates of crop water availability.

5. The question of whether new varieties of wheat should be promoted where water supplies will be limited suggest that the potential advantages of planting alternative crops better suited to deficit irrigation should be investigated more thoroughly.
6. One other important conclusion was that stand-alone software for irrigation scheduling (such as the WISE program originally intended for use in this project) is not a reliable tool. The evolution of both computer hardware and software rendered the WISE program obsolete within a few years of its release, which points up the need for web-based advisory programs such as the OISO program developed for this project.

Appendix A

Irrigation Management on Cooperating farms

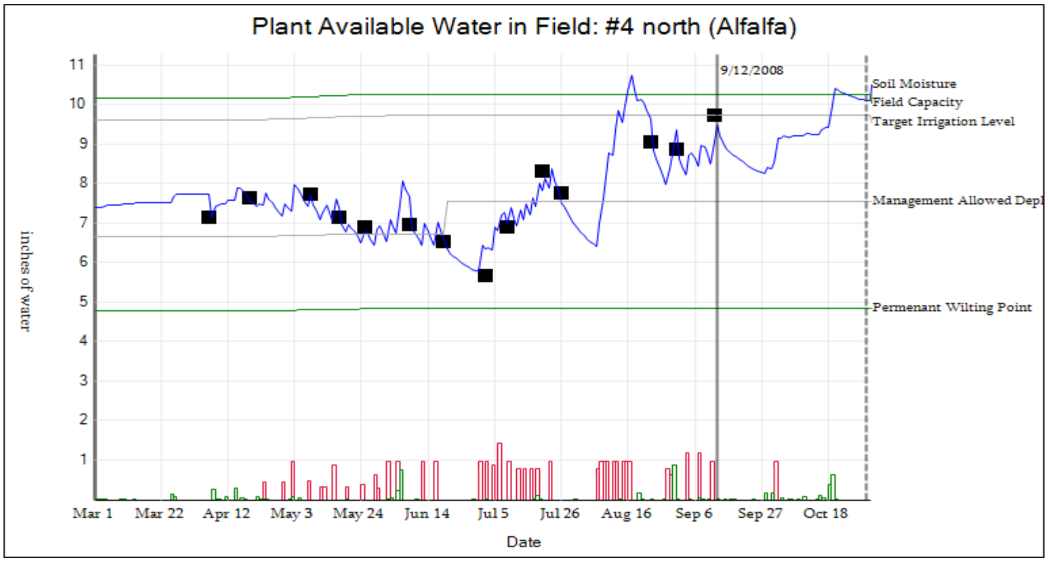
Three farms fully participated in the irrigation scheduling activities of the second and third project years. The following graphs show traces of estimated soil moisture for each field for each season, and periodic measurements of soil moisture (indicated by the black squares). These graphs are to illustrate the format of the irrigation advisory service developed for this project. They also indicate that these farms were managing irrigation reasonably well. Farm 2 under-irrigated early in the first season, but showed improvement in the second year that may have been attributable to the feedback provided by this project.

Farm 1 appeared to be managing water well in both years, as shown by the fact that soil moisture was maintained between field capacity and the allowable depletion for almost the entirety of both seasons, and only rarely exceeded field capacity when irrigated. This farm manager monitors soil moisture carefully on his own using a soil auger.

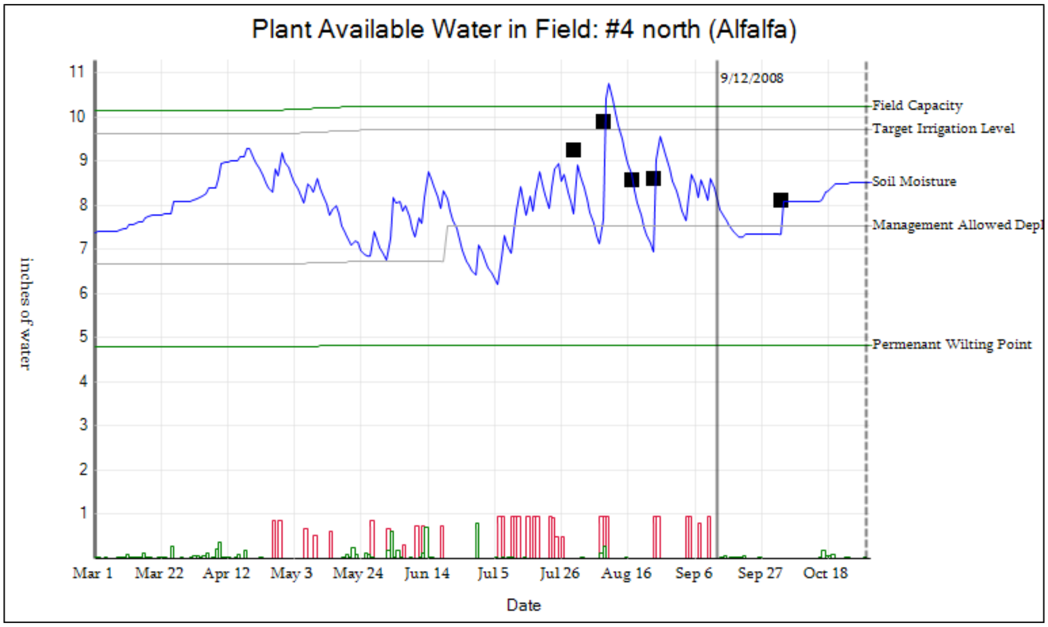
Farm 2 began irrigation late in the first season, and as a consequence the soil moisture was allowed to fall below the allowable depletion level much of the late spring until irrigation began in earnest in late June. In July and August he apparently over-irrigated until late August and then under-irrigated again for the balance of the season. In discussions with the farmer he indicated that he thought the indicated analysis was correct and he had learned from the feedback provided by the program. In the second season he did a much better job of holding soil moisture in the desired range and avoiding over-irrigation.

Farm 1

2007

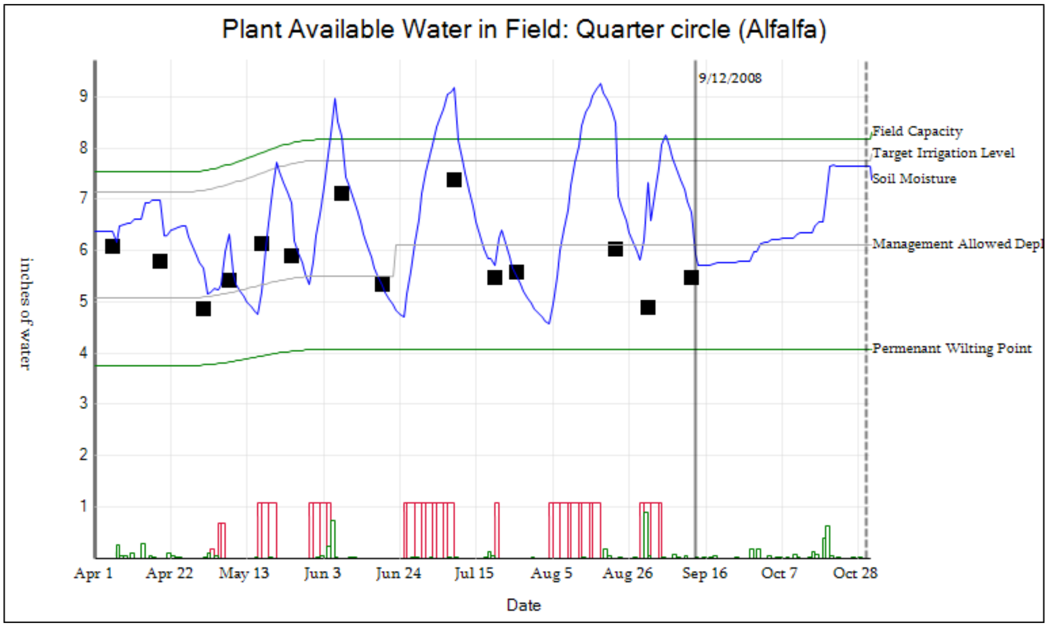


2006

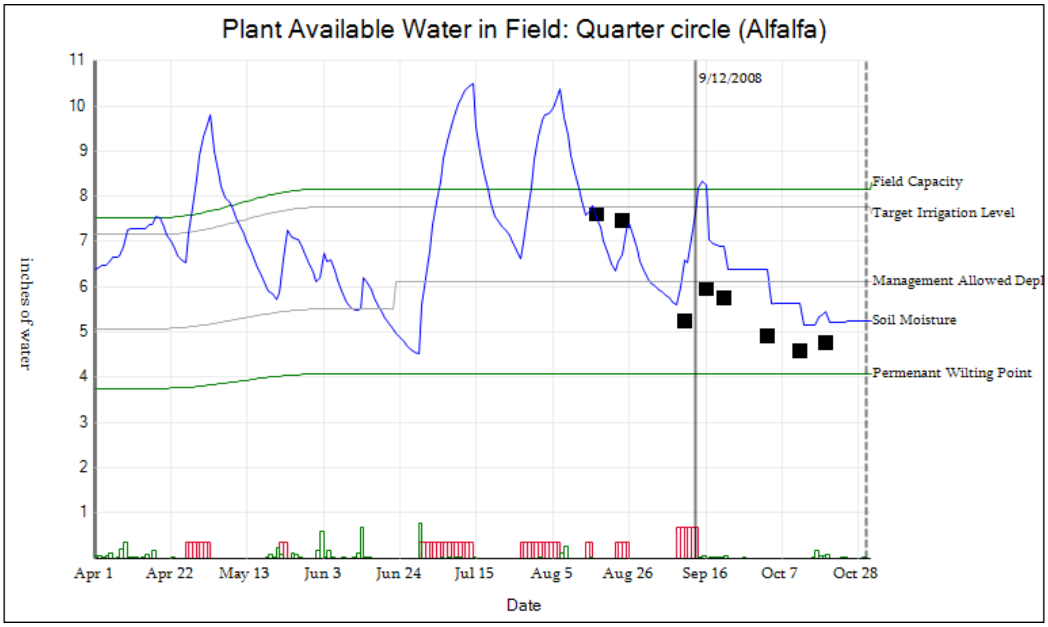


Farm 2

A. 2007

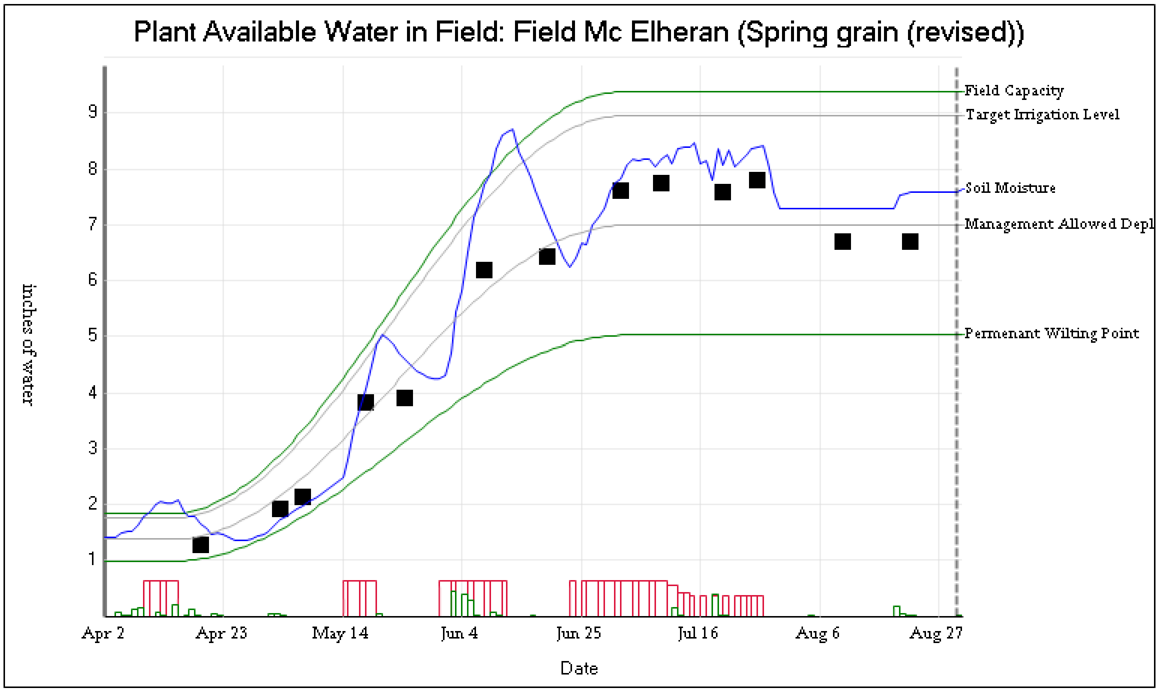


B. 2006

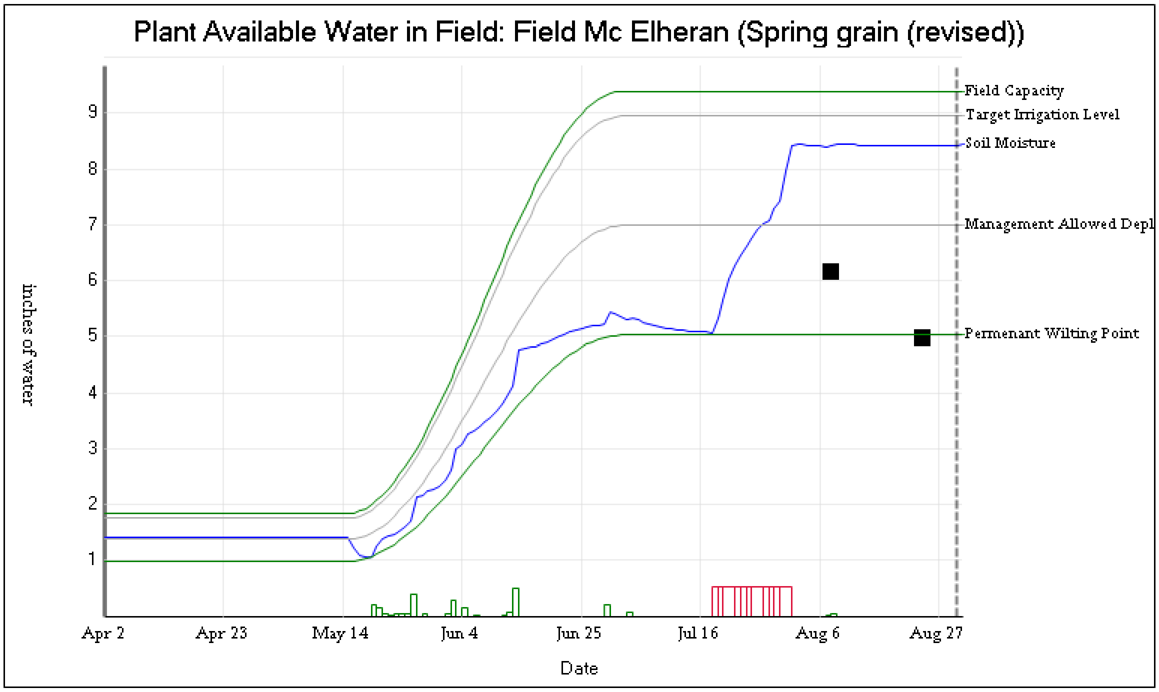


Farm 3

2007



2006



Appendix B
Sample Survey of Irrigation Systems in the Field

<u>Farm 1</u>

Prineville, 2005

Summary

I. **Uniformity**

- **a.** Pivot: poor uniformity; calculated CCU = 62 (See Figures 1 and 2). Three outliers associated with stuck diffuser plats are largely responsible (Figure 1). Tables 1 and 2 summarize the field tech reports of uniformity and observed problems with nozzles and pressure. However, the calculated effect on yields is not bad (Figure 3 and Table 3); yield loss due to pivot non-uniformity estimated at 6%.
- **b.** Wheel lines: it was not possible to conduct catch can measurements due to the height of the crop at the time we began work. Table 4 summarizes observations of the field technicians. The tight spacing of the hand lines implies potentially high uniformity, but the number of sprinkler heads that were stuck, crop interference and the number of plugged nozzles suggest the uniformity may be quite low.

II. **Irrigation scheduling**

Pivot schedule in Table 5 was used with OISO, based on Powell Butte Agrimet station. Results shown in Figure 4 and summarized in Table 6. The analysis was based on two key assumptions, since we did not have actual data for either: (i) soil moisture assumed to be at field capacity as of April 1, since late spring 2005 was unusually wet; (ii) the analysis used a pivot flow rate of 667 gpm based on the observed catch of 1.06 inches with a 24 hour pass.

III. **Needed for further analysis**

- **a.** It would be useful to augment Soil Survey information with on-site information (farm experience) with the soils involved, especially variations in soil depths. The soil survey indicates less than 20 inch depth for much of the field.
- **b.** Measured discharge rates are needed from the pivot.
- **c.** Pump evaluations will await final determinations of water distribution from the pump (number of lines, nozzles, etc.)
- **d.** Catch can analysis of the hand lines in the spring of 2006 would complete this analysis.

Figure 1

Center pivot system

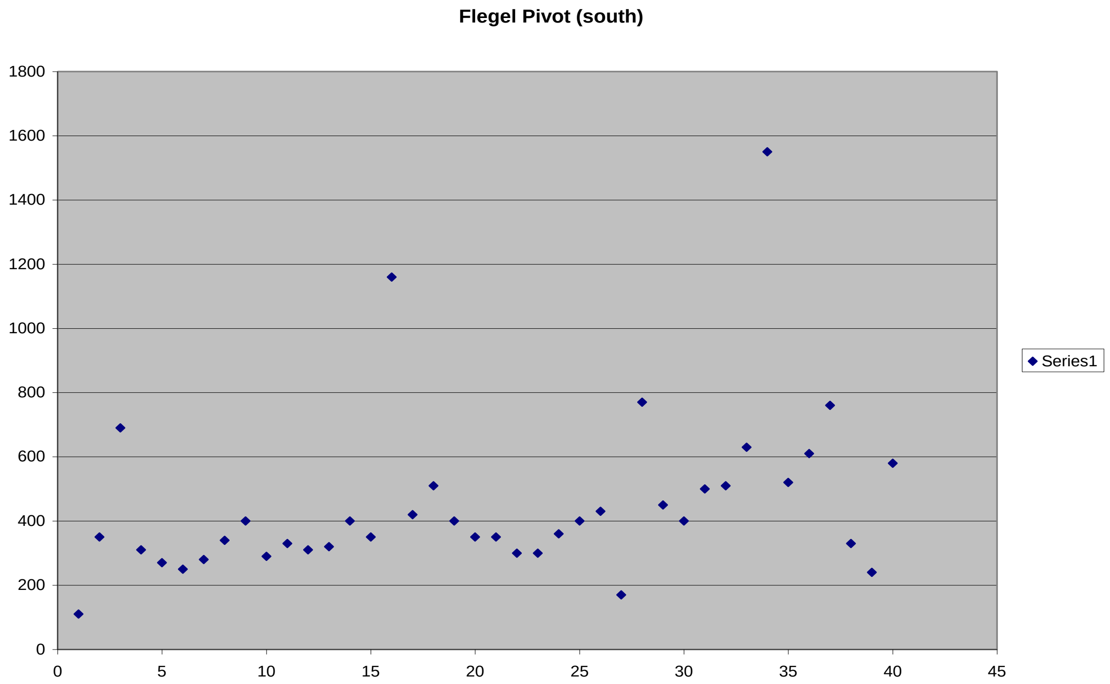


Figure 2

Histogram of catch can readings

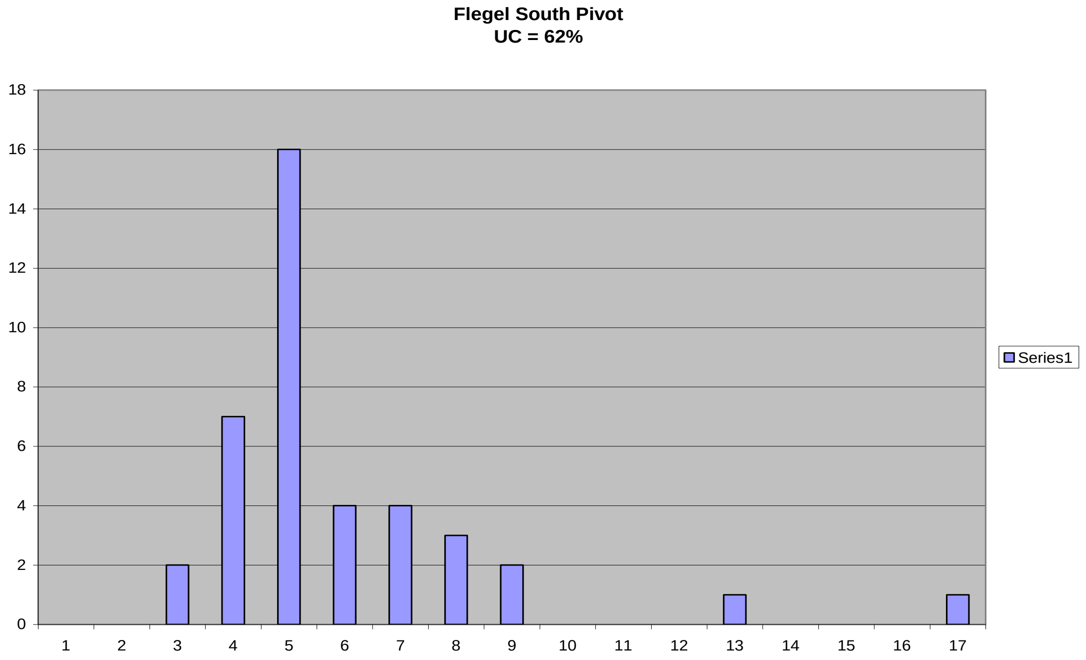


Table 1
South pivot uniformity test

July 1st Area of the cans: 176.6 cm2

Position	Measure (ml)	depth (mm)	Observations
1	110	6.23	
2	350	19.82	
3	690	39.07	Near leaking valve.
4	310	17.55	
5	270	15.29	
6	250	14.16	
7	280	15.86	
8	340	19.25	
9	400	22.65	
10	-	-	
11	-	-	
12	290	16.42	
13	330	18.69	
14	310	17.55	
15	320	18.12	
16	400	22.65	
17	350	19.82	
18	1160	65.69	Plate Stuck
19	420	23.78	
20	510	28.88	
21	400	22.65	
22	350	19.82	
23	350	19.82	
24	300	16.99	
25	300	16.99	
26	360	20.39	
27	400	22.65	
28	430	24.35	
29	170	9.63	2nd plate stuck
30	770	43.60	
31	450	25.48	
32	400	22.65	
33	500	28.31	
34	510	28.88	
35	630	35.67	
36	1550	87.77	2nd plate stuck
37	520	29.45	
38	610	34.54	
39	760	43.04	Clog
40	330	24.92	(3/4)
41	240	27.18	(1/2)
42	580	65.69	(1/2) Ponding

Table 2
Center Pivot Summary

Center Pivot evaluation.

Crop: Alfalfa
8 towers of 160 ft each
Pressure: 25 psi regulators working well.

Problems found:

1- clogging of one nozzle; see Figure 1.
2- Three plates stacked.
3- Valve leaking; see Figure 2.
4- Nearest nozzle to the pivot point applying too much water. (Ponding)

The result of these problems is non-uniformity of the water applied, as showed in table 1.

General analysis

Average depth (mm):	26.8
Standard Deviation (mm):	15.8
CV:	59%

If the problems described were solved, the uniformity in the application will improve as shown below

Excluding problems and changing nozzle of can 42

Average depth (mm):	22.87
Standard Deviation (mm):	6.5
CV:	28%

Clogged nozzle.

Valve leaking.

Figure 3

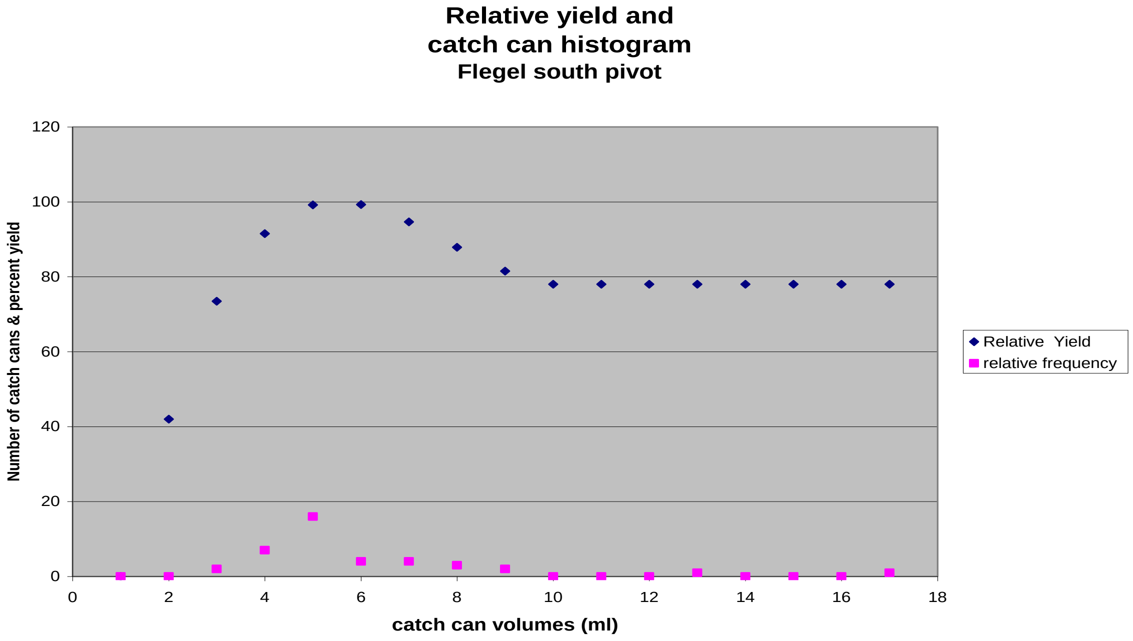


Table 3
Analysis of relative yield

Increment	Count		Relative depth	Relative Yield		Contr. To yield
0	0		0	0.00	0	0
100	0		0.22	42.00	0	0
200	2		0.44	73.47	2	147
300	7		0.67	91.53	7	641
400	16		0.89	99.18	16	1587
500	4		1.11	99.29	4	397
600	4		1.33	94.64	4	379
700	3		1.56	87.88	3	264
800	2		1.78	81.52	2	163
900	0		2.00	78.00	0	0
1000	0		2.22	78.00	0	0
1100	0		2.44	78.00	0	0
1200	1		2.67	78.00	1	78
1300	0		2.89	78.00	0	0
1400	0		3.11	78.00	0	0
1500	0		3.33	78.00	0	0
1600	1		3.56	78.00	1	78
			1	10.00	40.00	
					Rel. yield	93%
yield	**Coefficients**	-0.06	2.58	-2.00	0.50	-0.02

Table 4
Hand move sprinklers

Irrigation system evaluation July 1st

Irrigation System Observations

System – type and make	**Hand move sprinklers 1**	**Hand move sprinklers 2**	**Hand move sprinklers 3**
Crop	Wheat filling grain	Wheat filling grain	Wheat filling grain
Root zone depth			
Main line size and material			
Lateral size and material	3''? Aluminum	3''? Aluminum	3''? Aluminum
Lateral length			
Length of each pipe (tower)	40ft	40ft	40ft
# of sprinklers per pipe (tower)	1	2	3
Sprinkler spacing	40ft	40ft	40ft
Sprinkler height above ground	2 ft	3 ft	4 ft
Move distance			
Move time			
Time to complete one irrigation			
Time to complete one irrigation during Peak ET			

General Questions

Is there crop interference of the sprinkler pattern?	Yes, see Figure 3	No	yes
What percentage of the sprinklers are not rotating?	89%		60%
What percentage of the water is leaking?	Big leak 7th union (o-ring failure), See Figure 2.	None	none
What percentage of sprinklers are fully plugged?	(2/9) ntentionally 22%	none	none
Is sand wear noticeable on the nozzles or impact lever?	-	-	-

Nozzles and Regulators

Are low pressure nozzles used?	no	no	no
Are flow control nozzles or bases used?	no	no	no
Are there pressure regulators?	no	no	no
Is there excess pressure loss in the system?	16.7%	none	2.20%

First Sprinkler Row Behind the Barn – 1							
# In-line	**Nozzle**	**Rate (12lt)**	**Rate (m/12lt)**	**Flow (lt/min)**	**Flow (gpm)**	**Pressure**	**Notes**
1	9/64	1:00:45	1.0075	12.1	3.19	24	Stuck
2	5/32	0.50.94	0.8489	10.2	2.69	24	Stuck
3	5/32	0.47.79	0.7964	9.6	2.52	24	(none)
4	9/64	(none)				(none)	Intentionaly clog
5	5/32	0.50.94	0.8489	10.2	2.69	23	Stuck by Wheat
6	9/64	1:00:22	1.0036	12.0	3.18	22	Stuck, banging
7	9/64	1:07:24	1.1206	13.4	3.55	21	Stuck by wheat + big leak
8	5/32	0:50:42	0.8403	10.1	2.66	20.5	Stuck by wheat
9	9/64	1:03:01	1.0502	12.6	3.33	20.5	(none)
10	5/32	(none)	-	-	-	(none)	Intentionaly clog
11	9/64	1:01:59	1.0265	12.3	3.25	20	End of line
			Average:	11.4	3.01	22.1	
			Standard dev.:	1.39	0.37	1.67	
			CV:	12%	12%	8%	

Second Sprinkler Row Behind the Barn (3:45pm – 4:10pm) – 2						
# In-line	**Nozzle**	**Pressure**	**Rate**	**Rate (lt/min)**	**Rate (gpm)**	**Notes**
1	(none)	30	4000ml / 15 sec	16	4.23	Edge of field
2	(none)	30	6400ml / 15 sec	25	6.60	
3	(none)	30	4100ml / 15 sec	16.4	4.33	
4	(none)	30	3400ml / 15 sec	13.6	3.59	Middle of field
	Average:	30		17.8	4.69	
	Standard dev.:	0		4.99	1.32	
	CV:	0%		28%	28%	

First Sprinkler from road (3:00pm – 3:45pm) – 3						
# In-line	**Nozzle**	**Pressure**	**Rate**	**Rate (lt/min)**	**Rate (gpm)**	**Notes**
1	(none)	22	2500ml / 15 sec	10	2.64	
2	(none)	22	2250ml / 15 sec	9	2.38	
3	(none)	22	2750ml / 15 sec	11	2.91	Stuck
4	(none)	22.5	2875ml / 15 sec	11.5	3.04	Stuck
5	(none)	22	2750ml / 15 sec	11	2.91	
6	(none)	22	3100ml / 15 sec	12.4	3.28	Stuck
7	(none)	22	2800ml / 15 sec	11.2	2.96	Stuck
8	(none)	22	3300ml / 15 sec	13.2	3.49	
9	(none)	22	2800ml / 15 sec	11.2	2.96	Stuck
10	(none)	21.5	3000ml / 15 sec	12	3.17	Stuck
	Average:	22		11.3	2.97	
	Standard dev.:	0.24		1.18	0.31	
	CV:	1%		10%	10%	

o-ring failure.

crop interference.

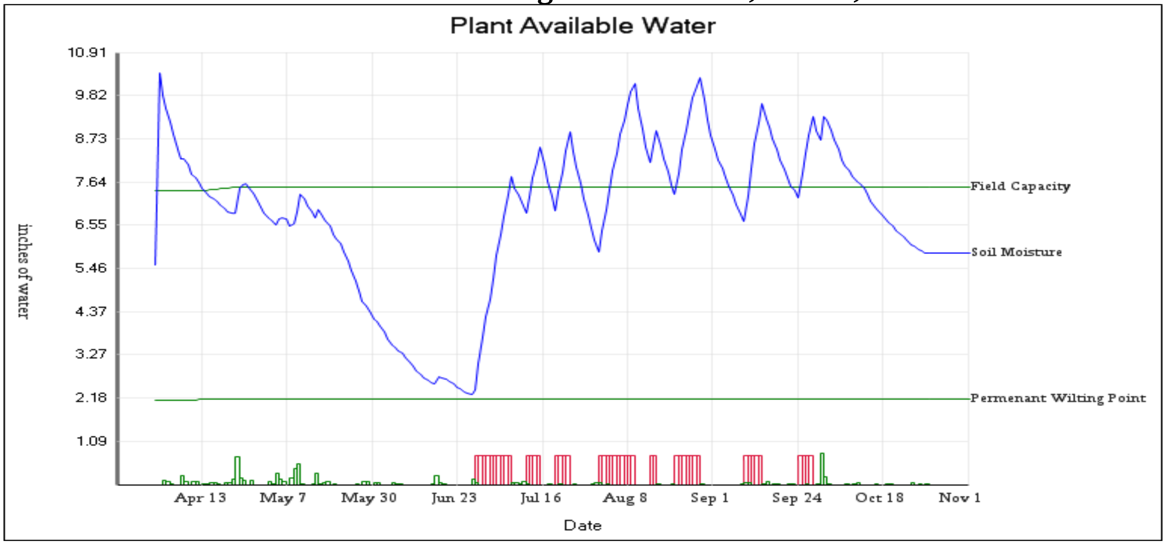
intentional clog.

Sprinkler Measurements

System	Sprinkler location	Pressure (psi)	Discharge (gpm)	Nozzle Diameter
Hand move 1	1	24	3.19	9/64
	2	24	2.69	5/32
	3	24	2.52	5/32
	4	-	-	9/64
	5	23	2.69	5/32
	6	22	3.18	9/64
	7	21	3.55	9/64
	8	20.5	2.66	5/32
	9	20.5	3.33	9/64
	10	-	-	5/32
	11	20	3.25	9/64
Hand move 2	1	30	4.23	
	2	30	6.60	
	3	30	4.33	
	4	30	3.59	
Hand move 3	1	22	2.64	
	2	22	2.38	
	3	22	2.91	
	4	22.5	3.04	
	5	22	2.91	
	6	22	3.28	
	7	22	2.96	
	8	22	3.49	
	9	22	2.96	
	10	21.5	3.17	

Figure 4
Irrigation Scheduling

Calculated irrigation schedule; alfalfa, 2005



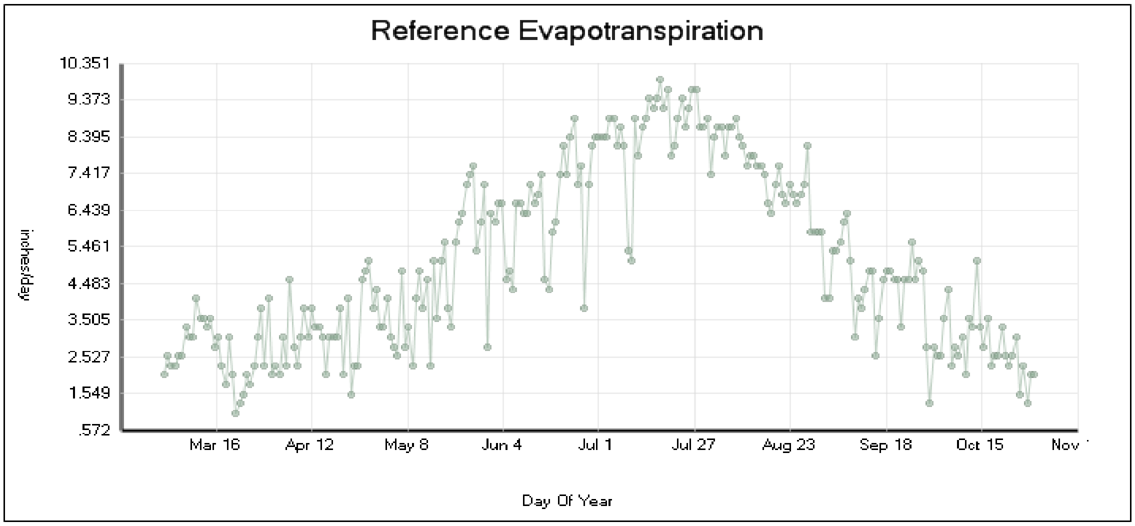


Table 5
Water Use and Disposition

Performance Summary	Depth (inches)
Total Applied (gross)	60.907
Total Applied (net)	32.542
Cumulative ET	36.156
Cumulative Prcip	6.672
Spray Loss	1.162
Deep Percolation	26.306
Run Off	2.419
Water Balance	-5.006

Table 6
Irrigation Schedule
South Pivot

Start date	Duration
June 28	10 days
July 12	4 days
July 20	4 days
	Cutting: July 25
August 1	10 days
August 15	2 days
August 22	7 days
	Cutting: July 25
Sept. 10	5 days
Sept 25	4 days

Pump evaluation

July 8th data

		Pump ID	Blue	Orange
Is the pump curve available?		No	No
Type of pump:		Centrifugal	Centrifugal
Manufacturers Plate			
	Required pump operating speed	-	-
	Brand	Berkley	Berkley
	Model	B4JPBH	B4JPBH
	Impeller Diameter	10.75	10.75
	Serial Number	M4251	M4251
Motor characteristics:		Baldor	Baldor
	Nominal horsepower	25	25

Measurement:

1- Pump speed		-	-
2- Total pumping head (**H**):			
	Pressure Head (psi)	44	44
	Pressure Head (*2.31ft/psi) (ft)	101.64	101.64
	Pumping lift (ft)	3	3
3- Outlet flow rate (**Q**) (gpm):		413	440.9
	WHP(Q*H/3960):	10.9	11.7
4- Electricity (fuel) consumption (**BHP**) kWhr:			
5- **EFFICIENCY** (WHP/BHP*100) **%**:			

Figure 1; Flow measurement.

Note: Wade expected more flow rate from the second pump, in spite of been the same pumps

Water delivery	***Pump 1***	***Pump 2***
Is there a flow meter?	No	No
What is the reading?	-	-
Water source	Channel	Channel
Is there a filtration system?	Yes	Yes
Type of infiltration system:	Screen with rotating sprinkler.	Screen with rotating sprinkler.
Flow rate measured by our flow meter.	413 gpm	440.9 gpm
Water market?		
Notes:	Moss in some nozzle deflectors.	Moss in some nozzle deflectors.

Appendix C

Comparison of ET estimates from all WEOP stations and two Agrimet stations (Madras and Powell Butte)