NRCS Conservation Innovation Grant – Final Report

Implementation of an Irrigation Management Program for Energy Conservation

Oregon State University

Summary:

The objectives of the above named project were: (i) to conduct a high visibility pilot demonstration of an advanced irrigation advisory program for developing and supporting energy conserving irrigation strategies to increase farm profit, and (ii) to motivate and facilitate use and/or adaptation of the program by other individuals and institutions.

Two engineers have been employed for the field data collection, web-site file setup, analytical operations and analyses. They are; (i) Lorraine ElKhoury, MS, focused on expanding the application of IMO at the Madison Ranch to encompass almost the entire farm, and managed most of the web-based operations; (ii) Dr. Yutaka Hagimoto, PhD, focused on field work at the BTF, provided additional field support for the work at Madison Ranch, and assisted with analyses. He also prepared recommendations for field data collection for a mobile lab. Additional support has been provided by Dr. Charles Hillyer, the systems analyst who developed the web-site and program.

Setup of IMO files for management of demonstration fields at the Greenwood Industries Boardman Tree Farm (BTF) was completed for eight field plots in March, 2012, in time for virtually the entire irrigation season. Field data collection operations were conducted independently but in parallel by OSU and BTF with the aim of comparing results.

Setup of web-based operations for seven fields at the Madison Ranch was completed in advance of the 2012 season, along with installation of supporting instrumentation. However, at the request of the cooperating farm owner the scope of the demonstration plots at Madison Ranch, which was originally intended to involve the original seven demonstration fields, was expanded early in the season to encompass almost the entire farm. Setup of 72 fields was completed late in the season, but field-by-field calibration of all fields to maximize system accuracy was not completed until the fall of 2012. Soil moisture data for selected fields were collected by OSU. Additional soil moisture data from a number of fields and pumping plant operating data from all farm pumping plants were provided by an outside contractors (IRZ Consulting) and Umatilla Electric, respectively.

Detailed recommendations for field data collection for a mobile lab designed to support IMO have been prepared. Those recommendations are summarized in Attachment 1.

An open-source version of IMO is ready for dissemination, pending completion of an open-source license through Oregon State University. The final discussions with the Oregon State University manager of intellectual properties and licensing are in progress at this writing.

There were a number of significant difficulties encountered in the course of the work to date. Some of those are being addressed at this writing. Additional efforts undertaken to resolve those difficulties have

been supported with supplemental funding provided by the Madison Farm and OSU Agricultural Research Foundation.

Two primary tasks remain to be completed:

1. The first task is an investigation of persistent discrepancies between water balance calculations and soil moisture measurements at BTF plots. Both Boardman Tree Farm and the project personnel at OSU have expressed a desire to meet for that purpose, but because of scheduling conflicts it was not possible to arrange that meeting before the fall, 2013.
2. The second task involves final release of an open-source version of IMO. That will involve completion of an open-source license through Oregon State University. Some expansion of the on-line documentation of the open-source code version of IMO will also be done. The internal documentation of the open-source software is sufficient for a user to understand the program and modify it as needed. However supporting on-line materials are to be added to explain the technical foundations and economic theory upon which IMO is based.

Madison Farms:

The original plan for the Madison Farm called for demonstration operations on 7 fields. However the scope was increased to encompass most fields on the farm at the request of the farm owner, though a few small fields were not included. The Madison Farm provided supplemental funding for the field tech to complete the full-farm setup. Final configuration for the farm involved 9 crops on 72 fields. Specific soil patterns for each field were set up in the data base using NRCS soil maps. Similarly, field-specific irrigation system parameters were also loaded into the data base. Attachment 2 enumerates the various system components in the final configuration.

Even with some fields eliminated, the 72 fields involved, combined with a water supply system driven by multiple pumps that were overlapping for a number of fields, made the system very complex. The expanded scope was undertaken to assess the capability of IMO to deal with large numbers of fields, but the resulting complexity proved to be beyond the capability of IMO to manage efficiently. Consequently the farm setup in IMO was re-configured as four individual farms with independent water management units. The 72 fields were allocated among these four independent farms. One immediate conclusion was that for a farm of this size and complexity IMO operations should be set up to manage a limited number of 'indicator fields' which will be managed and tracked to provide guidance for other similar fields.

Additional supporting work for the Madison farm involved background research on yield modeling for two of the primary crops, winter wheat and alfalfa. Lourraine El Khoury, evaluated two alternative yield models, the FAO 33 model and the *Water Optimizer* developed at the University of Nebraska, for use with the Madison Ranch cropping, in particular focusing on wheat production. The conclusion of that evaluation was to continue using the FAO 33 model, which is currently embedded in IMO. El Khoury also used field data from the Madison ranches to calibrate a specific yield model for alfalfa based on the FAO 33 algorithm.

The work undertaken at Madison Farm attracted the interest of the Northwest Energy Efficiency Alliance, which was initiating a parallel effort for a program of field demonstrations of advanced

technologies for improving energy efficiency in irrigated agriculture. Informed by the work at OSU, NEEA began a demonstration of multiple energy conservation technologies during the 2012 season that included four of the Madison fields using IMO as the system 'integrator'. That effort was continued on the Madison farm for a second year (2013), and a third year (2014) is pending.

Boardman Tree Farm

The BTF field project installed neutron probe access tubes and capacitance sensors in two BTF plots, identified as #408 and #409. Each plot consisted of four sectors, with different poplar varieties grown and different irrigation treatments applied in each sector. The BTF field instrumentation also varied from one sector to another as summarized in the table below.

Summary of neutron probe and capacitance sensor installation in the proposed field project at the GreenWood Resources Boardman Tree Farm.

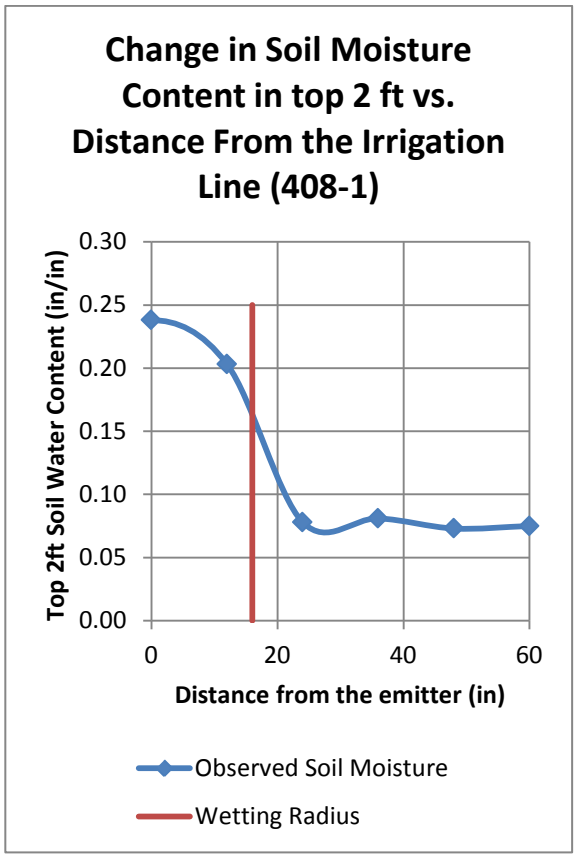
Field	Block/Location	Irrigation Level	*Neutron Probe	Capacitance Probe
409	1	Deficit Irrigation (-15%)	IN-F / BT-F	Yes
409	2	Over Irrigation (+25%)	IN-F / BT-F	Yes
409	3	Over Irrigation (+25%)	BT-R	
409	4	Over Irrigation (+25%)	BT-R	
409	ECH2O probe location		ECH-R	Yes
408	1	Over Irrigation (+25%)	BT-R	Yes
408	2	Over Irrigation (+25%)	BT-R	
408	3	Over Irrigation (+25%)	BT-R	
408	4	Over Irrigation (+25%)	BT-R	
408	ECH2O probe location		BT-R	Yes

*IN: access tube is installed near an emitter.
*BT: access tube is installed between irrigation pipes.
*ECH: access tube is installed near ECH2O sensor, and a point with similar condition in each block.
*-F: full observation (e.g., 5, 10, 20, 40, 60, 80 cm).
*-R: reduced observation will be made at ECH2O installation depth plus few more depths.

Initially the field study was designed to characterize patterns of soil water availability for different irrigation treatments ranging between 15% deficit and 25% over-irrigation schedules. In particular, it was important to derive an informed estimate of the wetting diameter of the drip system. Paired neutron probe access tubes capacitance sensors were installed at Block 1 (15% deficit irrigation) and Block 2 (25% over irrigation) of #409. One access pipe (IN-F) was installed near an emitter in an irrigation line to monitor soil water availability under the wetter condition, and the other access pipe (BT-F) was installed between two irrigation lines to monitor soil water availability under the dryer condition. At each pipe, neutron probe readings were made at 6 to 8 depths over 0 to 4 ft deep (full observation). An example of the resulting observations of the soil water depletion pattern illustrates

the general character of soil water depletion for the drip layout and tree planting pattern used at BTF (see below):

Sample Number	Distance from the emitter (Radius)		Water Content
	(ft)	(in)	(in/in)
Dummy	-1	-12	0.203
1	0	0	0.238
2	1	12	0.203
3	2	24	0.078
4	3	36	0.081
5	4	48	0.073
6	5	60	0.075



Calculation

Parameter	Unit	Value
Distance between irrigation lines	(in)	305
Distance between emitters	(in)	113
Effective Root Depth	(in)	24
Estimated Wetting Radius	(in)	16
Wetting Volue	(in)	19292
Total Volume	(in)	827160
Wetting volume	(%)	2.3

The second part of the BTF field study collected data from 7 over-irrigated blocks in order to: (i) observe any difference in SWA between two fields with different clones, and (ii) verify currently used ECH2O sensors. Additional neutron access pipes were installed Block 3 & 4 of #409 and Block 1 through 4 of #408. At each pipe, neutron probe reading were made at 4 depths over 0 to 3 ft deep. The observation depths and condition (distance from emitters and irrigation lines) were determined based on the condition of the ECH2O sensor in the first part of the study.

Installation of access pipes for the neutron probe method and capacitance sensors was completed by the end of March, 2012. Soil water content was measured at the time of the installation to quantify initial SWA. Between April and October, we visited the field bi-weekly, depending on the labor availability, for neutron probe readings and data download.

The model is set up for 7 blocks with various irrigation levels (e.g., 80%, 100%, 115% and 120%). The irrigation systems and their schdule at each block are set up based on the information released from the farm. Therefore, parameters for crop (e.g., Kc, root depth, etc) and soil (e.g., Ksat, water holding capacity, etc.) are to be calibrated using observed soil moisture content collected with the neutrop probe method and gravimetric samples. The crop coefficients to be used to estimate ET of the trees at various years of maturity and seasonal stages of canopy development. For that purpose we utilized standard Agrimet coefficients. However, our monitoring of soil moisture did not match the water balance modeling of ET using those coefficients, and it was not possible to recalibrate the IMO model in a reasonable way to fit the results. Attachment 3 illustrates the discrepancies observed and a series of attempts to recalibrate the IMO model.

The overall result of the work at BTF was that we were unable to arrive at a realistic calibration of the model using the field data or to reconcile BTF field data with the IMO model. At this writing we are renewing efforts to understand why. The problem may lie with the crop coefficients, though the weather data or moisture monitoring strategies could also contribute to the problem. BTF has derived crop coefficients for their own use for the varieties in place at the Boardman Tree Farm, but those coefficients are BTF proprietary, and therefore not freely available to us. However the apparent errors in soil water balance calculations need to be resolved in consultation with BTF, and it is for that purpose that we seek a no cost extension to allow additional time this winter to meet with the management of the Boardman Tree Farm to review the field data and analyses from the BTF plots.

Open Source Version of IMO

The web-based system has two primary components, IEM, which is the analytical engine, and IMO, the web-interface. These are to be licensed separately. It is anticipated that the interface product will have a limited usefulness since it needs updating and revision in various ways. The software is internally documented sufficiently well to enable an individual to use or adapt it as needed. However additional files will be provided on line to provide theoretical foundations and other user support. Both the software and the supporting documentation are continuing to evolve, and the latest versions will be the release versions. Anticipated release date is January, 2014.

OSU policy is that copyright for any intellectual property resides with OSU. Since the grant contract calls for release of an open-source version of the IMO system the university will provide an open source license at no charge to users. However there are certain stipulations that are associated with the license, such as attribution of OSU as the source and feedback of any modifications done to the software. Other stipulations may be desirable from the point of view of the authors, the department or the university. The principles for the project have met twice with the Office for Commercialization and Corporate Development, which has responsibility for licensing. At this writing the final terms and conditions controlling open source release are being reviewed by the primary system programmer (Charles Hillyer).

Attachment 1: Suggestion for a observation system for IMO

The proposed observation system is designed to support IMO users by 1) monitoring irrigation systems and field conditions, and 2) providing the observed data to IMO and the users. The proposed system will consist of a base station (BS), pump stations (PS) and field stations (FS). Each system will observed parameters necessary to estimate FAO 56 reference evapotranspiration. All stations will be connected through wireless communication.

Suggested system features:

- Each system consists of one base station (BS), pump stations (PS), and field stations (FS).
- All stations (PS, FS, and BS) communicate through wireless network using XBee technology (communication range up to 1 mile).
- Base station (BS), which consists of a personal computer and wireless receiver, 1) manages data from PS and FS, 2) provides the data to the user and 3) communicates with IMO.
- Pump stations (PS) monitor pump on/off, wind speed, relative humidity, air temperature, and possibly solar radiation.
- Field stations (FS) monitor soil water content, matric potential, and temperature. These stations also work as communication nodes to connect the network.

Base Station (BS): Incoming data from PS and FS are processed and presented to users. The personal computer, which receives data from the observation system, should display pump and field conditions to the user, communicate with IMO, and display IMO simulation results. Ideally, the processed data are automatically uploaded to IMO daily.

Pump Station (PS): Irrigation pump on/off is monitored by a force sensitive resister. Reading from LED or solar cell can be used to approximate solar radiation. Reading from a micro electric motor connected to anemometer cups can be used to approximate wind speed. Both relative humidity and air temperature can be measured by a RH/T sensor. Power for PS can be supplied from the pivot (or pump) control panel.

Field Station (FS): Soil water content can be monitored by a capacitance based sensor (e.g. Vegetronix VG400). Soil matric potential can be monitored by a gypsum block sensor (e.g. Watermark). Soil temperature, which is important for sensor reading correction and plant productivity, can be monitored by a thermistor sensor.

Sensor readings will be managed by LilyPad data logger (Leah Buechiey), and wireless network among stations (less than 1 mile) will be connected by XBee (Digi International). This setup should be affordable for many farms (e.g. $15/LilyPad and $26/XBee). In addition to the data management setup, inexpensive practical sensors are available from manufactures ($35/Vegetronix VG400, $35/Watermark, $29/RH/T sensor from Sparkfun electronics). Plus, practical approaches suggested for the setup (e.g. application of LED technology for solar radiation and micro motor for wind speed) could keep the cost for the observation system low.

Additional recommendation regarding leaf area index for trees:

Leaf Area Index (LAI) is an important factor to quantify actual evapotranspiration (AET) of trees. Currently, GWRBTF uses aerial image to monitor LAI, which may not provide the accuracy required by the irrigation management at the farm. If GWRBTF is interested in validating this practice using ground based measurement and purchasing equipment (for example AccuPAR from DECAGON Device, $3,100), IMO could provide labor for the operation. IMO staff can make LAI measurements at each site visit and report to GWRBTF. This additional work is suggested because information about soil water content (irrigation demand) as a function of LAI would provide additional information for the management decision-making support system of the farm.

Attachment 2:

Fields, crops, soils and pumping plant combinations at the Madison Farm

Field	Crop	WMU
M001	Alfalfa (peak,no cut)	Madison Farm #01
M002	Winter Grain-Madison Farm	Madison Farm #01
M002_Corn	Corn (field)	Madison Farm #01
M003	Winter Grain-Madison Farm	Madison Farm #01
M049	Corn (field)	Madison Farm #01
M049E	Potatoes (Shepody)	Madison Farm #01
M050	Corn (field)	Madison Farm #01
M043	Potatoes (Shepody)	Madison Farm #02
M044	Peas	Madison Farm #02
M045	Alfalfa (peak,no cut)	Madison Farm #02
M046	Alfalfa (peak,no cut)	Madison Farm #02
M047	Rapeseed (Canola)	Madison Farm #02
M048	Rapeseed (Canola)	Madison Farm #02
M110LY-107	Rapeseed (Canola)	Madison Farm #02
M111LY-112	Potatoes (Shepody)	Madison Farm #02
M112LY-113	Winter Grain-Madison Farm	Madison Farm #02
M004	Potatoes (Shepody)	Madison Farm #03
M005	Alfalfa (peak,no cut)	Madison Farm #03
M006	Potatoes (Shepody)	Madison Farm #03
M007	Corn (field)	Madison Farm #03
M008	Alfalfa (peak,no cut)	Madison Farm #03
M009	Spring grain	Madison Farm #03
M010	Winter Grain-Madison Farm	Madison Farm #03
M011	Winter Grain-Madison Farm	Madison Farm #03
M012	Potatoes (Shepody)	Madison Farm #03
M013	Winter Grain-Madison Farm	Madison Farm #03
M014	Rapeseed (Canola)	Madison Farm #03
M015	Alfalfa (peak,no cut)	Madison Farm #03
M016	Corn (field)	Madison Farm #03
M017	Alfalfa (peak,no cut)	Madison Farm #03
M018	Winter Grain-Madison Farm	Madison Farm #03
M019	Winter Grain-Madison Farm	Madison Farm #03
M021	Winter Grain-Madison Farm	Madison Farm #03
M022	Winter Grain	Madison Farm #03
M023	Alfalfa (peak,no cut)	Madison Farm #03

M024	Winter Grain	Madison Farm #03
M025	Potatoes (Shepody)	Madison Farm #03
M026	Corn (field)	Madison Farm #03
M027	Rapeseed (Canola)	Madison Farm #03
M020	Potatoes (Shepody)	Madison Farm #04
M028	Winter Grain	Madison Farm #04
M032	Peas	Madison Farm #04
M033	Alfalfa (peak,no cut)	Madison Farm #04
M034	Rapeseed (Canola)	Madison Farm #04
M035	Winter Grain	Madison Farm #04
M036	Alfalfa (peak,no cut)	Madison Farm #04
M037	Alfalfa (peak,no cut)	Madison Farm #04
M038	Alfalfa (peak,no cut)	Madison Farm #04
M039	Alfalfa (peak,no cut)	Madison Farm #04
M040	Rapeseed (Canola)	Madison Farm #04
M042	Alfalfa (peak,no cut)	Madison Farm #04
M067	Alfalfa (peak,no cut)	Madison Farm #04
M068	Peas	Madison Farm #04
M074	Alfalfa (peak,no cut)	Madison Farm #04
M074	Alfalfa (peak,no cut)	Madison Farm #04
M074	Winter Grain	Madison Farm #04
M078	Peas	Madison Farm #04
M081	Pasture	Madison Farm #04
M082	Winter Grain	Madison Farm #04
M083	Winter Grain	Madison Farm #04
M084	Winter Grain	Madison Farm #04
M085	Peas	Madison Farm #04
M086	Pasture	Madison Farm #04
M087	Alfalfa (peak,no cut)	Madison Farm #04
M089	Alfalfa (peak,no cut)	Madison Farm #04
M090	Peas	Madison Farm #04
M091	Alfalfa (peak,no cut)	Madison Farm #04
M092	Winter Grain	Madison Farm #04
M093	Winter Grain	Madison Farm #04
M094	Alfalfa (peak,no cut)	Madison Farm #04
M096	Rapeseed (Canola)	Madison Farm #04
M097	Winter Grain	Madison Farm #04

Assignments of pumping plants to Water Management Units

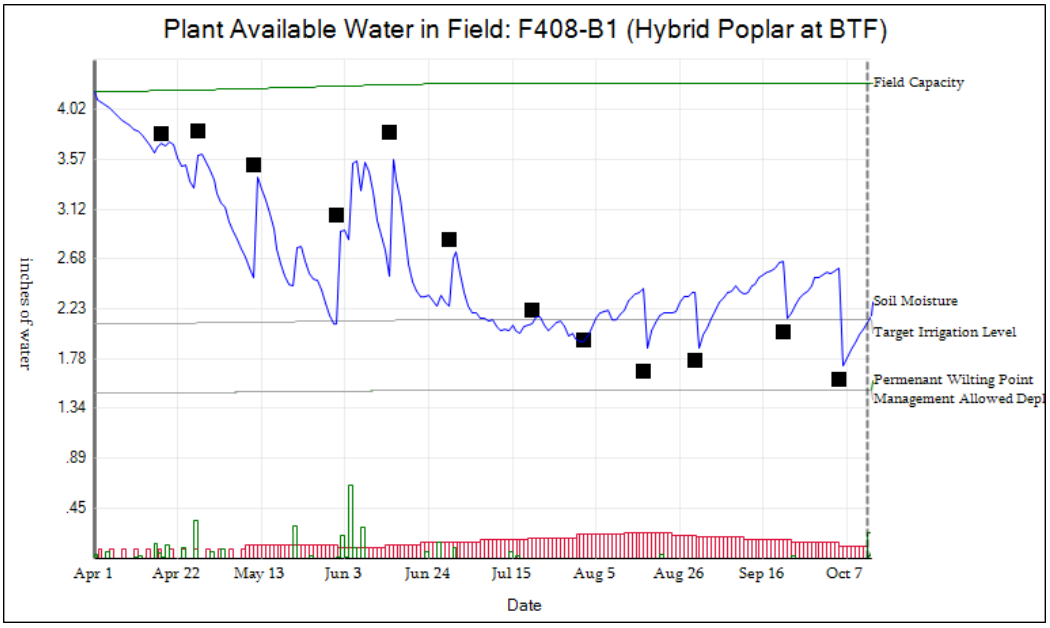
Name	WMU
booster_1	Madison Farm #02
booster_2	Madison Farm #02
Cano Booster	Madison Farm #03
West Booster	Madison Farm #03
CID pump	Madison Farm #01
booster_1	Madison Farm #03
Jills pump	Madison Farm #04
Rockpit	Madison Farm #04
Upper more well	Madison Farm #04
Butter Creek	Madison Farm #04
Windmill well	Madison Farm #04
Deep well	Madison Farm #04
no name	Madison Farm #02
no name	Madison Farm #02

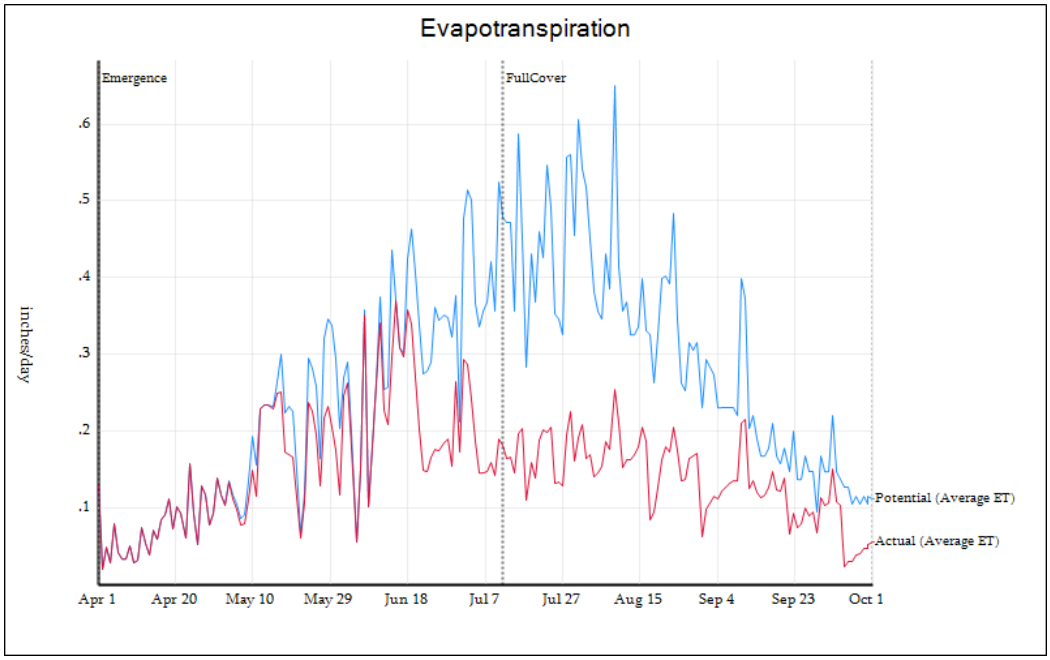
Attachment 3

Steps taken to reconcile observed and modeled soil moisture

Figures below shows the simulated soil moisture content and actual evapotranspiration (AET) through the calibration at Boardman Tree Farm.

First Step: Simulating IMO for Boardman Tree Farm (408-1, 80%) with NRCS soil data and AgriMet crop coefficient. This is the default model. According to AgriMet, Kc for hybrid poplar changes from 0.15 (initial Kc) to 1.00 (full Kc).



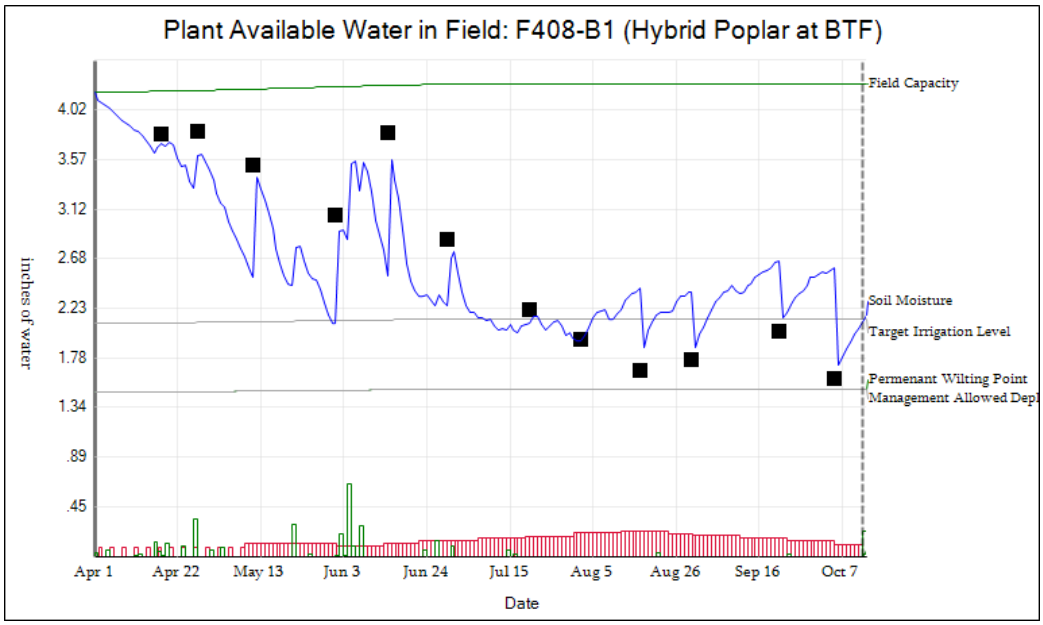


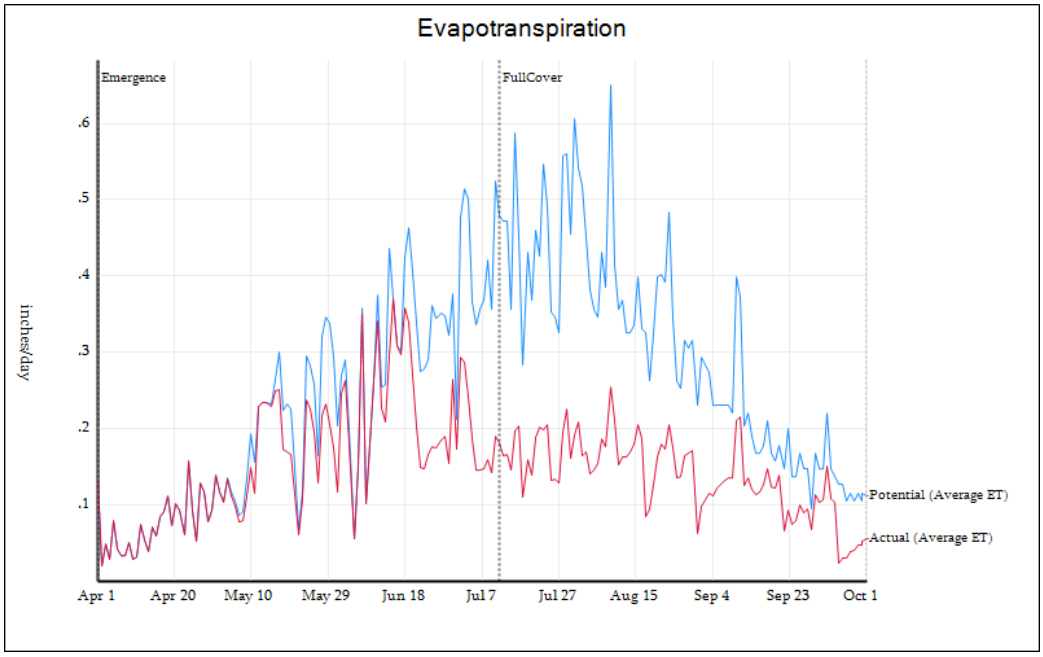
The simulation results indicate:

From April to July: AET is too high. Simulated soil water content drops too much.

From August to October: AET is too low. Simulated soil water content increases too much, but AET is suppressed.

Second Step: Change Kc to 0.10 (initial) to 1.20 (full Kc)

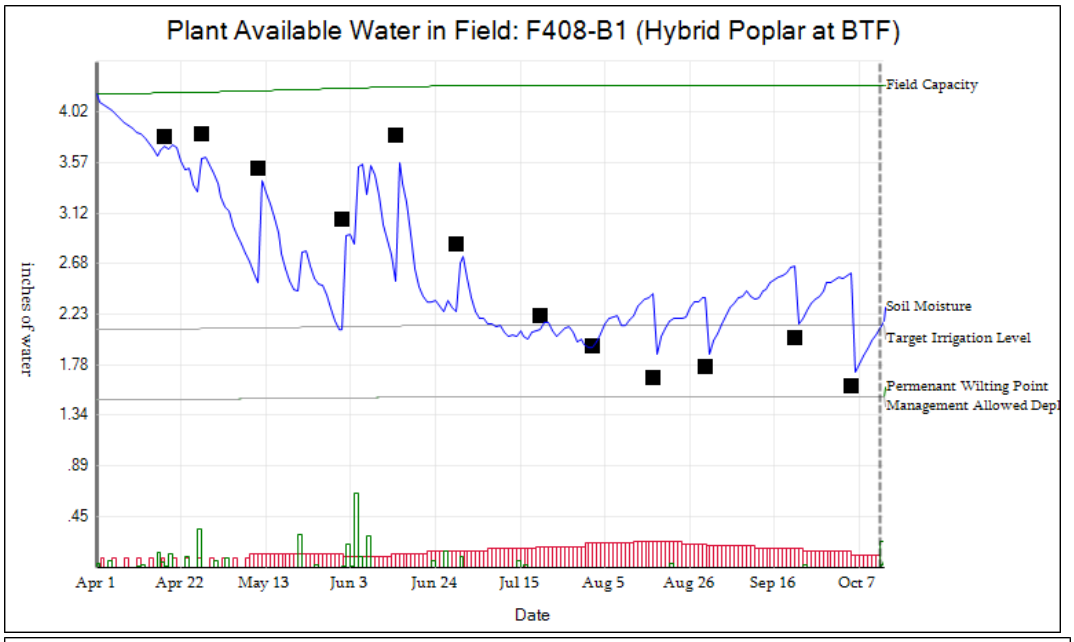


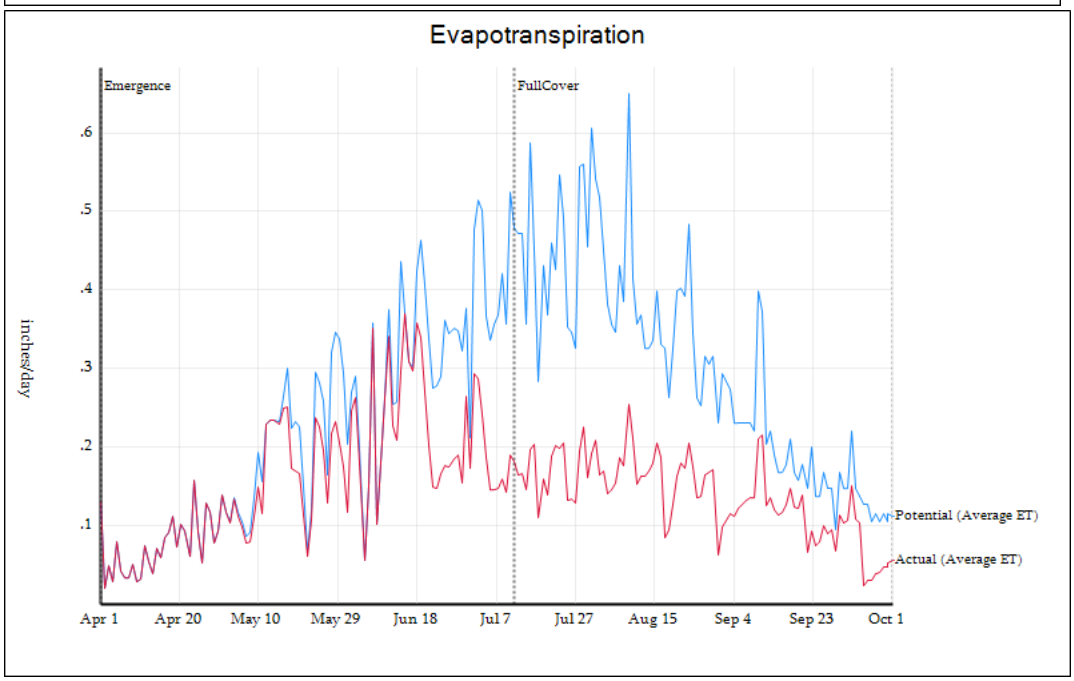


The simulation result:

Despite crop water demand is reduced by 5% in the earlier season and increased by 20% in the later season; there is no significant difference in both plots. This may indicate the controlling factor is not Kc, but soil hydraulic properties.

Third Step: Reduce Ksat by 50% (from 40 to 20 in/d).

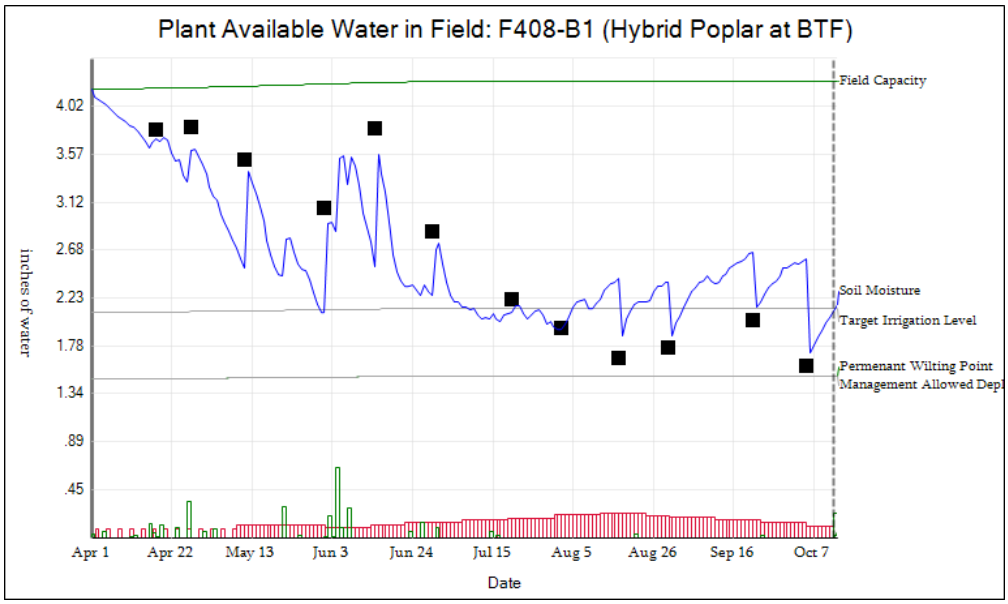


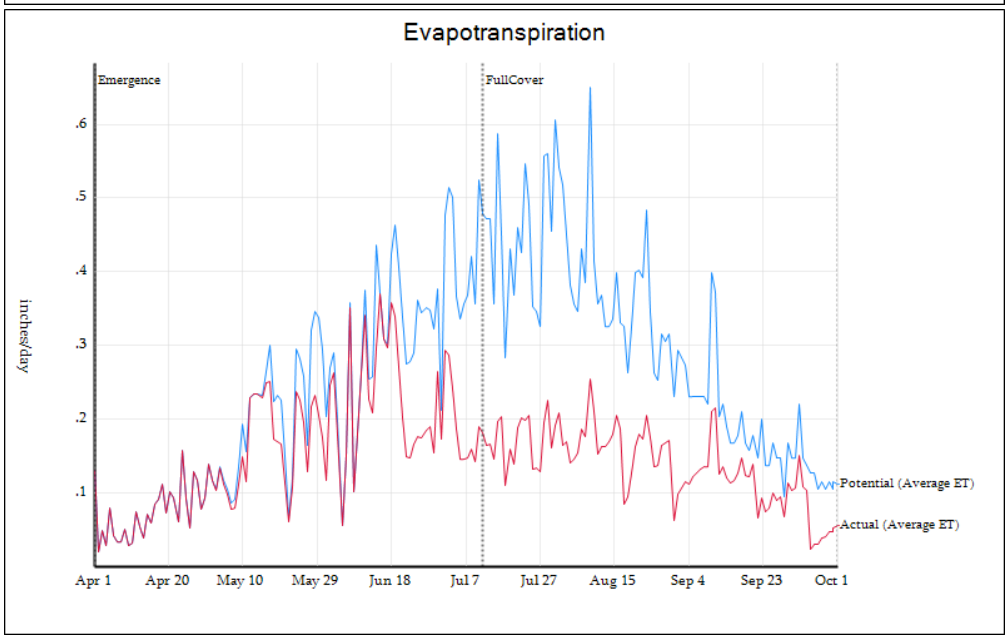


The simulation result:

Both figures don't show any significant change in soil moisture content and AET. Above three simulations indicate crop water demand (Kc) and soil hydraulic properties (e.g., Ksat) are not main controlling factor for this field.

Fourth Step: Change Effective wetted area from 23% to 20.0%.

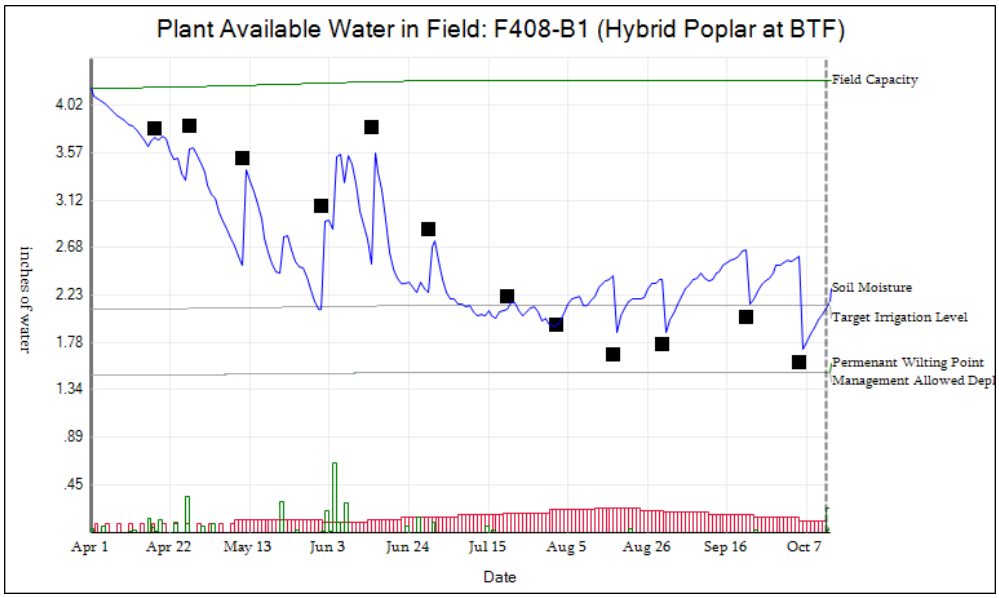


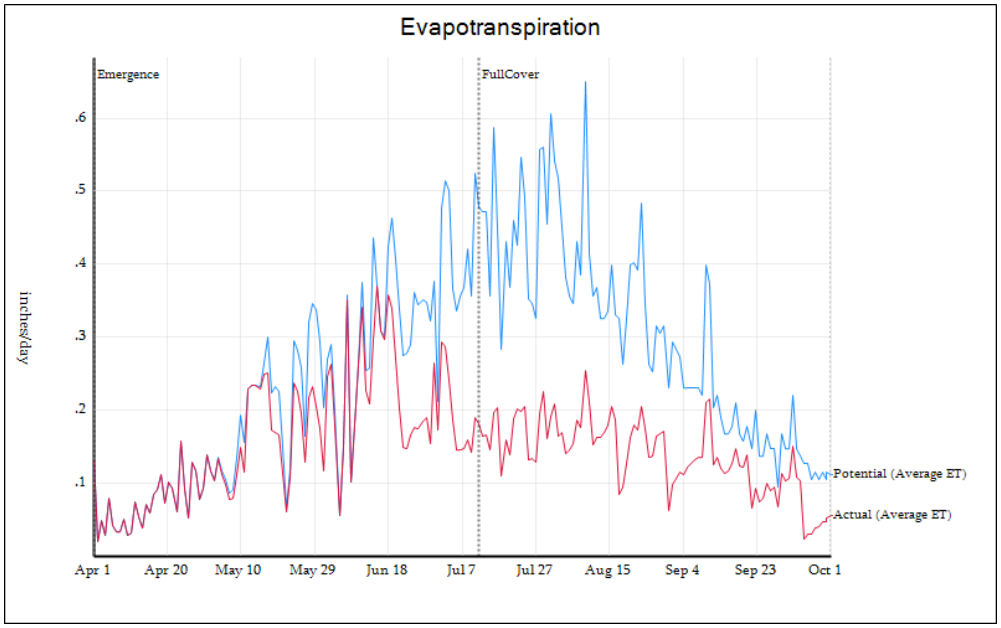


The simulation result:

Again, both figures don't show any significant change.

Fifth Step: Reduce root depth from 2 ft to 1 ft (soil depth remains 3 ft)





The simulation result:

This simulation was run just to see how the root depth affects the simulation. It seems there is no change in both figures.