METHOD FOR IRRIGATION SCHEDULING BASED ON SOIL MOISTURE DATA ACQUISITION

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ABSTRACT

The water requirements of crops are dependent on evapotranspiration (ET), soil chemistry, and the crop's maximum allowable depletion (MAD). Direct measurements of root zone soil moisture, water application along with published ET values and soil textures, can be used in a soil water balance model that can significantly optimize irrigation efficiency. Over the past five years, advancements in computer microprocessors, memory, and software development tools has improved data acquisition methods and made data acquisition system integration more reliable and more cost effective. We discuss here an irrigation scheduling method based on a volumetric soil moisture balance model and data acquisition.

INTRODUCTION

In the western United States, irrigation accounts for about 80% of the water consumed. (Hutson 2000). Concerns about changes in land use due to growing populations, climate change, and the protection of aquatic habitats are driving a need to conserve water. Optimization of irrigation will not only benefit the environment, but also benefit local economies.

Over irrigation may lead to dangerous increases in the total maximum daily loads (TMDL) of temperature, nitrates, and salinity in natural waters (Chapman 1992). Nitrate fertilizers leached out of the soils get transported to natural waters causing eutrophication and other aquatic impairments. Run off from over irrigation may affect water quality parameters such as pH, total suspended solids (TSS), and dissolved oxygen (Winter 2002). Other negative impacts associated with over irrigation include wastes of water and energy, and reduced crop yields.

The negative impacts associated with under irrigation are more intuitive. Under irrigation may reduce crop yields, which will reduce profit margins.

A soil water balance model incorporated into a data acquisition system is a power tool for scheduling and optimizing irrigation. Advancements in computer microprocessors, memory and software development tools has improved data acquisition methods and made data acquisition system integration more reliable and more cost effective.

The soil water balance model incorporates inputs of soil moisture, water application and evapotranspiration (ET). The soil moisture data acquisition system retrieves the input

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parameters via telemetry and populates software that accommodates the soil water balance model. The soil data acquisition software integrated with a soil water balance model is commercially available from Stevens Water Monitoring Systems, Inc.

SOIL MOISTURE BUDGET

To begin our discussion about soil moisture budgets, we first describe the components and the hydrological conditions of soil. In general, inorganic soil is composed of mixes of sands, silts and clays. Sands, silts and clays differ not only by particle size distribution, but also in the atomic arrangement and charge distribution at the molecular level (McBride 1994). Soil geomorphology is the process by which sands and silts chemically and physically transform into clays as the soil ages (Birkeland 1999).

The soil textural class is determined by the gravimetric percentage of sand silt and clay. Figure 1 shows the soil texture classifications based on gravimetric percentage.

Figure 1. Soil textural classes based on the percentage of sand, silt, and clay.

Sands, silts, clays, and organics represent the solid particle composition of soil while air and water fill the pore spaces between the solid particles. When soil is completely saturated with water, the porosity will be equal to the volumetric soil moisture content (Warrick 2003). The amount of organics in soil will affect the bulk density and the porosity. Some organic soils may have porosities of over 90%, but in general, most inorganic agricultural loams will have a porosity of near 50%. The pores can be nearly microscopic (micro-pores) or visible with the naked eye (macro-pores) (Brady 1974)

The hydrologic properties of soil play an important role in a crop's ability to transpire water with their root systems. Knowledge of volumetric soil moisture content (θ, m^3 m^{-3})

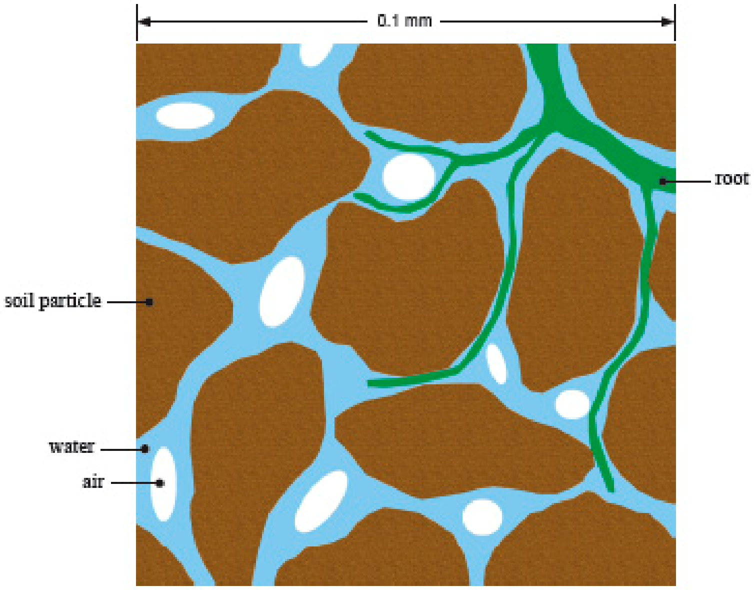

Figure 2. Unsaturated soil is composed of solid particles, organic material and pores. The pore space will contain air and water.

is an important input into the soil water balance model. Permanent wilting point (θ_{PW}) is the soil moisture level at which plants can no longer adsorb water from the soil. Plant transpiration and direct evaporation will decrease the moisture level in soil to a point below θ_{PW} and, in some cases, down to near dryness.

Field capacity (θ_{FC}) is defined as the threshold point at which the soil pore water will be influenced by gravity. Above field capacity, the gravitational force will overcome the capillary forces suspending the moisture in the pores of the soil allowing for down movement of water in the soil column. Below θ_{FC} , there will be a net upward movement of water driven by ET. Soil textural classes heavily influence field capacity and permanent wilting point, particularly clay content (Rowell 1994). Clays interact with water in ways uniquely different from sand, silt and organics. Clays will have a physical and chemical affinity for water due to the negative charge distribution and the planner molecular lattice. The positive portion of the water molecule will be oriented toward the negatively charged clay lattice and the oxygen's lone electron pair will be pointed outwards (Grim).

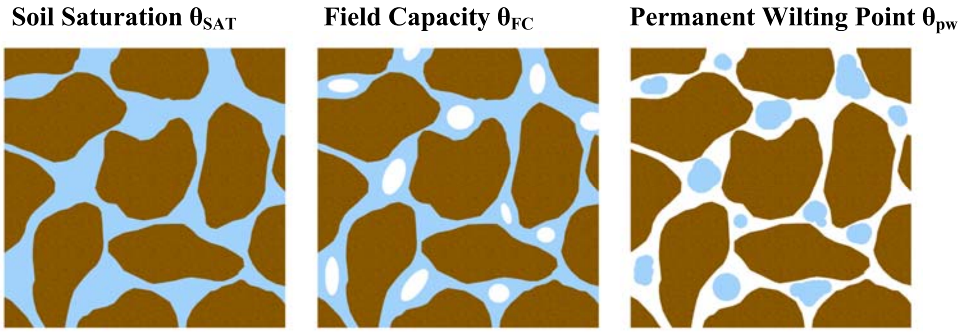

Figure 3. Soil saturation, field capacity and permanent wilting point.

Positively charged cations will also be influenced by the negative charged distribution of clay (McBride1994). Figure 3 shows two cations of different valance states (Ca^{++} and Na^{+}) chemically influenced by clay at the molecular level. Figure 3 also shows the charge distribution of the water molecule.

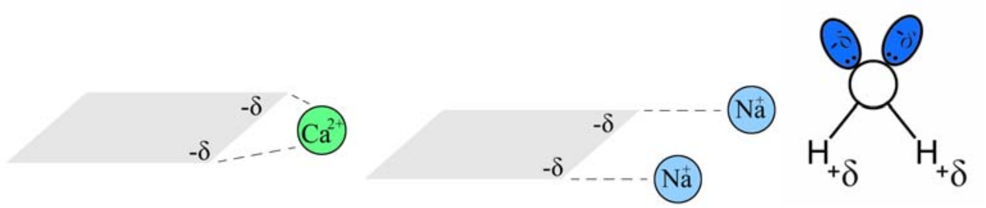

Figure 4. Planner clay lattice with a negative charge distribution and cation influence. Dipole moment of a water molecule.

The available water capacity (θ_{AC}) of soil is the water that is available to a plant. It represents the range of soil moisture values that lie above permanent wilting point and below the field capacity.

$$\theta_{PW} < \theta_{ac} < \theta_{FC} \qquad [1]$$

Table 1 shows the typical values for permanent wilting point and field capacity for common soil textural classes (Rowell 1995).

Plants are able to uptake water from soil if the soil moisture is above permanent wilting point. As the soil moisture approaches permanent wilting point, the plant will become increasingly stressed as the soil pore water becomes depleted. The point below field capacity where plants become stressed is called the maximum allowable depletion (MAD). The MAD value is expressed as a percent of the available water capacity. Table 2 shows typical MAD values for a few selected crops.

Table 1. Field Capacity and Permanent wilting points for common soil textural classes

	Field Capacity	Permanent Wilting Point
Sand	0.12	0.04
Loamy Sand	0.14	0.06
Sandy Loam	0.23	0.1
Loam	0.26	0.12
Silt Loam	0.3	0.15
Silt	0.32	0.165
Sandy Clay Loam	0.33	0.175
Silty Clay Loam	0.34	0.19
SiltyClay	0.36	0.21
Clay	0.36	0.21

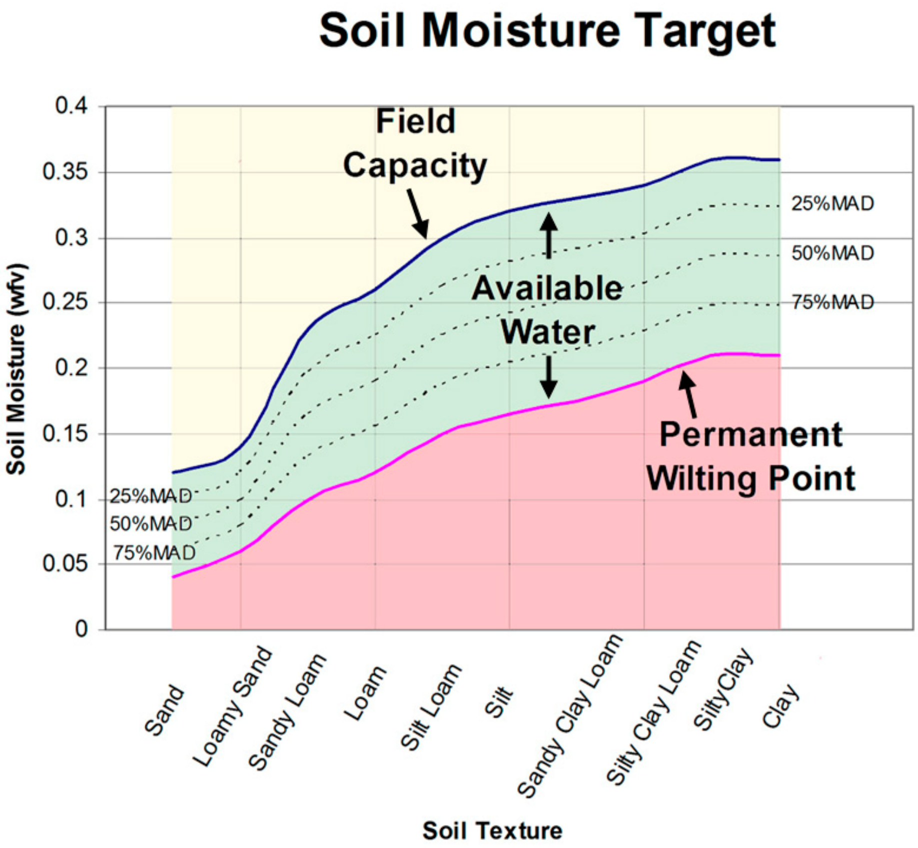

Figure 5. The relationship between soil textural classes and the hydrological thresholds θ_{PW} , θ_{AC} , θ_{FC} . The 25%, 50% and 75% MAD levels are displayed in the available water capacity region.

Table 2. Maximum Allowable Depletion based on crop. Effective Root Zone Depth. Taken from Smesrud 1998.

Crop	Maximum Allowable Depletion (MAD)	Effective Root Depth (Inches)
Grass	50%	7
Table beet	50%	18
Sweet Corn	50%	24
Strawberry	50%	12
Winter Squash	60%	36
Peppermint	35%	24
Potatoes	35%	35
Orchard Apples	75%	36
Leafy Green	40%	18
Cucumber	50%	24
Green Beans	50%	18
Cauliflower	40%	18
Carrot	50%	18
Blue Berries	50%	18

Figure 4 shows the soil field capacities and the permanent wilting points for common soil textural classes. The green region in figure 4 is the available water capacity showing 25%, 50% and 75% MADs. As shown in figure 4, the field capacity and the permanent wilting point will increase with the percentage of clay.

With specific knowledge of field capacity, soil textural class and the maximum allowable depletion, a soil moisture target can be determined for irrigation optimization (Brouwer 1985). The soil moisture target is the range of soil moistures that lie above the MAD but below the field capacity. Below the MAD value the crop will still have the ability to receive water from the soil, however the crop will become stressed after a period of time. If the crop becomes stressed due to the lack of water, the plant will have a reduced yield and become more susceptible to pathogens. If the soil moisture gets above field capacity, water will be transported downward by gravity potential wasting water and leaching nutrients.

Upper soil moisture target for the soils in the root zone will be the field capacity. The lower soil moisture target is determined by the MAD, θ_{FC}, and θ_{PW};

$$\text{Lower Soil Moisture Target} = \theta_{FC} - (\theta_{FC} - \theta_{PW}) \text{ X MAD} \qquad [2]$$

For example, green beans with a MAD of 50% have a root zone depth of 18 inches. If the green beans are growing in a silt loam, the field capacity will be 0.3 water fraction by volume (wfv) and the permanent wilting point will be 0.15 wfv. Using equation [2], the lower soil moisture target will be 0.23 wfv. In this example, the soil moisture target for the green beans will lie between 0.23 wfv and 0.3 wfv from 5 inches to 18 inches deep adjacent to the root ball. It is important to note that the values in table 1 are typical values and could vary slightly with bulk density of soil, mineralogy and organic content. Similarly, the MAD values in table 2 are typical values and may vary by species, age of crop, region and soil chemistry.

WATER APPLICATION

While soil moisture data provides information about the root zone, the measured application of water can be used concurrently with the soil moisture values to provide a more complete suite of tools for the irrigator. The measured application of water (*D*) is the amount of water applied to the crops with sprinklers, plus the amount of natural precipitation measured in inches/day. It is the total depth of water received by the crop.

Sprinkler Efficiency

In order to effectively use the application of water in a water budget model, a high sprinkler efficiency (E_f) is required. Sprinkler efficiency (E_f) is the measure of uniformity of water application. Ponding of irrigation water, and uneven application of water over the field is the result of poor sprinkler efficiency. Soil moisture data and rain gauge data are less meaningful if the monitoring site receives more or less water than the rest of the irrigation regime. Sprinkler efficiency is determined by placing catch cans or a set of uniform containers in the field. The catch cans can be placed in grid or uniformly distributed amongst the crops. After running the sprinklers for a length of time, the amount of water in the catch cans is measured. The sprinkler efficiency is expressed as a fraction and an E_f value of 1 is perfect uniformity. There are a number of methods for calculating E_f. The most common method for determining E_f involves averaging the lower 25% of the measured catchment of catch cans divided by the mean. An E_f value greater than 0.8 is preferred. Table 3 shows typical E_f values for several different types of sprinkler systems.

Table 3. Typical values for sprinkler efficiencies for various sprinkler systems. Taken from Smesrud 1998.

Irrigation System	Sprinkler Efficiency (E_f)	Sprinkler Efficiency (sprinkler spacing over 40 X40 feet)
Solid Set	0.70	0.63
Hand Move or Side Roll	0.80	0.74
Pivot or Linear Move	0.90	0.81
Offset Managed Hand Move	0.90	0.81

Evapotranspiration

An important factor for quantifying the water budget is the evapotranspiration rate (*ET*). Evapotranspiration is the water that is transpired out of the soil by the plant plus the amount of water lost to evaporation (Allan 1998). *ET* represents the rate of water consumed by the plant and lost by direct evaporation. The factors that affect the *ET* rate include wind, temperature, relative humidity, and solar radiation. The units for *ET* are inches/day.

Based on the Penman Monteith model for *ET* estimations, *ET* is not measured directly for an individual crop, but rather it is determined from a standard reference grass and then adjusted for different crops and plants with a crop coefficient (Allen 1998). The evapotranspiration for a reference grass is referred to as the potential evapotranspiration (ET^0). Potential evapotranspiration values will vary regionally and seasonally and are available in the literature. If literature values for ET^0 are not available or if the irrigator wishes to have a real time ET measurements, ET data acquisition systems are commercially available. ET data acquisition systems consist of weather sensors, telemetry and software that can retrieve the weather sensor inputs and perform the Penman Monteith model calculations. While an ET data acquisition system could potentially provide accurate real time ET^0 values, theses systems are very expensive and do not necessarily represent microclimates.

Because ET^0 is the *ET* for a standard reference grass, a crop coefficient (K_c) is necessary to determine the *ET* for the crop of interest. With information about sprinkler efficiency, crop coefficient and potential evapotranspiration, the water consumption (*ET”)* for a specific crop (in inches per day) are calculated from the equation [3],

$$ET'' = ET^0 \times K_c / E_f \quad [3]$$

Typically, K_c values will range from 0.75 to 1.25 depending on species of the plant, the growth stage of the plant, and vary regionally. In practice, ET^0 and K_c values can be obtained from a local government crop extension or a local crop advisor.

Applied water Scheduling

In general, the water application (D) in inches/day should be roughly equal to the system water loss (ET'') due to ET and sprinkler uniformity. The water loss calculated by equation [3] can be compared to the applied water measured with a rain gauge to set an irrigation target.

$$D \approx ET'' \quad [4]$$

If is difficult to keep $D \approx ET''$ on a hourly or daily basis due to factors such as pivot lap speed and soil infiltration rates. Equation [4] should define a water application target on a weekly basis. In general, depending on the crop and the irrigation system, crops should be irrigated 3 to 7 times a week and net weekly sum of the daily D values should be roughly equal to the net weekly sum of the daily ET'' values. Figure 5 demonstrates a weekly water application target. In figure 5, there are three irrigation events, and an ET'' rate of 0.26 inches per day. Based on an ET'' rate of 0.26 inches per day and the E_f, by the end of the week, 1.80 inches of water was consumed and approximately 1.80 inches would need to be applied.

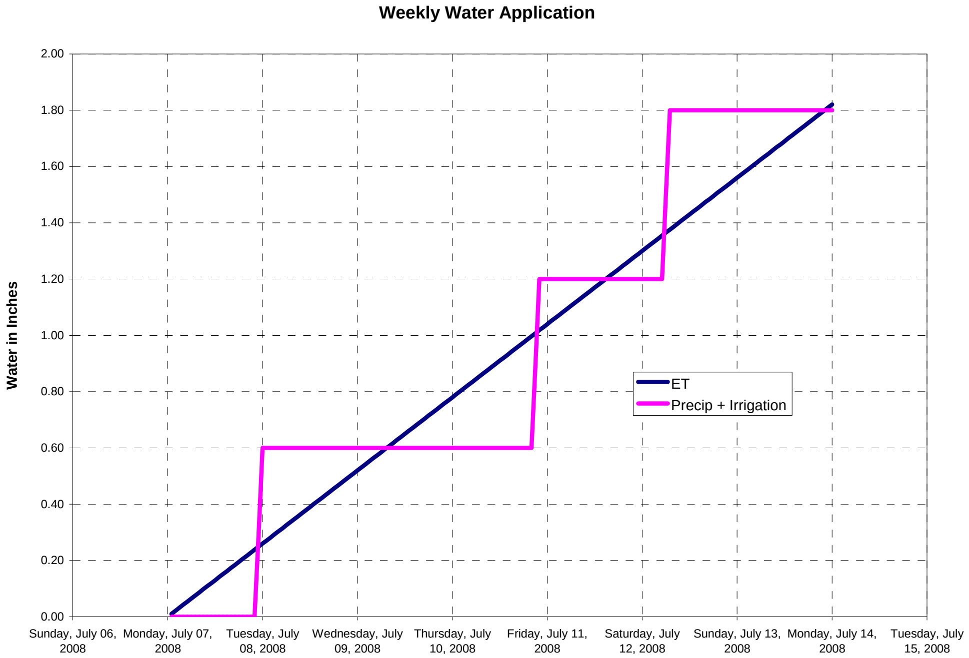

Figure 6. There are three irrigation events, and an ET'' rate of 0.26 inches per day. $D \approx ET''$ after the 3 irrigation event at the end of the week.

The application rate in figure 5 is 0.3 inches per hour for 2 hours. To minimize the water loss due to direct evaporation, the irrigation events take place between sunset and sunrise.

It is important to irrigate at a rate that is less than the infiltration rate of the soil. Runoff and ponding may occur if the rate of application exceeds infiltration rate of the soil. Table 4 provides infiltration rates of soils based on soil textural class (Brouwer 1988).

Table 4. Typical Infiltration rates based on soil texture.

Soil Texture	Typical Infiltration Rate (inches/hour)
Sand	1.5 or more
Sandy Loam	1 to 1.5
Loam	0.5 to 1
Clay Loam	0.25 to 0.5
Clay	0.05 to 0.25

The infiltration of water into soil will vary with texture, but it will also depend on soil moisture, vegetation, bulk density and soil goemorphology among other factors. Soil infiltration rates can be determined from tests and area soil surveys data.

DATA ACQUISITION

Data acquisition systems are the most effective tool for identifying and reaching soil moisture and water application targets for irrigation optimization. A data acquisition system with the water budgeting method was constructed and is commercially available from Stevens Water Monitoring Systems, Inc.. The Stevens Agricultural Monitoring (SAM) Package integrates the input from sensors, displays the data from the remote field locations and integrates the water balance method described in the previous section. The SAM package includes rain gauges, the Stevens Hydra Probe Soil Sensor, a Stevens DL3000 data logger, telemetry and the software program. Described below is the engineering that collects field data (soil moisture and precipitation) and the software program that acquires the data from the data loggers through the telemetry. The data is either exported to the internet or is imported into the SAM software where it can be used to make informed decisions about irrigation scheduling.

Soil Moisture Data Collection

The soil moisture is collected using the Stevens Hydra Probe. The Hydra Probe is the soil sensor used in the USDA's Soil Climate Analysis Network (SCAN) and NOAA's Climate Reference Network (CRN). The Hydra Probe uses electromagnetic waves to measure both the real and imaginary dielectric permittivity (Campbell 1990). The real component of the dielectric permittivity represents the energy storage based on the high rotational dipole moment of water compared to that of dry soil (Topp 1980). The measured real dielectric permittivity (ε_r) is used to accurately calculate the soil moisture in water fraction by volume in most soils (Seyfried 2005) with the calibration equation;

$$\theta = A\varepsilon_r^{1/2} + B \qquad [5]$$

Where A is 0.109 and B is equal to -0.179. The Hydra Probe is digital and equation [5] is written into the firmware of the probe.

The digital communication between the Hydra Probe and the data logger is the standard communication format Serial Data Interface at 1200 Baud (SDI-12). The advantages of SDI-12 include connecting many sensors on a single serial addressable bus and cable lengths up to 1000 feet from the sensor to the data logger. Multiple digital sensors are "daisy chained" together and the longer cable lengths provide flexibility in the architecture of the system in the field. Up to 4 or more SDI-12 soil moisture profiles can be installed up to 1000 feet away from the data logger reducing the cost by using common data loggers and telemetry.

Rain Data Collection

The precipitation and the irrigation from sprinklers are measured together with a tipping bucket rain gauge. A tipping bucket is a 6 to 10 inch in diameter cylinder with a screen at the top facing end and a drain out the bottom. Inside of the bucket is a dual sided tray that is located under a funnel. The tray will tip over and drain after receiving 0.01 inches of rain. After tipping, the other half of the tray will fill with water, tip and drain after receiving another 0.01 inches of water. Every time the tipping bucket's tray tips (0.01 inch of rain), an electrical pulse is sent to the DL3000 data logger. The data logger counts the tips and calculates the depth of rain fall over time. It is important that the tipping bucket remain level and is placed in a location that will receive a representative application of water from the sprinklers.

If an irrigation method is used that does not include the use of sprinklers such as furrow or drip irrigation, the method described in figure 5 and equation [4] will not be as applicable. In this case, one or no rain gauge would be used in the data acquisition package.

Data Logger and Field Station

The Stevens Data Logic 3000 (DL3000) data collection platform resides inside a weather proof fiber glass enclosure located in the field. The cable from each SDI-12 Hydra Probe enters the enclosure by running through bulkhead bushings located on the bottom of the enclosure. The Hydra Probe power, ground and SDI-12 communication wires are "daisy chained" together with a multiplex inside the enclosure. A single SDI-12 communication wire runs from the multiplexer to the DL3000's SDI-12 communication port. The DL3000 will log data on a set time interval typically every 30 minutes, and will hold up to 2 Gigabytes of data. The wire from the tipping bucket also runs into the enclosure through a bulkhead and is wired into the DL3000's pulse port. The data logger has a wireless RS232 communication radio attached. A coaxial cable runs from the radio out of the enclosure through the bulkhead to an Omni directional antenna.

Also contained in the field enclosure is a 9 Amp/hour 12 volt DC battery, and charge regulator for the solar panel power supply. Figure 9 describes a field station with a subsurface soil moisture monitoring profile.

Wireless Telemetry

After the data from the sensors is received by the data logger, the data is transmitted from the field to the base station computer via radio. The frequency and type of radio would depend on the distance from the field to the base station computer. The radio communication between the field and the base station is usually line of sight. Large obstacles such as buildings, mountains and trees will impede the radio signal and prevent the signal from reaching its destination. If there is a large obstacle in the way, a repeater station could be installed, however repeater stations will increase the overall cost of the system. Radio communication always takes place between two or more radios. The radio at the base station is called the server or master radio and the radios in the field are call client or slave radios.

The master radio is connected to the base station computer and a directional Omni antenna. Each radio has a Media Access Control (MAC) address written into the radio's firmware, identifying it. When the master radio needs communication with a specific radio, the master radio will address the radio with the MAC address. Radios will only respond their specific MAC address from the master radio. In a network of radios, the master radio will communicate with each slave radio one by one and retrieve the sensor data from each logger individually.

Distance from the field site to the base station is the main factor determining the most appropriate radio and frequency. In most agriculture applications, 900 MHz Spread Spectrum radio with a 5 miles line of sight range is the most common. While satellite communication is common in the water resources industry, it is less common at the farm level due to licensing and hardware costs. Table 5 lists the different kinds of telemetry solutions, the ranges and the frequencies.

Table 5. Summery of telemetry options and ranges.

Radio	Range	Frequency
Blue Tooth	100 m	2,400 to 2,483.5 MHz
Spread Spectrum	5 miles	902 to 928 MHz
Wi-Fi	100 m	2.4 GHz
VHF	30 miles	30 to 300 MHz
UHF	30 miles	300 to 1,000 MHz
Wi-Max	30 miles	2.3 to 3.5 GHz
Cellular Modem	Cell Coverage	824.01 to 848.97 MHz
Geosynchronous Satellite	1/3 the of Earth	401.7010 to 402.0985 MHz
Low Earth Orbiting Satellite	Global Coverage	148 to 150.05 MHz

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Soil Profile

Soil moisture probes at different depths in the soil column are referred to as a soil profile. Depending on the root zone depth, the typical soil profile consists of four soil sensors. One probe in the top soil (2 to 4 inches) two probes in the root zone (6 to 30 inches) and one probe below the root zone (36 inches). The Hydra Probe in the top soil will experience the greatest moisture fluctuation because it will be the most influenced by ET and downward flow. The top soil may reach saturation or reach a soil moisture value over the field capacity thus conducting water downward into the root zone of the crop. The lower soil moisture target for the two Hydra Probes in the root zone however are calculated from the MAD, θ_{FC} and θ_{PW} in equation [2] and the upper soil moisture target in the root zone will be the soil's field capacity. The soil sensor below the root zone should stay below field capacity. If the soil moisture below the root zone reaches values above field capacity, there will be downward conductance of water.

The soil profile should be placed in a location that will most represent the irrigated area. Soil moisture can be highly variable spatially (Western 2003). The factors that affect soil moisture variability are slope, vegetation type, bulk density, soil type, microclimate, and other variables. An irrigation regime represents an area that is homogenous enough that the soil moisture variability will be low and the soil moisture data will represent the entire irrigation regime. There should be at least one soil profile for every irrigation regime. Irrigation regimes are determined by crop type, crop age, soil type, slope, and irrigation method.

If the irrigation regimes are less than 1000 feet apart, it may reduce cost to tie multiple soil profiles into one data logger. By tying multiple profiles into a single data logger, the irrigator can save on the number of solar panels, batteries, radios, data loggers and other necessary accessories.

Data Acquisition Software

The central user interface of the data acquisition package is the software.
The Stevens Agricultural Monitoring (SAM) Software is commercial available and can be subsidized by some energy and water conservation grants. The SAM software runs on a computer that is connected to the master radio. A master radio is not necessary if the system has a field cellular modem or satellite transceiver. The SAM Software acquires the sensor data in the field from a polling sequence. The polling sequence runs at a user specified time interval, which is usually every 15 or 30 minutes. Communication begins with a serial command from the software to the data logger to take a current a current reading from all of the sensors. The SAM sends the command to the master with instructions to use a specific slave radio. The data logger becomes active after receiving the command and takes a current reading from all of the sensors that are connected to it. Next the data logger sends a comma delimitated string of sensor data back to the SAM software through the slave and master radio. The SAM software parses the data and populates the tables and graphical displays in the software.

The irrigator can then view the real time data and make decisions about when to irrigate based on the soil moisture targets and the rate of water consumption by the crop from the ET. Other features in the software include battery voltages for power management. In the SAM Software, a display of MAD, $\theta_{FC,}$, θ_{PW} and the lower soil moisture limit based on the calculations from equation [2] are superimposed unto the real time soil moisture data. The superimposed real time soil moisture onto the soil moisture targets are displayed on a screen similar to figure 8.

At the beginning of the irrigation season, the irrigator can manually input the weekly ET values or the values from equation [3] into the SAM setup page. A real time display similar to figure 6 is displayed. With real time displays of the real time data superimposed onto the targets in a graphical representation will allow the irrigator to easily interpret the data.

The flow chart below describes the process by which the SAM software communicates with the field stations. Figure 9 shows a diagram of a field station. The SAM Software will poll data from each station in consecutive order starting with the first field station. After retrieving the data from one field station, the software will move on to the next field station.

SAM Data Acquisition Polling Sequence For Station 1.

1) The Polling Sequence initiates on a fixed time interval.
2) The Acquisition command “Take Current Readings Data Logger 1” along with a command to the master radio to communicate with radio 1 with its MAC address. These two commands are sent by the software out the serial port of the computer.
3) With an RS232 or USB connection to the computer, the Master Radio receives the “Take Current Readings Data Logger 1” message and transmits this message to slave radio 1 as commanded by the SAM software.
4) Slave radio 1 receives the “Take Current Readings Data Logger 1” and passes the message to the data logger via a RS232 cable.
5) Data Logger 1 receives the command “Take Current Readings Data Logger 1” from the slave radio and one by one collects the current data readings from each sensor that is connected to it.
6) Data Logger 1 sends a comma delimited data string back to the SAM software through the radios and serial ports.
7) The SAM software receives the data string, parses the data, and populates the graphical displays and tables in the software viewable by the user.
8) After the SAM software receives the data from data logger 1, it repeats steps 1 through 7 for data logger 2 and slave radio 2.

BLUEBERRY FARM IN WASHINGTON COUNTY, OREGON, CASE STUDY.

A SAM Soil Moisture data acquisition package complete with telemetry and software was installed on a 200 acre blueberry farm in Washington County, Oregon.

The soil unit is Woodburn Silt Loam with less than 3% slope and the soil taxonomic description is Typic Plinthoxeralf. There are two irrigation regimes based on the age of the crop. Two stations, one in each irrigation regime, were installed with 4 Hydra Probe soil sensors, a tipping bucket rain gauge, and an air temperature sensor. Soils data for this location and most locations in the United States are provide for free by the US Department of Agriculture's Web Soil Survey Program, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx .

Figure 7 shows the annual precipitation and ET rate for blueberries in Washington County Oregon (Smesrud 1997). The ET exceeds precipitation from April to October and this generally defines the irrigation season.

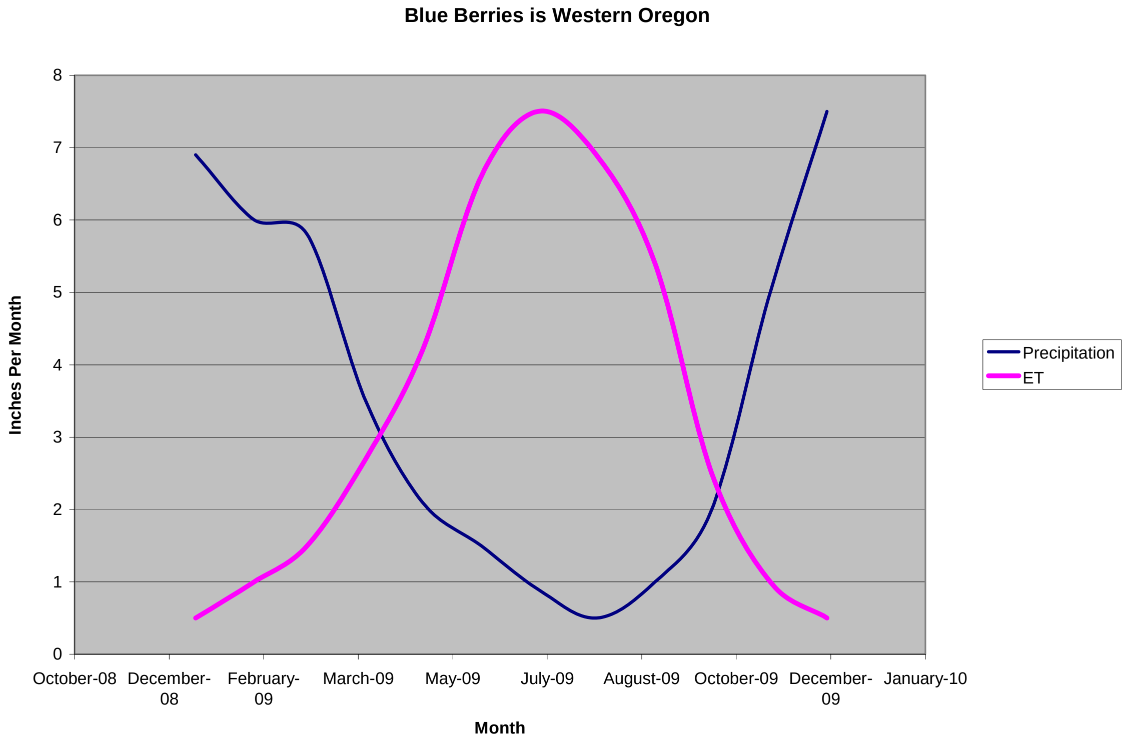

Figure 7. Typical values for monthly ET and Precipitation for blue berries in western Oregon

Each station is located 1 mile away from the computer with the master radio; therefore, this network uses spread spectrum radios. The stations each have one soil profile consisting of 4 Hydra Probes at various depths (2", 8" 16" and 30"). The SDI-12 Hydra Probe Soil Sensors are wired into a multiplexer which is connected to the Stevens Data Logger. Each station is power with a solar panel and the enclosure houses the battery, multiplexer, charge regulator and radio. The radio antennas are mounted to the same mast as the tipping bucket. Figure 9 illustrates one of the field stations with the soil profile.

Using table 1 and table 2, the permanent wilting point is 0.15 the field capacity is 0.3 and the MAD is 50%. The lower soil moisture target as calculated from equation [2] is 0.22.

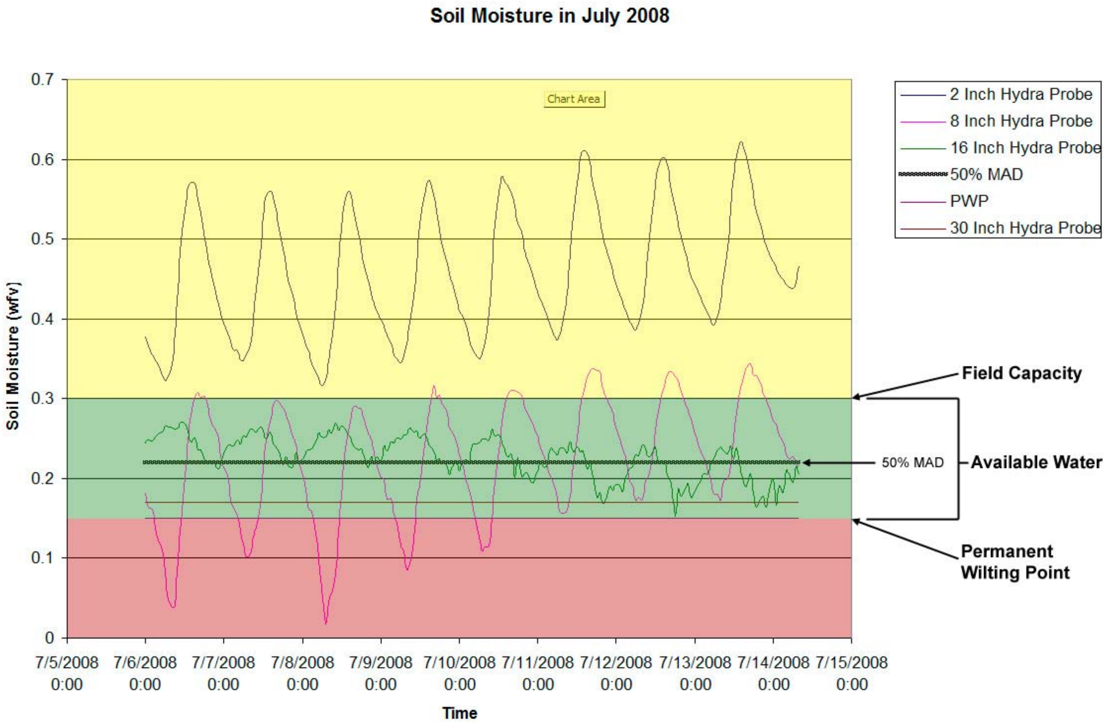

Figure 8. Soil moisture measurements in a profile 2, 8, 16 and 30 inches in depth. Daily irrigation events with subsequent decrease in soil moisture from a high ET rate.

Figure 8 show the soil moisture for a warm week in July 2008. The yellow region of the chart represents soil moisture levels over field capacity, the green region shows the range of soil moistures available to the crop (available water capacity) and the red region is below permanent wilting point. The two inch deep soil moisture values fluctuate the most for downward conductivity and ET and stays above field capacity. This is typical because if the top 2 inches of the soil stayed below field capacity then the root zone would not receive the water. The 8 inch soil moisture values fluctuate widely due to ET and there is a 4 hour lag time between the 2 and 8 inch soil moisture probes from the downward movement time of the wetting front. During extremely hot days, it is not uncommon to have the soil moisture values briefly drop below permanent wilting point between irrigation cycles. The 16 inch soil moisture mirrors the 8 inch values with a 4 hour latency from the soil moisture values above it and the raise and fall of soil moisture values with the irrigation events. The 30 inch deep soil moisture probe below the root zone is remaining constant about 0.10 wfv indicating that water is not peculating downward to the water table.

The solid set sprinklers rotator (with an efficiency of 0.90) apply water daily. For the month of July ET (ET^0 x Kc) is 0.25 inches per day. Using equation [3], the daily water consumption will be 0.28 inches. A weekly display similar to figure 6 is displayed in the software which will allow the irrigator to meet the soil moisture and water application targets.

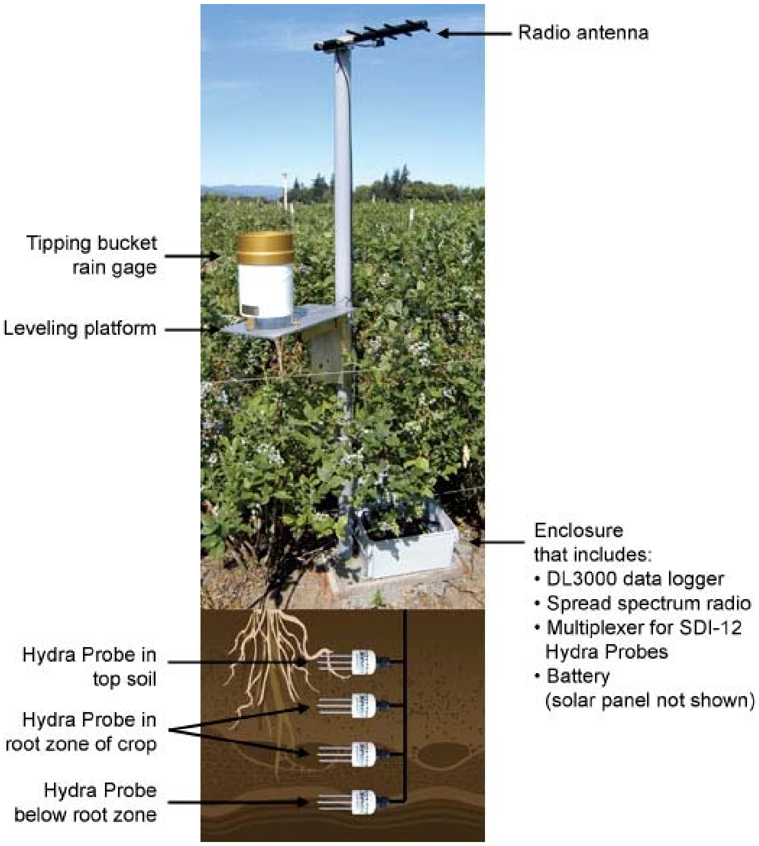

Figure 9. Typical soil moisture profile station which includes four Hydra Probe Soil Sensors, Stevens DL3000 data logger, radio, antenna and accessories.

CONCLUSION

As the demand for water increases, along with the need to protect aquatic habitats, water conservation practices for irrigation need to be effective and affordable. Precision irrigation will optimize irrigation by minimizing the waste of water, and energy, while maximizing crop yields.

The most effective method for determining the water demands of crops is the based on the real time monitoring of soil moisture, and direct water application used in conjunction with the information about soil hydrological properties and evapotranspiration.

The Stevens Agriculture Monitoring data acquisition system wirelessly acquires rain and soil data from the field and integrates the data into water management tools.
The water management tools use information about evapotranspiration, soil and the crop to set specific irrigation targets. These irrigation targets will help the irrigator optimize the amount of water used on a weekly basis. Optimization of irrigation water will increase crop yields while conserving water resources.

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