Automating Landscape Sprinkler Control Using Weather Data, Broadcast to Unlimited Properties

Steven E. Moore[1] *- North Logan, Utah - March 5, 2007*

Abstract

Some experts estimate that landscape irrigation systems waste 25% of culinary water resources (EPA, 2007). Inefficiencies in the control and distribution of water are the cause of this waste. Sprinkler timers are too often set, forgotten, and not adjusted with changes in the weather.

Weather conditions drive evaporation. Water lost from the landscape due to evaporation may be replaced by rainfall and most often is supplemented by irrigation. Effective landscape water management maintains a healthy moisture balance in the soil. A water manager must account for evaporative loss, rainfall, plant types, soil conditions, and the capabilities of the irrigation system to deliver water. Large golf, institutional, public, and commercial landscapes have effectively used weather stations to automate landscape water management for more than twenty years (CIMIS, 2000).

Evapotranspiration (ET) can be calculated from weather sensor input: solar radiation, temperature, wind, and humidity (ASCE, 2005). Reliable precision sensors must be properly sited, well maintained, and logged every hour. Proper implementation requires expensive equipment, and trained professionals to assure accurate, continuous measurements. Previously, complexity and cost has been a barrier to small and medium landscape applications.

Wireless technology provides a means to share data from well maintained precision weather stations in a community. An unlimited number of irrigation systems can receive wireless broadcasts of current weather information. A receiver calculates ET from this weather data and provides accurate control for landscape irrigation systems.

This technology, developed, tested, and implemented in many locations across the United States and Canada provides significant water savings. The system has proven reliable and end users have not been burdened with purchasing, locating, or maintaining weather sensors.

Sustained water conservation is achieved by automated control of landscape sprinkler systems that receive precise, hourly weather data.

Introduction

Reports across the country and in many places worldwide conclude landscapes receive twice the needed water (Kjelgren, 2003). A majority of this waste comes because sprinkler controllers are often set and forgotten. Water requirements of the landscape change with changing weather conditions. Unnecessary watering not only wastes water, but can adversely affect the health of the landscape. Weather-based technology, which automates landscape sprinkler control, reduces water waste without impacting the health of the landscape.

Expensive high-tech precision water management has been successfully implemented in large turf and agricultural environments for more than twenty years (Irrigation Association, 2005). The increasing need to conserve water resources pressures commercial and residential landscape water users to find a cost-effective solution to reduce water waste (Bureau of Reclamation, 2006). A cost effective automated solution for residential and commercial properties must be reliable, achieve sustainable results, and not sacrifice the health of the landscape.

Automated systems are dependent on sensors to provide data essential for accurate control. A community weather station can measure wind, temperature, humidity, and solar radiation conditions which affect landscape water use. Wireless technology provides a cost-effect, reliable method to broadcast measurements to an unlimited number of irrigation control systems. An overview of the science will provide a better understanding of the purpose behind each component implemented in the technology to reduce water use while sustaining beautiful landscapes.

Weather Influences Landscape Water Use

Water that evaporates from the landscape is replaced by rainfall and is supplemented by irrigation. Weather conditions affect evaporation rates. Solar radiation, temperature, wind, and humidity are the weather conditions that affect how quickly a landscape dries out. Solar radiation and temperature are energy sources that change liquid water to vapor. Wind accelerates evaporation. Humidity also affects the evaporative rate; in high humidity, evaporation slows as more energy is needed to convert liquid to vapor. Evaporation rates are much higher in arid climates as compared to moist environments. In the summer, landscapes are exposed to more intense solar radiation and high temperatures, so the evaporative rate is higher. But on a cool overcast day, solar radiation drops, humidity increases, and landscapes dry out slower. As quickly as the weather changes, so does the evaporation rate. To avoid wasting water, landscape irrigation schedules need to respond to changing weather conditions.

Scientists have developed methods to quantify evapotranspiration (ET) which is the amount of water lost from soil, and leaf surfaces by evaporation, and water used by plants through transpiration (ASCE, 2005). ET is expressed as a rate of water lost from the landscape in either inches or millimeters over a period of time. Evapotranspiration losses can be estimated using meteorological data measured by a weather station. Weather parameters measured to calculate ET include: solar radiation, temperature, wind, and relative humidity. Each weather parameter has a significant impact on evaporative rates. An exact calculation of ET is dependent on complete, accurate real-time data.

Numerous formulas have been developed, tested and refined over the years to calculate ET. Because there are so many ET equations the Irrigation Association formally requested that the American Society of Civil Engineers define and establish a benchmark or "standardized" ET equation. In November 2000 the committee presented the equation referred to as "The ASCE Standardized Reference Evapotranspiration Equation". The results were published and endorsed by the Irrigation Association in January 2005 as the industry standard to calculate ET. The standard sets forth the preferred formula using hourly measurements of all climatological conditions (Solar Radiation, Temperature, Wind, and Humidity). The publication also details recommended station sighting criteria and the importance of sensor accuracy and maintenance.

The basic principle behind ET-based landscape water management is to replace water lost from landscapes due to evapotranspiration. In addition to the weather parameters used to calculate ET, rainfall must also be measured as it replaces evaporated water. In some parts of the country, rain plays the primary roll in replenishing lost soil moisture, while in arid climates rain supplements irrigation.

Rainfall rates and intensities can vary. When rain falls faster than the soil can absorb, run-off occurs; this water is not available to plants. Prolonged rain may saturate the soil and percolate below the root-zone. In either case, not all rainfall may be available to the plants. Just as ET is measured in inches (millimeters) of water evaporated from the soil, effective rainfall is measured in inches of water applied to the landscape.

Plant Water Soil Relationships

The soil is a habitat for roots, providing stability, water, oxygen, and nutrients. Root depth and soil composition limit the capacity of the soil reservoir. To promote a deep healthy root system, soil moisture must be depleted to allow air into the root zone. Best Management Practices published by the Irrigation Association suggest that moisture levels should be depleted by 50% before watering (IA BMP, 2005). The cycle of deep, less frequent watering promotes a deep healthy root system. If the plant root zone is kept at or near a saturated condition, the roots remain shallow because they are deprived of essential oxygen. Frequent shallow watering evaporates faster and does not promote deep healthy roots.

The "Checkbook Method" of irrigation scheduling compares ET to a "withdrawal" of moisture from the soil moisture balance, while rainfall and irrigation are considered "deposits" (Wright, 2002). Once the "balance" reaches "0" (soil moisture is depleted), the irrigation system must make a "deposit" to replenish soil moisture. Irrigation should provide a deep watering to refill the soil reservoir.

Landscape Water Management

Irrigation scheduling practices take many approaches. In the worst case, sprinkler controllers are set to water for the hottest months, and are not adjusted to changes in weather. If watering schedules are adjusted, it is because the condition of the landscape prompts the change such as "the grass is drying out" or "it seems too wet." The user often does not know how much to adjust the schedule. Some users may turn sprinkler controllers off when it begins to rain, but are unsure when to resume watering. This reactive method of water management wastes water and negatively affects the health of the landscape. Users tend to over-water as much as four times the needed amount (Maheshwari, 2006).

Some water agencies attempt to cut this water waste through programs such as day-of-the-week watering restrictions and water budgeting. These approaches to water conservation do not reflect plant water needs (Kjelgren, 2000).

Responsible water managers consider all factors which influence the health of the landscape, including current weather conditions to adjust watering schedules. In some cases, computerized irrigation control systems connected to weather stations automate irrigation control. Internationally, golf courses, parks, school districts, campuses, theme parks, and large-scale landscapes successfully utilize automated weather-based control systems (Ali, 2006). Water waste is reduced, landscape health improved, and water and labor savings are achieved. Computerized central control systems are complex, expensive, and require the purchase and maintenance of precision weather stations.

Solution

A system has been developed that manages a network of weather stations and broadcasts weather data, via wireless commercial paging, to irrigation system controllers. The controllers are capable of managing irrigation systems by calculating ET, accounting for effective rainfall, recognizing the soil reservoir capacity and considering the capabilities of an irrigation system.

There are three key elements to sensor-based control:

- Sensors – Accurate weather data to calculate ET
- Connectivity – Communicate sensor measurements to the control system
- Control – Data input, processing, and output to control the irrigation system

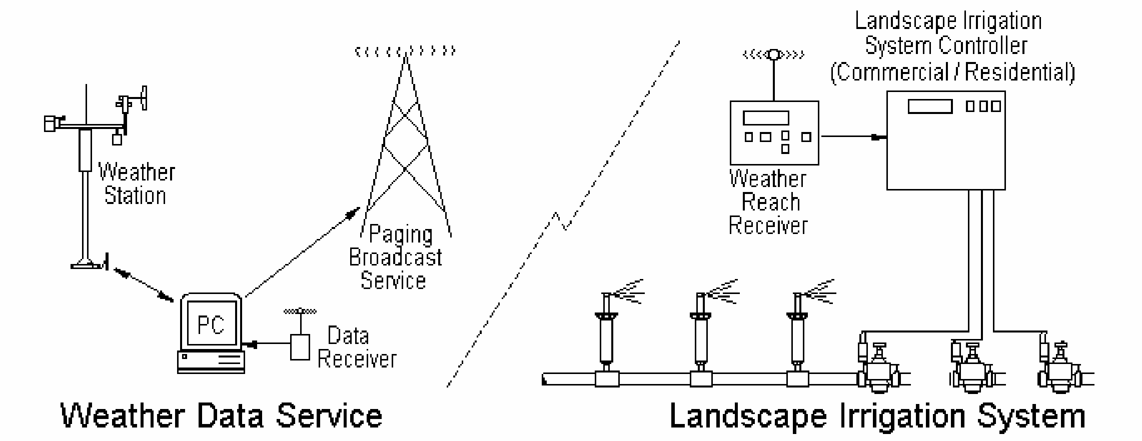
Sensors - This system begins with a weather station, properly sited and well maintained, within a community. Weather stations consist of weather sensors connected to a data logger, which stores sensor measurements. The location must be representative of community landscape conditions. Station sensors collect essential measurements including solar radiation, temperature, wind, humidity, and rainfall. Accurate results are dependent on precise reliable equipment.

Connectivity - A computer communicates with the weather station each hour to collect the last hours' sensor measurements. The system supports a variety of communication methods with the weather station, the most common being dial-up telephone, cellular or direct connection. Once data is collected and stored, the computer encodes a "message" containing current weather data and a weather region identification number. The "message" is sent, via the Internet, to a wireless commercial paging system to be broadcast in a local area to an unlimited number of controllers.

Commercial paging is used to share weather data with controllers because it has a well-established infrastructure. Paging can be used for either personal messaging or telemetry applications. It is a fast, reliable, low cost means of delivering small amounts of information. "Machine to Machine" applications using paging is growing. An unlimited number of controllers with paging data receivers may be programmed to receive the same "message."

An entity that needs to improve control of landscape irrigation systems may own and operate the system to service the needs of the controllers it represents. The system is scaleable to support one weather station for a small community or multiple stations for a statewide conservation program. Paging costs are paid by the system operator and are based on paging airtime. All controllers serviced by an entity receive the same message, so the cost of operating the system is the same for one controller or ten thousand. Cost increases as data from additional weather stations are broadcast. System operating costs may be recovered through a variety of methods.

The following diagram depicts the flow of data and components in the system:



Controller - A controller interface includes a paging radio to receive the weather data which uses weather data from the user-selected weather region. With each hour's weather data, ET is calculated to automate watering schedules.

Because rainfall can be localized, rainfall measurements at the community weather station may not represent on-site conditions. The controller interface can accept measurements from an on-site tipping bucket rain gauge.

Because there are numerous methods to control irrigation systems the controller interface offers several different methods to automate the control of an irrigation system.

- Integrated
- Common Interrupt
- Pulse
- Serial
- Trigger

Integrated - This control technology, integrated into a sprinkler controller, receives the weather data broadcast, calculates ET, and controls irrigation zone valves.

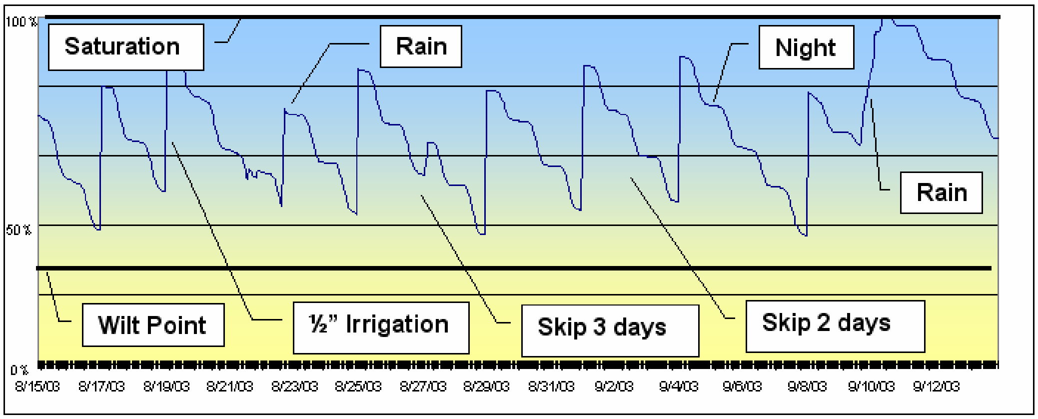
Common Interrupt - The controller interface can interrupt the common output of most standard 24 VAC sprinkler controllers and prevent watering until soil moisture has been depleted to an allowable level. A sprinkler controller is typically programmed to water every day, but the controller interface only allows watering when needed based on ET. The control interface keeps a running moisture balance, similar to the "Checkbook Method." The common output of a controller is enabled, once soil moisture is depleted, to a user-programmed allowable level. The allowed depletion method considers soil type and root depth to determine soil reservoir capacities and proper irrigation amounts.

The following table is an example of modeling moisture balance using ET, effective rain, and irrigation to determine watering frequency:

Date	ET	Effective Rain	Irrigate	Moisture Balance
4/1/06	0.15	0.05		0.65
4/2/06	0.11	0.23		0.75
4/3/06	0.05	0.68		0.75
4/4/06	0.08	0.75		0.75
4/5/06	0.06	0.12		0.75
4/6/06	0.13			0.62
4/7/06	0.18	0.02		0.46
4/8/06	0.14			0.32
4/9/06	0.11			0.21
4/10/06	0.08	0.03		0.16
4/11/06	0.11	0.05		0.10
4/12/06	0.17		0.50	0.43
4/13/06	0.18			0.25
4/14/06	0.05	0.21		0.41
4/15/06	0.11			0.30
4/16/06	0.09	0.18		0.39
4/17/06	0.19			0.20
4/18/06	0.17			0.03
4/19/06	0.19		0.50	0.34
4/20/06	0.18			0.16
4/21/06	0.17		0.50	0.49
4/22/06	0.06	0.01		0.44
4/23/06	0.02	0.52		0.75
4/24/06	0.13			0.62
4/25/06	0.12	0.02		0.52
4/26/06	0.09	0.03		0.46
4/27/06	0.12			0.34
4/28/06	0.20			0.14
4/29/06	0.20		0.50	0.44
4/30/06	0.20			0.24

An example of one full year of watering managed with the moisture balance method to control the frequency of watering is demonstrated in Appendix I.

Hourly data provides accurate soil moisture modeling as shown in the following example:



Current commercial models of the controller interface manage two valve commons independently. Typically, turf is watered more frequently than shrubs. One group of valves could be wired and programmed for turf zones and the second group for shrubs. This accommodates different soil types, root depths, and plant types at a site.

Pulse - Several sprinkler controller manufacturers have adopted a pulse input as a means to input ET. This method is based on a device developed several years ago called an Atmometer or ET Gage® (Suat Irmak, Payero & Martin, 2005). It produces a pulsed output for irrigation controllers. One switch closure represents 0.01" of ET. The ET value is used by sprinkler controllers to automatically adjust watering schedules.

The controller interface provides an ET pulse output that emulates the ET Gage by using a relay to create a closing switch contact for each 0.01" of ET. As weather data is received, ET is calculated and the controller interface creates a pulse for every 0.01" of ET.

Serial - A sprinkler controller can acquire ET, rainfall, and other weather data using a serial data transport interface connection to a small controller interface card. The controller interface card provides real-time conditions so the sprinkler controller can manage the irrigation system.

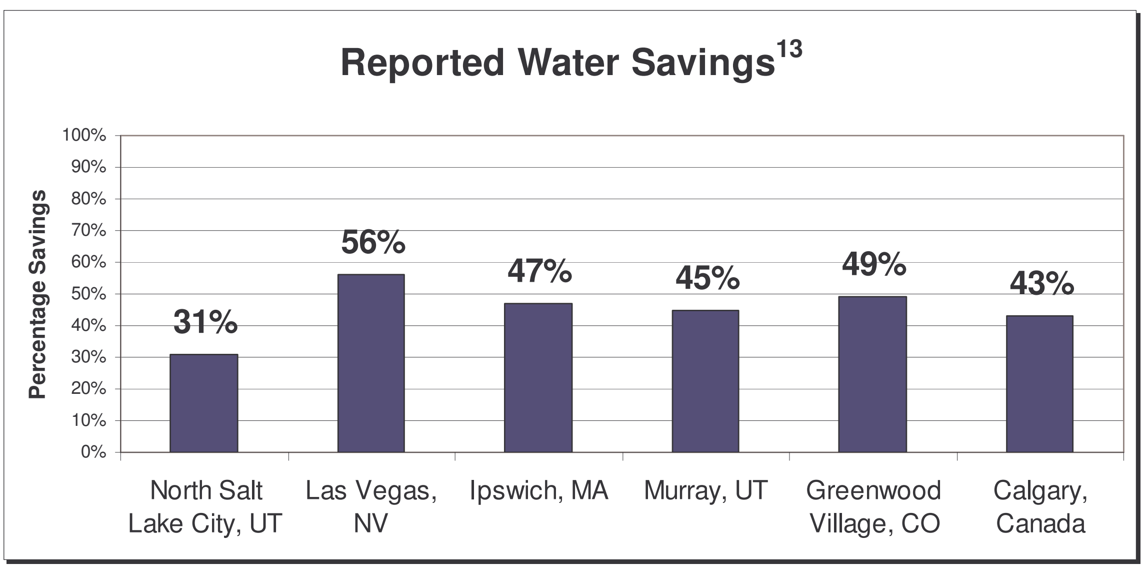
Trigger - A trigger method in the controller interface is very similar to the common interrupt method. The difference is that the controller interface triggers the start of a watering cycle. A sprinkler controller starts watering when it receives the trigger to begin a cycle.

CIT Testing

The Irrigation Association Smart Water Application Technology (SWAT) committee developed a protocol to validate the effectiveness of climatologically based, or "Smart" irrigation controllers. The Rain Bird® ET Manager is a commercially available product that incorporates this technology. It was tested at the Center for Irrigation Technology (CIT) in Fresno and results were released June 26, 2006. The report focuses on three factors; irrigation adequacy, schedule efficiency, and irrigation scheduling excess. In each of these areas, the Rain Bird ET Manager received a perfect score.

Independent Field Testing

The system became commercially available under the name Weather Reach Water Management System in July 2002. Field tests conducted by end users reported considerable amounts of water savings as indicated in the chart below.



Conclusion

The increasing demand for water is straining water resources in many parts of the world. Automated management can reduce waste to make more water available to meet the growing demand. To achieve successful results, automation must be reliable and effective, while maintaining the health of the landscape.

Weather based control of irrigation systems has been proven for more than 20 years to reduce water waste without sacrificing the quality of the landscape. As advancements are made in technology, cost-cutting efforts should not compromise proven science. The demands to reduce waste, coupled with technological advancements, allow commercial and residential customers to benefit from weather based automated control. It is not practical or necessary to put a weather station on every property. Sharing weather sensor data in a community is a cost effective way to assure accurate, reliable data to achieve sustainable conservation. Wireless technology provides an easily implemented link between sensors and an unlimited number of controllers. End users need not maintain on-site weather sensors to benefit from ET based control.

Water savings have been documented, improved landscape health has been reported, and time has been saved because watering schedules are automatically adjusted based on real-time conditions. Wireless weather-based sprinkler control will improve landscape health and help alleviate growing strain on water resources.

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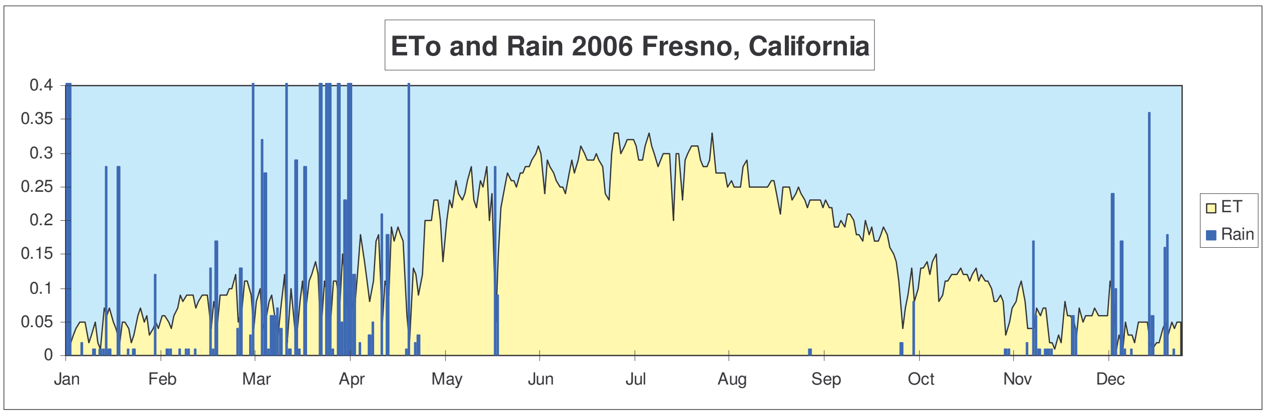
        - Water Use: 2000 -2001 – 13,068,000 gallons/year avg. 2002-2004 – 9,017,000 gallons/year avg.
          http://www.irrisoft.net/wr/sites/North%20Salt%20Lake.pdf
    - John Cherek - Las Vegas, Nevada - 56% Water Savings
        - Water Use: 2003 – 16,035 gallons, 2005 – 7,000 gallons (April to September)
          http://www.irrisoft.net/wr/sites/Las%20Vegas.pdf
    - Stanley Jacobs - Ipswich, Massachusetts - 47% Water Savings
        - Water Use: 2002 – 2,120,000 gallons, 2003 – 1,130,000 gallons (May to October)
          http://www.irrisoft.net/wr/sites/Ipswich%20Jacobs.pdf
    - Murray City Hall, Murray, Utah - 45% Water Savings
        - Water Use: 1999 - 2002 – 2,735,062 gallons/year avg. 2003 – 1,499,366 gallons (April to September)
          http://www.irrisoft.net/wr/sites/Murray%20City%20Hall.pdf
    - Greenwood Village Parks, Greenwood Colorado - 49% Water Savings
        - Water Use: 2003 – 1,044,000 gallons, 2004 – 538,000 gallons (May to October)
          http://www.irrisoft.net/wr/sites/Greenwood%20Village.pdf
    - Southcentre Mall - Calgary, Alberta - 43% Water Savings
        - Water Use: 2005 – 2,296,140 gallons, 2006 – 1,309,800 gallons
          http://www.exactet.com/results.asp

Appendix I

The flowing data comes from California Irrigation Management Information System (CIMIS) Fresno State - San Joaquin Valley - Station 80, and demonstrates soil moisture modeling based on ET, rainfall and irrigation. In this example the irrigation amount was set to 0.50" and is not crop specific using ET_o as opposed to a crop specific ET_c.



Watering Frequency Controlled by Real Time Weather Conditions				
	Total Eto	Total Rain	Watering Days	Irrigation Amount
JAN	1.28	3.46	0	0.0
FEB	2.19	0.54	3	1.5
MAR	2.46	4.58	1	0.5
APR	3.84	3.10	4	2.0
MAY	7.17	0.37	14	7.0
JUNE	8.46	0.00	17	8.5
JULY	9.20	0.00	18	9.0
AUG	7.79	0.00	16	8.0
SEP	5.75	0.01	11	5.5
OCT	3.43	0.10	7	3.5
NOV	1.72	0.41	2	1.0
DEC	1.38	1.30	1	0.5
TOTALS	54.67	13.87	94	47.0

Soil Moisture Balance

Fresno, California

Date	ET	Effective Rain	Irrigate	Moisture Balance	Date	ET	Effective Rain	Irrigate	Moisture Balance
1/1/2006	0.01	0.75	0.00	0.75	3/1/2006	0.11	0.00	0.50	0.50
1/2/2006	0.02	0.75	0.00	0.75	3/2/2006	0.09	0.03	0.00	0.44
1/3/2006	0.03	0.00	0.00	0.72	3/3/2006	0.04	0.59	0.00	0.75
1/4/2006	0.04	0.00	0.00	0.68	3/4/2006	0.08	0.00	0.00	0.67
1/5/2006	0.05	0.00	0.00	0.63	3/5/2006	0.10	0.00	0.00	0.57
1/6/2006	0.05	0.02	0.00	0.60	3/6/2006	0.04	0.32	0.00	0.75
1/7/2006	0.05	0.00	0.00	0.55	3/7/2006	0.06	0.27	0.00	0.75
1/8/2006	0.02	0.00	0.00	0.53	3/8/2006	0.08	0.01	0.00	0.68
1/9/2006	0.03	0.00	0.00	0.50	3/9/2006	0.09	0.06	0.00	0.65
1/10/2006	0.05	0.01	0.00	0.46	3/10/2006	0.05	0.06	0.00	0.66
1/11/2006	0.02	0.00	0.00	0.44	3/11/2006	0.03	0.07	0.00	0.70
1/12/2006	0.01	0.01	0.00	0.44	3/12/2006	0.07	0.04	0.00	0.67
1/13/2006	0.07	0.01	0.00	0.38	3/13/2006	0.12	0.00	0.00	0.55
1/14/2006	0.06	0.28	0.00	0.60	3/14/2006	0.02	0.42	0.00	0.75
1/15/2006	0.07	0.01	0.00	0.54	3/15/2006	0.10	0.01	0.00	0.66
1/16/2006	0.05	0.00	0.00	0.49	3/16/2006	0.06	0.00	0.00	0.60
1/17/2006	0.04	0.00	0.00	0.45	3/17/2006	0.02	0.29	0.00	0.75
1/18/2006	0.02	0.28	0.00	0.71	3/18/2006	0.08	0.01	0.00	0.68
1/19/2006	0.05	0.00	0.00	0.66	3/19/2006	0.11	0.00	0.00	0.57
1/20/2006	0.05	0.00	0.00	0.61	3/20/2006	0.06	0.28	0.00	0.75
1/21/2006	0.04	0.01	0.00	0.58	3/21/2006	0.11	0.00	0.00	0.64
1/22/2006	0.02	0.00	0.00	0.56	3/22/2006	0.12	0.00	0.00	0.52
1/23/2006	0.03	0.01	0.00	0.54	3/23/2006	0.14	0.00	0.00	0.38
1/24/2006	0.06	0.00	0.00	0.48	3/24/2006	0.12	0.00	0.00	0.26
1/25/2006	0.07	0.00	0.00	0.41	3/25/2006	0.03	0.43	0.00	0.66
1/26/2006	0.05	0.00	0.00	0.36	3/26/2006	0.11	0.00	0.00	0.55
1/27/2006	0.06	0.00	0.00	0.30	3/27/2006	0.09	0.48	0.00	0.75
1/28/2006	0.03	0.00	0.00	0.27	3/28/2006	0.03	0.70	0.00	0.75
1/29/2006	0.04	0.00	0.00	0.23	3/29/2006	0.11	0.01	0.00	0.65
1/30/2006	0.05	0.12	0.00	0.30	3/30/2006	0.11	0.00	0.00	0.54
1/31/2006	0.04	0.00	0.00	0.26	3/31/2006	0.08	0.50	0.00	0.75
2/1/2006	0.06	0.00	0.00	0.20	4/1/2006	0.15	0.05	0.00	0.65
2/2/2006	0.06	0.00	0.00	0.14	4/2/2006	0.11	0.23	0.00	0.75
2/3/2006	0.05	0.01	0.00	0.10	4/3/2006	0.05	0.68	0.00	0.75
2/4/2006	0.04	0.01	0.00	0.07	4/4/2006	0.08	0.75	0.00	0.75
2/5/2006	0.06	0.00	0.00	0.01	4/5/2006	0.06	0.12	0.00	0.75
2/6/2006	0.07	0.00	0.50	0.44	4/6/2006	0.13	0.00	0.00	0.62
2/7/2006	0.09	0.01	0.00	0.36	4/7/2006	0.18	0.02	0.00	0.46
2/8/2006	0.08	0.00	0.00	0.28	4/8/2006	0.14	0.00	0.00	0.32
2/9/2006	0.09	0.01	0.00	0.20	4/9/2006	0.11	0.00	0.00	0.21
2/10/2006	0.09	0.01	0.00	0.12	4/10/2006	0.08	0.03	0.00	0.16
2/11/2006	0.09	0.00	0.00	0.03	4/11/2006	0.11	0.05	0.00	0.10
2/12/2006	0.07	0.01	0.50	0.47	4/12/2006	0.17	0.00	0.50	0.43
2/13/2006	0.08	0.00	0.00	0.39	4/13/2006	0.18	0.00	0.00	0.25
2/14/2006	0.09	0.00	0.00	0.30	4/14/2006	0.05	0.21	0.00	0.41
2/15/2006	0.09	0.00	0.00	0.21	4/15/2006	0.11	0.00	0.00	0.30
2/16/2006	0.09	0.00	0.00	0.12	4/16/2006	0.09	0.18	0.00	0.39
2/17/2006	0.04	0.13	0.00	0.21	4/17/2006	0.19	0.00	0.00	0.20
2/18/2006	0.08	0.01	0.00	0.14	4/18/2006	0.17	0.00	0.00	0.03
2/19/2006	0.05	0.17	0.00	0.26	4/19/2006	0.19	0.00	0.50	0.34
2/20/2006	0.09	0.00	0.00	0.17	4/20/2006	0.18	0.00	0.00	0.16
2/21/2006	0.09	0.00	0.00	0.08	4/21/2006	0.17	0.00	0.50	0.49
2/22/2006	0.09	0.00	0.50	0.49	4/22/2006	0.06	0.01	0.00	0.44
2/23/2006	0.10	0.00	0.00	0.39	4/23/2006	0.02	0.52	0.00	0.75
2/24/2006	0.10	0.00	0.00	0.29	4/24/2006	0.13	0.00	0.00	0.62
2/25/2006	0.12	0.00	0.00	0.17	4/25/2006	0.12	0.02	0.00	0.52
2/26/2006	0.05	0.04	0.00	0.16	4/26/2006	0.09	0.03	0.00	0.46
2/27/2006	0.07	0.13	0.00	0.22	4/27/2006	0.12	0.00	0.00	0.34
2/28/2006	0.11	0.00	0.00	0.11	4/28/2006	0.20	0.00	0.00	0.14
					4/29/2006	0.20	0.00	0.50	0.44
					4/30/2006	0.20	0.00	0.00	0.24

Soil Moisture Balance

Fresno, California

Date	ET	Effective Rain	Irrigate	Moisture Balance	Date	ET	Effective Rain	Irrigate	Moisture Balance
5/1/2006	0.23	0.00	0.00	0.01	7/1/2006	0.30	0.00	0.00	0.18
5/2/2006	0.23	0.00	0.50	0.28	7/2/2006	0.31	0.00	0.50	0.37
5/3/2006	0.20	0.00	0.00	0.08	7/3/2006	0.32	0.00	0.00	0.05
5/4/2006	0.14	0.00	0.50	0.44	7/4/2006	0.32	0.00	0.50	0.23
5/5/2006	0.20	0.00	0.00	0.24	7/5/2006	0.32	0.00	0.50	0.41
5/6/2006	0.23	0.00	0.00	0.01	7/6/2006	0.31	0.00	0.00	0.10
5/7/2006	0.22	0.00	0.50	0.29	7/7/2006	0.29	0.00	0.50	0.31
5/8/2006	0.26	0.00	0.00	0.03	7/8/2006	0.29	0.00	0.00	0.02
5/9/2006	0.24	0.00	0.50	0.29	7/9/2006	0.31	0.00	0.50	0.21
5/10/2006	0.23	0.00	0.00	0.06	7/10/2006	0.33	0.00	0.50	0.38
5/11/2006	0.24	0.00	0.50	0.32	7/11/2006	0.31	0.00	0.00	0.07
5/12/2006	0.26	0.00	0.00	0.06	7/12/2006	0.30	0.00	0.50	0.27
5/13/2006	0.28	0.00	0.50	0.28	7/13/2006	0.28	0.00	0.50	0.49
5/14/2006	0.23	0.00	0.00	0.05	7/14/2006	0.29	0.00	0.00	0.20
5/15/2006	0.22	0.00	0.50	0.33	7/15/2006	0.30	0.00	0.50	0.40
5/16/2006	0.26	0.00	0.00	0.07	7/16/2006	0.30	0.00	0.00	0.10
5/17/2006	0.25	0.00	0.50	0.32	7/17/2006	0.30	0.00	0.50	0.30
5/18/2006	0.28	0.00	0.00	0.04	7/18/2006	0.20	0.00	0.00	0.10
5/19/2006	0.20	0.00	0.50	0.34	7/19/2006	0.30	0.00	0.50	0.30
5/20/2006	0.24	0.00	0.00	0.10	7/20/2006	0.30	0.00	0.00	0.00
5/21/2006	0.05	0.28	0.00	0.33	7/21/2006	0.23	0.00	0.50	0.27
5/22/2006	0.15	0.09	0.00	0.27	7/22/2006	0.29	0.00	0.50	0.48
5/23/2006	0.22	0.00	0.00	0.05	7/23/2006	0.30	0.00	0.00	0.18
5/24/2006	0.25	0.00	0.50	0.30	7/24/2006	0.31	0.00	0.50	0.37
5/25/2006	0.27	0.00	0.00	0.03	7/25/2006	0.31	0.00	0.00	0.06
5/26/2006	0.26	0.00	0.50	0.27	7/26/2006	0.31	0.00	0.50	0.25
5/27/2006	0.26	0.00	0.00	0.01	7/27/2006	0.29	0.00	0.50	0.46
5/28/2006	0.25	0.00	0.50	0.26	7/28/2006	0.28	0.00	0.00	0.18
5/29/2006	0.27	0.00	0.50	0.49	7/29/2006	0.28	0.00	0.50	0.40
5/30/2006	0.27	0.00	0.00	0.22	7/30/2006	0.29	0.00	0.00	0.11
5/31/2006	0.28	0.00	0.50	0.44	7/31/2006	0.33	0.00	0.50	0.28
6/1/2006	0.28	0.00	0.00	0.16	8/1/2006	0.27	0.00	0.00	0.01
6/2/2006	0.29	0.00	0.50	0.37	8/2/2006	0.27	0.00	0.50	0.24
6/3/2006	0.30	0.00	0.00	0.07	8/3/2006	0.27	0.00	0.50	0.47
6/4/2006	0.31	0.00	0.50	0.26	8/4/2006	0.27	0.00	0.00	0.20
6/5/2006	0.30	0.00	0.50	0.46	8/5/2006	0.25	0.00	0.50	0.45
6/6/2006	0.24	0.00	0.00	0.22	8/6/2006	0.26	0.00	0.00	0.19
6/7/2006	0.29	0.00	0.50	0.43	8/7/2006	0.25	0.00	0.50	0.44
6/8/2006	0.28	0.00	0.00	0.15	8/8/2006	0.25	0.00	0.00	0.19
6/9/2006	0.27	0.00	0.50	0.38	8/9/2006	0.25	0.00	0.50	0.44
6/10/2006	0.26	0.00	0.00	0.12	8/10/2006	0.28	0.00	0.00	0.16
6/11/2006	0.25	0.00	0.50	0.37	8/11/2006	0.29	0.00	0.50	0.37
6/12/2006	0.25	0.00	0.00	0.12	8/12/2006	0.25	0.00	0.00	0.12
6/13/2006	0.24	0.00	0.50	0.38	8/13/2006	0.25	0.00	0.50	0.37
6/14/2006	0.27	0.00	0.00	0.11	8/14/2006	0.25	0.00	0.00	0.12
6/15/2006	0.29	0.00	0.50	0.32	8/15/2006	0.25	0.00	0.50	0.37
6/16/2006	0.27	0.00	0.00	0.05	8/16/2006	0.25	0.00	0.00	0.12
6/17/2006	0.29	0.00	0.50	0.26	8/17/2006	0.25	0.00	0.50	0.37
6/18/2006	0.31	0.00	0.50	0.45	8/18/2006	0.25	0.00	0.00	0.12
6/19/2006	0.30	0.00	0.00	0.15	8/19/2006	0.26	0.00	0.50	0.36
6/20/2006	0.29	0.00	0.50	0.36	8/20/2006	0.26	0.00	0.00	0.10
6/21/2006	0.29	0.00	0.00	0.07	8/21/2006	0.24	0.00	0.50	0.36
6/22/2006	0.29	0.00	0.50	0.28	8/22/2006	0.21	0.00	0.00	0.15
6/23/2006	0.30	0.00	0.50	0.48	8/23/2006	0.25	0.00	0.50	0.40
6/24/2006	0.29	0.00	0.00	0.19	8/24/2006	0.25	0.00	0.00	0.15
6/25/2006	0.28	0.00	0.50	0.41	8/25/2006	0.25	0.00	0.50	0.40
6/26/2006	0.24	0.00	0.00	0.17	8/26/2006	0.23	0.00	0.00	0.17
6/27/2006	0.23	0.00	0.50	0.44	8/27/2006	0.24	0.00	0.50	0.43
6/28/2006	0.30	0.00	0.00	0.14	8/28/2006	0.25	0.00	0.00	0.18
6/29/2006	0.33	0.00	0.50	0.31	8/29/2006	0.24	0.00	0.50	0.44
6/30/2006	0.33	0.00	0.50	0.48	8/30/2006	0.23	0.00	0.00	0.21
					8/31/2006	0.22	0.00	0.50	0.49

Soil Moisture Balance

Fresno, California

Date	ET	Effective Rain	Irrigate	Moisture Balance	Date	ET	Effective Rain	Irrigate	Moisture Balance
9/1/2006	0.23	0.01	0.00	0.27	11/1/2006	0.08	0.00	0.00	0.34
9/2/2006	0.23	0.00	0.00	0.04	11/2/2006	0.09	0.00	0.00	0.25
9/3/2006	0.23	0.00	0.50	0.31	11/3/2006	0.08	0.00	0.00	0.17
9/4/2006	0.23	0.00	0.00	0.08	11/4/2006	0.03	0.01	0.00	0.15
9/5/2006	0.22	0.00	0.50	0.36	11/5/2006	0.05	0.01	0.00	0.11
9/6/2006	0.23	0.00	0.00	0.13	11/6/2006	0.07	0.00	0.00	0.04
9/7/2006	0.22	0.00	0.50	0.41	11/7/2006	0.08	0.00	0.50	0.46
9/8/2006	0.22	0.00	0.00	0.19	11/8/2006	0.10	0.00	0.00	0.36
9/9/2006	0.19	0.00	0.50	0.50	11/9/2006	0.11	0.00	0.00	0.25
9/10/2006	0.19	0.00	0.00	0.31	11/10/2006	0.08	0.00	0.00	0.17
9/11/2006	0.20	0.00	0.00	0.11	11/11/2006	0.04	0.02	0.00	0.15
9/12/2006	0.19	0.00	0.50	0.42	11/12/2006	0.04	0.00	0.00	0.11
9/13/2006	0.21	0.00	0.00	0.21	11/13/2006	0.04	0.17	0.00	0.24
9/14/2006	0.21	0.00	0.50	0.50	11/14/2006	0.07	0.06	0.00	0.23
9/15/2006	0.20	0.00	0.00	0.30	11/15/2006	0.06	0.01	0.00	0.18
9/16/2006	0.18	0.00	0.00	0.12	11/16/2006	0.07	0.00	0.00	0.11
9/17/2006	0.18	0.00	0.50	0.44	11/17/2006	0.07	0.01	0.00	0.05
9/18/2006	0.17	0.00	0.00	0.27	11/18/2006	0.02	0.01	0.00	0.04
9/19/2006	0.20	0.00	0.00	0.07	11/19/2006	0.02	0.01	0.00	0.03
9/20/2006	0.18	0.00	0.50	0.39	11/20/2006	0.01	0.00	0.00	0.02
9/21/2006	0.19	0.00	0.00	0.20	11/21/2006	0.03	0.00	0.50	0.49
9/22/2006	0.17	0.00	0.00	0.03	11/22/2006	0.02	0.00	0.00	0.47
9/23/2006	0.17	0.00	0.50	0.36	11/23/2006	0.08	0.00	0.00	0.39
9/24/2006	0.18	0.00	0.00	0.18	11/24/2006	0.06	0.00	0.00	0.33
9/25/2006	0.19	0.00	0.50	0.49	11/25/2006	0.06	0.00	0.00	0.27
9/26/2006	0.18	0.00	0.00	0.31	11/26/2006	0.05	0.06	0.00	0.28
9/27/2006	0.16	0.00	0.00	0.15	11/27/2006	0.03	0.04	0.00	0.29
9/28/2006	0.15	0.00	0.50	0.50	11/28/2006	0.07	0.00	0.00	0.22
9/29/2006	0.14	0.00	0.00	0.36	11/29/2006	0.05	0.00	0.00	0.17
9/30/2006	0.11	0.00	0.00	0.25	11/30/2006	0.06	0.00	0.00	0.11
10/1/2006	0.04	0.02	0.00	0.23	12/1/2006	0.06	0.00	0.00	0.05
10/2/2006	0.07	0.00	0.00	0.16	12/2/2006	0.06	0.00	0.50	0.49
10/3/2006	0.09	0.00	0.00	0.07	12/3/2006	0.07	0.00	0.00	0.42
10/4/2006	0.13	0.00	0.50	0.44	12/4/2006	0.06	0.00	0.00	0.36
10/5/2006	0.08	0.08	0.00	0.44	12/5/2006	0.06	0.00	0.00	0.30
10/6/2006	0.10	0.00	0.00	0.34	12/6/2006	0.06	0.00	0.00	0.24
10/7/2006	0.13	0.00	0.00	0.21	12/7/2006	0.06	0.00	0.00	0.18
10/8/2006	0.13	0.00	0.00	0.08	12/8/2006	0.11	0.00	0.00	0.07
10/9/2006	0.14	0.00	0.50	0.44	12/9/2006	0.08	0.24	0.00	0.23
10/10/2006	0.12	0.00	0.00	0.32	12/10/2006	0.01	0.10	0.00	0.32
10/11/2006	0.14	0.00	0.00	0.18	12/11/2006	0.03	0.00	0.00	0.29
10/12/2006	0.15	0.00	0.00	0.03	12/12/2006	0.01	0.17	0.00	0.45
10/13/2006	0.08	0.00	0.50	0.45	12/13/2006	0.05	0.01	0.00	0.41
10/14/2006	0.09	0.00	0.00	0.36	12/14/2006	0.03	0.00	0.00	0.38
10/15/2006	0.11	0.00	0.00	0.25	12/15/2006	0.03	0.01	0.00	0.36
10/16/2006	0.11	0.00	0.00	0.14	12/16/2006	0.02	0.00	0.00	0.34
10/17/2006	0.12	0.00	0.00	0.02	12/17/2006	0.05	0.00	0.00	0.29
10/18/2006	0.12	0.00	0.50	0.40	12/18/2006	0.05	0.00	0.00	0.24
10/19/2006	0.12	0.00	0.00	0.28	12/19/2006	0.05	0.00	0.00	0.19
10/20/2006	0.13	0.00	0.00	0.15	12/20/2006	0.05	0.00	0.00	0.14
10/21/2006	0.12	0.00	0.00	0.03	12/21/2006	0.02	0.36	0.00	0.48
10/22/2006	0.12	0.00	0.50	0.41	12/22/2006	0.01	0.06	0.00	0.53
10/23/2006	0.11	0.00	0.00	0.30	12/23/2006	0.02	0.00	0.00	0.51
10/24/2006	0.12	0.00	0.00	0.18	12/24/2006	0.02	0.00	0.00	0.49
10/25/2006	0.13	0.00	0.00	0.05	12/25/2006	0.04	0.00	0.00	0.45
10/26/2006	0.11	0.00	0.50	0.44	12/26/2006	0.05	0.16	0.00	0.56
10/27/2006	0.12	0.00	0.00	0.32	12/27/2006	0.03	0.18	0.00	0.71
10/28/2006	0.11	0.00	0.00	0.21	12/28/2006	0.05	0.00	0.00	0.66
10/29/2006	0.11	0.00	0.00	0.10	12/29/2006	0.04	0.01	0.00	0.63
10/30/2006	0.10	0.00	0.50	0.50	12/30/2006	0.05	0.00	0.00	0.58
10/31/2006	0.08	0.00	0.00	0.42	12/31/2006	0.05	0.00	0.00	0.53