Modeling Crop Water Use in the Pacific Northwest: The USBR AgriMet Program

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Abstract

Water supplies are limited in the arid western United States, and demands on water resources continue to grow. Environmental concerns for fish and wildlife, endangered species, and recreation call for reductions in consumptive use, leaving more water in rivers, lakes and streams. In many states in the west, irrigated agriculture accounts for an overwhelming majority of total consumptive water use. Recognizing the opportunity for water conservation in irrigated agriculture, the U.S. Bureau of Reclamation, in partnership with Bonneville Power Administration, began installing a network of agricultural weather stations in the Pacific Northwest in 1983. From an initial 3 stations, the network has grown to over 50 stations in Idaho, Oregon, Washington, and Montana. The network, called AgriMet (for Agricultural Meteorology), measures the weather parameters required to model crop evapotranspiration, or "ET". These data are telemetered by satellite to a receiving station in Boise, Idaho, where they are incorporated into the Kimberly-Penman ET equation. Each day during the growing season, crop water use charts are developed and disseminated via the World Wide Web and a dial up computer system to irrigators and agricultural consultants in the Northwest. By knowing the water holding capacity of the soil and the root depth of the crops, irrigators can use ET information to apply the right amount of water to their crops at the right time. Benefits of scientific irrigation scheduling include water conservation, reduced energy and fertilizer cost, reduced soil erosion, and protection of water quality by reducing runoff and groundwater infiltration of pesticide and fertilizer laden water.

Introduction

In 1902, Congress created the U.S. Bureau of Reclamation, charging the agency with reclaiming arid lands in the West through irrigation in order to stimulate settlement and economic development. Over the last century, that charge has come to fruition, probably beyond all expectations. In 1987, Reclamation began shifting its program emphasis from water resource development to water resource management. This shift was in response to increasing environmental concerns, budget constraints, and competing demands for limited water resources. In order to meet these new demands, Reclamation is looking to new and innovative opportunities for effective, efficient management and conservation of existing water resources.

In the West, irrigated agriculture is the largest single off stream user of water. In Idaho, for example, agriculture accounts for approximately 99 percent of consumptive water use (Carr et. al., 1990). Obviously, the most potential for water conservation lies in irrigation water management. Potential benefits include more water availability for other uses, lower costs for irrigators, and improved quality of both surface and ground water supplies.

In an effort to conserve both water and energy, Reclamation and the Bonneville Power Administration (BPA) entered into a formal agreement in the mid-1980's to promote irrigation water efficiency. This agreement resulted in the installation of a network of automated agricultural weather stations called "AgriMet" (for Agricultural Meteorology) in the Pacific Northwest. These stations collect and telemeter the meteorological parameters required to model crop evapotranspiration, or ET. This information is used by irrigation districts, farmers, resource conservation agencies, and agricultural consultants for irrigation scheduling and related purposes. Since the initial installation of 3 stations in 1983, the network has grown to over 50 stations in the Pacific Northwest (Figure 1). Seven additional AgriMet stations are operated by Reclamation's Great Plains

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Region in the Missouri River basin in western Montana. Reclamation has established partnerships with more than 25 entities, including other federal and state agencies, soil and water conservation districts, universities, public utilities, and private enterprise to fund the operation of the AgriMet network.

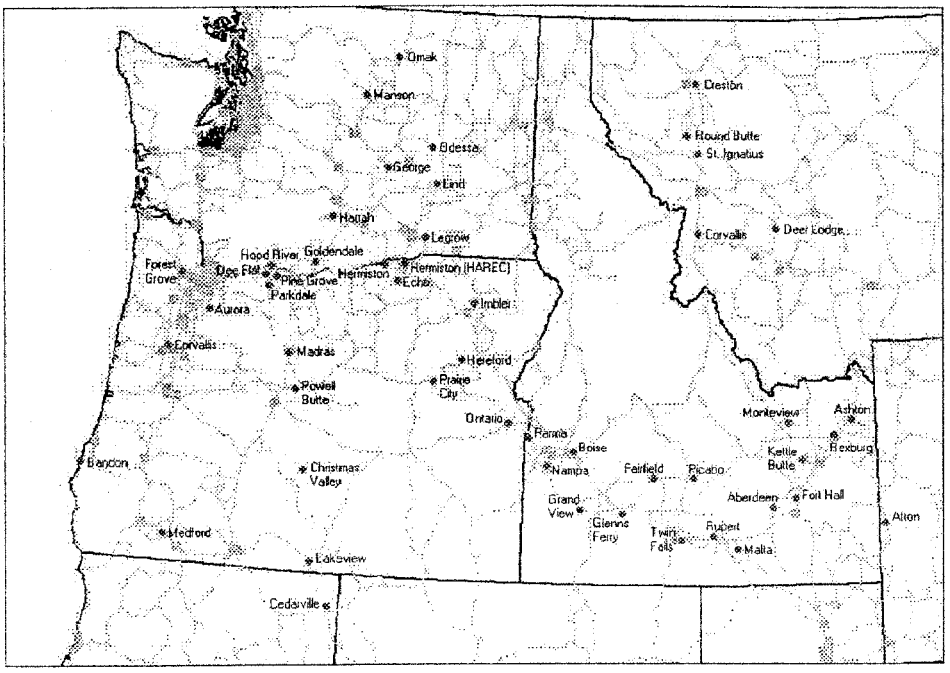

Figure 1: AgriMet Weather Station Locations

AgriMet Operation

AgriMet stations are located in agricultural areas throughout the Pacific Northwest in Idaho, Montana, Oregon, and Washington, with additional stations located in northern California and western Wyoming. The stations are typically located right on the edge of irrigated fields so that the data collected approximates the meteorological conditions affecting the cultivated crops in the area (Figure 2). Each AgriMet station is configured with a standard set of sensors, including air temperature, precipitation, solar radiation, wind speed and direction, and relative humidity. These standard sensors collect the meteorological parameters required for modeling crop ET. Some sites have special sensors, including soil temperature sensors, shadowband pyranometers for special solar radiation studies, crop canopy temperature thermistors, and evaporation pan sensors.

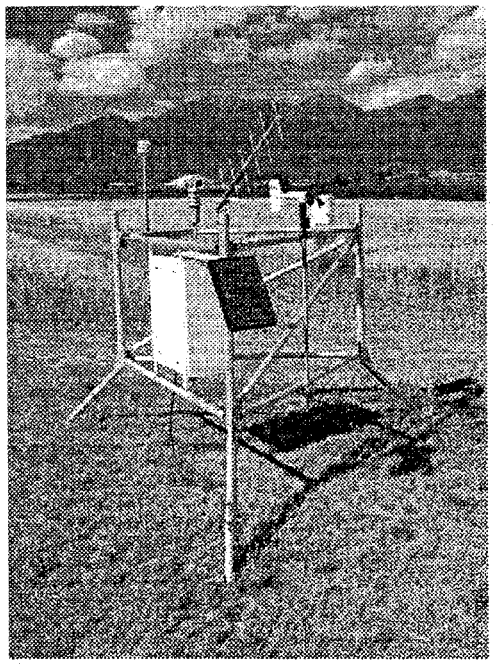

Figure 2: Typical AgriMet Weather Station

The complete AgriMet site, including sensors, solar panel, antenna, and data collection platform (DCP) are mounted on a sturdy aluminum tripod. Sensors are mounted at standard sensor heights for agricultural weather data collection requirements. Power for the site is provided by a special automotive type storage battery which is recharged daily by a solar panel.

Data Collection and Transmission

The DCP at the site interrogates each of the sensors for current data at regular intervals (every 15 minutes or every hour, depending on the data requirements for each sensor). Cumulative type data, such as wind run, solar radiation, and precipitation are accumulated at the site prior to data transmission.

Data are transmitted from the DCP via the GOES satellite (Geostationary Operational Environmental Satellite) in a one minute window every four hours according to a strict transmission schedule. Six transmissions per day are required to deliver an entire day's complement of 15-minute and hourly data. The DCPs can also be programmed to transmit at non-scheduled reporting times for special purposes, such as flood warning during heavy precipitation events or fruit frost forecasting. These "random" reports are initiated by the DCP when the sensor data exceeds preset sensor limits (upper or lower boundaries) or rate of change.

The data transmissions are a digital UHF FM signal in the 401-402 megahertz range, and the frequency and timing are coordinated with the National Environmental Satellite, Data, and Information Service (NESDIS). The telemetered information is down linked at the Bureau of Reclamation's Pacific Northwest Regional Office in Boise, Idaho. This Direct Read-Out Ground Station serves not only AgriMet, but also Reclamation's Hydromet system, which monitors streamflow and reservoir conditions throughout the region. Data is also downlinked at the receive site for several other cooperating federal agencies.

Data Quality Control Procedures

As soon as the weather data is received at the downlink site, it is subjected to a variety of automated quality control procedures. These validation tests include a parity check, message length check, illegal character check, upper and lower limit screening, and rate of change tests. If the incoming data fails any of these tests, it is marked with a flag indicating the nature of the failure before being added to the database. These flagged values are not used in subsequent calculations, such as computation of average daily temperatures or daily ET rates. After these automated quality control processes are completed, the 15 minute (and hourly) data are stored in a "dayfiles" database. Standard AgriMet dayfile parameters include air temperature, relative humidity, dew point, and wind direction -- all on 15 minute intervals. Hourly data includes accumulated wind run, accumulated solar radiation, and accumulated precipitation.

Between 5:00 and 5:30 am each morning, several automated processes run on the dayfiles data, producing summary parameters for each day, including daily maximum, minimum, and average air temperatures, total daily wind run, average wind direction, total daily precipitation, accumulated solar radiation, mean relative humidity, and mean dew point. These data are stored in an "archive" database and are kept on-line indefinitely.

Additional manual quality control procedures are performed on the data each working day. Data collected during weekends or holidays are reviewed on the next working day. These procedures include review of satellite transmission quality parameters which may point to data quality problems not detected by the automated procedures. Other checks include graphical review of sensor data by groups of sites which have similar climatic characteristics. Apparent anomalies are examined for possible data quality problems, and bad data is removed or estimated. Archive parameters and ET values are then recalculated using the revised data parameters.

AgriMet Technical Advisory Committee

In order to ensure the technical competency of the AgriMet program, a technical advisory committee was formed in 1991. Membership included representatives from the USDA Agricultural Research Service and Soil Conservation Service (now the Natural Resources Conservation Service), Bonneville Power Administration, the University of Idaho (State Climatologist), and a private agricultural consultant. This group has met several times since 1991 to discuss such topics as operation and maintenance of the weather stations, sensor standards, data quality control standards, user access, crop models, crop water use charts, reference ET, and the need for new stations. This group's continued role as an advisory arm of the program will help ensure a high quality of technical competency into the future.

Site Maintenance and Calibration

All AgriMet sites receive an annual maintenance and inspection visit in the spring that includes calibration and cleaning of all sensors by program specialists and electronic technicians. DCP transmission performance parameters are checked and adjusted as needed, including transmit frequency and clock accuracy. System battery voltage, solar panel output, and voltage regulator output are checked; these items are cleaned, replaced, or adjusted as needed. Forward and reflected power of the transmit antenna are checked along with the coax cable connections.

Solar radiation pyranometers are checked against a reference standard and conversion equation coefficients are corrected if necessary. Tipping bucket precipitation gages are checked for calibration by metering precise quantities of water into the gage and comparing the number of counts recorded. Units which are out of calibration are either adjusted in the field or the mechanism is replaced. Weighing mechanisms for Belfort precipitation gages are replaced annually with a bench calibrated unit. Relative humidity sensors are compared against a bench calibrated sensor and an aspirated psychrometer. Sensors which are out of calibration are removed and replaced with laboratory calibrated sensors. Temperature sensors are compared against a precision thermometer and replaced if necessary. Calibration of the wind sensor is tested by using a special device that spins the shaft at several different speeds. Tests are made at 5 different wind velocities ranging from 5 to 30 mph. Wind speed and peak gust parameters are both verified in this procedure. Bearings in the nose cone of the anemometer are tested for torque, and wind direction is verified with a magnetic compass. Units that do not meet specifications are replaced.

This special attention given to the sites during these annual calibration and maintenance visits provides high quality data not only for crop water use modeling, but also for a variety of research and other weather related applications.

Modeling Evapotranspiration

Soil moisture is depleted through a process called evapotranspiration (ET), which is the combination of evaporation of soil water into the atmosphere and transpiration by plants. Parameters affecting ET include such things as root distribution and density, soil water potential and aeration within the root zone, soil hydraulic conductivity, stomatal sensitivity to leaf water potential, and internal plant resistance. Modeling ET is not straightforward, due to the complicated nature of atmosphere, crop and soil moisture relationships. Several different methods of modeling ET have been devised; the relative merits of each depend on such variables as data availability, ease of computation, user acceptance, and time increment between computations.

Net radiation is the primary climatic factor controlling ET when soil moisture supplies are not limited (Jensen et. al., 1990, p. 25). Another important factor is advection, or wind movement, which moves the saturated air away from the soil and plant surfaces. Hence, procedures which combine these two functions to model ET provide the best results, particularly for daily time intervals (USBR, 1983).

Combination method equations integrate net radiation (the "heat function") and advective energy transfer (the "wind function") into a single equation. This energy balance concept was first applied to cropped surfaces in 1948 by Penman, and his equation has been used throughout the world in ET research (Jensen, 1974). A

modified form of the original Penman equation was developed by the USDA Agricultural Research Service (ARS) in Kimberly, Idaho by Dr. James Wright in 1982 (Jensen, 1990, p.98), and is sometimes referred to as the 1982 Wright-modified Penman equation. This procedure requires several meteorological inputs for modeling ET, including maximum and minimum daily air temperatures, relative humidity, daily solar radiation, and daily wind run. All of these parameters are collected by the AgriMet system.

The modified Penman equation calculates the theoretical amount of water that a well watered crop of alfalfa with 30 cm. of top growth would use. Alfalfa is a widely recognized "reference crop" for ET calculations, and the calculated ET value is known as "reference ET", or Etr. Crop coefficients for other crops (typically expressed as percent of Etr during the progression of the growing season) have been developed by a variety of researchers and research methods. (Jensen, 1990, p. 113). The ET value for other crops besides alfalfa is the product of the reference ET (alfalfa) and the specific crop coefficient for that particular stage of the crop's growth. The result is a table of daily ET for each crop grown in the vicinity of each AgriMet station.

Dissemination of AgriMet Products

There are three major products provided by the AgriMet program:

- A table of daily ET values for the last five days for a reference crop (Alfalfa) and specific crops grown in the area. This table includes a 7 day, 14 day, and growing season ET total. In addition, a forecast of ET for the current day is displayed (based on the average of the last three days ET value) (Table 1).
- A table of weather parameters for the last 5 days for each station (Table 2).
- A summary of ET for each day of the growing season for each crop grown in the vicinity of each station

ESTIMATED CROP WATER USE - JUL 6, 1998 AHTI

CROP	START DATE	DAILY CROP WATER USE-(IN) PENMAN ET - JUL 2	3	4	5	DAILY FORE CAST	COVER DATE	TERM DATE	SUM ET	7 DAY USE	14 DAY USE
ALFP	501	0.35	0.32	0.29	0.23	0.28	625	925	9.3	2.0	3.3
ALFM	501	0.30	0.27	0.25	0.20	0.24	625	925	8.4	1.8	2.9
PAST	420	0.24	0.22	0.20	0.16	0.19	610	925	8.1	1.4	2.3
LAWN	420	0.28	0.26	0.23	0.18	0.22	601	925	9.9	1.6	2.7
WGRN	415	0.35	0.32	0.29	0.23	0.28	625	815	12.1	2.0	3.3
SGRN	520	0.34	0.31	0.29	0.23	0.28	801	901	5.6	2.0	3.2
POTA	620	0.12	0.12	0.11	0.09	0.11	815	1015	1.2	0.7	1.1

Table 1: Daily AgriMet Crop Water Use Chart

The AgriMet system currently has two automated methods for product dissemination: a dial-in computer system and a home page on the World Wide Web. The dial-in computer system was established in the early 1980's to provide users with a source of timely ET data and related ag-weather information. This system requires a login and password for access. Users place a phone line call to a mini-computer server located in Reclamation's regional office in Boise, Idaho. Telnet connectivity is also available for users with Internet access. Once

connected, the user is presented with a menu from which they can select the primary AgriMet products (ET table, ET summary, and weather summary). In addition, historical weather data (including daily ET) is available for all sites for the period of record. To become a registered user, contact the Bureau of Reclamation, AgriMet Program Coordinator at (208) 378-5283.

In response to the growing popularity of the Internet and the World Wide Web, an AgriMet home page was established in 1996. This source of information provides "point and "click" access to the three primary AgriMet products (ET table, ET summary, and weather summary). Related site information (such as location, elevation, etc.) and tips on irrigation water management are also available from the home page, as well as on-line access to historical weather information. The URL of the AgriMet home page is:

WY	Station	Parameter	Wed JUL01	Thu JUL02	Fri JUL03	Sat JUL04	Sun JUL05
98	AHTI	PEN_ET	0.270	0.350	0.320	0.290	0.230
98	AHTI	AVG_TMP	65.164	66.549	68.001	65.373	66.692
98	AHTI	MIN_TMP	49.749	48.824	51.218	48.237	49.675
98	AHTI	MAX_TMP	80.167	88.485	83.285	80.230	77.441
98	AHTI	ACCPCIP	4.820	4.820	4.820	4.820	4.820
98	AHTI	PRECIP	0.000	0.000	0.000	0.000	0.000
98	AHTI	WY_PCIP	13.110	13.110	13.110	13.110	13.110
98	AHTI	SOLAR	679.620	692.239	691.788	704.874	538.007
98	AHTI	AVG_HUM	71.061	64.891	60.015	65.277	60.958
98	AHTI	GRODEGD	15.083	18.000	17.252	15.115	13.721
98	AHTI	AV_WSPD	5.427	5.832	6.340	5.046	3.931
98	AHTI	AV_WDIR	111.139	79.492	140.459	187.882	157.589
98	AHTI	WINDRUN	130.240	139.978	152.150	121.111	94.333
98	AHTI	MI_SOL4	59.714	60.657	61.443	61.837	63.016
98	AHTI	MI_SOL8	60.343	61.601	62.465	63.016	64.038
98	AHTI	MX_SOL4	70.956	72.136	72.136	73.315	72.765
98	AHTI	MX_SOL8	65.217	66.239	66.947	67.733	67.576
98	AHTI	AVG_DEW	54.032	51.936	51.945	52.059	51.225
98	AHTI	AV_SOL4	64.980	65.966	66.623	67.333	68.275

Table 2: Daily AgriMet Weather Data

http://www.pn.usbr.gov/agrimet

Several local newspapers in the region obtain AgriMet crop water use from the dial-in computer system or from the Internet. This information is then published in these newspapers, providing an additional means of local dissemination.

Uses of AgriMet Products and Information

The principal product produced by the AgriMet network is site and crop specific evapotranspiration. This information is integrated into various on-farm technical assistance programs by local agricultural consultants, the Cooperative Extension Service, and the USDA Natural Resources Conservation Service. As competition for limited water supplies increases as well as the cost of pumping for irrigation, farmers are turning more and more to scientific irrigation scheduling.

The most common method for irrigation scheduling is known as the "checkbook method", which accounts for deposits and withdrawals to the soil moisture account. For this procedure, the farmer must first know the water holding capacity of his soil. This information is typically available from detailed soil surveys of the area, or from site specific soil tests. After each irrigation during the growing season, the farmer tracks the daily crop specific ET. When the cumulative water use equals the Management Allowable Depletion (MAD) for that crop, it's time to irrigate again. Specific knowledge of the irrigation system, combined with ET information from

AgriMet, allows a farmer to apply the right amount of water at the right time for optimum crop production. Not only does the farmer realize savings in water and pumping costs, but reduced leaching results in reduced costs for fertilizer, herbicides, and pesticides. Various agricultural consultants have reported water and power savings ranging from 15 to 50 percent through the use of AgriMet supplied ET data. In some locations, this reduction has resulted in real savings of $9.00/acre in pumping costs (Dockter, 1996, p. 43). Indirect benefits of scientific irrigation scheduling include reduction in non-point source surface water pollution (through reductions in nutrient and chemical laden irrigation tailwater) as well as protecting ground water supplies through reduced leaching of agricultural chemicals.

Several AgriMet stations in the Hood River, Oregon area have historically been used for fruit frost forecasting. In the spring, these stations were programmed to operate in the event reporting (random) mode. When air temperature dropped below a pre-determined level, the site transmitted every 10-15 minutes until the temperature rose above the threshold level. The National Weather Service Forecast Office in Portland, Oregon used this information as part of their agricultural weather program, issuing fruit frost forecasts when conditions warranted. This service has since been discontinued.

In the Lake Chelan area of Washington, the local irrigation district uses AgriMet data for site specific irrigation scheduling (Cross, 1997). Soil moisture measurements are taken weekly at 2-4 sites per orchard in over 60 fruit orchards in the area. Daily AgriMet data is used to estimate the theoretical crop consumptive use. This soil moisture is plotted on a time series bar graph, showing soil moisture content at several depths through the growing season. When the AgriMet derived evapotranspiration data indicates that the soil moisture has dropped to the allowable depletion level, the producer irrigates the orchard. The next field measurement shows the new soil moisture levels, and the daily consumptive use values from AgriMet are systematically subtracted from the soil moisture levels until the next irrigation is scheduled. This process is repeated throughout the growing season, and updated information is mailed to each producer on the same day the soil moisture measurements are taken. In the future, electronic mail and Internet posting of this information will further enhance this progressive irrigation scheduling program.

Requests for current and historical weather information from the AgriMet network are common. Agricultural producers depend on wind speed and direction for scheduling such practices as field burning and pesticide applications. Several electric utilities use solar radiation information to forecast daily energy requirements. University researchers frequently request historical weather and ET information for a variety of applications, ranging from regional water consumptive use modeling to locating new orchards and vineyards.

Seven AgriMet sites are part of the Pacific Northwest Regional Solar Radiation Monitoring Program, coordinated by the University of Oregon. This network collects solar radiation data primarily for siting solar electric generating facilities, but the information is used in a variety of other research and operational applications as well.

Summary

In response to new directions in water management, the U.S. Bureau of Reclamation, in partnership with Bonneville Power Administration, developed a network of agricultural weather stations in the Pacific Northwest. From the original three sites installed in 1983, the "AgriMet" system has now grown to over 50 sites in Idaho, Oregon, Washington, Montana, Wyoming, and California.. Reclamation has cultivated partnerships with over 25 federal, state, and private interests to fund the operation of the network.

The AgriMet system collects the weather data required for modeling crop evapotranspiration, transmitting this information via satellite to a downlink site at Reclamation's Regional Office in Boise, Idaho. Every day during the growing season, crop water use charts are developed for crops grown in the vicinity of each AgriMet station. This information is available daily through dial up computer facilities, the World Wide Web, and in many local newspapers throughout the region. The information is used by federal and state agencies, conservation districts, irrigation districts, extension agents, agricultural consultants, corporate farms, and individual irrigators for water management purposes. The weather data collected is also used by researchers for a wide variety of

applications. A rigorous field calibration and maintenance program ensures a high level of data quality and integrity.

Competition for limited water resources is increasing, cost of irrigation water and pumping is rising, and concerns for surface and ground water quality are heightening. In response to these factors, scientific irrigation scheduling is becoming more commonplace. AgriMet is providing the information required to meet these challenges in the Pacific Northwest.

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