J9.4 AGRICULTURAL WATER RESOURCES DECISION SUPPORT SYSTEM AND EVAPOTRANSPIRATION TOOLBOX

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1. INTRODUCTION

Water resources in the Upper Rio Grande Basin are in ever increasing demand for such diverse uses as irrigation, municipal, industrial, endangered species, and recreation. Evapotranspiration (ET) of irrigated crops and riparian vegetation, and open water evaporation accounts for about 60 percent of the water depletions along the Rio Grande. Consequently, there is a critical need for rapid improvement in calculating and forecasting daily agricultural and riparian water consumptive use demands. To help meet this need, the Bureau of Reclamation (Reclamation) and other Federal and State agencies entered into a Memorandum of Understanding to collaborate on the development of the Upper Rio Grande Water Operations Model (URGWOM). The URGWOM is a computer surface water model that will cover the Rio Grande from its headwaters in Colorado to Fort Quitman, Texas. The primary purpose of this model will be a daily water operations accounting tool that can be used for basin-wide water management and planning.

In late FY1997, Reclamation's Albuquerque Area Office became aware of a newly developed Agricultural WAter Resources Decision Support (AWARDS) system for the Lugert-Altus Irrigation district in southwest Oklahoma. The Albuquerque Area Office requested that the AWARDS system be implemented in the Rio Grande, primarily as the foundation for the development of the desired ET Toolbox. The goal of the ET Toolbox project is to develop a methodology for automatically inputting daily riparian and crop water use estimates, open water evaporation estimates, and rainfall estimates into RiverWare, which is the river modeling and water accounting system used by the URGWOM.

2. AWARDS

The AWARDS system is an automated information system to assist water users by providing easy access to rainfall and daily crop water use estimates. These estimates are based on real-time data obtained from WSR-88D (Weather Surveillance Radar - 1988 Doppler) radar systems and automated weather stations. The purpose of the AWARDS system is to improve the efficiency of water management and irrigation scheduling by proving guidance on when and where to deliver water, and how much to apply.

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AWARDS systems that have been implemented east of the Continental Divide use the WSR-88D Stage III multi-sensor (radar and gage) hourly product produced by the National Weather Service's (NWS) River Forecast Centers (RFCs). The Stage III product uses the NWS Hydrologic Rainfall Analysis Project (HRAP) nominal 4 km x 4 km resolution grid. Every hour, the Stage III data files are automatically collected into the AWARDS computer via file transfer protocol (FTP) from the Missouri Basin, Arkansas-Red Basin, and West Gulf RFCs. NWS 24-hour quantitative precipitation forecasts (QPF) are also automatically collected from the RFCs. Automated weather stations in AWARDS system areas transmit surface weather data via radio signal, phone, or satellite to local computer systems. The daily and hourly data are then automatically collected from the local computer systems, via FTP, into the AWARDS computer.

Various Geographic Information System (GIS) data resources are used, such as watershed, hydrologic, political boundary, irrigation district conveyance system, and other features, for developing the base maps for the AWARDS system. These data are transferred to longitude-latitude coordinates for input to a graphics program available from the National Center for Atmospheric Research, called NCAR Graphics. The HRAP grid cells are plotted and overlaid with the WSR-88D precipitation estimates and weather station rain gage measurements.

Once the day's data are accumulated, computer programs produce 24-hour summary images and make them available on the Internet Web site. Lastly, the Modified-Penman based ET crop water use estimates, weather data, QPF, and ET forecasts are integrated into the images via pop-up charts. Reservoir operators, water managers, and on-farm water users access the AWARDS system products via the Internet to make their operational decisions. Details on the AWARDS system are available in Hartzell et al., 2000.

3. ET TOOLBOX

The ET Toolbox builds on the AWARDS system, adding GIS land use to specify crop, riparian, and open water acreage, as well as the vegetation type and coverage within each HRAP grid cell. The primary purpose of the ET Toolbox is to accumulate the grid cells' daily rainfall and water use estimates within specified river reaches used in RiverWare. The initial development work is focused on the Middle Rio Grande area from Cochiti Dam to San Marcial, which is just south of the Bosque del Apache National Wildlife Refuge in New Mexico. These daily ET estimates and summary year-to-date cumulative ET estimates are available to users and water managers via the Internet. The daily river reach consumptive use estimates are provided to the URGWOM by RiverWare, using a Data Storage System developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center.

3.1 Land Use Classifications

Several GIS vegetation data sets that cover portions of the area were evaluated. The Middle Rio Grande Land Use Trend Analysis GIS Data Base for 1992/93 and aerial photography taken during a June 1999 ET field study are the current land use resources. All of the vegetation data sets are transposed to the HRAP grid cell resolution and compared to determine changes in the vegetation and water depletion over time. An Ikonos satellite 4-meter multi spectral resolution land use data set from July 2000 is planned for use commencing sometime in late 2001. Such land use data sets are expensive to process and are somewhat outdated by the time they are available for use. Therefore, there is a need to develop a methodology for estimating seasonal and daily crop and riparian ET, and open water evaporation along the Rio Grande using remote sensing technology that is both timely and cost permissive.

3.2 Radar Rainfall Estimates

High resolution rainfall estimates based on the WSR-88D multi-sensor Stage III data are incorporated into the ET Toolbox to offset vegetation water use and open water evaporation. The 24-hr rainfall for each HRAP grid cell located over the irrigated and riparian acreage along the Rio Grande is used in the water use calculations.

Figure 1 is an example of the Rio Grande Basin ET Toolbox Project area, available from Reclamation's NEXRAD website at http://www.usbr.gov/rsmg/nexrad. The area from Alcalde, New Mexico to the southern boundary of the Middle Rio Grande Conservancy District (MRGCD) is shown. The shaded 24-hr WSR-88D Stage III rainfall estimates are shown in inches for March 7, 2001, Mountain Daylight Time (MDT) as received from the NWS West Gulf River Forecast Center (WGRFC).

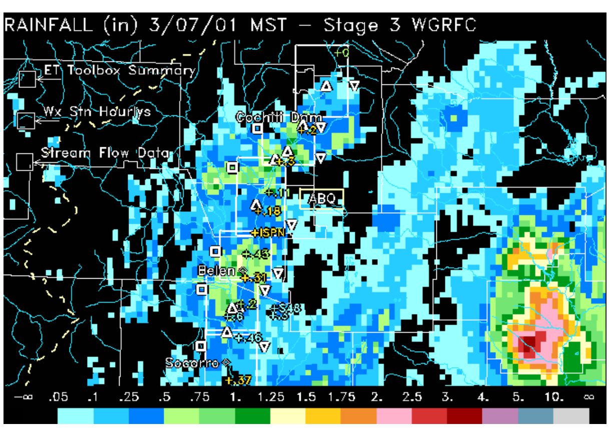

Figure 1. Example of an interactive image showing the 24-hr WSR-88D Stage III rainfall estimates.

3.3 Weather Station Data

A requirement for computing evapotranspiration for the ET Toolbox is acquisition of appropriate daily weather data, which includes temperature, dew point temperature or relative humidity, solar radiation, wind speed, and rain gage measurements. The weather data are obtained from the New Mexico Climate Center at the New Mexico State University, The University of New Mexico's Sevilleta Long-Term Ecological Research (LTER) Program, and the MRGCD. Daily data are used in the ET calculations, and the 1-hr data are made available to the NWS for fine tuning WSR-88D Stage III rainfall estimates. The white sub-window boxes are designed to include the agricultural areas between Rio Grande diversion dams that provide water to users within the MRGCD. Clicking within these white sub-window boxes allows the user to further pop-up detailed ET charts for each crop grown in the area.

The small white boxes to the left of the sub-window boxes in Figure 1 allow the user to pop-up the more detailed features of the ET Toolbox as shown in Figure 2. Daily weather station values are available for Internet access by clicking on the + signs in Figure 2 and hourly values are accessed from the "Wx Station Hourly" box in Figure 1. The white triangles link to the USGS Internet site offering near real-time streamflow and river stage information. Most of the features of the images in Figures 1 and 2, including the MRGCD water distribution system, were imported from various GIS coverages. These maps are produced for the AWARDS - ET Toolbox Web site using the NCAR Graphics product.

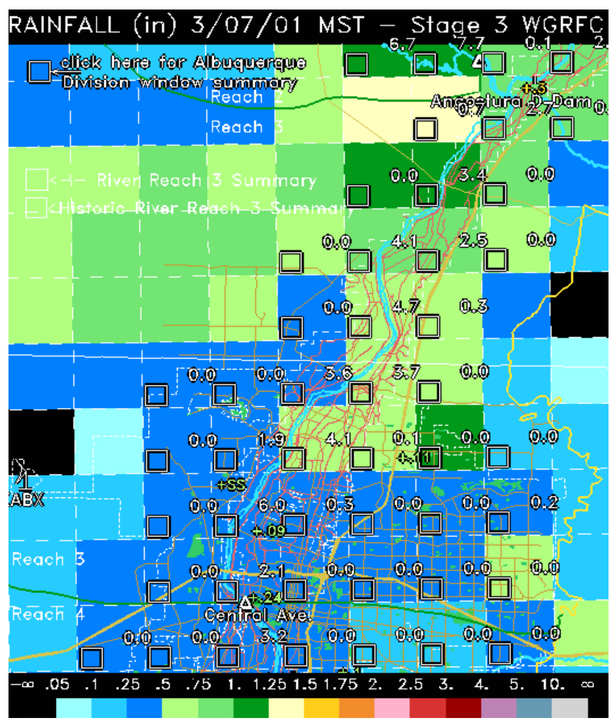

Figure 2. Example of an interactive image showing the grid cell 24-hr ET estimates and shaded 24-hr WSR-88D Stage III rainfall estimates.

3.4 Evapotranspiration (ET)

Researchers at the New Mexico State University chose a modified version of the Penman equation for calculating reference evapotranspiration (Eto). This value is empirically derived from experimental data based on a grass referenced method that combines energy balance and heat and mass transfer functions (ASCE, 1990). A vegetative coefficient (Kc) is applied to the Eto to determine the daily ET, in inches, as applied in the ET Toolbox, using the formula:

$$ET = Kc \times Eto$$

Graphs of vegetative coefficients can be presented as a function of time, seasonal growth stages, percent of effective cover from zero to 100, or Growing Degree Days (GDD). Sammis (1985) states that since the plant development depends on the heat units, a physiological clock can be developed based on GDD. Vegetative coefficients as a function of GDD developed under a particular climate condition can easily be transferred to areas with a different climate.

GDDs are accumulated heat that will contribute to plant growth and development from the period of planting until harvesting, or bud break to defoliation. The average method was chosen in New Mexico (King et al., 2000) for determination of GDD using:

$$GDD = ((\text{daily max temp} + \text{min temp}) / 2) - \text{base temp}$$

The maximum and minimum temperatures are replaced with cutoff temperatures when the limits are exceeded. In order to avoid negative GDD, the base temperature is set to the minimum temperature where growth .

Crop coefficients were taken from King et al., (2000) and Jensen (1998). The coefficients for saltcedar and cottonwood (predominate riparian types) were received from Dr. Salim Bawazir, New Mexico State University (personal correspondence) as a result of extensive field studies in 1999 at the Bosque del Apache National Wildlife Refuge. Jensen (1998) preformed a study on open water evaporation for the Lower Colorado River. The monthly coefficients for open water in the Parker Dam to Imperial Dam reach along the Lower Colorado are being used for the Middle Rio Grande.

3.5 ET Toolbox Calculations and Results

Computer processes were developed to collect all of the required data sets and calculate the daily consumptive use (DCU) in acre-feet for each vegetative type using:

$$DCU = Eto\ (in) \times Kc \times Acres\ / 12\ (in/ft)$$

where Eto is the reference evapotranspiration in inches, Kc is the vegetative coefficient, and Acres is the vegetative acreage of the grid cell.

All of the crop and riparian (including open water) acre-feet values (DCUs) are summed to arrive at an estimated consumptive use for each cell. These cell values are printed to a pop-up interactive image on the Web site as shown in Figure 2. By clicking on the printed value within the cell, a pop-up ET Toolbox cell detail table will appear. Pop-up cell summaries are available from the individual cell boxes shown in Figure 2.

Figure 3 is an example of a pop-up graph summary of daily water (consumptive) use for the area from Cochiti Dam to San Marcial for a time period in year 2000. The Total trace is influenced by rain, but the Agricultural, Riparian, and Urban (includes irrigated parks and golf courses) traces are presented to show the water use had it not rained. Similar graphs are available on the Web site for all diversions and reaches within the area, including options for choosing 5 and 10-day running averages. The user can also interactively generate water use graphs by type for any time period.

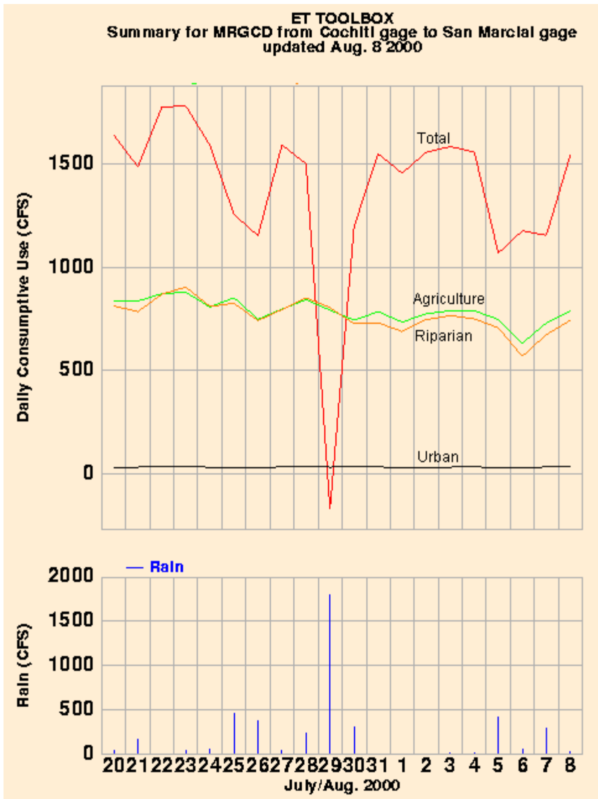

Figure 3. Example of a pop-up daily water use graph.

3.6 MRGCD Gaging Information

The MRGCD has contributed in the development of the ET Toolbox for the Middle Rio Grande. Figure 4 is a schematic of the MRGCD gaging system. By clicking on a gage box, the user can pop-up a graph of the current conditions as of the last hour, as shown in Figure 5. The groupings on the right are the irrigation diversion points. The valley cross sections on the left indicate depletion analysis points defined by USGS gages (river reaches), and provide graphs of discharge against the daily ET for that river reach.

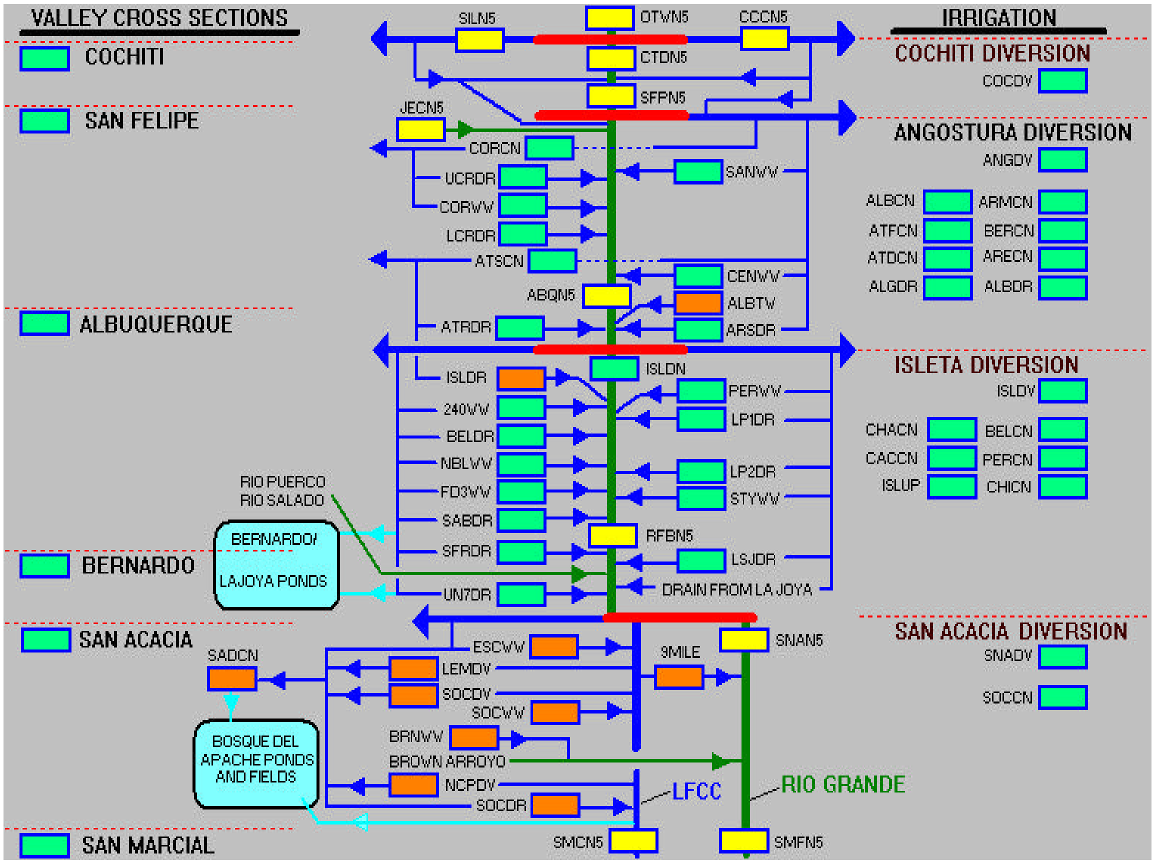

Figure 4. Schematic of the Middle Rio Grande Conservancy District gaging system.

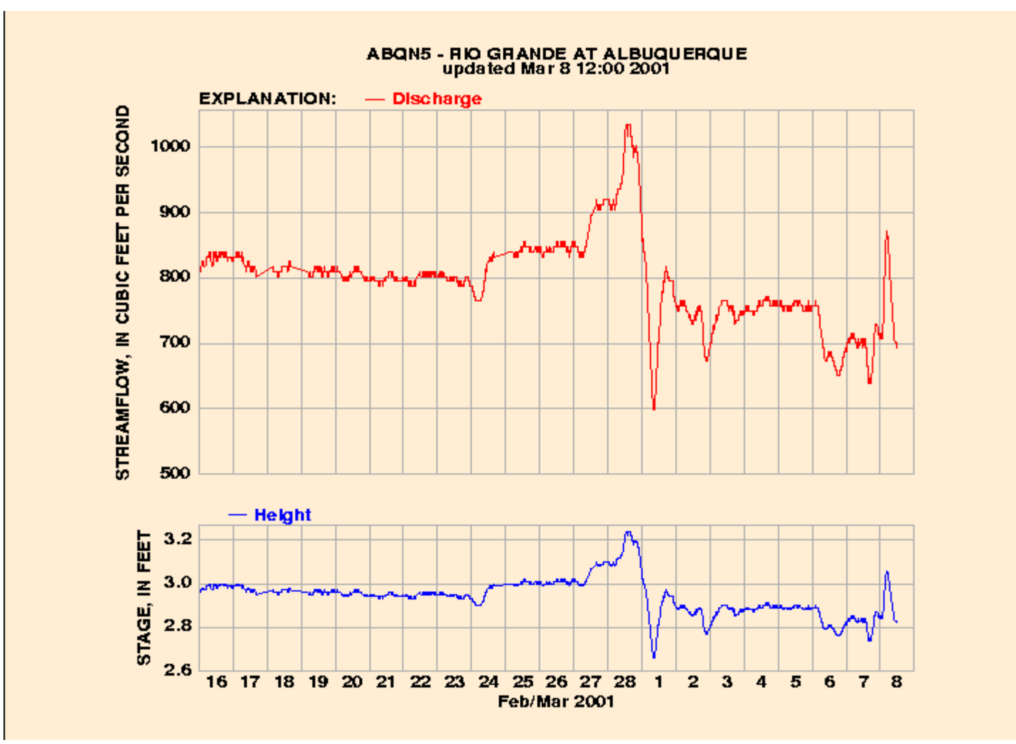

Figure 5. Example graph of discharge and river stage conditions.

Reclamation and MRGCD water operations staff use the ET summary and gaging data to better manage daily water releases from the reservoirs while satisfying downstream water use requirements for agricultural crops, riparian vegetation, open water evaporation, and fish & wildlife.

3.7 Eta Model Forecasts

ET Toolbox system enhancements are being made to provide specialized support. One recent enhancement is the implementation of using National Centers for Environmental Prediction (NCEP) Eta model weather forecast parameters at 20-km grid resolution to improve the ET Toolbox's 24-hr and 48-hr ET forecasts. The ET Toolbox uses the Eta model 0600 UTC (0000 MDT) run's 3-hr forecasts for temperature, relative humidity, and wind speed, plus the forecast cumulative solar radiation and precipitation for 0600-0600 UTC. From the 3-hr forecast values, the ET Toolbox selects the maximum and minimum temperatures, and calculates the average relative humidity and wind speed.

The Eta model-based 24-hr ET forecasts from the previous day are used in the ET Toolbox when weather station data are unavailable. Figure 6 shows a comparison of the forecast total solar radiation, maximum and minimum temperatures, and average relative humidity, with measurements from a weather station located within the 20-km Eta grid cell. The Eta positive bias in surface solar insolation was expected as it has been documented by a number of Eta model verification studies (Mitchell, et al., 2000). For this sample, the maximum temperatures were in good agreement, there was a positive bias in the minimum temperature, and a negative bias in the average relative humidity. The differences in minimum temperature and relative humidity, as well as wind speed which is not shown, are likely due to the mean height of the Eta grid cell being about 320 feet higher than the weather station, and the weather station being located near the Rio Grande and protected by vegetation.

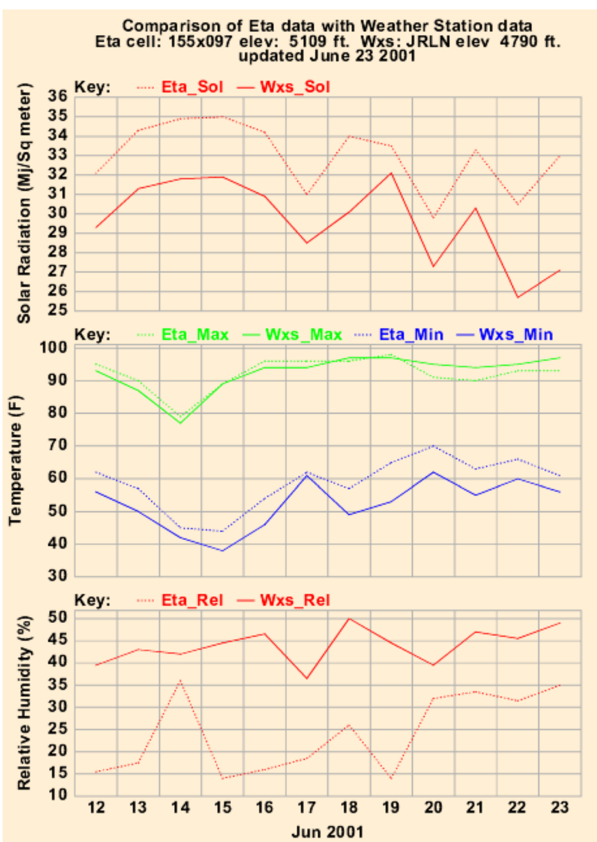

Figure 6. Example of a comparison of one Eta model 20-km grid cell forecast parameters with measurements from a weather station located within the grid cell.

3.8 Use of ET Toolbox for Daily Operations

During the irrigation season and when water supply conditions require close attention to operations, the Reclamation, MRGCD, and State water managers use the Middle Rio Grande Web site on a daily basis. The Chief of Water Operations at Reclamation's Albuquerque Area Office used the Web site several times a day to direct critical water releases for the threatened Silvery Minnow and to meet other irrigation demands during the severe 2000 drought. He found that the ET Toolbox information was "invaluable" for his decision making.

4. UPPER COLUMBIA BASIN ET TOOLBOX

Reclamation is currently implementing the ET Toolbox technology for portions of the Upper Columbia River Basin in the Pacific Northwest. The daily water use estimates for subareas within river reaches will be input to versions of RiverWare that are being adapted for Reclamation's Yakima, Upper Columbia, and Umatilla projects. One difference from the Middle Rio Grande system is that water managers will use RiverWare directly for water supply operations.

The most significant difference in the AWARDS - ET Toolbox system in the Pacific Northwest area is the radar-based precipitation estimates. The accuracy of standard WSR-88D precipitation products such as Stage III, based on the default $Z_e = 300R^{1.4}$ relationship with no range correction, is not sufficient for Reclamation's operational needs. Therefore, a $Z_e = aR^ß$ precipitation accumulation algorithm (PAA) based on WSR-88D Level III base reflectivity data was developed to improve the quantitative precipitation estimates (QPE). This version of the PAA allows site specific selected a and ß values, minimum and maximum precipitation thresholds, and range correction factor (Hartzell et al., 2001).

Improvements have recently been made to the PAA that restores the range correction function with a true vertical profile of reflectivity, based on clearance between a radar beam center and the terrain. Also, the precipitation type in the radar beam is classified as dry snow, melting snow, and rain, based on model soundings. The three classes will have a different a, but ß will remain 2.0 (Hunter et al., 2001).

5. SUMMARY

- The AWARDS - ET Toolbox system developed for the Middle Rio Grande demonstrates a methodology that integrates high resolution WSR-88D 1-hr rainfall estimates, weather station data, atmospheric model forecasts, crop and riparian ET requirements, GIS information, and land usage, with modern computer communication, and Internet technologies for improved water resources management.
- Daily consumptive use estimates (agriculture + riparian + open water + urban - rain) are accessible on the Web site in tables and plotted graphs (daily, 5-day and 10-day running averages) for the individual river reaches and the total MRGCD plus the Bosque del Apache National Wildlife Refuge.
- The total daily agriculture, riparian, open water, and urban consumptive use estimates, plus the cumulative rainfall for the defined river reaches, are automatically provided for use in RiverWare, which is the river modeling and water accounting system used by the URGWOM.
- Pop-up charts and graphs of weather station data, streamflow and river stage, the MRGCD schematic of the gaging system, and the 1-hr WSR-88D Stage III images are updated in near real time.
- Forecast parameters at 20-km grid resolution from the NCEP Eta model are being used in the ET Toolbox to replace missing weather station data for calculating daily ET, and to make 24-hr and 48-hr river reach consumptive use forecasts.
- Middle Rio Grande water operations managers who accessed the Web site, often on a daily basis during critical periods, found that the ET Toolbox information was invaluable for their decision making.
- Reclamation is implementing the AWARDS - ET Toolbox technology in the Upper Columbia Basin using a Reclamation-developed PAA to obtain QPE in place of the NWS RFC Stage III product.

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Data from the automated weather stations are provided by the New Mexico Climate Center (Dr. Ted Sammis), Middle Rio Grande Conservancy District (David Gensler), and the Sevilleta LTER Program (Doug Moore). The WSR-88D Stage III multi-sensor product and the 24-hr quantitative precipitation forecasts are obtained via FTP from the NWS West Gulf River Forecast Center (Robert Corby). The 20-km Eta model forecast parameters are obtained via FTP from NCEP's Environmental Modeling Center (Dr. Geoff DiMego).

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