COMPARISON, CALIBRATION AND REFINEMENT OF TRADITIONAL CROP COEFFICIENT CURVES IN THE SOUTH PLATTE RIVER BASIN USING MAPPING EVAPOTRANSPIRATION AT HIGH RESOLUTION WITH INTERNALIZED CALIBRATION

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ABSTRACT
Quantification of water consumptive use in Colorado is increasingly important as water resources are placed under growing tension by increased users and interests. For crop production systems, evapotranspiration (ET) accounts for almost all the water that is consumed. Since ET is directly related to crop yield, the typical goal for irrigation management is to supplement rainfall with just enough water to meet full ET unless the water supply is inadequate. If irrigation along with rainfall is insufficient to meet ET demand, yield reduction is likely.

ET from agricultural fields is usually estimated by multiplying the weather-based reference ET by crop coefficients (Kc) determined according to the crop type and the crop growth stage. There is typically some question regarding whether the crops grown compare with the conditions represented by the Kc values, especially in water short areas. In addition, it is difficult to predict the correct crop growth stage dates for large populations of crops and fields.

This paper describes procedures being investigated by Riverside Technology, inc. (RTi) and Northern Colorado Water Conservancy District (NCWCD) for the temporal calibration and refinement of traditional crop coefficients curves in the South Platte River basin using Mapping Evapotranspiration at High Resolution with Internalized Calibration - METRIC™ (Allen et. al 2007). This could enable existing consumptive use models to be enhanced, resulting in better water demand forecasting, water rights management, water resources planning, and water regulation. METRIC, an image-processing model for calculating actual ET as a residual of the surface energy balance, utilizes the thermal band on various satellite remote sensors.

INTRODUCTION

Quantifying the consumption of water over large areas and within irrigation projects is essential for water demand forecasting, water rights management, water resources planning and water regulation. Due to the difficulty of capturing this information, however, it is often poorly understood and thus a weakly represented component of water resources management decision support tools. Evapotranspiration (ET) from agricultural fields is typically estimated by multiplying a weather-based reference ET (ETr) by crop coefficients (Kc), determined according to the crop type and the crop growth stage. ETr is a standardized estimate of potential ET calculated at an appropriately sited weather station and for a specific vegetation condition (e.g. 0.5 m height and full ground cover).

In practice, crop ET is estimated by selecting derived crop coefficients corresponding to the crop growth stage, and multiplying by the ETr value. Aggregated ET over a large area is then calculated by summing across all irrigated parcels within the area (where specific field-crop information is available), over a growing period. This aggregation requires creating and regularly updating GIS crop maps. There are several limitations to this approach for accurate estimation of crop ET. For example, the actual field and crop conditions must be assessed relative to the base
conditions represented by the Kc values, especially in water short areas. In addition, crop growth stages are quite variable for large populations of crops and irrigated parcels. These and other limitations have led RTi and NCWCD to investigate alternative methods for estimating irrigated crop ET.

Recent developments in satellite remote sensing ET modeling have enabled an accurate estimate of ET and Kc for large populations of irrigated parcels. These methods are being used successfully for quantifying surface water use and for quantifying net groundwater pumping in areas. There are two approaches that are commonly used for this work, including the Surface Energy Balance (SEBAL) developed by Bastiaanssen (1998), and, (ii) Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC) developed by Allen (2007). METRIC is in fact a variant of SEBAL, and both SEBAL and METRIC continue to evolve with refinements of various components of the energy balance (e.g. Allen, et al., 2005a, b). METRIC is the most suitable for the current work as the model has been extended to provide better integration with ground-based ETr, enhancing its repeatability and accuracy.

METRIC is an image-processing model comprised of multiple sub-models for calculating ET as a residual of the surface energy balance. METRIC has been applied widely with Landsat images in southern Idaho, southern California, Colorado (by RTi), Washington State (by RTi), and New Mexico to predict monthly and seasonal ET for water rights accounting and for operation of ground water models. ET “maps” (i.e., images) produced by the METRIC model provide the means to quantify, in both the amount and the spatial distribution, ET on a parcel-by-parcel basis. The ET images generated by METRIC also show the temporal distribution of ET during a growing season in addition to the spatial distribution.

Improvements in the accuracy of ET estimates or in the processing efficiency of consumptive use demand for large irrigated lands and associated verification can greatly benefit core NCWCD modeling efforts to better understand the temporal and spatial relationships between water demand and water availability, ultimately leading to better water planning decisions and water management. Having complete information on ET is essential to the better understanding of consumptive use and soil moisture availability.

RTi has advanced ET-remote sensing science and applications in the past year with its ArcGIS ET-Server technology. This technology allows users to select and analyze remote sensing-based ET data in areas-of-interest by digitizing on-screen or by geographic analysis - for example, by selecting all data (pixels) that lie within a specified irrigation service area or crop type. The analysis function calculates and displays total ET for the specific spatiotemporal query as a single date, 24hr ET interpolation, and monthly or seasonal interpolations. User query of seasonal values returns a graph (ET curve) on screen; this ET curve can be co-plotted with ET curves derived from other sources (e.g. conventional methods) to enable the user to assess and interpret the difference between the two methods. This ArcGIS ET-Server application will enable all stakeholders to assess the results of the METRIC mapping and compare with results from conventional ET estimation methods. In addition, this ET-Server application will provide rapid and transparent access to the data enabling external QA/QC and general assessments by users during the data development stages.

OVERVIEW OF METHODS USED TO ESTIMATE CONSUMPTIVE USE IMPLEMENTED IN THIS STUDY

Conventional Method to Measuring Consumptive Use over Large Areas in the South Platte River Basin

As part of the Colorado Water Conservation Board’s (CWCB) South Platte Decision Support (SPDSS) effort, basin consumptive use, water allocation, and groundwater models are being implemented. Key to this has been the identification of irrigated lands (parcels, crops, irrigation methods) and the water supply (ditches, wells) associated with the lands. This detailed mapping, in conjunction with detailed historical water use data collected by the State of Colorado, has allowed comprehensive historical models to be developed that can be used to analyze future scenarios and for demand forecasting. Baseline data sets are being developed to enable users to model specific basin and sub-basin scenarios related to water demands, water consumption, and water movement. The core data developed to support modeling (e.g., databases and spatial data layers) are heavily utilized by stakeholders, statewide.

SPDSS is utilized by, among others, the NCWCD, a public agency created in 1937. The main function of the District is to administer the Colorado-Big Thompson (C-BT) project for the USBR. Water is supplied for agricultural, municipal, and industrial use in northeastern Colorado. In 2004, NCWCD provided irrigation water for 695,551
irrigated crop acres within its 1.6 million acre boundaries. The District currently provides agricultural and urban landscape water users with practical information and demonstrations of best irrigation management practices. A 27-station weather network provides weather data and calculations of crop evapotranspiration (ET) to growers for irrigation scheduling purposes. Other water resources engineers at NCWCD use crop ET data in water demand forecasting, well augmentation plans and quantification of water balances for improving water management.

Currently, agricultural consumptive use is computed for SPDSS based on estimates of ET for individual crops. Crop ET is estimated as a fraction (i.e., crop coefficient) of computed ET for a reference crop. Reference ET is a standardized estimate of potential ET calculated at an appropriately sited weather station and for a specific vegetation condition (0.5 m height and full ground cover). In practice, crop ET is estimated by selecting derived crop coefficients corresponding to the crop growth stage and multiplying by the reference ET value. Aggregated ET over a large area is then calculated by summing across all fields within the area, if specific field-crop information is available. This aggregation requires the creation and regular update of GIS crop-type maps, which are often costly to produce.

Locally calibrated coefficients for the major crop types irrigated throughout the plains (i.e. from the front-range foothills eastwards) of the SPDSS study area were developed through calibration with the ASCE Standardized Penman Monteith method (ASCE 1990) due to the unavailability of lysimeter data. The ASCE Standardized method can be applied using a set of short reference crop (grass) or tall reference crop (alfalfa) coefficients. Alfalfa has been suggested as the preferable reference crop for arid climates (ASCE, 1990) This calibration was performed by comparing gross potential consumptive use (PCU) estimates between modified Blaney-Criddle and ASCE Standardized methods prior to reducing for effective precipitation. The modified Soil Conservation Service’s (SCS) Blaney-Criddle consumptive use methodology estimates potential consumptive use (PCU) on a monthly basis using monthly average temperature and daylight hours estimated from latitude. Because this data is readily available for long study periods, this widely used methodology was recommended for use in the SPDSS. However, the modified Blaney-Criddle crop coefficients available from the SCS publication Irrigation Water Requirements Technical Release No. 21 (TR-21) were developed to represent general conditions around the western United States and may not represent local conditions in the SPDSS study area. Therefore locally calibrated Blaney-Criddle crop coefficients were developed for SPDSS.

The average monthly temperature data and frost dates required for the modified Blaney-Criddle consumptive use method were obtained from the National Climate Data Center through the National Oceanic and Atmospheric Administration (NOAA), who is responsible for operation of the stations, and are included in the State’s central database, HydroBase. Daily maximum temperature, minimum temperature, wind speed, solar radiation, and vapor pressure data required for the ASCE Standardized calculations were obtained from the NCWCD and the Colorado Agricultural Meteorological Network (CoAgMet). Longer periods of record are available for CoAgMet climate data. Three CoAgMet climate stations and one NCWCD climate station were selected for use in the calibration of modified Blaney-Criddle crop coefficients. The SPDSS Lower Plains calibrated coefficients were originally developed using data from the CoAgMet Holyoke climate station and later updated using NCWCD Sterling climate station data.

In addition to this, growing season parameters outlined in SCS TR-21 were used with the Standardized ASCE method. These parameters define the beginning and ending of the growing season, maximum root zone depth, maximum application depth, and cutting parameters for each crop type, and are typically used with the modified Blaney-Criddle method commonly applied in water rights analyses throughout the SPDSS study area. Later phases of this study will incorporate crop coefficients and growing season parameters currently being used by NCWCD.

The modified Blaney-Criddle method was used with the calibrated coefficients for the plains regions to estimate PCU. PCU was aggregated for each modeled surface water structure, group of surface water structures, or group of wells in the SPDSS area by assigning total acreage and acreage by crop type obtained from the GIS crop-type maps. Crop irrigation water requirement (IWR), the potential consumptive use less effective precipitation, was determined using the calibrated crop coefficients at the locations of the key climate stations for Alfalfa, Corn Grain, Dry Beans, Grass Pasture, Small Grains, and Sugar Beets. Effective precipitation was estimated using the SCS effective rainfall method outlined in TR-21. It should be noted that the derived crop coefficient values were used to calculate PCU that represents ET under conditions of full water supply. Figure 1, shows a 3-D rendering of consumptive use by crop type in a selected area of the South Platte River Basin estimated for SPDSS using the modified Blaney-Criddle method and GIS crop-type maps. The height of the cylinders in Figure 1 represent the depth of PCU and only varies by crop type. This illustrates how this method does not account for spatial variability of ET and stress factors that result in less-than full supplies.
Mapping Evapotranspiration at High Resolution with Internalized Calibration -METRIC (Energy balance)

In the second method considered in this study, a time series of multiple Landsat images throughout the 2001 growing season was analyzed and estimates of ET for each pixel of each image in the time series were produced. These multi-temporal Landsat-based ET data were developed using the METRIC model (Allen 2007). The METRIC methodology integrates ground-based reference ET and has been applied with Landsat images to estimate monthly and seasonal ET for water rights accounting and for development of groundwater models.

The METRIC methodology for estimating and mapping ET requires a satellite image with thermal (surface temperature) information and high quality, hourly weather data from one or more weather stations located for the computation of reference ET (ETr) using ACSE standardized evapotranspiration equation (Allen, 2003; Allen, 2005). Using an energy balance at the surface (Bastiaanssen 1998), energy consumed by the ET process was calculated, pixel by pixel, as a residual of the surface energy equation:

\[
LE = Rn - G - H (1)
\]

where, LE is the latent energy consumed by ET, Rn is net radiation (sum of all incoming and outgoing shortwave and longwave radiation at the surface), G is sensible heat flux conducted into the ground, and H is sensible heat flux convected into the air. The utility of using energy balance is that actual ET rather than potential ET (based on amount of vegetation) is computed, so that reductions in ET caused by limited soil moisture and agronomic management variables are captured (see Figure 2). Rn will be computed from Landsat data, specifically broadband reflectances and surface temperature; G will be estimated from Rn, surface temperature, and vegetation indices; and, H will be estimated from surface temperature ranges, surface roughness, and wind speed using buoyancy corrections. Thus, METRIC requires high quality, hourly weather data from one or more weather stations located in an agricultural area for the computation of reference ET (ETr) using ACSE standardized evapotranspiration equation (Allen, 2003; Allen, 2005). Hourly values of ETr are required for the computation of H at the “cold” anchor pixel (described below) and for the computation of the ETr fraction (ETrF) that is used to estimate 24-hour and seasonal ET. Alfalfa ETr is preferred over clipped grass ETr because the alfalfa ETr more nearly represents the upper limit of ET from well-watered vegetation.
The weather data also are used by METRIC to provide the ultimate validity of the ET estimates. Therefore, assessments of weather data integrity and quality need to be conducted before the data are utilized in METRIC (Allen, 1996; Allen, 2003; Allen, 2007); The weather data used in this study was obtained from Eaton and Sterling weather stations that are part of the NCWCD weather station network. NCWCD thoroughly reviewed, assessed, and controlled the quality of weather data. In some instances, NCWCD applied corrections to account for poor sensor calibrations. However, due to the high quality of the NCWCD weather data, these corrections were the exception. The following weather data was required for applying METRIC:

- Wind speed (required, hourly data is preferred)
- Precipitation (daily data are recommended for a several week period prior to the image to estimate any residual evaporation from bare soils)
- General value for dew point temperature or vapor pressure is needed during calculation of atmospheric transmissivity (when not available, daily average dew point temperature can be estimated as equal to daily minimum air temperature less 3°C)

In addition to the above data, other weather data was needed to calculate hourly and daily reference evapotranspiration (ETr) as required by METRIC, considering that ETr represents ET from a well-watered reference crop of alfalfa. If standardized estimates of ETr data are not already available for the image area, then the following data will be required:

- Humidity (hourly data such as vapor pressure or dew point temperature)
- Solar radiation (hourly is preferred)
- Air temperature (hourly is preferred)

The wind speed (u) at the time of the satellite overpass was required for the computation of sensible heat flux (H) and for the ETr calculation. Precipitation data was used to evaluate the general “wetness” of areas that may have received rain within four or five days prior to the image date. Solar radiation data are useful for identifying and accounting for any thin Sirius clouds on the image day and for adjusting the atmospheric transmissivity (τsw).

The Eaton and Sterling weather stations were selected because the exceptional quality of their data and their central location within the irrigated lands in the SPDSS and NCWCD area. This ensured the proximity of the weather stations to the locations of the “hot” and “cold” anchor pixels. The METRIC process utilizes two “anchor” pixels to fix extreme, or boundary, conditions for the energy balance. These are the “hot” and “cold” pixels and are located in the area of

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Figure 2. METRIC-derived (left-multicolor by pixel) and traditional Kc consumptive use (right-grey color cylinder) estimated values for selected center pivot irrigated fields in the South Platte River Basin.
interest. The “cold” pixel (sometimes referred to as the “wet” pixel) is selected in METRIC as a wet, well-irrigated crop surface having full ground cover by vegetation. The surface temperature and near-surface air temperature are assumed to be similar at this pixel. The “hot” pixel (sometimes referred to as the “dry” pixel) is selected as a dry, bare agricultural field where ET is assumed to be zero. Both of these “anchor” pixels should be located in large and homogeneous areas that contain more than one band 6 pixel (i.e. 60m×60m for Landsat 7 and 120m×120m for Landsat 4 and Landsat 5).

In METRIC, as in SEBAL, H is predicted from an aerodynamic function:

\[
H = \rho C_p \frac{dT}{r_{ah}}
\]  

(2)

where, \( \rho \) is air density, \( C_p \) is specific heat of air at constant pressure, and \( r_{ah} \) is aerodynamic resistance between two near surface heights (generally 0.1 and 2 m) computed as a function of estimated aerodynamic roughness of the particular pixel and using wind speed extrapolated from a blending height above the ground surface (typically 100 to 200 m), with an iterative stability correction scheme based on the Monin-Obhukov functions (Allen 2007). The \( dT \) parameter represents the near surface temperature difference between the two near surface heights. The \( dT \) parameter will be used because of potential difficulties in estimating surface temperature (\( T_s \)) accurately from satellite information. In addition, \( T_s \) as measured by satellite (i.e., radiometric temperature) can be several degrees different from “aerodynamic” temperature that drives the heat transfer process (Kustas 1994; Norman 1995; Qualls 1996). \( dT \) is designed to “float” above the surface, beyond the height for sensible heat roughness (\( z_{oh} \)) and zero plane displacement, and will be approximated as a relatively simple linear function of \( T_s \):

\[
dT = a + bT_s
\]  

(3)

For this study, the National Land Cover Dataset (NLCD), prepared by the USGS, was used to produce a generalized land use map for the analysis. A land use map is not a requirement for METRIC but it is recommended to improve parameterization and estimation of the surface roughness parameter (\( z_{om} \)). This land use map was combined with the irrigated lands maps developed for SPDSS and used to divide the area of interest into various general classes of land use such as agriculture, city, water, desert, forest, grassland, etc. that may have different roughness characteristics (i.e., height and density of vegetation).

During calibration, parameters were computed by setting \( dT = (H r_{ah})/(\rho C_p) \) at \( T_s \) of a “hot” pixel that is dry enough so that one can assume that \( LE = 0 \) and, therefore, \( dT = ((Rn-G) r_{ah})/(\rho C_p) \). A daily surface soil water balance was run for the hot pixel to confirm that ET = 0 or to supply a nonzero value for ET for the hot pixel for calibration. For the lower calibration point of \( dT \) in METRIC, a well-vegetated pixel having relatively cool temperature was selected and \( dT \) at that pixel will be calculated as:

\[
dT = \frac{(R_a - G - k ETr) r_{ah}}{\rho C_p}
\]  

(4)

where, \( k \) is an empirical factor set to 1.05 to describe evaporative behavior of the cooler, wetter pixels relative to the ETr reference that represents ET from 0.5 m tall, dense vegetation. With Landsat images, fields of alfalfa or other high leaf area vegetation can generally be identified that are close to or at full cover, so that the ET from these fields can be expected to be near the value of “reference ET” (ETr) computed for an alfalfa reference. In METRIC, the standardized ASCE Penman-Monteith equation is used for alfalfa reference (Allen, 2005). Generally, METRIC can be applied without crop classification, since specific crop type is not required, reducing the need for costly crop mapping on a regular basis. Nonetheless, if available, a crop classification can be very useful for the the selection of hot and cold pixels, as well as for subsequent analyses of consumptive use (e.g., by crop type, or for crop coefficient refinement).

The extrapolation from observation time to the 24-h period was done using the fraction of reference ET (ETrF). ETrF is the ratio of ET to ETr (in the case of METRIC, ETr is the alfalfa reference), and ETrF is essentially the same as crop coefficient, \( Kc \) (for an alfalfa reference basis). ETrF has been demonstrated to be stable and nearly constant during the day (Trezza 2002; Tasumi 2005a; Tasumi 2005b; Tasumi and Allen 2007) and is better able to capture impacts of advection and changing wind and humidity conditions, as expressed in the ETr calculation (which is computed hourly and summed daily). Multiple Landsat images were used used for the selected growing season (e.g.
April – October). This was necessary to construct a seasonal Kc curve by which consumptive use was derived (see Figure 3 for example).

![Example of 24 hour ET estimates for 7 Landsat images derived using METRIC in the South Platte River Basin for the 2001 growing season. These data were produced by RTi under the current NASA ROSES research grant.](image)

**Figure 3.** Example of 24 hour ET estimates for 7 Landsat images derived using METRIC in the South Platte River Basin for the 2001 growing season. These data were produced by RTi under the current NASA ROSES research grant.

### COMPARISON OF BOTH METHODS USING THE ARCGIS ET SERVER WEB APPLICATION TOOL

As described in the introduction, RTi has developed an Internet map server that is powered by ESRI ArcGIS Server technology. The tool has been developed by RTi under a research and development grant from NASA (Research Opportunities in the Earth Sciences) with the cooperation of the U.S. Bureau of Reclamation (USBR), the Northern Colorado Water Conservancy District (NCWCD), and the University of Idaho. This web-mapping tool has
analytical geospatial capabilities that enable the user to query and select irrigated parcels by crop and irrigation type (e.g. Corn, Sprinkler), basins, and ditch service areas and then compute total ET for that selection. Similarly, a user can select an area of interest by digitizing on-screen, and compute ET for that area. This tool can be used for analyzing consumptive use via a web browser and without the need for GIS software. **Figure 4** shows RTi’s ArcGIS ET server application functionality and the consumptive use information it provides in tabular and graphical form.

In this project, monthly and seasonal ET estimates were computed using linear or, when possible, cubic spline interpolations. These estimates were derived by interpolating ETrF between processed images and multiplying, on a daily basis, by the reference evapotranspiration (ETr) for each day. This was conducted under the assumption that ET for the entire area of interest changes in proportion to the change in the ETr at the weather station. This is a generally valid assumption and is not unlike the conventional application of Kc x ETr (Allen 2007; Allen 2007), making results from the two approaches comparable. ETr is computed for a specific location and therefore does not represent the actual condition at each pixel. However, since ETr is used only as an index of the relative change in weather, specific information at each pixel is retained through ETrF. This approach is effective in estimating ET for both clear and cloudy days in between the clear-sky satellite image dates (Tasumi 2005a). The assumption is further supported by the use of ETr from the same weather location as is used to derive ETrF at image time, so that any bias caused by differing weather conditions in some part of an image will be mostly cancelled by using the same ETrF for both instantaneous and 24-hour period as well as for days between image dates (Allen 2007; Allen 2007).

The interpolated pixel-based ET estimates were aggregated by crop type, irrigated parcels, diversion structure and other GIS boundary layer data obtained from SPDSS and NCWCD for comparison with conventional methods of estimating ET, as described above. This process was conducted using spatial analysis and standard zonal statistics techniques using GIS software. The zonal statistics analysis required extracting values from the input raster - the
estimated ET image - and calculating a function or statistic (e.g., sum of all ET values) using the value for each pixel located within a specified zone (i.e., all cells contained within to the same basin, sub-basin, irrigation service area, parcel, etc.).

ET values can be summarized in attribute tables, maps and graphics by crop type, diversion structure, or as required by the user, making the ArcGIS ET server application a powerful instrument for the calibration and refinement of crop coefficients in the SPDSS and NCWCD area. The analysis will be conducted by comparing METRIC consumptive use estimates with conventional methods for 5 agricultural seasons. An example of such comparison for the 2001 agricultural season is presented in Figure 5, where comparative consumptive use curves derived from METRIC ETrF (white) and traditional Kc (red) applications are presented. The METRIC data was produced from 7 Landsat images over the South Platte for the 2001 growing season (see Figure 3). The curves were assembled with information collected from 6821 fields of corn within the images. The results of this analysis will allow CWCB and NCWCD to refine crop coefficients for future water demand forecasting, water rights management, water resources planning and water regulation in this area.

![Figure 5. Comparative consumptive use curves derived from METRIC ETrF (blue) and traditional Kc (red) applications.](image)

**DISCUSSION**

Colorado and the Western United States, in general, face an increasing threat from drought – and the social, economic, and environmental impacts that come with it. The combination of diminished water supplies along with increasing demand for urban and other uses is gradually depleting surface and ground water reserves traditionally allocated for agricultural use. Quantification of water consumptive use is increasingly important as water resources are placed under growing tension by increased users and interests. Scarce water supplies can be managed more efficiently through use of comprehensive information and prediction tools, accurate information on irrigation infrastructure and systems, and timely information on the extent of irrigate lands, crop health, and actual evapotranspiration.

Current widely implemented methods estimate consumptive use based on a reference ET for a crop at a point location. Reference ET is the amount of water consumptively used by a full cover crop of either alfalfa or grass under well-watered conditions. In reality, most of the arid west does not resemble the well-watered agriculture field used for reference ET estimates and, thus, the estimates of actual crop ET are often inaccurate. The procedures described in this
paper to refine crop coefficients using METRIC may provide a rapid solution by enabling existing consumptive use models to be enhanced. This could in turn result in the development of a new consumptive use benchmarks for the estimation and management of return flows and ground water recharge in the NCWCD, SPDSS, and other areas.

METRIC represents a maturing technology for deriving a satellite-driven surface energy balance for estimating ET from the earth’s surface. This technology has the potential to become widely adopted and used by domestic and international water resources communities providing critical support to a host of water decision support tools. ET maps created using METRIC or similar remote-sensing based processing systems could be routinely used as input to daily and monthly operational and planning models for water demand forecasting, reservoir operations, ground-water management, irrigation water supply planning, water rights regulation, and hydrologic studies.

The ArcGIS ET server application described in this document provides a vehicle through which METRIC technology can be made more accessible to decision makers. It will enable all stakeholders to assess the results of the METRIC mapping and compare with results from conventional ET estimation methods. In addition, this ET-Server application will provide rapid and transparent access to the data enabling external QA/QC and general assessments by stakeholders during the data development stages. We trust that the ArcGIS ET-Server application and the interaction that it will foster, will result in better calibrated crop coefficients and consequently more accurate consumptive use estimates in the SPDSS, NCWCD and other areas.

Thus ArcGIS ET server has the capacity to streamline the flow of data into the Decision Support Systems. METRIC imagery distributed and analyzed via the ArcGIS ET server will be used to build upon existing SPDSS and NCWCD work by providing additional input data to complement the consumptive use, surface water planning, ground water planning, and water budget models. Regular dissemination of METRIC images will allow for temporal calibration and refinement of traditional crop coefficients.

Nonetheless, more work needs to be done. Efforts are currently under way to make the the ArcGIS ET server more user-friendly. In addition to this, the application is currently being developed to incorporate other tools that will provide decision makers at the State and local levels with enhanced capabilities to better manage water resources.

REFERENCES


