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Water Use by Agricultural Crops and Riparian Vegetation: An Application of Remote Sensing Technology

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New Mexico is experiencing great changes in land use, population growth and cropping patterns. These changes, combined with extended drought, provide challenges to the management and appropriation of the state's limited water supplies. Currently, more than 75 percent of New Mexico's water is used in agriculture. Furthermore, exotic riparian vegetation such as saltcedar results in significant water consumption throughout the state.

Evapotranspiration (ET), or water use by crops and riparian vegetation, is a true depletion or loss from a hydrologic system. Estimates of ET values are used in irrigation water management, water rights allocation, hydrologic modeling, as well as overall water resource planning and management. Traditionally, crop ET is estimated by multiplying aggregate crop coefficients (Kc) by a standardized reference evapotranspiration (ETsz) (Allen et al. 2005). The Kc represents plants and the soil environment while ETsz represents climatological factors that provide the energy that drives ET. However, this methodology is limited to localized estimation of ET and is not practical or economical for large scale use due to spatial and temporal variability of vegetation, soils, and management techniques. Recently developed technologies use sensors that can directly measure ET over the vegetation canopy. However, these technologies are costly and are limited to small areas.

While direct measurement provides localized values of ET, these measurements are limited and do not account for the diversity of ET across the watershed. Remote sensing technology combines ground measurement of ET with large scale remotely sensed vegetation canopy data and ground level climatological data to calculate regional values of ET. This combination of ground-level and remotely sensed data provides the most advanced and economical approach for estimating ET over a large area.

Direct Measurement of Water Use with an ET Flux Tower

Recent technological advances have made it possible to directly measure ET over vegetation on a real-time basis (Bawazir 2000). Figure 1 shows an eddy covariance ET flux tower installed in a pecan orchard in New Mexico's Mesilla Valley. This equipment measures heat flux densities in the energy budget within the canopy boundary layer. Figure 2 shows an example of daily ET measured over a pecan orchard in the Mesilla Valley during calendar year 2003. Figure 3 shows daily ET measured in saltcedar at New Mexico's Bosque del Apache National Wildlife Refuge during calendar year 2003.

ET is commonly expressed in terms of depth of water lost from a cropped surface per unit time. For example, for an area of one hectare, a loss of 1 mm/day (0.001 m/day) is equivalent to 10,000 m^2 x 0.001 m/day or 10 m^3 per ha per day (143 ft^3/day or 0.00328 acre-ft/acre per day).

Estimation of ET Using Remotely-Sensed Data

The Regional ET Estimation Model (REEM) was developed at New Mexico State University to estimate regional ET values for agricultural and riparian vegetation (Samani et al. 2003). REEM

Figure 1. Eddy covariance flux tower installed in pecan orchard in Mesilla Valley, New Mexico.

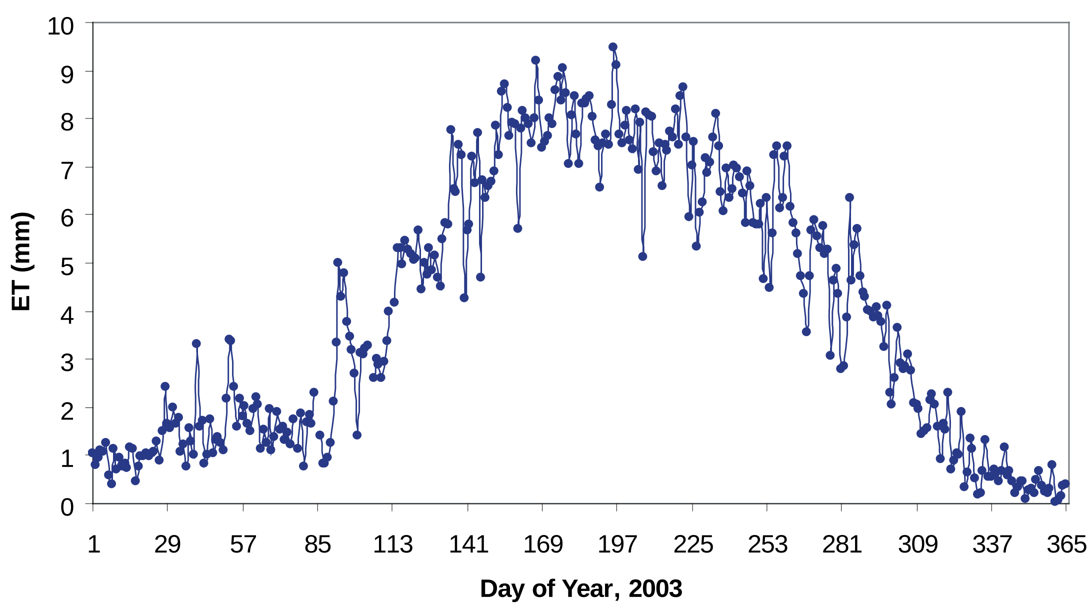

Figure 2. Daily ET values of pecan measured by eddy covariance flux tower in 2003. Total annual ET = 1.5 m (4.9 ft).

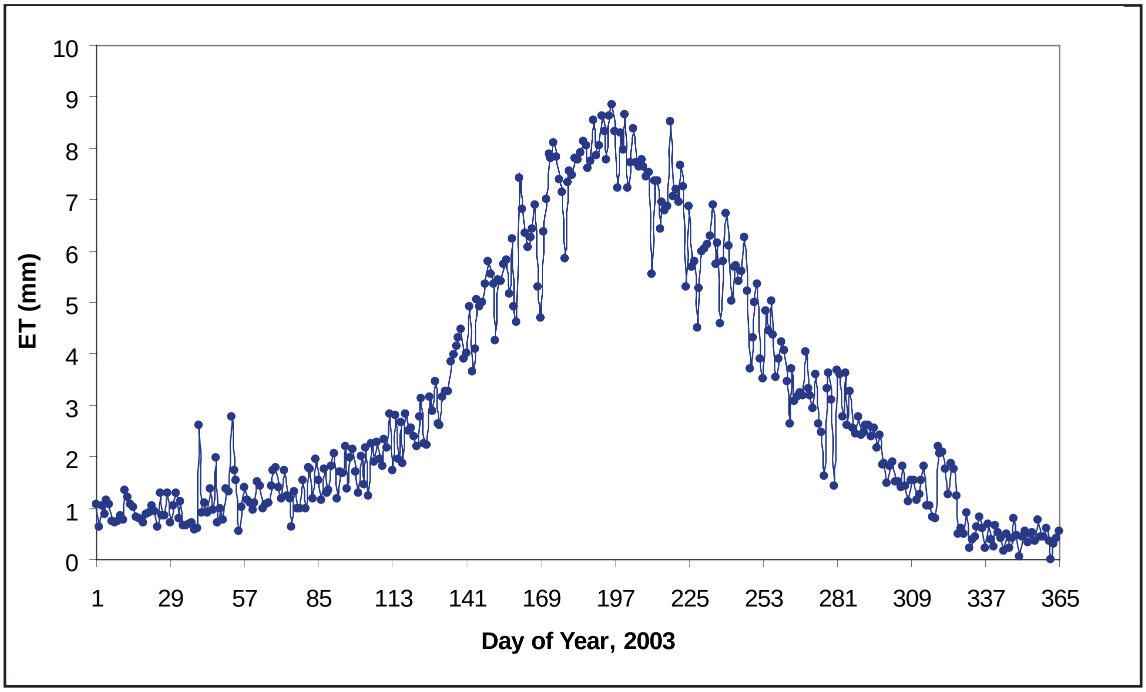

Figure 3. Daily ET values of saltcedar measured by eddy covariance flux tower in 2003. Total annual ET = 1.2 m (3.94 ft).

uses remotely sensed satellite data to calculate ET as a residual of the energy balance. The energy balance accounts for various amounts of energy within the boundary layer of vegetation over a time period (Figure 4). The components of energy includes net radiation (Rn), soil heat flux (G) and sensible heat flux (H). The latent heat flux (λE) or ET is calculated as a residual of the energy balance. The Rn, G and H are estimated using remotely sensed data from satellites (Samani et al. 2003). The satellite data are from the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer on NASA's Terra satellite (Yamaguchi et al. 1998). ASTER has three bands in visible/near infrared with 15 m resolution and five bands in the thermal infrared at 90 m spatial resolution. It has a 60 km swath and a 16-day repeat cycle.

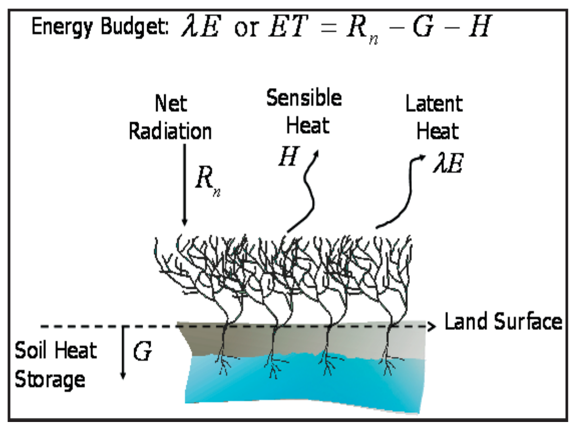

Figure 4. Energy balance equation used in calculating ET.

Figure 5 shows an example of an ET map generated for the Mesilla Valley using the REEM model. The map shows clearly the variation of ET in the Mesilla Valley. The fictitious colors represent ET ranging from low (blue color) to high (red color). The red color fields in the map were identified as ET from agricultural areas including pecan fields, alfalfa and other crops, and large grassy areas such as golf courses. Variability of ET within individual fields is also visible. The observations demonstrated in Figure 5 are very encouraging and indicate that the technology could play a vital role not only in estimating ET but also in assisting farmers in improving management of their crops and fields. The REEM model results can aid in identifying soils that need additional fertilizer, plants that are stressed due to disease or pest infestations, water infiltration related problems, inadequate leveling of the field, and other management issues. A comparison of eddy covariance measurements using the one-propeller eddy covariance technique (OPEC) to remote sensing estimates using the REEM model is presented in Table 1. The absolute difference for six days of available satellite data comparison ranged from 0.20 mm to 1.20 mm.

Remote sensing technology was also used to estimate ET of riparian vegetation. Using REEM, estimates of riparian vegetation ET in the Bosque del Apache National Wildlife Refuge are mapped in Figure 6. The Bosque del Apache National Wildlife Refuge is located in the Middle Rio Grande about 21 km (13 miles) south of Socorro, New Mexico. The total area of the refuge covers about 23,162 ha (57,234 acres).

As shown in Figure 6, the area of dense saltcedar (dark blue color) infestation has the highest level of concentrated ET on the day reported (10 June 2003). The ET in saltcedar on June 10, 2003 was about 10 mm. The labeled cottonwood area has a lower level of ET, while the desert areas surrounding the riparian area are shown to have very low levels of ET due to sparse vegetative cover. Two eddy covariance flux towers (white dots) for measuring ET are located in the middle of the Figure 6, in an area of dense saltcedar coverage (dark blue color). Another flux tower is located across the dense saltcedar on the left side (west).

Extensions of the Research and Implications

Evapotranspiration (ET) is water that is lost from the hydrologic system. There is normally a positive relationship between ET and crop biomass growth which leads to crop yield (Samani et al. 2004). The general ET-yield relationship is Yield = a + b (ET), where a and b are empirical values that depend on climate and crop. Reduced ET normally leads to reduction and quality of yields.

In the Mesilla Valley, actual crop yields tend to be lower than potential yields due to deficit irrigation practices, inadequate water management, and a lack of understanding of crop water needs (ET). For example, pecan yields range from 650-2200 pounds per acre (727-2460 kg/ha). Using REEM, similar variability has been observed in ET across pecan orchards throughout the Mesilla Valley (as shown in Figure 5). Better estimates of ET can lead to improved water management, higher water productivity, higher yields, and increased economic returns to the water used in agricultural irrigation. Remote sensing technology provides the means to cost-effectively evaluate water use in hundreds of individual fields on a real time basis.

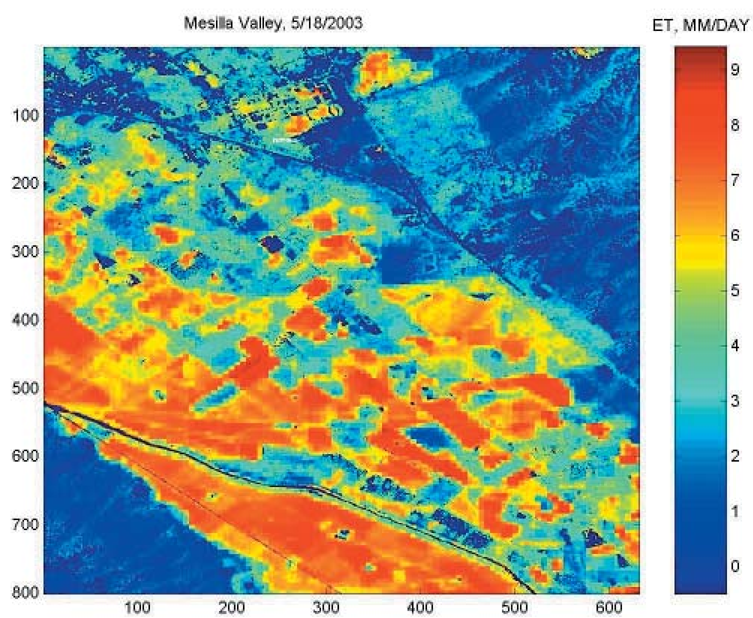

Figure 5. REEM generated ET map for New Mexico's Mesilla Valley, 18 May 2003.

Table 1. Comparison of eddy covariance (OPEC) measurements and REEM estimates of ET, Mesilla Valley, New Mexico, selected days, 2003.

Day of Year, 2003	Eddy Covariance (OPEC) Measured ET, mm	REEM, Estimated ET, mm	Absolute Difference, mm
113	3.89	3.67	0.22
129	6.30	7.50	1.20
138	7.65	8.58	0.93
161	7.81	8.10	0.29
241	7.11	7.31	0.20
250	6.71	6.35	0.36

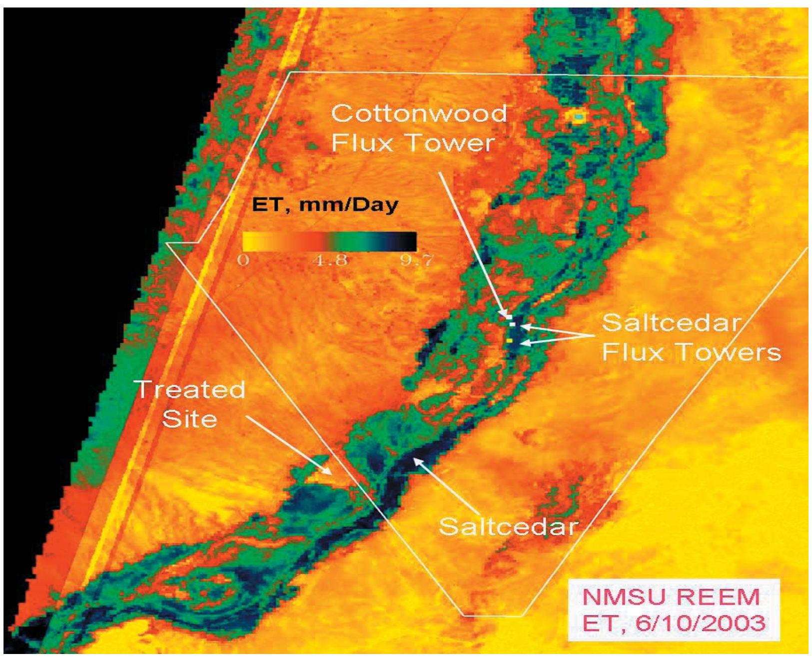

Figure 6. REEM estimates of riparian ET, Bosque del Apache, New Mexico, 10 June 2003 (Flux tower locations are approximate).

Furthermore, REEM-generated estimates of ET in riparian areas can provide an important tool to evaluate the impact of removing and managing undesirable riparian vegetation on the hydrology of a basin and for assessing the economic return from riparian management projects. Remotely sensed ET estimates provide a valuable tool to assist with decision making for riparian restoration projects.

Conclusion

Remote sensing technology permits the calculation of water use over a large scale for various crops, riparian vegetation and soil conditions without the complications associated with traditional methods of assessing ET. The remotely sensed information can be used in irrigation scheduling, irrigation system design, water rights adjudication, conveyance system design, and vegetation management or restoration. Other uses include improved management of water in agricultural irrigation and for both firm-level and aggregate decision making. Remote sensing technology introduces capabilities that have not been available to water managers in the past.

Remote sensing technology also makes possible additional accountability on the part of water users and water managers. Accurate accounting of current basin-wide water use in New Mexico and other regions is an important step to ensuring the equitable distribution of water resources based on existing legal entitlements. Furthermore, if water resources are to be reallocated through market or other means, accurate accounting of water use is essential. Making water available for future population growth and economic development depends on the increased accountability facilitated by remotely sensed estimates of consumptive use.

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