Estimating Irrigated Agricultural Water Use through Landsat TM and a Simplified Surface Energy Balance Modeling in the Semi-arid Environments of Arizona

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Abstract
Quantifying evapotranspiration (ET) is a key element for achieving better water management, especially in regions where agriculture is the main water consumer. A hybrid model combining the SEBAL and RESSET models (S-RESSET) was developed to effectively estimate actual ET (water use) of the agriculture sector around the Phoenix metropolitan area. To examine how irrigated agriculture water consumption varies with climate, the S-RESSET model was applied under wet and dry climatic conditions. Results show that the average ET for active agriculture is 9.3 mm/day (± 3.8 mm/day) during the study period. Seasonal water use was 438 mm for 2000 (drought) and 494 mm for 2008 (wet). Based on the seasonal ET, we concluded that farmers in arid region use the same amount of water regardless of climatic conditions, implying that the agriculture sector as a whole may not be sensitive to drought as long as there is sufficient water from irrigation. This finding carries significant implications for the region's water security.

Introduction
Current pressure of global change, including both climatic and societal, continuously elevates competitions for fresh water between different uses. Monitoring water consumption has become a critical tool in water resources management, especially in arid environments where water is scarce, droughts are frequent, and climate is predicted to become warmer and drier (Mariotto et al., 2011; IPCC, 2007). Evapotranspiration is considered to be one of the key elements in the water cycle that needs to be quantified to achieve better water management.

Evapotranspiration (ET) is defined as the sum of evaporation from soil surface, plant surface, and transpiration from plants. Controlled mainly by solar radiation, ET is a major component of the hydrological cycle and energy transport between the biosphere, atmosphere, and hydrosphere (Idso et al., 1975; Liu et al., 2007). Globally, ET from land surface accounts for 60 percent of average precipitation (Zhao-Liang et al., 2009). Of the water which falls over the continental USA, 70 percent to 90 percent is believed to return to the atmosphere by evapotranspiration (Rosenberg, 1974). This return replenishes atmospheric moisture and leads to precipitation recycling. However, ET is probably the most difficult water cycle components to measure due to its wide spatial variation and invisibility (Mariotto et al., 2011; Allen, 2008).

Traditional methods for ET estimations, such as lysimeter, Bowen ratio system, or eddy covariance system, are time consuming and expensive. Moreover, these methods are point based. Remote sensing can estimate ET as a residual of the energy balance, thus reduces the need for ground data while providing regional coverage and information on the spatial and temporal variability of actual consumption (Elhaddad and Garcia, 2008; Bastiaanssen et al., 1998a; Kustas and Norman, 1996). Over the last two decades there have been ongoing developments of energy balance models utilizing remote sensing data for ET estimations. A comprehensive review of models can be found in Kustas and Norman (1996) and Zhao-Liang et al. (2009).

The most widely used models are SEBAL and METRIC, i.e., one-source models that consider soil and plants as a single component (Mariotto et al., 2011). They are designed to minimize the use of ground data by using two extreme conditions: “hot” (bare soil) and “cold” (full vegetation cover). Allen et al. (2007) described the procedure required to calculate actual ET using the surface energy balance method that employs the “hot” and “cold” pixel approach developed by Bastiaanssen et al. (1998a and 1998b). SEBAL has been widely validated for irrigated agriculture in Egypt (Bastiaanssen et al., 1996), Spain (Pelgrum and Bastiaanssen, 1996), Turkey (Bastiaanssen, 2000) and several others. Roerink et al. (1997) and Bastiaanssen et al. (2001) combine SEBAL with field data to assess irrigation scheme, crop ET, soil moisture, and biomass growth in Argentina and Brazil. METRIC uses an internal calibration by utilizing