Enhancing Water Supply through Invasive Plant Removal: A Literature Review of Evapotranspiration Studies on Arundo Donax

Removal of the invasive, non-native plant *Arundo donax* (Arundo, giant reed) along riparian corridors is being considered by groundwater sustainability agencies as a potential water savings strategy that could provide co-benefits for groundwater sustainability as well as native ecosystem restoration. Arundo is a fast growing, densely vegetated reed that has purportedly high-water consumption (i.e., transpiration). This paper is intended to help agencies develop estimates of the water supply benefits that could be realized from Arundo removal.

A review of published literature and unpublished studies indicate a range of annual evapotranspiration (ET) rates for Arundo from 1 to 48 acre-feet/acre/year (AF/ac/yr). A summary of ranges of ET by method is provided in Table 1. Factors affecting ET estimates include: temporal variability, biomass (plant size and age, stand density, leaf area), hydrology (depth to groundwater, soil moisture availability), and climatic conditions. Strengths, weaknesses and assumptions of various methodologies are available here: Evapotranspiration Measurement Methods table. Table 1 provides ranges of annual ET estimates based on three main categories of methods:

1) Leaf porometry scaled by leaf area index (LAI)

Porometry measures leaf-gas exchange in a chamber. These leaf-scale transpiration measurements are then empirically scaled up to stand level estimates, based on relationships of biomass to ET using leaf area measurements.

A review of the literature where leaf porometry/LAI methods were used shows ET estimates from Arundo ranging from 10 and 48 (AF/ac/yr). The range is primarily due to the biomass density differences, with lower ET correlating to lower LAI values (~5 m^2 leaf/m^2 ground area) on the lower Rio Grande River in Texas (Watts et al. 2011) and higher LAI values (~15 m^2 leaf/m^2 ground area) along the Santa Clara River in California (Dudley and Cole 2018, Abichandani 2007, Giessow et al.

2011). Higher density stands have been measured throughout coastal California (Giessow et al. 2011) and the Central Valley of California (Giessow et al., in prep) with LAI adjusted mean values of 15.8 and 9.6 m^2 leaf/m^2 ground area, respectively. As noted by (Giessow et al., in prep), field measurements of Arundo LAI from coastal California and the Central Valley of California (Giessow et al 2011 & in prep) are much higher due to the monitoring of naturally occurring, mature arundo stands in riparian habitats (i.e., high biomass), compared to young experimental field plots with lower biomass.

2) Water budget field measurements

Water budgets measure the different components of the water balance, including measuring inflows, soil moisture, and outflows to estimate the ET, and often comparing to representative ET rates as well. Some studies include soil and vegetation water content changes via lysimeter or tensiometers.

Arundo ET estimates from field-based water balance methods range from 2.1 and 14 AF/ac/yr (Triana et al, 2015, Tuttolomondo et al. 2015, Tzanakakis et al. 2009, Christou et al. 2003). The four studies were conducted under nonlimited water conditions; the fourth study also included more limited water stress conditions. Possible explanations for the lower ET estimates consider the plant density/biomass. Because these studies were evaluating arundo as a biofuel or wastewater treatment system, the arundo plants were annually harvested and had low biomass. The one model-based water balance ET estimate (Jain et al. 2015) is a 15-year average of 6.7 ac-ft/ac/yr (with a range of 5.7 – 7.2) for the 821 square mile Nueces River Headwaters watershed in Arizona.

3) Remote Sensing

Remote sensing approaches use the surface energy balance equation to estimate heat fluxes from multispectral and thermal infrared imagery, wherein the latent heat flux is the ET.

The ET rates based on remote sensing methods are ~2 AF/ac/yr. The two studies reviewed here (Neale et al. 2011, Formation Environmental 2018) were conducted in Arundo stands and native riparian invasive plant stands. Neale et al. (2011) conducted in the Mojave Desert included three study areas, two with deep groundwater levels that reduced the water supply to the Arundo and resulted in reduced ET rates. The Santa Clara River estimate (Formation Environmental 2018) is also representative of drought stressed plants and a constrained water supply.

Conclusion

The studies summarized in Table 1 present a very wide range of annual ET rates of Arundo from 1 to 48 ac-ft/ac/yr, with porometry/LAI estimates in the high end, water balance estimates in the mid to low range and remote sensing on the low range. In addition to the methodology, other important factors (temporal variability, biomass, hydrology, and climatic conditions) also have an influence on the ET rates. In particular, biomass and water availability (whether due to hydrologic or climatic conditions) are important factors explaining the wide range of values.

Table 1 Literature Summary of Arundo Annual Evapotranspiration Rate Estimates

Source	**Location**	**Annual ET** (ac-ft/ac/yr) [mean (minimum-maximum)]	**Method**	**Years of Study**
Giessow et al. (2011)	Coastal Southern California	24	Field Study: Porometry/LAI	2010
Giessow et al. (in prep)	Central Valley, California	19.4	Field Study: Porometry/LAI	2018
Dudley and Cole (2018)	Santa Clara River, California	10	Field Study: Porometry/LAI	2017
Abichandani (2007)	Santa Clara River, California	48 (39-58)	Field Study: Porometry/LAI	October 2005 - September 2006
Watts & Moore (2011)	Lower Rio Grande, south Texas	10.9	Field Study: Porometry/LAI	June 2007 - July 2008
Triana et al. (2015)	Pisa coastal plain, Italy	3.6 (3.3-3.8)	Field Study: Water Balance (Penman-Monteith method) - Lysimeter	2010, 2011
Tuttolomondo et al. (2015)	West of Sicily, Italy	14 (13.1-14.8)	Field Study: Water Balance (Penman-Monteith method)	2012, 2013
Tzanakakis et al. (2009)	Iraklio, Greece	5 (4-6)	Field Study: Water Balance	2001, 2001, 2003
Christou et al. (2003)	Greece & Italy	2.1 (1-dry treatment - 3.2-highly irrigated)	Field Study: Water Balance	1998/99; 1999/2000; 2000/2001
Jain et al. (2015)	Nueces River, TX	6.7 (5.7 - 7.2)	Model Study: Water Balance	1995-2010
Neale et al. (2011)	Mojave River, California	2.2 (1.8-2.8) [April-Nov only]	Remote Sensing: Surface Energy Balance System (Two-Source Model)	2007, 2010
Formation Environmental (2018)	Santa Clara River, CA	1.8 (0.8-3.8)	Remote Sensing: Surface Energy Balance System	Oct 2015-Sept 2016

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