4.0 IMPACTS OF *ARUNDO*: *Arundo* Water Use and Stand Transpiration

4.1 Determining *Arundo* Water Use (Stand transpiration)

Water loss from watershed systems resulting from *Arundo donax* invasion is a topic of serious concern, but realistic or direct estimates of such losses are scarce. This chapter attempts to estimate water loss (in mm per day per m^2 of ground area) from *Arundo* stands in southern California as a function of *Arundo* leaf transpiration. Study estimates utilize reported transpiration rates for *Arundo* from a variety of areas coupled with leaf area indices and cane densities measured in the study area. Comparisons are also made between this study's estimates of stand-level water loss to those reported by others.

4.1.1 Background:

Vegetation in a system contributes to water loss primarily as function of *transpiration* through the leaves (E), but *evaporation* of water from exposed soil (i.e., not covered by plant canopy or litter) is also a contributing factor. Combined water loss via plant transpiration and surface evaporation is termed *evapotranspiration* (ET). Measuring ET is often a complicated process (Allen et al. 1998), but plant physiology studies often directly measure E using individual plant leaves and gas analyzers. The leaf-based measurements (E_l) can then be scaled up, based on leaf area per unit area of ground ("leaf area index" or LAI), to yield estimates of water loss at the stand scale via plant transpiration (E_{stand}, or water lost per unit area of ground). In a mature vegetation stand, where much of the ground is shaded, E_{stand} will account for the majority of total water loss via ET (Allen et al. 1998).

4.1.2 Methods

In an effort to estimate water loss from *Arundo* stands in the study area, published scientific and unpublished gray literature was searched for direct estimates of *Arundo* transpiration (E) or evapotranspiration (ET) from *Arundo* stands. The search yielded three Master's thesis studies that measured *Arundo* E_l (Abichandani 2007, Watts 2009, Zimmerman *unpublished data*), two of which then scaled up to E_{stand}. One direct measurement of ET was also found from a Mediterranean region study reported in a conference proceedings (Christou et al. 2003) and one additional internet report in which stand-scale *Arundo* water loss was estimated using data from Zimmerman's thesis work (Hendrickson & McGaugh 2005). LAI values are a very important factor in calculating stand transpiration rates. Additional data on *Arundo* stand LAI is also reported for papers that examined stand structure (Sharma et al. 1998, Spencer 2006).

The *Arundo* leaf-scale transpiration rates (E_l) reported in the three Master's theses were fairly similar. To be conservative, the lower measured value from the Abichandani study was used to estimate stand-scale water loss via transpiration (E_{stand}) for this study. In order to scale up from the average reported E_l to E_{stand} for the study area LAI for the study area was calculated based on filed sampling of *Arundo* stand structure. *Arundo* cane density and a number of structural traits on canes taken from 14 sites in the southern California study area were measured (Figure 2-1). Sites were selected in the field to represent mature *Arundo* stands, not areas that had been previously controlled, burned or otherwise disturbed. Mature *Arundo* stands are the majority of the acreage in the study area. The goal of this study is to measure water use of mature *Arundo* stands. Mature *Arundo* stands do vary significantly in cane density and robustness of growth- predominantly as a function of water availability. For this reason samples were taken from 11 'wet' sites (73%) and 3 'dry' sites (27%). This is approximately the proportion of wet and dry stands observed in field mapping within the study area.

One or two representative "old" (>1yr) *Arundo* canes were collected from each of the 14 sites (17 canes total) and one "new" (1st year) cane from three of the sites (Table 4-1). Leaf area was calculated as length*width*0.74 based on an examination and measurement of leaf shape. Structural traits measured on old canes included (a) length of and number of leaves on the leader portion (i.e. the portion of the central branch with green leaves) and (b) number and length of secondary branches. Individual leaf area for all leaves was then measured on a subset of leader canes (3 canes, 60 leaves) and secondary branches (18 branches, 200 leaves). Only the green photosynthetic area was measured on leaves. Cane (stem) surface and leaf sheaths were not included in calculations of photosynthetic area. The sum of measured leaf areas for each leader or branch was used to determine the average total leaf area per unit length of leader cane or secondary branch (26.8cm^2 leaf area/cm leader and 5.7cm^2 leaf area/cm secondary branch). Total expected leaf area was then calculated for all 17 old canes collected as a function of their leader and total secondary branch lengths multiplied by the appropriate leaf area/cm branch value.

Structural traits measured on new canes included the length of the cane, number of leaves and total leaf area, calculated as the sum of areas measured for each individual leaf (3 canes measured, 69 leaves). An average leaf area for a new cane was then calculated. To determine site-specific LAI, the total expected leaf area of each collected old cane was multiplied by the number of old canes counted in a representative square meter within the site and added to the average total leaf area of a new cane multiplied by the density of new canes in that same square meter (Table 4-2). Stand adjusted LAI is also given, representing for true stand-based leaf area (adjusts for area with no canes emerging, see Section 2.3). As there are significantly more old canes per unit area in a mature *Arundo* stand, greater effort was expended in calculating old cane leaf area.

Secondary branch leaf area relationships were explored using three different formulas: a linear regression, a quadratic regression and the branch length to leaf area relationship that was used. All three relationships were fairly consistent, generating final secondary branch LAI values ranging from 15.0 (linear), 19.0 (quadratic), and 17.0 (average leaf area per cm) (Figure 4-1, Table 4-2).

While leaf-based transpiration (E_l) is often reported in mmol $\text{m}^{-2}_{\text{leaf area}}\ \text{s}^{-1}$, different studies utilize discrete (and sometimes unspecified) methods for scaling up to the level of the stand. Consequently, there appears to be no clear convention in units used to report such water loss (e.g., kg $\text{m}^{-2}\ \text{hr}^{-1}$ or mm/day, etc.). For ET water loss is often reported in mm/time (Allen et al. 1998), which is roughly equivalent to a water loss of 1 liter/m^2/unit time. Following the assumption that the bulk of evapotranspirative loss in a mature stand is accounted for by transpiration, mm/day was used to report this study's calculated E_{stand} for *Arundo*. To scale from E_l to E_{stand} in mm/day: (1) average E_l was multiplied by the molar mass of water, giving grams H_2O $\text{m}^{-2}_{\text{leaf area}}\ \text{s}^{-1}$; (2) divided by the density of water at 25C, giving m^3 H_2O $\text{m}^{-2}_{\text{leaf area}}\ \text{s}^{-1}$; (3) multiplied by the LAI (in m^2 leaf area per m^2 ground area), giving m^3 H_2O $\text{m}^{2}_{\text{ground area}}\ \text{s}^{-1}$; (4) divided m^3 H_2O by 0.001 to yield mm H_2O $\text{m}^{-2}_{\text{ground area}}\ \text{s}^{-1}$; and (5) multiplied by 34,679 s/day of daylight (9.6 hrs or 3,516 hrs/yr - this value is based on average sunlight per day for the study area with 932 hours subtracted for winter dormancy. To compare this study's E_{stand} estimate with those reported in the other papers, reported E_{stand} values were sometimes converted from other units. Thus, some conversion error should be expected. However, when possible and for the greatest consistency in comparisons, E_{stand} was recalculated using average E_l and LAI values from the paper and following the general method above. These recalculated values are reported along with those given directly in the paper (Table 4-3). This re-calculation of values for other studies validates the process being used in this study to scale up from leaf-based transpiration to stand-based transpiration.

Table 4-1. Structural characteristics measured on *Arundo* canes collected from 14 sites in southern California study area.

Plot	Cane height (m)	Cane diam (mm)	Leader Length (cm)	Leader # leaves	Ave leader single leaf area (cm^2)	# secondary branches	Ave branch length (cm)	Ave branch # leaves	Ave branch leaf area	New cane # leaves	Ave new cane single leaf area
CC1	5.1	20	19	10	-	15	47.7	-	-	21	168.7
CC2 #1	9.71	28	90	23	83.7	57	11.7	4.5	10.5	-	-
CC2 #2	8.45	27	82	23	117.3	9	70.9	13.0	63.2	-	-
SA1	6.11	25	45	17	-	34	21.4	-	-	-	-
SA2	6.06	25	32	15	58.5	31	36.2	23.0	44.4	-	-
SA3	7.74	27	74	28	-	33	10.7	-	-	-	-
SA4	7.42	26	33	12	-	48	20.0	13.5	29.5	-	-
SC1	9.9	25	23	12	-	31	46.0	11.0	34.8	-	-
SC4	4.16	22	0	0	-	34	41.3	14.0	19.2	-	-
V1	8.41	26	0	0	-	28	43.4	-	-	21	216.2
V2	6.21	24	76	20	-	14	41.8	-	-	-	-
SD#1a	8.08	26	65	16	-	29	56.1	10.9	34.9	-	-
SD#1b	8.1	24	66	13	-	25	60.0	-	-	-	-
SC2	4.33	22	11	7	-	11	37.0	-	-	-	-
SC3	4.22	18	19	7	-	7	37.1	-	-	27	227.9
SC5 Lg	3.77	25	13	8	-	10	26.2	-	-	-	-
SC5 Sm	2.61	15	12	7	-	5	22.8	-	-	-	-

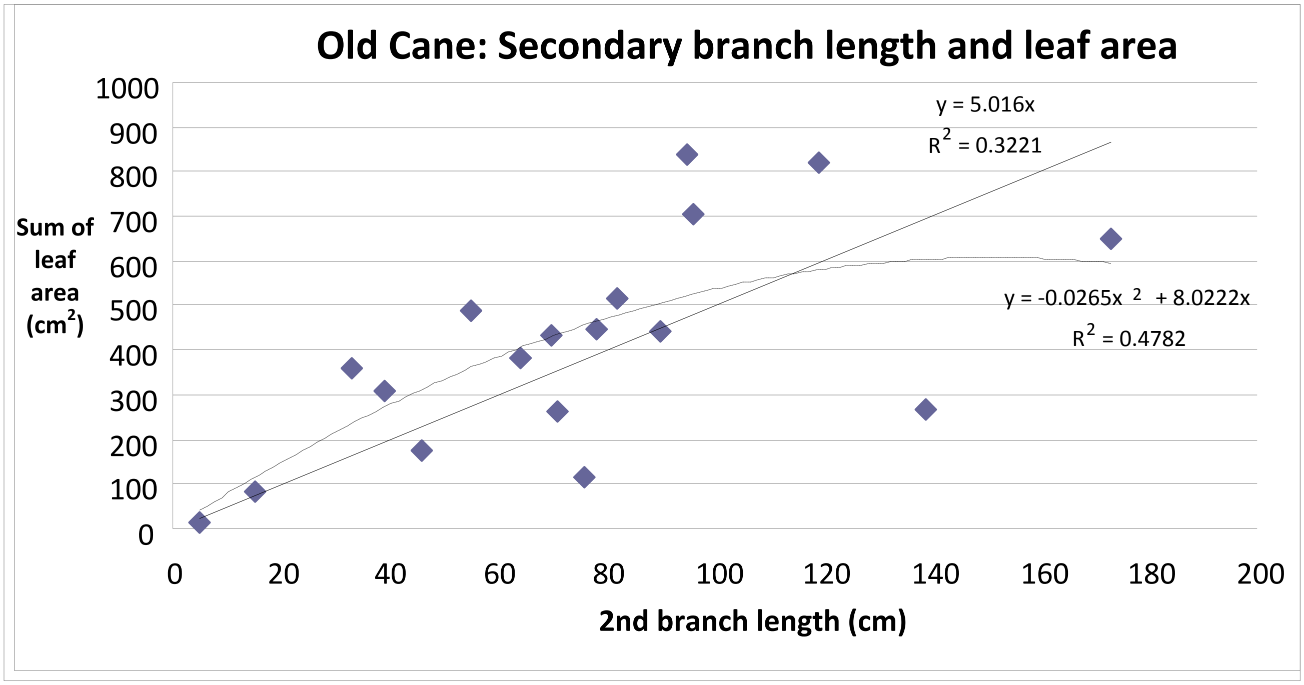

Figure 4-1. Secondary branch leaf area to length relationship.

Table 4-2. *Arundo* cane densities and leaf area indices (LAI) for 13 of the 14 study sites.
The contribution of leader canes, secondary branches, and new canes toward the total LAI for the site is shown. Cane densities were not measured on the San Diego site, thus LAI could not be computed.

Plot	Hydrology	Leaf area (m^2) per cane				Cane density/m^2		Leaf area/m^2 ground (LAI)				
		Leader: old cane	2ndry branch	Total old cane	New cane (<1yr)	Old cane	New cane (<1yr)	Leader old cane	2ndry branch	New cane	Total: old+new	Stand adjusted (70%)
CC-1	Wet	0.05	0.41	0.46	0.47	53	4	2.7	21.6	1.9	26.2	18.3
CC-2	Wet	0.23	0.37	0.6	0.47	29	4	6.7	10.8	1.9	19.4	13.6
SA-1	Wet	0.12	0.41	0.53	0.47	66	2	7.9	27.4	0.9	36.2	25.4
SA-2	Wet	0.09	0.64	0.73	0.47	30	2	2.6	19.2	0.9	22.7	15.9
SA-3	Wet	0.20	0.20	0.4	0.47	84	11	16.6	16.9	5.2	38.8	27.1
SA-4	Wet	0.09	0.55	0.64	0.47	19	4	1.7	10.4	1.9	14.0	9.8
SC-1	Wet	0.06	0.81	0.87	0.47	25	2	1.5	20.3	0.9	22.8	15.9
SC-4	Wet	0.00	0.80	0.8	0.47	36	4	0.0	28.8	1.9	30.7	21.5
V-1	Wet	0.00	0.69	0.69	0.47	28	5	0.0	19.4	2.4	21.8	15.2
V-2	Wet	0.20	0.33	0.53	0.47	30	5	6.1	10.0	2.4	18.5	12.9
SD1	Wet	0.18	0.89	1.07	0	44	0	7.7	39.2	0.0	46.9	32.8
SC-2	Dry	0.03	0.23	0.26	0.47	24	2	0.7	5.6	0.9	7.2	5.1
SC-3	Dry	0.05	0.15	0.2	0	40	0	2.0	5.9	0.0	8.0	5.6
SC-5	Dry	0.03	0.09	0.12	0.47	26	2	0.7	2.4	0.9	4.0	2.8
	Mean:	**0.09**	**0.47**	**0.56**	**0.41**	**38.1**	**3.4**	**4.1**	**17.0**	**1.6**	**22.6**	**15.8**
	StdDev:	**0.08**	**0.26**	**0.27**	**0.17**	**18.3**	**2.7**	**4.6**	**10.3**	**1.3**	**12.4**	**8.7**

Table 4-3. Summary of *Arundo* transpiration (E) and evapotranspiration (ET) reported in literature or calculated as described in the text.

Study	**Location**	**Stand biomass (t/ha)**	**Average single leaf area (cm^2)**	**Average # leaves per cane**	**Leaf area per cane (m2)**	**Average # canes per m^2**	**LAI (m^2 leaf/m^2 ground)**	**Peak (mid-day) E_l (mmol/m^2/s)**	**E_{stand} (mm/day)**
Direct Measurements of transpiration (E)									
Abichandani 2007	Santa Clara River, CA		163.3 (132.5-215.9)[1]	25.0 (21.5-28.4-27.9)	Newer (1 to 3 yr): 0.4082	Ave 34.9 (riverbed 29.2, n= 43; terrace 40.6, n=26)	14.25	4.03 (1.89-5.80)[a]	41.1 (36.4)[a]
Watts 2009	Rio Grande River, TX						4.1 (3.4-6.1) and 4.5	4.3 (1.6-8.4)[b]	9.1 (11.0)[b]
Zimmerman (unpublished)	Napa River, CA							6.3 (2.5-11) Summer only	
Indirect calculation of stand-level transpiration									
Cal-IPC (this study)	Southern California	155	1st yr: 206.3 > 1 yr: leader 86.5, 2ndry branch 33.9	1st yr: 23 (SD3.5) >1 yr old: leader 12.6 (SD8.3) + 2ndry branch lvs 271.6 (SD 174.9) = 284.2	1st yr: 0.474 >1yr: 0.556 (leader 0.100, 2ndry branch: 0.457)	41.5 (SD 19.7)	15.8	Used 4.03 in calcs	40.0
Iverson 1998	Based on rice								4.7[d]
Hendrickson & McGaugh 2005	Cuatro Cienegas, Mexico								17.3[d]
Other structural data									
Spencer 2006	16 sites across US (leaf area is north CA)	171	1st year: 520.7	1st yr:10.3(SD 6.1) >1 yr old: 100.6	1st yr: 0.5362 > 1yr old: 0.1162	74.5	11.22	Used 4.03	28.3[c]
Sharma et al. 1998	India	36-167				53 to 82	12.6 to 28.7		
Direct Measurements of Evapotranspiration									
FAIR 2000-EU study	Europe								3.22
Christou et al. 2003	Greece & Italy	21.1							1.6 (ET)

[a] Average across season, and wet and dry sites; [b] E_{stand} as calculated using formulas applied to this study; [c] E_{stand} calculated using formulas from this study using LAI from the that paper; [d] E_{stand} reported in paper, but insufficient additional data to use formulas in this study.

4.1.3 Results and Discussion

Examination of calculated water loss values for *Arundo* (both reported and results from this study) reveals a substantial amount of variation in E_{stand} (Table 4-3). While some of this variation may be an artifact of differences in scaling procedures and conversion factors, variation should be expected. Both *Arundo* transpiration (E) and evapotranspiration (ET) are affected by prevailing ambient conditions (temperature, humidity, wind, and available soil water) as well as characteristics of the vegetation. For example, both Abichandani (2007) and Watts (2009) found higher leaf-based transpiration (E_l) rates for *Arundo* in areas with higher available soil moisture. Zimmerman's unpublished *Arundo* transpiration data showed E_l also increases with temperature, while Abichandani and Watts found higher E_l rates in summer and spring when temperatures are higher. Thus, variation should be expected among regions where such conditions are likely to vary both within a season and on average across a year. Nonetheless, the average E_l rates (accounting for seasonal and hydrological variation) reported by Abichandani and Watts are quite similar despite the different study regions (Table 4-3). Zimmerman's average E_l is higher, but those measurements were only taken during the summer while the others studies included cooler seasons.

Given the similarities in E_l, variation in E_{stand} across studies must be primarily driven by factors other than leaf-scale transpiration rates. Watts (2009) showed much lower E_{stand} than either Abichandani (2007) or this study, and it should be noted that Watts' estimate includes refinements that would lead to a lower average. Specifically, prior to scaling-up transpiration rates, Watts divided the *Arundo* canopy into vertical layers and adjusted E_l rates downward for shaded leaves. In addition, Watts accounted for diurnal fluctuations in E_l in his scaling operations. It is unclear whether Abichandani's tabled E_{stand} values include such refinements, but this study's calculations are based on average peak E_l rates for sunlit leaves without any adjustment downward for shading or diurnal drops in leaf transpiration. As a result, the E_{stand} estimate for this study is probably more representative of an average maximum water loss, rather than an overall average. Yet, these adjustments are still unlikely to be the primary cause of the large differences seen in E_{stand} among studies. It is reported LAI that appears to be driving different stand based transpiration estimates. The average LAI reported by Watts (4.1) is much lower than that reported by Abichandani (14.25), which is slightly lower than results found on this study's sites (15.8) (Table 4-3). Consequently, differences in *Arundo* stand structure are likely the primary factor driving variations in E_{stand} across all studies reviewed.

Structural differences probably explain the lower estimate of E_{stand} reported by Hendrickson & McGaugh (2005) despite their likely use of a higher E_l rate than used in this study (i.e., Zimmerman's summer measures). However, it is not clear exactly what E_l rate they used or exactly how their scaling-up from leaf to stand was performed, though some adjustments for lower daily and seasonal E_l rates were incorporated. Variation in *Arundo* stand structure could also partly explain the lower daily ET rate derived by Christou et al. (2003) in the Mediterranean (Table 4-3). For example, the studies by both Abichandani (2007) and Christou et al. were performed on relatively young, artificially created *Arundo* stands, which may have shorter canes or less leaf area overall than naturally-occurring, mature stands. In Abichandani, the stand was 3-4 years old. Average cane densities were similar to those found in this study (Table 4-3), but the average area of a single leaf was larger and more comparable to leaves on new canes from this study (Table 4-1, average = 206.3cm^2). In addition, the average number of leaves per cane reported by Abichandani (Table 4-3) is comparable to the average number of leaves counted on just the leader portion of a cane plus only one secondary branch in this study (Table 4-1). Thus, it seems likely Abichandani's planted stand had bigger but far fewer leaves overall, as reflected in the lower LAI compared to this study. This may also be true of the Mediterranean stands reported in Christou et al., which were 1-3 years old during the study. Christou et al. did not report any leaf area data, but their reported average *Arundo* biomass (21.1 tons/ha) is roughly 7 times lower than the average biomass estimate generated for this study's stands (156.8 tons/ha). Given such large differences in stand structure among the study regions, it is likely that even a more refined measurement for this region would still be much higher than those in the other regions reviewed.

However, the large disparity between the daily ET rate derived from Christou et al. and the E_{stand} rates reviewed here becomes more pronounced when one considers that water lost via transpiration and evaporation combined should be higher, even if only slightly, than transpiration alone. It is unlikely that structural differences, differences in regional climate, and errors in converting data from one unit convention to another can fully explain the large differences seen here in E_{stand} versus ET. Instead, the comparison demonstrates the difficulty of generating realistic estimates of water loss from *Arundo* stands. Utilizing locally measured rates of leaf transpiration and stand structure is a good start, but complex scaling procedures will likely yield better estimates of stand-scale transpiration losses. Ultimately, though, actual locally measured ET may be more reliable, though perhaps more costly. Future studies need to focus on determining ET of mature *Arundo* stands that are comparable to *Arundo* stands in the field that have high leaf area and high biomass per unit area.

4.2 *Arundo* Water Use Across Study Area

This study found an average leaf area (LAI) for *Arundo* stands of 15.8 m^2/m^2. This value was within the range of LAI values reported by other studies (4.1 - 28.7; Table 4-3). The study area LAI value was then used with published leaf transpiration values to generate a stand-based transpiration value of 40 mm/day (Table 4-3). There are only two published studies for *Arundo* stand based transpiration. One study found a similar stand transpiration value of 41.1mm/day (Abichandani 2007). It was conducted on the Santa Clara Watershed which is one of the watersheds within this studies project area. Stand structure, density and leaf area were all comparable to data collected for this study. The other published paper found a much lower stand based transpiration value of 9.1 mm/day (Watts 2009). This study was on the Rio Grande River in Texas. Stands there were shorter and had significantly lower leaf area (Table 4-3).

The current study and the two other published studies would be classified as 'leaf area transpiration measurements scaled up using LAI'. Additional studies looking into stand based water use are definitely needed and would preferably utilize a range of methods used to measure stand based transpiration/water use. Other methods include: lysimeters (tank with soil and plants with controlled water supply), base flow separation studies (stream inflow and outflow studies), analysis of diel groundwater fluctuations, semiemperiacal models, micrometeorological approaches (Brown Ration Energy Balance) and eddy covariance (as outlined in Shafroth 2005).

Using the stand-based transpiration values from this study to calculate water use per acre generates water use estimates that are very high (Table 4-4). Water consumption per acre of *Arundo* is 48 ac ft/yr, and this is far above published values for most vegetation (Johns 1989). Even with the high LAI values measured in this and other studies, an average annual stand-based transpiration is likely to be closer to 20 mm/day, which equals 24 ac ft/yr/ac of water use. The value of 20 mm/day is still at the high end of values published for other 'water hungry' vegetation types such as *Phragmites* (Moro et al. 2004), which is similar in structure and habit to *Arundo*, albeit smaller (less biomass and lower LAI values reported).

Water loss via ET in an *Arundo* stand would not equal the water gained or 'saved' through *Arundo* control. Removal of *Arundo* from riparian systems would likely increase water lost to evaporation, runoff, and any water use of re-colonizing vegetation (see Watts 2009 and/or Shafroth 2005 for additional discussion and references).

A replacement vegetation water use value of 3.3 mm/day or 4 ac-ft/yr/ac was used in our analysis (Table 4-4). This was based on a 'typical' vegetation mix that replaces *Arundo*, which is composed of: 25% trees, 25% shrubs, 25% herbs, and 25% open/un-vegetated. Water use was estimated based on data collected in a major water use review paper that compiled data from hundreds of studies using a wide range of water use measuring methods (Johns 1989). This data, along with a review by Shafroth et al. (2005), were used to approximate replacement vegetation water use. Compared to the estimates shown here for *Arundo,* the lower and more restricted range of replacement vegetation water use estimates suggests that most types of replacement vegetation will potentially use significantly less water.

As within *Arundo* stands, water loss under alternative states is probably best determined through direct measurement or complex models, and very few reports of such exist for riparian vegetation within the study area. Reported estimates of ET or E_{stand} for native riparian vegetation in other areas may be a good starting point for comparison, but many of these studies were conducted in the more arid southwestern portion of the U.S. where water availability may be significantly less than the coastal watersheds of southern California (especially considering the artificial water augmentation from urban and agricultural runoff that has transformed most systems into perennially flowing rivers and streams).

Willow water use from eight studies ranged from 0.9 to 3.3 mm/day (Johns 1989). Mixed riparian vegetation water use from three studies ranged from 0.9 to 1.6 mm/day (Johns 1989). Cottonwood water use from three studies ranged from 2.8 to 6.5 mm/day (Johns 1989). *Typha* (cattail) water use from six studies ranged from 2.4 to 13.8 mm/day (Johns 1989). Mulefat water use from two studies ranged from 2.2 to 3.9 mm/day (Johns 1989). Other riparian/wetland studies looking at other non-native plants found widely ranging water use. E_{stand} based on eddy-covariance from a site dominated by *Tamarix ramosissima* (salt cedar) reached up to 7 mm/day (Cleverly et al. 2002). In a similar study, E_{stand} from sites dominated by mixtures of native and invasive woody species reached peak values of approximately 9 mm/day (Dahm et al. 2002). E_{stand} in a pond lined by *Phragmites australis* in Nebraska was estimated at 4 mm/day in a stand that had a maximum LAI of 2.6 (Burba et al. 1999). E_{stand} in *P. australis* in Germany was estimated at 10 to 16 mm/day in stands with summertime LAI of about 5 (Herbst and Kappen 1999). *P. australis* in semi-arid Spain has been shown to have average midsummer E_{stand} values of about 23 mm/day in a stand with LAI values of 8.9 (Moro et al. 2004).

The final estimated net water savings from removing an acre of *Arundo* was 16.7 mm/day or 20 ac ft/yr/ac (Table 4-4). This represents a very large potential water savings, even if it represents a peak or maximum savings yield. If future studies are able to corroborate water savings of similar magnitude, *Arundo* control could represent an important water conservation action that will benefit multiple uses including habitat, urban and agricultural water use.

Arundo Impacts: Transpiration and Water use

- Due to high leaf area of mature stands, stand-based transpiration is very high (E_{stand} 40 mm/day). There are two other studies evaluating stand-based *Arundo* transpiration. One study on the Santa Clara watershed (within this project's study area) is in agreement (41.1 mm/day). The other study on the Rio Grande River is lower (9.1 mm/day). (Section 4.1).
- Stand-based transpiration rates of *Arundo*, when used to calculate total water over larger areas, indicate very high levels of water use: 48 ac-ft/ac per year. (Section 4.2)
- Net water savings for areas after *Arundo* removal are high (16.7 ac-ft/yr), even when *Arundo* water use is lowered to 20 mm or 24 ac-ft/ac per year to reflect levels that may be closer to physiological water transpiration limits. (Section 4.2)
- New studies using different approaches to measure stand-based water use of *Arundo* are needed to corroborate and refine stand-based water use found in this and other studies. New studies

need to be on mature stands of *Arundo*. Stands under treatment or in post-fire or flood recovery should be excluded, as these are not representative of the majority of *Arundo* stands within the study area. (Section 4.2)

Water use by *Arundo* appears to be a significant impact on invaded systems. Water use by vegetation is difficult to measure. Additional baseline and comparative studies are needed.

Table 4-4. Estimated water use by *Arundo*, replacement vegetation and net water savings from *Arundo* control.

Hydrologic Unit	**Net *Arundo* Acreage**	**ESTIMATED WATER USE (Ac-ft/yr/ac)**			
		***Arundo*: This study** (using 40mm)	***Arundo*: likely maximum** (using 20mm)	**Native vegetation** (using 3.3mm)	**Net gain from *Arundo* control** (using 16.7mm)
One acre of Arundo	*1*	*48*	*24*	*4*	*20*
Calleguas	229	10,983	5,487	905	4,582
Carlsbad	148	7,088	3,542	584	2,957
Los Angeles River	131	6,297	3,146	519	2,627
Otay	19	891	445	73	372
Penasquitos	24	1,129	564	93	471
Pueblo San Diego	15	719	359	59	300
Salinas	1,332	63,828	31,890	5,262	26,628
San Diego	149	7,164	3,579	591	2,989
San Dieguito	175	8,387	4,190	691	3,499
San Gabriel	44	2,124	1,061	175	886
San Juan	173	8,312	4,153	685	3,468
San Luis Rey	684	32,778	16,377	2,702	13,674
Santa Ana	2,534	121,442	60,675	10,011	50,664
Santa Clara	1,019	48,829	24,396	4,025	20,371
Santa Margarita	689	33,018	16,497	2,722	13,775
Santa Monica Bay	18	886	443	73	370
Southcoast	30	1,429	714	118	596
Sweetwater	42	2,002	1,000	165	835
Tijuana	131	6,261	3,128	516	2,612
Ventura	250	11,977	5,984	987	4,997
Other watersheds	28	1,359	679	112	567
TOTAL:	**7,864**	**376,948**	**188,333**	**31,075**	**157,258**