

## 2.10 TRANSPIRATION OF DESERT RIPARIAN FOREST CANOPIES ESTIMATED FROM SAP FLUX

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### 1. ABSTRACT

The heat pulse velocity method was used to estimate canopy transpiration at a perennial stream site on the upper San Pedro River watershed in southeastern Arizona. Short term variations in transpiration were strongly influenced by photon flux density. Our data also suggest that stand structure and landscape position have large influences on daily and seasonal patterns of canopy transpiration in these forests. Variation at this level should be considered when estimating fluxes from whole basins or predicting ecosystem responses to future climate or hydrologic conditions.

### 2. INTRODUCTION

Closure of regional energy and water budgets in semi-arid and arid basins necessitates reliable estimates of riparian corridor evapotranspiration. Transpirational flux from phreatophytic tree species in these corridors can be substantial. Unfortunately, we have little information on how climate variation influences riparian tree transpiration or how stomata, responding to internal and external stimuli, regulate transpiration at different scales. Our lack of knowledge about the processes controlling riparian water fluxes is compounded by technical difficulties associated with micrometeorological estimations of evapotranspiration from these narrow strips of vegetation.

Micrometeorological techniques are most commonly used for estimating evapotranspiration over large areas and involve balancing fluxes of sensible and latent heat with total energy incident on an area. These techniques are most effective when applied to agricultural crops where the plant canopy is homogeneous both in composition and in height, and the fetch is relatively large. For some natural systems, though, estimation of transpiration using micrometeorological techniques is difficult (Hippis *et al.*, this issue).

Desert riparian forests, for example, are typically characterized by long narrow strips of vegetation directly adjacent to stream channels, or in multiple strips if more than one channel exists. These strips of forest are often not more than 20m wide on either side of a watercourse and may consist of several different species and size classes of trees.

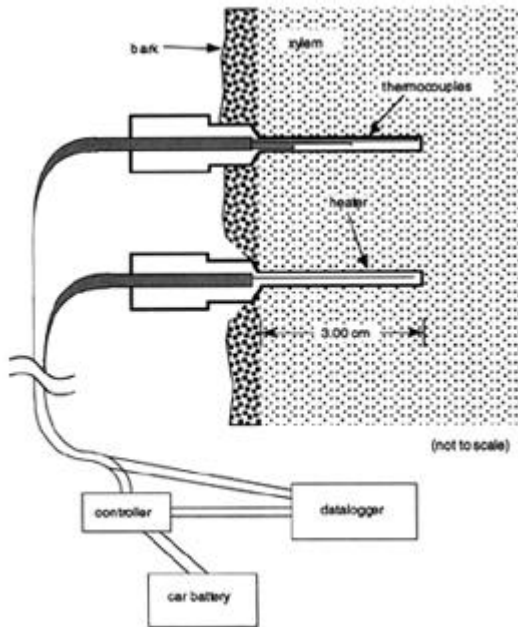
In order to estimate transpiration in these natural systems the heat pulse velocity method can be utilized. This method measures the instantaneous velocity of sap moving through a point within the active xylem tissue of the stem of a plant. The transpiration of an entire stand can be arrived at through scaling of the direct measurements of the amount of water used by individual trees each of a particular species and size class. The application of heat pulse velocity theory to measurement of sap flux was first described by Marshall (1958) and further refined by Cohen and Fuchs (1981) and Swanson and Whitfield (1981). The technique involves inserting a probe consisting of two needles; one containing a line heater, the other containing one or more thermocouple junctions (Fig. 1). A pulse of heat is generated by the line heater. The time the pulse takes to travel a given distance and the amplitude of the pulse are measured by the thermocouples. Using these relationships, the velocity of sap within the xylem can be determined.

Here we report initial results on transpiration from phreatophytic tree species in a semi-arid riparian habitat estimated from sap flux. We use these results to evaluate biotic and climatic driven variations for individual plant and stand transpiration. These estimates are a critical part of SALSA ( Semi-Arid Land Surface Atmosphere Program) objectives to understand processes controlling seasonal and interannual fluxes of water from strips of forested vegetation on the San Pedro River (Goodrich *et al.*, this issue). The natural system of interest for this study is a riparian corridor forest consisting of Frémont cottonwood (*Populus fremontii*) as the dominant component and Goodding willow (*Salix gooddingii*) as a subdominant species.

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Size class (DBH, diameter at breast height) distributions with their respective sapwood area and bark area relationships will be developed for each species. By measuring sap flux densities for individual trees of differing size classes, a relationship describing transpiration per unit basal area can be developed. Stand structure information, along with climatological data, will give some insight into the processes controlling riparian water fluxes and allow aggregation of fluxes over large regions (Qi *et al.*, this issue).



**Figure 1.** Schematic diagram of heat pulse stem flow system used in measurement of riparian trees.

### 3. MATERIALS AND METHODS

The Lewis Springs study site was located in southeastern Arizona, USA on the San Pedro River just north of where it intersects with state route 90 (31°33'N, 110°07'W), within the San Pedro National Riparian Conservation Area. The elevation of the site was approximately 1250 m. The site was dominated by riparian forest vegetation consisting of Frémont cottonwood as a dominant overstory species and Goodding willow as a subdominant species. Mesquite (*Prosopis velutina*) and seep-willow (*Bacharis glutinosa*) existed in the understory. There was a significant difference in size classes in relation to distance from the current primary channel for both cottonwood and willow with larger trees being

located on older, once primary, channels further away from the active channel.

Vegetation surveys were conducted in order to establish stand characteristics such as species composition and vegetation structure. Four transects were laid down on each side of the stream running perpendicular to the stream channel and extending to the limit of the riparian zone. Transects were 30m wide and broken into 10m long sections. Total counts of individual trees, as well as their corresponding DBH's were recorded for each species. From these data, size class distributions for willow and cottonwood were developed.

Heat pulse velocity probes (Thermal Logic, Pullman WA) were implanted in a range of trees of differing diameters proportional to size class distributions determined from vegetation surveys of both cottonwood and willow. Nine trees of cottonwood were selected with DBH's ranging from 0.14 to 0.75m. Six trees of willow were selected with DBH's ranging from 0.15 to 0.24m. Each tree, depending on its size, received from three to five probes, placed equidistant around the trunk at breast height (1.5m). Bark was removed until the cambium was exposed and sensors inserted into holes drilled parallel with the grain of the wood. Before insertion, probes were coated with G5 compound to ensure good thermal contact. After insertion, exposed cambium was covered with G5 compound, to reduce evaporation from the wood surface, and then covered with foil to reduce ambient temperature effects.

Thermocouples on probes were connected to multiplexers (AM416, Campbell Scientific, Logan UT) and heating elements were controlled by relay drivers (A21REL-12, Campbell Scientific, Logan UT). Multiplexers and relay drivers were controlled and data was collected using dataloggers (CR10X, Campbell Scientific, Logan UT). Heating elements and dataloggers were powered by standard 12V deep-cycle marine batteries (Fig. 1).

Eight second pulses of heat were generated by the upstream heating elements and three downstream thermocouples (at 10, 20, 30mm deep into the xylem) measured xylem temperature for 60s; the time to maximum temperature rise, as well as the maximum temperature difference, was recorded. Sap velocity  $V$  (length per unit time) was calculated using equation (1) derived from Cohen *et al.* (1981):

$$V = r \frac{\sqrt{(1 - t_m/t_{m0})}}{t_m} \quad (1)$$

where  $r$  is the distance between heater and thermocouple (6mm),  $t_m$  is time to maximum recorded temperature, and  $t_{m0}$  is the time to maximum temperature at zero flow (assumed to be at pre-dawn, 0200 to 0400 hours). Mass flow of sap  $J$  (volume per unit time) was calculated using equation (2) also from Cohen *et al.*, (1981):

$$J = \rho c / \rho_w c_w \sum V_i A_i \quad (2)$$

where  $\rho c$  and  $\rho_w c_w$  are the volumetric specific heat (density times specific heat) of wet wood and water respectively.  $V_i$  and  $A_i$  are the sap velocity and the cross sectional area of the  $i^{\text{th}}$  increment of sapwood being measured by a thermocouple.  $\Delta T_m$  is the maximum temperature rise recorded by the thermocouple.

$Q$  is the heat input ( $\text{J m}^{-1}$ ) The volumetric specific heat of wet wood ( $\rho c$ ) was determined during a period of zero flow using the relationship for dissipation of a heat pulse with no fluid correction developed by Campbell *et al.*, (1991) and is shown in equation (3):

$$\rho c = \frac{Q}{(e\pi r^2 \Delta T_m)} \quad (3)$$

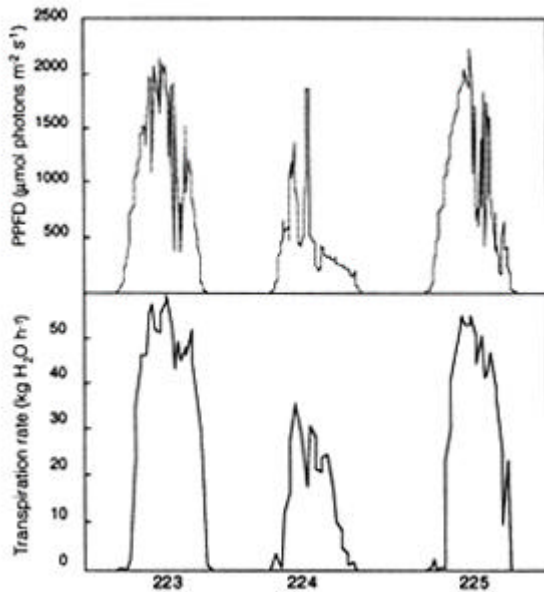
of the heat pulse and is calculated using equation (4):

$$Q = I^2 \left( \frac{R_h}{L} \right) \quad (4)$$

$t$  is the heating time (8s),  $I$  is the heater current, and  $R_h/L$  is the resistance per meter of the heater ( $1141 \Omega/\text{m}$ ).

**Table 1.** Physical characteristics along with transpiration for 9 cottonwood and 4 willow trees along the San Pedro River. Data are for julian day 223 (August 11). DBH is bole diameter at 1.5m height. Sapwood area = basal area - heartwood area - bark area.

Tree Species	DBH (m)	Sapwood Area (m <sup>2</sup> )	Maximum Flow (kg H <sub>2</sub> O hr <sup>-1</sup> )	Maximum Flux (cm <sup>3</sup> cm <sup>-2</sup> hr <sup>-1</sup> )	Total Daily Water Use (kg d <sup>-1</sup> )
Cottonwood	0.14	0.009	3.0	32.7	20.4
	0.19	0.015	6.6	43.7	50.2
	0.20	0.016	4.7	29.2	35.9
	0.43	0.068	25.1	37.2	219.9
	0.48	0.081	28.2	34.9	256.8
	0.50	0.085	34.4	40.4	308.4
	0.69	0.143	68.5	48.1	574.1
	0.71	0.150	58.8	39.1	520.1
	0.75	0.162	87.8	54.3	702.9
Willow	0.15	0.002	4.6	42.5	36.7
	0.24	0.027	14.9	66.5	120.7
	0.24	0.027	5.1	19.3	39.7
	0.24	0.027	7.9	29.9	52.1



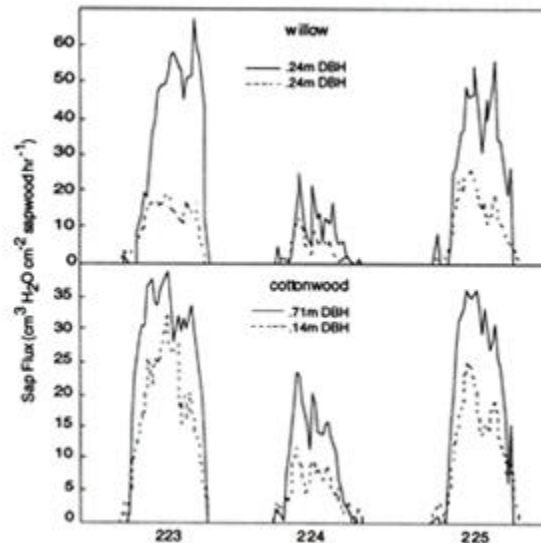
**Figure 2.** Diurnal course of photosynthetic photon flux density (PPFD) and transpiration from a large cottonwood tree (0.71m DBH) for julian days 223-225 (August 11-13).

#### 4. RESULTS

Table 1 shows all trees measured for sap flux at Lewis Springs during the August 1997 SALSA field campaign. DBH and sapwood area are given for each tree, as well as maximum observed daily transpirational rate ( $\text{kg H}_2\text{O hr}^{-1}$ ), maximum flux density ( $\text{cm}^3 \text{H}_2\text{O cm}^{-2} \text{sapwood hr}^{-1}$ ), and the total daily transpiration ( $\text{kg H}_2\text{O d}^{-1}$ ) for julian day 223 (August 11). Mass flow rate ( $\text{kg of H}_2\text{O hr}^{-1}$ ) for a large cottonwood tree (0.71m DBH) is shown in Fig. 2, along with the photosynthetic photon flux density (PPFD,  $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ ) for julian days 223-225 (August 11-13). Maximum flow is  $58.8 \text{kg hr}^{-1}$  on day 223 (the day with the highest PPFD). Day 224 was mostly cloudy for the entire day and this was reflected in the low transpiration rates for that day. Sap flux on a sapwood area basis ( $\text{cm}^3 \text{H}_2\text{O cm}^{-2} \text{sapwood hr}^{-1}$ ) is shown (Fig. 3) for a large and small cottonwood tree (0.71 and 0.14m DBH respectively) as well as for two equally sized willow trees (both 0.24m DBH). Maximum flux is similar for both cottonwood trees, but varies considerably between the willow trees. Cottonwood shows little difference in flux between large and small individuals while willow shows a marked difference in flux between two individuals of the same size.

#### 5. DISCUSSION

Diurnal variations in whole tree transpiration appear to be strongly influenced by short term fluctuations in photosynthetically active radiation (Fig. 2). Other studies of transpiration (Cohen *et al.*, 1993; Meinzer *et al.*, 1995; Schulze *et al.*, 1985; Smith, 1991) have shown that diurnal patterns of transpiration are highly influenced by solar radiation. Snyder *et al.* (this issue) show that cottonwood is largely phreatophytic.



**Fig. 3.** Sap flux density for two representative cottonwood and two representative willow for julian days 223-225 (August 11-13).

It appears that cottonwood has a relatively stable water source to drawn on, and consequently patterns of transpiration are driven by climatic conditions (i.e. solar radiation) and less by soil water availability.

Snyder *et al.* (this issue) found that midday plant water potential remained constant for cottonwood over a variety of climatic conditions, suggesting that these plants may be adjusting stomatal aperture to regulate water potential and transpirational flux. The observation that sap flux density is similar between individuals of cottonwood of different size supports the idea that these trees may be operating at some threshold level for transpirational flux.

Position in the canopy may also play an important role in sap flux. Both cottonwood trees in Fig. 3, although of different size, had portions of their crowns located in the overstory. This would put them in a position to receive unobstructed solar radiation throughout the day. Of the willow

trees however, only the one with the highest flux shown in Fig. 3 had any portion of its crown located in the overstory. It was located on the western edge of the forest and was in a position to receive unobstructed afternoon sunlight. These differences in overall stand structure may lead to large differences in sap flux, and transpiration for sub-dominant species or individuals, but relatively small differences for dominant/co-dominant species or individuals.

In conclusion, stand structure and climatic factors both play important roles in controlling riparian water fluxes. Canopy position (dominant, co-dominant, and sub-dominant) affects the amount of solar radiation incident on an individual plant canopy. This information could support the effort to scale the consumptive water use of individual trees to the level of the stand and provides important information about species' roles in ecosystem processes (Williams *et al.*, this issue).

## 6. ACKNOWLEDGMENTS

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