DETERMINING THE BEST METHOD FOR CALCULATING WATER USE

Results and Discussion

During this study, four types of groundwater data curves were observed (Fig. 9 - 12). A normal diurnal pattern was observed most of the time during the growing season (Fig. 9). During a "normal" pattern the water table increased or decreased with a discharge and recovery each day. All calculation methods worked when fluctuations were "normal".

Under different circumstances, the groundwater table can decline without distinct highs and lows (i.e. discharge during the day without recharge at night) (Fig. 10), increase without a low (i.e. recharge exceeds transpiration through one or more days) (Fig. 11), or increase with highs and lows (i.e. water table level increases over one or more days) (Fig. 12). Not all of the methods worked well under these conditions. For instance, the daily high and low water levels are necessary for components of the calculation in Methods 1, 2, 3, 4, and 5. For methods 5, 6, and 7 the difference between the high water levels are necessary for calculating the water use. If the second high were greater than the first high (i.e. the water table is rising with diurnal fluctuations present) the water use for the day could be negative.

Specific yield is a component of all the water use calculation methods. Since it is a constant characteristic for each well it does not affect the method of calculation; however, it affects the final water use estimated.

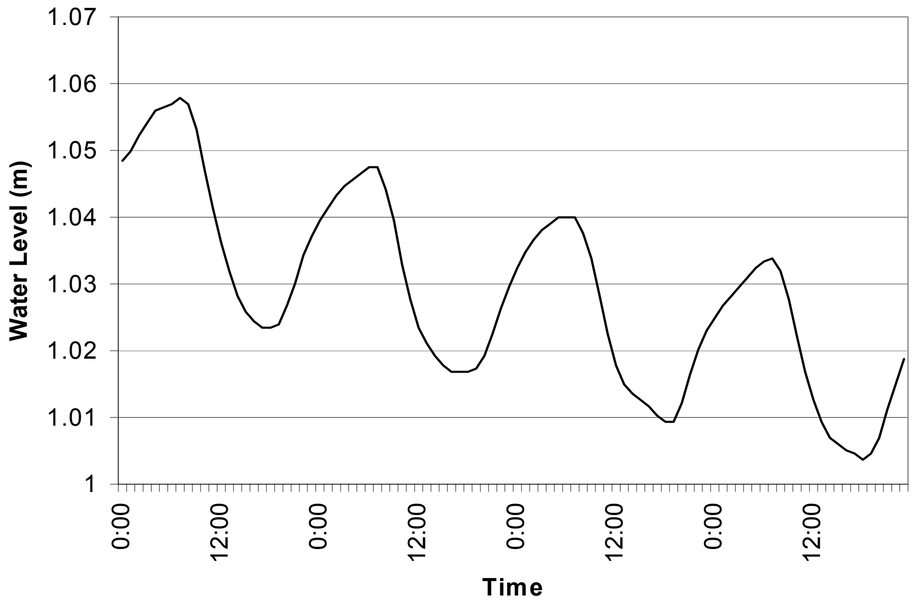

Fig. 9. Example of a "normal" daily diurnal fluctuation. The water table increases or decreases with a discharge and a recovery each day.

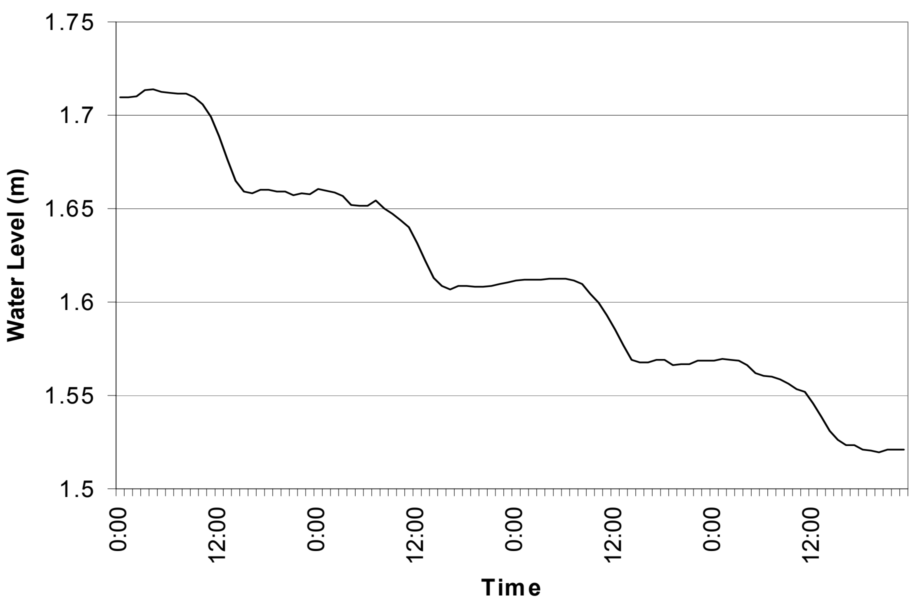

Fig. 10. Example of a fluctuation pattern where there was discharge during the daytime but no recharge at night.

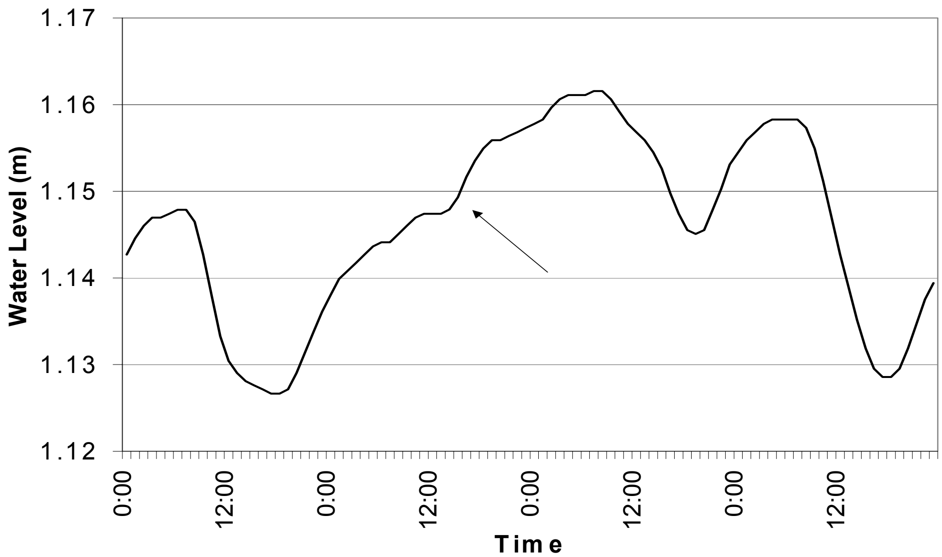

Fig. 11. Example of a fluctuation pattern where recharge exceeded transpiration throughout one or more days (↑).

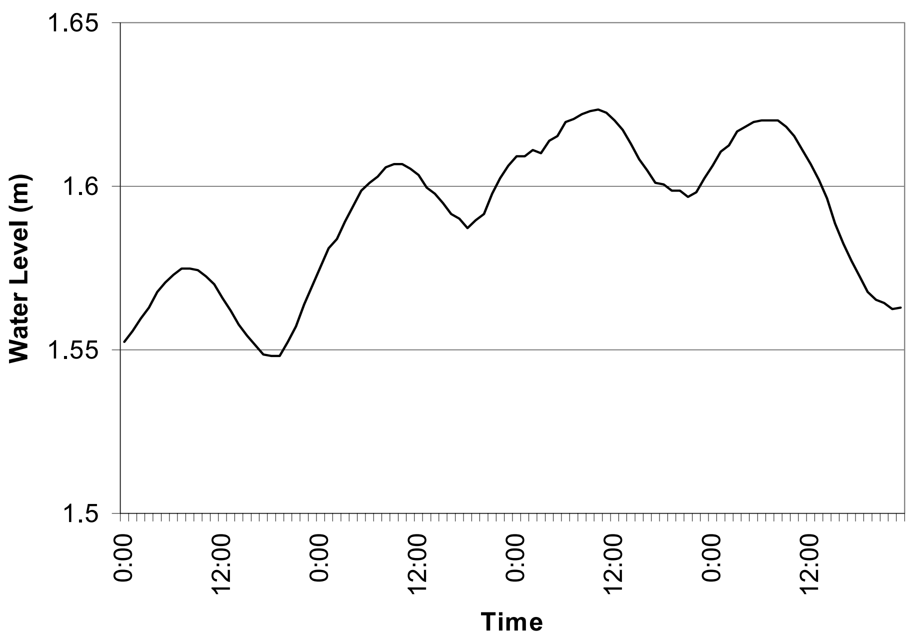

Fig. 12. Example of a fluctuation pattern where the water table level increased over one or more days.

Seven methods were evaluated for use in this study (Table 6). Each method was used for all locations and all wells for the entire growing season. Each method used data from the daily diurnal water table fluctuations (Fig. 13).

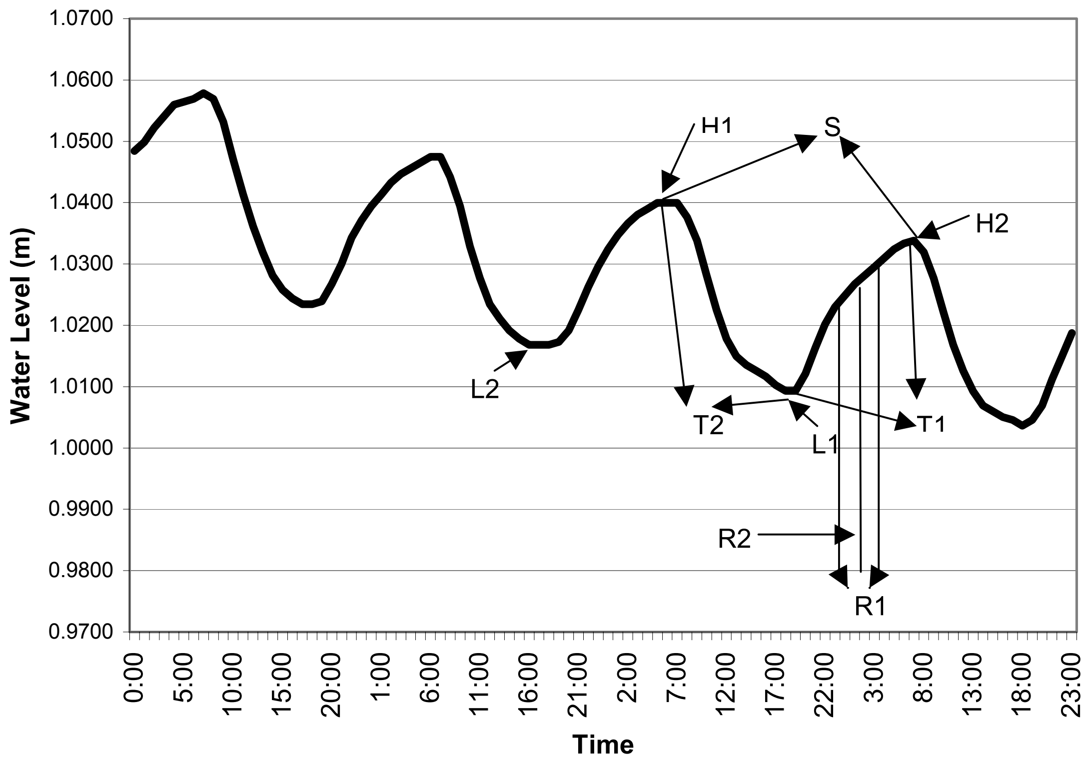

Fig. 13. Example of variables used in water use calculations from Well 2 at the Colorado Location (June 4, 2001) Measurements in meters for 6/4/01 are as follows: H_1= 1.040 m, H_2= 1.0338 m, L_1= 1.0168 m, S= 0.0062 m, R1= 0.0016 (m/hr), and R2= 0.0012 (m/hr).

Method 1

Method 1, $Q=(H_1-(L_1+L_2/2))(sy)$, was described by Dulohery (2000); however, he did not include specific yield in the formula. The specific yield was added to the formula by the investigator. This method only considers the highs and lows. It did not include any "corrections" for recharge during the time of discharge, transpiration at night, or the change in water table from one day to the next. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0270 meters. This does not include a correction for specific yield.

Method 2

Method 2, $Q=((H_1-L_1)-(H_1-H_2))(sy)$, measures the daily amplitude of the curves and subtracts the differences between the high from one day to the next. This method does not account for the recharge that takes place while evapotranspiration is occurring, or transpiration at night. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0245 meters. This does not include a correction for specific yield.

Method 3

Method 3, $Q=((H_1-L_1)+(H_1-H_2))(sy)$, is similar to Method 2. In Method 3 the difference between the two high water levels are added instead of subtracted. This method does not account for recharge that takes place while evapotranspiration is occurring, or transpiration at night. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0368 meters. This does not include a correction for specific yield.

Method 4 – Draw Down Recharge

Method 4, $Q=((H_1-L_1)+((H_2-L_1/T_1)xT_2))(sy)$, also uses the highs and low water level readings from the well hydrograph. However, this method also includes a recharge rate calculation. This formula works by taking the high for the night minus the low for the day (similar to Methods 1-3). However, a conservative estimate of recharge during this draw down period is estimated by subtracting the low from the next nights high divided by the number of hours during the recharge period to determine an estimated recharge rate. This is a conservative rate since some transpiration occurs at night. The amount of daytime draw down is added to the recharge rate times the number of hours during draw down to equal the estimate of water discharge for the well for the day. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0551 meters. This does not include a correction for specific yield.

Method 5

Method 5, $Q=(((H_1-L_1)+((H_2-L_1/T_1)xT_2))+(H_1-H_2))(sy)$, is the same as Method 4 but it includes adding the difference between the two highs (s). The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0631 meters. This does not include a correction for specific yield.

Methods 6 and 7

Method 6, $Q=sy(24r_1+s)$, and Method 7, $Q=sy(24r_2+s)$, are essentially the same. The difference is the rate of recharge is calculated for a shorter period in Method 7. Method 6 was developed by White (1932) for using groundwater fluctuations to determine water use by plants. Recharge was calculated by multiplying 24 by the average hourly rise of the water table from midnight until 4:00 am (midnight until 2:00 am for Method 7). This number was then added to (s) the difference between the high water levels from one day to the next. The calculated water use for June 4, 2001 (Fig. 13) for Method 6 was 0.0458 meters and 0.0347 for Method 7. This does not include a correction for specific yield.

Results and Discussion

The estimated growing season water use varied by method and location from a low of 0.22 meters by Method 2 at the Colorado location to a high of 4.05 meters by Method 5 at the Canadian location (Table 7).

Biologically water use by saltcedar and associated vegetation occurs throughout the entire diurnal cycle and year round from live plants. During the wintertime transpiration would be minor compared to the growing season when leaf area is highest. Leaf area is one of the essential components of all of the direct transpiration measurement techniques. However, it is nearly impossible to extrapolate transpiration losses for an entire stand of saltcedar from measurements taken from a few leaves on a few trees.

Table 7. Average estimated water use in meters and standard deviation (STD) by each method for the growing season at each study site.

Method	Canadian 4/25/01 - 10/4/01	Colorado 5/1/00 - 10/5/00	Colorado 4/25/01 - 10/30/01	Pecos A* 4/25/01 - 10/4/01	Pecos B* 4/25/01 - 10/4/01
1	1.82 (0.50)	0.28 (0.21)	0.23 (0.21)	1.06 (0.75)	1.55 (0.26)
2	2.03 (0.51)	0.27 (0.21)	0.22 (0.21)	0.99 (0.69)	1.57 (0.23)
3	2.81 (0.51)	0.37 (0.20)	0.32 (0.18)	2.10 (0.94)	2.43 (0.23)
4	3.69 (0.95)	0.53 (0.36)	0.46 (0.34)	1.94 (1.44)	2.76 (0.14)
5	4.05 (0.91)	0.58 (0.35)	0.50 (0.34)	2.54 (1.52)	3.28 (0.23)
6	3.64 (0.60)	0.52 (0.23)	0.37 (0.33)	2.32 (1.26)	2.50 (0.84)
7	3.77 (0.77)	0.48 (0.10)	0.39 (0.25)	2.19 (1.19)	2.54 (0.68)

*Well 5 not included in calculation at Pecos Sites A and B

Well monitoring, on the other hand, reflects the entire impact of the climate and plant populations. The difficulty with well monitoring is that transpiration and recharge occur at the same time and at different rates throughout the diurnal cycle. This is further complicated in river systems where stream flows can fluctuate rapidly and influence recharge and discharge from surrounding soil profiles. Inglis et al. (1996) indicated that stream stage should be used to adjust water use calculations; however, he did not explain how to do this adjustment.

A narrow river system is a small body of water in relation to the riparian zones. The diurnal fluctuations in the river may be reflecting the diurnal water use and recharge from the riparian zone. Therefore, the diurnal fluctuations in the river may not need to be adjusted to estimate water use. A lake or large river system would be different.

Observations from these data suggest the transpiration from the riparian zone is causing the diurnal fluctuations in the river. The relatively high water uses observed in this study (Canadian and Pecos locations) under base flow conditions along miles of stream could account for the diurnal fluctuations in the river.

Very rapid changes in the flow of the river, if sustained, would raise the water table in the surrounding landscape due to recharge laterally and through flood plain percolation. During the period of this study, no high flows/flooding were experienced.

Thus, recharge rates would be a very important consideration in calculating water use. The water loggers accurately measure, during the draw down, the amount of evapotranspiration exceeding recharge. Since recharge is occurring at the same time, evapotranspiration (i.e. water use) would have to be considerably higher than just a calculation of draw down. Therefore, Method 1 that only used highs and lows for calculating water use would be inaccurate and extremely conservative compared to actual evapotranspiration during the entire 24-hour period.

Methods 2 and 3 used the same approach as Method 1 but included the change in nighttime highs from one day to the next. Although transpiration is considered low at night, this nighttime high occurs when transpiration and recharge are equal and lowest for the diurnal cycle.

The argument for using the difference between the high from one day to the next (s) is that if the water table rises in the 24 hour period that the head was greater and that recharge rates had increased for this 24 hour period over when the water table was stable or declining. Therefore, if the recharge rates were greater (s) would be negative and subtracted from results from other components of the equation in Methods 3,5,6, and 7 and added in Method 2 to compensate for high rates of recharge.

Method 4 encompasses (s) in its estimate of recharge because it calculates recharge from the low to the high. Method 4, believed to be a more accurate estimate of the average recharge rate during the diurnal cycle, accurately measures recharge which is changing in relation to the fluctuations, and is a better estimate of recharge rate for the day that includes the (s) concept. However, it does not compensate for transpiration at night. Therefore, it would result in a conservative water use estimate.

The change in the daily high water levels (s) should be added when soil water inflow/outflow are equal or does not occur. In these river systems (s) is believed to be greatly influenced by changes in the river water levels and should not be considered as evapotranspiration by plants. Therefore, adding (s) could bias results.

In order to determine which method worked best for the three study locations several characteristics were evaluated for each method of calculation (Table 8). Methods 6 and 7 were the only ones that considered transpiration at night. Method 1 was the only one that did not use or encompass the (s) concept, and Methods 4 and 5 were the only methods to consider the amount of time in which discharge takes place.

Method 4 considered recharge, the amount of time for discharge and encompassed the (s) concept. Method 5 is very similar to Method 4 (Method 5 just adds (s) to Method 4) however; by adding (s) in Method 5 the water use is probably overestimated because the (s) concept is already a part of the calculation of average recharge rate.

Method 6 and 7 considered recharge and daily changes in the water table level (s). However, (Troxell 1936) believed that these methods had problems because they assume that the recharge rate (r) remains constant for the 24 hour period, and Nichols (1993) believed that these methods underestimate water use because they do not account for water moving laterally or vertically through the aquifer during times of increased groundwater gradients.

Table 8. Characteristics evaluated in determining the "best" method of calculation from daily diurnal groundwater fluctuations.

Method	Recharge considered	Amount of time for discharge	Transpiration at night	Change in water table (s)	*Estimated water use June 4, 2001
1	No	No	No	No	0.0270 m
2	No	No	No	Yes	0.0245 m
3	No	No	No	Yes	0.0368 m
4	Yes	Yes	No	**No	0.0551 m
5	Yes	Yes	No	Yes	0.0631 m
6	Yes	No	Yes	Yes	0.0458 m
7	Yes	No	Yes	Yes	0.0347 m

*Does not include specific yield
**Encompasses the (s) concept

Conclusions

Method 4 was selected for determining water use in this study. A nighttime transpiration factor could be added but measurements for these sites are not available to determine an appropriate value. However, these estimates may be conservative by as much as 25% based on Gatewood's (1950) transpiration correction factor of 1.25. Hereafter Method 4 will be referred to as the Draw Down Recharge Method.