Riparian Contributions to Evapotranspiration in Austin, TX

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Introduction

The management of urban water resources is a significant and growing problem for two major reasons. Population migration to urban areas from rural and suburban areas is increasing across the United States, but more significantly, these increases seem to be greatest in cities in the American south and southwest, where water quantity is an issue. Austin, the capital city of Texas, is one such location. Austin is growing at the second fastest rate of any American city [*Anon*, n.d.], yet its climate, classified as 'semiarid' [*Fowler*, n.d.], does not provide enough precipitation each year to comfortably satisfy the population.

To combat this issue, policymakers have and will continue to implement water use regulations. Effective water use policy, however, requires a general estimate of the water budget for the city, because it is impossible to effectively mandate quantities necessary for conservation unless the quantities and fluxes of water that currently exist are known.

This project looks to investigate evapotranspiration, a specific component of the water budget within Austin. Evaporation is difficult to quantify both because it cannot be directly measured and because it requires some sort of scaling from points to large areas. These complications lead to a broad array of assumptions, each of which holds some inherent error. However, the implementation of GIS software in making large-scale calculations can help to constrain this error by making good assumptions at a fine resolution.

This project takes two avenues to address evapotranspiration in Austin. First, to highlight the usefulness of GIS over large areas, the project utilizes the National Land Data Assimilation System (NLDAS) models [*Rodell*, n.d.] to calculated bulk ET across the city of Austin for January and July of 2010. Second, to highlight the usefulness of GIS at a fine resolution, the project employs the Penman-Monteith (1972) model across the riparian zones of the city to determine its contribution to total evapotranspirative loss in Austin.

II. Methods

a. NLDAS Analysis of the City of Austin

A number of GIS data files were required to run this analysis. First, the aerial extent of the City of Austin was required and obtained from the City of Austin's GIS database (ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html). The data used to determine Austin evapotranspiration was garnished from the NLDAS model and acquired via the "LDAS NOAH downloader" courtesy of Gonzalo Espinoza at The University of Texas at Austin. The dataset downloaded was "Total Evapotranspiration (kg/m^2)" and the time extents gathered were January 1-31 and July 1-31 in the year 2010. This dataset was then zonally averaged using the "ZonalAverage.py" program created by Dr. David Tarboton at Utah State University. Austin's political boundary shapefile was used as the aerial extent of the city used for zonal averaging. The zonally averaged ET value was then accumulated across the extent of the area of Austin (704 km^2, [*Anon*, 2013]) to determine a total ET flux for the month. Additionally, instantaneous ET rates were plotted for each time extent.

b. Penman-Monteith Modeling of Riparian Zones

A number of parameters are required for an accurate computation of the Penman-Monteith model. They are listed and described below [*Allen et al.*, 2006]:

$$\lambda E = \frac{\Delta(R_n - G) + \rho c_p(e_s - e_a)/r_{ah}}{\Delta + \gamma\left(1 + \frac{r_s}{r_{ah}}\right)}$$

Figure 1: The Penman-Monteith Equation (Allen et al. 2006)

Variable	Term	Source
Δ	Slope of the saturation vapor pressure curve	A function of temperature, which was garnished from local weather station data
$(R_n - G)$	Net radiation minus ground heat flux	Determined from a local weather station
ρ	Density of water	Constant (1000 kg/m^3)
C_p	Specific heat of water	Constant (2260 kJ/kg)
$(e_s - e_a)$	Vapor pressure deficit	A function of temperature and humidity, which was garnished from local weather station data
r_{ah}	Air resistance	A function of wind speed and vegetation height. Wind speed was garnished from weather station data and vegetation height was estimated from photographs
γ	Psychrometric constant	Constant (66.5 pa/K)
r_s	Stomatal resistance	Determined from a literature review of the dominant vegetation species in each ecoregion of Austin

The model for Penman-Monteith is partially dependent on stomatal resistance, a vegetation-specific term. The City of Austin is unique in that it sits on the border between two climactic zones, and thus two distinct ecoregions with different vegetation profiles. The southeastern portion of Austin falls in the "Blackland Prairie" ecoregion, which receives, in general, more regular precipitation per year than the northwestern portion of Austin (the "Edwards Plateau"). This affects the vegetative profiles in these regions, and thus affects average stomatal resistance in these regions as well.

This was accounted for in GIS by acquiring shapefiles for the Blackland Prairie and Edwards Plateau and intersecting them with the City of Austin's political boundaries. The resulting map can be seen below (Figure 2).

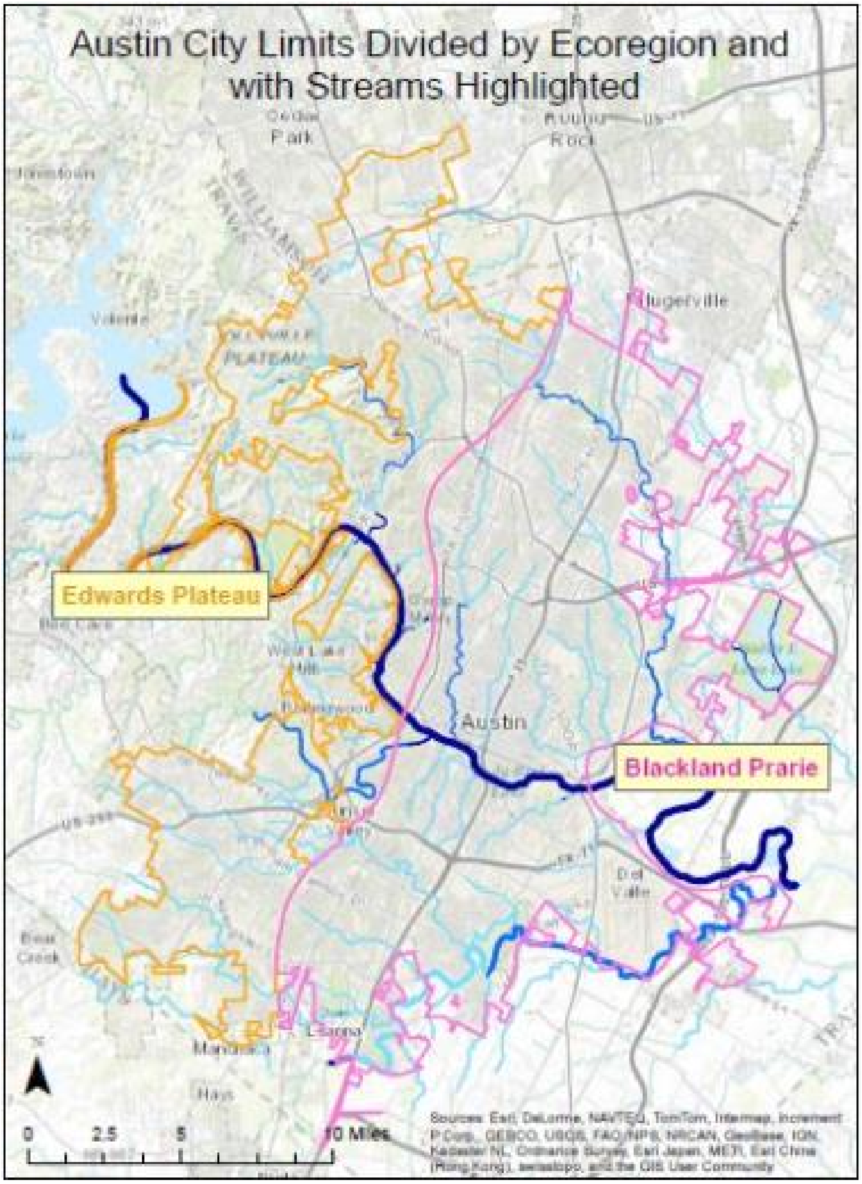


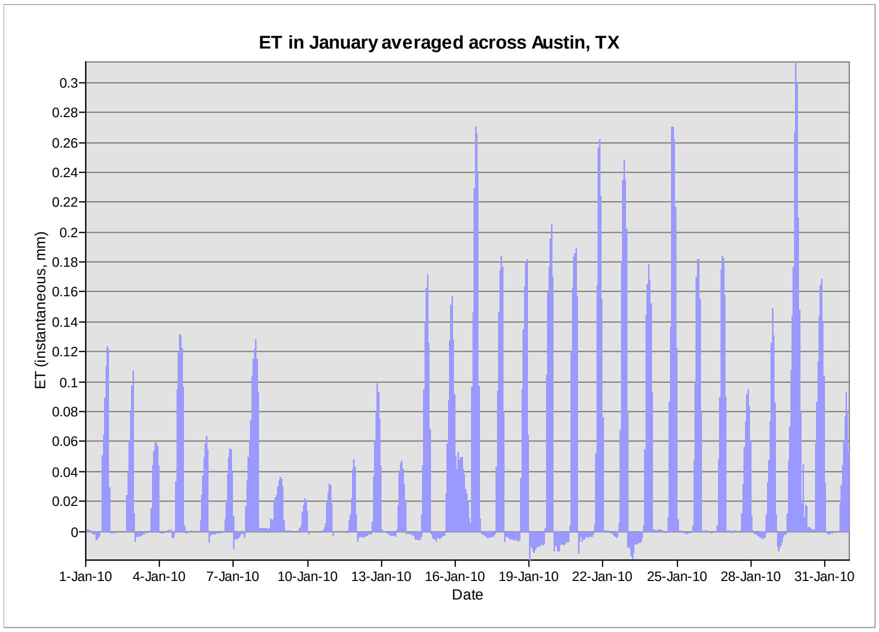
Figure 2: The City of Austin, highlighting specific ecoregions and riparian zones

Additionally, when considering riparian zones for the City of Austin, the quality of stream must be taken into account. In other words, streams must be classified as perennially flowing versus intermittently flowing, because that will affect the water availability of the plants for transpiration and thus their stomatal conductance. For this, the NHDPlusv2 dataset was sorted based on streamflow quality and separated. Thus, there were four streamflow conditions that existed:

Condition 1: Stream quality: Perennial Ecoregion: Edwards Plateau	**Condition 2:** Stream quality: Intermittent Ecoregion: Edwards Plateau
Condition 3: Stream quality: Perennial Ecoregion: Blackland Prairie	**Condition 4:** Stream quality: Intermittent Ecoregion: Blackland Prairie

Stomatal conductances were determined for each condition and the Penman-Monteith model was run for each condition. The average ET values calculated for each condition (mm/day) were then accumulated across the aerial extent of each stream condition and accumulated for an entire month. The values were then compared with the ET values determined through the NLDAS model to determine riparian contribution.

III. Results



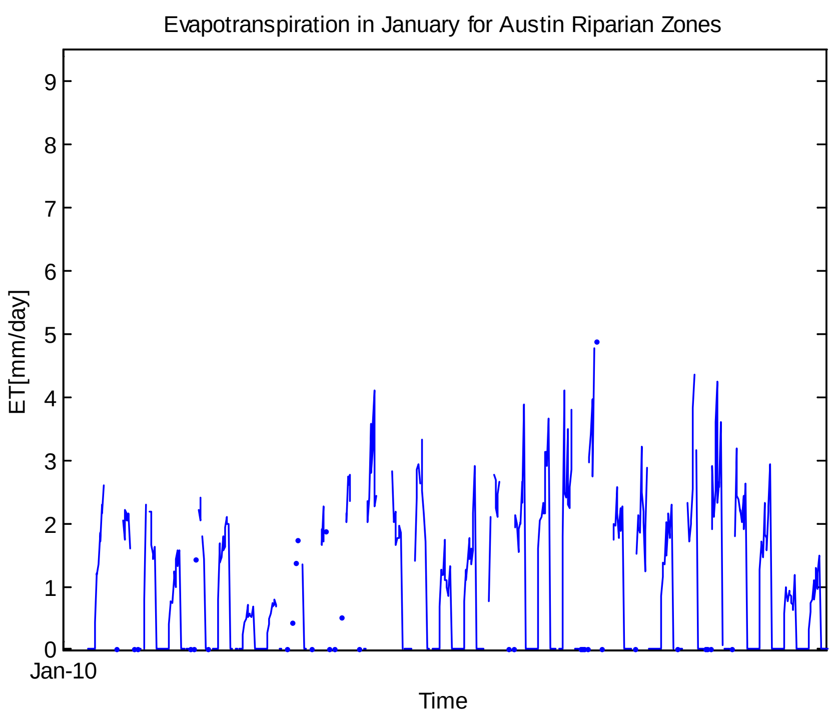
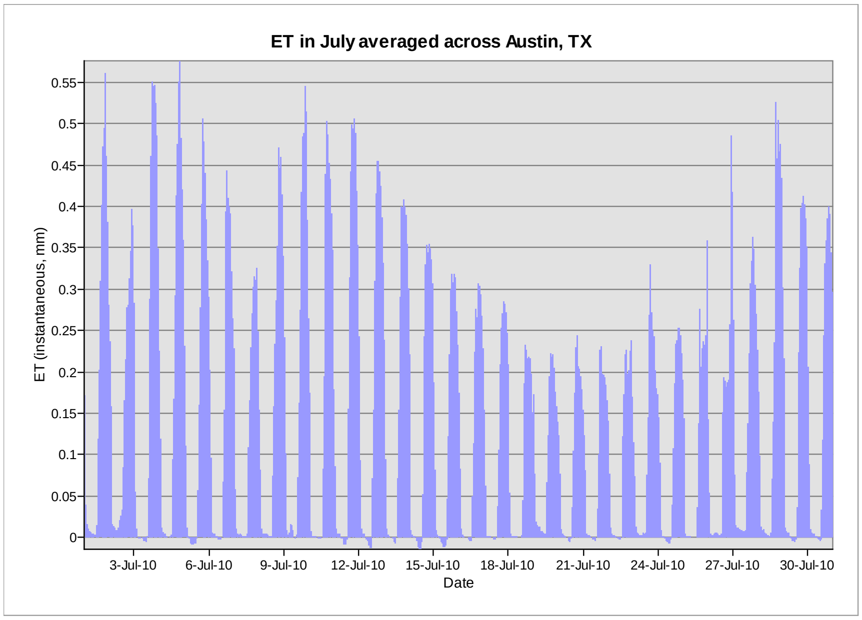


Figure 3: ET as modeled from NLDAS (top) and Penman-Monteith for riparian zones in January



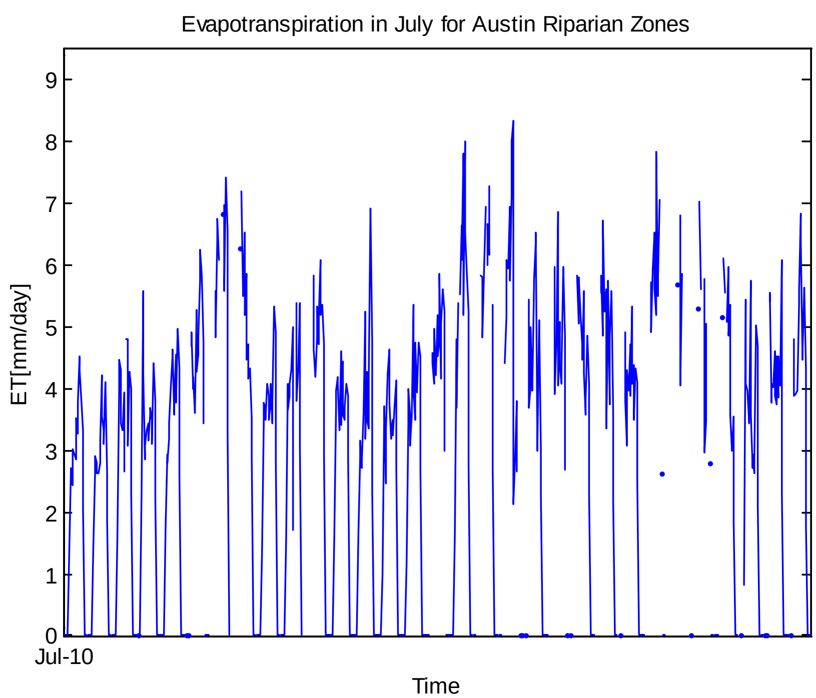


Figure 4: ET as modeled from NLDAS (top) and Penman-Monteith for riparian zones in July

Table 1: Cumulative City-Wide Daily ET measurements (comparing Riparian and Total)

	January	July
Total ET measured across Austin (cubic meters per day)	1,187,572	4,643,906
Total ET measured in Austin Riparian Zones (cubic meters per day)	10,819	24,540
Percentage of riparian contribution to total ET	**0.91%**	**0.53%**
Percentage of Austin covered in Riparian Zones	**0.81%**	**0.81%**

IV. Discussion

As the above graphs show, in general, the Penman-Monteith model and the NLDAS model datasets agree in shape for both January and July. This is a good first quantitative check to determine the validity of the models for comparison. The main driver in the shape of the Penman-Monteith equation is radiation (all other factors *detract* from that original radiation number), so this essentially means that the radiation data used for Penman-Monteith calculations agrees with that for the NLDAS model.

Secondly, the data shows that, as expected, Austin on a whole transports very large amounts of water to the atmosphere every day (on the scale of millions of m^3). This is, in general, a sizeable amount of water: consider, for example, that the Colorado River, Austin's largest surface water flux, transports on average 200,000 m^3 per day. This means that evapotranspirative losses are causing for the loss of between 5 and 20 times of the flow of the Colorado per day, depending on radiation conditions. This verifies that ET is an immensely important quantity to discern for a water budget.

It is interesting to note that in the winter, the ratio of ET in riparian zones to ET overall exceeds its area fraction, but in the summer it is fails to account for its area fraction. This could be explained through the presence of water and plant dynamics within these two seasons. In 2010, the winter months were, somewhat surprisingly, drier than the summer months, which could have led to non-riparian plants engaging drought-tolerant mechanisms that limit ET. However, in riparian zones, moisture is more abundant, so ET in those zones would not be so inhibited. Additionally, in the summer months, there could be more annual plants that sprout and grow leaves around the city, whereas in riparian zones, the vegetation is more or less perennial due to the water availability. The presence of these new plants could drive up city-wide ET while not affecting riparian ET. One final explanation could be the prevalence of lawn-watering in fields and yards across the city during the summer months, which brings more water into the system and thus allows for more water to transpire. This hydraulic redistribution could lead to increases of ET fluxes in non-riparian areas.

V. Conclusions

The analyses provided above based on GIS datasets and observational models show that evapotranspiration is a significant component of the water budget in Austin. They also show that Austin's riparian zones are not significantly skewing the overall ET profile for the city. The above chart demonstrates that riparian zones are less affected by changes in temperature than the rest of the city, however.

A continuing study could make these models more accurate through a number of avenues. First, a continuing study could analyze more data to get a larger sample size. Second, it could achieve better vegetation estimates for the riparian zones, and third, it could potentially use 'direct' ET measurements such as an evaporation pan or sap-flow flux meter to further verify models.

V. References

Allen, R. G. et al. (2006), A recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method, *Agricultural Water Management*, *81*(1–2), 1–22, doi:10.1016/j.agwat.2005.03.007.

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