

# Evaluating the Role of Evapotranspirative Processes for Stormwater Management in Coastal South Carolina Watersheds with Shallow Groundwater

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**ABSTRACT.** In the face of dual pressures in coastal South Carolina - residential and commercial development along with potential climate change impacts - stormwater management becomes a formidable challenge. Hydrologic processes in coastal forested watersheds with shallow groundwater are typically driven seasonally by evapotranspiration (ET). As a response to increasing urbanization, low impact development (LID) practices that are designed to decrease stormwater runoff and volumes by mimicking natural hydrology via infiltration and/or ET are being investigated. This presentation focuses on ET criteria for sustainable land and water decision-making guidance for coastal South Carolina, specifically in upland forested and lowland wetland areas. Forest and wetland water budgets in watersheds with flat topography and shallow groundwater are being refined with the goal of determining pre-development conditions, including the seasonal influence of ET on water table elevation as it drives highly variable watershed outflow throughout the year. Stormwater control measures, specifically engineered wetland and bioretention systems, are being investigated to determine hydraulic and water quality performance based on the influence of groundwater. An assessment of the evapotranspirative processes for both existing vegetation and installed practices (green infrastructure) - as well as their benefits via ecohydrological services at various scales - can provide useful guidance toward water resource protection with the goal of creating resilient communities, whether via conservation or restoration efforts or better site design. These landscape elements are complex within and between these varying scales. Results have implications for watershed planning and site engineering, including stormwater management and design, as well as implications conservation and restoration priorities. With accurate measures and predictions of ET rates and the appropriate hydrological metrics, sustaining coastal water resources may be

achieved to protect from flooding, water quality impairment, and degraded ecological health of downstream receiving waters.

## INTRODUCTION

In this paper, we examine components of a forested water budget - specifically ET including canopy interception and stand water use - that contribute to reduced runoff in low gradient coastal watersheds with shallow groundwater (Figure 1) and with comparison to bioretention system water budgets. The work presented here is a combination of previously unpublished and recently published research conducted in coastal South Carolina. This paper highlights ongoing ecohydrological research on the role of forested coastal landscapes as well as infiltration-based practices in runoff management for land use planners and stormwater decision-makers.

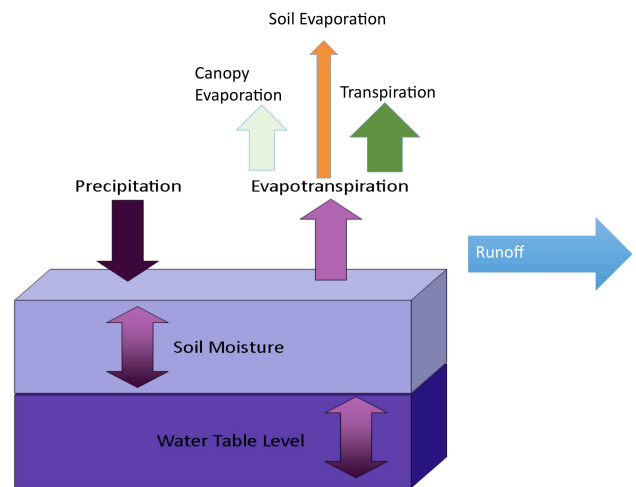


Figure 1. Representation of coastal forested water budget with focus on the evapotranspirative components.

## PROJECT SUMMARY

While there is often high spatial and temporal variability in forest hydrodynamics, recent studies have attempted to quantify some of these complex processes. The first (Epps, 2012) provides an estimation of relationships between precipitation and canopy throughfall and thus interception for mixed pine and hardwood forests – a predominate land cover in coastal South Carolina. The second (Krauss et al., 2014) provides a review of a local sapflow study that estimates stand water use for the same watershed as the Epps study. The third study (Palazzolo, 2014) demonstrates calculation of ET demand as a function of precipitation and potential evapotranspiration (PET) for infiltration-based bioretention practices. This latter metric may serve in the development of seasonal ranges of soil storage available for stormwater management, and more specifically as a method for evaluating the spatial and temporal feasibility of infiltration versus retention-based practices.

## METHODS

### Canopy Throughfall and Interception

By a combined approach of using published literature values as well as collected open field and subcanopy rainfall data, regression equations were developed for canopy throughfall and interception as related to rainfall (Epps, 2012). Intercepted rainfall leads to canopy evaporation. Figure 2 shows land cover classifications and locations of subcanopy rain gages in the 100-ha Upper Debidue Creek watershed (33.38° N, 79.17° W). Open field rain gages were located within a 3 km radius of the center of the watershed. Rainfall and throughfall were measured over one year in 2011-2012.

### Stand Water Use

Using field collected sapflow data and a modeling approach, Krauss et al. (2014) have published results for stand water use of forested watersheds with shallow groundwater, including the same site provided in Figure 2. Per their cited work, sapflow was measured in paired 20-m x 25 m plots using heat dissipation probes (TDP-30-100, Dynamax, Inc., Houston, Texas) on sweetgum, laurel oak, ash, and loblolly pine trees installed into trunks at 1.5, 2.5, and 5.0 cm radial depth to capture variability across the sapwood area of each tree. Stand water use was determined for each plot area by scaling up from individual tree sapflow rate data per unit area of total sapwood surface area. The researchers provide a thorough explanation of this rigorous procedure in their recently published work.

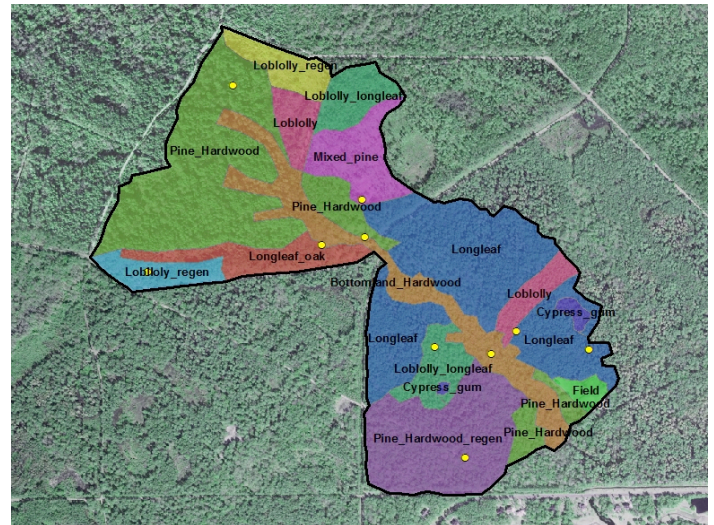


Figure 2. Land cover and subcanopy rain gages (yellow points). Open canopy rain gages are not shown. Image courtesy Dr. Bo Song and Dr. Tom Williams, Clemson – Baruch Institute.

### ET Demand for Coastal Bioretention

Palazzolo (2014) conducted water budget analyses at four bioretention sites in Georgetown and Horry Counties (Figure 3) that varied in size, surrounding land use and drainage area, native soils, proximity to tidal waters, and proximity to water table position.

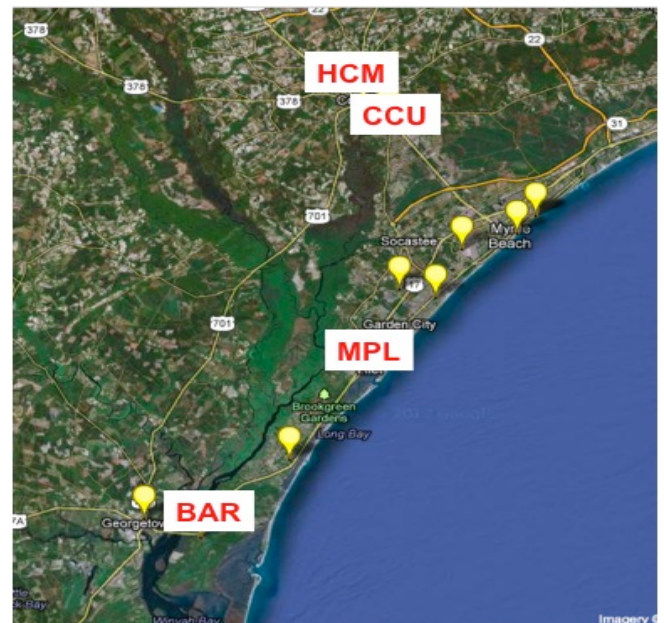


Figure 3. Locations of bioretention cells where water budget analyses were conducted. BAR = Clemson - Baruch Institute near Georgetown, MPL = Morse Park Landing in Murrells Inlet, CCU = Coastal Carolina University in Conway, and HCM = Horry County Municipal Building in Conway.

Analyses included measurements of rainfall and water table elevations, as well as parameters used to calculate Turc PET (mm per day) (Lu et al., 2005) that included daily mean ambient air temperature (T in °C), daily mean relative humidity (RH in %) and daily mean solar radiation ( $R_s$  in MJ per m<sup>2</sup>) in the following equations:

When RH < 50%:

$$PET = 0.013((T/(T+15))(R_s+50)((1+(50-RH/70)))$$

When RH > 50%:

$$PET = 0.013((T/(T+15))(R_s+50)$$

Cumulative ET demand was then calculated as the difference between rainfall and Turc PET on a daily continual basis using the 17 months of data collected.

## RESULTS AND DISCUSSION

### Canopy Throughfall and Interception

Interception was calculated as the difference between gross rainfall from open rain gage data and throughfall from each subcanopy gage. These results were plotted as precipitation (P in mm) versus interception (I in mm) to develop the regression model with coefficients (a,b) as follows:

$$I = aP + b$$

A weighted composite regression model was developed based on percentage of land cover type over the 100-ha watershed, resulting in a = 0.13 and b = -0.02. This translates to approximately 13% of rainfall being intercepted by canopy, or if 2.5 cm (~ one inch) of gross total rainfall occurs, then 0.3 cm of rainfall is intercepted (12%) and 2.2 cm of effective rainfall passes (88%) through the canopy, though seasonal and spatial variability should be further explored.

### Stand Water Use

Using mean sapflow data, Krauss et. al (2014) determined daily stand water use to range from 1.06 – 3.32 mm with a mean of 2.28 mm in 2009, and 0.81 – 3.40 mm with a mean of 2.36 mm in 2010 between the two plots. These results translated to a mean annual stand water use of 430.5 mm per year over the two years of collected data and the resulting modeling effort. The study reports a wide difference in stand water use between the two plots over the two year period – 355 mm and 506 mm – which was attributed to stand structure and stress, as well as to some error and uncertainty that is expected with the methods presented.

### ET Demand for Coastal Bioretention

Daily Turc PET values were summed by month and compared with monthly rainfall and change in minimum versus maximum water table elevation (Figure 4). Total PET for 2013 was 925, 875, 838, and 880 mm respectively for BAR, MPL, CCU, and HCM. Total rainfall for 2013 was 1186, 944, 1260, and 966 mm at each of the sites, respectively. These data for 2013 result in rainfall surpluses of 261, 69, 422, 128 mm respectively, and as ranked by site as CCU > BAR > HCM > MPL.

When ET is calculated on a monthly basis, the seasonal drivers become evident as in Figure 4 with higher ET occurring in summer months (growing season). Yet when ET demand is calculated on a cumulative daily time step, as P – PET, (Figure 5), we see the rainfall surplus more pronounced in some cases and less in others, with cumulative daily results at 573 mm, 140 mm, 368 mm, and 68 mm, respectively for BAR, MPL, CCU, and HCM with the rank changing to BAR > CCU > MPL > HCM. For perspective, the HCM site nearly has a “zero budget” returning to 6.8 cm of surplus, while the BAR site gains a surplus of 57.3 cm over the period.

## FUTURE DIRECTIONS

The compilation of new water budget data may allow us to better understand the ecohydrologic role of vegetation in stormwater management, whether in terms of a forested landscape scale or at an individual stormwater practice scale. It is evident that more data must be collected and longer term calculations made to better evaluate and understand trends in canopy interception, stand water use, and overall evapotranspiration at it relates to microclimatic conditions, rainfall patterns, and water table influences.

Future efforts should include overlapping data sets, for here we have canopy interception measurements in 2011-2012, stand water use from 2009-2010, and bioretention PET from 2013-2014. While it's difficult enough to extrapolate spatially and between scales, it is even more complicated to do so in differing years with varying microclimatic conditions. Future work will also expand upon infiltration rates and water table position, which are hypothesized to have significant contribution to the water budgets. A final need is to further explore plant available water and soil evaporation, both of which should have a high influence on water loss from these systems, especially during growing seasons. In order to move from these “apples to oranges” comparisons, more data collection and analyses - and more collaboration - will be necessary.

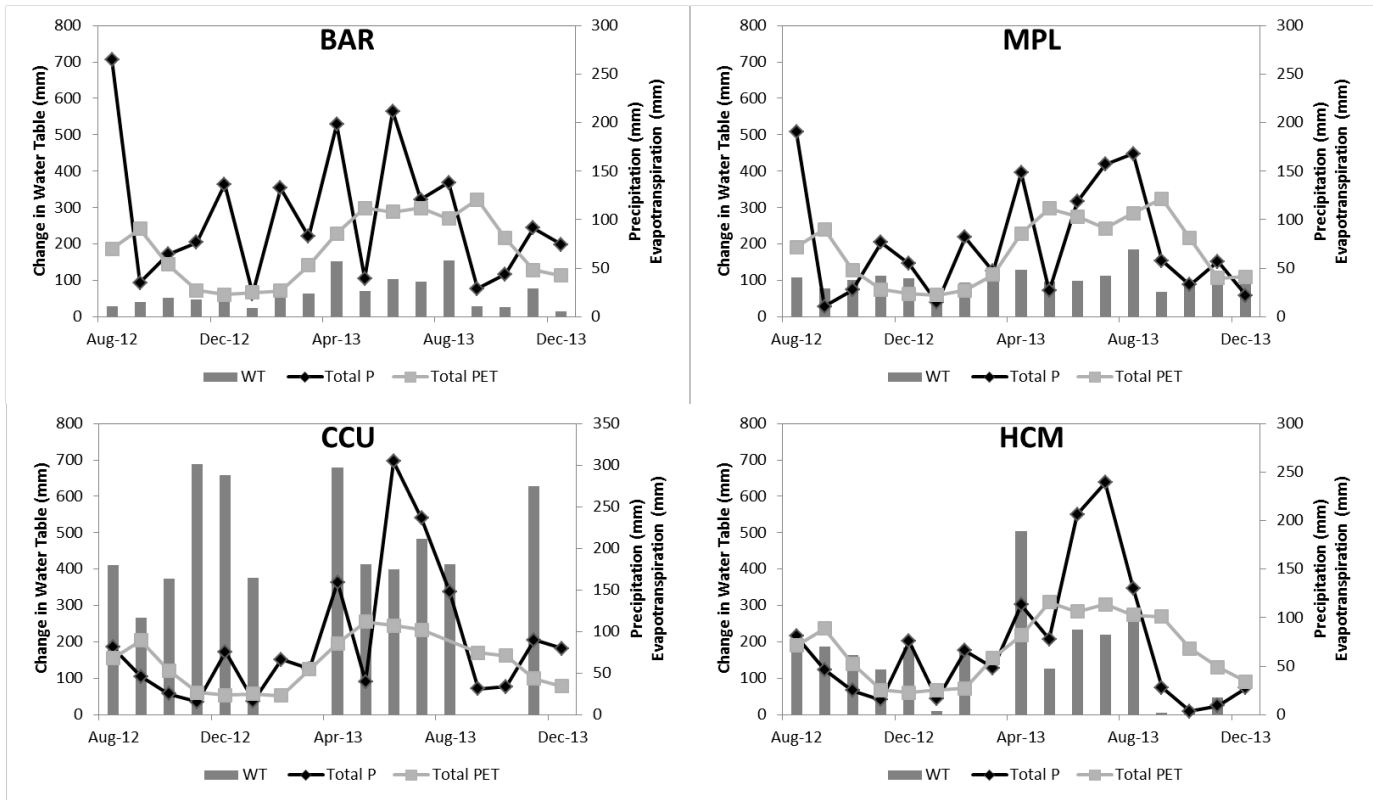


Figure 4. Monthly total rainfall, PET, and monthly maximum change in water table elevation for 17 months at the four bioretention site locations from Figure 3.

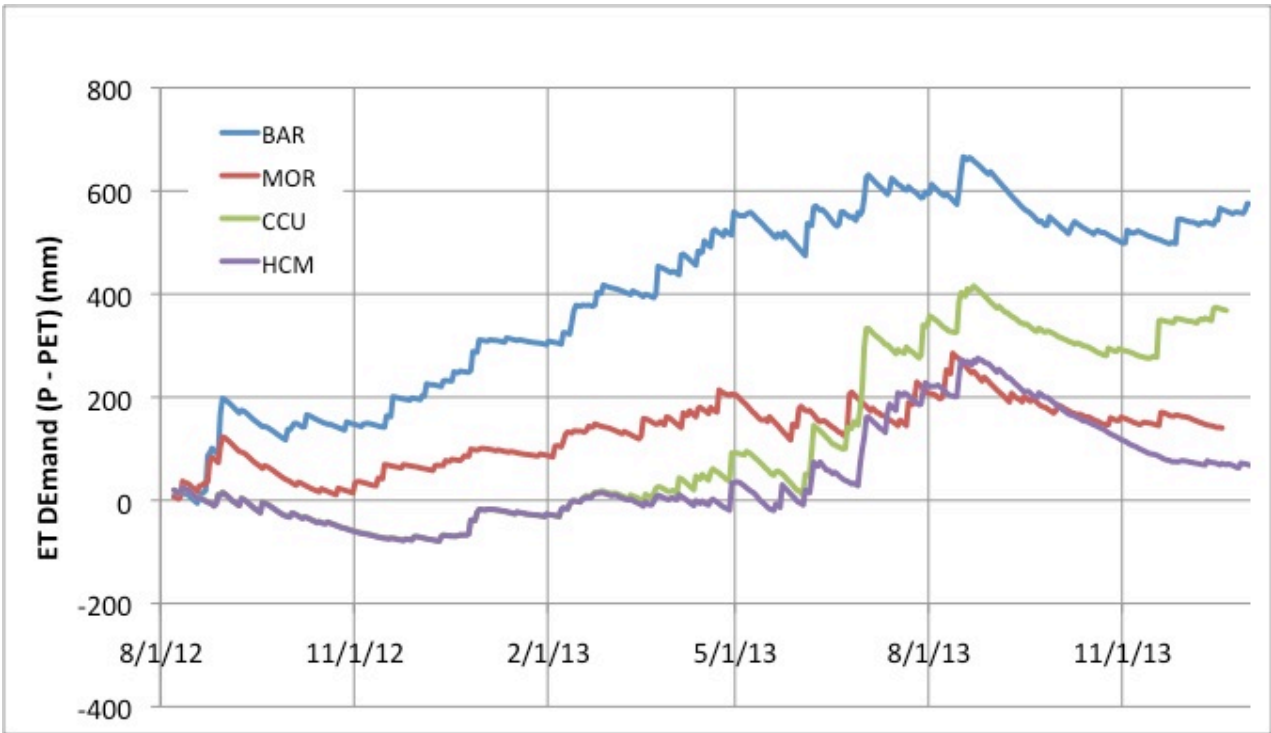


Figure 5. Cumulative ET demand for each bioretention site over the period of study. Rainfall surplus is clearly evident based on the accumulation at each site; however infiltration was not included in this analysis.

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