

HYDROLOGIC INFLUENCES WITHIN A TIDAL FRESHWATER FORESTED WETLAND

Brooke V. James¹, Carl C. Trettin², Timothy J. Callahan¹

AUTHORS¹ Environmental Studies Graduate Program, College of Charleston, Charleston, SC, USA²
Center For Forested Wetland Research, USDA Forest Service, Cordesville, SC, USA
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ABSTRACT. The hydrologic regime of bottomland hardwood swamps is typically characterized as being determined by the inundation period caused by flood events. However, in the lower coastal plain of South Carolina there are large areas of bottomland hardwood swamps that adjoin freshwater tidal creeks. There has been little work in South Carolina to ascertain whether the tidal creek affects the hydrologic regime of the forested riparian zone. We established a stream stage gauge in Huger Creek, a tidal freshwater creek that drains into the Charleston harbor estuary, and a network of wells in the adjoining riparian zone to assess the hydrologic linkages between the stream and riparian zone. Groundwater levels were influenced by the tidal stream with decreasing affect as distance from the channel increased. Water table behavior adjacent to the creek was primarily controlled by tidal forcing. Groundwater levels in the interior wetland were closely related to stream stage, but mostly lacked the daily tidal signal and displayed a larger response to precipitation events. However, tidal influence was clearly evident across the floodplain near the spring tides. Our data demonstrate subsurface connectivity between the water table in the riparian zone and the tidal stream. These data highlight the need to recognize that riparian zones adjacent to freshwater tidal creeks may exhibit a distinct hydrologic regime as determined by the stream. Presently, these ecosystems are not recognized as different from an inland bottomland hardwood swamp.

INTRODUCTION

Tidal freshwater forested wetlands (TFFWs) occur at the interface of tidal aquatic and terrestrial

ecosystems and are characterized functionally by gradients of biophysical conditions, ecological functions and biological communities (Day et al., 2007). Not unlike their bottomland hardwood counterparts, functionally, they offer numerous ecosystem services to adjacent communities, such as, storm water runoff mitigation, storm-surge protection, and provide structure and protection for animal habitats. However, due to their low position in the landscape, TFFWs are especially vulnerable to changes in sea-level rise and salinity because of their connection to coastal marine environments (Doyle et al., 2007).

There is an abrupt change in vegetative communities between marsh and forest habitat primarily due to a salinity gradient. TFFWs exist landward near the head of tidal influence and above the saltwater - freshwater interface, which is defined as waters less than 0.5 ppt (parts per thousand) salinity. Chronic increases in salinity has shown to cause vegetation stress and mortality as saline water migrates inland, thus causing a retreat of forested communities which are subsequently replaced by freshwater or brackish marsh vegetation (Doyle et al., 2010). While the marsh – forest border is easy to detect on a map, the tidal freshwater forest and terrestrial non-tidal upland boundary is more dynamic due to changes in seasonal changes in river discharge and sea level, which affects tidal range (Anderson and Lockaby, 2011a).

The extent of TFFWs has been poorly characterized and is largely unknown due to lack of research or established metrics to inventory tidal freshwater forest communities (Doyle et al., 2007). The conservative estimate of TFFWs in South Carolina is 40,000 hectares; this is attributed to the low topographic gradient and the large number of rivers that discharge into coastal estuaries (Field et al., 1991). To date, several studies have focused

on both salt and freshwater marsh dynamics, and non-tidal upland wetland, but less is understood about TFFWs that potentially cover a significant area of the South Carolina coastal plain. However, as sea level rises, and climate patterns become more extreme due to global climate change, it is crucial to gain a better understanding of how these transitional areas function in the landscape.

Background

Hydrologic regime and ecological functions of salt and freshwater marshes connected to large estuaries are directly related to fluctuations of astronomical tides, where the wetland surface is inundated daily by water, and salinity gradients control species distribution. In non-tidal riparian wetlands, hydrology is governed by surface water runoff (river discharge and overland flow), precipitation, evapotranspiration, and groundwater discharge (Mitsch and Gosselink, 2007). Hence, the hydrologic regime of tidal freshwater forested wetlands represents a combination of the two, where hydrology is predominantly controlled by the tides and river discharge, but also influenced by precipitation, evapotranspiration, surface runoff and subsurface drainage (Doyle et al., 2007).

Until recently, the bulk of available research related to the hydrology of tidal systems has concentrated on ecological and chemical processes present in salt and freshwater marsh communities (Harvey et al., 1987; Nuttle, 1988; Hughes et al., 1998; Seybold et al., 2002; Neubauer, 2011). Studies concerning new information about sea level rise and salinity intrusion have recognized the importance of expanding hydrology research to include tidal freshwater forested wetlands (Day et al., 2007; Doyle et al., 2010; Hackney et al., 2007; Courtwright and Findlay, 2011; Anderson and Lockaby, 2011a, b) in an effort to better understand the shift between tidal freshwater and upland terrestrial environments.

The traditional definition concerning the connectivity between a tidal wetland (marsh or forest) and its creek reflect a rapid decline in tidally-induced water table fluctuations with increasing distance from the creek, and thought to be negligible at distances within several meters of the creek bank (Nuttle, 1988). This is in part due to heavy sediments that restrict horizontal and vertical water flow. Nuttle (1988) identified semi-diurnal fluctuations within 2.5 m of the creek bank in a New England salt marsh where the horizontal movement of water beyond the creek bank (2.5 – 15 m) was only observed during periods of surface

inundation associated with spring tide cycles. In their study, Hughes et al. (1998) determined that the groundwater response to tidal fluctuations in a salt marsh in coastal Australia extended over a greater distance due to the sandy characteristics of the underlying surficial aquifer.

Studies concerning TFFWs have shown that wetland water table elevations are closely related to their associated tidal water bodies causing wetland soils to remain nearly always saturated, even during periods of low river flow, a key difference between non-tidal bottomland hardwood forests and TFFWs (Hackney et al., 2007). In a study conducted along the Apalachicola River, Florida, findings indicated that wetland hydroperiod underwent periodic tidal pulsing, but showed large seasonal variations coinciding with periods of high sea levels and of low river discharge (Anderson and Lockaby, 2011b). Hackney et al. (2007) studied several TFFWs along the Lower Cape Fear River finding that during periods when the tide did not flood the wetland surface, water levels declined below the soil surface. However, it was noted that soils remained nearly saturated at all times because the time periods between surface inundations were brief. Other studies focusing on hummock and hollow microtopography as a basis for vegetation distributions have identified relationships between tide and duration of hollow flooding (Duberstein and Conner, 2009; Rheinhardt and Hershner, 1992; Courtwright and Findlay, 2011).

STUDY OBJECTIVES

The objective of this study is to evaluate the interactions between surface water and groundwater related to tidal forcing at the upper extent of tidal influence, which we hypothesized is the driver of the riparian zone hydrologic regime. We evaluated stream stage and groundwater patterns over several months at Huger Creek, near South Carolina Hwy 402 in Berkeley County, in the western part of the Francis Marion National Forest.

METHODS

Study Area

Huger Creek is a fourth-order stream draining approximately 16,500 ha, primarily within the

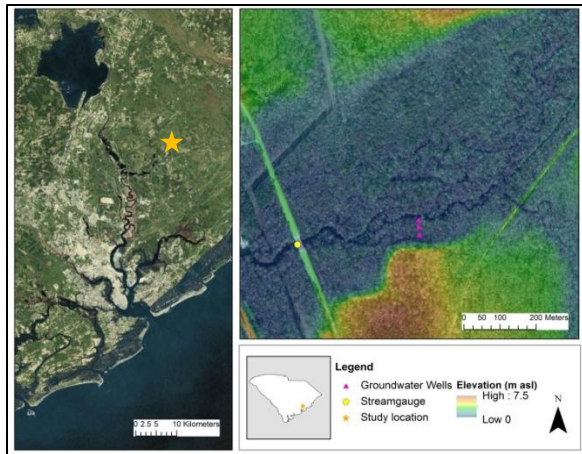


Figure 1. Location map showing Huger Creek study area in relation to the South Carolina coast (left), and elevation of study site using LiDAR imagery, including stream gauge and well transect (W1, W2, and W3 - north to south) location (right).

Francis Marion National Forest 60 km northeast of Charleston, South Carolina (Figure 1). Two - 3rd order watersheds, Nicholson and Turkey Creek form Huger Creek at their confluence. Huger Creek is later joined by Quinby Creek to form the East Branch of the Cooper River, which eventually discharges the Charleston Harbor estuary. The entire length of Huger Creek is influenced by semi-diurnal astronomical tides. The area of interest for this study reflects the uppermost tidal extent of a coastal plain river that at no time experiences surface inundation by overbank flooding of tide water.

Data Collection

The study was conducted within the Santee Experimental Forest. Stream stage was measured using a water level sensor located on Huger Creek beneath an overpass on South Carolina State Highway 402. Housing was constructed of 5.8 cm diameter, perforated polyvinyl chloride (PVC), and functioned as a stilling well for the pressure transducer (WL-16; Global Water, Inc., Gold River, CA) that was set to record data at fifteen minute intervals. The stream gauge was installed in February 2011, and has continually collected stage data. A well transect containing three ground water monitoring wells at distances of 3.5 m (W1), 24.3 m (W2), and 49.5 m (W3) from the creek bank was installed 350 meters upstream from the stream gauging site. Wells were constructed of 3.8 cm diameter PVC, and

instrumented with pressure transducers (Solinst, Ltd., Georgetown, Ontario, Canada) set to record at thirty minute intervals. Well casings were vented the entire length installed to a minimum of a 2 meter depth, to allow measurement of the water table. All data were subsequently compensated for barometric pressure with a Solinst Barologger at a nearby site. Raw data were transformed into depth below surface, and tied with surface water measurements to a common datum (mean sea level) for analysis. Water table wells were installed during May 2011 and have continuously recorded data since installation.

Elevations were determined using 1 meter horizontal, +/- 15 cm vertical resolution LiDAR data, which were confirmed in the field by manual leveling to an established benchmark elevation. Precipitation data taken at 15 - minute intervals was collected from a USGS stream gauging site (USGS 2172035) located approximately 1 km upstream on Turkey Creek, at South Carolina State Highway 41.

Soils in the study area are described as fine, mixed, active, thermic Typic Albaqualfs of the Meggett series, and are characteristically poorly drained, nonacid, and clayey (NRCS, 2005). Meggett soils are characterized as having a high specific retention – the tendency to hold on to water, and a low specific yield – the amount of pore space available to take on excess water. Hence, we would expect a disproportionately large increase in water table from precipitation events. The saturated hydraulic conductivity is low (1.3×10^{-2} m/d (0.021 in/hr)) which only allows a slow rate of water movement within the soil matrix.

RESULTS

Surface Water

Near the outlet of the watershed, the measured the mean tidal range is 1.03 meters (1.5 years of record). Salinity levels are negligible and did not exceeded 0.1 ppt for the duration of the study. The South Carolina coast is characterized as mesotidal (tide ranges 1.8 – 3.7 m) with semi - diurnal tidal fluctuations. The long term mean range in Charleston Harbor is 1.6 meters with decreasing range moving upstream towards the study site (NOAA, 2009).

Water Table

Our complete dataset indicates that the water table elevation remains near the surface throughout

the year (0.76 meters asl (above sea level), or 0.48 m below ground surface). The magnitude of water table fluctuations in response to the tidal forcing was inversely related to distance from the creek. Tidal pulses were evident in W1 hydrographs with each incoming and outgoing tide cycle during both the spring and neap tide cycle (Figures 2 and 3). The corresponding water table amplitude averaged 0.10 – 0.30 meters during neap and spring tides respectively. Water table levels peaked with the corresponding high tide shortly after the maximum stage was reached in the creek, and showed a delayed response in W2 and W3, and experienced a lag time to leave. The observed lag was attributed to the high specific retention of the Meggett soils.

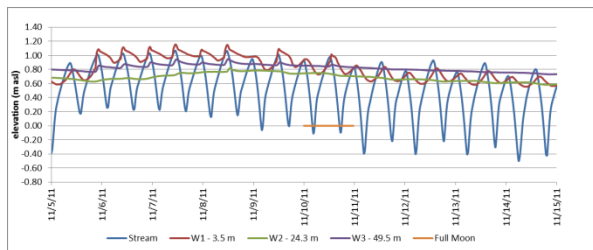


Figure 2. Hydrograph of Huger Creek stream stage and water table response at W1, W2, and W3 to spring tide forcing.

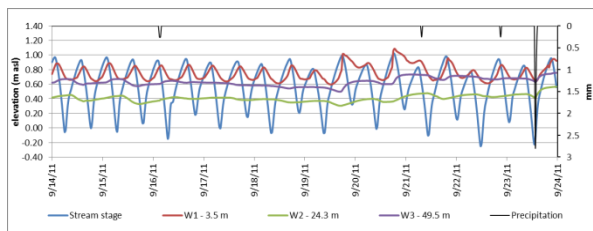


Figure 3. Hydrograph of Huger Creek stream stage and water table response at W1, W2, and W3 to neap tide forcing with precipitation (mm) on secondary y-axis.

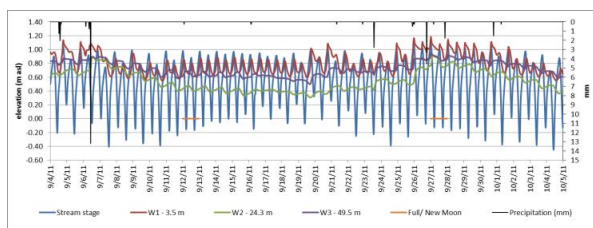


Figure 4. Hydrograph of Huger Creek stream stage and water table response at W1, W2, and W3 over an entire lunar cycle with precipitation (mm) on secondary y-axis.

In wells W2 and W3, the magnitude of daily tidal groundwater fluctuations were reduced, but still evident, and associated with the larger of the two daily high tides. Figure 3 details the typical response to of the water table to a neap tide cycle. Although daily tidal signal appears to be largely absent, the data suggest that over the neap tide cycle, maintenance of water table elevation was a function of the tide. The tidal forcing function supplied a larger volume of groundwater to the riparian wetland than would exist in the absence of tidal input, thereby sustaining water table elevation in the absence of significant precipitation. Figure 4 shows an entire lunar cycle; this graph suggests that on a monthly time scale, wetland hydroperiod is primarily regulated by stream stage. The water table response to a precipitation event occurring 9/6/2011 appears to be reduced by the tidal groundwater fluctuations, especially in W1. Given the nature clayey of Meggett soils we would generally expect a larger increase and slower drawdown if this were a non-tidal bottomland riparian wetland. Instead, the tide appears to remove extreme rises and falls in the water table, and closely tracks stream stage. Further evidence for tidal regulation is apparent near 9/21/11 where water table elevations increase with the oncoming spring tide cycle in the absence of precipitation.

DISCUSSION

Our data suggest that tidal forcing is the primary hydrological component for regulating water table elevation in the riparian zone of our study area. Precipitation plays a secondary role, and the effect on water table appears to be dampened by tidal groundwater fluctuations. These findings agree with those found in other published studies related to tidal groundwater fluctuations in both coastal marshes and tidal forested ecosystems. In Hughes et al.'s (1998) study, similar results were recorded; the strongest tidal forcing occurred around the spring tides and groundwater moved laterally in the saturated sand aquifer ($K = 0.5\text{-}27 \text{ m/day}$) beneath the mucky upper layer of sediment. Despite the much lower hydraulic conductivity of the Meggett soils, which would reduce rate of water table response to tidal forcing, our data suggest that groundwater responds to tidal forcing in a similar mechanism.

Rheinhardt and Hershner (1992) used water table wells installed within hollows 100 – 300

meters from the stream channel to assess the hydrology of a tidal swamp on the Pamunkey River. They proposed that the daily hydrologic regime of the swamp was highly dynamic due to alternating daily high and low tide cycles, but that the overall long term regime would be relatively low due despite atmospheric effects, due to the maintenance of water table by the tidal water body. Again, our observations align with this; tidal regulation appears to abate climatic factors such as seasonal discharge, precipitation, and daily evapotranspiration rates by maintaining relatively stable water table elevations.

Although our study site was located at the uppermost point extent of tidal influence, we still observed a significant response in the water table directly related to tidal forcing. In their study on the Apalachicola River, a major tributary of the microtidal (<1.0 m tidal range) Apalachicola Bay, Anderson and Lockaby (2011b) found small tidal fluctuations in groundwater wells installed 70-140 meters from the channel. In the most upstream gauged sites, tidal fluctuations were reduced or absent during the winter months when sea levels were at their lowest. Fluctuations were more prominent during the summer to autumn months which coincided with low river discharge and higher sea levels (Anderson and Lockaby, 2011b). Our long term observations indicated that water table levels were influenced and fluctuated with tide stage regardless of season. However, more observations and multiple data sets are needed to provide an accurate analysis of our observations. This contrast may be attributed to the differences in tidal ranges between the coasts of South Carolina and Florida. The large tidal range within the Charleston Harbor coupled with the low topographic gradient allowed for a larger volume of water to travel upstream.

CONCLUSIONS

This study showed that the tidal forcing extended laterally in the saturated zone below the floodplain surface. The water table of the riparian the zone directly adjacent to the creek is predominantly controlled by stream stage. Our data suggest that the hydrology of the wetland is regulated mainly by tidal fluctuations in Huger Creek. We have provided data to demonstrate that the hydrology of TFFWs may be more alike coastal marsh systems than non-tidal bottomland upland habitats. The tidal water table fluctuations

present in these systems may provide ecosystem services and ecological processes that are still unknown or misunderstood. Although multiple years of data are need to provide a basis for assessing sea level rise and forest retreat from saltwater intrusion, this work highlights the need for more assessments focused on the hydrology and actual extent of TFFWs that occupy the coastal plain of South Carolina.

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