

COASTAL PLAIN SOILS AND GEOMORPHOLOGY: A KEY TO UNDERSTANDING FOREST HYDROLOGY

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Abstract—In the 1950s, Coile published a simple classification of southeastern coastal soils using three characteristics: drainage class, sub-soil depth, and sub-soil texture. These ideas were used by Warren Stuck and Bill Smith to produce a matrix of soils with drainage class as one ordinate and subsoil texture as the second for the South Carolina coastal plain. Soils with sandy clay loam sub-soils (the most widely distributed soils on the coastal plain) were further divided by sub-soil depth into three categories: > 40 inches, 20-40 inches, and <20 inches. In 1974 Donald Colquhoun classified geomorphology of the lower SC coastal plain by relationship to seven former marine terraces. Sediments were associated with beach, offshore, or back barrier deposits while river valleys were associated with either fluvial or estuarine deposits. Using GIS, soils in the matrix can be mapped to the geomorphic features revealing a geomorphic explanation for the distribution of soils across the coastal plain. Beach and offshore deposits have sand throughout the soil profile, while back barrier deposits tend to have clay or clay loams. Fluvial terrace deposits have sandy clay loam sub-soils while some estuarine valleys have entirely organic soil profiles. Classification of drainage class is directly related to the average water table depth of soils. Within a single sub-soil type (sands), average water table depth is directly predicted by drainage class. Soil subsurface type also greatly influences drainable porosity (the porosity that is filled or emptied by a small change in water table). Geochemical analysis of flows on sandy subsoil (near Georgetown) and clay sub-soils on Turkey Creek and Watershed 80 (near Charleston) show this difference in drainable porosity and water table fluctuations to be related to the source of storm runoff. Sandy sub-soils have higher drainable porosity, smaller water table fluctuations, and a prevalence of soil water chemistry in runoff. Clay sub-soils have lower drainable porosity, greater water table fluctuation as a response to rainfall and ET, and stream runoff chemistry more similar to that of rainwater.

INTRODUCTION

Forest hydrology has been widely studied in the southeastern Coastal Plain that is typified by watersheds with shallow water table depths due to the mild slopes. Depth of the water table is an important determinant of not only forest productivity but also of the volume of runoff (Elsheman and others 1994, Harder and others 2007, Williams 1979, 2007). The southeastern coastal plain is geologically young and fluvial processes have had little time to develop drainage patterns, resulting in landscapes dominated by older estuarine and marine geomorphic features. Buol (1973) found soils on these old marine features formed catenae (catena being adjacent soil series in the same parent materials that form a soil drainage sequence) with best drained soils near streams and most poorly drained at inter-stream divides opposite of what is expected in areas with mature fluvial geomorphology. Prior to the advent of Light Detection and Ranging (LIDAR) technology, much of the subtle elevation differences in soil setting were not obvious, making interpretation of spatial distribution of soils very difficult.

Soil properties are also a very important aspect of forest productivity. Coile (1952) established that soil texture, depth to a heavy textured layer, and soil drainage (depth to water table) were the main factors that predicted forest growth rates. Using similar principles, Warren Stuck (1976) presented a simple classification chart of South Carolina coastal soil series. All soil series listed on that chart were arranged into six drainage classes and seven subsurface texture/depth classes. The six drainage classes were excessively-well, well, moderately-well, somewhat-poorly, poorly, and very-poorly drained. Texture classes were classified as: sand, 10-18 percent clay, 18-35 percent clay, 35-45 percent clay, and >45 percent clay. Since many coastal sub-soils contained 18-35 percent clay, these were further divided into depth of sub-surface layer of > 40 inches (102 cm), 20-40 inches (51-102 cm), and < 20 inches (51 cm).

South Carolina coastal geomorphology consists of eleven former marine terraces (Cooke 1936, Colquhoun 1974) that represent former stands of sea level. Colquhoun (1974) mapped the eastern most six of these terraces with interpretation of geomorphic features associated with rise or fall of sea level. Terrace features were either offshore

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deposits, beach deposits, or back barrier marsh deposits. Riverine deposits were either floodplain, estuarine, or deltaic deposits.

Current soil surveys and GIS technology allow a qualitative comparison of that simple soil classification to the classes of geomorphic feature, which were mapped for the South Carolina coast. The objective of this paper present the techniques used to make such a comparison and to examine the hydrologic implications of such a soil classification.

PROCEDURES

Soil surveys of the coastal South Carolina counties were obtained from the South Carolina Department of Natural Resources (SCDNR 2013) along with survey maps for each coastal quadrangle. These soil polygons were then merged by series to produce a continuous map of the coastal plain soils within a GIS environment (ARC-GIS 10.1).

GIS was used to create an overlay of the Colquhoun (1974) map to the present soil survey. The original map, 1:1,000,000 scale, was photocopied in page-sized blocks. These blocks were then hand colored, mosaicked, and photographed as a 35 mm slide in 1980. In 2014, the slide was scanned (1200 dpi) and converted to a digital image file. The original map included lines representing major highways present in the 1970s. A current digital road GIS layer (1:24,000) was used to georeference the image of the original map.

Long-term estimates of average water table depth and standard deviations were collected from Williams (2007) for a study site in Hobcaw Barony site near Georgetown and Williams and Amatya (2010)) for the Turkey Creek watershed at the Santee Experimental Forest. These values were placed within the soil classification matrix where the studied soil series occurred. Likewise, drainable porosity values were collected from Williams (1978) and Harder and others (2007) and again placed in the appropriate matrix block.

RESULTS

Soil surveys included a number of soil series not included on the chart presented by Stuck (1976). The original chart was modified in several ways to accommodate the additional soils. The break points in soil texture corresponded to standard soil texture names: sands < 10 percent clay, sandy loam 19-18 percent clay, sandy clay loam 18-35 percent clay, clay loam or sandy clay 35-45 percent clay, and clay > 45 percent. Changing to named categories also revealed a shortcoming of the original in that only clay content was considered. Soils with silt loam or silt sub-soils were undifferentiated from sandy loams. There are 13 current series with such subsoils, requiring an additional subsurface texture class. The original chart had only six drainage classes, yet now there are six

series that are classed as somewhat excessively drained, requiring an additional class. Also, the original very poorly drained class included both mineral and organic soils. These were separated by adding an additional very poorly drained organic class. The original chart has been modified to be an 8x8 matrix of drainage class and sub-soil texture (Fig. 1).

The classification in Figure 1 groups 194 separate soil series into 64 categories. Nineteen of those categories are blank since excessive drainage does not occur on soils with more than 18 percent clay in the subsoil, and there are relatively few organic soils or soils with sub-surface clay more than 102 cm deep.

Despite the blank cells, representing the relationships among 194 soils in 45 separate classes on a single map still presents a challenge. The key method to accomplish that was to use systematic color variation among classes. Colors were assigned to cells by hue, saturation, and value (HSV) within a Geographic Information System (GIS) polygon of symbol properties. Drainage class was designated by values with: excessive well (100), somewhat excessively (93), well (85), moderately well (77), somewhat poorly (67), poorly (54), very poorly mineral (24), very poorly organic (0). Subsoil texture was designated by hue with: clay (0)- red, clay loam-sandy clay (28) orange, sand (62)- yellow, sandy loam (68), greenish yellow, sandy clay loam >102 cm – 91- yellowish green, sandy clay loam 51-102cm- 138-green, sandy clay loam <51cm -155-blueish green, silt loam -288-purple.

Despite a large number of highway intersections and a small root mean square error of rectification, the geomorphic overlay could not be evaluated for geospatial accuracy due to the multiple distortions induced by the many manipulations of the image that we performed.

DISCUSSION

Soils and Geomorphology

By refining the drainage and sub-surface texture classification to include an extra drainage class of very poorly drained organic soils and an extra texture class to include subsoils high in silt, all soils mapped on the South Carolina Coastal plain were included in one of the 64 resulting categories (Fig. 1). Additionally, a colorization scheme using the same classification scheme that also included both hue for texture and value for drainage was incorporated in a map of South Carolina coastal plain soils (Fig. 2).

The resulting coastal plain soils map includes a number of prominent features that are similar to features of coastal terrace geomorphology. Colquhoun (1974) revised Cooke's (1936) earlier mapping of coastal terraces into 11 separate terraces (Fig. 3 insert). He also interpreted

Sub surface soil texture

Drainage Class	Sand	Sandy Loam	Sandy Clay Loam >40"	Sandy Clay Loam 20-40"	Sandy Clay Loam <20"	Silt Loam	Clay Loam or Sandy Clay	Clay
Excessively Well	Foxworth Kershaw Lakeland Cherokee Newnan Cainhoy	Frapp Candler						
Somewhat Excessively	Wakulla Alga Tarboro Eustis		Pocahontas					
Well	Wando	Conetoe Athyville Kennansville Foreston Blanton	Brogden Edwards Fuquay	Suffolk Hockley Ailey Blaney Lucy Wagram	Naboco Cowarts Norfolk Barnwell Orangeburg Dothan Kalamia Red bay Cahaba Altavista Wickham Pondera Vauluse	Riverview Nason Coconee Badin Georgeville Hawessee	Emporia Caroline Faceville Kinston Greenville Neeses Marlboro Vanna Nankin Sunsweet	Summerton Clayham
Moderately Well	Seabrook Centenary Echaw Pactoculus	Barth Bertie Tomahawk Nansmond Olanta Charleston		Bonhau Chisolm Coosaw	Goldboro Onslow Clarendon Johns Yauhannah Eunola	Cherney Craven	Angie Exum Gilead Duplin Izadora Hornesville	Namours Petersburg Wicksburg Eurens
Somewhat Poorly	Scranton Kilbuck Sewee Wetherbee	Stallings	Albany Ocilla MirandEdisto	Seagate	Andria Quitman Lynchburg Yemassee	Chewalla Jedburg Tawcaw	Augusta Uches Dunbar Wahes Nahunta	Lenoir Okatie Smithboro
Poorly	Osher Ridgeland Leon Baratan St. John's	Bibb Elmore Woodington Plummer		Orton Pellham William	Rains Winadive Tombley Myst Wadmalaw Ogeechee Younger Moulton Lumbie	Leaf	Corville Gourdin	Bladen Argent Meggett Grady Cortey Chastan Bethera Rembert McColl "Leaf"
Very Poorly	Rutledge Pickney Rosedu Dawood LynchHelen Torturita	Pocomoke Johnston Paxville Stono		Nakina Portsmouth	Partridge Deloss Hobcaw	Hyde	Santee	Cape Fear Bayboro Brookman Byars Levy(m) Capers (m) Bovick(m) Hansboro (m)
Very Poorly Organic	Pamlico Dorovan Hobonty > 90"					Ponzer		Pungo

Figure 1—South Carolina coastal soils arranged by drainage class, subsoil texture and depth of subsurface. Individual cells are colored with hues that reflect sub-surface texture and values that reflect drainage class.

coastal geomorphic features to reflect features associated with rising or falling sea level. Rising sea level features are common to the present coast of prominent barrier beach deposits, with salt marsh plains landward, and sloping offshore plains seaward. Falling sea level produced mainly erosional reworking of former rising deposits. Riverine deposits included overbank floodplain deposits, estuarine, and deltaic deposits (Fig. 3).

Sandy features are prominent as both riverine dunes (yellow on both maps) and barrier beaches (red in Fig. 3, yellow in Fig. 2). The riverine dunes are one of the few prominent features deposited during low sea level, associated with dry glacial periods (Ivester and Leigh 2003). Barrier beaches of the Talbot and Pamlico terraces are also well defined with sandy soils, although with less excessively well drained soil than the riverine dunes.

Heavy textured subsoils (orange and red in Fig. 2) tend to be associated with former salt marsh plain deposits (brown in Fig. 3) and also estuarine deposits in the inland terraces of the Pee Dee floodplain. On the Santee floodplain, similar terraces are more likely to have silt in the subsoil, although some silt is also found on the more inland Pee Dee floodplain terraces. Marsh plains are widespread in the southern coastal plain while in the

northern coastal plain marsh, plains tend to be located just east of many barrier sands, being the farthest western extent of the next lower marine terrace.

Sandy clay loam subsoils tend to be associated with former river deltas (greens on both Fig. 2&3). These are quite extensive on the oldest terraces that Colquhoun (1974) mapped. In Figure 2, these soils are also more prominent on the older terraces located between Wicomico and the sand hills. On the lower coastal plain, the most pronounced delta is south of the Santee River above the Talbot terrace. The Francis Marion National Forest (FMNF) is located on this feature and the marsh plain just to the northwest. The distribution of soils and geomorphology are comparable in the area surrounding the Turkey Creek watershed (Fig. 4).

Soils and Hydrology

The position of the water table has been shown to greatly control the hydrology of coastal forested watersheds (Elsheman and others 1994, Harder and others 2007, Williams 1979, 2007, Amatya and other 1996, Amatya and Skaggs 2001). Forest hydrology research on the lower coastal plain has been the focus of three long-term research areas; the Santee Experimental Forest, the

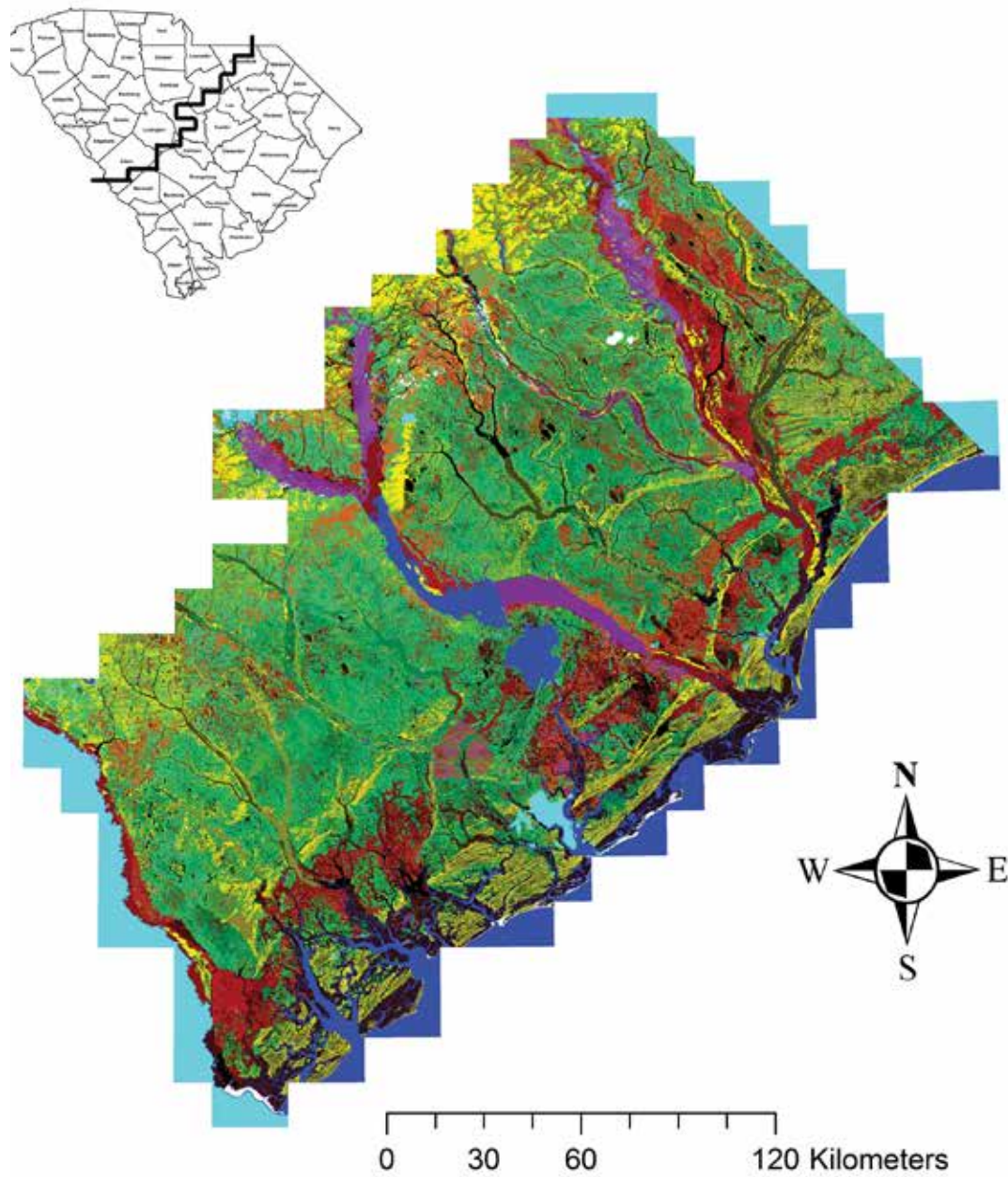


Figure 2—Map of South Carolina Coastal plain soils. Soil classes are colored to match cells in figure using soil series names.

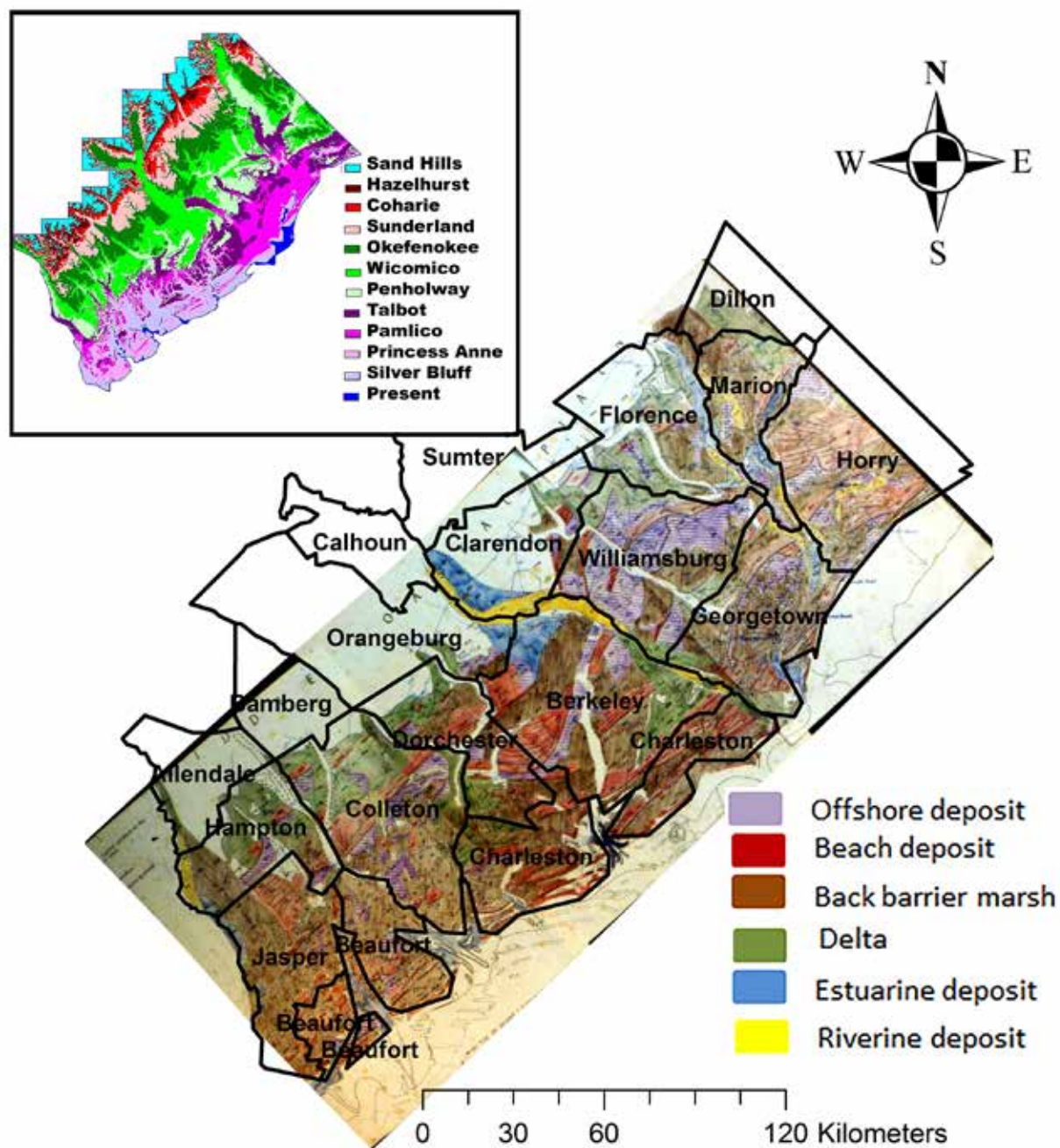


Figure 3—Geomorphic terraces of coastal South Carolina. Inset map shows position of coastal plain terraces from Cooke (1936) and Colquhoun (1974) while map represents individual features of the lower coastal terraces.

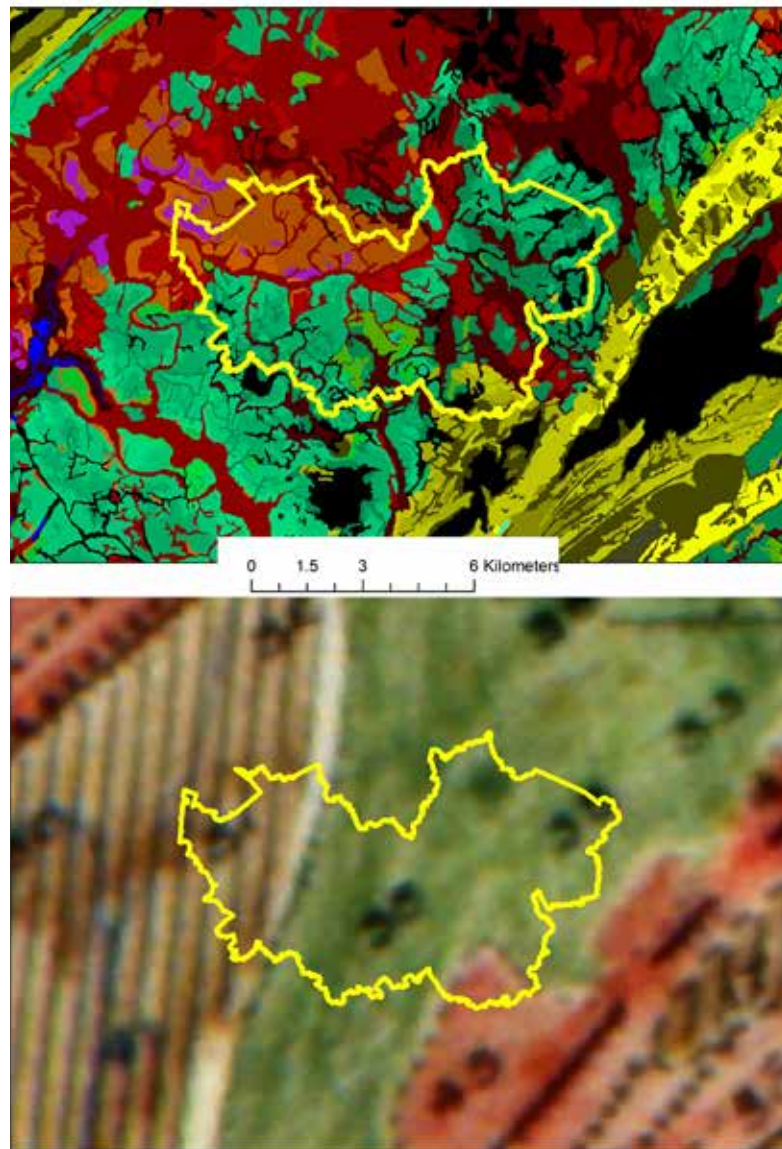


Figure 4—Map of Turkey Creek watershed outline on soils as in Figure 2 and on geomorphic features in Figure 3. Note the higher resolution of the county soil maps compared to the statewide geomorphic map.

Baruch Institute of Coastal Ecology and Forest Science in South Carolina, and the Weyerhaeuser Carteret tract in North Carolina. Long-term water table estimates only a few of the categories in Figure 1 at those sites. Average water table depths and standard deviations are given for those in Figure 5. These data tend to show that drainage class reflects average water table depth quite well, especially for similar subsoil types. Between types, there seems to be a tendency for deeper average water table depths for the same drainage class as the subsoil texture becomes heavier. As subsoil texture becomes heavier, the variance of the water table elevation increases with the coefficient of variation near 100 percent for most of the heavy textured subsoils. Since drainage class

includes both average water table and probability a soil will saturate, heavier textured soils with the similar water tables would tend to be in a wetter drainage class due to the increased variability.

Drainable porosity (the portion of soil pore space that drains with a small change in water table depth) has only been determined on five classes (Williams 1978, Harder and others 2007, Amataya and others 1996) but tend to reinforce the tendency seen in variance of the water table depth. Sandy subsoils have porosity values > 0.1 (10 percent), sandy clay loam at 0.09 (9 percent) while clay loam and clay are 0.07 (7 percent) and 0.05 (5 percent), respectively. This implies that 1 mm of rain or drainage on a sandy subsoil will change the water table

Sub surface soil texture								
Drainage Class	Sand	Sandy Loam	Sandy Clay Loam >40"	Sandy Clay Loam 20-40"	Sandy Clay Loam <20"	Silt Loam	Clay Loam or Sandy Clay	Clay
Excessively Well	209± 68							
Somewhat Excessively								
Well	93±38							
Moderately Well	90± 61			121± 84	120± 60 <u>0.093</u>			
Somewhat Poorly	56± 39			58± 50			88± 88 <u>0.070</u>	34± 35
Poorly	58± 41 <u>0.105</u>				44± 54			<u>0.050</u>
Very Poorly	44± 34 <u>0.113</u>				53±39			
Very Poorly Organic								
Long term depth to water table (cm below surface) and standard deviation Underlined numbers are soils where drainable porosity were determined.								

Figure 5—A reproduction of the cells in Figure 1, with average water table depths of soils that have data for long-term water table averages. Five cells also have data on the value of drainable porosity, that portion of total soil volume that drains with a small change in water table.

7-9 mm while 1 mm on clay subsoil will change the water table 20 mm.

Subsoil texture may also impact the processes by which runoff is produced for coastal plain watersheds. Griffin and others (2014) found runoff from watersheds with heavy textured subsoils (same as Harder and others 2007) had chemistry similar to rainwater (45-67 percent), while watersheds with sandy subsoil produced runoff with chemistry 56-61 percent similar to groundwater. They suggested that the difference was due to a faster saturation of the heavy textured subsoil. Drainable porosity values of 5 percent on the heavy textured soil would suggest less rain would be required to saturate such soils, compared to 10-11 percent for sandy subsoils.

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