10.1.2 Geomorphological and Soils Investigations at and in the Vicinity of the Gray Farm Site (7K-F-11/169), Kent County, Delaware by John Stitler

The study area lies within the Mid-Drainage Zone of the Lower Atlantic Coastal Plain physiographic province, which extends for approximately 3500 km along the East Coast of the U.S., from the New York Bight to Florida. It is the emergent extension of the shallow continental shelf which extends seaward from the shoreline to the break in slope along the outer continental shelf comprising a wedge-shaped accumulation of marine and coastal sediments produced by reworking of alluvium delivered to the coastal margin by continental rivers. The province today is characterized by low relief, with low gradient stream and river valleys shallowly incised into the planar exposed marine sediments and separated by low, rolling upland interfluves. All drainage flows east to the Delaware Bay.

The exposed Coastal Plain, which slopes very gently southeastward, records 100 million years of marine transgressions and regressions across the region. These were driven by major changes in sea level, most recently (in the Quaternary period) the result of the expansion and melting of continental glaciers. These cyclic oscillations controlled the deposition and distribution of sedimentary material on the Coastal Plain. During periods when sea level rose, the sea transgressed landward; laying down sandy marine sediments which merged near the newly established coastline into fluviomarine and coastal (bay, fluvial, and coastal swamp) deposition. When sea level fell, streams and rivers incised the newly exposed surfaces, creating canyons or gorges. Finer sediments were delivered to the coastal margin and gravels were concentrated as lag in valley bottoms.

The latest fluctuation in sea level occurred as a result of the Late Pleistocene Wisconsinan glaciation. Sequestration of atmospheric water in vast continental ice sheets resulted in a draw-down of the world's oceans. A generally accepted figure for the fall in sea level at the last glacial maximum or LGM (the height of the expansion of the glaciers) around 20,000 years BP is in the range of 100 m (Bloom 1983). This drop in base level triggered another period of incision by coastal rivers. With the wasting of the ice sheets in the terminal Pleistocene, sea level began a rebound which continues to this day.

One notable result of sea level rise throughout the Holocene was that coastal rivers underwent a change in valley form and channel morphology. When sea level was low, rivers on the continental margin extended their valleys across the expanded coastal plain. Rising sea level completely submerged the lower reaches of these valleys. The valley reaches along the newly reestablished coastline gradually became drowned valleys, embayments such as the Delaware Bay, Chesapeake Bay, and Raritan Bay. Slightly further upstream in both the trunk streams (e.g., the Delaware River) and tributaries (e.g., the Murderkill River) the rise in base level reduced river gradient, resulting in increased alluvial deposition and valley floor aggradation. The streams and their tributaries, which almost certainly were characterized by straight channels occupying the narrow floors of "V" shaped valleys at the LGM, took on more meandering forms. With continued sea level rise in the later Holocene, the lowest reaches of the river valleys became estuarine settings, with saline tidal marshes near the coastal margin and brackish marshes further upstream.

Surficial deposits of the study area belong to the Scotts Corners Formation, which, along with the older Lynch Heights Formation, makes up the Delaware Bay Group (Ramsey 2007). Ramsey interprets the sediments of the Scotts Corners formation to be of fluviomarine origin, deposited in beach, bay, estuarine channel, and coastal marsh settings (Ramsey 2007), laid down on the margin of an ancestral Delaware Bay during a late Pleistocene (pre-Wisconsinan) marine transgression (Ramsey 1997). The Scotts Corners deposits are relatively thin (15-25') (Ramsey 1997) deposits, largely made up of coarse to fine sand, gravelly sand, and pebble gravel with rare discontinuous beds of organic-rich clayey silt, clayey silt lacking organics, and pebble gravel. The Scotts Corner Formation profile is frequently capped by one to two feet of silt to fine sandy silt (Ramsey 2007). The older, underlying Lynch Heights Formation consists of light yellowish and light reddish brown to gray medium, quartz sand with discontinuous beds of fine to very fine silty sand, reddish brown to brown clayey silt, and organic-rich clayey silt to silty sand. Lesser amounts of medium to coarse pebbly sand with scattered cobbles and coarse to granule sand also are present. The unit is up to 50 feet thick and thins from east to west (Ramsey 1997).

At the study area and to the east, the Delaware Bay Group sediments are underlain by the coarse sand to fine silty sand of the Middle to Upper Miocene Choptank Formation (Ramsey 2007). Further to the west, both the Scotts Corners and Lynch Heights Formations overlie the Columbia Formation - light reddish brown to white, cross-bedded, medium to coarse sand with scattered thin beds of pebbles and gravel. Some discontinuous, thin beds of reddish brown clayey silt and medium to fine sand are present as well as rare beds of greenish gray clayey silt to silty very fine sand. It ranges from only a few feet thick where it is truncated by the overlying Lynch Heights Formation to about 80 feet thick west of Milford where it is the surficial unit (Ramsey, 1997).

In describing an exposure of the Columbia Formation at a privately owned borrow pit, Ramsey reports that pebbles and thin beds of gravel are found at the base of cut-and-fill structures, with some of the pebble layers traceable for lateral distances of a hundred feet or more. A few cobbles, with long axes less than a foot in length, were also found in the exposure. Lithology of the pebbles was dominated by quartz and chert (Ramsey 1997). Both the Lynch Heights and Scotts Corners Formations contain cobbles and gravel reworked from the Columbia Formation (Ramsey 2011, pers. com.) and in both of these formations – as in the Columbia Formation – these clasts are available for human exploitation as lag deposits in stream channel and in stream cutbanks.

Soils of the study area are mapped by the USDA-NRCS as the Downer series (DoA and DoB) (Soil Survey Staff 2011), formed in fluviomarine deposits – sediments laid down in a near-shore marine setting and reworked by coastal currents. The soils of the series are very deep and well drained and are mapped on broad interfluves and sideslopes. A typical profile in a cultivated setting consists of an Ap/BA/Bt/C sequence. In an undisturbed setting, a typical profile consists of an A/E/Bh/BA/Bt/C sequence; the A/E/Bh sequence typically has a total thickness of 15 cm. Texture of the A or Ap, BA, Bh, and Bt horizons is typically loamy sand to sandy loam. The E horizon (if present) and C horizon may range from sand to sandy loam. (All descriptions from Soil Survey Staff 2011). It should be noted that the soils of the study area were formerly mapped as the Sassafras series but were reassigned to the Downer series in 2006 as a part of digitization and revision of the Kent County soils databank (King personal communication 2011).

The Site 7K-F-11 APE is located immediately north of the confluence of the Murderkill River and a major tributary, Spring Creek. The setting is the southwest-facing lower slope of a low, rolling upland, bounded on the east by SR 1, on the west by SR 12, and on the south by the lowest reach of Spring Creek. The village of Frederica is located just to the southwest across Spring Creek. Most of the upland is under tillage, as was the APE until commencement of archaeological fieldwork. Elevations at the APE range from 1.5 meters above mean sea level (m amsl) to 4 m amsl. The summit of the upland, 900 m northeast of the APE, lies at an elevation of 9 m amsl.

The Murderkill River, a fourth-order stream, originates 14 km west of Site 7K-F-11 and along with its tributary Spring Creek drains about 200 km^2 upstream from the site. The debouchure of the Murderkill River at Bowers Beach lies 8 km to the northeast. The drainage basins of both the main stem of the Murderkill River and Spring Creek extend into areas where the Columbia and Lynch Heights Formations constitute the surficial formations and channels there are incised into these deposits.

A spring-fed first-order stream originates on the upland 400 m north of the site and follows a course along the western edge of SR 12, 75-100 m west of the APE, to a confluence with Spring Creek. The stream originates at an historic farmstead (7K-F-169), where a shallow excavation at the source created a small farm pond.

Both the Murderkill River and Spring Creek are tidally influenced to a point just upstream from the APE (US EPA 2005) and tidal marshes line the channels of both streams near Site 7K-F-11. Adjacent to the site, a band of phragmites (Phragmites australis) 25-30 m wide occupies the riparian zone between the Spring Creek channel and the cultivated toe of the upland. At the site, there is no pronounced topographic break between the toe of the upland and the channel edge, with the exception of a slight step of 20-30 cm at 20 m north of the channel, within the phragmites. As in many East Coast tidal and estuarine marshes, the stand of phragmites is essentially monocultural, with few or no other plant species present. Recent research (e.g., Saltonstall 2002) indicates that while phragmites are probably native to coastal North America, the aggressively invasive nature exhibited by phragmites in modern estuaries may have been enhanced by the introduction of genetic stock from Europe. This suggests that the pre-contact Late Holocene tidal marsh may have supported a more diverse plant community than seen at present. Custer has described the interface of saltwater and freshwater biomes on rivers such as the Murderkill and St. Jones as one of the most highly productive environmental settings in central Delaware during the Middle Holocene, with dependable water and estuarine resources that made it a setting that was "richer, and perhaps more attractive, than any surrounding areas" (Custer 1989:223-224).

Episodes of aeolian erosion and transport on the Delmarva Peninsula appear to have taken place several times during the Late Pleistocene and the Holocene. Much evidence suggests that there was extensive wind erosion at around the time of the last glacial maximum, when cold and dry climatic conditions resulted in decreased vegetative cover south of the glacial boundary. Stolt and Rabenhorst have concluded that the bay basins formed as a result of wind erosion in the period from 20,000 to 15,000 years BP (Stolt and Rabenhorst 1987a, 1987b). Markewich et al. have defined at least three time periods between 32,000 and 15,000 BP when dune formation by

prevailing northwest winds took place both east and west of the Chesapeake Bay, citing exposed floodplain surfaces as the source areas (Markewich et al. 2009). Lowery and colleagues have identified two episodes of loess deposition on the western Delmarva peninsula at 41,000-25,000 BP and at in the terminal Pleistocene at ca. 12,700 – 11,500 BP, with an intervening period of erosion between 18,000 and 12,800 BP (Lowery et al. 2010). In research at an upland bay basin setting 20 km north of Site 7K-F-11, Daniels found evidence of aeolian deposition associated with the last glacial maximum (prior to 21,000 BP) (Daniels 1995). Daniels identified a later episode of aeolian deposition of fine to medium sand which he associated with a period of severe drought from 8800-5680 BP, occurring within a prolonged period of drying from 10,300 to 2800 BP (Daniels 1995). Daniels finds evidence for increased environmental moisture regionally after 2800 BP.

It seems highly likely that sediment of aeolian origin has been incorporated into soil profiles in and around the APE. Presence of shallow closed depressions on uplands 2.0-2.5 km north of the APE along the north side of Barratts Chapel Road, 2.5 km due west of the APE along the north side of SR 12, 1.5 km southeast of the APE, and 3.0-3.2 km southwest of the APE within the Burton-Derrickson State Nature Preserve suggests that wind transport has taken place locally. These topographic features – commonly called bay basins, bay/basins, or blowouts – are widely, although not universally, regarded by researchers to be products of wind erosion. No bay basins are present within or immediately adjacent to the APE. The great majority of the shallow depressions within 2-3 km of the APE are under tillage and, although standing water may be present periodically in the wettest seasons of the year, water is not perennially present. Further evidence of localized wind transport of sediment is offered by the presence of a large area mapped as the Runclint soil series – formed in aeolian parent material – located on a sideslope 700-800 m NNW of the APE (Soil Survey Staff 2011), immediately southeast of a long southeast-trending reach of the Spring Creek valley.

Hayes, in a study conducted for a Phase I archaeological investigation of Site 7K-F-11, suggests that some fine sandy to silty aeolian sediment is present throughout much of this area, varying in thickness (Hayes 2004). For the most part, this was a thin cap of material laid down over the older fluviomarine sediments and has now been mechanically admixed into the plow zone. However, Hayes noted the presence of pebble-free silty sand forming as much as 60 cm of the upper profile in several locations – in contrast to many profiles containing gravel throughout – and conjectured that while "(w)eathering process associated with soil formation had masked obvious sedimentary structures that could help distinguish water- from wind-transported sediments, (…) the lack of pebbles within the matrice and apparent dominance of very fine sand suggest possible eolian deposition" (Hayes 2004). The implication would seem to be that this is material that formed low dunes or accumulated in shallow swales in a thickness that exceeds plowing depth, though Hayes does not specifically state this. If so – because the periods of aeolian deposition identified by various researchers overlap with the time frame in which humans have occupied the region – this would allow for the potential presence of stratified burial of cultural artifacts within the aeolian material. Hayes observed that while "the age and depositional mode responsible for these near-surface fines is not clear, they were noted to occasionally include Holocene-age, prehistoric archaeological materials in subplowzone context, while within gravel-rich portions of the project area most archaeological materials (historic and prehistoric) were recovered from in and near disturbed surface (plowzone) context. Altogether,

characteristics of both the archaeological assemblage and surrounding matrices, within a relative subsurface context, in an area where eolian activity apparently occurred, demonstrate an unresolved potential within sections of the project area for the preservation of archaeological site components within a buried and possibly stratified context (Hayes 2004).

Soil profiles examined in archaeological excavation units (EUs), shovel test pits (STPs) and bucket auger probes (APs) were generally consistent throughout the APE, largely consisting of an Ap/E/Bt/BC/C sequence formed in a single fining-upward sequence 60-100 cm thick. In some profiles, no E horizon was described, presumably having been subsumed into the Ap horizon. In a few profiles, two Bt horizons (Bt1 and Bt2) were described, the Bt2 horizon being distinguished from the Bt1 by a slightly lower clay content in the Bt2. In all of the Bt horizons, the illuviated clay was manifested as thin clay films on individual sand grains and as clay bridges between sand grains. In some profiles, a Bw horizon was described between the Bt and BC horizons. In these cases, pedologic development and accumulation of iron oxides in the lower profile had proceeded to a degree somewhat greater than the minimal development of a BC horizon but the degree of clay accumulation did not justify labeling the zone a Bt horizon. In many excavation profiles there was a visually apparent zone of accumulation of iron oxide at the boundary of the BC and C horizons. This accumulation, probably due at least in part to the perching of infiltrating soil water at a textural boundary, produced a distinctly red band 1-7 cm thick and resulted in varying degrees of cementation of the medium to coarse sand at the boundary. Excavation into the C horizon in some locations revealed that this band was the uppermost and most strongly expressed of several lamellae.

Soil column samples were taken at several locations at the site, both within features and in areas determined to be relatively undisturbed. Column samples were generally taken at either 5 cm or 10 cm increments over the depth of the profile or were taken as representative samples from each identified horizon. Selected samples were submitted to Cornell Nutrient Analysis Laboratory, Cornell University, Ithaca, New York, for soil particle size (pipette method) and chemical analysis (extractable P and NO3, K, Ca, Mg, Fe, Mn, Al, pH, and organic matter content – loss on ignition method).

A series of bucket auger probes was excavated perpendicular to Spring Creek at the south end of the APE. The probes, placed along the project's E530 grid line, were conducted to examine the extent to which the profile in that area had been accreted by slopewash from the upland or by overbank alluvium from Spring Creek. AP1 and AP2 were conducted on March 25, 2009. AP1 was conducted at N510 E530, approximately 30 m south of the APE boundary. The profile was much as described for the site in general, consisting of an Ap/Bt/BC/C sequence. The Ap and Bt horizons – to an overall depth of 50 cm bs – were formed in sandy loam containing a small amount of rounded gravel. The BC horizon – 50 to 65 cm bs – was coarse sandy loam to loamy sand. The surface of the gravelly coarse sand C horizon was at 65 cm bs; water began entering the hole at that depth. AP2 was located 10 m south of AP1 (at N500 E530) and 2-3 m north of the edge of the phragmites bordering the channel. The profile was largely as described for AP1, with the surface of the gravelly coarse sand C horizon at 50 cm bs. Water began entering the hole at the BC/C boundary.

AP5-5-1 (conducted 5/5/09) was located 10 m south of AP2, within the phragmites and approximately 20 m from the channel. At 1 m south of AP5-5-1 is a 20-30 cm step to a slightly lower surface which was largely covered by shallow standing water when AP5-5-1 was excavated. The profile was much as described for the site in general, though somewhat reduced because of frequent saturation, and consisted of an Ap/Bt1/Bt2/C sequence. The Bt2 horizon, from 40 to 75 cm bs, contained more clay than generally seen throughout the site. Both the Bt1 and Bt2 horizons contained a small amount of rounded quartz gravel. The C horizon, from 75 cm bs to base of excavation at 180 cm bs, was coarse sand containing varying amounts of rounded gravel.

AP7-1-1 (conducted 7/1/09) was located 4 m south of AP5-5-1, on the slightly lower surface. The profile was much as seen throughout the site but was heavily reduced, consisting of an A/Bg/Btg1/Btg2/C sequence to base of excavation at 80 cm bs. The A horizon (0-20 cm bs) was silt loam containing 25-30% phragmites roots and organic matter. A small amount of rounded gravel was also present. The Bg horizon (20-30 cm bs) was gleyed sandy loam. The Btg1 and Btg2 horizons, to an overall depth of 60 cm bs, were formed in gleyed sandy clay loam showing little soil structure and containing a small amount of rounded gravel. The C horizon (60 cm bs to base of excavation at 80 cm bs) was gravelly loamy coarse sand showing less reduction than the upper horizons. Water stood at 15 cm bs after 5 minutes.

AP7-1-2 was located 8 m south of AP7-1-1 and 8 m north of the channel. The profile consisted of an A/BCg/Cg sequence to base of excavation at 100 cm bs. The A horizon (0-33 cm bs) was heavily reduced silt loam containing 30-40% phragmites roots and organic matter. The BCg horizon, from 33 to 65 cm bs, was sandy loam containing a small amount of rounded gravel and showing little pedologic development. The Cg horizon was gleyed loamy sand containing rounded gravel. Water was present at 25-30 cm bs during excavation of the probe.

The profiles seen in the transect of auger probes indicated that there has been little if any accumulation of overbank alluvium or slopewash in the APE either over the course of the Holocene or within the Historic period. Depth to the unweathered, gravel-rich C horizon was similar throughout the APE and between the APE and the Spring Creek channel. The plow zone at the base of the slope, which is also proximal to the Spring Creek channel, showed no evidence of sediment accretion, nor does the area now vegetated in phragmites bordering the channel.

Over 300 subsurface features were identified at the site and investigated by A&HC archaeologists. Among these were a number of large (1.0-3.0 m in each dimension in plan view), round to ovoid stains revealed at the Ap/subsurface boundary after stripping of the plow zone. Bisection and excavation of these features revealed large pits that in many cases were characterized in profile by one steeply sloping side and one rounded or more gently sloping side. In a number of instances, a dark linear stain with a tapering form extended for a short distance from one side of the oval stain. These appendages extended 30 to 60 cm from the oval stain and were generally 15 to 30 cm wide, tapering at the distal end. In each case, the linear stain originated on the side of the oval exhibiting a more rounded profile. The profiles of these appended stains were shallow, extending 2 to 8 cm into the upper subsoil and were deepest on the proximal end, adjacent to the oval stain. The fill in the pits generally exhibited zonal differentiation of color in both plan and profile view; the extent of the expression of these

discrete zones varied from feature to feature. The most common manifestation was the presence of bands (usually crescent-shaped in plan view) of dark, organic-enriched A horizon soil material along two sides of the oval stain, generally bordered by an area of pale, bleached soil (E or EB horizon material). In many of the large features, an area of gravelly medium to coarse sand C horizon material was present adjacent to the bleached E horizon material.

In a few of the large pit features, cross-sectioning revealed vertical stratigraphy that strongly suggested, on visual examination, the A/E/Bt/C horizontal stratigraphy of the site rotated 90° (Photographs 1 and 2). Two pairs of soil sample columns were taken to test the hypothesis, developed in the field, that at least some of the larger features were formed by rotation of a section of soil column. Each pair consisted of one column of samples taken horizontally from the profile produced by bisection of a feature which visually suggests a rotated (Features 344 and 187/305) and a second vertical control column taken nearby from what was assessed to be an undisturbed E/EB/Bt/C sequence. In each of the features, samples were taken at contiguous 5 cm increments in a 70 cm horizontal column; the upper limit of each sample was 5 cm below the stripped surface and the lower limit was 25 cm below the stripped surface. The vertical control columns were taken immediately north of each feature. Seven to ten samples were taken in contiguous 5 cm increments constituting columns that included all horizons.

Results of soil particle size analysis, presented in Table 1, show a strong correlation in particle size distribution between the two sample and control columns. Most telling in each pairing is the clay content. As would be expected, clay content is low in the eluviated E horizon of the control columns and increases markedly in the Bt horizon – where clay transported from the E horizon has accumulated – only to fall away to very low levels in the unweathered C horizon. The same pattern is seen in the horizontal sample columns. Also notable is the sharp increase in the coarse sand content in the control C horizons, mirrored in the feature sample columns. Soil chemical analysis was also conducted on the columns. Results of the chemical analysis show less correlation between the control and sample columns (Table 2). This is to be expected, particularly in the case of cations (e.g. Ca, K, Mg) and elements such as iron. These are easily mobilized and transported downward in the soil profile, particularly in sandy soils, and weathering in the period since the profile was rotated has redistributed these elements. Weathering and infiltrating soil water would be far less likely to alter particle size distribution than to alter soil chemistry.

Based on physical appearance and the results of soil particle size analysis, the vast majority of the large features characterized by banded fill and a dark appendage are interpreted to have been formed by tree throws – the uprooting of trees by strong winds, the weight of ice and snow, or a combination of these forces, possibly in conjunction with saturated soil conditions. Where a zone of dark A horizon soil was present adjacent to the sandy C horizon soil, opposite the dark appendage, it is interpreted to have formed in organic material that accumulated in the open pit at the base of the rotated root mass shortly after the tree had fallen. Uprooting of modern trees by natural forces generally produces a shallower area of disturbance than seen in the features at Site 7K-F-11. However, uprooting of these relatively small third and fourth growth trees do not necessarily provide a valid analog for the effects created by the uprooting of very large, old-growth timber.

Photograph 1. Feature 187-305, Profile showing soil horizons.

Photograph 2. Feature 344, Profile showing soil horizons and soil column samples.

Table 1
Soil Particle Size

Sample ID	Provenience Horizon	Depth (cm)	Very Coarse Sand (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Very Fine Sand (%)	TOTAL Sand (%)	TOTAL Silt (%)	TOTAL Clay (%)	Computed Texture*
F 344 control column											
1	E	5-10	5.1	26.3	19.9	10.1	1.9	63.4	30.0	6.6	CoSL
2	E	10-15	6.0	26.0	19.2	9.6	1.9	62.6	30.8	6.5	CoSL
3	E/B	15-20	4.9	25.5	19.7	9.9	1.8	61.7	29.2	9.1	CoSL
4	E/B/Bt	20-25	6.7	26.6	18.3	8.6	2.0	61.8	26.1	12.2	CoSL
5	Bt	25-30	4.3	24.2	20.0	9.8	1.6	59.9	25.6	14.4	CoSL
6	Bt	30-35	5.7	26.9	20.8	10.0	1.5	64.9	19.7	15.4	CoSL
7	Bt/BC	35-40	5.5	28.1	21.4	11.6	1.8	68.3	16.9	14.8	CoSL
8	BC	40-45	10.7	36.8	22.9	10.2	1.0	81.6	9.3	9.1	CoSL
9	BC	45-50	10.1	37.9	24.5	11.8	1.3	85.7	6.6	7.7	CoSL
10	C	50-55	12.2	36.6	24.5	13.7	1.8	88.7	5.2	6.1	CoSL
F 344 sample column											
11	E	180-185	7.5	29.6	20.6	10.3	1.8	69.8	24.6	5.6	CoSL
12	E	185-190	6.3	28.3	20.5	10.6	2.1	67.7	26.3	5.9	CoSL
13	E	195-200	5.0	26.2	21.0	11.2	2.2	65.6	27.9	6.5	CoSL
14	E	200-205	6.3	28.5	20.7	10.2	1.9	67.6	25.7	6.7	CoSL
15	EB	205-210	6.2	27.8	20.5	10.1	1.9	66.4	24.2	9.3	CoSL
16	EB	210-215	7.1	28.5	21.7	10.3	1.8	69.5	18.6	12.0	CoSL
17	Bt	215-220	8.3	31.1	21.4	9.6	1.4	71.8	15.4	12.8	CoSL
18	Bt	220-225	6.8	31.4	22.5	11.2	1.5	73.4	12.4	14.2	CoSL
19	Bt/BC	225-230	8.5	32.9	23.8	11.7	1.4	78.3	8.5	13.2	CoSL
20	BC	230-235	11.1	36.1	24.0	11.6	1.2	84.0	6.2	9.8	CoSL
21	C	240-245	12.9	34.2	23.4	15.7	2.6	88.8	5.3	5.9	CoSL
F 256 sample column											
22	AE	230-235	4.7	23.9	19.9	10.6	2.2	61.3	31.7	7.0	CoSL
23	E	240-245	4.8	22.5	20.3	10.9	2.4	60.8	32.0	7.2	CoSL
24	E	250-255	4.4	21.9	20.4	10.8	2.6	60.0	31.8	8.2	CoSL
25	EB	260-265	4.1	20.6	18.8	9.8	2.5	55.8	32.3	11.8	SL
26	EB/Bt	270-275	4.0	20.9	17.9	8.9	2.0	53.7	29.8	16.5	SL
27	Bt	285-290	3.8	22.1	21.1	11.3	2.0	60.3	20.8	18.9	CoSL
28	Bt	290-295	5.2	23.7	23.4	15.1	2.6	69.9	14.0	16.1	CoSL
29	C	310-315	22.9	33.8	24.1	11.4	0.7	92.8	3.3	3.9	CoSL
F 256 control column											
30	E	5-10	4.7	23.7	21.8	12.0	2.5	64.7	29.6	5.8	CoSL
31	E	15-20	4.1	24.2	23.1	11.3	2.1	64.9	30.0	5.1	CoSL
32	EB	25-30	4.5	24.0	24.0	11.7	2.0	66.2	26.3	7.5	CoSL
33	EB	30-35	5.3	28.2	24.3	10.6	1.5	69.9	18.7	11.4	CoSL
34	Bt	40-45	7.0	29.9	26.1	11.7	1.3	75.9	9.8	14.3	CoSL
35	Bt	45-50	7.1	28.0	26.4	14.3	1.6	77.3	8.9	13.8	CoSL
36	C	55-60	22.3	35.2	19.9	13.7	1.1	92.2	2.8	4.9	CoSL

* CoSL = Coarse Sandy Loam
SL = Sandy Loam

Table 2
Soil Chemistry Analysis

Provenience		Phosphorus	Calcium	Iron	Magnesium	Organic Matter	Total Carbon
Horizon	Depth (cm)	lb/Ac	lb/Ac	lb/Ac	lb/Ac	%	%
F 344 control column							
E	5-10	2	360	3	65	0.6	0.26
E	10-15	1	370	3	75	0.4	0.18
EB	15-20	<det	660	4	125	0.7	0.19
EB/Bt	20-25	<det	890	4	175	0.9	0.21
Bt	25-30	<det	1140	4	245	0.9	0.2
Bt	30-35	<det	1170	3	275	1	0.14
Bt/BC	35-40	<det	1070	3	265	0.8	0.11
BC	40-45	<det	800	2	180	0.4	0.1
BC	45-50	1	720	2	160	0.4	0.08
C	50-55	1	510	1	105	0.3	0.02
F 344 sample column							
E	180-185	7	380	3	45	0.6	0.2
E	185-190	4	280	4	35	0.4	0.2
E	195-200	4	310	4	40	0.4	0.13
E	200-205	1	370	2	55	0.4	0.08
EB	205-210	1	560	2	85	0.6	0.29
EB	210-215	<det	750	2	125	0.7	0.16
Bt	215-220	<det	750	3	150	0.7	0.16
Bt	220-225	<det	670	2	150	0.8	0.13
Bt/BC	225-230	<det	1470	6	200	0.7	0.1
BC	230-235	1	1040	4	140	0.6	0.14
C	240-245	3	680	4	75	0.4	0.07
F 256 sample column							
AE	230-235	5	1530	5	110	1.1	0.56
E	240-245	3	1030	4	90	0.8	0.31
E	250-255	2	760	2	65	0.6	0.14
EB	260-265	<det	1460	3	125	0.9	0.2
EB/Bt	270-275	<det	2220	4	235	1.2	0.16
Bt	285-290	<det	2570	3	275	1.2	0.15
Bt	290-295	<det	2000	4	255	0.9	0.11
C	310-315	2	600	1	65	0.1	0.08
F 256 control column							
E	5-10	3	900	2	105	0.7	0.27
E	15-20	2	740	1	90	0.5	0.14
EB	25-30	<det	900	3	115	0.5	0.08
EB	30-35	<det	1380	3	195	0.7	0.14
Bt	40-45	<det	1670	3	260	0.9	0.15
Bt	45-50	<det	1520	3	230	0.8	0.13
C	55-60	2	660	2	85	0.2	0.04

If the features were created by human agency as large pits and then backfilled either by humans or by natural processes, it is extremely unlikely that the infilling would manifest the horizontal stratigraphy seen in the features. Nor would infilling by either of these methods produce the lateral increase and decrease in clay content and abrupt increase in coarse sand content in the horizontal columns that so closely mirrors that seen in the vertical control columns. The narrow dark appendage characteristic as a part of many of these features is interpreted to mark the former presence of the lowest part of the fallen tree trunk. In part, the stain may be a result of the abundance of organic matter (the large, old-growth tree bole) in direct contact with the soil, with some organic matter incorporated into the upper subsurface by invertebrates. In some cases, the base of the tree bole may have physically intruded into the subsurface by "plowing" as the bole and root mass slid backward into the open pit produced by the uprooting.

Presence of prehistoric artifacts in the fill of some of these features might be explained in several ways. Artifacts present on the ground surface near the tree at the time the tree fell would easily be transported down into the subsurface. Alternatively, it is by no means improbable that Native Americans might make use of the pit produced by the tree-throw (e.g., for refuse disposal) and that artifacts might thus become incorporated into the subsurface.

A collateral effect of sea level rise and a decrease in coastal river base level such as occurred with glacial recession in the Late Pleistocene is a rise in level of shallow groundwater in coastal areas, particularly in areas bordering the affected rivers. At least two effects – one cultural and one environmental – can potentially be ascribed to a rise in elevation of the local groundwater over the course of the Holocene at the Site 7K-F-11 site. The clearest of these is an effect on the depth to which subsurface features might practically be excavated without the danger of groundwater intrusion. In the course of the 2009 archaeological excavation at the site, some of the deeper subsurface features were found to intrude into the local groundwater table. While this was most pronounced in spring of the year, deeper features were found to intrude into the local groundwater table, even during the driest part of the year.

The second potential effect of a rise in groundwater levels is a decrease in the effective rooting depth of trees in the affected area. While some tree species (e.g., willow, red maple, sweetgum, some species of birch, etc.) are hydrophitic and capable of surviving in areas of high water table, prolonged periods of soil saturation damage or destroy root systems in species not adapted to these conditions. Trees in an area subjected to rapid water table rise may be damaged and weakened; unadapted species growing in an area of high water table may survive for some time but suffer from restricted depth of rooting and be prone to toppling by wind, snow, ice, etc.

In modeling the effect of sea level rise on groundwater elevation in sandy soils adjacent to a tidally-influenced river – comparable to the setting of the Site 7K-F-11 APE – Masterson and Garabedian postulate a rise of 17 cm in the elevation of the fresh groundwater surface in response to a 32 cm rise in sea level (Masterson and Garabedian 2007). The modeling additionally indicated that the subsurface lens of fresh groundwater would thin as denser underlying saline water rose beneath it, at least in part because groundwater discharge to the adjacent stream would increase. According to a reconstruction by Kraft, sea level in the Delaware Bay has risen approximately 6 m over the last 5000 years (Kraft 1976). This rise has

almost certainly not taken place in a smooth fashion and some researchers have found evidence of a Late Holocene acceleration in the rate of rise (e.g., Fletcher et al. 1993; John and Pizzuto 1995), beginning around 1800-2000 BP.

As part of fieldwork for a doctoral dissertation, Yi extracted and analyzed a soil core from the estuarine marsh that flanks the Spring Creek channel (Yi 1992). The core, extracted at a point approximately 90 m west of the current study area, extended to 4 m below surface. According to Yi's interpretation, pre-Holocene gravelly sand was encountered at 3 m bs. Apart from a thin (13 cm) stratum identified as fluvial sand at 247 to 260 cm bs, the overlying sediments are identified by Yi as stratified organic-rich freshwater marsh and "mudflat" deposits. The base of the core, between 260 and 300 cm bs, is characterized by Yi as soft, water-saturated clay ("mudflat" deposition).

Dr. Kelvin Ramsey, of the Delaware Geological Survey, has stated that he has reviewed and concurs with Yi's interpretation of a Holocene depositional boundary at 3 m bs and has stated that in an examination of soil core borings from along the Murderkill River floodplain downstream from the current study area he has identified the lower boundary of Holocene deposition at around 13 m bs (Ramsey, personal communication 2011). Taken together, these data support the reconstruction proposed above of a deeply incised Late Pleistocene Murderkill River valley characterized by a much higher gradient than is the case today and suggest a 3-4 m rise in river level adjacent to the current study area over the course of the Holocene. The dearth of silty or sandy alluvium and lack of a clearly defined fining-upward character in Yi's core suggests a rapid transition from a setting that was adjacent to an incised channel and received little overbank deposition to a marshy setting subject to frequent or constant inundation. This in turn suggests that much of the rise in the mean low water level on the Murderkill and Spring Creek – and resultant rise in the local shallow groundwater table – probably took place in the Late Holocene.

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