Stream Origin Assessment
South Creek, NC (PCS Phosphate Company)
NC Division of Water Quality
December 7, 2006

The Division of Water Quality (DWQ) and North Carolina State University (NCSU), in association with a North Carolina Department of Transportation (NCDOT) initiated a project in early 2004 to map intermittent and perennial streams and origins (IPSO) across the state. The project consists of gathering detailed field sample data with respect to stream origins and generating predictive models to estimate landscape controls on origin locations. As part of an effort to gain additional knowledge about stream origins, effort beyond the official stream project is continually conducted as stream origin data becomes available from various sources in North Carolina. In 2005, CZR Incorporated, by request from PCS Phosphate Company, field mapped intermittent and perennial streams in the South Creek region of PCS Phosphate Company land on the outer coast plain as part of the 404 permitting process. These data were used to assess stream origin characteristics in the South Creek area.

Stream origins in North Carolina are affected by multiple natural and anthropogenic characteristics. The complete analysis of these characteristics is being researched and documented within the stream mapping project framework. The goal of this assessment is to review a subset of stream origin related factors for potential use in management applications. Soil, slope, current contributing drainage area and historic contributing drainage area were evaluated with respect to stream origins in the PCS Phosphate study area.

Study Area

The mapping area includes streams draining to South Creek, a tributary to the Pamlico River near Aurora, NC (Figure 1) in Beaufort County. This area is located in Level III EPA Ecoregion Middle Atlantic Coastal Plain (63) and Level IV Chesapeake-Pamlico lowlands and tidal marsh (63b)(Griffith et al. 2002) South Creek and its tributaries are underlain by Quaternary marine fluvial, aeolian and lacustrine deposits consisting of sand, clay, gravel and peat. Relief is extremely low relative to the rest of North Carolina and stream gradients are typically less than 0.5 %. As in most coastal areas of North Carolina, ditching to redirect drainage is common around South Creek and has existed in the 200 years since European settlement. In response to ditching, it is likely that stream origins and flow regimes have adapted to changing drainage patterns.

Methods

Stream Identification

CZR, Inc. conducted stream identification and flow duration delineation using the DWQ methodology described in the Stream Identification Manual version 3.1 (2005). This methodology was originally developed by DWQ, NCSU along with other agency and private industry personnel, and was implemented as state policy in 1998. The upper and lower limits of

streams were verified on site by regulatory representatives from the US Army Corps of Engineers and the NC Division of Water Quality. Once identified, all streams were professionally surveyed by licensed surveyors (Figure 2). Data were processed in CAD and ARCMAP.

Additional Data

Digital soil maps (Figure 3) were obtained from the North Carolina State University (NCSU) GIS library (Soil Survey of Beaufort County 1995) and the 20ft Digital Elevation Model (DEM) was downloaded from the North Carolina Flood Mapping Program (NCFM) Server. Hancock and Evans (2006) determined that a minimum grid size of 10X10 meters is needed to accurately assess channel origins. The 20-ft grid used in these analyses is equivalent to a 6.5 meter grid and so is within the range of acceptable grid size. Additionally, CZR, Inc. personnel estimated historic (pre-ditching) watershed boundaries using soil and topography maps (Figure 4). Historic watersheds were digitized and delivered to DWQ as an ARC shape file. Initially, ARC Hydro was used to delineate the current contributing watershed area upstream of origins. These areas were estimated based on flow accumulation generated using the NCFM 20ft DEM. However, the results of the ARC application proved unreliable due to the extensive ditching network. Contours were then generated from the DEM and current contributing area was estimated by 'heads up' digitizing directly on the computer screen using an ARC script to calculate area. Slopes were estimated in ARC MAP based on the DEM and the local slope upstream of the origin was estimated for analysis. Data are shown in Appendix 1.

South Creek Study Area
Beaufort County, NC

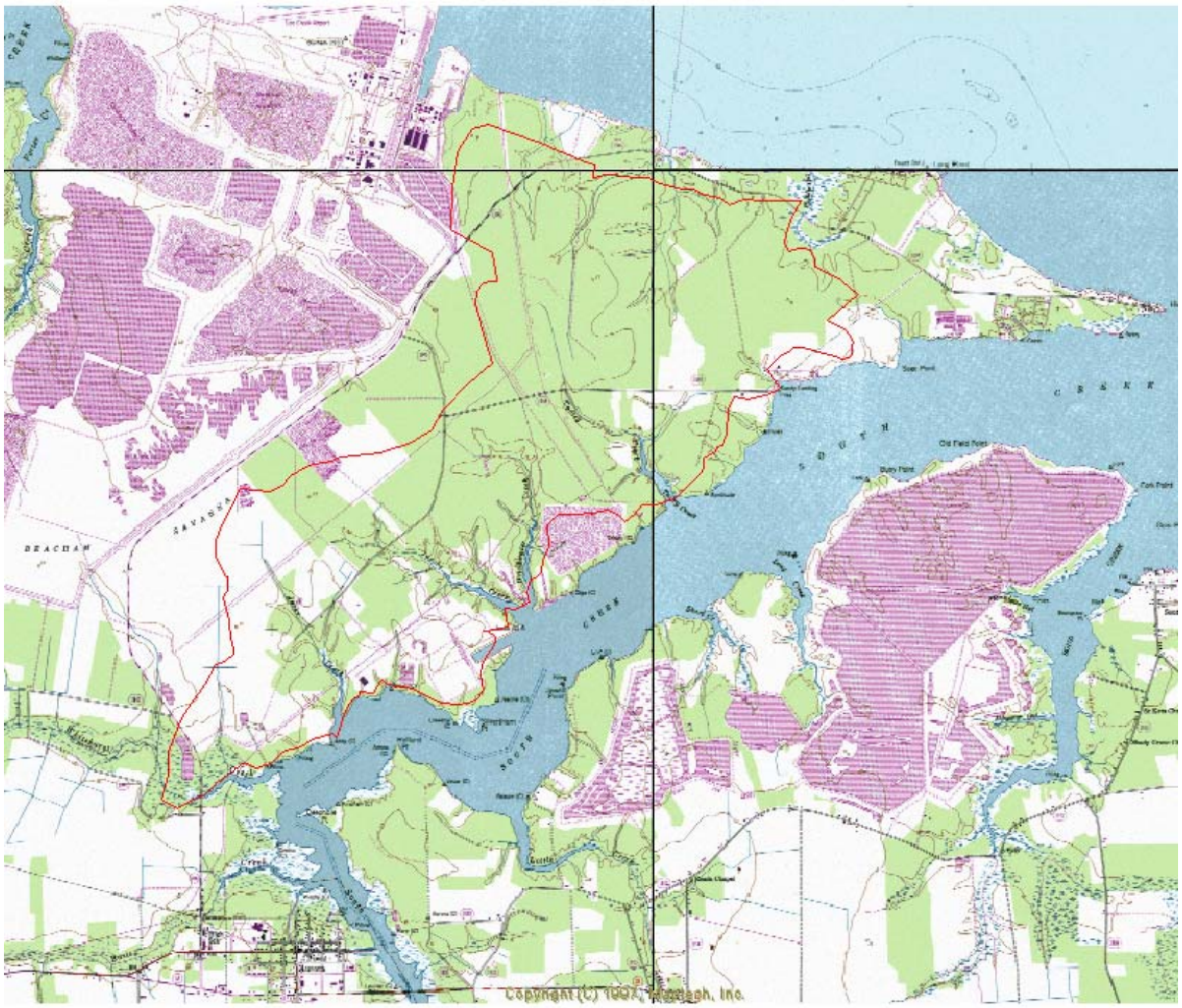


Figure 1: South Creek Study Area

Figure 2: Intermittent and Perennial Streams
PCS Phosphate Company Study Area
Beaufort County, NC

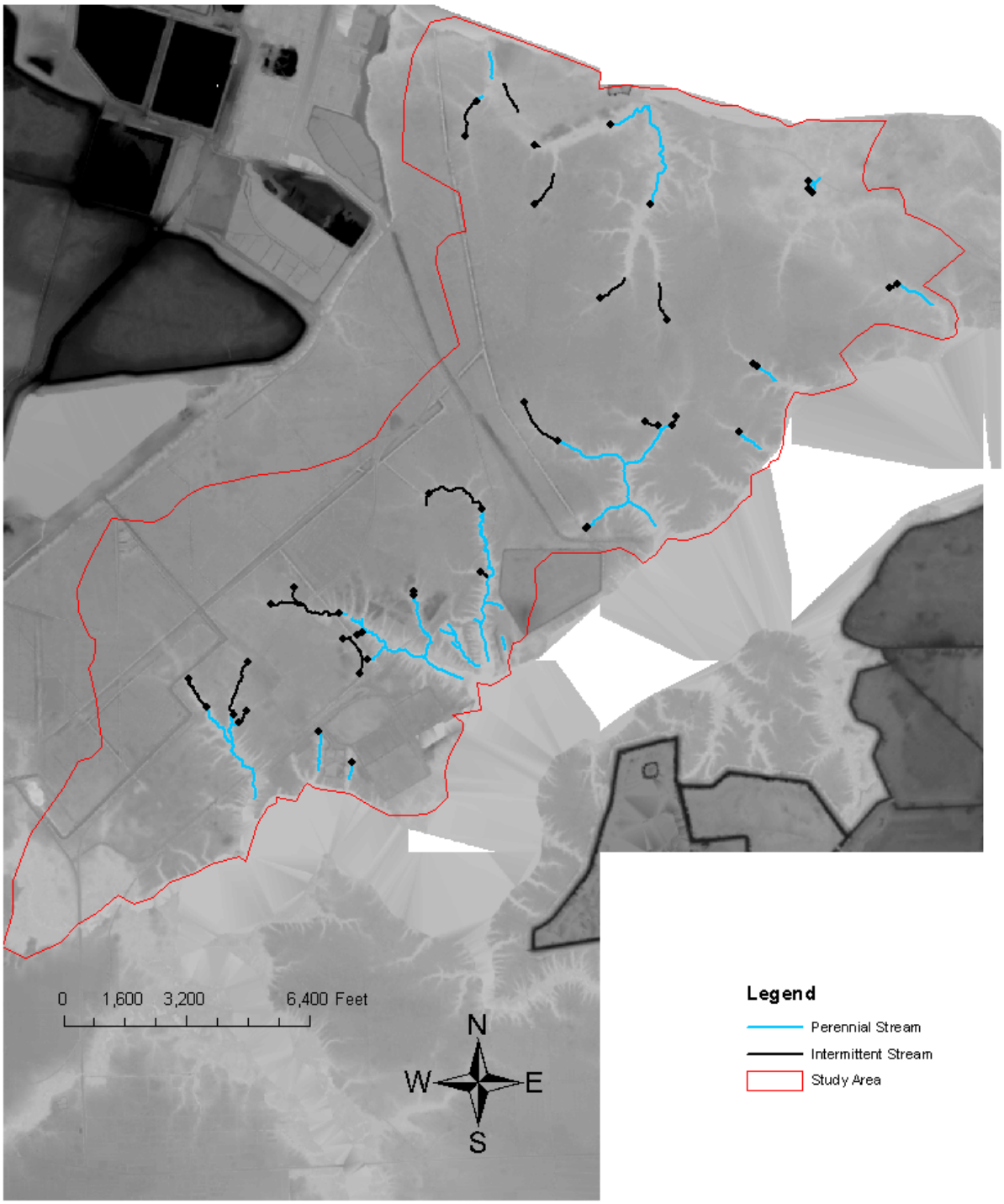


Figure 3: Area Soils
PCS Phosphate Company Study Area
Beaufort County, NC

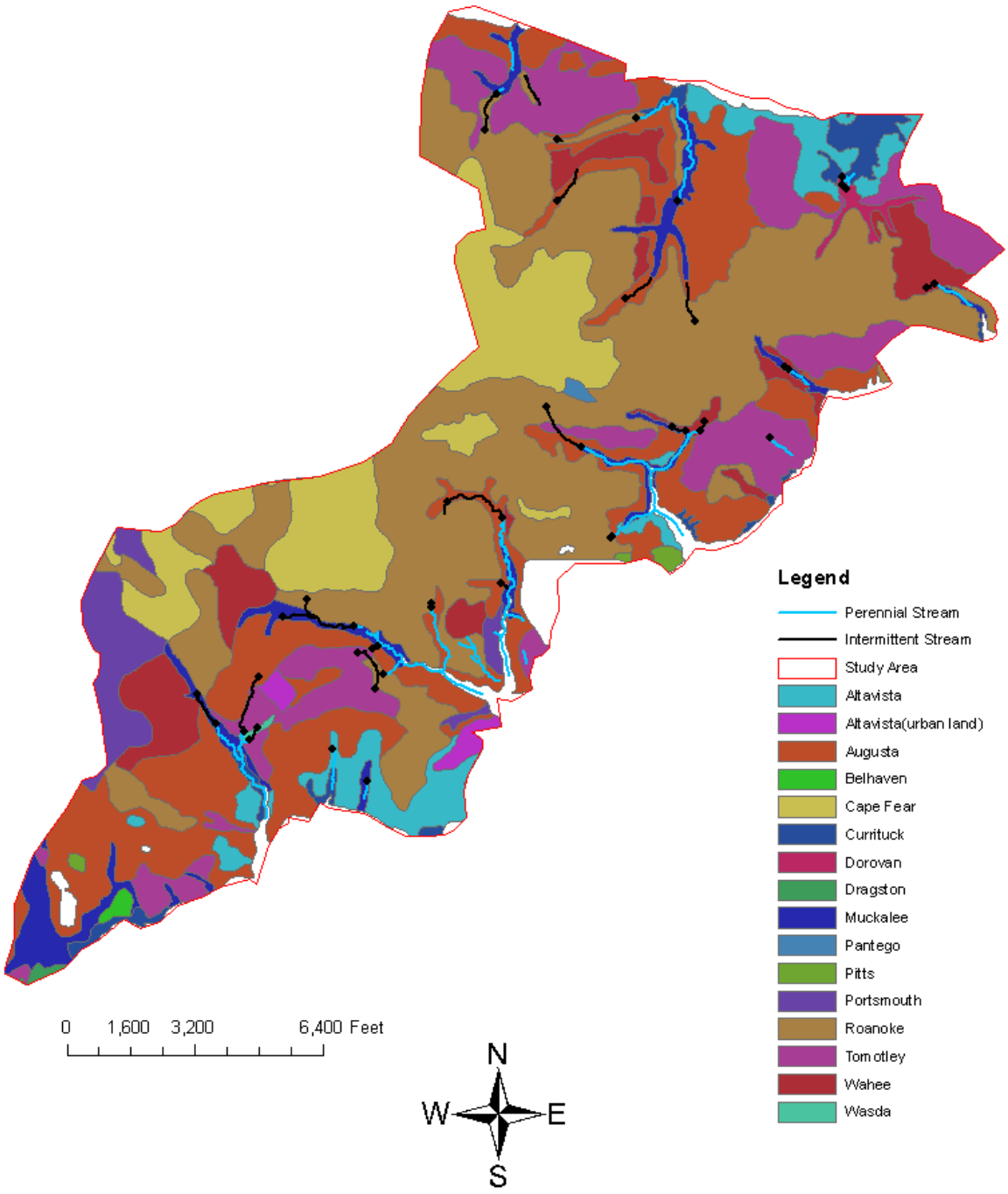
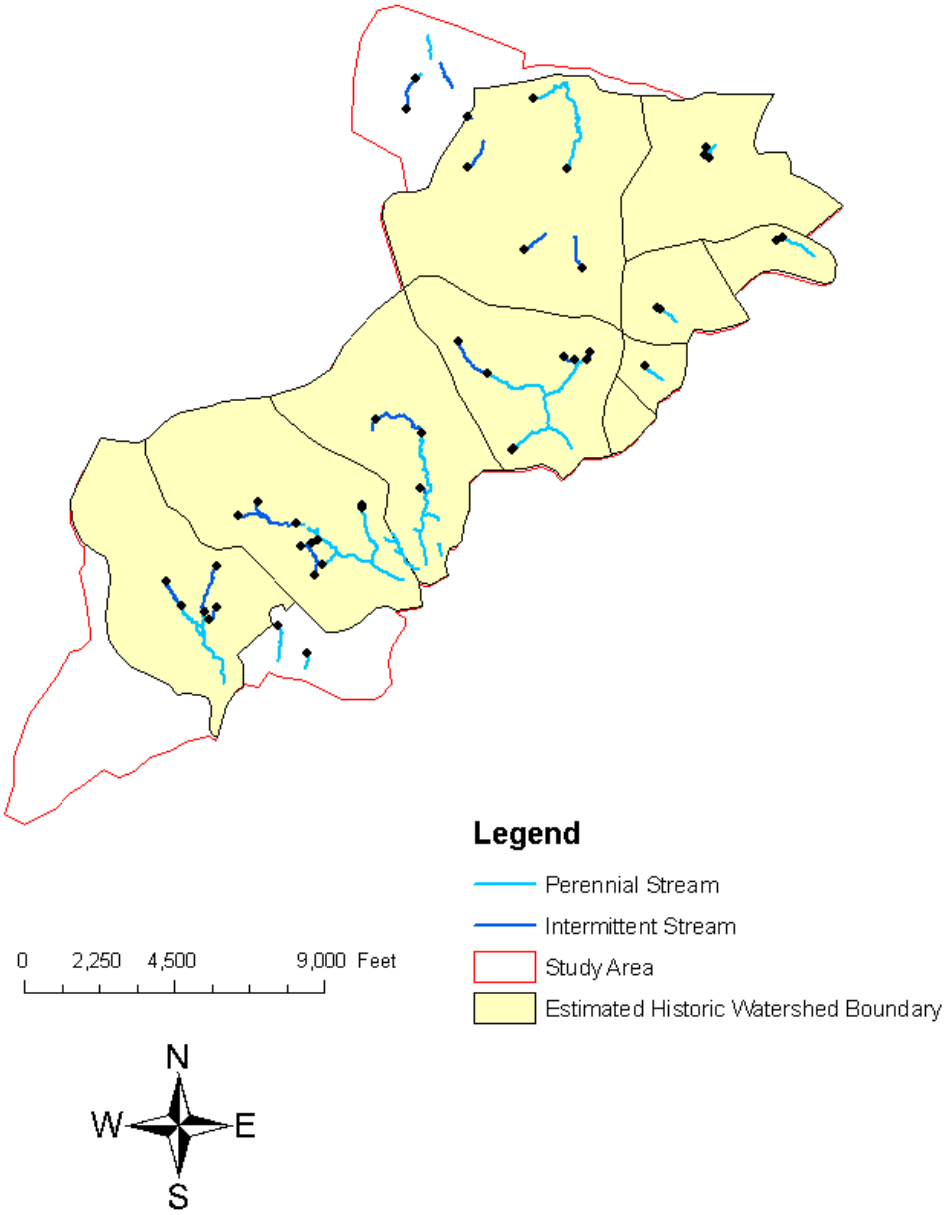


Figure 3: Estimated Historic Watersheds
PCS Phosphate Company Study Area
Beaufort County, NC



Results

Historical and Current Conditions

Forty five stream origins were mapped and evaluated, of which 23 are intermittent and 22 are perennial. The distribution of contributing watershed area for current and historic conditions spans 0.44 acres to 411 acres for all origin flow durations (Figure 5). The range of historical contributing drainage area is generally broader than current drainage area reflecting the changes in drainage patterns due to ditching. However, it is also possible that historic stream origin locations differed from current locations and that increases or decreases in contributing area resulted in the migration of the origin upstream or downstream respectively. Essentially, current contributing drainage area may be described as the area required to maintain the current flow duration for a particular stream.

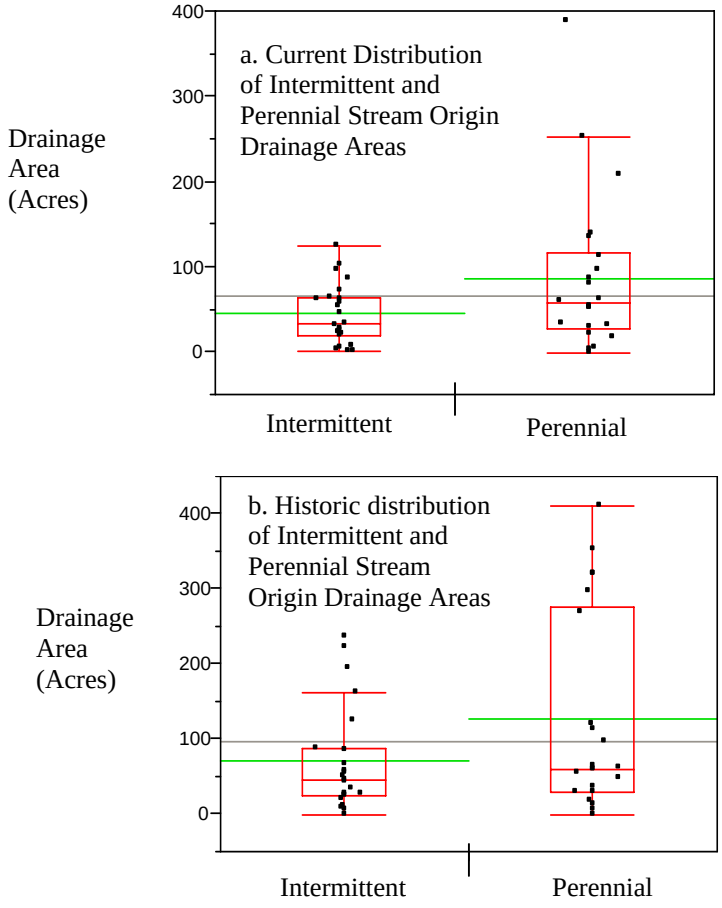


Figure 5a,5b: Current and Historic Drainage Area Distributions. Box plots indicate quantiles, green line represents mean, gray line is grand mean.

Distribution of current drainage area (Table 1) for intermittent streams ranges from approximately 1 to 125 acres with a median of 35 acres and a mean of 46 acres. Perennial stream areas have a broader range from 0.42 to 389 acres with an approximate median of 58 acres and mean 87 acres. While drainage area independently may not account for the variability in flow duration, it is reasonable to expect greater drainage area contributions for perennial flows. Historic contributing areas tend to be greater than current areas suggesting the influence of altered drainage in ditching efforts. It is also possible the location of the origin as well as the flow duration for streams has changed due to altered drainage patterns, but data are not available to investigate potential changes. Adequately addressing location and flow duration changes from past to present would require a detailed study that would include the influence of ground water.

Table 1: Distribution of Stream Origin Current and Historic Drainage Areas

Quantiles	Current Contributing Area (Acres)		Historic Contributing Area (Acres)	
	Intermittent	Perennial	Intermittent	Perennial
Minimum	1.23	0.42	0.44	0.84
10%	3.68	3.84	7.73	8.62
25%	22.14	20.88	25.24	30.61
Median	35.09	57.78	46.19	61.33
Mean	46.48	86.52	71.01	127.20
75%	65.28	118.12	88.18	277.01
90%	100.54	240.40	211.98	344.11
Maximum	125.36	388.65	237.51	411.51

Assuming flow duration and origin location remained relatively constant over time, intermittent streams netted a 50% change in contributing area from historic to current conditions. Approximately 68% of perennial streams lost contributing drainage area with an average change of – 39.50 acres. The range of change in intermittent drainage area is – 236 to 54 acres where the range for perennial area is –265 to 52 acres (Appendix 2).

Soils

Intermittent and perennial stream origins were also evaluated by soil type. Table 2 illustrates the frequency of origins by soil and the density of origins by soil. Density serves to normalize the number of origins by the soil area to more accurately describe the influence of soil type. These data were obtained by intersecting the origin layer with the soil layer in ARC MAP and so reflect any error (unknown) associated with soil mapping. Overall, Roanoke and Muckalee soils have the greatest number of streams of both flow durations, though the Muckalee had a greater density. The one origin in Wasda was mapped closely to a contact zone between soil types, as were 5 others in Tomotley and Roanoke. The data indicate more intermittent origins in Roanoke and Augusta and more perennial origins in Muckalee. Although Currituck, Wahee and Dorovan have a greater density of origins, the low number of origins along with the potential error in soil mapping limits a confident conclusion. Belhaven, Cape Fear, Dragston, Pantego, Pitts and Portsmouth soils are not associated with stream origins in this area.

Table 2: Current Contributing Area by Soil Type

Soil	Area (acres)	Intermittent Frequency	Perennial Frequency	Total Frequency	Density (Freq/Area)
Tomotley	128.64	2	4	6	0.05
Roanoke	177.62	8	4	12	0.07
Altavista	10.56	0	1	1	0.09
Augusta	37.75	6	1	7	0.19
Currituck	4.55	0	1	1	0.22
Wahee	7.88	2	2	3	0.38
Dorovan	2.16	0	2	2	0.93
Muckalee	12.00	5	7	12	1.00
Wasda	0.36	1	0	1	2.75

Erosion Threshold Index

Past researchers have mathematically described the stream origin or channel head as the exceedance of an erosional threshold that is influenced by geology, soils, climate regime and land use (Montgomery and Dietrich 1988,1989). The threshold is specific to the controlling water delivery mechanism, i.e., overland flow or seepage erosion, and is a function of contributing drainage area and the local ground slope (Dietrich et al. 1992, 1993; Montgomery and Dietrich 1994; Hancock and Evans 2006). Drainage area is commonly used in channel initiation models since drainage area is positively correlated with discharge and may serve as a surrogate. The slope-area plot for current conditions (Figure 6) indicates the relationship between slope and contributing area for each flow duration.

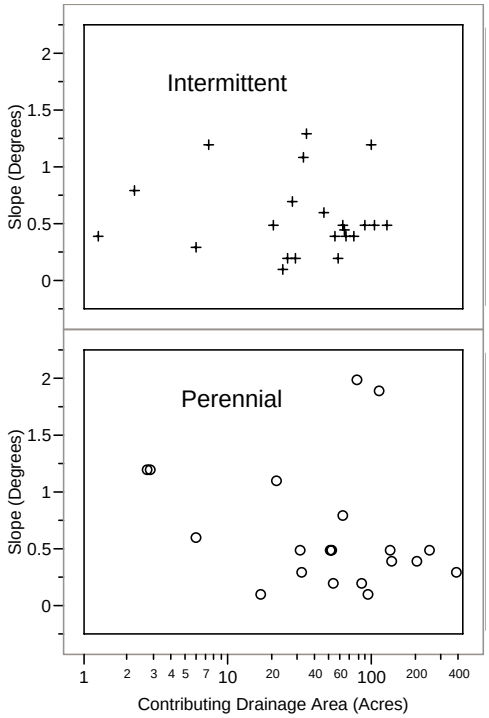


Figure 6: Local Slope vs Contributing Drainage Area

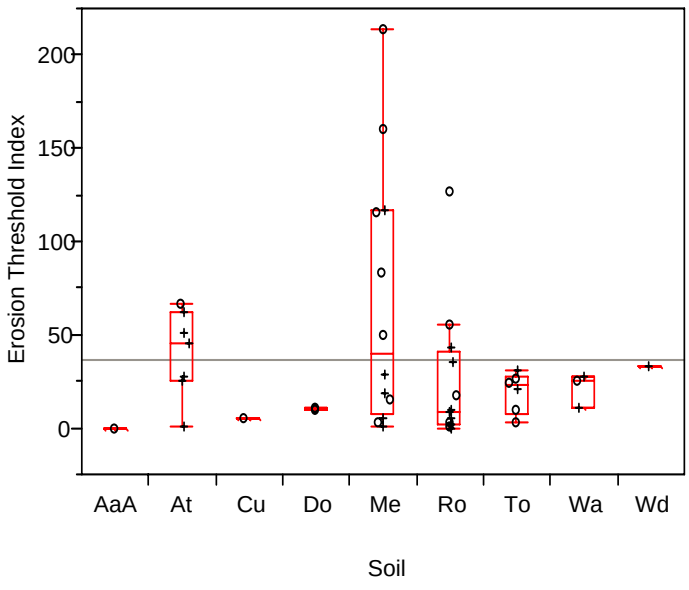
Generally, an inverse relationship exists for perennial origins. This result is consistent with other studies investigating slope and area dependence and channel origins (Montgomery 1994, 1999; Montgomery and Dietrich 1994; Dalla Fontana and Marchi 2003; Hancock and Evans 2006). However, an inverse is not evident for intermittent origins. In most studies, 100 or more origin points were obtained for analysis to adequately represent the variability of the data. The low number of data points and map-derived slope estimates are both limiting factors for analysis. Specifically, since the true slope range in the outer coast plain is narrow (0-2% average), slope estimates contain greater error than they would if derived in a steep, mountainous area. Additionally, slope, area and soils are not the only contributing factors to intermittent and perennial origin locations. In the South Creek area where ditching has altered the natural flow regime, the method of capturing contributing drainage area from digital maps masks the local characteristics of flow patterns. Major and minor ditching is likely to have large effects on flow paths that can not be discerned at the 20-ft DEM resolution. Field measurement of local slope and additional origin points would provide for more accurate analysis and would provide the information for better interpretation.

The raw data used for the slope-area relationship was also used to calculate an erosion threshold index with the equation

ET index = DA*S

where DA is the contributing drainage area and S is the generalized local slope at the origin.

In Figure 7 below, ET serves as an overall index of stream origin formation. ET represents the relative difference between stream origins. Figure 7 illustrates the relative ET ranges of intermittent and perennial origins based on soil types.



Soil	Abbreviation
Altavista	AaA
Augusta	At
Currituck	Cu
Dorovan	Do
Muckalee	Me
Roanoke	Ro
Tomotley	To
Wahee	Wa
Wasda	Wd

Figure 7: Distribution of Erosion Threshold Index by Soil Type.
Intermittent (+); Perennial (o)

The distribution of the erosion threshold index across soil types indicates the largest range of ET lies within Muckalee soils. The same number of origins (12) was mapped in Roanoke soils but the range of ET is smaller even though the total area of Roanoke soils in the study area is much greater than Muckalee. Muckalee soils cover an area of 12 acres compared to the Roanoke soil area of 177 acres. These data strengthen the general hypothesis that stream origin and formation processes differ between soil types. Muckalee loams tend to be poorly drained, floodplain soils with moderate permeability and water capacity and experience frequent flooding due to high seasonal water table elevations. Roanoke fine sandy loams are also poorly drained, but tend to be located along stream terraces and therefore a bit higher in elevation so are not subject to frequent flooding. The difference between water table elevations within each soil type is indicative of the range of slope and drainage area required to maintain flow regimes. The higher elevation of the water table in Muckalee soils may allow for higher variation in the slope-area product due to the availability of water regardless of the slope. The Augusta soils (also fine sandy loam) tend to maintain intermittent streams at an ET range of 25 to 58 and perennial streams slightly above at 67.

Conclusions

The data used in this investigation are insufficient for statistical analysis since other factors beyond slope, soil type and drainage area contribute to the variability in flow regimes and their origins. Outer coastal plain streams are also strongly influenced by water table elevations that are, in turn, are affected by land use and ditching. The magnitude of these additional influencing factors is unknown. However, the slope-area plots may be useful as a supplementary guide to land managers in making management decisions. Erosion threshold ranges within soil types may also allow for slope-area adjustments for site specific conditions or site limitations. These indices provide qualitative information regarding the slope and drainage area required to maintain current flow regimes of streams. Since the slope and drainage area were derived from digital maps, additional origins and field measured slopes would enhance the reliability of the analysis. Field measured local slope would at least provide the data for error analysis between map and field derived slopes. More rigorous analysis should include the effects of ditching on flow paths to capture more accurate drainage areas contributing to stream origins and their flow regimes.

References

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Soil Survey of Beaufort County, North Carolina, 1995. NRCS, USDA

APPENDIX 1

originnum	Slope (Degrees)	Area (acres)	originid	Flow Duration	Soil	Contributing Drainage Area (Acres)	Erosion Threshold Index
0	0.6	6.0609802	0	pe	Ro	6.06098021	3.636588126
1	1.2	7.1729304	1	in	Ro	7.172930413	8.607516495
2	0.5	134.68223	2	pe	At	134.6822311	67.34111553
3	0.5	20.372777	3	in	Ro	20.37277692	10.18638846
4	0.1	17.053958	4	pe	Ro	17.05395837	1.705395837
5	0.5	87.418265	5	in	Ro	87.41826454	43.70913227
6	0.4	209.0734	6	pe	Me	209.0734028	83.62936114
7	0.5	62.531992	7	in	To	62.53199173	31.26599586
8	0.8	2.1874031	8	in	At	2.187403135	1.749922508
9	1.2	2.795691	9	pe	Me	2.795690992	3.35482919
10	0.4	140.45123	10	pe	Ro	140.4512331	56.18049324
11	0.4	54.553688	11	in	To	54.55368819	21.82147528
12	0.3	5.9222906	12	in	Me	5.922290578	1.776687173
13	0.4	65.286319	13	in	At	65.28631914	26.11452766
14	1.2	2.9343806	13	pe	To	2.934380623	3.521256748
15	1.5	22.141678	14	in	Wd	22.141678	33.21251701
16	1.1	22.148977	15	pe	To	22.14897746	24.3638752
17	0.2	29.173486	16	in	Me	29.17348563	5.834697127
18	0.4	1.2263083	17	in	Ro	1.22630832	0.490523328
19	0.5	253.83122	19	pe	Ro	253.8312234	126.9156117
20	1.09	32.652892	20	in	Ro	32.65289218	35.59165247
21	0.5	102.5476	20	in	At	102.5476001	51.27380006
22	0.1	23.689162	22	in	Ro	23.68916231	2.368916231
23	0.5	52.247061	23	pe	Wa	52.24706064	26.12353032
24	0.45	63.463889	24	in	Wa	63.46388872	28.55874993
25	0.4	73.060238	25	in	Me	73.06023796	29.22409518
26	2	80.48135	26	pe	Me	80.48134982	160.9626996
27	0.3	33.270913	27	pe	To	33.27091264	9.981273792
28	0.2	58.14502	28	in	Wa	58.1450197	11.62900394
29	0.5	52.804252	29	pe	To	52.80425231	26.40212616
30	1.9	112.59895	30	pe	Me	112.5989487	213.9380025
31	1.2	97.535308	31	in	Me	97.53530818	117.0423698
32	0.2	25.77194	32	in	Ro	25.77193994	5.154387987
33	0.8	63.205975	33	pe	Me	63.20597467	50.56477974
34	0.5	31.884016	34	pe	Me	31.88401633	15.94200816
35	0.6	46.023059	35	in	At	46.02305928	27.61383557
36	0.2	87.072757	36	pe	Ro	87.07275704	17.41455141
37	0.5	125.36902	37	in	At	125.3690184	62.6845092
38	0.1	96.299267	38	pe	Do	96.29926726	9.629926726
39	0.1	60.266728	39	pe	Cu	60.26672775	6.026672775
40	0.7	27.752525	40	in	Me	27.7525252	19.42676764
41	0.3	388.65458	41	pe	Me	388.6545772	116.5963732
42	0.2	0.4209352	42	pe	AaA	0.420935197	0.084187039
43	1.3	35.098209	43	in	At	35.09820936	45.62767217
44	0.2	55.303099	44	pe	Do	55.30309883	11.06061977

APPENDIX 2
Change in Historic and Current Contributing Area For Intermittent Streams

Historic Area (acres)	Current Area (acres)	Flow Duration	Current - Historic (acres)
11.348	65.286	Int	53.94
46.197	97.535	Int	51.34
28.626	62.532	Int	33.91
25.241	58.145	Int	32.90
44.241	73.060	Int	28.82
26.560	54.554	Int	27.99
10.103	32.653	Int	22.55
86.565	102.548	Int	15.98
27.835	35.098	Int	7.26
56.775	63.464	Int	6.69
0.443	2.187	Int	1.74
6.155	7.173	Int	1.02
21.027	5.922	Int	-15.10
35.585	20.373	Int	-15.21
50.556	23.689	Int	-26.87
57.863	22.149	Int	-35.71
67.743	25.772	Int	-41.97
88.182	46.023	Int	-42.16
194.457	125.369	Int	-69.09
162.470	87.418	Int	-75.05
124.517	27.753	Int	-96.76
223.672	2.934	Int	-220.74
237.510	1.226	Int	-236.28

APPENDIX 2 (cont)

Change in Historic and Current Contributing Area For Perennial Streams

Historic Area (acres)	Current Area (acres)	Flow Duration	Current - Historic (acres)
60.693	112.599	Per	51.91
97.857	140.451	Per	42.59
48.508	80.481	Per	31.97
30.673	52.804	Per	22.13
17.895	33.271	Per	15.38
56.267	60.267	Per	4.00
0.838	2.796	Per	1.96
60.528	55.303	Per	-5.22
6.019	0.421	Per	-5.60
14.677	6.061	Per	-8.62
61.966	52.247	Per	-9.72
30.405	17.054	Per	-13.35
37.286	22.142	Per	-15.14
411.512	388.655	Per	-22.86
121.094	96.299	Per	-24.79
64.393	29.173	Per	-35.22
113.962	63.206	Per	-50.76
321.264	253.831	Per	-67.43
353.765	209.073	Per	-144.69
270.427	87.073	Per	-183.35
321.607	134.682	Per	-186.93
296.774	31.884	Per	-264.89