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Final Report

Development of Guidelines for the Restoration of Forested Wetlands in North Carolina

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The Center for Transportation and the Environment
North Carolina State University

Final Report

Development of Guidelines for the Restoration of Forested Wetlands in North Carolina

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16. Abstract

We described the vegetation of swamp forest stands along stream systems in the coastal plain of Carolina in relation to elevational, hydrologic, and edaphic gradients. Direct gradient analyses combined with plot ordinations derived from detrended correspondence analyses and canonical correspondence analyses suggested that compositional and structural differences in vegetation between the stands were primarily the result of variations in growing season flooding frequency, % base saturation, cation exchange capacity, and other edaphic factors. We discuss the implications of the these relationships for wetlands restoration.

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ABSTRACT

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INTRODUCTION

Road projects often intrude into wetlands, requiring the North Carolina Department of Transportation to create or restore other wetlands as "mitigation" of the ecosystem services lost. The more complex the wetland system, the more difficult it is to restore or create it, and forested wetlands are particularly difficult. There are a variety of forest communities, each a result of unique combinations of soils, hydrologic regimes, and other ecological factors. These can be difficult to describe, and if any are not duplicated adequately, the desired plant community is not likely to be persistent and self-sustaining. Because of this complexity, most forested wetland creations and many restorations are not successful. Current restoration techniques often fail to establish many of the basic functions of forested wetlands due, in part, to a lack of scientific knowledge about wetland structure and function. Long-term ecological research is quite costly, and consequently little is conducted. Particularly lacking are descriptions of hydrologic regimes which support particular plant communities.

The US Geological Survey (USGS) has monitored the flows of many streams throughout the United States for several decades. These data can be exploited at reasonable expense to describe environmental factors governing plant community attributes in wetlands. Our objective is to analyze the plant community compositions of forested wetlands that occur along North Carolina coastal plain streams in relation to long term flooding regimes and soil characteristics. These wetlands are relatively abundant and are often impacted by road projects.

METHODS

Site Selection

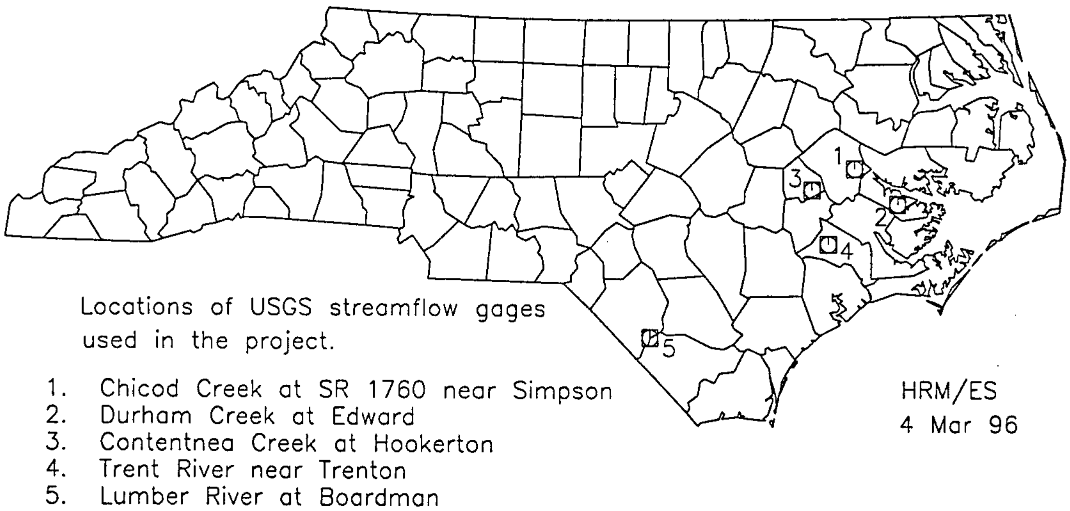
Sites were selected from forested wetland communities along streams and rivers located on North Carolina's coastal plain. Sites chosen had no recent site disturbance (within the last 20 years) and hydrologic data from a USGS gaging station for 10 years or more. Five sites were included in the study (Figure 1):

1. Chicod Creek near Grimesland, Pitt County, NC
2. Contentnea Creek at Hookerton, Greene County, NC
3. Trent River at Trenton, Jones County, NC
4. Lumber River at Boardman, Robeson County, NC
5. Durham Creek at Edward, Durham County, NC (collected for another study, only those appropriate for this study were used)

Hydrologic Data

Streamflow and stage data for each gaging station were obtained from the USGS. The daily flows recorded at each gage were converted to stage values using USGS rating curves. The stage at the sites were calculated using three methods: long term discharge records from the USGS gaging stations, Manning's equation, and regression analysis of short-term water level recorders and long-term USGS records.

Figure 1. Location of USGS gaging stations.



For each method, the following surface effects were found: average daily stage, percent inundation, consecutive submerged and unsubmerged days, and the average maximum depth of water associated with each submerged duration (*i.e.*, the number of consecutive submerged days). These effects were calculated for the growing season (April - October) and the dormant season (November - March). Average maximum depth is the average of the maximum depths measured relative to the plot elevation. A series of consecutive days is referred to as an event.

Two annualized distributions were found helpful in describing the number of consecutive submerged and unsubmerged days: the actual distribution and the at-least distribution. The actual distribution describes the exact frequency of a submerged, or unsubmerged, event of a specified duration for an average year. The at-least distribution tells how many submerged (or unsubmerged) events occur that have at a minimum the specified duration for an average year. It is the opposite of the cumulative distribution.

Manning's equation was used to calculate the flow in a channel reach:

$$Q = (1.49/n)AR^{2/3}S^{1/2} \qquad \text{(Eq. 1)}$$

where:
- Q is the discharge in cubic feet per second
- n is the Manning coefficient of roughness (dimensionless)
- A is the cross-sectional area of the channel in square feet
- R is the hydraulic radius in feet
- S is the slope of the energy gradient in feet fall / feet run.

The mean depth, y, may be substituted for the hydraulic radius in a wide, shallow channel without causing significant error (Chow 1959). After substitution, the equation is solved for the slope of the energy gradient, which can be written as:

$$S = [(n/1.49)QAy^{2/3}]^2 \qquad \text{(Eq. 2)}$$

The slope of the energy gradient (S) can also be written as the change in elevation or stage divided by the distance between the USGS gaging station and the short-term gage:

$$S = (y_{\text{gaging station}} - y_{\text{study site}}) / L \qquad \text{(Eq. 3)}$$

where: $y_{\text{gaging station}}$ is the stage at the gaging station in feet
$y_{\text{study site}}$ is the stage at the site in feet
L is the distance between the gaging station and the study site in feet

Rearranging terms in equation 3 results in:

$$y_{\text{study site}} = y_{\text{gaging station}} - (SL) \qquad \text{(Eq. 4)}$$

Equation 2 can be substituted for the slope term in equation 4, and written as:

$$y_{\text{study site}} = y_{\text{gaging station}} - [(n/1.49)QAy^{2/3}]^2L \qquad \text{(Eq. 5)}$$

We used equation 5 to estimate stage at the study sites. The coordinates of the study sites were determined by using a global position system, and the distances between the USGS gaging stations and the study sites were determined. Step functions were formulated to describe the cross-sections of the channels. It was assumed that the stream channels did not change significantly between the gages and the study sites The roughness coefficients were assumed to remain constant over the range of stages resulting at each site. They were estimated by comparing channel conditions to photographs in *Roughness Characteristics of Natural Channels* (Barnes, 1967). The roughness coefficient was also calculated from equations 2 and 3. The elevations of the water surface at the USGS gaging station and the study sites were measured by surveying. One elevation measurement was taken immediately after the other. The slope of the hydraulic gradeline for this set of elevations was found by solving equation 3. The channel length (L) was found as previously described, and equation 2 was solved.

Stage relationships for the site were also estimated by establishing a linear relationship between the stage at the study site and the discharge at the USGS gages at the Lumber River and the Trent River. The linear relationship at Contentnea Creek was for the stage at the study site and the stage at the USGS gage. The resulting linear coefficients were used to hindcast the stage values at the wetland sites.

Vegetation

A variation of the methods and plot arrangement described by the North Carolina Vegetation Survey was used to describe the vegetation (Peet, *et al.*, 1990). A 20m x 50m (0.1 ha) plot was used to gather plant community data at each site. Some of the plots were smaller (e.g., 10m x 50m or 20m x 30m) due to area constraints at some sites. The 20m X 50m plot was divided into ten 10m x 10m subplots. Four of the 10m x 10m subplots contained two 3.16m x 3.16m intensive sampling plots (Figure 2). All stems emerging from the intensive plots were recorded and assigned a percent cover value. Cover of any species not found in the intensive sampling plots but occurring in the 10m x 10m subplots containing the intensive plots was determined. Species found in any of the remaining subplots that were absent from the plots already sampled were recorded as residual species and assigned a cover value. All woody species over 1 meter in height originating in the 20m x 50m plots were recorded along with the diameter at 1.3 meters (dbh). Trees of dbh 2.5 cm to 20.3 cm were categorized as midstory; those of dbh greater than 20.3 cm were overstory. Plant species nomenclature is according to Radford, *et al.* (1968). Plot centers were surveyed to a benchmark to determine the elevation of each plot relative to the USGS gage.

Soils

Soil cores were taken from the upper 25 cm of the profile. A composite sample from each 10m X 10m subplot was tested for percent humic matter, cation exchange capacity (CEC), percent base saturation (%BS), hydrogen ion concentration, exchangeable acidity, and for calcium, magnesium, potassium, and phosphorus concentrations. The soil profile at the plot center was determined by extracting soil to a depth of 100 cm. Other soil characteristics that were measured include: depth to the least permeable horizon; depth to distinct mottling; the color and thickness of each horizon, and; percent sand, silt, and clay for the A horizon and the least permeable horizon.

Data Analyses

Analysis of variance and Tukey's procedure were used to compare each surface hydrologic effect among all the plots using SAS/STAT software.

Importance values (I.V.) for overstory and midstory trees were calculated using the average of relative basal area and relative frequency for each species by plot:

$$\text{I.V.} = \frac{\text{relative basal area + relative density}}{2} \qquad \text{(eq. 6)}$$

Relative percent cover was used as the I.V. for understory species.

Detrended correspondence analysis (DCA) (DECORANA program, Hill, 1979) was used to examine the relationships between environmental factors and plant community composition. DCA axis scores were correlated to a secondary matrix of soil nutrient factors, soil physical properties, and growing season flood frequencies for 1-day through 10-day, 15-day, and 30-day flood events. Flood frequency in the growing season was found to be important in explaining the variation in species composition among the plots.

Principle components analysis (PCA) was used to ordinate flood frequencies for the growing season to determine how DCA axis 1 scores were related to flood frequencies. An analysis of variance was used to test the significance of the relationship between ordination scores for plant communities and scores for flood frequencies. A level of significance of P = 0.05 was used unless otherwise stated. We used Canonical correspondence analysis (CCA) to further examine relationships between plant communities and environmental factors.

RESULTS

Comparisons of Stage Estimation Methods

For each site, except those along Durham Creek, the average daily stage was calculated for the three stage estimation methods: USGS gage data; Manning's equation; and regression (see Table 1; the USGS has no rating table for Durham Creek).

Table 1. Summary of average daily stage values at study sites for methods of stage estimation.

Method:	USGS Gage Data		Manning's Equation		Regression	
	feet (meters)	coefficient of variation %	feet (meters)	coefficient of variation %	feet (meters)	coefficient of variation %
Chicod Creek	6.14 +/- 0.76 (1.87 +/- 0.23)	12	6.13 +/- 0.75 (1.87 +/- 0.23)	12	-	-
Contentnea Creek	5.35 +/- 2.76 (1.63 +/- 0.84)	52	4.69 +/- 2.25 (1.43 +/- 0.69)	48	7.37 +/- 1.47 (2.25 +/- 0.45)	20
Lumber River	5.06 +/- 1.66 (1.54 +/- 0.51)	33	4.72 +/- 1.36 (1.44 +/- 0.41)	29	2.03 +/- 1.08 (0.62 +/- 0.33)	53
Trent River	4.86 +/- 2.46 (1.48 +/- 0.75)	51	4.19 +/- 1.87 (1.28 +/- 0.57)	45	3.23 +/- 1.41 (0.98 +/- 0.43)	44

The stages estimated by Manning's equation and by regression generally had smaller standard deviations. Of note is the high average daily stage value recorded for the regression method at Contentnea Creek. The regression relationship for Contentnea Creek only describes surface flooding which usually occurs at the study site when the stage at the gaging station is approximately more than 9.5 feet above the gage datum. Stages below 9.5 feet would correspond to subsurface water levels that would be overestimated by the formulated regression equation.

Even though the average daily stages differed, there were similarities in the number of consecutive submerged and unsubmerged days at some of the sites. The Lumber River was the only site that exhibited extreme differences between the three methods. The results for the gage data and Manning's equation were similar and indicated long periods of flooding. The regression data indicated that the site had less continuous flooding and more periods of continuous dryness.

In general, any of the methods could be used to help describe the hydrology of a site. For the purposes of the rest of this study the stages estimated by the regression method were used for describing the effects of consecutive submerged and unsubmerged days and percent inundation for the plots at the study sites.

Comparisons Of Plots Within Sites

During the growing season, the plots at Chicod Creek have similar percent inundations. Plot 2 is statistically different from the other plots, most notably plot 4. During the dormant season, plot 2 is different from plots 4 and 1, both in percent inundation and inundation frequencies.

At the Trent River, plots 1, 2, and 3 were at one location and plots 4, 5, and 6 were at another location. Of these sites plot 3 is the wettest and plot 4 is the driest. Plot 3 has the highest frequency of inundation events greater than fifteen days during the growing and dormant seasons than the other plots as shown in Table 14. In addition, plot 4 is the only plot significantly drier than plot 3 during both seasons. Plots 1, 2 and 3 are statistically similar except for the frequency of inundation events greater than thirty days during the dormant season (Table 3). For this inundation event, plot 3 had more occurrences. Plots 1 and 2 have similar characteristics, but plot 1 has a higher occurrence of consecutive unsubmerged days greater than thirty during the growing season.

At the Trent River, plots 1, 2 and 3 are significantly wetter than plot 4 during the dormant season. These wetter plots have more frequencies of long inundation events (greater than fifteen days) during the dormant season. This may also be true for the growing season, but the frequencies may not be significantly different. Plot 3 is significantly wetter than plots 5 and 6

Table 2. Differences in Surface Hydrology Effects for Chicod Creek.

		annual frequency			
Season	flood length	Plot 1	Plot 2	Plot 3	Plot 4
Growing	10-Day	0.26	0.13	0.18	0.23
	15-Day	0.12	0.00	0.00	0.10
	30-Day	0.03	0.04	0.07	0.01
	% Inundation	0.33	0.15	0.24	0.31
Dormant	10-Day	0.07	0.10	0.09	0.10
	15-Day	0.04	0.20	0.12	0.07
	30-Day	0.01	0.00	0.04	0.03
	% Inundation	0.75	0.43	0.66	0.75

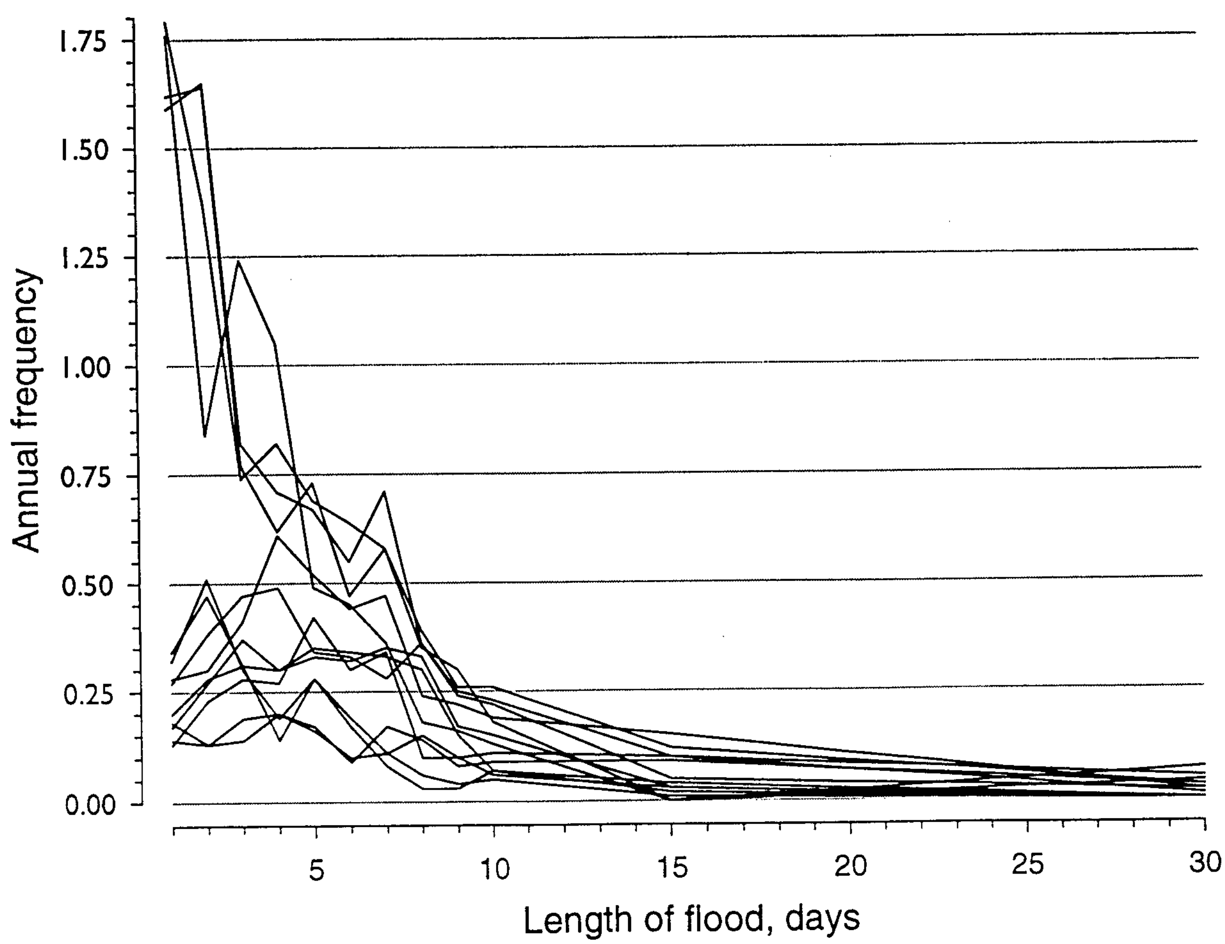
Table 3. Frequencies of Selected Events and Percent Inundations for Trent River Sites.

Season	Hydrologic Effect	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Growing	> 15 Submerged Days	0.48	0.47	1.00	0.09	0.18	0.22
	> 30 Submerged Days	0.05	0.07	0.22	0.02	0.02	0.02
	Percent Inundation	0.16	0.16	0.24	0.07	0.10	0.11
Dormant	> 15 Submerged Days	1.34	1.33	1.65	0.10	0.50	0.66
	> 30 Submerged Days	0.41	0.42	0.97	0.01	0.07	0.12
	Percent Inundation	0.38	0.38	0.52	0.14	0.21	0.24

during the dormant season, but not during the growing season. During the growing season, plot 3 has more occurrences of inundation events between ten and fifteen days than plots 5 and 6. Plots 5 and 6 have no significant variation in their flooding frequencies.

The sites differed in growing season flood frequencies and percent inundation. The frequencies in Figure 4 represent the number of times per year a flood lasting for a particular period of time in the growing season occurs. For example, at Contentnea Creek plot 1, a flood lasting for 1 day occurs 0.34 times per year or once every 2.9 years (1/.34=2.9). A flood lasting 10 days or longer at this plot occurs once every 4.2 years (1/.24=4.2). The values for percent inundation represent the percent of time in the growing season the plot is flooded. The Lumber River site has a comparatively lower flood frequency for the short-term floods, but a much higher flood frequency of floods greater than 30 days in duration. Also evident is the high frequency of shorter floods at Chicod Creek, most notably for the 5-day or less flood frequencies. There is considerable within-site variation in the vegetational and hydrologic features at this site. Plot 2 at Chicod Creek, for example, is much drier than other plots at this site as indicated by a lower frequency of the longer floods. This plot also has a lower percent inundation than other plots at this site. Plots at the Trent River also have measurable hydrological differences. Plot 2 has a higher growing and dormant season percent inundation and frequency of floods greater than 15 days when compared to other plots at that site.

Figure 2. Frequencies of floods of different durations.



The decreasing stage values calculated for the Trent River may indicate that the channel cross-section significantly changes between the gage and the study sites, that the channel is too long (the site is too far from the gage), or that the meanders in the stream channel affect the stage. Meanders in a stream channel dissipate energy and reduce the velocity of the water. In addition, the length of meandering streams tend to be 1.5 or 2 times the length of non-meandering streams (Linsley, *et al.*, 1975). Reducing the channel length may solve the problem of negative stages.

The USGS compiled roughness coefficients, ranging from 0.024 to 0.075, for over fifty stream channels (Barnes, 1967). These values apply when the stream discharge is within the channel banks. A site located at Rolling Fork near Boston, Kentucky, was also evaluated for flooded conditions. When the river flowed into the floodplain, the roughness coefficient increased from 0.046 to 0.097. Chow (1959) reported a roughness coefficient of 0.10 for woods. Our research confirms values this high and higher for flow within the forest floodplain.

Vegetation

Plots within a particular site tended to be similar in species composition, with the exception of Chicod Creek. The most important overstory species at Contentnea Creek as determined by importance values were *Acer rubrum* (red maple), *Liquidambar styraciflua* (sweetgum), *Quercus michauxii* (swamp chestnut oak), and *Q. phellos* (willow oak) (Table 4). The midstory was dominated by *A. rubrum* and *Carpinus caroliniana* (ironwood) (Table 4). Plots at the Lumber River were dominated by overstory trees such as *Nyssa sylvatica* var. *biflora* (swamp blackgum), *A. rubrum, Q. laurifolia* (laurel oak), *L. styraciflua,* and *Taxodium distichum* var. *distichum* (baldcypress). The midstory consisted mostly of *A. rubrum* and *Q. laurifolia* (laurel oak). Plots at Chicod Creek were dominated by *Fraxinus* spp. (ash) and *N. aquatica* (water tupelo). The well-developed midstory was composed of *A. rubrum, C. caroliniana, Fraxinus* spp., *N. aquatica, Planera aquatica* (planer-tree), *and Ulmus americana* (American elm). The overstory species that dominated plot 1 at the Trent River were *A. rubrum, Carya aquatica* (water hickory), *F. pennsylvanica* (green ash), *Q. laurifolia,* and *U. americana.* The midstory trees with the highest importance values were *C. caroliniana, Q. lyrata,* and *U. americana.* Plots 2, 3, 4, and 5 at the Trent River had an overstory with *T. distichum* var. *distichum, F. pennsylvanica,* and *A. rubrum* as the most important species. *A. rubrum, C. caroliniana, Q. lyrata,* and *U. americana* dominated the midstory of plots 3, 4, and 5 at the Trent River.

The understory at Contentnea Creek was sparse, consisting mainly of a very few *A. rubrum* seedlings. The understory at the Lumber River was not well-developed either, perhaps because the site is flooded most of the summer. The understory was more developed at Chicod Creek, with *Saururus cernuus* (lizard's tail) and *Itea virginica* (Virginia willow) most abundant (Table 4). The understory of Trent River plot 1 was dominated by *Carex* spp. *Arundinaria gigantea* (giant cane) and *Carex* spp. (sedge) were the most important understory species in plots 3, 4, and 5. Plot 2 at the Trent River had very little understory vegetation.

Plots had relatively uniform overstory species richness (number of species). Lumber River plot 2 had the lowest species richness with 4 species and Trent River plot 5 had the highest with 10 species. Other plots ranged from 5 to 7 species in the overstory. Again, the midstory species richness also varied little among plots. Chicod Creek plot 4 had the lowest species richness with 4 and Trent River plots 4 and 5 had the highest with 13 and 11 midstory species respectively. The understory species richness varied more among plots than the midstory and overstory species richnesses. Trent River plots 1, 3, 4, and 5 had 22 to 38 species per plot and were higher in richness as compared to other plots. Plots from the Lumber River, Contentnea Creek, and Chicod Creek had from 11 to 19 species per plot.

Table 4. Species composition of study sites.

	Contentnea Creek		Lumber River		Chicod Creek				Trent River				
	1	2	1	2	1	2	3	4	1	2	3	4	5
Importance values for dominant overstory species													
Quercus phellos	0.31	0.33			0.05								
Liquidambar styraciflua	0.26	0.19	0.19	0.20	0.05	0.18	0.07	0.02			0.10	0.17	0.08
Quercus michauxii	0.21	0.00											
Nyssa sylvatica	0.11	0.05	0.28	0.53									
Quercus lyrata	0.11									0.10		0.07	0.05
Acer rubrum		0.41	0.25	0.13	0.08	0.04	0.07	0.06	0.13	0.05	0.20		0.13
Quercus laurifolia			0.15	0.14					0.13			0.05	0.19
Taxodium distichum			0.11				0.04	0.21		0.60	0.35		0.23
Nyssa aquatica					0.65	0.18	0.49	0.58					
Fraxinus caroliniana					0.03		0.04				0.03		
Fraxinus spp.						0.33							
Fraxinus pennsylvanica						0.23	0.27	0.11	0.24	0.17	0.23	0.67	0.14
Ulmus americana						0.04	0.02	0.02	0.19	0.06	0.05	0.05	0.06
Carya aquatica									0.14	0.03			
total no. of species	5	5	6	4	6	6	7	6	7	6	7	5	10
Importance Values for dominant midstory species													
Carpinus caroliniana	0.51	0.26			0.18				0.67	0.01	0.15	0.21	0.41
Acer rubrum	0.23	0.33	0.49	0.25	0.06	0.11	0.23	0.40	0.04	0.14	0.32	0.04	0.15
Planera aquatica	0.02	0.09				0.18							
Fraxinus pennsylvanica		0.03			0.21	0.07	0.49	0.07		0.05	0.12	0.13	0.02
Quercus laurifolia			0.17	0.34		0.02				0.02		0.24	0.15
Nyssa aquatica					0.39	0.07	0.14	0.38					
Fraxinus caroliniana					0.12		0.04	0.09			0.32		
Fraxinus spp.						0.37							
Ulmus americana						0.12	0.09	0.04	0.11	0.07	0.13	0.12	0.14
Quercus lyrata									0.12	0.56		0.01	0.02
total no. of species	7	7	5	5	6	8	5	4	5	8	6	13	11
Relative cover for dominant understory species													
Saururus cernuus				0.05	0.62	0.25	0.06	0.01			0.07	0.05	0.03
Itea virginica				0.01	0.13	0.10	0.02				0.03	0.04	0.04
Carex spp.								0.11	0.03		0.07	0.10	0.17
Arundinaria gigantea											0.13	0.10	

Contentnea Creek and Lumber River Plots are not included in this table as the understory at these sites was only sparsely vegetated.

Soils

Soil characteristics within a particular site tended to be similar, with some differences among sites. The Lumber River plots had soils in the Johnston series which are very poorly drained and tend to be very strongly acid. The pH at the Lumber River was lower than at the other three sites (3.9 as compared with 4.3 to 5.8 at other sites). Contentnea Creek plots have soils in the Kinston series, which are poorly drained and typically acid. Soils at Chicod Creek were in the Bibb series and were poorly drained and of medium acidity. %BS, CEC, and percent calcium were lowest at Contentnea Creek and the Lumber River. Trent River soils were in the Muckalee series. These soils are poorly drained, of medium to neutral acidity, and are frequently flooded for brief periods. Only plots at Contentnea Creek and plot 1 at the Trent River had soil mottling, which was not correlated to species composition, so it was eliminated from the analysis.

Ordination Analyses

A graph of the ordination scores for overstory importance values on the first and second DCA axes is shown in Figure 3. The first DCA axis represents most of the variation among plot ordination scores. Plots that occur close together in this graph are more similar in species composition than plots that occur farther apart. CEC, %BS, pH, percent calcium, and concentrations of phosphorus, potassium, and sodium were highly negatively correlated with the first ordination axis (see Table 5). With increasing axis 1 scores, these factors decrease in value; the Lumber River and Contentnea Creek plots have lower CEC, percent base saturation, and pH than plots at Chicod Creek. In addition, 1-day through 10-day growing season flooding frequencies were highly negatively correlated with the first axis. The environmental factors in this table are not independent. For example, CEC is related to percent base saturation and pH and is also based on the mineral properties of the soil. Flood frequencies are also interdependent to some extent, e.g., the 4-day flood frequency is correlated to the 3-day flood frequency ($r = 0.93$). This correlation falls off at the 30-day flood frequency. One explanation for this is a 30-day flood event probably requires unusual storm conditions, whereas shorter duration floods may occur more frequently under normal events.

The DCA axis 1 ordination scores for the overstory importance values are correlated with PCA scores for growing season flooding frequency ($r^2 = 0.88$). Further examination of the ordination data reveals that of the flood frequencies correlated with DCA axis 1, the 6-day growing season frequency had the highest correlation ($r = -.91$). A graph of 6-day flood frequency versus the DCA axis 1 scores for the overstory importance values shows a significant linear relationship between these two variables (Figure 3). The frequency of the 6-day flood explains most of the variation among plots; in fact, it is more important than all of the growing season flood frequencies combined.

For the midstory importance values, DCA axis 1 scores were highly correlated with concentrations of phosphorous, potassium, zinc, copper, and percent sand and percent clay in the A horizon and the least permeable horizon (Table 6). Midstory DCA scores for axis 1 are also highly correlated with the 1-day through 5-Day flood frequencies. The Chicod Creek plots at the higher flood frequencies drive the linear relationship. For understory vegetation, again a variety of soil factors were correlated with DCA axis 1 scores, including CEC, %BS, pH, and

Table 5. Pearson correlation factors for DCA Axis 1 scores for overstory importance values to environmental factors. Correlation coefficients in bold type are significant to P=0.05 and coefficients in normal type are significant to P=0.10.

	dca	*HM%*	*CEC*	*BS%*	*pH*	*P*	*K*	*Ca%*	*Mg%*	*Mn*	*Zn*	*Zn-Al*	*Cu*	*S*	*Na*	*%s*	*%si*	*%c*	*%s-l*	*%si-l*	*%c-l*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*15*
HM%																																
CEC	**-0.81**																															
BS%	**-0.81**		**0.90**																													
pH	**-0.65**		**0.81**	**0.93**																												
P	**-0.68**		**0.64**																													
K	**-0.66**		**0.69**	0.50		**0.96**																										
Ca%	**-0.80**		**0.89**	**0.99**	**0.90**																											
Mg%								-0.50																								
Mn		-0.49					0.51		**0.65**																							
Zn						**0.92**	**0.90**		**0.57**	**0.64**																						
Zn-Al						**0.92**	**0.91**		**0.57**	**0.65**	**1.00**																					
Cu		0.53				**0.85**	**0.77**				**0.82**	**0.81**																				
S	-0.48		**0.68**			**0.76**	**0.77**				**0.69**	**0.70**	**0.62**																			
Na	**-0.55**		**0.63**	0.45	0.52	0.61	0.58	0.44						**0.79**																		
%s			-0.52			-0.52	**-0.65**				-0.48	-0.49	-0.55	-0.50																		
%si		0.50														**-0.81**																
%c	-0.52		**0.62**			**0.72**	**0.83**			0.48	**0.69**	**0.70**	**0.65**	**0.61**	0.46	**-0.94**																
%s-l			**-0.57**			**-0.63**	**-0.70**				**-0.57**	**-0.58**	**-0.64**	-0.52	-0.48	**0.89**		**-0.92**														
%si-l																**-0.77**		**0.69**	**-0.90**													
%c-l	-0.54		**0.63**			**0.77**	**0.86**			0.49	**0.74**	**0.75**	**0.70**	**0.64**	**0.56**	**-0.88**		**0.97**	**-0.96**	**0.74**												
1	**-0.60**					**0.90**	**0.87**			**0.69**	**0.93**	**0.92**	**0.81**	0.52		-0.49		**0.71**	**-0.66**		**0.78**											
2	**-0.60**					**0.89**	**0.88**			**0.62**	**0.87**	**0.87**	**0.80**	0.49				**0.62**	-0.52		**0.67**	**0.91**										
3	**-0.66**					**0.74**	**0.72**			**0.74**	**0.77**	**0.78**	**0.56**					**0.62**	**-0.58**		**0.69**	**0.90**	**0.74**									
4	**-0.76**		0.51			**0.76**	**0.68**			**0.60**	**0.73**	**0.73**	**0.56**		**0.58**			**0.55**	-0.54		**0.64**	**0.85**	**0.66**	**0.93**								
5	**-0.85**		**0.70**	**0.64**	**0.55**	**0.89**	**0.86**	**0.56**			**0.73**	**0.73**	**0.64**	0.54	**0.50**			**0.63**	**-0.57**		**0.68**	**0.82**	**0.87**	**0.73**	**0.77**							
6	**-0.91**		**0.73**	**0.71**	**0.62**	**0.85**	**0.81**	**0.66**			**0.71**	**0.70**	0.53	**0.56**	**0.60**			0.55	-0.44		**0.60**	**0.78**	**0.76**	**0.75**	**0.84**	**0.94**						
7	**-0.90**		**0.73**	**0.66**	0.51	**0.85**	**0.77**	**0.63**			**0.62**	**0.63**	**0.63**	**0.57**	**0.53**						0.52	**0.71**	**0.78**	**0.64**	**0.72**	**0.93**	**0.92**					
8	**-0.78**			0.49		0.49		0.52							0.42								0.55		0.53	**0.63**	**0.71**	**0.77**				
9	**-0.86**		0.53	0.53	0.44	0.66	**0.57**	0.53			0.48				**0.59**							**0.63**	**0.65**	**0.57**	**0.73**	**0.80**	**0.87**	**0.87**	**0.92**			
10	**-0.67**					0.53									0.37							**0.57**	**0.67**	0.53	**0.62**	**0.71**	**0.67**	**0.75**	**0.83**	**0.88**		
15																															0.49	
30		**0.41**									0.48		0.60		**0.53**							0.53			0.52							

dca = overstory DCA axis 1 scores
HM% = % humic matter
CEC = cation exchange capacity
BS% = % base saturation
P = phosphorus index
K = potassium index
Ca% = % calcium
Mg% = % magnesium
Mn = manganese index
Zn = zinc index
Cu = copper index
S = sulfur index
Na = sodium
%s = % sand at a depth of 6 cm
%si = % silt at a depth of 6 cm
%c = % clay at a depth of 6 cm
%s-l = % sand in the least permeable horizon
%si-l= % silt in the least permeable horizon
%c-l=% clay in the least permeable horizon

Numbers 1 through 30 are flood frequencies for 1-day through 10-day, 15-day, and 30-day floods.

Table 6. Pearson correlation factors for DCA Axis I scores for midstory importance values to environmental factors.
Correlation coefficients in bold type are significant to P=0.05 and coefficients in normal type are significant to P=0.10.

	dca	HM%	CEC	BS%	pH	P	K	Ca%	Mg%	Mn	Zn	Cu	S	Na	%s	%si	%c	%s-l	%si-l	%c-l	1	2	3	4	5	6	7	8	9	10	15
HM%																															
CEC	-0.49																														
BS%			**0.90**																												
pH			**0.81**	**0.93**																											
P	**-0.80**		**0.64**																												
K	**-0.84**		**0.69**	0.50		**0.96**																									
Ca%			**0.89**	**0.99**	**0.90**																										
Mg%								-0.50																							
Mn	-0.53	-0.49					0.51		**0.65**																						
Zn	**-0.83**					**0.92**	**0.90**		**0.57**	**0.64**																					
Cu	**-0.82**	0.66				**0.85**	**0.77**				**0.82**																				
S	-0.61		**0.68**			**0.76**	**0.77**				**0.69**	**0.62**																			
Na			**0.63**			**0.61**	0.58				0.52		**0.79**																		
%s	**0.77**		-0.52			-0.52	**-0.65**				-0.48	-0.55	-0.50																		
%si		0.50													**-0.81**																
%c	**-0.86**		**0.62**			**0.72**	**0.83**			0.48	**0.69**	0.65	0.61		**-0.94**	**0.56**															
%s-l	**0.80**		**-0.57**			**-0.63**	**-0.70**				**-0.57**	-0.64	-0.52		**0.89**	**-0.58**	**-0.92**														
%si-l	-0.56														**-0.77**	**0.67**	**0.69**	**-0.90**													
%c-l	**-0.88**		**0.63**			**0.77**	**0.86**			0.49	0.74	0.70	**0.64**	**0.56**	**-0.88**		**0.97**	**-0.96**	**0.74**												
1	**-0.84**					**0.90**	**0.87**			**0.69**	**0.93**	**0.81**	0.52		-0.49		**0.71**	-0.66		**0.78**											
2	**-0.73**					**0.89**	**0.88**			**0.62**	**0.87**	**0.80**	0.49				**0.62**	-0.52		**0.67**	**0.91**										
3	**-0.75**					**0.74**	**0.72**			**0.74**	**0.77**	0.56					**0.62**	-0.58		**0.69**	**0.90**	**0.74**									
4	**-0.62**		0.51			**0.76**	**0.68**			**0.60**	**0.73**	0.56	0.46	**0.58**			**0.55**	-0.54		**0.64**	**0.85**	**0.66**	**0.93**								
5	**-0.61**		**0.70**	**0.64**	**0.55**	**0.89**	**0.86**	**0.56**			**0.73**	**0.64**	0.54				**0.63**	-0.57		**0.68**	**0.82**	**0.87**	**0.73**	**0.77**							
6	-0.53		**0.73**	**0.71**	**0.62**	**0.85**	**0.81**	**0.66**			**0.71**	0.53	0.56	**0.60**			0.55			**0.60**	**0.78**	**0.76**	**0.75**	**0.84**	**0.94**						
7	-0.52		**0.73**	**0.66**	0.51	**0.85**	**0.77**	**0.63**			**0.62**	0.63	0.57	0.53						0.52	**0.71**	**0.78**	**0.64**	**0.72**	**0.93**	**0.92**					
8				0.49		0.49		0.52														**0.55**		0.53	**0.63**	**0.71**	**0.77**				
9			0.53	0.53		**0.66**	0.57	0.53						**0.59**							**0.63**	**0.65**	**0.57**	**0.73**	**0.80**	**0.87**	**0.87**	**0.92**			
10						0.53															**0.57**	**0.67**	0.53	0.62	**0.71**	0.67	**0.75**	**0.83**	**0.88**		
15																															
30												**0.60**		0.53	-0.15	-0.11					0.53			0.52							

dca = midstory DCA axis I scores
HM% = % humic matter
CEC = cation exchange capacity
BS% = % base saturation
P = phosphorus index
K = potassium index
Ca% = % calcium
Mg% = % magnesium
Mn = manganese index
Zn = zinc index
Cu = copper index
S = sulfur index
Na = sodium
%s = % sand at a depth of 6 cm
%si = % silt at a depth of 6 cm
%c = % clay at a depth of 6 cm
%s-l = % sand in the least permeable horizon
%si-l= % silt in the least permeable horizon
%c-l=% clay in the least permeable horizon

Numbers 1 through 30 are flood frequencies for 1-day through 10-day, 15-day, and 30-day floods.

Table 7. Pearson correlation factors for DCA Axis I scores for understory importance values to environmental factors.
Correlation coefficients in bold type are significant to P=0.05 and coefficients in normal type are significant to P=0.10.

	dca	HM%	CEC	BS%	pH	P	K	Ca%	Mg%	Mn	Zn	Zn-Al	Cu	S	Na	%s	%si	%c	%s-l	%si-l	%c-l	1	2	3	4	5	6	7	8	9	10	15
dca																																
HM%																																
CEC	-0.86																															
BS%	-0.82		0.90																													
pH	-0.73		0.81	0.93																												
P	-0.46		0.64																													
K	-0.47		0.69	0.50		0.96																										
Ca%	-0.86		0.89	0.99	0.90																											
Mg%	0.57							-0.50																								
Mn		-0.49					0.51		0.65																							
Zn						0.92	0.90		0.57	0.64																						
Zn-Al						0.92	0.91		0.57	0.65																						
Cu		0.53				0.85	0.77				0.82	0.81																				
S			0.68			0.76	0.77				0.69	0.70	0.62																			
Na	-0.55		0.63		0.52	0.61	0.58	0.44			0.52	0.52		0.79																		
%s			-0.52			-0.52	-0.65				-0.48	-0.49	-0.55	-0.50																		
%si		0.50		-0.01												-0.81																
%c			0.62			0.72	0.83			0.48	0.69	0.70	0.65	0.61	0.46	-0.94	0.56															
%s-l			-0.57			-0.63	-0.70				-0.57	-0.58	-0.64	-0.52	-0.48	0.89	-0.58	-0.92														
%si-l																-0.77	0.67	0.69	-0.90													
%c-l			0.63			0.77	0.86			0.49	0.74	0.75	0.70	0.64	0.56	-0.88		0.97	-0.96	0.74												
1						0.90	0.87			0.69	0.93	0.92	0.81	0.52		-0.49		0.71	-0.66		0.78											
2						0.89	0.88			0.62	0.87	0.87	0.80	0.49				0.62	-0.52		0.67	0.91										
3	-0.49		0.45			0.74	0.72			0.74	0.77	0.78	0.56					0.62	-0.58		0.69	0.90	0.74									
4	-0.55		0.51			0.76	0.68			0.60	0.73	0.73	0.56		0.58			0.55	-0.54		0.64	0.85	0.66	0.93								
5	-0.58		0.70	0.64	0.55	0.89	0.86	0.56		0.44	0.73	0.73	0.64	0.54	0.50			0.63	-0.57		0.68	0.82	0.87	0.73	0.77							
6	-0.68		0.73	0.71	0.62	0.85	0.81	0.66			0.71	0.70	0.53	0.56	0.60			0.55			0.60	0.78	0.76	0.75	0.84	0.94						
7	-0.65		0.73	0.66	0.51	0.85	0.77	0.63			0.62	0.63	0.63	0.57	0.53						0.52	0.71	0.78	0.64	0.72	0.93	0.92					
8	-0.57			0.49		0.49		0.52															0.55		0.53	0.63	0.71	0.77				
9	-0.60		0.53	0.53		0.66	0.57	0.53			0.48				0.59							0.63	0.65	0.57	0.73	0.80	0.87	0.87	0.92			
10						0.53																0.57	0.67	0.53	0.62	0.71	0.67	0.75	0.83	0.88		
15																															0.49	
30											0.48		0.60		0.53							0.53			0.52							

dca = understory DCA axiz I scores
HM% = % humic matter
CEC = cation exchange capacity
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P = phosphorus index
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S = sulfur index
Na = sodium
%s = % sand at a depth of 6 cm
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%c = % clay at a depth of 6 cm
%s-l = % sand in the least permeable horizon
%si-l= % silt in the least permeable horizon
%c-l=% clay in the least permeable horizon

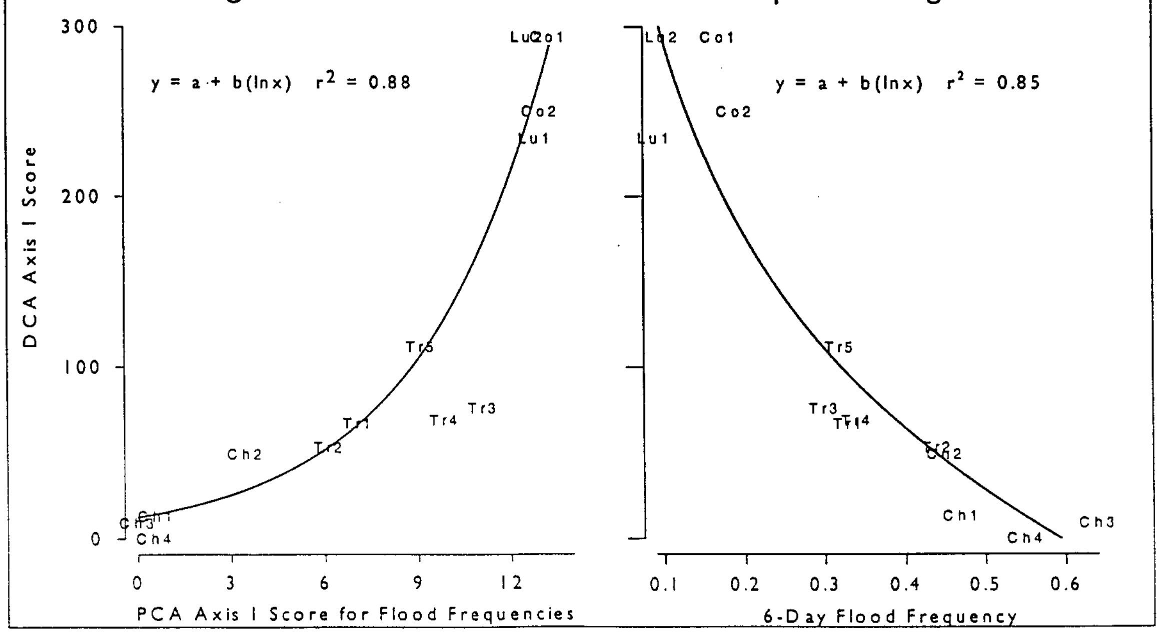
Numbers 1 through 30 are flood frequencies for 1-day through 10-day, 15-day, and 30-day floods.

percent calcium (Table 7). The 4-day through 9-day flood frequencies are significantly correlated with the first DCA axis, with the 6-day flood frequency having the highest correlation (r = -0.68). Concentrations of phosphorus, potassium, manganese, zinc, copper, percent clay in the A horizon and least permeable horizon, and percent sand in the least permeable horizon are highly correlated to the second DCA axis. As with the overstory, the PCA ordination scores for the flood frequencies indicate a relationship between DCA axis I score and flood frequency. The 6-day flood frequencies do not explain all of the variation in DCA axis I scores; CEC also contributes to the variation (Table 8).

Table 8. Linear regression between two environmental factors and DCA axis I scores for understory. N =13.

	degrees of freedom	Sum of squares	Source	R^2
Frequency of 6-day flood	1	98,000	0.0018	0.75
Cation exchange capacity	1	62,000	0.0072	
Error	10	55,000		
Total	12	215,000		

Figure 3. Ordination scores and relationship to flooding.



IMPLICATIONS FOR WETLANDS RESTORATION

Our research demonstrates that wetland plant communities are a function of hydrology and soil properties, among other factors. Restoration plans typically emphasize planting of the desired species. However, for wetland restoration to succeed, both the appropriate soil and hydrologic regime for the desired plant community must be provided, if that plant community is to be productive and persistent without continual management. It is, in fact, more important to establish the physical requirements (soil and water) than the biological components (plant species). With the correct soil and water, the desired plant community is likely to establish over time by natural succession; without them, the desired plant community will never persist. Restoration plans must contain details for restoration of soil and water.

In our study, the 6-day flood frequency in the growing season explains most of the variation among groups of plots, and might be useful in the restoration of an appropriate hydrologic regime. Use of a particular flood frequency could simplify the manipulation of hydrologic parameters for wetland restoration projects. Other researchers have suggested the use of very detailed water budgets to increase the chances of successful restoration of wetlands (LaBaugh, 1986; Novitski, 1989). We suggest that a particular flood frequency such as the growing season 6-day flood frequency may be sufficient in bringing ecologists closer to successful restoration of forested wetlands since constructing a detailed water budget may prove impractical for all projects due to cost and time constraints. This assumes that the wetland will be established in the correct landscape position, so that it can be assumed that the other length floods correlated with the 6-day floods will occur as well.

Soil is more difficult to establish and modify, and will change as the hydrology changes. Soil at the restoration site should resemble the soils on which the desired plant community naturally occurs. Horizons should be of similar compostion, texture, and thickness. Topsoil can be added if necessary. Some chemical properties can be altered with judicious use of fertilizers, lime, and other amendments. If the surface grade must be changed, it is important to recover the horizons that can be used to construct the desired soil.

After the appropriate soil and water have been established, energy and expense can expended on establishing the plant community. Emphasis should be placed on the species that are not likely to become established naturally, e.g., heavy-seeded tree species.

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