Final Report to the NC Ecosystem Enhancement Program

North River Wetland Restoration Research

Submitted by:

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Date Submitted:
July 31, 2009

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Project Website - http://www.bae.ncsu.edu/topic/wetlands/index.html

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Acknowledgements

This project has been a great example of multi-agency and multidisciplinary team work, a key component in the success of this project. There are many people that without their help, this project would not have been possible.

The authors of this report would like to first thank the primary contacts in NCEEP that have provided funding, guidance, and encouragement - Mac Haupt, Kevin Miller, and Jeff Jurek.

The North Carolina Coastal Federation, whose purchase of North River Farms through funds from the NC Clean Water Management Trust Fund essentially initiated the project, has continued to be a great partner. We received much support from Todd Miller, Tracy Skrabal, Sara King (now with CWMTF) and Lexia Weaver.

Larry Eaton from NCDWQ provided much needed help with benthic surveys conducted on the Phase II tidal stream in 2008 and 2009.

NCSU-BAE personnel supported our efforts particularly during the beginning of the monitoring phase of Phase I and Phase II included L.T. Woodlief, Mike Adcock, and Jonathon Smith.

Dave Penrose (BAE) and Chris Niewoehner (Soil Science) provided sampling support for aquatic organisms and marsh vegetation respectively within the Phase II tidal marsh.

Research by graduate students Jason Wright, Jennifer Shelby, Jennifer Burdette, Alex Baldwin, Nick Lindow, Jodi Lindgren, Tracy Morris, Evan Corbin, Bobby Jarzemsky, and Randall Etheridge formed the foundation for the data and conclusions generated during this study and described in this report. Without their hard work and diligence over the last 7 years, this report would not have been possible.

Our efforts were also supported by a host of undergraduates - Marcus Moore, Christopher Muhs (Penn State), Allison Melton, Laura Lord, and Spencer Davis. The experience that these students gained during this project will hopefully be beneficial in directing their future career aspirations.

1.0 – Introduction

The goal of wetland restoration/creation projects is to effectively construct a system that exhibits the same structure and beneficial functions as a targeted wetland community. Poor site selection, inappropriate designs and inefficient implementation will result in restorations that are too expensive and fall short of achieving target ecosystem services, whether the restoration/creation project is required for compensatory mitigation or a volunteer effort.

In late 2002, to advance the understanding of design and construction techniques used in restoration in eastern NC, faculty from the Departments of Biological and Agricultural Engineering (BAE), Soil Science (SSC), and Forestry and Environmental Resources (FER) at North Carolina State University (NCSU) teamed with the NC Wetland Restoration Program (NCWRP, now the Ecosystem Enhancement Program (NCEEP)) and the North Carolina Coastal Federation (NCCF). Through a grant from the NC Clean Water Management Trust Fund (CWMTF) NCCF purchased North River Farms in Carteret County, NC (White Oak River Basin, DWQ subbasin 03-05-04), which was approximately 2400 ha (6,000 acres) in size, to restore wetland function to this land that had been drained for agricultural row-crop production. Restoration was seen as a measure that could improve water quality to the nearby North River, which was the receiving body of water for a large portion of the drainage water originating from North River Farms and nearby Open Grounds Farm.

The NCWRP/NCEEP supported Phase I of the project, which included funds for the design and construction of 100 ha (250 acres) of non-riverine wet hardwood wetland, post-construction monitoring of that site and a reference wetland community, pre-construction monitoring of a 43 ha (106 acre) Phase II stream and wetland complex, and design of that system. NCEEP then funded the construction of the tidal marsh portion of the Phase II effort and subsequent post construction monitoring of that area. None of this work was undertaken for compensatory mitigation.

From 2002-2009 the NCSU team provided restoration designs, construction oversight, and restoration research for 145 ha (356 acres) of restored wetlands and over 2600 m (8500 ft) of constructed freshwater and tidal streams at North River Farms. Wetland communities restored included 123 ha (304 acres) of non-riverine wet hardwood, 14 ha (35 acres) of tidal marsh, and 7 ha (17 acres) of riparian wetlands.

The main goal of the effort has been to improve downstream water quality in the North River estuary by reducing drainage outflows and diverting agricultural drainage water from an adjoining farm across the restoration. Wetland restoration at this site has been unique because it has employed innovative and varied designs, several of which were compared in side-by-side plots for hydrologic response. After nearly 7 years of research, important findings concerning restoration design, construction techniques, and restoration success have emerged. These findings will be useful to enhance the success of future NCEEP restorations. This endeavor has been supported (at least in part) by 8 faculty, 3 research technicians, 10 graduate students and five undergraduates during this period, and resulted in numerous graduate theses, presentations and proceedings papers at professional meetings and conferences. At the time of this report, several publications to be submitted to peer reviewed journals are being prepared.

The intention of this report is to succinctly provide lessons learned and recommendations, in a manner that can be effectively utilized by NCEEP personnel in future restoration. This report is structured similarly to a conference proceedings, with each chapter dealing with a separate research topic studied at the North River restoration site. More detailed datasets can be provided in the future as requested and can be augmented through journal articles and extension documents that have or will be produced in the upcoming months. The report will be sectioned into primary topic areas that were studied in this effort.

This site should continue to be used for research, training, and outreach. To visit the site, the main entrance to North River Farms is located on US-70 east. From Morehead City, travel US-70 east, cross over North River and Wards Creek and travel through the town of Otway. Pass SR1332 (Harkers Island Road) before reaching the entrance of the farm on the left, marked with a large yellow "North River Farms" sign. There is a gate that requires a key, so contact Mike Burchell (919-513-7372) with NCSU-BAE or Lexia Weaver (252-393-8185) with the NCCF to arrange a visit.

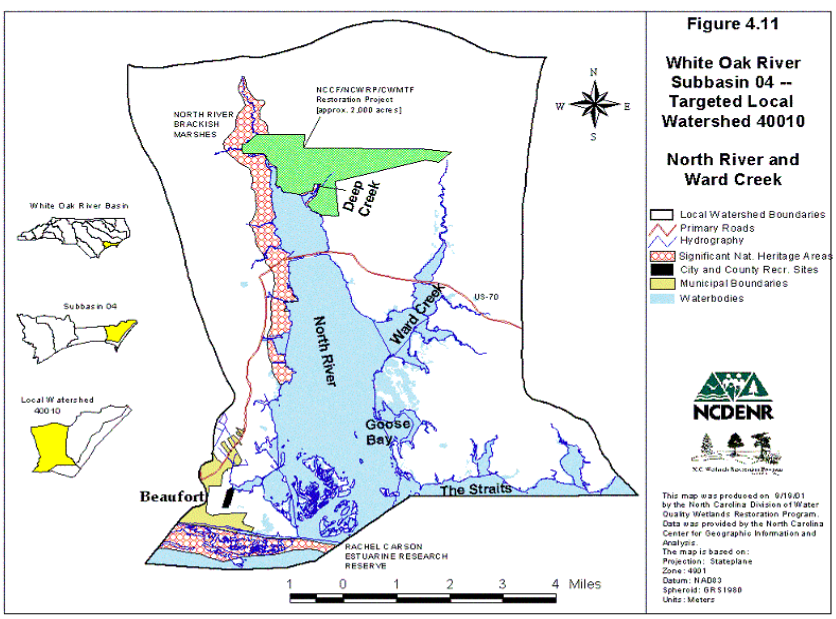


Figure 1. Map that highlights the area targeted in this report (NCDENR, 2001)

2.0 - Phase I – Restoration of 100 ha (250 acres) of non-riverine wet hardwood wetland

(Aerial photograph of Phase I, Blocks 1 and 2 taken in June 2009)

2.1 - Introduction and Research Goals

Following an initial site survey and identification of a reference wetland it was determined that the target wetland community for the first phase of restoration (100 ha (250 acre)) would be non-riverine wet hardwood. Soils at the site were mostly Deloss, with pockets of Wasda muck and Leon sand. The restoration design was geared towards achieving an in increase wetland habitat, hydrologic function, and improve local water quality; and, it included a research component that would lead to improved future wetland restorations. The primary research goals for this project included:

1. Determine the influence of surface conditions on achieving target wetland hydrology and soil conditions
2. Evaluate survival of trees planted within the restoration without fertilization and herbicide application
3. Determine the water quality improvement of outflow from the wetland during the first three years following restoration

During the first phase of the restoration project (completed in March 2003), 100 ha (250 acres) of prior converted cropland non-riparian hardwood wetland were restored by plugging existing field ditches, utilizing three distinct soil surface construction techniques (to be discussed in more detail later), and installation of 9 flashboard risers to control water table level and outflow. Wetland features such as open water areas and simulated tree falls were also added across the site in regular intervals to increase topographic diversity.

The construction was completed in approximately 4 months and the site was planted with native wetland trees such as oaks (*Quercus spp*.), water tupelo and black gum (*Nyssa aquatic* and *Nyssa sylvatica*), bald cypress (*Taxodium disticum*), atlantic white cedar (*Chamaecyparis thyoides*), green ash (*Fraxinus pennsylvanica*), and longleaf pines (*Pinus palustris*) on the sandier soils. Over 89,000 trees were planted at the site, although at the time of planting, some of the seedlings were not viable and deemed to have a low probably of survival or establishment due to a variety of issues that are discussed in section 2.4.

Two-thirds of the Phase I restoration were separated into 3 Blocks of 3 plots each to use in the post-construction hydrology, soils, tree survival, and water quality research. Results from the research are discussed in the following 5 sections.

2.2 - Hydrologic Response of Three Different Wetland Restoration Techniques

2.2.1 Introduction

Achieving adequate wetness is key component in successful wetland restoration. However, this does not imply that a wetter site is better. Natural wetlands alternate seasonally between dry and wet conditions. This is a major reason that at least one and preferably multiple reference wetlands be identified prior to restoration to determine the target hydroperiod.

At a minimum, to achieve wetland hydrology in prior converted wetlands, ditches that were installed for agricultural drainage must be plugged in the converted areas to reduce drainage from the site. Removing the field crown and adding microtopography in addition to ditch plugging may improve the chances of meeting wetland hydrology requirements, but it does increase costs. Studies have suggested that these restoration techniques may be beneficial because they increase stormwater storage, prolong surface moisture during dry periods, and provide a more diverse habitat. However, there is currently a lack of data to strongly support a particular treatment practice for restoring wetland hydrology. This research on the specific effects of microtopography was designed to further the understanding of design techniques that ensure appropriate hydrology in restored wetlands.

Our hypothesis entering this research was that removal of field crowns established to accelerate surface drainage for agricultural production would be necessary to restore the natural hydroperiod and local microtopographic gradients that contribute to the patterns and richness of plant communities in forested wetlands. Furthermore, we hypothesized that surface roughening without crown removal might be a more cost effective construction technique for restoring hydrology and microtopograhic roughness in lieu of the more expensive crown removal technique. Lastly, it was hypothesized that mere plugging of field ditches, while a necessary component of hydrologic restoration, might not be adequate to restore jurisdictional hydrologic criteria in the center of fields where agricultural crowns are the highest. This component of the research effort has been beneficial since it has included long term (2003-2008) water table and outflow measurements at the site. This allows for more conclusive determinations and recommendations to be made for future restoration activities in eastern NC.

2.2.2 Methods and Materials

Two separate studies have been conducted at the site by Wright (2005) and Jarzemsky (2009). Plots for the three different surface construction techniques were implemented in triplicate. Ditches in the fields were plugged and the surface construction techniques studied were:

1. None - therefore maintaining the smooth surface and field crowns common in crop production
2. Surface roughening - irregular, roughened surface providing increased micro topography and surface storage
3. Crown removal - removal of the turtle-back profile "crown" thereby establishing a relatively flat but rough profile.

Each restoration technique was replicated in triplicate forming three blocks in a randomized block design. Each of the replicates was separated by low earthen berms, constructed at the mid-point between the intermittently plugged agricultural ditches. The intermittently plugged ditches remained in the center of each treatment and provided a low gradient channel for gradual conveyance of surface water towards the outlet. Flashboard riser water control structures were installed in the outlet of each ditch to provide water level and subsequently drainage control, and to provide a mechanism to accommodate accurate measurement of outflow. The water level control elevation of the flashboard risers corresponded to the approximate land surface elevation of the restored areas.

The initial study by Wright (2005) evaluated and compared the hydrology of the restoration techniques to the hydrology of a natural, non-riverine wet hardwood wetland hereafter referred to as the reference wetland. The reference wetland was not anticipated or intended to precisely represent the target restoration hydrology because the reference occupies a slightly different landscape position than the restoration site. Instead, the reference site was selected and instrumented to quantify the natural range of hydrologic variability that might occur in a natural wetland. The reference site selected was also the only relatively pristine (no obvious evidence of anthropogenic activity within several decades) non-riverine hardwood wetland of significant size in close proximity to the restoration area.

Monitoring wells were installed in the research areas in 2002 along a transect with two wells in each treatment (Figure 1). Water table depth was monitored with INFINITY continuous water table recorders (Infinities USA Inc., Daytona Beach, FL) installed in 4 inch diameter PVC wells. Flow from each treatment was controlled and monitored using water control structures with 30^{o} v-notch weirs. Potentiometers with a pulley-float system were used to measure the head over the weir, and measurements were stored in a datalogger at each location (SGT Engineering, Champaign, Ill). Three transects with three water table monitoring wells each were installed in the reference with well diameters and water table recorders as described above (Figure 2). Precipitation was collected at 3 locations on site using tipping bucket rain gauges and HOBO dataloggers.

The hydrology of the restoration and the reference sites was analyzed using the following criteria (Note: Criteria 3-5 were evaluated independently for 2 durations: 1) during the growing season and 2) annually during the entire study period):

1) number of times that jurisdictional wetland criteria was met
2) the range of the water table fluctuation;
3) number of days the water table was at or above the surface;
4) number of days the water table was within 30 cm (12 in) of the surface;
5) $SEW_{30,}$ the measure of the duration and frequency that the water table is above a threshold depth of 30 cm (12 in).

Additionally, outflow volumes from all treatments were calculated and compared between treatments. Long term hydrologic simulations for the site were performed using the model DRAINMOD, calibrated using the first two years of groundwater data from the site.

To address additional research questions raised in the initial two year study, a follow- up study by Jarzemsky (2009) included a more intense topographic survey, installation of four additional manual groundwater observation wells in each restoration replicate, and two additional automatic water table wells installed in two of the three transects within the reference wetland. Water table data for 2006-2008 from the restoration treatments and the reference wetland were evaluated using what was determined to be the most important four hydrologic criteria:

1) Longest continuous period of water table within 30 cm (12 in) of surface during growing season
2) Average water table depth (full year)
3) SEW_{30} (full year)
4) Number of days of surface inundation (full year)

Outflow data from each treatment area were also analyzed to determine treatment effects.

Data was analyzed statistically using SAS statistical software (SAS Institute Inc, 1985). An ANOVA means test with the Tukey adjustment was applied to the data. The Tukey method was applied to control the type-I experiment-wise error rate since multiple pair-wise comparisons were made.

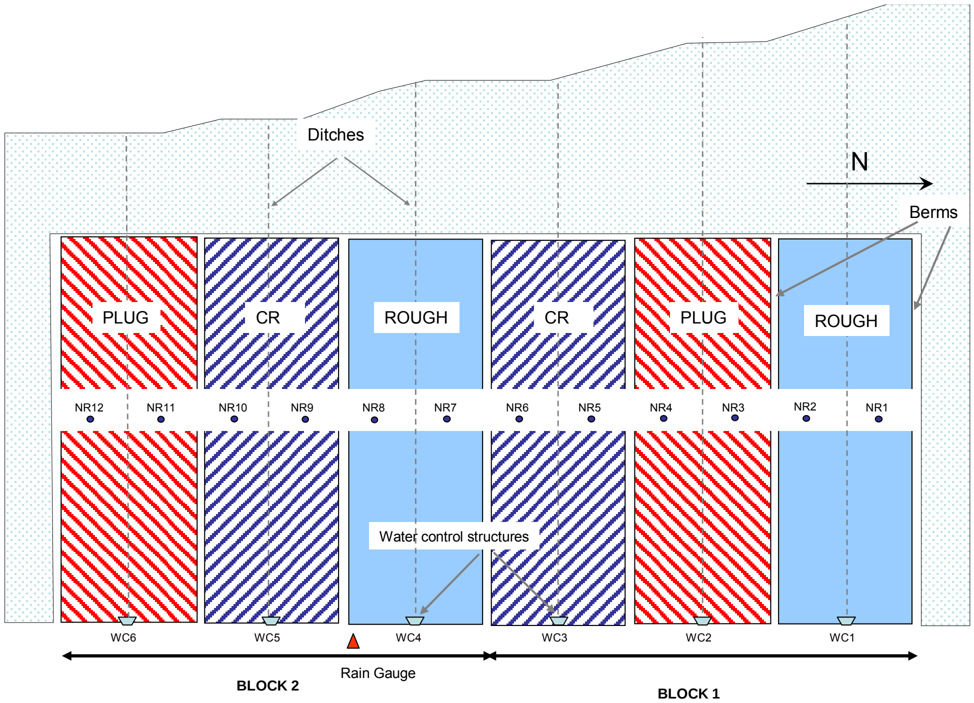


Figure 1. Restoration treatments monitoring design (not to scale).

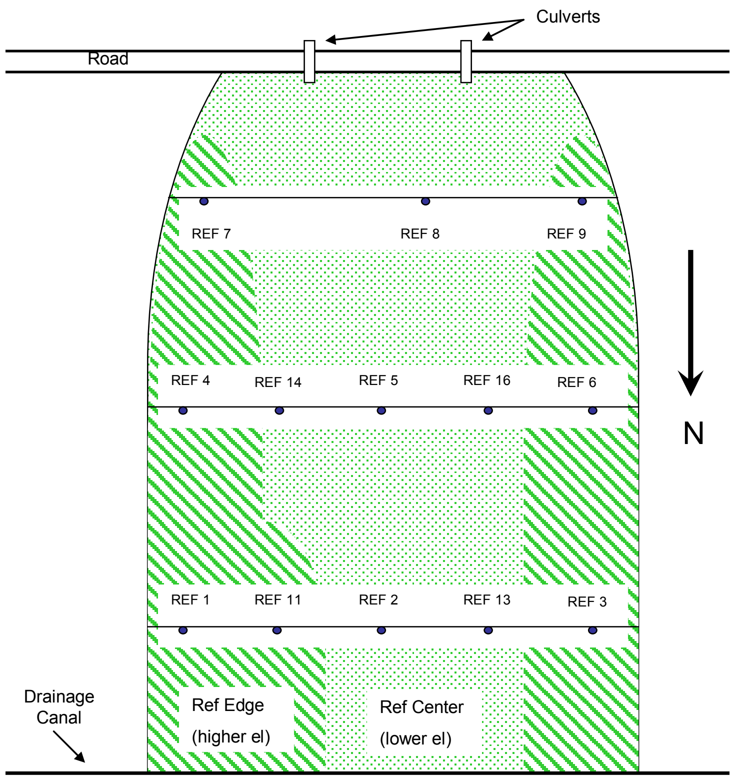


Figure 2. Reference wetland monitoring design (not to scale).

2.2.3 Results and Discussion

Precipitation

Rainfall at the site was highly variable (Table 1). Wetland response to extremely wet, near normal, and dry periods were captured during this period. This is ideal for determining hydrologic variability; however, it can also present problems, especially extreme conditions during vegetation establishment which was the case during this study. Precipitation extremes is a primary reason that multiple years of wetland monitoring should be employed when determining success criteria or best design/implementation practices.

Average precipitation at the site (159 cm; 63 in) was slightly greater than the long term average for nearby Morehead City (148 cm; 58 in). Two years, 2004 and 2006 were below average but were within the USACE definition of normal (between 25 and 75 percentile). Both 2003 and 2005 exceeded normal and 2003 was the highest precipitation on record (100 percentile). The excessive rainfall in 2003, particularly March to June, was extremely problematic as many locations on the restoration site were inundated in excess of 15 cm for prolonged periods. This resulted in drowning of many seedlings, especially smaller (shorter) oaks and Atlantic white cedar that were completed submerged for several days or weeks. Many of these seedlings would have likely survived under normal precipitation; however, the premature restoration of hydrology due to administrative funding constraints coupled with the abnormally high rainfall immediately after planting was a primary cause of significant seedling mortality (see section 2.4).

Table 1. Yearly precipitation totals measured at North River Farms

Year	Precipitation (cm)
2003	209
2004	129
2005	190
2006	120
2007	154
2008	150
6-year site average	**159**
Morehead City - 50 year average	**148**

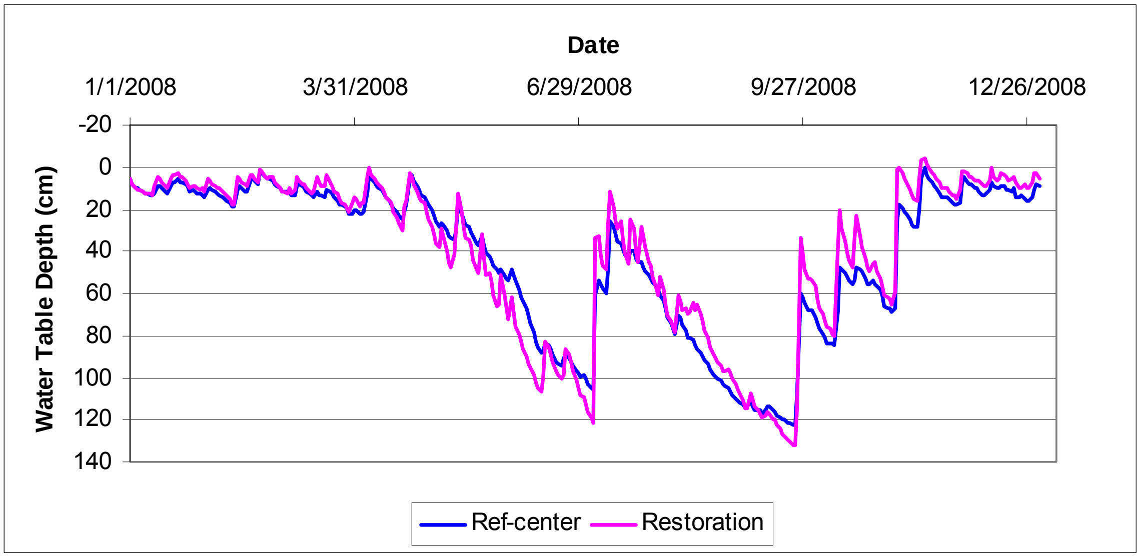


Figure 3. Mean water table profiles for the restoration and the reference wetland during 2008 (150 cm [59 in] rainfall).

Groundwater hydrology

Hydrology of the reference and restoration site was typical of eastern NC wetlands that are precipitation driven. Water table elevations were generally the highest during the winter or following tropical events, and the lowest during the mid to late summer months following periods of high evapotranspiration (ET). Figure 1, the mean water table profile computed from all continuously recording wells within the restoration area and the center wells of the reference wetland from 2008, shows this phenomenon.

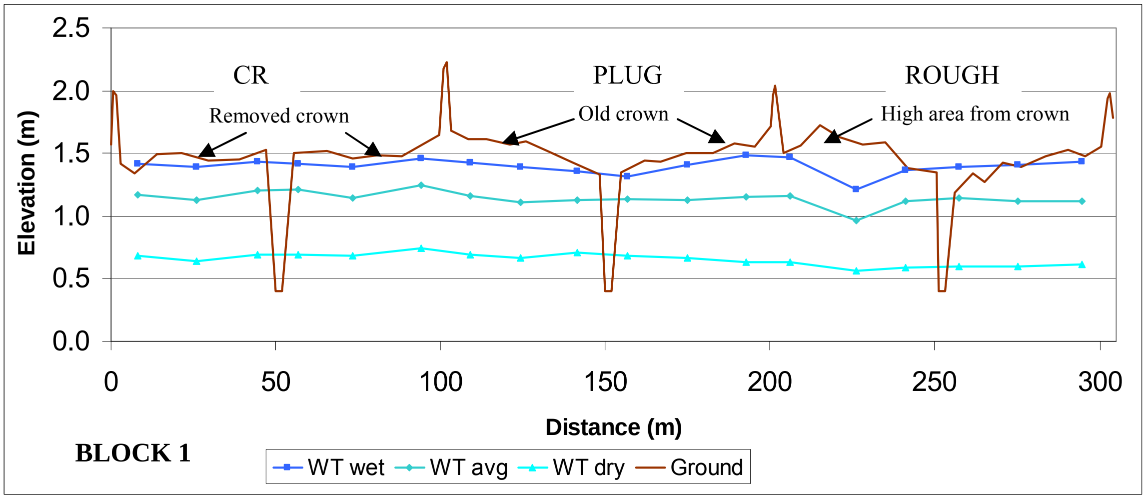
The restored wetland clearly met minimum USACE wetland jurisdictional criteria, (water table within 30 cm (12 in) of the surface for 5% of the growing season, equivalent to 12 days in Carteret Co) in all years in all treatments. Therefore in its most basic sense, all three restoration techniques/practices yielded a wetland by hydrologic jurisdictional standards.

As stated earlier, from a research perspective, the principle hypothesis was that removal of field crowns would be necessary to restore the natural hydroperiod and local microtopographic gradients that contribute to the patterns and richness of plant communities in natural forested wetlands. In simple terms, this means that it was hypothesized that removing the crown (CR) would likely create the wettest conditions. Furthermore, we hypothesized that surface roughening without crown removal might be a more cost effective construction technique for restoring hydrology and microtopograhic roughness in lieu of the more expensive crown removal technique. Lastly, it was hypothesized that mere plugging of field ditches might not be adequate to restore jurisdictional hydrologic criteria in all areas of the restoration site, particularly the center of fields where agricultural crowns are the highest.

Evaluation of the groundwater table during 2003-2004 by Wright (2005) using the 8 criteria mentioned earlier showed no clear hydrologic difference between the treatments. The average water table profiles were all similar to that of the reference wetland. The results were further scrutinized, as it was thought that the similarity in water table profiles may have been influenced by excessive rainfall in 2003 The amount of rainfall above normal in 2003, 50 cm (20 in), is several times larger than the subtle elevation differences between the treatments, <15 cm (6 in). As a result, treatment effects are masked during periods of excess rainfall, and the higher the rainfall, the more the treatment effects are masked. As suspected by Wright (2005) and later verified by Jarzmesky (2009) through an as-built survey along the monitoring transect, the random assignment of treatments within each block was also an important factor. When averaged across treatments, the significantly lower elevations in the PLUG treatment and the higher areas in the CR treatment in Block 3 tended to mask treatment differences in Blocks 1 and 2. The water levels in Block 3 were much higher (wetter) and lower (drier) than the corresponding PLUG and CR treatments in Blocks 1 and 2 (Figure 4), resulting in a random experimental bias and unintended large standard deviations in the mean water table elevations measured across treatments.

Therefore, the focus of the analysis has been on Blocks 1 and 2, as surveying also revealed that these areas were built much closer to specifications in the areas monitored. Even though this weakened our statistical power to evaluate the treatments, we believe that evaluating criteria within these two blocks was a more accurate representation of our original restoration design, and therefore observations from these areas would yield more conclusive recommendations.

In a follow-up paper by Wright (2006) that focused on just Blocks 1 and 2, two of the hydrologic criteria showed differences between some treatments. Also observed were similarities of the restoration areas to the center, more frequently wet, areas in the reference wetland. Table 2 shows the number of days and the percentage of the entire year or growing season that the water table was within 30 cm of the surface. The only statistical difference noted was that the water table in restored wetland areas and the center of the reference was within 30 cm more days than the drier reference wetland edge (which was on average 20-30 cm [8-12 in] higher in elevation than the center of the reference wetland). Closer inspection of the means of the wetland treatments showed that the CR treatment was the wettest treatment on average. However, it was the ROUGH treatment that appeared to have water table levels within 30 cm of the surface for periods most similar to the center of the reference wetland.



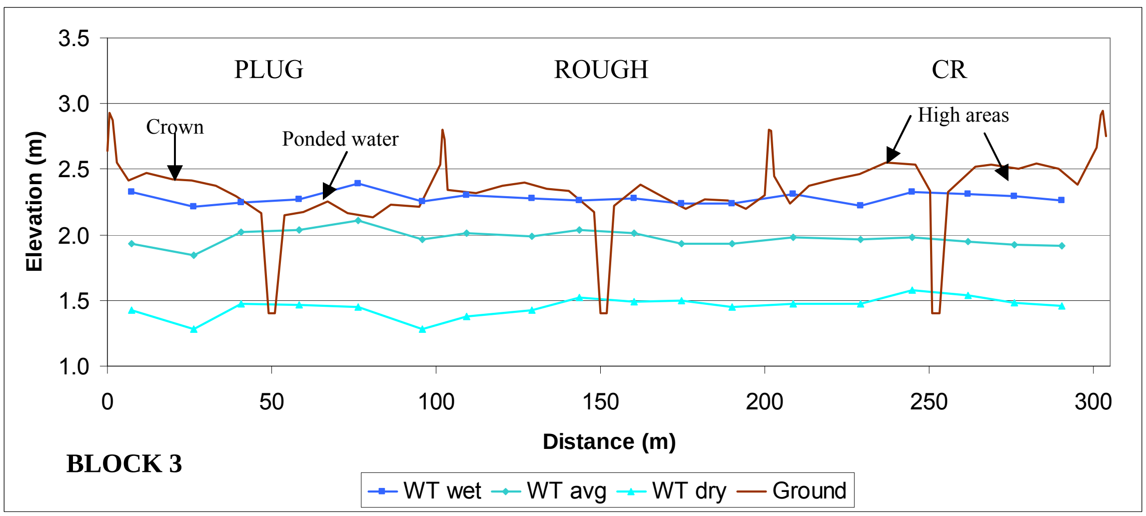


Figure 4. Comparison of as-built surveys of Block 1 and Block 3. Note the frequently ponded area in Block 3 in the PLUG treatment and the areas that were drier in the CR treatments. This can be seen pictorially in Appendix 2 Figure 10. (**Note highest areas and lowest areas on the cross sections represent berms and plugged ditches, respectively).

Table 2. Number of days and the percentage of the entire year or growing season that the water table was within 30 cm of the surface

		2003	2004	Total
Entire year	Reference Center (wet)	169 (75%)	159 (49%)	328 (56%)(a)
	CR	189 (77%)	188 (55%)	377 (62%)(a)
	ROUGH	175(69%)	172 (50%)	347 (58%)(a)
	PLUG	152 (62%)	150 (44%)	302 (51%)(a)
	Reference Edge (dry)	65 (31%)	47 (14%)	112 (21%)(b)
Growing Season	Reference Center (wet)	127 (69%)	80 (33%)	207 (48%)(a)
	CR	147 (72%)	94 (38%)	241 (54%)(a)
	ROUGH	128 (63%)	80 (33%)	208 (46%)(a)
	PLUG	112 (55%)	70 (28%)	182 (41%)(a)
	Reference Edge (dry)	41 (24%)	13 (5%)	54 (12%) (b)

Values followed by the same letter are not significantly different within criteria within each year (α=0.05)

A more robust criterion, the SEW_{30}, describes both the duration and intensity at which the water table remained within 30 cm of the surface. We found that the SEW_{30} was the most descriptive metric used for evaluating the near-surface hydrology found in wetlands. SEW_{30} is calculated using the formula

$$SEW_{30} = \sum_{i=1}^{n} (30 - X_i),$$

where
SEW_{30} = sum of excess water above 30 cm (cm*days)
X_i = Daily average water table depth (cm)
n = number of days of interest.

Again, the reference edge was clearly drier than all other areas (Table 3). However using this metric, the CR restoration treatment not only was the wettest on average of all of the restoration treatments, but was wetter than the center of the reference wetland area. This increased wetness was statistically significant when the entire year was considered.

Jarzemsky (2009) extended the period of study to include data collected from 2006-2008. This data was enhanced and provided more insight to how the treatments were behaving, since an intensified survey of the site was conducted, additional observation wells were installed across the transect, and the wetland had matured to a greater extent.

When evaluating the replicates in Blocks 1 and 2, as well as within the reference wetland, for the entire year (not the growing season), similar conclusions were reached – the CR treatment was the wettest portion of the restored wetland for multiple criteria, and the ROUGH treatment appeared to match the average values of SEW_{30} found in the center of the reference.

Table 3. Sum of excess water in the top 30 cm (12 in) of soil (SEW_{30}) for the entire year or growing season.

		2003	2004
Entire year	Reference Center (wet)	3308 (ab)	2402 (a)
	CR	4470 (b)	4124 (b)
	ROUGH	3131 (ab)	2831 (ab)
	PLUG	2922 (a)	2507 (a)
	Reference Edge (dry)	511 (c)	286 (c)
Growing Season	Reference Center (wet)	2312 (a)	867 (a)
	CR	3385 (a)	1761 (a)
	ROUGH	2311 (a)	1184 (a)
	PLUG	2141 (a)	1034 (a)
	Reference Edge (dry)	310 (b)	88 (b)

Values followed by the same letter are not significantly different within criteria within each year (α=0.05)

Table 4. Summary of hydrologic criteria 2006-2008.

		2006	2007	2008	Total
Average Water Table Depth (cm)	PLUG	42	45	39	42 (a)
	ROUGH	43	50	43	42 (a)
	CR	35	37	31	34 (b)
	Ref-center	33	44	42	40 (c)
	Ref-edge	52	65	65	61 (d)
SEW_{30} (cm*days)	PLUG	2394	2521	3488	8403 (a)
	ROUGH	2255	3672	3360	9287 (b)
	CR	4166	4502	5301	13969 (c)
	Ref-center	3507	3054	3240	9801 (b)
	Ref-edge	574	490	426	1490 (d)
Days of surface inundation	PLUG	9	12	18	39 (a)
	ROUGH	3	38	5	46 (a)
	CR	33	41	53	127 (b)
	Ref-center	4	2	2	8 (c)
	Ref-edge	0	0	0	0 (c)

Values followed by same letter vertically are not statistically different (α = 0.05).

Further analysis has evaluated how the restoration treatments can be compared to the driest, median, and wettest wells in the reference, that actually met jurisdictional criteria during the study (reference wells 1, 3, 4, and 7 on the edge of the wetland fell below minimum jurisdictional criteria and were not included in the analysis). This method helped describe in a slightly different manner if the wetland treatments fell in the range of the hydrology observed in the reference wetland. Note: The wells in the "reference" were selected to demonstrate and document the variability that occurs in natural wetlands. Well locations were selected to allow measurement of this range from the wettest areas in the reference to drier areas that were expected to marginally satisfy jurisdictional criteria. Five years of data have documented these ranges.

The four criteria considered included longest duration that the water table is within 30 cm of the surface (growing season), average water table depth (entire year), SEW_{30} (entire year), and surface inundation (entire year) (Figures 5-8).

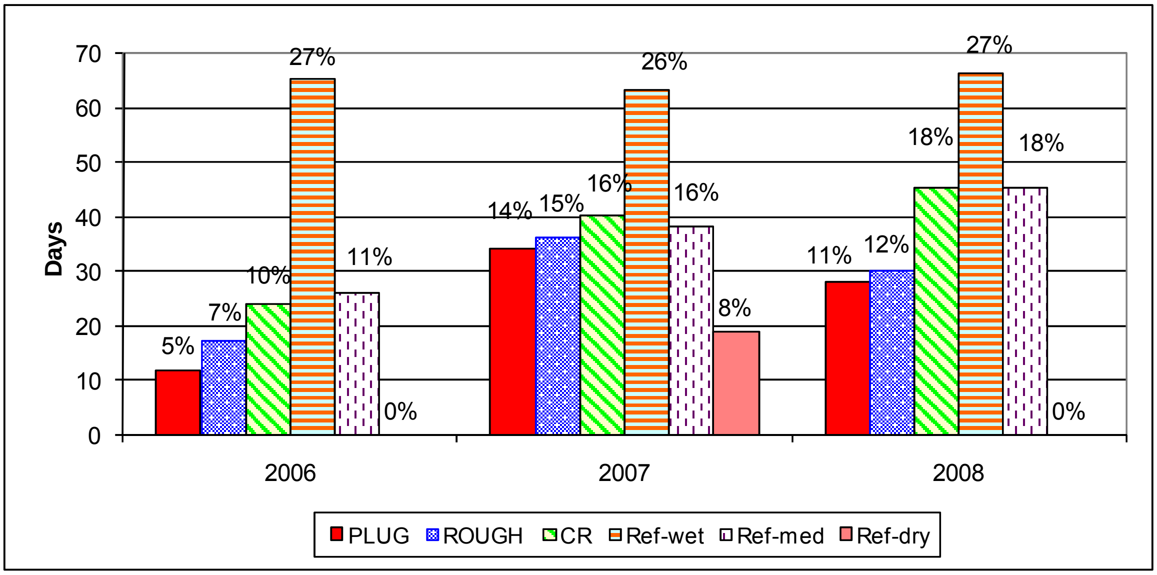


Figure 5. Longest duration that the water table is within 30 cm (12 in) of the surface during 2006 – 2008 (growing season)

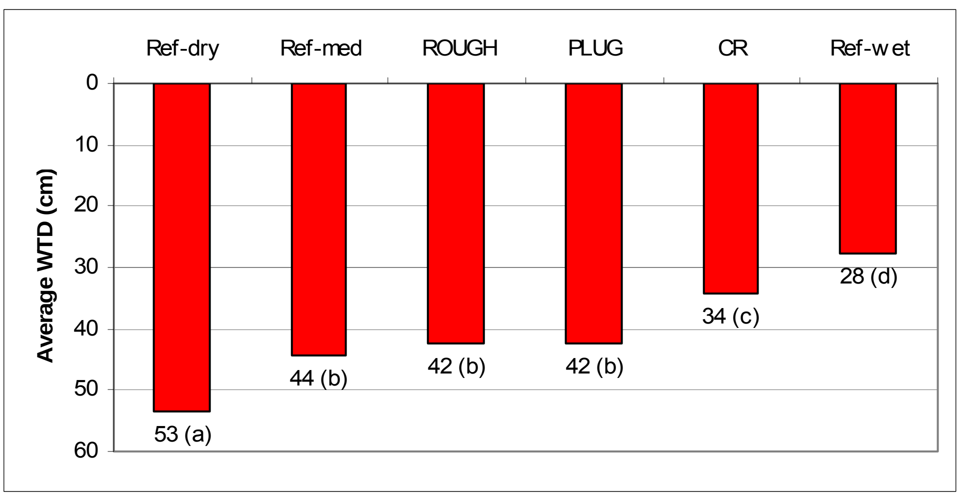


Figure 6. Average water table depth for 2006 – 2008 (entire year) (values with same letter are not significantly different, $\alpha = 0.05$).

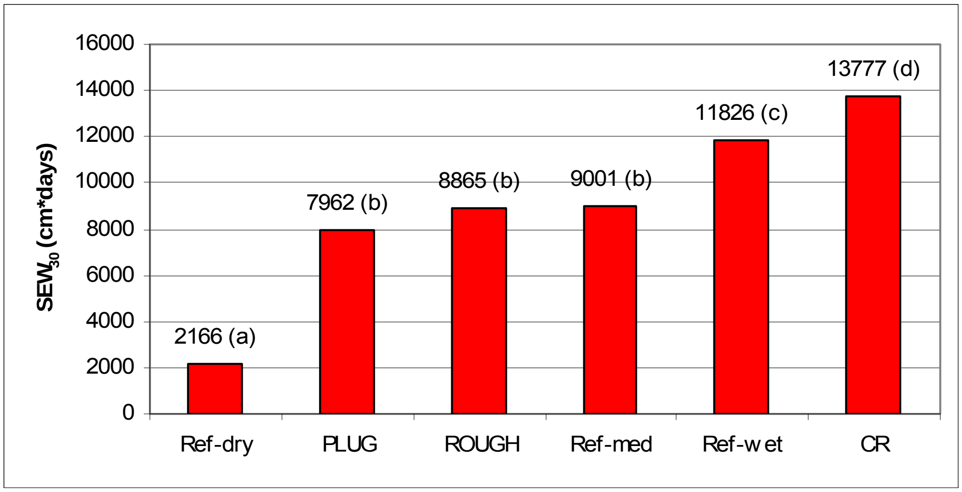


Figure 7. SEW_{30} for 2006 – 2008 (entire year)
(values with same letter are not significantly different, $\alpha = 0.05$).

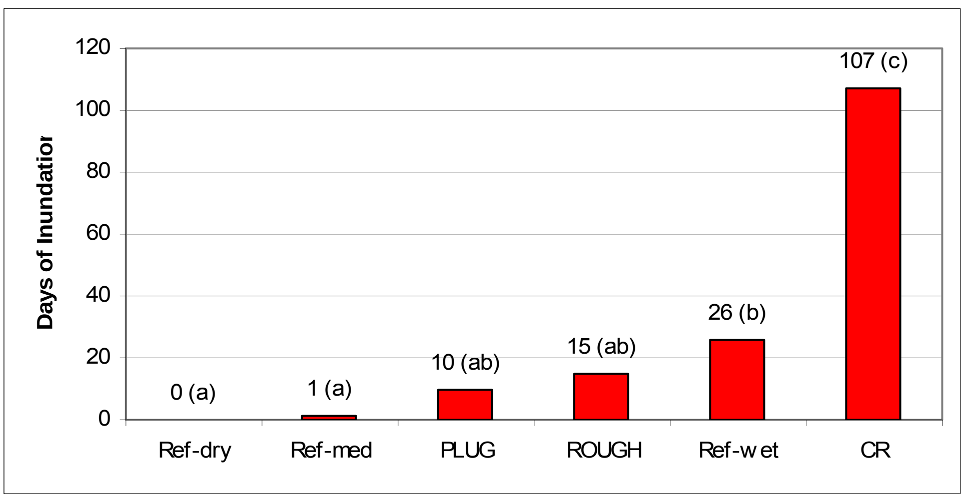


Figure 8. Number of days of surface inundation for 2006 – 2008 (entire year)
(values with same letter are not significantly different, $\alpha = 0.05$).

Figure 5-8 provide good evidence that the CR treatment is clearly wetter than the other two treatments and wetter than most locations in the reference. These results clearly demonstrate that one hydrologic criteria such as jurisdictional criteria is not adequate to fully describe wetland hydrology or as an indicator of hydrologic restoration success. In the case of SEW_{30} and surface inundation, the CR treatment is wetter than the wettest portion of the reference, yet it falls between the reference extremes in terms of inundation duration and average water table depth. The PLUG and ROUGH treatments are similar to the median wetness condition within the wetland which demonstrates that if the average condition of the reference was the targeted restoration hydrologic regime, then the design hydrology could be achieved with either the PLUG or ROUGH treatment. However, if the wetter portion of the reference were the targeted restoration hydrologic regime, the

CR treatment would be deemed more successful. In general, these results are as expected in that the reference locations graded from extremely wet to areas that did not satisfy jurisdictional criteria. The three treatments were all jurisdictional and fell within the extremes observed in the reference.

Surface Outflow

Based on the observations that the CR treatment produced the wettest conditions of all of the wetland restoration areas, it was not surprising that it also produced significantly less total outflow during the 2003-2004 and 2006-2008 periods. Figure 9 shows data during the 2006-2008 period.

It was originally hypothesized that the PLUG treatment would have the greatest outflow, while there would be significantly reduced outflow in the ROUGH and CR treatments but there would be little difference between them. However, the ROUGH treatment contributed significantly more outflow during the study than did the CR treatment. This difference on average was about 10 cm (4 in) per year. Surveying conducted in 2006 revealed that some surface water conveyance paths were created during the roughening process. Since the crown was not removed in the ROUGH treatments, these conveyances apparently facilitated preferential surface flow towards the plugged ditch.

Long term DRAINMOD simulations conducted by Wright (2006) indicated that all of the restored wetland areas would meet minimum USACE wetland jurisdictional criteria (water table within 30 cm continuously for 5% of the growing season) in 41 or more out of 50 years, while the 12.5% criterion would be achieved in at least 18 out of 50 years. In comparison the 5% and 12.5% criteria would be met in the center of the reference wetland in 46 and 24 out of 50 years respectively. Simulated outflow from mature restored wetlands revealed that outflow from this area would be reduced by 40% from the CR areas, and by 29% from the ROUGH treatment areas, when compared to agricultural drainage conditions.

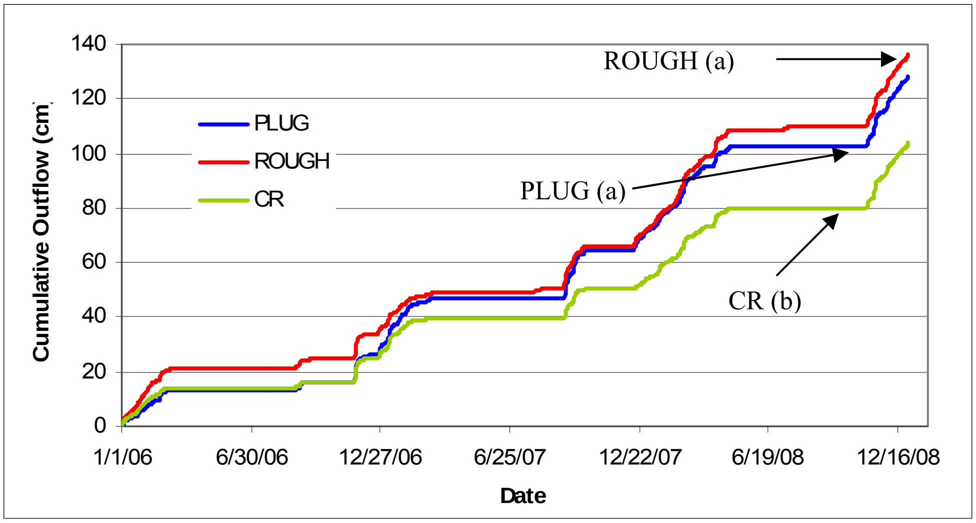


Figure 9. Cumulative outflow for 2006 – 2008
(values with same letter are not significantly different, α = 0.05).

2.2.4 Conclusions

Based on data collection and analysis from 2003-2008, the following conclusions have been reached about the hydrologic restoration of the prior converted site at North River Farms (Phase I):

1. The restored non-riverine wet hardwood wetland treatments clearly met minimum USACE wetland jurisdictional criteria (water table within 30 cm [12 in] continuously for 5% of the growing season) for all wetland treatments evaluated.

2. The hydrologic results demonstrate that the hydrologic structure of natural wetlands is variable and that it is inappropriate to rely on one measure of hydrologic structure, namely jurisdictional criteria, as the only measure of hydrologic success. For example, the longest continuous duration that the water table was within 30 cm of the surface during the growing season (related to jurisdictional criteria) was longer in the wet reference compared to the crown removal, suggesting that the reference was wetter than the crown removal. However, other hydrologic indicators such as SEW_{30} and duration of ponding showed the crown removal to be significantly wetter than the wet section of the reference.

3. Long term simulations with the hydrologic model DRAINMOD indicated that the restored and reference wetland will meet minimum jurisdictional criteria (saturation above 30 cm continuously for >5% of the growing season) in >41 out of 50 years. The upper end of the jurisdictional criteria (water table within 30 cm

continuously for 12.5% of the growing season) will be satisfied in 20 out of 50 years in the restored area, compared to 24 out of 50 years in the center of the reference wetland.

4. The crown removal (CR) restoration technique resulted in the wettest conditions within the restoration area and appeared wetter than the reference wetland for some groundwater hydrologic criteria considered. This technique exported the least outflow from the wetland.

5. Hydrologic criteria evaluated for the surface roughening treatments (ROUGH) yielded results most similar to the median values obtained in the reference wetland. However, the most water was exported from this treatment, likely due to surface flow conveyances that developed due to surface grading during construction.

6. There were no statistically significant differences between plugging the ditches (PLUG) and the ROUGH restoration technique observed for this location during the study period. As noted earlier, treatment differences can be subtle compared to precipitation extremes. On average, precipitation was above normal during the six year study period. A prolonged period with precipitation near the lower range of "normal" may produce treatment differences. Treatment differences between PLUG and ROUGH were observed in studies in Craven and Beaufort counties (see Tweedy and Evans, 2001).

7. Long term hydrologic modeling with DRAINMOD indicated that as the wetland matures, outflow to the estuary will be reduced by 29% with ROUGH technique, and by 40% with the CR technique, when compared to agricultural drainage conditions.

8. The hydrologic structure of a reference wetland should be quantified using several of the methods discussed herein, with the same methods being applied to quantify the hydrologic structure of a restored wetland. It was also demonstrated that as the target wetness for a restored wetland increases, more extensive construction techniques will be required to achieve the desired hydrologic wetness.

9. Establishment of the hydrologic regime at this site at the time of planting (March, 2003) compounded by the abnormally high precipitation during the growing season (2003 was the highest precipitation on record) was an obvious cause of poor seedling establishment and mortality (see section 2.4).

2.2.5 PC Farmland Restoration Recommendations

Restorations of drained farmlands require plugging of field ditches and/or outlet control. It is recommended that designers establish target elevation ranges during the design phase, based on reference topographic surveys. Based on these elevation ranges, a topographic survey should be conducted to determine if fields to be resorted fall within the target range. Areas that are higher than the target range should be excavated if maximum wetland area is to be achieved. Excavated materials could be redistributed to lower areas on site if they exist, unless the design utilizes lower areas for open water.

Additional construction technique recommendations are as follows:

1. Surface roughening is recommended for all restorations to maximize surface storage, create habitat diversity similar to natural wetlands, and enhance biogeochemical conditions (i.e low redox potential) within the soils.

2. Surface roughening techniques should employ methods where the creation of surface water conveyances to the outlets are minimized, in order to minimize outflow from the wetland.

3. In wetter areas with minimal field crowns, (<30 cm; 12 in), surface roughening with ditch plugging will likely be adequate to achieve the desired hydrologic restoration.

4. If field crowns are excessively high (>30 cm; 12 in), these center areas of the field may not achieve target wetland hydrology following ditch plugging. In this case, crown removal is recommended and depending on depth of topsoil, topsoil may need to be stockpiled and replaced in these areas. The higher the field crown, the more extensive the earthwork that will be required.

5. Areas that prior to agricultural conversion only minimally met wetland jurisdictional criteria may also require more extensive earthwork such as crown removal to achieve restoration success.

2.2.6 References

Jarzemsky, R.D. Hydrologic evaluation of a restored wetland in eastern NC. 2009. M.S. Thesis. North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC

Tweedy, K.L. and R.O. Evans. 2001.Hydrologic characterization of two prior converted wetland restoration sites in eastern North Carolina. *Transactions of the ASAE* 44(5) 1135-1142.

Wright, J.D. 2005. The evaluation and modeling of the effects of surface treatments of a restored wetland in the Coastal Plain of North Carolina. M.S. Thesis. North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC

Wright, J.D., M.R. Burchell II, J.D. Shelby, and R.O. Evans. 2006. Hydrologic effects of three restoration techniques on prior-converted wetlands in eastern NC. *In:* Hydrology and Management of Forested Wetlands– Proceedings of the ASABE International Conference New Bern, N.C. April 8-12.

2.3 – Wetland assessment using the hydric soil technical standard

2.3.1 Introduction

The Hydric Soil Technical Standard (HSTS) uses site-specific data to determine the hydric status of a soil. Developed by The National Technical Committee for Hydric Soils, the HSTS requires direct field measurements of saturated and anaerobic conditions to verify a hydric soil determination (NTCHS 2009). Our study utilized the HSTS parameters of soil redox potential, soil saturation, pH, and precipitation records as indicators of wetland function. The results were used as measures of restoration success, to evaluate construction techniques, and to compare the equivalence of restored agricultural fields to a nearby reference wetland.

The presence of a depleted matrix in a non-wetland soil is the best and most often used indicator for a potentially viable wetland restoration site. Field indicators based on relict morphological features present within the soil at a wetland restoration site do not indicate whether saturated and anaerobic conditions have been successfully restored. As in wetland creation projects where wetland hydrology is imposed on formerly upland soils, only development of contemporaneous hydric soil morphologies would provide evidence that conditions of saturation and anaerobiosis were restored. Hydric soil morphologies usually require a much longer time frame to develop than the 5-year monitoring period commonly used by the USACE to determine restoration success.

These complications posed by hydric soils in wetland restoration and creation explain in part why the hydric soil parameter is not generally used as a performance standard to evaluate restoration success for compensatory mitigation purposes. It can also be attributed to the lack of methods for measuring the current functional status of hydric soils prior to 2000.

2.3.2 Materials & Methods

Site Description

The research was conducted on former agricultural fields located on the outer coastal plain of North Carolina in Carteret County that were cleared and graded around the mid to late 1970s. Ditches spaced approximately 100 m (330 ft) apart and approximately 120 cm (48 in) deep provided drainage to manage a rotation of corn, soybeans, and winter wheat. Farmers crowned areas between ditches approximately 20 cm (8 in) in height to promote drainage.

Two separate fields make up the restoration areas of Phase I. Both fields are relatively flat with an elevation range of less than 2 m (7 ft) without natural drainage features or creeks. The fields are precipitation flats positioned at the edge of a large interstream divide nearly completely occupied by Open Grounds Farm. Although organic soils occupy the majority of the interstream divide, mineral soils with a high organic content developed along the edges of the divide including within the restoration area. Soils within the restoration areas consist primarily of very poorly drained Deloss fine sandy loam classified as fine-loamy, mixed, thermic Typic Umbraquults.

Nonriverine wet hardwood forest (NWHF) was selected as the primary target plant community from the Classification of the Natural Communities of North Carolina – Third Approximation. The selection was based on the landscape position, soils, and local restoration goals.

Reference Wetland Description

A nonriverine swamp forest/small stream swamp forest located near the restoration area serves as the reference wetland). This wetland occupies a depressional area elongated along the north-south axis. There is approximately 30 cm (12 in) of elevation difference between the center of the depression and the edge. This forested wetland grades into marsh to south where it connects to Wards Creek, a tributary to North River.

Wasda muck is the primary soil series present in the reference wetland based on soil profile descriptions from auger borings. Swamp black gum (*Nyssa sylvatica*) and red maple (*Acer rubrum*) dominate the overstory of the reference wetland while horse sugar (*Symplocus tinctoria*), red bay (*Persea borbonia*), and wax myrtle (*Morella cerifera*) make up the understory. Leucothoe (*Leucothoe axillaris*), fetter-bush (*Lyonia lucida*), and Virginia chain fern (*Woodwardia areolata*) cover most of the forest floor along with many roots.

Study Design

The study consists of three surface treatments randomly assigned to three blocks resulting in three replicates of each plot. The northern field contains two blocks, and the eastern field contains the third and final block.

One treatment, referred to as microtopography (referred to as ROUGH in Section 2.2), involved roughing the soil surface to mimic the micro-highs and lows often found in forested wetlands. Contractors used a farm plow adjusted to excavate approximately 15 cm (6 in) and pile it adjacent to the excavation to create surface micro-highs and lows. Approximately 25 to 50 percent of the ground surface in the microtopography plots received this treatment.

The second treatment was crown removal (referred to as CR in Section 2.2). It was imposed by grading the field so that it was essentially flat with a slightly roughed surface. The third treatment was the control, which left the crown as it was when the field was used for crop production (referred to as PLUG in Section 2.2). Earthen berms were constructed around each plot to separate them hydrologically and allow for water quality and quantity sampling. A conceptual cross-section of the treatments is provided in Figure 1. The Department of Biological and Agricultural Engineering (BAE) installed and maintained two continuous recording monitoring wells within each plot along a transect placed approximately through the middle of the study area in each field. Wells were installed to depth of 2 m (7 ft) below ground surface and situated midway between the ditch and berm in each plot. BAE maintained and collected the data from these wells (Wright 2005). We located Hydric Soil Technical Standard (HSTS) monitoring stations for this study along this same transect of wells.

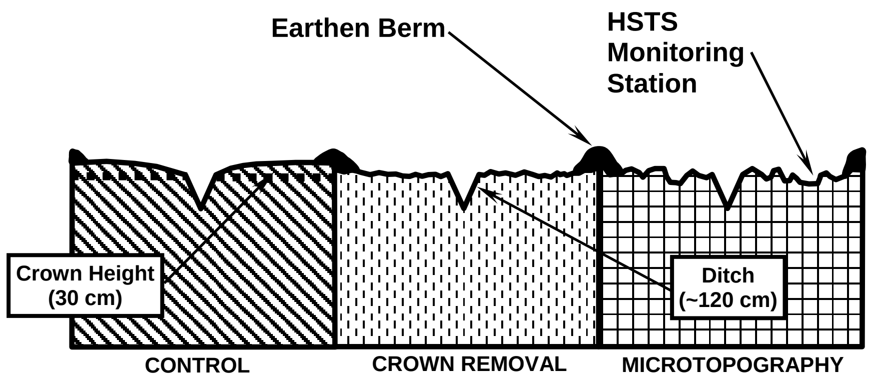


Figure 1. A conceptual cross-section of treatments shows the different surfaces created in this study. (Note from section 2.2, CONTROL=PLUG, and MICROTOPOGRAPHY = ROUGH)

Monitoring Stations

Platinum electrodes provided soil redox potential (Eh) data for determining the presence of anaerobic conditions required to meet the HSTS. As specified in the HSTS for loamy and clayey soil materials, each station contained a bank of five platinum electrodes installed at 25 cm (10 in) as measured from the muck or mineral surface. Another bank of five platinum electrodes was installed at depth of 61 cm (24 in) although this deeper bank of electrodes is not required by the HSTS.

A set of four piezometers and one open well were used to determine the presence of saturated conditions. We installed two piezometers at 25 cm (10 in) and two more at 100 cm (39 in). Each station was installed adjacent to one of the previously described open wells in order to verify the piezometer data with auto-recorded, well data. A schematic of the monitoring station setup is shown in Figure 2.

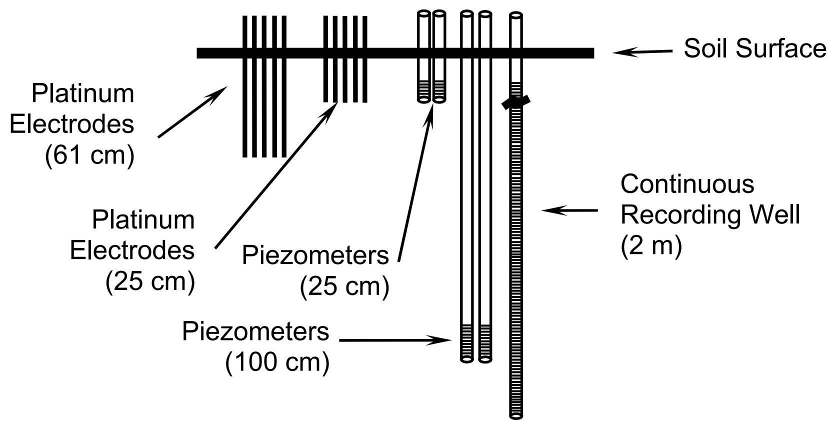


Figure 2. A schematic of HSTS equipment and supplemental electrode bank illustrates the monitoring station components.

Data Collection

Soil redox and free water within each piezometer was measured weekly for approximately 15 months beginning September 2003. We measured pH 25-cm and 61-cm (24 in) from the ground surface at each monitoring station twice during the study. Precipitation was measured within each restored field on the site using Davis Rain Collector tipping bucket recorders equipped with HOBO® data loggers (Wright 2005). Historical precipitation data was obtained from the nearest WETS Table station to the project site located near Morehead City, NC.

If redox potential values for at least three out of the five probes were lower than the threshold redox potential value, then anaerobic conditions are presumed present for that particular depth, station, and point in time. The HSTS requires both anaerobic conditions and saturation in order to confirm that a soil is functioning as a hydric soil.

Free water in at least one of the shallowest piezometers (25 cm) confirmed the presence of saturated conditions. Although saturation and anaerobic conditions indicate that a soil is functioning as a hydric soil at that point in time, there are additional criteria established to ensure that the duration and occurrence frequency are sufficient for a hydric soil to develop. Saturated and anaerobic conditions must persist for at least 14 consecutive days to meet the duration criteria. The minimum duration must also occur more than 50 percent of the time or more than 1 out of 2 years to meet the frequency criteria of the HSTS.

The HSTS assumes that the frequency criteria for a currently functioning hydric soil would be satisfied if the data were collected during a 30 to 70 percentile precipitation probability. Also referred to as the normal range of precipitation, this information is available from the aforementioned WETS tables. We compared monthly totals of on-site precipitation during the study period to the normal range of precipitation. Each month of the study was classified as having wetter than normal, normal, or drier than normal precipitation conditions depending on whether the precipitation total was above, within, or below the normal range of monthly precipitation, respectively. According to the HSTS, only data collected from those months in which the precipitation conditions were normal are useful in determining whether the HSTS was met.

Although not explicitly allowed by the HSTS, we used months in which the precipitation conditions were drier than normal as well as normal to determine if the HSTS was met. We reasoned that if soils were wet enough to meet the HSTS during drier than normal precipitation conditions then it would also meet the HSTS during normal precipitation conditions.

2.3.3 Results and Discussion

Evaluation Tool for Restoration Success

Water table and soil redox potential data from all twelve stations located in the restoration were averaged together to provide an overall picture of the restoration's performance. Figure 3 shows the relationship between saturation, in this case resulting from a high water table, and soil redox potential within the restoration area. An average water table depth of 25 cm (10 in) or shallower confirms the presence of saturated conditions. Anaerobic conditions are present when the average soil redox potential drops below 290 mV.

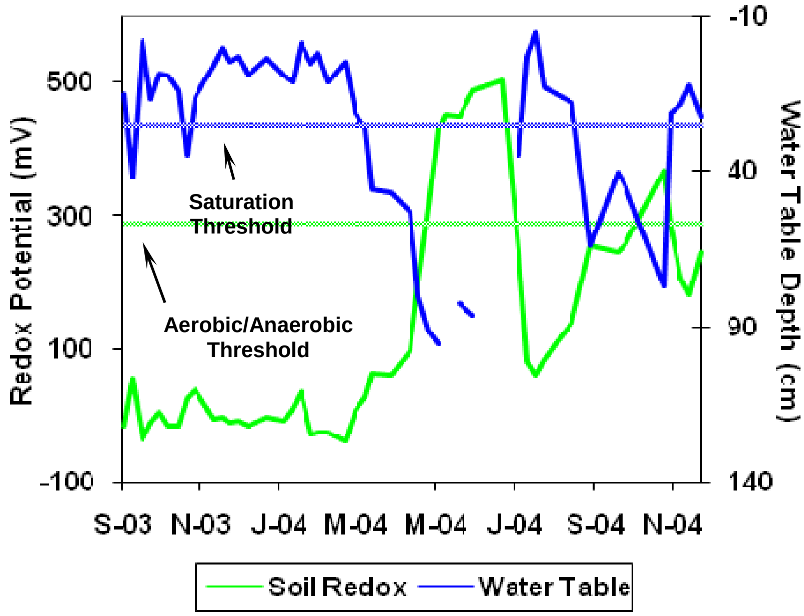


Figure 3. Average soil redox and water table depth for restoration area

Using water table and soil redox potential data collected during normal or drier than normal precipitation conditions, we determined whether the HSTS was met for each station. The HSTS requires saturated and anaerobic conditions to persist for at least 14 consecutive days during normal or drier than normal precipitation conditions in order for the standard to be met. Figure 4 illustrates the consecutive periods during 2004, in which the HSTS was met in both the reference wetland and restoration areas. This was the only time during the study when normal or drier than normal precipitation conditions prevailed.

All monitoring stations within the restoration areas met the HSTS. The monitoring station within the restoration areas exhibiting the longest extent of saturated and anaerobic conditions was strikingly similar to the wettest of the reference wetland stations.

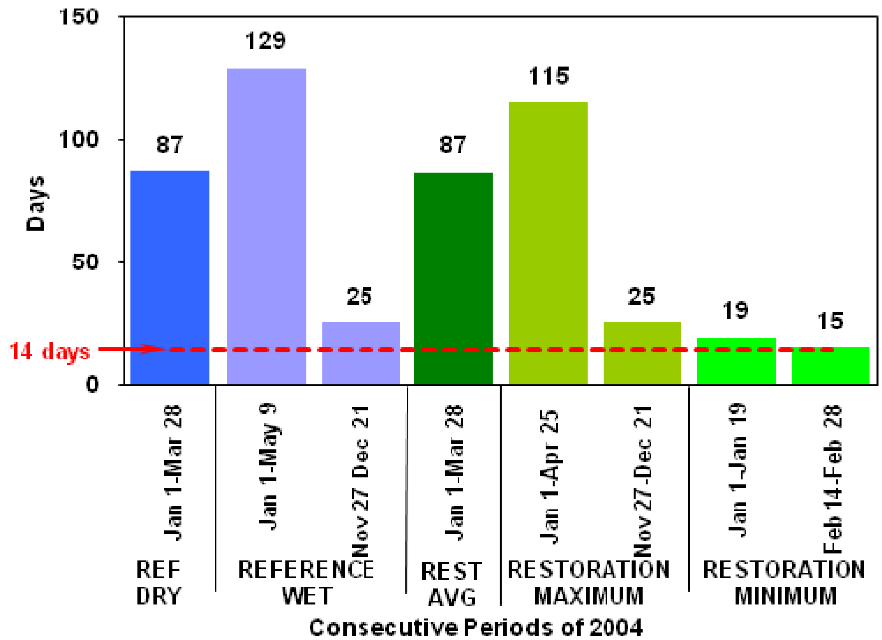


Figure 4. Comparison of consecutive periods restoration and reference met HSTS criteria during 2004

Assessment of Surface Treatment Effects

Using water table and soil redox potential data collected during normal or drier than normal precipitation conditions once again, we determined whether the HSTS was met for each station in the restoration area by treatment. The consecutive periods in which the HSTS was met during the normal or drier precipitation conditions of 2004 are shown in Figure 5.

As previously shown for the entire restoration area, all of the treatments met the HSTS. The microtopography treatment had the longest consecutive period of saturated and anaerobic conditions, while the control treatment had the shortest. However, this difference is not large at only 15 days. The treatments did not meet the HSTS for as long a duration as the wettest reference station located in the center of the wetland. However, they did meet the standard the same number of times as the wettest reference station, which is one additional consecutive period more than the driest station. Therefore, the presence of saturated and anaerobic conditions in the wetlands restored by all three treatments falls within the range of these conditions found in a nearby natural wetland.

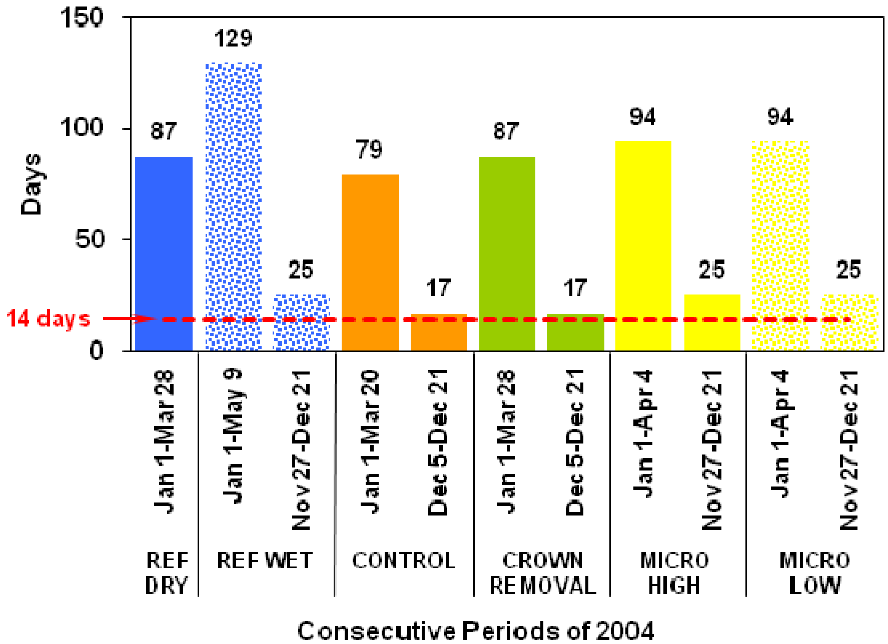


Figure 5. Consecutive periods that treatments met HSTS criteria during 2004

We also examined the difference in how the HSTS was met between the microtopographic high and low positions to determine if this treatment resulted in high areas that do not function as hydric soils. Figure 6 shows the consecutive periods in which the HSTS was met in these two microtopographic positions. Only data collected during normal or drier than normal precipitation conditions were used for the determination as required by the HSTS. Monitoring stations positioned on high positions met the HSTS only slightly less than their lower elevation counterparts. Therefore, replication of microtopographic relief does not appear to create nonfunctioning areas within the restoration area when it is accomplished in a similar manner and physical setting.

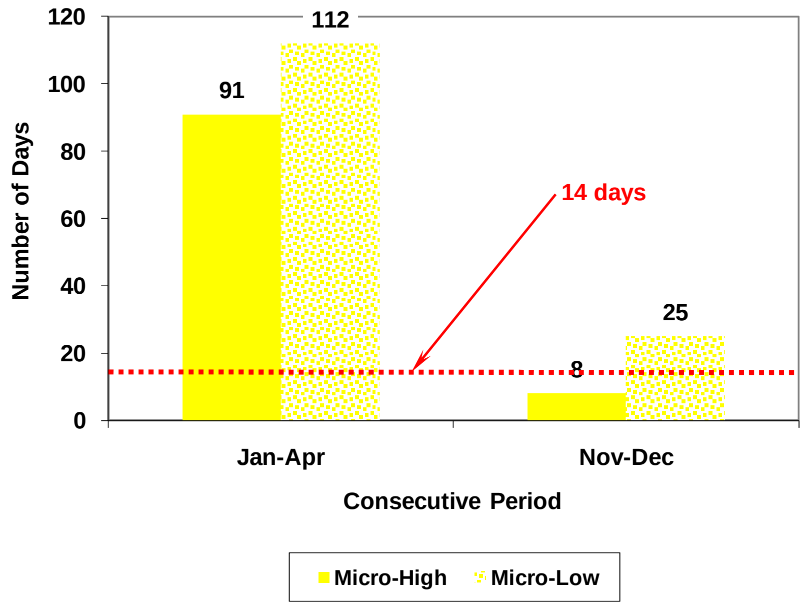


Figure 6. Consecutive periods during which microtopographic position met HSTS criteria during 2004

2.3.4 Conclusions

This study shows that the HSTS is an important tool for understanding and quantifying the effects of soil saturation and anaerobic conditions that occur in natural wetlands and as a performance measure for restored or created wetlands. Soils at each monitoring station within restored wetland areas met HSTS showing that the hydric soil parameter had been successfully restored within less than two years from the initial site work. A comparison of the HSTS results from the restored and the reference wetland indicated that saturated soil and anaerobic conditions similar to the reference wetland had been achieved. The HSTS provides a standardized method to directly measure the current functional status of the soils in a restored wetland. It provides a performance measure for the commonly neglected hydric soils parameter in wetland restoration.

Restoration areas where microtopographic relief was constructed as part of the original site work met the HSTS a greater number of days than the crown removal treatment and the control treatment where no ground disturbance occurred. The microtopography treatment appeared to be more important in creating saturated soil and anaerobic conditions in drier areas of the restored wetland. Using the HSTS to compare the microtopographic lows to the microtopographic highs within the microtopography treatment, showed that the low areas met the HSTS requirements a greater number of days than the high areas. However, the microtopographic high areas met the HSTS confirming a functioning hydric soil in these areas as well as the low areas.

2.3.5 References

National Technical Committee for Hydric Soils (NTCHS), Natural Resource Conservation Service, United States Department of Agriculture. Technical Note 11 Available online at ftp://ftp-fc.sc.egov.usda.gov/NSSC/Hydric_Soils/note11.pdf. [Accessed 14 July 2009]. USDA-NRCS, Lincoln, NE

Wright, Jason D. 2005. The Evaluation and Modeling of the Effects of Surface Treatments on Hydrology of a Restored Wetland in the Coastal Plain of North Carolina. MS Thesis. North Carolina State University, http://www.lib.ncsu.edu/theses/available/etd-04212005-122043/unrestricted/etd.pdf (accessed April 21, 2005).

2.4 - Development Of Plant Communities

2.4.1 Site Description

Trees were planted in three different combinations, with the species distributed according to the underlying soils and anticipated hydrologic condition after restoration. For this discussion, the reforestation area is divided into three sections: Site 1, site 1b, and site 2 (as labeled on Figure 1 below).

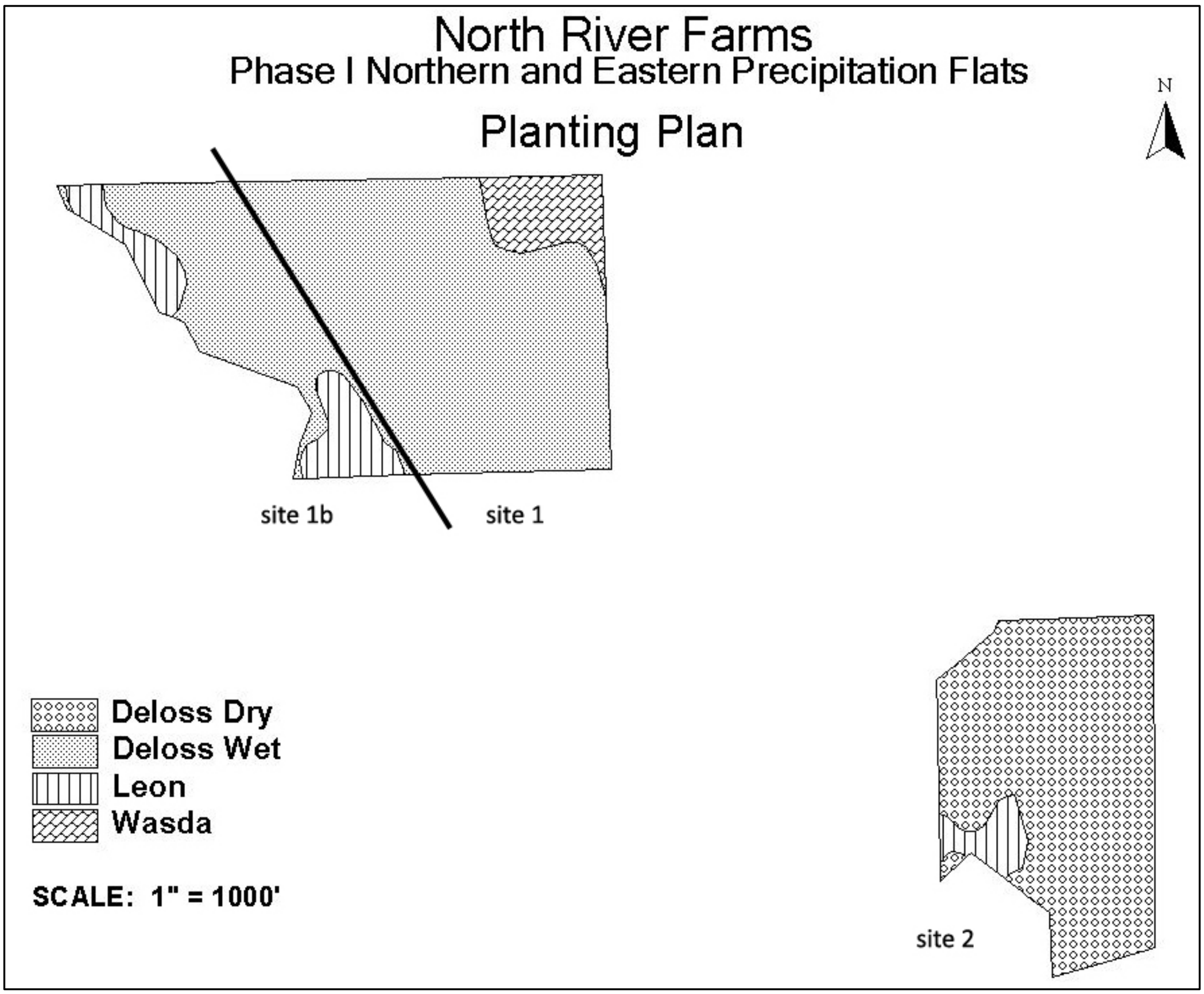


Figure 1. Soils in the restoration areas were considered in the planting plan

Site 1 has both Deloss wet and Wasda soils, which in their undisturbed state would have a seasonally high water table at or near the surface. The Wasda soil is wetter than the Deloss, as indicated by black muck in the upper surface. Site 1b is Leon sands, which also have a seasonally high water table despite being composed mainly of sand grains. Site 2 is primarily Deloss soils, though of a drier nature than those in Site 1.

The following combinations of trees were planted in each area:

Site 1: Atlantic white-cedar
Overcup Oak
Bald cypress
Water tupelo
Green ash
Longleaf pine

Site 1b: Longleaf pine

Site 2: Laurel oak
Water oak
Green ash
Swamp tupelo

Trees were bare-root seedlings from the NC Division of Forest Resources nursery, and containerized stock from Coastal Plain Conservation Nursery. The trees were not chosen to restore any particular community type. Because the trees were purchased shortly before planting, we had to take what was available and did not have the opportunity to contract for the species necessary to establish natural communities.

Trees were planted on approximately 12'x12' spacings, which resulted in an initial stocking of about 300 trees per acre. We had intended to plant at a density between 425-450 trees per acre, but there were not enough trees available by the time the state was able to purchase them.

2.4.2 Performance

Trees were monitored throughout the course of the project.

There was very low survival of the longleaf pine at Site 1b. Longleaf pine has a well-described grass stage, which can persist for years or decades. We were careful to search for seedlings in this stage. There are a few remnant survivors scattered around the site, in both the grass and sapling stages. For all practical purposes, the planting completely failed. A few longleaf pine were found in Site 1, as the planting of Site 1b overlapped Site 1.

The number and sizes of trees at Site 1 and Site 2 are shown in Table 1 below. We searched for both planted and volunteer trees, and both are shown. Oaks can difficult to distinguish by species, so data for all species were combined. Willow saplings were so numerous at Site 2 that we tried to estimate them to the nearest hundred per plot.

The average stocking of planted trees at Site 1 was 176 per acre, at Site 2 it was 95. Site 2 was dominated by volunteer willow trees. Trees were not evenly distributed across the site, with many areas devoid of any trees. All of the planted trees were small and growing slowly, with heights about half and volumes an order of magnitude less than typical planted trees.

Table 1. Stocking and height of planted and volunteer trees.

	PLANTED			**VOLUNTEER**	**ALL**
	Mean # of trees/acre	Mean height, meters	Mean height, feet	Mean # of trees/acre	Mean # of trees/acre
SITE 1					
All species	176			50	226
By individual species					
Bald cypress	64	2.1	6.8		
Oaks	49	2.0	6.4		
Green ash	35	2.2	7.1		
Atlantic white-cedar	23	1.8	5.9		
Loblolly pine		1.2	4.1	43	
Sweetgum		1.2	4.1	7	
Longleaf pine		0.8	2.5	4	
Red maple		1.0	3.3	<1	
SITE 2					
All species	95			1,000's	1,000's
By individual species					
Oaks	51	1.9	6.3		
Green ash	44	2.0	6.5		
Black willow				1,000's	
Loblolly pine		1.4	4.6	26	
Red maple		2.3	7.4	10	
Black cherry		1.1	3.4	<1	
Poplar		2.5	8.2	<1	

2.4.3 Discussion

The longleaf pine planting at Site 1b failed. Longleaf pine is a species that requires some management both at planting and after establishment. At planting, it is essential that vegetation competition be controlled. This can be done chemically or mechanically. I made written prescriptions for vegetation control for all of the sites, but others made the decision not to implement them. It is long established that planting longleaf pine without competition control is futile. After establishment, longleaf pine communities must be regularly burned to maintain the longleaf pine as the dominant tree species. The owners of the project did not attempt to establish any maintenance plan. The site is now occupied predominately by loblolly pine.

Stocking of planted trees at Sites 1 and 3 is low. Initial stocking was low, and less than half the trees survived. This is attributable to several stressors, though it is impossible to quantify the effects of each:

1) The genetic origins of many of the trees are not known. This often is the case when trees are not contract grown according to buyer specifications, but are purchased from stock grown speculatively. The problems associated with planting trees of inappropriate genetic origin are well documented.

2) The seedlings were not always properly handled at the time of planting. I provided a list of specifications for plant handling that were part of the call for bids for planting. The State accepted the lowest bid, and the winning contractor did not want to honor the specs. It was decided that he would be released from those requirements.

3) The recommended competition control was not implemented, and subsequent weed competition was intense. This will cause some seedlings to die, others will persist but grow very slowly for several years. This is one reason why the trees were so small for their age at the end of the project.

4) The hydrologic regimes at each site were not designed or maintained to resemble any found in nature. Rather they were intended to maximize the potential for the sites meeting the Corps of Engineers delineation criteria for wetlands. Dikes were constructed around the sites to aid in water retention. During the first growing season, the sites were continuously flooded. We established a number of reference sites throughout the region, and while they were wet throughout that same time, they did not continuously pond water. Much of the mortality occurred during the first year after planting.

These forests are or will soon be composed primarily of volunteer pioneer species, which in absence of management will dominate the sites for many decades. Both sites have a small oak sapling component. While at low densities, these trees should persist. Heavy-seeded species invade sites of this size very slowly, and these trees will contribute important diversity to the site over the next century.

The primary concern is whether or not the resulting vegetation community met the goals of restoration. If a goal of this restoration was to establish a recognized natural community of North Carolina, or to develop a specific type of habitat, then the goal was not met. If the goal was establish any community with a reasonable amount of primary productivity regardless of species composition, then the restoration was successful. For example, if the goal of restoration was to stop the application of farm chemicals, stabilize the soils, and improve water quality, then the community composition is of little concern.

2.4.4 Research Work

We have completed a considerable amount of research in relationship on plant communities to the hydrologic and edaphic characteristics of a site. We established a series of references monitoring sites throughout the Coastal Plain of non-riverine wet hardwood forests and non-riverine swamp forests, and continue to monitor them. These are the community types that were likely to have been growing on the Deloss and Wasda soils before anthropogenic disturbance. We investigated trends along a fine-scaled wetness gradient utilizing a novel wetness index that incorporated indicators of saturated soils.

In many instances, evaluations of restored wetland forests do not adequately determine if target communities have been or will be attained. Current performance criteria have led to a population of restored and created wetlands that do not capture the range of natural variation. In North Carolina, performance is typically judged by vegetation condition and hydrology. We developed a technique that provides rigorous, definite, and pragmatic performance standards that allow for the identification of successful restoration of specific wetland community types by predominant mean height growth and yearly hydrograph. Autoregressive moving average models partition the important hydrologic influences on the series into those relating to previous values of the observed variable (autoregressive terms) and previous error values (moving average terms).

These works are described in:

Morris, Tracy Catharine. 2004. Tree composition along edaphic and hydrologic gradients in nonriverine wet hardwood forests. NCSU Masters Thesis.

O'Loughlin, David Kevin. 2007. A statistical approach to evaluating the performance of southern United States forested wetland restoration. NCSU Masters Thesis.

Johnson, Yari. 2009. Describing wetland hydrology with Indicators of Hydrologic Alteration. NCSU Masters Thesis (in prep).

2.4.5 Recommendations for plant community restoration

1. Recognized natural communities of North Carolina should be chosen as targets for restoration. There are several classifications schemes that define natural communities in the state.

2. A reference community should be established. A single reference site is never sufficient, as it is impossible to make any statistical comparisons. With a single reference site, any replication used in statistical analysis is pseudo-replication.

3. If soils are not appropriate for the desired plant community, modify the soils or choose a different community.

4. Restore a hydrologic regime that is known to support the target plant community. It is often desirable to establish the hydrologic regime after the first or second growing season, rather than prior to planting.

5. Always use plant material that is genetically adapted to the climatic, hydrologic, and edaphic conditions of the restoration site. This will usually mean that seedlings must be contract grown and not purchased on the spec market. Plant material must be stored, handled, and planted appropriately to maximum survival. There are many guides for seedling plant handling available.

6. Prepare the planting site by controlling competition if high survival and early growth are desired. For plant communities that require a disturbance regime in order to persist, such as frequent burning of longleaf pine dominated communities, a management plan should be prepared before restoration.

2.5 – Water quality response of outflow from the restored area

2.5.1 Introduction

Agriculture has been identified as the largest contributor of pollutants causing impairment of North Carolina streams and estuaries (NCDWQ, 1996). Water from nutrient rich agricultural lands is quickly drained to the state's rivers and estuaries potentially causing eutrophication. The drainage canal that transports the water from the restored North River wetlands and other nearby agricultural lands has estimated flows of over 23,000,000 m^3/year (810,000,000 ft^3/year). With an average total nitrogen concentration of 2.7 mg/L from three years of data, this results in an estimate of 63,000 kg (140,000 lbs) of nitrogen being added to the North River every year. The average total phosphorus concentration in the canal is 0.43 mg/L resulting in an estimated export of 10,000 kg (22,000 lbs) of phosphorus from this drainage canal every year. This illustrates the amount of nutrients coming from one sub-watershed. Wetland restoration can contribute to the reduction of nutrient loads to nearby estuaries in three ways:

- Reduce nutrient concentration
- Reduce water outflow
- Reduction in both nutrient concentration and outflow

2.5.2 Water Quality Objectives

- Evaluate restoration techniques designed for ideal wetland hydrology to determine if there is also an improvement in water quality compared to agricultural drainage
- Reduce nutrient loads to North River
- Reduce drainage water outflow volumes
- Quantify improvements in nutrient loads as a result of restoration of a prior converted agricultural site

2.5.3 Materials and Methods

Water control structures were installed in the existing drainage ditches to provide control of water levels within the wetlands and a means of monitoring outflow. Berms were constructed between the treatments to minimize surface water flow between them. Stage was monitored and logged at each of the water control structures using a float-pulley water level datalogger. The water stage along with a v-notch weir in the structure allowed outflow from the wetlands to be determined.

Water quality grab samples were collected from the control structures during outflow events in the restored wetland area. Samples were collected automatically daily and composited weekly from a nearby drainage agricultural drainage canal and near the outlet of the reference wetland. These samples were analyzed for total phosphorus (TP), nitrate (NO_3-N) and total kjehldahl nitrogen (TKN). The sum NO_3-N and TKN was used to determine total nitrogen (TN). The Wilcoxon Rank-Sum test was used to determine statistical differences between the treatments, the agriculture drainage canal, and the reference wetland (Helsel and Hirsch, 2002).

2.5.4 Results and Discussion

Nitrogen Concentration

Water quality samples were collected and analyzed for the period from April 2003-March 2006. The Wilcoxon Rank-Sum test results for TN concentrations are shown in Table 1 for each of the restoration surface treatments described in Section 2.3, the entire restoration, the agricultural drainage canal, and the reference wetland.

Table 1. Results of Wilcoxon Rank-Sum test (α=0.05) for TN concentrations at the North River restoration site from 2003-2006.

Treatment 1	Treatment 2	p-value	Significantly Different
ROUGH	PLUG	0.1201	No
ROUGH	CR	0.0024	Yes
PLUG	CR	0.1269	No
Ag. Drainage Canal	Reference Wetland	0	Yes
Ag. Drainage Canal	Restored Wetlands	0.0001	Yes
Reference Wetland	Restored Wetlands	0.0049	Yes

**Note – restoration treatments are as follows:
PLUG = ditch plugging only ROUGH = surface roughening CR = Crown removal

For the entire monitoring period, total nitrogen (TN) concentrations were significantly less in the restored wetlands than in the nearby agricultural drainage canal. For the period 2003-2006, TN concentrations differed between the ROUGH and CR treatments, with the ROUGH wetland areas exhibiting the lowest outflow concentrations. The PLUG treatment was not significantly different from the two other treatments. The concentrations in the restored wetlands reached levels similar to that measured in the reference wetland 12 months after the restoration was completed (Figure 1). In the third year of monitoring (April 2005 to March 2006) the export concentrations were similar for all of the treatments and the reference wetland (Figure 2). The drainage canal concentrations were significantly different than those of the reference wetland and the treatments. Reductions in nitrogen concentrations in the restored wetlands are attributed to cessation of fertilizer application to the restored area, wetland biogeochemical processes such as denitrification, and plant uptake.

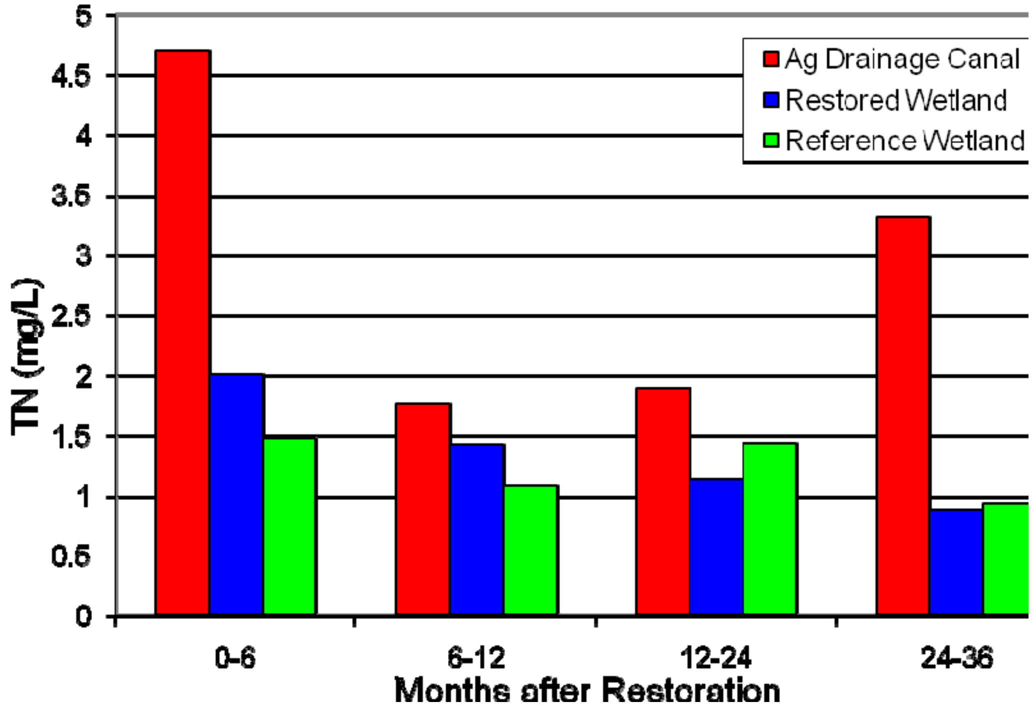


Figure 1. Comparison of average total nitrogen concentration in the restored wetland to the reference wetland and the agriculture drainage canal

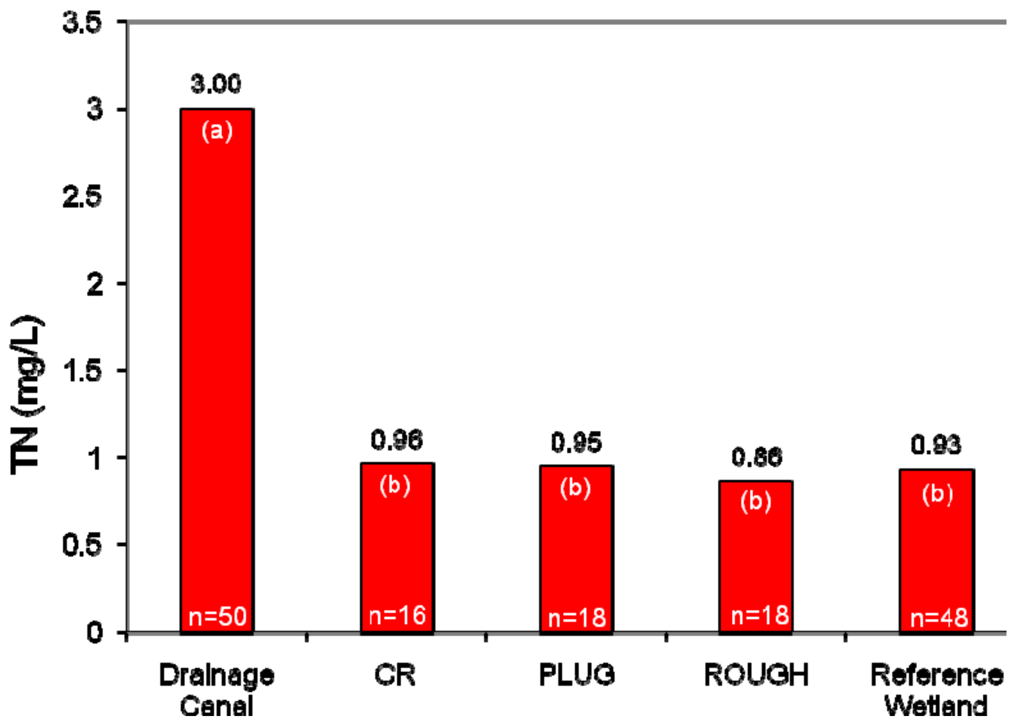


Figure 2. Average total nitrogen concentration for each of the restoration techniques, the reference wetland, and the agriculture drainage canal in year 3 of monitoring (α=0.05)

Nitrogen Export

Using water quality analysis and flow data from three years of monitoring the nitrogen export from the research plots was calculated and averaged. Figure 3 shows the mass of nitrogen exported annually per hectare of each restoration technique and the overall restoration. These are likely overestimated due to the nitrogen concentrations in the restored wetlands not returning to reference conditions until after the first year of monitoring. The ROUGH treatment on average exports more nitrogen annually than the other treatments despite having a lower total nitrogen concentration, because the to the ROUGH treatment had a higher outflow than the other treatments. It is estimated that the overall restoration will export 14,000 kg (31,000 lb) of nitrogen over 30 years based on the three years of collected data.

To estimate the nutrient savings due to the wetland restoration, pre-restoration nitrogen exports had to be estimated. Post-restoration data was available for flows and pre-restoration flows were estimated for the restoration area using the hydrologic model DRAINMOD (Wright, 2005).

Using an intermediate nitrogen concentration found in agricultural drainage ditches in Eastern North Carolina (Osmond et al., 2003) and the estimated pre-restoration flows, it was estimated that 39 hectares (96 acres) of farmland would contribute over 65,000 kg (143,000 lb) of nitrogen to the North River over 30 years of agricultural use.

Other research conducted on agricultural land in Eastern North Carolina had estimated the loss of nitrogen per unit of area (Deal et al., 1986). Using soils similar to the Deloss soil found in the restored wetland area, pre-restoration exports were estimated between 54,000 and 59,000 kg (119,000 – 130,000 lb) over 30 years (Figure 4). This shows a minimum 40,000 kg (88,000 lb) reduction in nitrogen exported over 30 years due to the restoration of 39 hectares of wetlands.

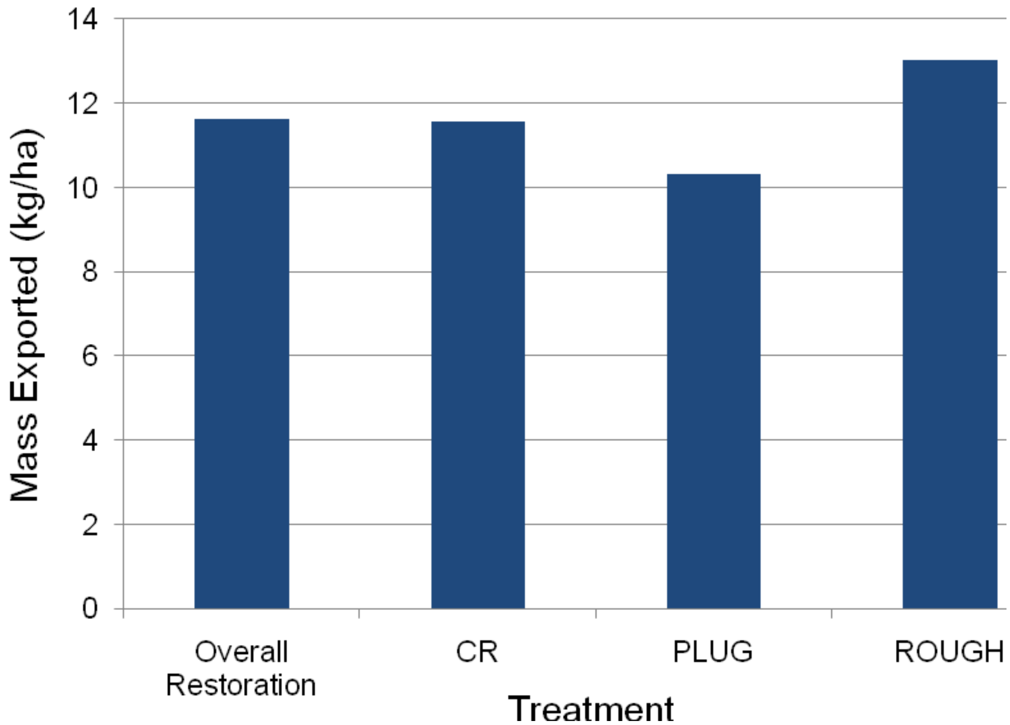


Figure 3. Comparison of nitrogen exported per year from a hectare of each wetland restoration technique based on a yearly average from April 2003 to March 2006

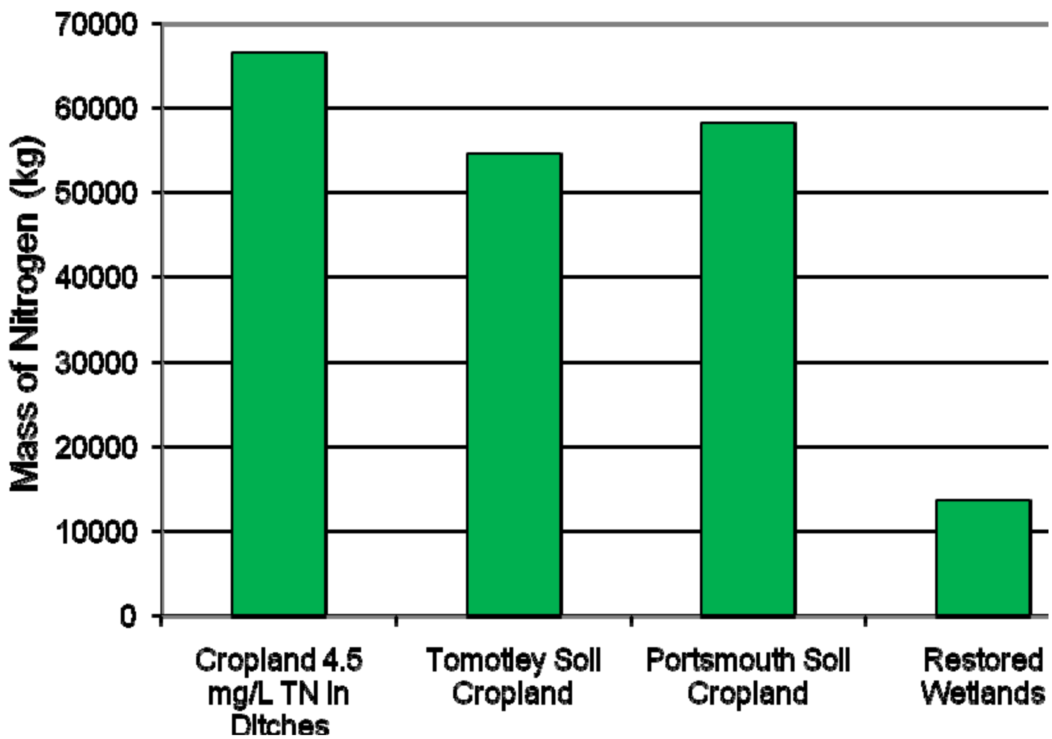


Figure 4. Comparison of nitrogen loading from restored wetlands and estimated exports as agricultural production land (39 ha area)

Phosphorus Concentration

The Wilcoxon Rank-Sum test results for total phosphorus concentration are in Table 2.

Table 2. Results of Wilcoxon Rank-Sum test (α=0.05) for TP concentrations at the North River restoration site from 2003-2006.

Treatment 1	Treatment 2	p-value	Significantly Different
ROUGH	PLUG	0.0434	Yes
ROUGH	CR	0.0004	Yes
PLUG	CR	0.0604	No
Ag. Drainage Canal	Reference Wetland	0	Yes
Ag. Drainage Canal	Restored Wetlands	0	Yes
Reference Wetland	Restored Wetlands	0.0001	Yes

Total phosphorus (TP) concentrations leaving the restored wetlands were significantly lower than the concentrations in the agriculture drainage canal throughout the three years of monitoring. The ROUGH treatment had the lowest phosphorus concentration and the CR had the highest concentration. The PLUG treatment was not significantly different from the CR treatment. The concentrations leaving the restored wetlands reached levels similar to those leaving the reference wetland after the first year as shown in Figure 5. In the last year of monitoring there was not a significant difference in the total phosphorus concentration of the treatments and the reference wetland (Figure 6). The concentration in the agriculture drainage canal continued to be different than the restored or reference wetlands. The reduction in phosphorus concentration can be attributed to ending the application of fertilizer and utilization by plants.

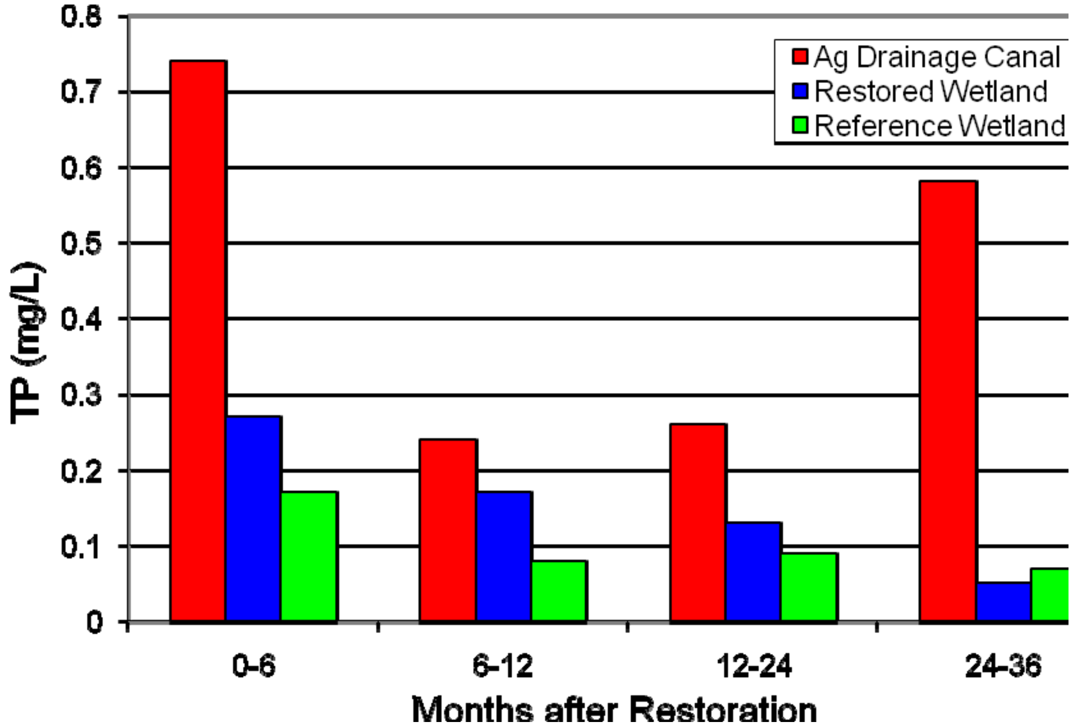


Figure 5. Comparison of average total phosphorus concentration in the restored wetland to the reference wetland and the agriculture drainage canal

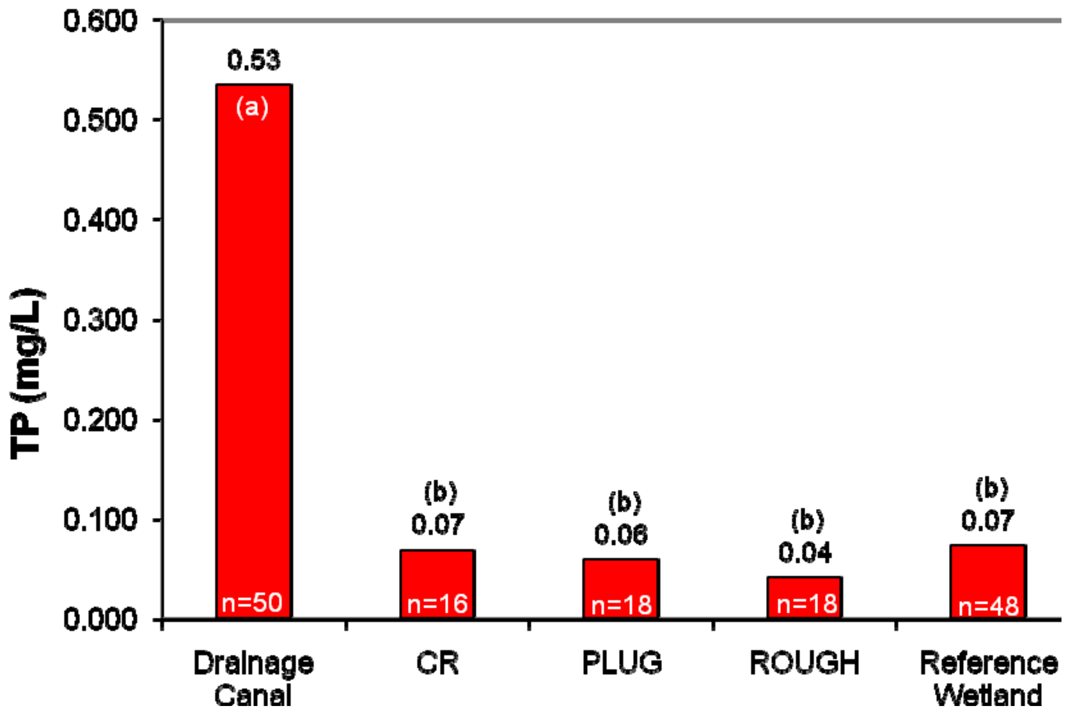


Figure 6. Average total phosphorus concentration of the three restoration techniques, the reference wetland, and the agriculture drainage canal in year 3 of monitoring (α=0.05)

2.5.5 Conclusions

Wetland restoration using any of the three techniques was effective at lowering the nitrogen loading compared to that of agricultural land. Through reducing the concentration of nitrogen and the volume of outflow, the total mass of nitrogen was reduced. With the phosphorus concentrations reaching levels similar to those leaving the reference wetland, the mass of phosphorus being exported from the land is less than when the land was in agricultural production. Wetland restoration and the resultant nutrient load reduction in key areas have the potential to benefit coastal estuaries. However, it may take one or more years for nutrient concnentrations leaving resotred areas to be similar to natural wetland systems.

2.5.6 References

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2.6 – Changes to Soil Properties in a Forested Wetland Following 8 Years of Restoration[1]

2.6.1 Introduction

The goal of wetland restoration is to recreate the conditions found in natural or reference wetlands in sites that have been drained and had their original wetland vegetation removed. The specific objectives for this project were to: 1) compare soil morphological, physical, and chemical properties in a restored wetland for two time periods – before restoration and 8 years after restoration, and 2) to compare these properties between the restored site and a natural wetland. Through these comparisons we hoped to identify soil properties that can be used as indicators of wetland restoration success.

2.6.2 Materials and Methods

Two sites were studied south of Aurora (N 35° 15.24', W 76° 48.31') in Beaufort County, NC. The sites consisted of a restored non-riverine wet hardwood forest (NRWHF), and a natural NRWHF that was used as a reference wetland for this study.

Restoration began in April of 1995 and included alterations that prevented precipitation from leaving the site as NRWHF wetlands are precipitation driven. Ditches were plugged, and two restoration treatments were imposed: smooth (unaltered surface) and contoured (created microhighs and microlows). A control treatment was also evaluated where a ditch was left open and the field perimeter remained open to runoff and run on of surface water.

Smith (1998) determined initial soil conditions after surface treatments were imposed. This included profile descriptions and obtaining soil samples from a soil pit in each sampling location. The restoration site was re-sampled in August 2003 for this study. Soil profile descriptions were completed and samples collected in the same sampling locations used by Smith in 1995.

Control and smooth surface treatments plots included one profile description per soil pit. Reference and contoured surface treatment plots contained two profile descriptions per pit, one described the micro high and the other described the micro low. Therefore, in contoured surface treatments the soil pits were dug perpendicular to the micro topography.

[1] Note: This section was added to guide expectations of soil conditions flowing multiple years of restoration. This work was supplemental to the work at North River Farms.

2.6.3 Results

Morphological Changes

Very little change in thickness and color of the A horizon occurred over 8 years (1995-2003) since the wetland was restored. The matrix color of the A horizon showed almost no change within most of the restored surface treatments from 1995 to 2003. The Munsell values of the smooth surface treatment increased by one unit and was significant at the $p = 0.10$ level. This may have indicated that carbon was being oxidized resulting in a lighter color in the soil.

At depths between 0 and 45 cm (18 in), all three surface treatments showed a significant ($p<0.05$) increase in the percentage of redox concentrations (red mottles) from 1995 to 2003. Both surface treatments of the restored site also had approximately 10% more redox concentrations when compared to the reference. The largest difference occurred in the micro-low where the percentage of redox concentrations was three times higher in the restored site at the 0 to 30 cm depth range.

Physical Property Changes

Soil textural classes were identical across all treatments for the 0 to 15 cm (6 in) depth range, and depths below 30 cm (12 in). For the 15 to 30 cm depth range, the micro-low treatments had a sandy clay loam textural class in both the restored and reference sites. The other treatments had a sandy loam textural class. This indicated that the Bt horizon was closer to the surface in the micro-lows in both the reference and restored sites. The surface contouring operation at the restoration site produced similar textural classes at similar depths as compared to the target reference wetland.

Bulk density values are reported in Table 1. The micro-highs in both the reference and restoration site tended to have lower bulk densities than the micro-lows. This is most likely due to the micro-lows having had their original surface removed to a depth of approximately 20 cm (8 in), with the tillage pan, below the original A horizon, being brought to within 15 cm of the new surface. Tillage pans typically have bulk densities >1.65 g cm^{-3} (Vepraskas, 1988).

Table 1. Mean bulk density for the upper 15 cm of the surface treatments of the 8 year old restored site and the reference site. The number of plots sampled is shown in parentheses. Measurements were not made in 1995.

Surface Treatment	Restoration (n)	Reference (n)	Difference
	------------------------------------g cm^{-3}	------------------------------------	------------------------------------
Smooth	1.61 (8)	n/a	n/a
Micro-High	1.57 (8)	1.13 (2)	0.44
Micro-Low	1.72 (8)	1.37 (2)	0.35
Mean	*1.63 (24)*	*1.25 (4)*	*0.38*

*The control plots (n=2) had a mean bulk density of 1.69 gcm^{-3}

Mean bulk density values were higher across all treatments for the restoration site than compared to the reference site. Root limiting bulk density values have been found to vary with soil texture (Daddow and Warrington, 1983). Bulk density values greater than 1.65 g cm^{-3} are high enough to slow root growth and prevent roots from growing below the layer in sandy loam and sandy clay loam soils. In general, only the micro-low treatments in the restored site were found to have root limiting bulk densities in the A horizon. Loosening of this layer with tillage using chisel plows may benefit plant growth, and should be practiced as part of the restoration plan. Eight years after restoration bulk density values were still higher than those found in the reference site.

Chemical Property Changes

The mean total-organic carbon (TOC) and mean total kjeldahl-nitrogen (TKN) decreased significantly ($p<0.01$) since 1995 for both the smooth surface and micro-high surface treatments. None of the C:N ratios were significantly different when comparing 2003 to 1995.

Values for TOC and TKN values in the reference were significantly higher than the values observed in the restored site during 2003. This difference is most likely attributed to the different ages of the two sites. The reference site represented a climax forest community, while the restored site was more indicative of an old-field succession. Summer temperatures were substantially higher (unmeasured) in the poorly shaded constructed wetlands. Elevated soil temperatures may increase chemical and biological activity, as well as rates of evaporation. Elevated soil temperatures and a lack of organic matter are not ideal conditions to accumulate TOC. These effects should diminish as the constructed wetland matures and the forest vegetation begins to shade the hydric soils. Much of the N in these systems is in the organic form, and consequently, the N levels follow the elevated C levels in the reference wetlands (Gwin and Kentula, 1990). With time, C and N levels in the constructed wetlands will increase. How long this will take is unknown, but it might depend on soil temperature being cooled by a closed canopy of a mature forest.

Levels of phosphorus (P) decreased by approximately one-half across all treatments from 1995 to 2003 in the restored site (Table 2). Decreases in P can occur as a result of plant uptake or by leaching in ground water. Phosphorus is released to the soil solution from iron compounds once the soil becomes reduced. It is possible that P is moving offsite in ground water. Phosphorus in the micro-lows did decrease, but not significantly. This change is most likely a result of the uptake by plants. Initial low levels of phosphorus in the micro-low treatments were probably due to the removal of topsoil from these areas during wetland construction.

Manganese (Mn) also significantly increased in the micro-high and micro-low treatments after 8 years. This trend was also observed in the smooth surface treatment however it was not a significant increase. Mn is mobile under reduced conditions and tends to move with the soil water. Manganese becomes reduced before iron, since there was an increase in redox (iron rich) concentrations percentages it was expected to increase as well. Most likely this was a result of the water table fluctuating in the upper 45 cm of the soil, which allowed the Mn to become reduced and then oxidize within the 0 to 15 cm depth range.

Calcium (Ca) and base saturation (BS) both decreased after 8 years. The two were expected to correlate as Ca is used to calculate BS. BS like Ca was a broad measurement of soil fertility and since this was the conversion of a field previously under agricultural production the expectation is to see BS decline with time. All surface treatments were significantly ($P < 0.05$) different for both Ca and BS. Ca and BS should continue to steadily decrease with time. BS will likely take longer to reach levels found in the reference as it measures several cations. Ca is of particular interest as previous studies have indicated that most of the plant available Ca is diminished 10 to 15 years after a field goes out of agricultural production.

A decrease in pH was observed between 1995 and 2003 for the micro-high and micro-low surface treatments, with only the micro-low being statistically different. This indicated the soil is becoming more acidic. Values of pH normally shift towards 7 under anaerobic and saturated conditions for soils that have a pH between 4 and 7. The restored soils had been heavily limed for agricultural production before restoration and had a high initial pH. The pH decreased as a result of the created saturated and anaerobic conditions in the restored site, and appropriately correlated with the decreased values of Ca and BS.

It was noted earlier that all the selected NCDA soil nutrient properties had decreased from 1995 to 2003 at the 0 to 15 cm (6 in) depth. However, the restored levels remained above conditions in the reference after 8 years (Table 3). Phosphorus in the restored micro-highs is still twice that of the reference phosphorus levels. The micro-lows are only 1 mg kg^{-1} phosphorus greater than levels found in the reference. Phosphorus in the micro-lows of the restored site was most similar to the reference.

Manganese (Mn) increased after 8 years, rather than decreasing to levels found in the soils in the reference non-riverine wet hardwood forest. The restored micro-highs still contain approximately three times the amount of Mn found in the reference micro-highs. The restored micro-lows have approximately four times the amount of Mn found in the reference micro-lows. The hydrology of the restored site has not provided an outlet for Mn to leave the soil. The flux of the water table during transitional periods between saturated/anaerobic and unsaturated/aerobic conditions are believed to cause the Mn to accumulate in the upper 15 cm of the restored soil.

Calcium levels in soils in the restored micro-highs were three times greater than the reference micro-highs. Ca in the restored micro-lows was 25% higher than levels found in the reference micro-lows. Base saturation is almost four times the amount in the restored micro-highs as compared to the micro-high, which correlates with the Ca. We expect Ca levels in the restored soil to reflect the natural soil before BS. The pH followed the same declining trends as Ca and BS; however, there was little difference between the two surface treatments.

Table 2: Summary of selected mean results from the NCDA soil testing for the upper 15 cm of soil in the restored site. Values with the same letter indicate a significant difference at $p < 0.01$.

NCDA Measurement	Year	Surface Treatments			
		Control n = 2	Smooth n = 8	Micro-High n = 8	Micro-Low n = 8
Phosphorus (mg kg^{-1})	1995	87.0	74.8^{a}	$63.^{b}$	27.7^{c}
	2003	30.6	31.5	26.7	15.8
	Statistical Difference	nd	p < 0.0001	p < 0.0001	p = 0.08
Manganese (mg kg^{-1})	1995	5.08	4.2^{a}	5.10^{b}	2.69^{c}
	2003	4.65	5.06^{a}	6.96^{b}	4.68^{c}
	Statistical Difference	nd	p = 0.27	p = 0.02	p = 0.01
Calcium ($cmol_c$ kg^{-1})	1995	1.79	1.84	1.84	2.06
	2003	1.35	1.40	1.26	1.70
	Statistical Difference	nd	p = 0.01	p = 0.001	p = 0.03
Base Saturation %	1995	89.5	85.8	86.9	92.0
	2003	80.1	72.7^{a}	74.7^{b}	81.6^{c}
	Statistical Difference	nd	p < 0.0001	p = 0.0001	p = 0.001
pH	1995	5.80	5.06^{a}	5.61^{b}	6.20^{c}
	2003	5.56	5.10	5.31	5.62
	Statistical Difference	nd	p = 0.04	p = 0.10	p = 0.01

*Statistics are presented below the values being compared; a statistical difference is represented by a P-value < 0.01. Different lower case letters beside the value represent a statistical difference between surface treatments within a given year. Statistics could not be applied to the control plots as the sample number was too small (nd = not determined).

Table 3. Summary of selected mean results from the NCDA soil testing for the upper 15 cm of soil in the restored (2003) and reference sites. Statistical analysis was not available for this comparison.

Year and Depth (cm)	Surface Treatments			
	Control	Smooth	Micro-High	Micro-Low
Restored - 2003	n = 2	n = 8	n = 8	n = 8
Phosphorus ($mg\ kg^{-1}$)	30.6	31.5	26.7	15.82
Manganese ($mg\ kg^{-1}$)	4.65	5.06	6.96	4.68
Calcium ($cmol_c\ kg^{-1}$)	1.35	1.40	1.26	1.70
Base Saturation %	80.1	72.7	74.7	81.6
pH	5.56	5.10	5.31	5.62
Reference	n/a	n/a	n = 2	n = 2
Phosphorus ($mg\ kg^{-1}$)	n/a	n/a	14.0	14.77
Manganese ($mg\ kg^{-1}$)	n/a	n/a	2.04	1.14
Calcium ($cmol_c\ kg^{-1}$)	n/a	n/a	0.43	1.22
Base Saturation %	n/a	n/a	20.9	38.1
pH	n/a	n/a	3.98	4.47

The same selected NCDA nutrients were compared by depth for the micro-highs and micro-lows between the restored and reference site in Table 4. Statistical analysis was not applicable to this comparison, as the sample size for the reference was too small. However, this table does provide useful information that allowed us to speculate about how and why phosphorus, manganese, calcium, base saturation, and pH are changing in the soil of the restored site.

Phosphorus is most abundant in the upper 15 cm (6 in) of the soil for both micro treatments. Amounts of P diminish with depth in both the micro-highs and micro-lows of both sites. Only the restored micro-highs had detectable amounts of P at the 30-45 cm

(12-18 in) depth range. Phosphorus decreased the least from the 0-15 cm depth to the 15-30 cm (6-12 in) depth in the restored micro-highs. Most likely a result of this soil being the last to become saturated and anaerobic, and allowing mire P to remained bound to Fe and Al oxides and hydroxides. Phosphorus decreased the most from 0-15 cm depth to the 15-30 cm depth in the micro-lows of the restored site. This resulted from this depth being saturated and reduced longer and having the presence of P, thereby allowing the Fe and Al oxides to become reduced and release P into the soil water. This has caused P levels at the 15-30 cm depth in the micro-lows of the restored site to drop below levels found at the same depth in the micro-lows of the reference. This should not have a negative impact on the status of the restored site.

Manganese like phosphorus is most abundant in the upper 15 cm for both the micro-highs and micro-lows in both the restored and reference sites. The amount of manganese in the soil decreased with depth for both surface treatments in both sites. Manganese amounts drop the most going from the 0-15 cm (0-6 in) depth to the 15-30 cm (6-12 in) depth. This is attributed to the upper 15 cm (6 in) being the first part of the soil to become unsaturated and aerobic, which allowed the manganese to oxidize and precipitate in the soil. Manganese is found in larger amounts in the micro-high as compared to the micro-lows. This was a result of the micro-lows being saturated and anaerobic longer than the micro-highs, which allowed manganese to remain in a reduced state longer and remain more mobile.

Table 4: Summary of selected mean results from the NCDA soil testing analysis for three different depths: 0-15 cm, 15-30 cm, and 30-45 cm relative to the soil surface in the restored (2003) and reference sites. Statistical analysis was not available for this comparison.

NCDA Measurement	Depth (cm)	Micro - Highs Rest. 2003 n = 8	Micro - Highs Reference n = 2	Micro - Lows Rest. 2003 n = 8	Micro - Lows Reference n = 2
Phosphorus ($mg\ kg^{-1}$)	0 – 15	26.7	14.02	15.82	14.77
	15 – 30	17.17	2.65	1.09	4.60
	30 – 45	2.09	0	0	0
Manganese ($mg\ kg^{-1}$)	0 – 15	6.96	2.04	4.68	1.14
	15 – 30	4.06	0.48	1.30	0.27
	30 – 45	1.36	0.30	0.75	0.51
Calcium ($cmol_c\ kg^{-1}$)	0 – 15	1.26	0.43	1.70	1.22
	15 – 30	1.69	0.19	3.19	1.85
	30 – 45	3.27	0.80	3.59	1.92
Base Saturation %	0 – 15	74.74	20.90	81.58	38.13
	15 – 30	81.24	16.20	88.01	49.13
	30 – 45	89.68	30.17	87.93	58.57
pH	0 – 15	5.31	3.98	5.62	4.47
	15 – 30	5.77	4.34	5.86	4.75
	30 – 45	6.12	4.52	5.78	5.08

Calcium followed the opposite trend of manganese and phosphorus. Calcium was found in smaller amounts in the 0-15 cm (0-6 in) depth range and increased with depth. Except for the micro-highs in the reference, which showed a decrease at 15-30 cm (6-12 in) before it increased in the 30-45 cm (12-18 in) depth range, to levels higher than found at the 0-15 cm depth. A likely explanation for the decrease is a well-developed E horizon, which was intensely weathered and had most of the calcium had leached. The 15-30 cm depth range in the restored micro-highs did not show this effect because not enough time has passed for this process to occur. Base saturation followed all of the same trends as calcium. The data reflected the evidence of a well-developed E horizon in the reference micro-highs and the lack of an E horizon in the restored micro-highs.

Both of these soils would be considered acid soils, as the pH values ranged from 3.98 to 6.12. In general the pH of these acid soils would increase towards 7 under anaerobic conditions. In this study the pH of the 30-45 cm (12 -18 in) depth range was always higher than the pH at the 0-15 cm (0-6 in) depth range. The pH of the micro-lows in the restored site decreased at the 15-30 cm (6-12 in) depth but was higher at the 30-45 cm (12 -18 in) depth.

Hydric Soil Technical Standard

The hydric soil technical standard (HSTS) measured the time the soils were anaerobic and saturated. Hydric soil conditions were met if the soil was anaerobic and saturated for three consecutive weeks, during a period of normal rainfall. The smooth, micro-high, and micro-low in the restored site met the hydric soil technical standard (HSTS) for approximately the same time at three different 3-week intervals during the study period. There were three three-week periods when the soil was saturated and anaerobic within 25 cm of the soil surface and occurred during a time of normal rainfall. As only one 3-week period is required to meet the HSTS, therefore all of the treatments produced a hydric soil as defined by the HSTS. The control plot also met the HSTS in January 2004 and March 2004 to the end of May 2004.

The micro-highs and micro-lows in the reference also met the HSTS. The reference soil met the HSTS during the first two periods of normal rainfall, just as the restored site did. The reference site had not yet become anaerobic and saturated during the third period of normal rainfall. This indicated that the restored site wets up faster than the reference site. This is most likely a result of the water table dropping deeper in the ground in the reference site and takes longer to rebound to the 25 cm (10 in) depth than the restored site does, as the restored water table only drops to about 90 cm (36 in) during the summer. As a result, the soil in the reference met the HSTS fewer days than the soil in the restored site (see Figure 1).

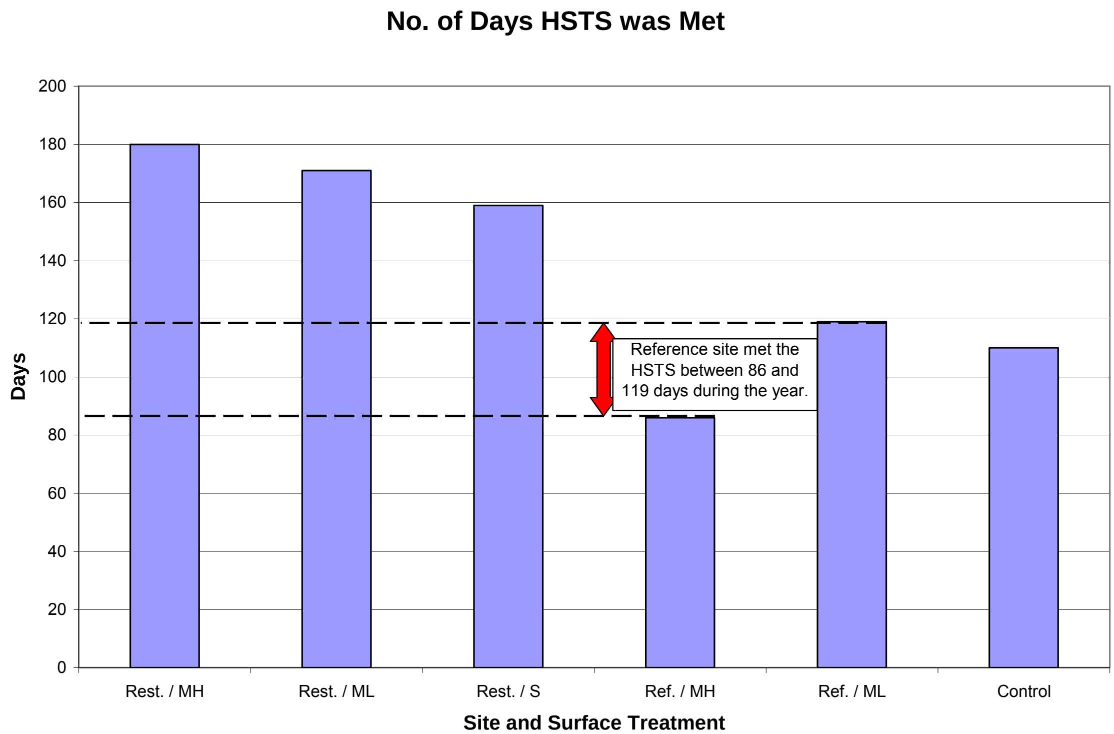

Figure 1. Total number of days each surface treatment successfully met all requirements for the HSTS.

2.6.4 Discussion

This study found that 8 years after restoration of wetland hydrology, the soil morphological, physical, and chemical properties changed. Redox concentrations increased significantly ($p=0.05$) in the restored site for all three surface treatments. The largest increase was 10% at the 30 to 45 cm (12-18 in) depth. Redox concentrations in the reference were less abundant than in the restored site in 2003, primarily in the 0 to 30 cm (0-12 in) depth. Largest differences in redox concentrations occurred in the micro-lows where the mean for the micro-low in the reference had as little as 0%, compared to the restored micro-low that had as many as 32%.

Bulk densities were higher in the restored site as a result of plowing when the soil was under agricultural production. The micro-lows in the restored site had a mean bulk density of 1.72 g cm^{-3}, which could restrict root growth. Light tillage of the micro-lows to loosen the soil could benefit plant growth.

TOC and TKN both decreased after 8 years in the restored site, while values found in the reference were close to three times higher than those found in the restored site. Phosphorus (P), calcium (Ca), and base saturation (BS) all decreased significantly after 8 years in all three surface treatments of the restored site. Levels of these nutrients were all above the values sampled from the reference. Manganese (Mn) increased in the upper 15 cm (6 in) of the restored site, and values were greater than those found in the reference site.

All treatments at both sites, including the control, met the HSTS. However, the restored site met the standard 40 to 90 days longer than the reference, indicating that the restored site was “wetter” than the reference site.

The use of soil characteristics has potential in being a valuable early indicator of restoration success. Changes in redoximorphic features would be capable of providing a field method, once a relationship between feature abundance and the water table are established. Collecting soil samples for NCDA soil test is a relatively inexpensive and easy method to determine if the soil is returning to its natural state. Testing the soil of a reference wetland and a restored wetland with the HSTS is a scientific method that can determine if a restored site has characteristics similar to a natural wetland.

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3.0 - Phase II –Research on 14 ha (35 acres) of tidal marsh restoration

Aerial photograph of the Phase II marsh area taken in June 2009

3.1 Introduction and Research Goals

During the second phase of construction, (completed in 2007 with final tree planting in 2008) 22 ha of non-riparian hardwood wetland, 9 ha of riparian freshwater wetlands, and 14 ha of tidal marsh have been constructed. This phase required much more extensive earthwork than Phase I, so much insight into design on construction techniques was gained. The use of specialized equipment suited for extreme wet conditions, well planned construction sequencing and timing, and topsoil replacement are examples of ways to efficiently ensure restoration success while minimizing cost.

The tidal marsh portion created in this second phase has provided a unique demonstration in terms of location (prior converted farmland), scale (14 ha), and species planted (included infrequently used but native *Juncus roemerianus*). Research on the marsh has focused mainly on the stability of the tidal stream, downstream water quality (since agricultural drainage water also has been diverted through the system), and vegetation survival. Primary research goals for this effort included:

1. Evaluate the design and construction techniques utilized in restoring a large-scale coastal marsh.
2. Asses the ideal target elevations for the marsh vegetation used in the planting plan
3. Determine the post-construction stability of the tidal stream portion of the marsh restoration.
4. Establish whether the tidal marsh provides water quality improvement to drainage water diverted into the site, in terms of N, P, and fecal bacteria
5. Provide NCEEP with recommendations based on our research experience at the site that will guide future tidal marsh restorations

Figure 1 shows the final restoration design for the Phase II site. The tidal marsh research was focused on the tidal stream portion on the western and southern portions of the restoration, as indicated by the box in Figure 1.

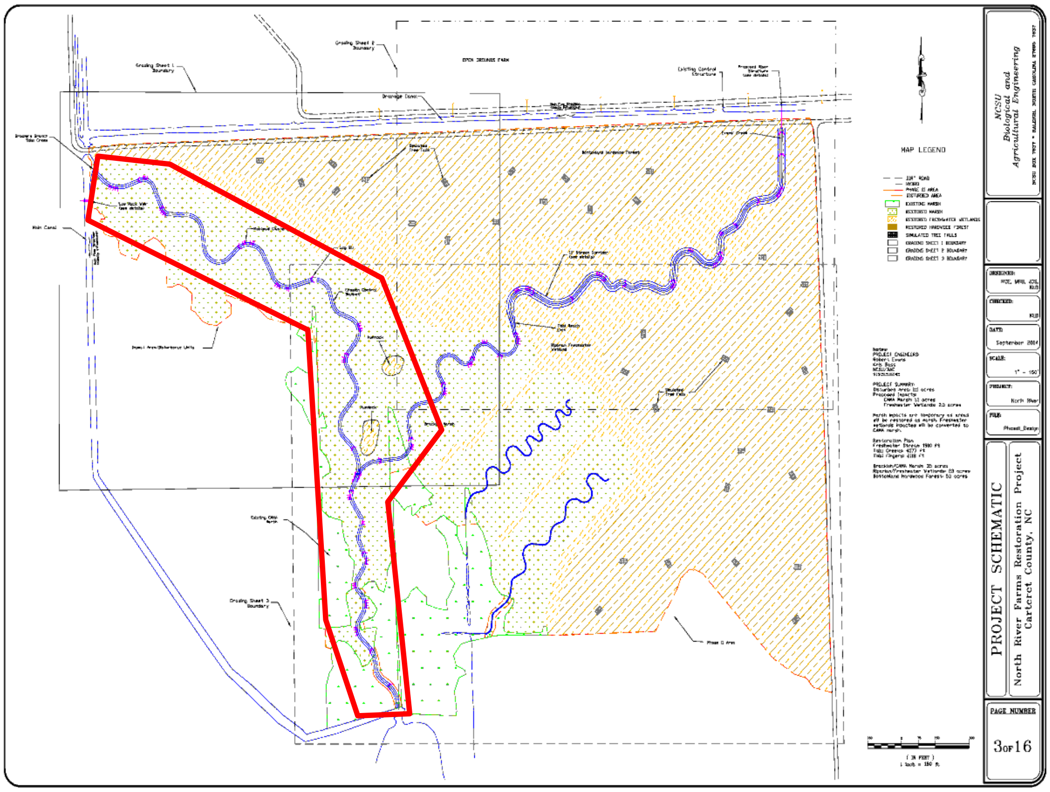

Figure 1. Final restoration design developed and implemented by the NCSU team. Research area on the tidal marsh portion of the restoration indicated in the red box.

3.2 – Design and construction recommendations for tidal marshes

3.2.1 Introduction

Tidal marshes have long been recognized as one of the most important and most complex wetland ecosystems on earth. Accordingly, the in-lieu fee required by NCEEP to fulfill compensatory mitigation requirements is the highest by far of all ecosystems considered. Restoration or creation of these ecosystems can be extremely difficult, given their landscape position and their importance to coastal ecology, water quality, and local economy. Therefore, the Phase II restoration effort was recognized as a unique opportunity to study the design, construction practices, and the post-construction performance of a tidal marsh in order to produce recommendations for similar restoration efforts overseen by NCEEP in the future, to increase success rate of these projects.

3.2.2 Methods (Tidal marsh construction summary)

The NCSU design team completed the tidal marsh design and the permit application process for this project during the spring of 2005, and all permits were acquired by the end of the summer. The North Carolina Coastal Federation (NCCF) chose Backwater Environmental as their contractor for the project. The contractor was hired to provide all earthwork and grading services for the project. An additional contract for planting was negotiated by the NCCF. NCSU provided on-site guidance for the duration of the construction process.

The construction was completed in two phases. The first phase was between the fall of 2005 and spring of 2006. During this phase, the entirety of the Broome’s Branch area of the site was completed (Fields 1-4). This comprised of approximately 6.9 ha (17 acres) of brackish marsh and 1000 m (3300 ft) of tidal creek.

Initial construction activities began in the lower sections of Broome’s Branch and the tidal marsh in August of 2005. The excavation process involved the removal and stockpile of topsoil, mass grading for the marsh surface, stream construction, and finally replacement of topsoil. The fall hurricane season brought rains to the project site and caused some construction delays. Hurricane Ophelia skirted the NC coast and associated rains flooded the site in mid September. Once the site was suitable for work, continued excavation completed stream and marsh in fields 1-4 in the Broome’s Branch area of the site. The site was seeded and covered in straw prior to the contractor stopping operations (January 31) until spring. In early April 2006, stream structures such as rootwads, erosion control matting, and final grading was completed on the Broome’s Branch area. Marsh planting was completed in the summer of 2006.

The second phase of the work began in the winter of 2006 and was completed by early spring 2007. This phase included the excavation of two tidal fingers, adjoining marsh, and the construction in the Evan's Creek portion of the site (Fields 5-8). An additional 18 acres of marsh was prepared during this phase, including 640 m (2100 ft) of tidal fingers. Evan's Creek is composed of 580 m (1900 ft) of freshwater stream and 365 m (1200 ft) of tidal creek. Final grading was completed in late winter, and shrubs were planted at this time. Marsh planting was completed in mid-summer 2007.

Final pieces of the construction included installation of a water control structure at the head of Evan's Creek, and installation of a low rock weir in the main canal at the head of Broome's Branch. The water control structure was installed in early spring 2007 and the low rock weir in the fall of 2007. The completed installation of these structures marked the end of the major construction activities for the project. A final planting of trees was completed in February of 2008, and a supplemental planting of marsh grasses was completed in the summer of 2008 and in 2009.

Table 1. Phase II project timeline.

Activity	Date-Duration
Design complete/All permits acquired	Spring/Summer 2005
Construction begins	August 2005
Marsh and Broome's Branch excavation	Sept 2005.
Rain starts!	Mid Sept. 2005
Continued excavation	Fields 1-4. Oct-Jan 2006.
Work break	Jan 31. 2006
Complete channel and marsh, plant	April 2006.
Tidal fingers and Evans Creek	Winter 2006-2007.
All grading complete!	May 2007.
Riparian and marsh plantings	Spring/Summer 2007.
Low rock weir diversion installed	Fall 2007
Tree plantings	Winter 2007/2008.
Supplemental marsh plantings	Summer 2008 and 2009

3.2.3 Construction Recommendations

Coastal plain construction projects encounter a number of unique construction challenges. Sandy soils and shallow water tables create difficult conditions for excavation and grading activities. Non-cohesive soils can be difficult to grade precisely and stabilize as stream banks. The North River Phase II construction was a lengthy experience where much was learned about construction management for these systems. Recommendations are separated into two categories. The first category includes advice specifically regarding construction activities. The second category includes recommendations developed based on monitoring and post construction observations at the site. Incorporating this guidance into future projects should improve success of any coastal or marsh restoration site.

During-Construction Lessons

1. Large scale projects benefit from a well thought out construction sequence.

   Putting some thought into how the construction on one portion of the site might affect activities on another, will help planning efforts. This is especially the case for managing traffic on a site. Repeated trafficking on wet, sandy soils can lead to heavy compaction or unstable conditions for stream banks. The creation and maintenance of a planned temporary road will help prevent delays and focus repairs. Roadways should avoid stream crossings if possible and thorough repairs must be made when removing the roadway.

   The construction sequence must be planned around the hydrology of the site and to ensure drainage that will allow work to continue. If the site can be built in the dry, utilizing a pump around or diversion, significant gains in efficiency can be achieved. A sequence that progresses from downstream to upstream can help ensure drainage and progress of the work. Stabilizing each area before proceeding to the next will help limit traffic, compaction, and other erosion problems.

   A pumping system and a plan for managing water on the site should be a project requirement. Critical construction phases may require some pumping to create suitable conditions. A planned erosion control basin or pumping area will allow greater access and flexibility for completing needed tasks even in wetter conditions.

   It is likely that the construction of a significantly sized site will require several separate mobilizations. The timing of activities such as mass grading, fine grading, and planting should be well thought out and planned for in advance. Specifications should indicate the time of year activities shall be completed to get the best and most efficient results. Many grading activities should be done in early summer months if possible. Tree plantings should be done over the winter, and any marsh planting absolutely requires a spring mobilization.

2. <u>Involvement of an experienced, local contractor can improve project efficiency and quality.</u>

   An experienced contractor that is familiar with local conditions can anticipate problems before they occur. A pro-active approach to managing grading and traffic issues can generate significant time savings. Experience working in local soil conditions will also provide opportunities for increased efficiency.

   Local contractors will have greater flexibility to bring significant resources to a site during dry periods, make the most of dry working days, and to leave the site if necessary during wet times. Experience with the local weather and proximity to the site will save on travel expenditures and reduce wasted effort. This flexibility will allow construction managers to make the most of their on-site oversight time.

   In potentially wet soil conditions, it is helpful to complete construction activities correctly the first time, and to avoid traffic associated with making corrections or repairs. An experienced contractor and providing resources for oversight can improve accuracy and minimize errors.

3. <u>Contractors should commit significant resources to grading activities during dry periods.</u>

   It is our highest recommendation to mobilize a significant construction crew during dry periods to accomplish as much work as possible. Dry conditions allow for a more efficient traffic pattern, more precise grading, and allow final soil preparations that are not possible in saturated soils. Wet periods such as after a hurricane or over the winter may slow work significantly or prevent it entirely. Resource flexibility should be secured to plan for such scenarios and to be prepared to adjust for them as needed. A dramatic improvement in project efficiency was observed at this site during very dry conditions.

4. <u>Specialized equipment can be useful and efficient in the coastal plain.</u>

   Low pressure or track based equipment have particular advantages in wet soils. If mass grading is expected, the use of a track mounted dump truck will provide needed flexibility. Swiveling bucket attachments are helpful for creating stream meanders. A four wheel drive tractor with a variety of attachments is also useful for fine grading, and maintaining traffic lanes. Tractor accessories such as box blade and tilling implements will be especially useful on a marsh project.

Post Construction Lessons

1. Stream feature ‘extras’ are worth it.

   Extras such as topsoil, erosion control matting, rootwads, and other types of wood structures are typically incorporated into stream projects. The expense of adding these items is generally not large compared with the cost of significant earthwork. However, the stability of the stream, success of vegetation, and added habitats that depend on these items are a big part of the project success. It is encouraged to utilize as much of these features as can be afforded by the project.

2. Tidal stream construction

   Tidal streams are different than their freshwater counterparts. Tidal streams are subject to constant water level variation, with stages reaching the bankfull level or higher twice per day. However, velocities are usually low, and large storm events are typically coupled with high downstream stages resulting in overbank flows with low stream stress. Tidal streams will typically have extremely low slopes, with sandy beds and silt deposits. A reference tidal creek will have a fairly consistent geometry, with some irregularity associated with tributaries, overbank runoff, areas with little or no vegetation, and debris. As a result, designs of these streams should focus on tidal elevations and site constraints. Providing the proper interaction with the tide will be critical for establishing vegetation, and making this work within the confines of a particular site will be a special concern. Construction of these streams should focus on geotechnical stability and vegetation establishment more than on the sequence of features such as meanders and riffles or pools.

   This site was constructed at a nearly constant slope. No pools or riffles were constructed. However, based on our monitoring, pools are forming in meanders and near rootwads. Details on stream morphology and development are a part of research completed at the site and are included in a later portion of this report.

   It is our recommendation that detailed construction of bed features is not a necessary part of sand bed stream restoration. The use of meanders and woody features is promoted to provide desired complexity. It is expected that this construction template should dramatically simplify tidal stream construction compared to upland freshwater systems. Resources should instead be spent on incorporating other recommended features.

3. Erosion control matting and vegetation for stream banks

The installation of erosion control fabric can provide initial bank stability while vegetation is established. A lightweight straw based matting with a biodegradable net is typically sufficient in low energy coastal systems. The matting is generally not necessary to prevent scour from high velocity waters. Its main purpose is to provide geotechnical support to the bank slope and to prevent a slide or similar erosion event. This is especially important on a marsh project, where the bank can be subject to groundwater pressures and much of the streambank may remain unvegetated due to tidal fluctuations. On a large scale project, benefits can be maximized by targeting matting for the outside of meander bends. In addition, the installation of fabric on sandy soils is an easy task compared to installation in mountain or clayey soils.

At this site, the design stream got larger as the project proceeded downstream. The most downstream portions of the project utilized matting along both banks. Middle portions used matting only on the outside of meander bends. Based on our observations, bank heights lower than 2 feet do not need erosion control matting to help support banks. Higher banks will benefit from matting, especially along the outside of meander bends. On several of our projects, we have found banks to be most unstable during periods immediately following construction and as runoff can concentrate over the tops of the banks. Once some vegetation has established, banks stabilize rapidly. As a result, it is recommended to install fabric as construction proceeds, and spread seed as soon as possible.

Dense planting of the streambanks and near stream zone is a highly desired component. Aggressive primary colonizers such as *Spartina alterniflora* are highly recommended species. An excellent stand was established at this site by planting plugs on a 2 ft spacing.

4. Rootwads, log vanes, and woody features

The incorporation of woody material into a coastal stream project should be an expected part of any project that involves improving aquatic habitats. Sandy, coastal systems can require decades of watershed inputs combined with large storm cycles to develop complex habitat features. Installing wood features is the only way to duplicate this process on a reasonable time scale.

Rootwads can provide important structure to the outside of meander bends. This is especially true where higher banks are planned, in areas where traffic volumes are expected, and where crossings of existing ditches or tributaries will complicate conditions. The installation of rootwads in a coastal setting can be a much different process that those in mountain or piedmont areas. Softer subsoils allow rootwads to be driven or pressed into place easily, especially with the use of a trackhoe with a hydraulic thumb. In a coastal setting, pine trees or any trees of suitable size can be utilized. Since high energies are not expected, rootwads may be much shorter than in mountain areas.

Log vanes are also simple to install and cost effective compared to rock vanes typical of other stream systems. A few logs staggered on top of each other, installed flush with the streambed, is all that is needed to promote pool development and provide some habitat complexity. Our monitoring and research has shown that log vanes can be used to develop and sustain pools, and that hardened streambed features are important for aquatic habitat.

In addition, those constructing tidal creeks may wish to consider the use of oyster clutch or rock in the streambed. In our biological surveys of the site, hardened habitat has been attractive for oyster colonies. If the target creek is connected to oyster habitat, adding some rock to the streambed will provide a habitat that cannot be provided any other way.

5. <u>Topsoil</u>

Many coastal plain sites, and especially those located on farms, will have an existing topsoil layer. Utilizing this topsoil can be critical to the development of a site and to promoting rapid vegetative establishment. In most coastal sites, excavation may lead to banks and floodplain surfaces that are primarily sandy subsoil. This subsoil may lack nutrients and organic matter that are necessary to establish desired vegetation. In addition, construction traffic can disturb soil structure and cause compaction. The process of amending the surface with topsoil helps reduce these impacts. It is our recommendation that the stockpile of on-site topsoil, replacement, and deep tilling be a requirement on most coastal plain projects.

At this site, as on many large sites, it was not economical to replace topsoil over the entire project. Careful consideration of soil conditions, and excavation depths can help focus topsoil replacement to needed areas. In general, areas of the site that had topsoil replaced had superior vegetation establishment compared to those without. In addition, the upper layers of topsoil may have added seedbank potential. Areas with topsoil additions generated a larger amount of volunteer species. This is especially true of areas in the vicinity of tidal ditches, which may have been accumulating seed deposits for many years.

In terms of economics and feasibility, topsoil replacement is not as time consuming as it sounds. An organized stockpile scheme will have little impact on excavation time, and be easy to spread, replace, and incorporate. In areas where topsoil is replaced, bulk grading can be less precise and the fine grading process in the floodplain can actually be smoother and easier. The method used at this site was to target topsoil replacement in the near stream corridor, where rapid vegetation establishment is needed most. Rows of stockpiled topsoil were deposited along the outer boundaries of this corridor, then replaced with the help of a bulldozer and a tractor.

6. <u>Marsh grading/construction equipment traffic</u>

The general theory of marsh construction is that the marsh must be built in the proper tidal elevation range, have access to the water, and also be able to drain. The last of the criteria require marsh construction to involve a detailed fine grading. The marsh should be sloped slightly towards the water source to avoid excessive standing water and concentrated build up of salts in the marsh. The slope of a restored marsh will depend on the site constraints and tidal range, but it is important to oversee this process carefully. At this site, it has been clear that spending extra attention on this grading was a benefit to the density of plant establishment.

The downstream portion of this site was subjected to repeated traffic of heavy equipment. The construction schedule also required this area to be graded multiple times. Upstream portions of the site were minimally disturbed and less traffic was necessary. The results of this activity was evident - the upstream portions of the marsh developed dense stands of vegetation much faster than the lower portions.

7. <u>Marsh planting</u>

This site was planted with a variety of marsh species and on a variety of densities. In addition, there were several marsh areas that were left unplanted and observed for volunteer growth. A detailed research study was performed on species survival and growth, which is presented later in this report (Section 3.3).

In general, it is recommended that every marsh project in NC be planted densely with nursery grown marsh plugs. Streamside zones should be planted at 0.6 m (2 ft) spacing or less. Areas away from the stream or shoreline can be planted at wider spacing as resources allow. The larger areas of this site were planted on 1 m (3 ft) spacing. Areas planted at the closer spacing filled in rapidly and have developed very dense stands in several growing seasons. Areas planted at wider 1 m (3 ft) spacing have also filled in well. However, these areas have taken a little longer to establish and some bare areas still exist, even after a few growing seasons. Areas that were not planted at all have seen little volunteer growth. Some areas that are directly adjacent to existing marsh have seen some spread of grasses. Species of *Spartina* have experienced tremendous growth, excellent survival, and spread. *Juncus* species have also shown good survival, but grow and spread more slowly. It is recommended to focus new marsh planting on *Spartina* species when rapid marsh coverage is desired. If *Juncus* or other species are desirable, plant in smaller amounts and possibly mix them in with *Spartina* species in the mid elevations of the marsh.

3.3 Vegetation response at multiple tidal marsh elevations

3.3.1 Introduction

Tidal marshes are extremely important to coastal ecological functions. These complex ecosystems can be very difficult to restore. Ensuring successful vegetation colonization during a marsh restoration is extremely important, as it plays an important role for the ecology, hydrology and geomorphology of the salt marsh. Marsh vegetation acts as both habitat and food source for local fauna, helps to dampen the effects of storms, regulates and processes sediment, and ameliorates water quality. Planting vegetation within large salt-marsh restorations, though important, can be extremely expensive, so it is imperative that the initial planting plan and implementation are successful at the onset.

Some of the common species that have specialized to such an environment are *Spartina cynosuroides*, *Spartina patens*, *Spartina alterniflora*, *Juncus roemerianus*, *Distichlis spicata*, *Salicornia spp.*and *Cladium jamaicense*. In natural systems, it is thought that factors such as elevation and water table gradient (See Figure 1), as well as soil salinity determine the orientation of species within a natural tidal wetland. It is the challenge for the tidal marsh designer to predict the target species and orientation for a given restoration.

The vegetation design for the 14 ha (35 acres) of tidal marsh restored was largely based on data collected from reference marshes in the surrounding the area. The data collected included the most common species and the elevations at which they occurred. Data available in literature and the experience of NCSU design team were also considered (Broome and Craft, 2000; Craft et al., 2002; Kusler and Kentula, 1990; Lewis, 1994; Mitsch and Gosselink, 2000; Reimold, 1977; Woodhouse and Knutson, 1982). The vegetation design included three species at three specified elevation ranges. *Spartina alterniflora* (smooth cordgrass) was planted on the stream bank and the low marsh with the target elevation range of 0.5 m - 0.67 m (1.7 ft - 2.2 ft) MSL. *Juncus roemerianus* (black needlerush) was planted with the target elevation range of 0.67 m - 0.8 m (2.2 ft - 2.6 ft) MSL. The high marsh was planted with *Spartina patens* (salt meadow cordgrass) at the target elevation of 0.8 m - to 0.91 m (2.6 ft - 3.0 ft) MSL. The *Juncus roemerianus* and *Spartina patens* was planted across the marsh on 1 m (3 ft), while *Spartina alterniflora* was planted on the tidal stream banks and extreme lower marsh on 0.6 m (2 ft) spacings.

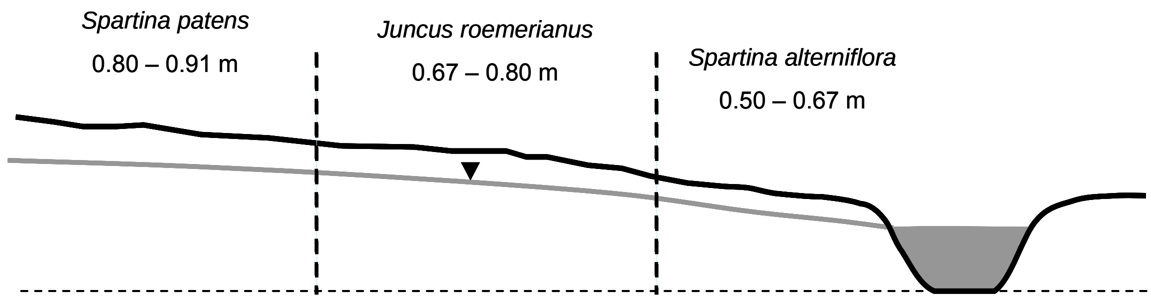

Figure 1. Planting plan for Phase II tidal marsh

Restored wetlands do not develop the full ecological functions seen in natural, established wetlands for many years. The amount of time for a restored wetland to establish the desired ecological functions may be decreased with improved knowledge. Knowledge of the factors affecting ecological establishment, immediately after construction, could improve restoration success and decrease the time to fully recovering ecological processes.

The overall goals for this research project were as follows:

- Determine the success of *Spartina alterniflora, Juncus roemerianus,* and *Spartina patens* in three different marsh elevations during the first 2 growing seasons
- Determine the species that contributes the most biomass within the restored marsh
- Evaluate environmental conditions that may influence success of each species at each of the target elevations
- Based on the results of this plot study, make recommendations of the species that should be used in future restorations

3.3.2 Methods and Materials

Three replicate blocks containing the target marsh vegetation were established along the created tidal stream. Their location, selected based on represented elevation range, is shown on the phase II restoration plan view (Figure 2). Each block contained three-4x4 Latin squares, which represented the three target elevation ranges of the plant species. There were four treatments in each square: *Spartina alterniflora, Juncus roemerianus, Spartina patens*, and an unplanted control. Figure 3 shows the design layout of Block 1. The 12-meter (40 ft) squares were arranged in a Latin square design, which required a random assignment of treatments. However, each of the four treatments could occur in every column and row only once. Four treatment replications per square enabled potential variation within a square to be represented. With three blocks considered, twelve replication plots per elevation range for each treatment was monitored. Each three-meter (10ft) treatment plot contained 20 plants, which were planted by the NCSU research group. The 20 plants were distributed among four columns and five rows with 60 cm (2 ft) spacing (Figure 3). At the time of planting, the 720 greenhouse plants representing a single species were selected with similar heights and vigor. The *S. alterniflora* and *S. patens* were planted in mid June 2006. However, *J. roemerianus* was not planted in until late July 2006 due to a delay in the greenhouse stock.

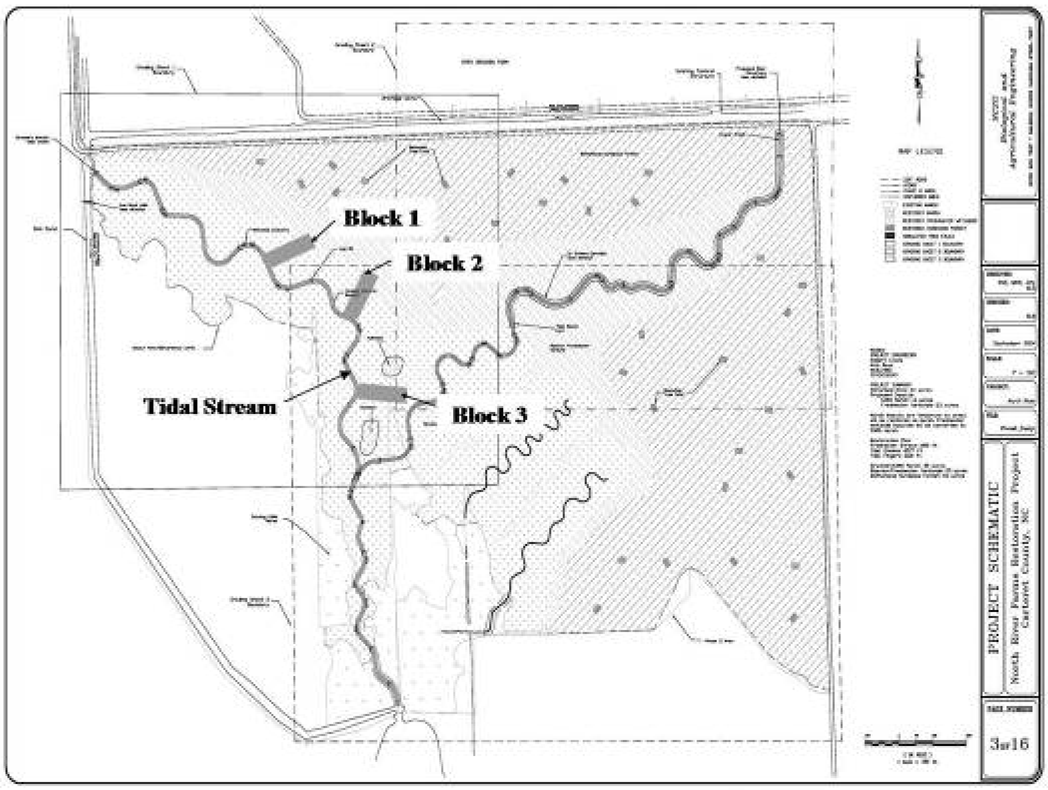

Figure 2. Tidal restoration plan view illustrating location of experimental blocks

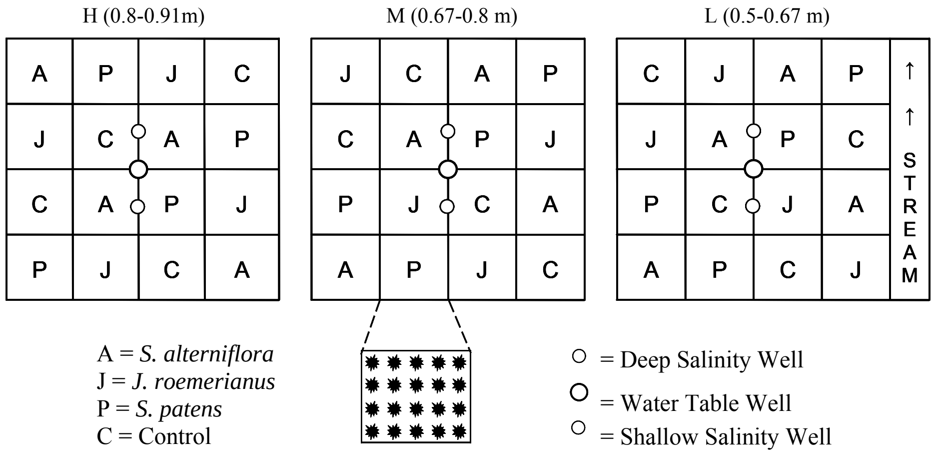

Figure 3. Experimental block containing the three Latin squares and a larger view of a single plot.

To quantify the success of the vegetation, a combination of methods was used including photographic documentation, plant survival and stem counts, and a destructive aboveground biomass harvest. Photographic documentation was collected in the form of close proximity aerial photographs.

The first stem count was completed in August of 2006 shortly after *J. roemerianus* was planted. The stems of each individual research plant was counted and recorded. A second live stem count was completed in March 2007. The mortality of individual plants was also noted. If an individual research plant could not be identified in a planted area, the assumption was made that it failed to survive the winter. The March 2007 stem and survival count served as the baseline condition for the 2007 growing season. The average number of stems was found for each elevation range allowing for the percent increase from August 2006 to March 2007 to be determined. The percent survival was also determined for each species at each elevation range.

In October of 2007 and 2008, a destructive biomass harvest was completed. A 1 m^2 (10.8 ft^2) aboveground biomass sample was collected from each replicate. The collected samples were sorted to isolate the research species from any volunteer species. The portion of the samples comprised of the research species was measured for basal diameter, average tallest stem and dry mass weight. The samples were then oven dried at 100º C for 72 hours and weighed to determine average dry mass weight. The average moisture content was determined and subtracted from all samples of that species to determine the dry weight of each biomass sample.

3.3.3 Results and Discussion

The original hypothesis was that the *Spartina alterniflora* (SA) would dominate the low marsh, *Juncus roemerianus* (JR) would dominate the mid marsh, and *Spartina patens* (SP) would dominate the high marsh. Table 1 shows the initial survival of each species. As expected, initial survival of SA was greatest in the low marsh near the tidal stream, and lowest in the high marsh. Survival of JR and SP was the greatest in the high and medium elevation of the marsh, but survived at a rate that was > 92% in the low marsh.

Table 1. The percent of survival considering all Latin squares representing each elevation.

Survival Rate	High	Medium	Low
Spartina alterniflora	72.5%	94.2%	100.0%
Juncus roemerianus	99.6%	99.6%	97.1%
Spartina patens	98.8%	100.0%	92.5%

Figure 4 shows the average above ground biomass produced from each species within the research plots, regardless of elevation. SP dominated biomass production in both 2007 and 2008, followed by JR and SA. Biomass production significantly increased for both SP and JR in 2008. The reduced biomass production observed in SA was due to significantly reduced growth in the upper portions of the marsh (that will be discussed later), and the physiological differences in the above ground biomass when compared to SP and to a lesser degree JR. SP grew in dense clumps with the largest basal diameter, where SA shoots were a thin blade. The SA grew prolifically in most locations in the low marsh with high soil coverage, yet the lack of stem density resulted in overall low biomass production on an areal basis.

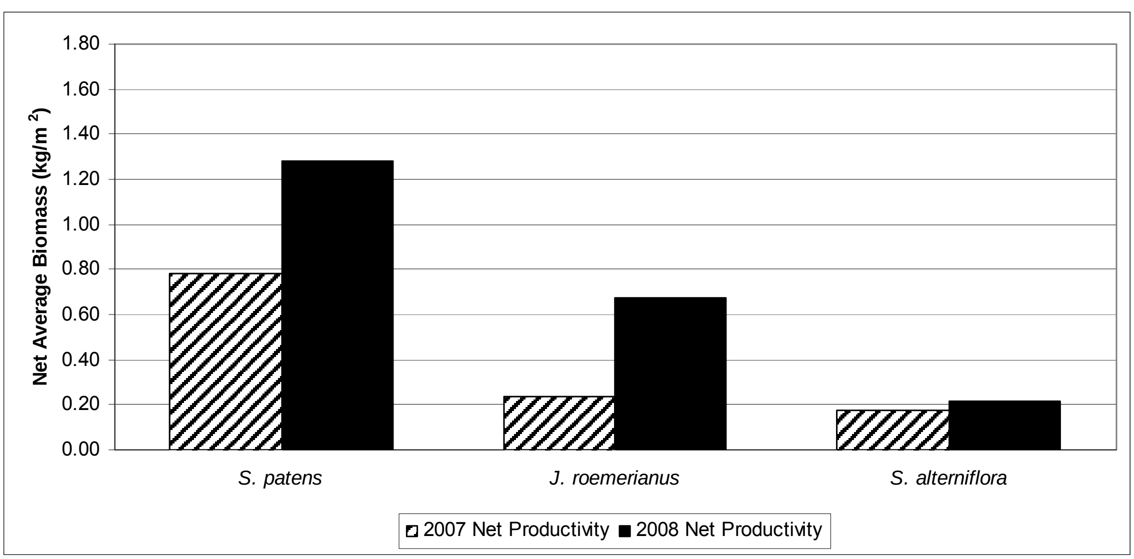

Figure 4. 2007 and 2008 average above-ground biomass of all replicates at all elevations for each species

Figure 5 describes the mean observed aboveground biomass for all species studied. Biomass production of SP was the greatest of all species at all elevations. Growth in the SP and JR were greatest within the high and mid marsh elevations. A significant reduction (35%) in biomass production was observed in SP in between the mid and low marsh elevations in both 2007 and 2008. Approximately 25% biomass production was observed in JR between the high and low elevations. On the other hand, in 2008, an approximately 70% and 60% increase in SA aboveground biomass production was observed between the high and low and the mid and low elevations, respectively. It should be noted, however, that the total biomass produced by both SP and JR exceeded that of SA in the low marsh. SA dominated the soil coverage in this area, but SP and JR have physiologically denser stems which result in higher biomass per area soil coverage. Soil coverage in this area near the tidal stream is much more important due to the need for soil stability in the areas where overwash frequently occurs from tidal events and flow from upstream drainage areas.

Figure 6 shows the above ground biomass collected in 2008 from each of the salt-marsh species and within the control plots. In the vast majority of the lowest elevation research control plots, very little marsh vegetation populated the area in the first growing season, leaving bare soil. Growth in these areas during the second growing season was minimal in most areas. Other controls were invaded aggressively, particularly by *Spartina alterniflora*, from nearby planted plots, or weakly, by species such as *Salicornia spp*. or *Distichlis spicata* that were in the soil seed bank. Some restoration experts claim that in some cases, natural vegetation succession should be left to occur at these sites. However, it was clear that not planting this marsh would have resulted in an extremely slow development that would have been dependent on a limited seed bank and seed dispersion from nearby marshes. The expense and effort for planting this site was clearly needed to help successfully establish the targeted tidal marsh.

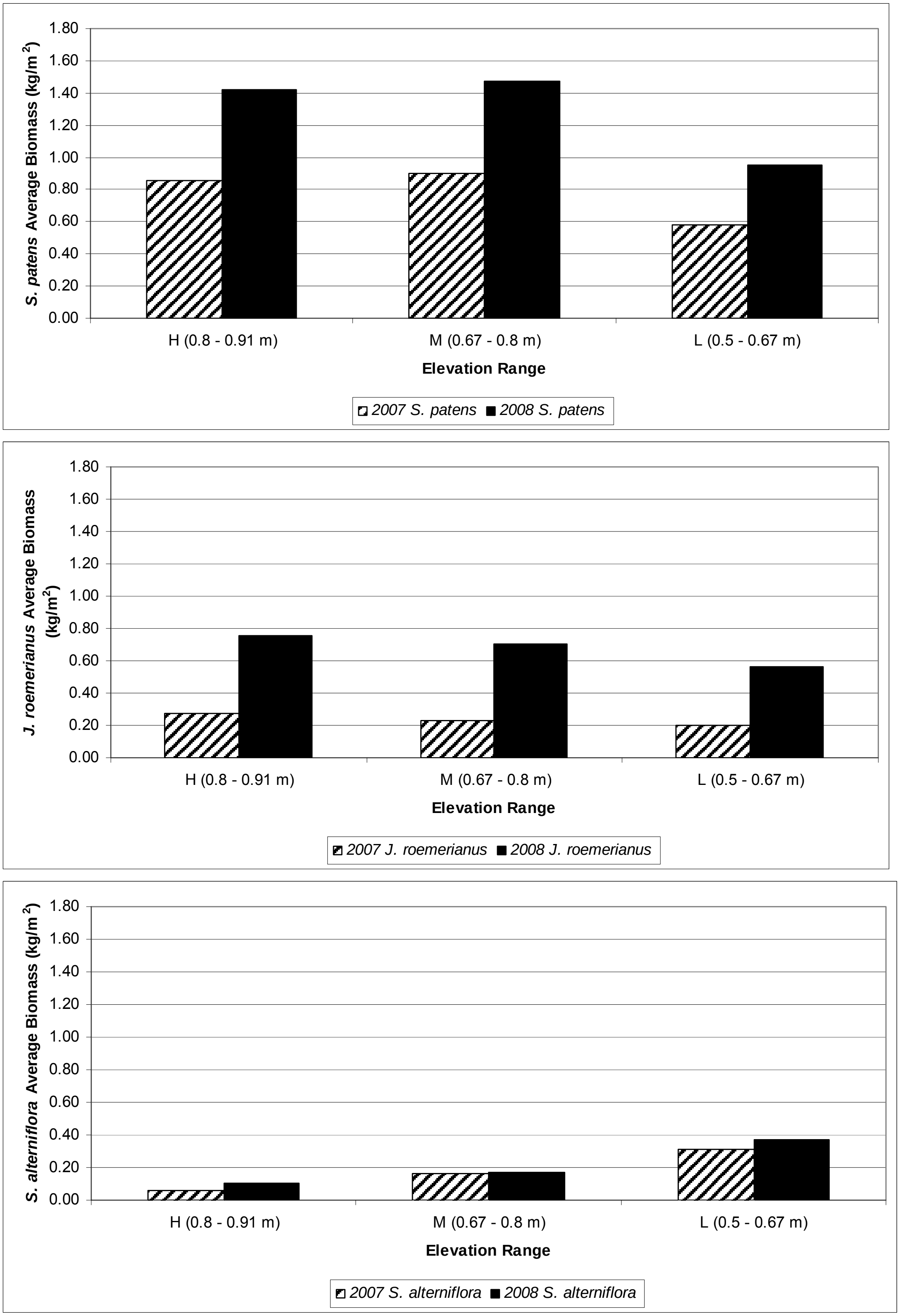

Figure 5. 2007 and 2008 mean *Spartina patens, Juncus roemerianus, and Spartina alterniflora* above-ground biomass from all blocks at each elevation range

In Figure 6 it is obvious that planting marsh vegetation increased the potential for biomass coverage in all marsh elevations. Biomass located in the control in the high marsh were usually not target marsh species. Mostly these were plants such as *Baccharis spp., Solidago spp.* (goldenrod), *Conyza spp.* (horseweed), etc. Along with these plants. occasional *Distichlis spicata, Spartina patens, and Salicornia spp.* were observed in the control sections of the middle elevation control plots. Vegetation in the lowest control plots especially in Blocks 2 and 3 were dominated by *Spartina alterniflora* by 2008, resulting in larger biomass weights. It must be noted, that the biomass in the control plots in the low areas would have been much lower had they not been invaded by SA planted nearby. Based on other areas of the tidal marsh outside the research plots that were not planted these areas would have been sparsely covered by *Distichlis spicata* and *Salicornia spp.*

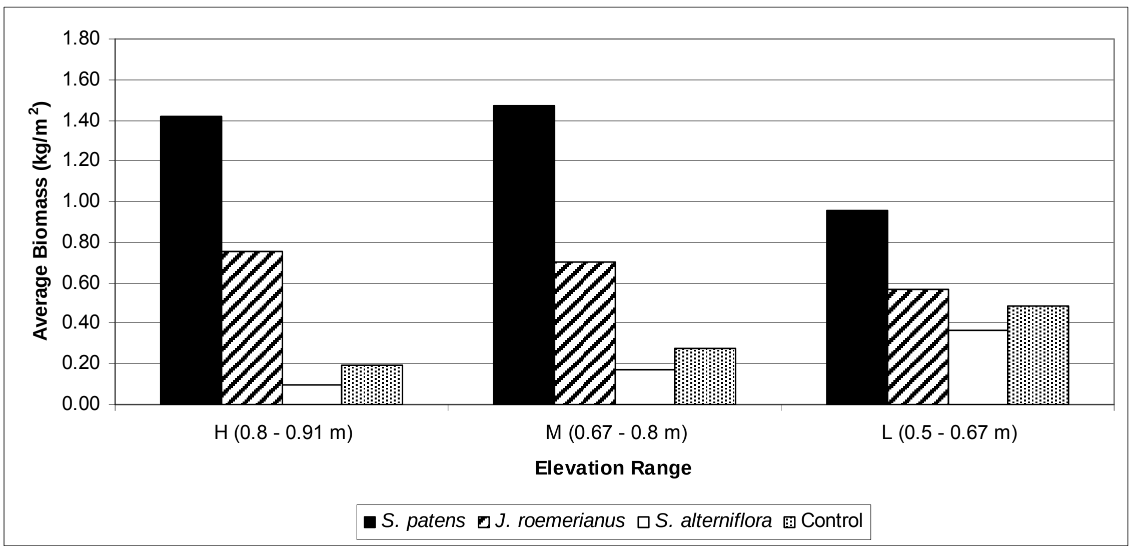

Figure 6. 2008 average biomass for each species at each elevation range, compared to the control plots

3.3.4 Conclusions

Planting of the tidal marsh was absolutely necessary and has increased the successional processes critical for tidal marsh development. The original planting plan and thus the original hypothesis was that that *Spartina alterniflora* (SA) would dominate the low marsh (0.5-0.67 m), *Juncus roemerianus* (JR) would dominate the mid marsh (0.67-0.8 m), and *Spartina patens* (SP) would dominate the high marsh (0.8-0.91 m). The results of the above ground biomass study revealed that SP produced the most biomass at all marsh elevations. SP and JR were the most successful in the high and mid elevations. If JR was not available during the time of planting, it appears that the SP could have been planted in not only the high but the mid elevations of the marsh. SA did not produce as much biomass as the rest of the species studied, but provided the best coverage near the tidal stream. The nature of the soil coverage provided by SA still makes it the ideal selection for areas near the tidal stream. It should be noted that the research plots were not extended down the banks of the tidal stream, because we were concerned that foot traffic would result in bank erosion. We believe that had JR and SP been planted in the intertidal zone along side SA, SA would have been the highest biomass producer. Only SA has been observed growing on the banks of the tidal stream throughout the restoration.

3.3.5 Recommendations

1. Design a tidal marsh planting plan based on the diversity of vegetation common to nearby marshes. Survey the marsh to establish elevations at which each species tends to colonize to determine suitable elevations for restoration planting.

2. When possible, maximize the diversity observed in the reference marsh. Figure 7 shows the diversity that can be obtained. Be aware that the planting zones are likely to fluctuate to account for subtle difference in elevations that develop during and following construction.

3. If maximum biomass production is a restoration goal, consider planting *Spartina alterniflora* (SA) on the banks only, and maximize the coverage of *Spartina patens* (SP) and/or *Juncus roemerianus* (JR) in a wider mid-marsh portion if elevations allow.

4. Planting high marsh (where there is typically the steepest slopes as the upland transitions into marsh) with *Spartina patens* (SP) is always recommended as it colonizes quickly and stabilizes soil very well following construction.

Figure 7. Photograph of the tidal marsh taken outside the research plots in 2007. Note the light green coverage of the *Spartina alterniflora* (SA) near the tidal stream and the darker green *Juncus roemerianus* (JR) in the mid-marsh. *Spartina patens* (SP) can be seen in the upper right hand side of the picture, in the upper marsh.

3.3.5 References

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3.4 - Post Construction Tidal Stream and Marsh Stability

3.4.1 Introduction

Monitoring of the morphology of the constructed tidal stream (Broome's Branch) and marsh was conducted over a three year period (2006-09). The results of the monitoring show that the stream and marsh are stable, with no significant changes in stream dimension, pattern, or profile.

3.4.2 Materials and Methods

Stream stability monitoring consisted of periodic cross section (twice yearly) and longitudinal (yearly) surveys. A total of 27, 12.2 m (40 ft) wide permanent cross sections (10 pools+17 runs) were established along the stream corridor (Figure 1) and surveyed seven times from August 2006 to June 2009. The sag tap method (Figure 2) was used to measure the geometry of the stream channel, with measurements taken every 0.9 m (3 ft) outside the channel and every 0.3 m (1 ft) inside the channel. The data were plotted and used to calculate and analyze changes in channel dimension and geometry. Additionally, three longitudinal surveys (completed 1/07, 3/08, and 3/09) of the thalweg, top and bottom of the stream bank were conducted using a total station to monitor changes in stream pattern and profile.

3.4.3 Results and Discussion

In the three years of post construction monitoring, very little change has occurred in the dimension and pattern of the tidal stream. Each cross section has maintained fairly consistent bankfull cross sectional areas (Table 1) and width to depth ratios (Table 2). There is no evidence of bank failure at any point along the stream. The channel size increases (wider and deeper) upstream to downstream, with the major change in cross sectional area beginning at cross section 15. The confluence of the restored tidal stream and the restored freshwater stream occurs between cross sections 8 and 10 (cross section 9 is located on the freshwater reach and is not included in this analysis). Separating the stream into three reaches (cross sections 1-8, 10-15, and 16-27) suggests that the channel is most stable below the confluence of the two streams and is more dynamic in the smaller sized reach. Evidence of filling in the bed of the channel was most prevalent in cross sections 14, 15, 17, 18, 20, 22-24, and 28.

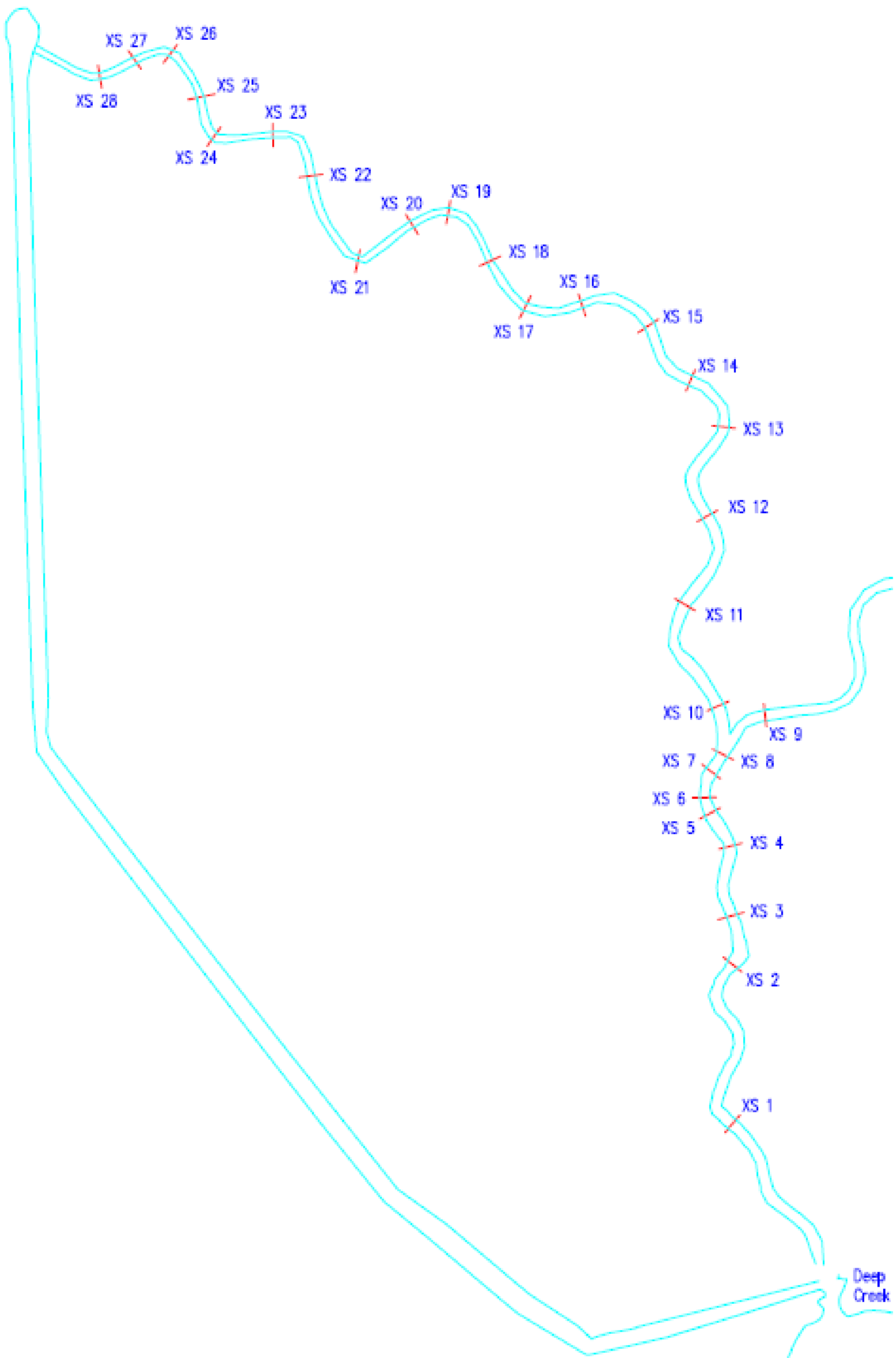


Figure 1. Cross section locations on the tidal stream

Figure 2. Sag tape surveying method

Table 1. Tidal stream bankfull cross-sectional areas (XS1 = downstream location)

		Area (m^2)								
XS	Feature	8/8/06	10/12/06	7/23/07	12/18/07	6/3/08	12/16/08	6/1/09	Mean	Stdev
1	Run	3.20	3.30	3.16	3.26	3.23	3.18	3.22	3.22	0.05
2	Run	2.71	2.73	2.85	2.81	2.78	2.87	2.84	2.80	0.06
3	Run	2.54	2.69	2.67	2.57	2.46	2.57	2.60	2.59	0.08
4	Pool*	2.85	2.85	2.75	2.75	2.76	2.84	2.83	2.80	0.05
5	Run	2.77	2.75	2.88	2.73	2.74	2.74	2.70	2.76	0.06
6	Pool*	2.36	2.37	2.38	2.20	2.37	2.54	2.55	2.40	0.12
7	Run	2.78	2.97	2.94	3.00	2.94	2.96	3.03	2.95	0.08
8	Run	3.07	3.16	3.17	3.07	3.08	2.94	2.99	3.07	0.08
10	Pool	2.93	3.21	2.99	3.03	3.00	2.88	3.00	3.01	0.10
11	Run	3.26	3.24	3.13	3.29	3.28	2.96	3.21	3.20	0.12
12	Run	2.96	3.17	3.01	2.96	2.93	2.79	2.87	2.96	0.12
13	Pool	2.83	2.93	2.82	2.76	2.73	2.62	2.62	2.76	0.11
14	Run	3.44	3.41	3.19	2.90	2.80	2.66	2.58	3.00	0.35
15	Run	2.42	2.62	2.45	2.17	2.21	2.09	2.14	2.30	0.20
16	Run	1.27	1.32	1.32	1.33	1.40	1.37	1.42	1.35	0.05
17	Pool	1.58	1.60	1.53	1.38	1.36	1.36	1.36	1.45	0.11
18	Run	1.76	1.72	1.59	1.31	1.29	1.25	1.27	1.46	0.23
19	Pool	1.18	1.24	1.17	1.20	1.22	1.15	1.15	1.19	0.03
20	Run	1.53	1.47	1.35	1.39	1.36	1.30	1.37	1.40	0.08
21	Pool	1.17	1.16	1.00	1.15	1.13	1.18	1.14	1.14	0.06
22	Run	1.43	1.50	1.28	1.16	1.29	1.29	1.31	1.32	0.11
23	Run	1.35	1.35	1.11	1.13	1.17	1.14	1.17	1.21	0.10
24	Pool*	1.89	1.90	1.56	1.61	1.44	1.32	1.37	1.58	0.24
25	Run	1.02	0.99	0.92	0.88	1.00	0.99	0.98	0.97	0.05
26	Pool	1.26	1.23	1.08	1.07	1.10	1.09	1.16	1.14	0.08
27	Run	0.95	0.96	0.86	0.90	0.95	0.99	0.97	0.94	0.04
28	Pool	1.00	1.01	0.98	0.85	0.90	0.90	0.92	0.94	0.06

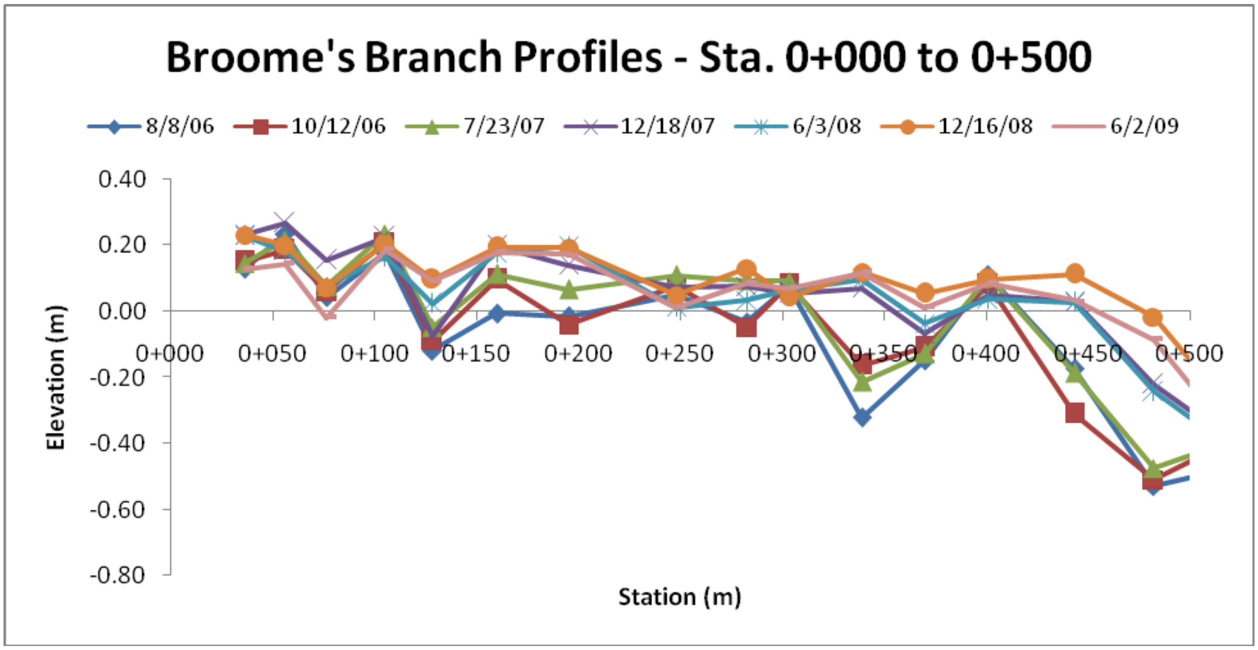
*Pools with root wads

Table 2. Tidal stream width to depth ratios (XS1 = downstream location)

		W/D								
XS	Feature	8/8/06	10/12/06	7/23/07	12/18/07	6/3/08	12/16/08	6/1/09	Mean	Stdev
1	Run	10.47	10.18	10.61	10.27	10.38	10.53	10.43	10.41	0.15
2	Run	16.60	16.47	15.78	16.00	16.17	15.64	15.82	16.07	0.36
3	Run	16.14	15.22	15.34	15.94	16.64	15.92	15.74	15.85	0.48
4	Pool*	13.02	13.05	13.54	13.51	13.45	13.10	13.12	13.26	0.23
5	Run	16.25	16.34	15.59	16.49	16.41	16.43	16.62	16.31	0.33
6	Pool*	14.24	14.13	14.12	15.22	14.13	13.21	13.17	14.03	0.70
7	Run	20.89	19.57	19.76	19.34	19.74	19.62	19.15	19.73	0.56
8	Run	14.64	14.23	14.16	14.64	14.62	15.29	15.04	14.66	0.40
10	Pool	13.97	12.77	13.71	13.54	13.65	14.25	13.64	13.65	0.46
11	Run	13.79	13.87	14.36	13.65	13.72	15.21	14.01	14.09	0.55
12	Run	10.16	9.48	10.00	10.18	10.28	10.78	10.50	10.20	0.41
13	Pool	9.48	9.17	9.53	9.71	9.82	10.23	10.26	9.74	0.40
14	Run	11.92	12.00	12.82	14.13	14.64	15.40	15.88	13.83	1.60
15	Run	12.43	11.49	12.31	13.84	13.65	14.37	14.09	13.17	1.09
16	Run	16.50	15.79	15.80	15.70	14.94	15.22	14.72	15.52	0.61
17	Pool	11.55	11.36	11.90	13.18	13.43	13.43	13.42	12.61	0.96
18	Run	13.49	13.79	15.00	18.22	18.51	18.99	18.67	16.66	2.46
19	Pool	20.08	19.21	20.28	19.76	19.53	20.67	20.75	20.04	0.57
20	Run	11.86	12.36	13.50	13.15	13.38	14.03	13.33	13.09	0.73
21	Pool	15.51	15.64	18.21	15.84	16.06	15.38	15.93	16.08	0.97
22	Run	16.58	15.81	18.60	20.46	18.47	18.45	18.19	18.08	1.51
23	Run	9.88	9.88	12.00	11.86	11.42	11.70	11.43	11.17	0.91
24	Pool*	11.05	10.98	13.40	12.95	14.53	15.88	15.29	13.44	1.94
25	Run	17.82	18.39	19.72	20.59	18.28	18.42	18.49	18.82	0.97
26	Pool	16.57	17.01	19.35	19.48	19.05	19.20	18.01	18.38	1.19
27	Run	21.95	21.89	24.30	23.22	21.97	21.13	21.45	22.27	1.10
28	Pool	13.36	13.24	13.71	15.82	14.92	14.94	14.47	14.35	0.96

*Pools with root wads

The yearly total station surveys of the plan form of the stream show that there has been little to no lateral migration of the stream channel. After three years, the banks appear to be holding form and the sinuosity of the stream is similar to that of the design at 1.3. Both the cross sectional and longitudinal profile surveys show evidence of changes in bed slope (or profile). The entire reach shows a pattern of pool and run features located in the expected plan-form locations. A plot of the thalwegs of each cross section (Figure 3) shows some aggradation in the channel bed, particularly in the middle of the reach from approximately Sta. 0+130 to Sta. 0+680. Aggradation appears to be occurring in both pool and run locations, but no significant changes in channel dimension have been observed. We found no difference in stability between pool and run cross sections. Pools with root wads installed in the banks weren't significantly deeper or larger than those without. Low stream velocities (which averaged 0.15 m/s (0.5 ft/s)) on the outgoing tide, and bidirectional flow appeared to be a contributor to many of these observations.



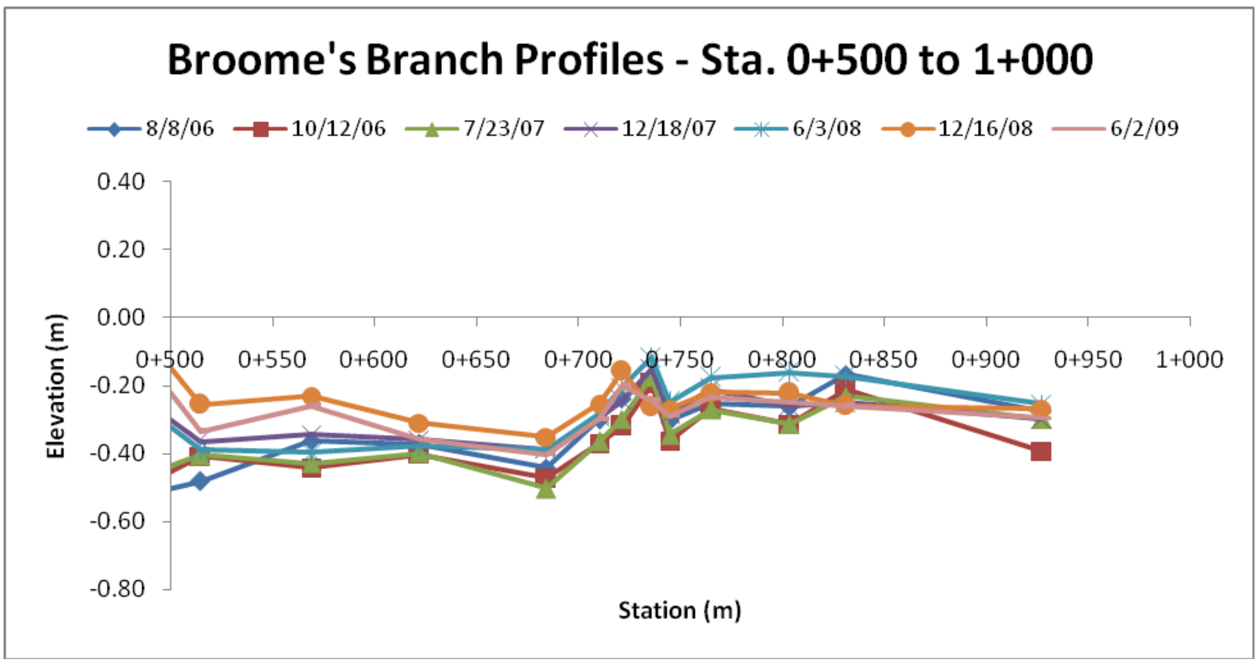


Figure 3. Broome's branch thalweg profiles

3.4.4 Conclusions

Based on the three years of monitoring data, the tidal stream and marsh appear to be stable. The stream appears to be maintaining its dimension and pattern, and there is evidence of pool/run development throughout the stream reach. However, some aggradation in the channel bed has been noted of late, and has most notably contributed to deceased depth of a few pools formed previously in the meander bends. Due to the apparent stability of the banks, the largest probable source of the aggrading sediment is upstream of the Phase II site. Pools near installed root wads show no greater development than those without, likely due to low velocities and bi-directional flows. Not to undermine their importance, root wads still provide bank stability, habitat, and woody debris in this stream. The changes in stream profile are not significantly affecting channel dimensions, and the stream appears to still be able to convey design flows and maintain good floodplain connection. Backcuts have formed in several locations along the stream bank, and have naturally developed in low areas as water drains from the marsh to the tidal stream following high tide events and/or precipitation events. They do not appear to be a stream stability concern; in fact they appear to be an amenity that we have observed in natural marshes. Fish and shellfish have been observed utilizing these areas for habitat and access to the marsh floor.

3.5 - Nutrient and bacteria dynamics within the tidal stream

3.5.1 Introduction

Water quality monitoring of the restored tidal stream (Broome's Branch) was conducted for two years post construction (2007-09). Samples were also collected from the main drainage canal from Open Grounds Farm from 2003-06 and from the reference tidal stream from 2007-09 to serve as a baseline for analysis. The purpose of this monitoring was to determine if the restored stream and marsh provide any water quality benefits to influent agricultural drainage water. The results from the monitoring indicate that the restored stream is reducing loads of nitrate (NO_3-N) and total phosphorus (TP) from upstream to downstream, but show no significant improvement in bacteria loading.

3.5.2 Materials and Methods

Water quality monitoring consisted of a combination of grab and time weighted composite sampling. Automated ISCO samplers (Figure 1) were installed at three locations (BBup, BBmid, and BBdown) along the Broome's Branch (BB) (Figure 2). The samplers were programmed to collect 140 ml samples every 24 hours and 50 minutes (approximate length of tidal cycle) at approximately the middle of the falling tide. The samples were composited weekly in pre-acidified bottles and collected monthly. Monthly grab samples were collected at each sampler location, from the main drainage canal from Open Grounds Farm (MD01) and from the reference tidal stream (P2Ref). The samples were analyzed for total kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and total phosphorus (TP). Additional monthly grab samples were collected on rising and falling tides from each location and analyzed for bacteria (Fecal Coliform and *E. coli*) by Dr. Bill Kirby-Smith at the Duke Marine Lab.

Figure 1. Example ISCO Sampler Setup

Area-velocity modules were installed with each sampler to record water levels and velocities every 10 minutes. This data was combined with cross-sectional survey data to calculate flows at each location. Net weekly outflows were calculated and combined with weekly composite water quality concentration data to calculate nutrient loading in the restored stream. Grab and bacteria sample data were used to compare the water quality of the restored tidal stream to the agricultural drainage water in the canal and to the reference stream.

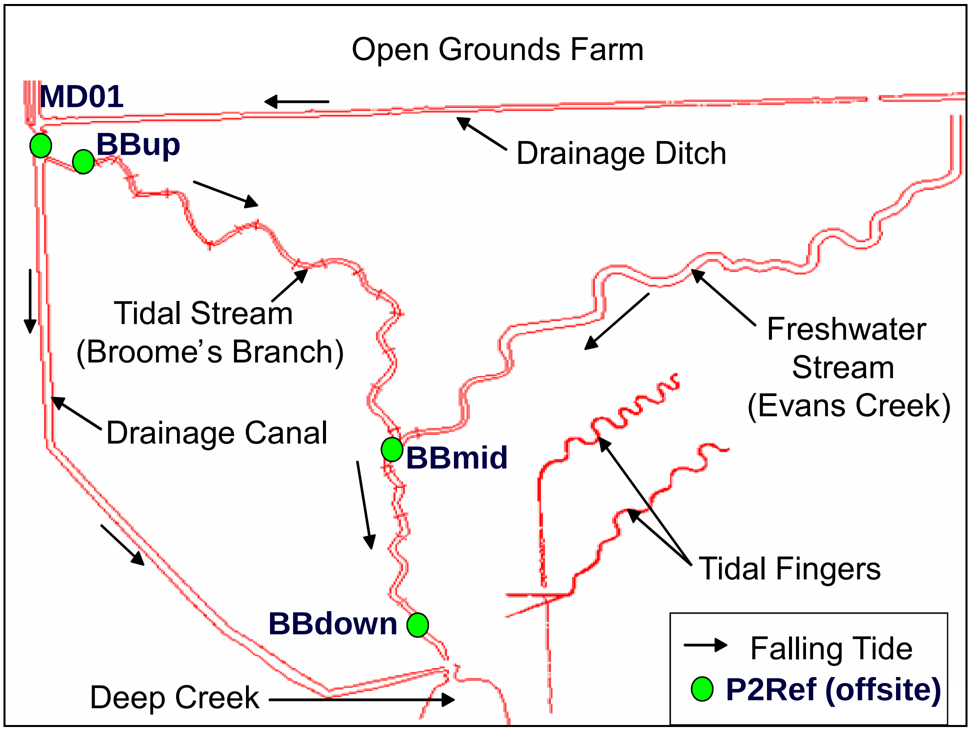


Figure 2. Sampling Locations

Additional hydrological and water quality monitoring included continuous rainfall recording, 23 water table wells, monthly ground and surface water salinity measurements, and a two day dye tracer study to determine travel time through the restored stream. Rhodamine WT dye was slug injected into the head of the tidal stream and the drainage canal above the rock weir at the beginning of two falling tide cycles. Samples were collected along each reach and dye concentrations were measured using a Turner Design fluorometer. The data was used to compare the travel times between the two systems.

3.5.3 Results and Discussion

Nutrients

Analysis of monthly grab samples show all sites to have higher (0.7 to 1.1 mg/L) median concentrations of TKN compared to the median concentrations of NH_4-N, NO_3-N, and TP (all <0.2 mg/L) (Figure 3). Nutrient concentrations were lower at reference stream

(P2Ref) than in the restored tidal stream (BB) and the agricultural drainage canal (MD01). TKN and TP concentrations decreased from upstream to downstream in BB. NO_3-N concentrations were similar at all three sites in BB, but less than MD01 and greater than P2Ref. No significant trends were observed for NH_4-N.

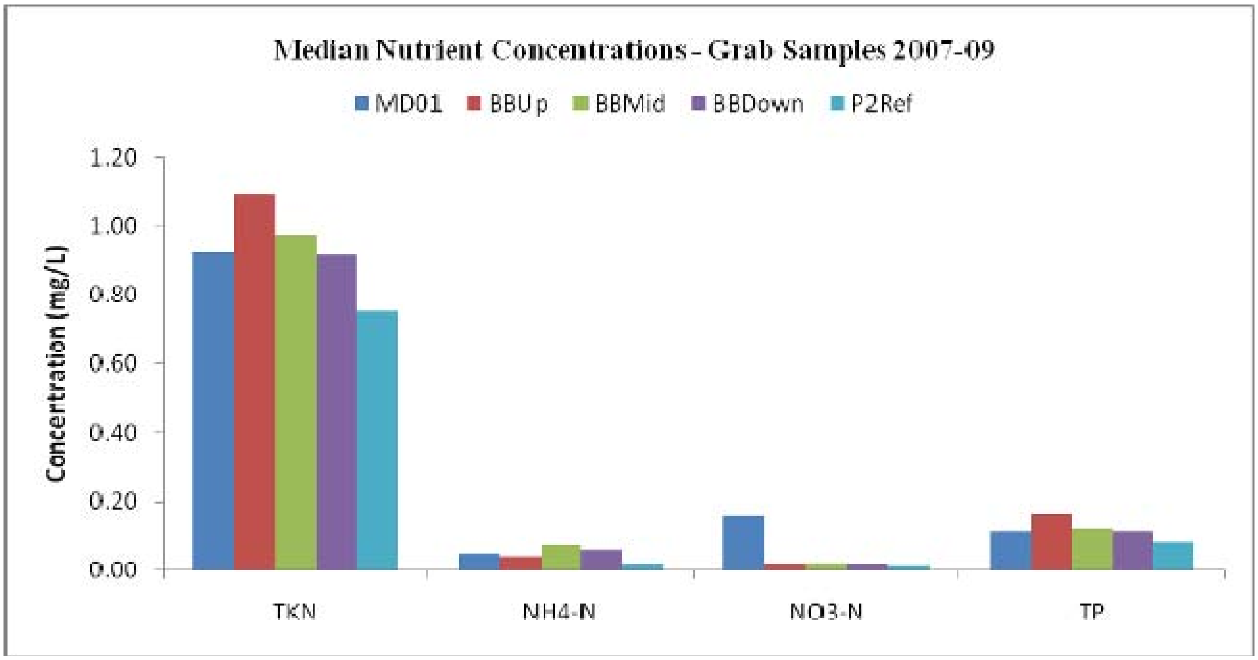


Figure 4. Median nutrient concentrations

Due to possible sample contamination and erroneous level and velocity readings due to equipment malfunctions, nutrient loads were calculated only for the last six months (12/08-6/09) of monitoring, after these issues were resolved. Over this period, average net weekly outflows were estimated at 18,000 m^3 (636,000 ft^3) , 20,000 m^3 (706,000 ft^3), and 21,500 m^3 (759,000 ft^3) at BBUp, BBMid, and BBDown, respectively. TKN and NH_4-N was export within the tidal stream increased from upstream to downstream, indicating no net retention in the system(Figure 4). However, loads of NO_3-N and TP were reduced by 30% and 40%, respectively, indicating retention of these nutrients within the marsh over these six months. Through not directly studied, export of TKN and NH_4-N are likely due to natural organic forms of N present within the stream due to recent soil disturbance and plant decay. Retention of NO_3-N could be to biological uptake or denitrification within the stream sediments, while TP retention could be due to sorption to sediment or some biological uptake.

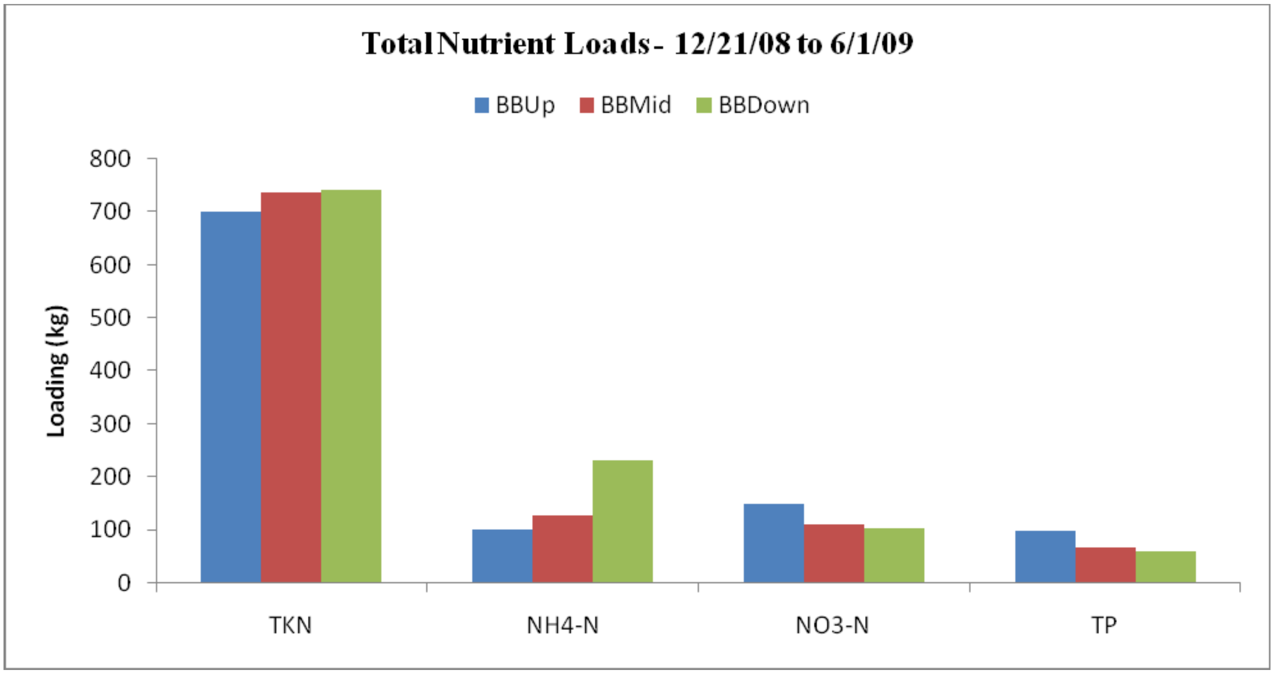


Figure 5. Tidal Stream Nutrient Loading 12/08-6/09

Bacteria

The results of the bacteria sampling are highly variable from site to site and between rising and falling tides. The highest counts were observed in the reference stream for falling tides (Figure 5); however this sample set only consisted of three samples. The reference site was only sampled once monthly (sometimes on rising tides, sometimes falling) whereas the remainder of the sites were sampled on both the rising and falling tides each month. Counts frequently exceeded testing limits (1600 MPN) and no immediate trends have been detected in the restored stream or between rising and falling tides. It is difficult at this time to determine whether the restored marsh has any capacity to reduce bacteria levels. However what is evident is that the bacteria concentrations observed at the restored tidal marsh are within the range of what was observed in the reference stream.

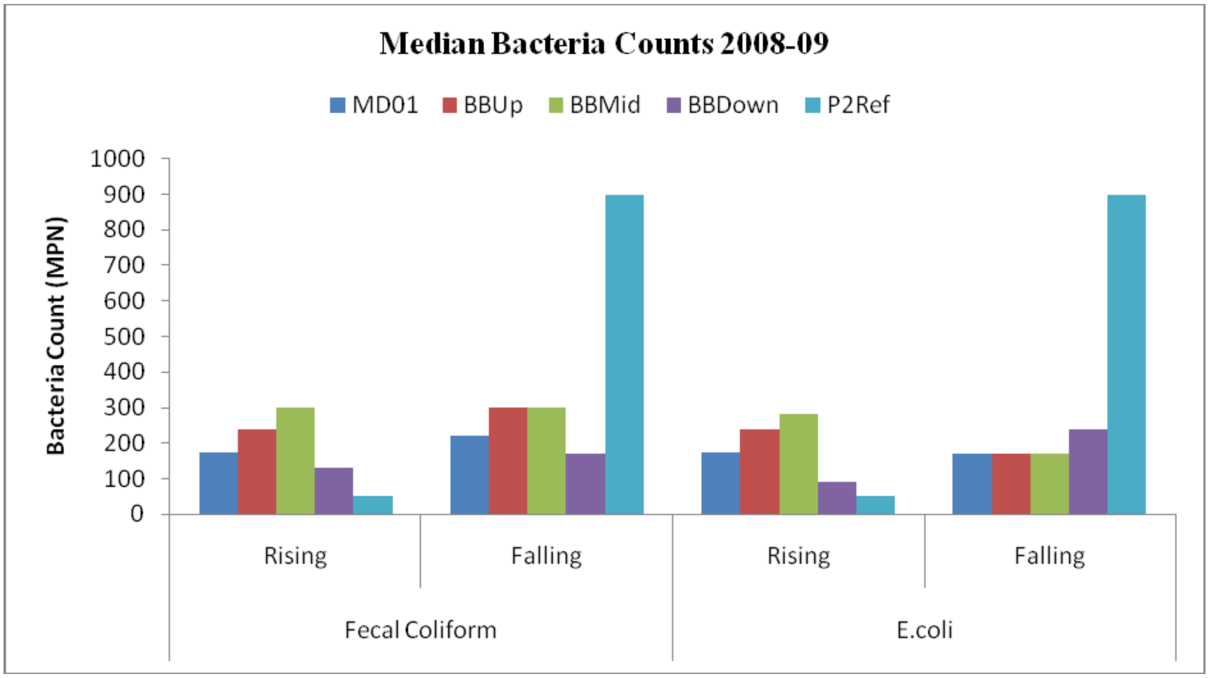


Figure 6. Median Bacteria Counts

Dye Tracer Study

In order to compare hydraulic retention times of the tidal stream versus the bypassing agricultural drainage canal, a dye tracer study was conducted. The travel path from the dye injection location to the sampling location was about 40 m (5%) longer in Broome's Branch. The travel times were an average of two falling tides, recorded on consecutive days in July 2008. Analysis of the dye samples collected from the lower ends of Broome's Branch and the drainage canal show that the travel time through the constructed tidal stream is approximately one hour (60%) longer than down the canal (Table 1). Reduced velocities in the tidal stream are attributed to increased sinuosity, decreased width, and increased frictional resistance from vegetated banks. Increased retention within the marsh provides increased water quality improvement potential to the drainage water flowing through the system.

Table 2. Dye Tracer Study Results

	Total Distance (m)	Average Travel Time (h:mm)
Stream	910	2:51
Canal	870	1:47
Difference	40	1:04
% Increase	4.6%	59.7%

3.5.4 Conclusions

The two years of post construction monitoring show the restored tidal stream to be providing some water quality treatment, particularly reducing loads of NO_3-N and TP. This indicates that the tidal stream and marsh are providing an environment for denitrification, nutrient uptake by marsh vegetation, and/or settling of sediments and associated bound nutrients. The results of the dye tracer study show that there is increased travel time in the restored stream and thus greater opportunity for these processes to occur. Periodic flooding of the marsh also contributes to the treatment potential of the system.

The results of the bacteria monitoring are not as conclusive. The restored stream and marsh could potentially be a source of bacterial contamination due to the increasing number of wildlife species present. The system may not be providing the appropriate environment for bacteria die-off (exposure to UV light, salinity, high temperatures) or ample time for treatment. It must be noted that similar concentrations of bacteria were observed in the reference stream area. Further investigation into the sources of bacteria at both locations would be beneficial.

3.6 Benthic and aquatic sampling in the North River tidal stream restoration

(sections contributed by Larry Eaton, NCDWQ)

3.6.1 Introduction

The habitat function of the restored tidal stream was considered an important component to the restoration. We observed shortly after completion the migration of mammals, reptiles, crabs, fish, birds and insects utilizing the marsh. What was not immediately observed was what organisms were using the tidal stream for habitat. To address this, 2 aquatic sampling events were conducted in March of 2008 and 2009.

3.6.2 Methods

On March 4 and 5 2008, Dave Penrose and Larry Eaton sampled four sites on the restored stream and three sites on the reference stream. Samples consisted of two sweep samples and one wash of available hard substrates and taxa abundance was recorded as Rare (1-2), Common (3-9), Abundant (10-29) or Very Abundant (>30). Water chemistry, including salinity/conductivity, was not collected, however samples were collected based on previously collected data and changes in streamside fauna. Site 1 in both the Reference and Restoration streams were selected to be well into the freshwater zone, Site 2 was chosen to be near the fresh/salt interface and the last site was as far into the estuarine zone as practical. Restoration Site 3 was sampled near the bottom of the tidal, while Restoration Sites 1 and 2 were located in the freshwater portions of the resorted area.

The site was sampled for a second time on March 4, 2009. Weather in 2009 was much colder than in 2008 and may have affected species richness. The sampling design was varied slightly from the previous year. The reference sites were dropped because the hydrologic regime was not comparable to the restoration. Also, Station 2 was moved from the freshwater estuarine interface on the stream below Station 1, to the bridge over the tidal stream.

3.6.3 Results

<u>2008</u>

It appears that the two largest drivers determining what lives in each stream were salinity and instream structure. Appendix 1 is a list of a taxa collected at all sites including their relative abundance an some indication of whether the taxon is more related to estuarine or fresh water. In both reference and restoration streams the percentage of freshwater species and abundance decline from the freshwater to the estuarine. The two sites closest to the fresh/salt interface (sites 2) had the fewest number of species in either the reference

(17) or restored (13) stream. The difference in abundance (66 in reference and 29 in restored) probably is due to the near lack of habitat at the restoration (sand, algae and only a few sticks) and much more hard substrate at the reference. The two sites with the greatest number of species and largest abundance were the two sites with the most artificial substrate – Restoration site 1, with freshwater flow over rocks (both nearly nonexistent in the outer coastal plain) and Restoration site 4 (the site with highest salinity), where submerged rocks provided the hard substrate required to support oysters and the animals that are associated with them (estuarine crabs, mussels and an isopod). These estuarine species include some of the commercially important species found in North Carolina estuaries (blue crab – *Callinectes sapidus*, oyster – *Crassostrea virginica* and spot/croaker larvae).

It appears that the salinity gradient in Ward Creek (reference stream) is lower than the gradient in North River (restoration). As a result, Ward Creek (Reference site 3) supports oligohaline species such as the marsh clam *Polymesoda caroliniana*, while approximately the same distance from fresh water in North River (Restoration site 4) supports mesohaline species such as oysters, mussels, crabs, shrimp and estuarine fish (silversides, hogchoker and spot/croaker).

Another interesting phenomenon is that several species that are common in coastal plain agricultural ditches, but rare in estuarine areas, appear at restoration sites 3 and 4. The dragonflies *Pachydiplax longipenis* and *Sympetrum* and the snails *Physella* and *Psuedosuccinea columella* appear to be washed downstream into the estuarine reach – a phenomenon that does not appear to happen in the reference stream, possibly due to the lower flows.

2009

Unlike last year, there was no flow at Station 1 (freshwater stream) because the canal that supplies water to that stream had been lowered several feet. While the community at this site was still freshwater with approximately the same number of species (24 in 2008 and 22 in 2009), the community had shifted from a flowing water community with mayflies and a good diversity of midges, to a ponded community with more dragonflies and beetles.

Site 2A suffered from very limited habitat, but 15 species were collected here, most estuarine. The community was dominated by the midge *Orthocladius oliveri* and the amphipod *Gammarus fasciatus*. Sweeps were made, but not collected, upstream in two locations. One was at a bend where an old channel had been filled and another was by the upstream gage house. It appeared that the aquatic community was similar at these sites to station 2A.

Station 3, approximately at the confluence of the Station 1 (freshwater) and Station 2A (tidal stream) tributaries, had many fewer species in 2009 than 2008 (14 vs 20). This was probably due to lower salinity in 2009, since most of the species missing in 2009 were freshwater midges and the % freshwater taxa declined from 45% in 2008 to 21% in 2009.

Station 4, the site furthest downstream and closest to the estuary, was located at some rip rap that was supporting oysters (*Crassostrea virginica*) and their associated community, including hook mussels (*Ischadium recurvum*), scorched mussels (*Brachidontes exustus*), a mud blister worm (*Polydora socialis*), and a mud crab (*Rhithropanopeus harrisi*) that was found only at this site.

3.6.4 Conclusions

Oligohaline (low salinity) systems are very variable and stressful to species trying to live there. Usually, only a relatively few, tolerant, opportunistic, species can survive here. It appears that many of these species are already established in this restoration, whose channel didn't exist before the project was built two years ago. It appears that organisms are colonizing this area, and these areas should be sampled in the future to monitor additional colonization.

Appendix 1 - List of papers, presentations, and workshops

2004

Presentations

Burchell, M.R., J.D. Wright, R.O. Evans, J.D. Shelby, J. Burdette, and S.W. Broome. 2004. North River Farms Wetland Restoration: Phase I and II. Restore America's Estuaries 2nd National Conference on Coastal and Estuarine Habitat Restoration. Seattle Washington. September 12-15, 2004.

Thesis

Morris, T. 2004. Tree composition along edaphic and hydrologic gradients in nonriverine wet hardwood forests. M.S. Thesis. North Carolina State University. Department of Forestry. Raleigh, NC

2005

Proceedings

Shelby, J.D., R.O. Evans, MR Burchell and KL Bass. Evaluation of a stream and wetland design and methods in coastal NC. ASAE Annual International Meeting, Tampa, FL Jul 17-20, 2005.

Wright, JD, M.R Burchell II, JD Shelby, and RO Evans. Evaluation of the effect of surface treatments on the hydrology of a prior converted wetland in the coastal plain of North Carolina. ASAE Annual International Meeting, Tampa, FL Jul 17-20, 2005.

Presentations

Burchell II, M.R., J.D. Wright, R.O. Evans, and J.D. Shelby. Hydrologic effects of three wetland restoration techniques on a prior converted site in eastern NC. Society of Wetland Scientists 26th Annual Meeting Charleston, SC June 5-10, 2005.

Posters

Burdette, J., S.W. Broome, M.J. Vepraskas, and M.R. Burchell. 2005. Utilization of the Hydric Soil Technical Standard to evaluate success and compare surface treatments for restoring agricultural land to forested wetlands. Soil Science Society of NC 48th Annual Meeting, Raleigh, NC.

Thesis

Wright, J.D. 2005. The evaluation and modeling of the effects of surface treatments of a restored wetland in the Coastal Plain of North Carolina. M.S. Thesis. North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC

2006

Proceedings

Wright, J.D., M.R. Burchell II, J.D. Shelby, and R.O. Evans. 2006. Hydrologic effects of three restoration techniques on prior-converted wetlands in eastern NC. *In:* Hydrology and Management of Forested Wetlands– Proceedings of the ASABE International Conference New Bern, N.C. April 8-12.

Presentations

Burchell, M.R., J.D. Wright, and R.O. Evans. 2006. Assessing the effectiveness of wetland restoration techniques at North River Farms. Restore America's Estuaries 3rd National Conference on Coastal and Estuarine Habitat Restoration. December 11-13. New Orleans, LA.

2007

Proceedings

Bass, KL., RO Evans, and M.R. Burchell. Comparing design methods for restoring small streams in NC's coastal plain. 2007. Proceedings of the ASCE-EWRI World Environment and Water Resources Congress. Karen C. Kobbes - Editor. May 15-19, Tampa FL.

Lindgren, J.A., R.O. Evans, S.W. Broome, M.R. Burchell, and K.L. Bass. 2007. Elevation and salinity effects on vegetation in a created tidal marsh in eastern North Carolina. ASABE Paper No. 077097 ASABE-AIM Minneapolis, MN June 17-20.

Workshops

"North River Farms Wetland Restoration Update and Site Tour for NCEEP" Morehead City, NC December 17th, 2007. 10 attendees.

2008

Proceedings

Burchell, M.R., R.O. Evans, K.L. Bass. S.W. Broome, J.D. Wright. and J.A. Lindgren. 2008. Restoration of a prior converted farm in eastern NC with multiple target wetland communities. ASABE publication #701P0208cd. ASABE - 21st Century Watershed Technology: Improving Water Quality and Environment. Concepcion, Chile. March 31-April 3, 2008.

Presentations

Jarzemsky, R.D., M.R. Burchell, J.D. Wright, R.O. Evans. 2008. The hydrologic response of a restored wetland during tropical events in eastern NC. ASABE-AIM Providence, RI June 29-July 2, 2008.

Broome, S.W. M.R. Burchell, and J.A. Lindgen. 2008. Advancing techniques to establish vegetation in a tidal marsh created at North River Farms. Restore American Estuaries 4th National Conference on Coastal and Estuarine Habitat Restoration. Providence, RI. October 11-15, 2008.

Burchell, M.R., K.L. Bass, R.O. Evans, S.W. Broome, and J.D. Wright. 2008. North River Farms -five years of lessons learned about restoration of multiple wetland communities. Restore American Estuaries 4th National Conference on Coastal and Estuarine Habitat Restoration. Providence, RI. October 11-15, 2008.

Corbin, W.E., M.R. Burchell, W.W. Kirby-Smith, and K.L. Bass. 2008. Water quality analysis of a restored tidal stream in eastern NC. 2008 SRP Stream Restoration Conference, Asheville, NC. November 2-6, 2008.

Thesis

Baldwin, A.E. Changes in soil properties in a forested wetland following 8 years of restoration. M.S. Thesis. North Carolina State University. Department of Soil Science. Raleigh, NC

Workshops

"North River Farms Wetland Restoration Update and Site Tour for NCEEP". Seminar Sept 11, 2008 Raleigh, NC (14 attendees) and site tour Sept 12, 2008 Beaufort NC (10 attendees).

2009

Poster

Etheridge, J.R. and M.R. Burchell. 2009. Reduction in nitrogen loads from a large-scale wetland restoration in eastern NC. Poster No. 096301. ASABE-AIM Reno, NV June 21-24, 2009.

Presentations

Corbin, W.E., M.R. Burchell, G.D. Jennings, S.W. Broome, W.W. Kirby-Smith, and K.L. Bass. 2008. A water quality and morphological analysis of a restored tidal marsh and stream system in coastal NC. ASABE-AIM Reno, NV June 21-24, 2009.

<u>Thesis</u>

Jarzemsky, R.D. Hydrologic evaluation of a restored wetland in eastern NC. M.S. Thesis. North Carolina State University. Department of Biological and Agricultural Engineering. Raleigh, NC

***Note: 3 additional theses/dissertations are in preparation (2 BAE and 1 in SSC)**

Appendix 2 – Project Photos

Phase I

Construction Phase

Figure 1. Earthwork (Winter 2003)

Figure 2. Berms to separate treatments, shortly after completion (Winter 2003)

Figure 3. Earthwork near water control structures (Jan 2003)

Figure 4. Some equipment utilized in site construction and grading (Feb 2003)

Figure 5. Water control structures (flashboard risers) shortly after installation (Winter 2003)

Figure 6. Dr. Robert Evans installing flashboards that controlled outflow from the restored wetlands (Spring 2003)

Figure 7. Planting crew (Feb 2003)

Post-restoration photos:

Figure 8. Reference wetland with water quality monitoring station

Figure 9. Block 1 and 2 in May 2003 following extensive rainfall
(photo courtesy Restoration Systems)

Figure 10. Block 3 in May 2003 following extensive rainfall
(photo courtesy Restoration Systems)

Figure 11. Blocks 1 and 2 in early Fall 2006 without excessive rainfall *(photo courtesy NCCF)*

Figure 12. Blocks 1 and 2 in early summer 2009 without excessive rainfall. Note the changes in vegetation between 2003 and 2009.

Figure 13. Close-up of Block 2 in early summer 2009 without excessive rainfall.

Figure 14. Ground shot in Blocks 1 and 2 (June 2003)

Figure 15. Ground shot in Blocks 1 and 2 (July 2009)

Figure 16. Ground shot in Blocks 1 and 2 (July 2009)

Research

Figure 17. Jen Shelby and Dr. Garry Grabow collect water quality samples from the main drainage canal (Spring 2003)

Figure 18. Jason Wright collects stage data from one of the wetland outlet structures (Spring 2004)

Figure 19. Randall Etheridge collects water table data (June 2005)

Figure 20. Bobby Jarzemsky during a Phase I topographic survey (March 2007)

Phase II

Construction Phase

Figure 21. Phase II field in fallow conditions prior to construction (2005)

Figure 22. Phase II construction (Sept 2005)

Figure 23. Tidal marsh being fully connected to the estuary (June 2006)

Figure 24. Aerial view of Phase II tidal marsh areas mid-way through construction (Nov 2006)

Figure 25. Planting crew in the marsh supplementing initial planting in 2006 (Summer 2007)

Figure 26. Installation of the water control structure that feeds the freshwater portion of the restoration (Summer 2007)

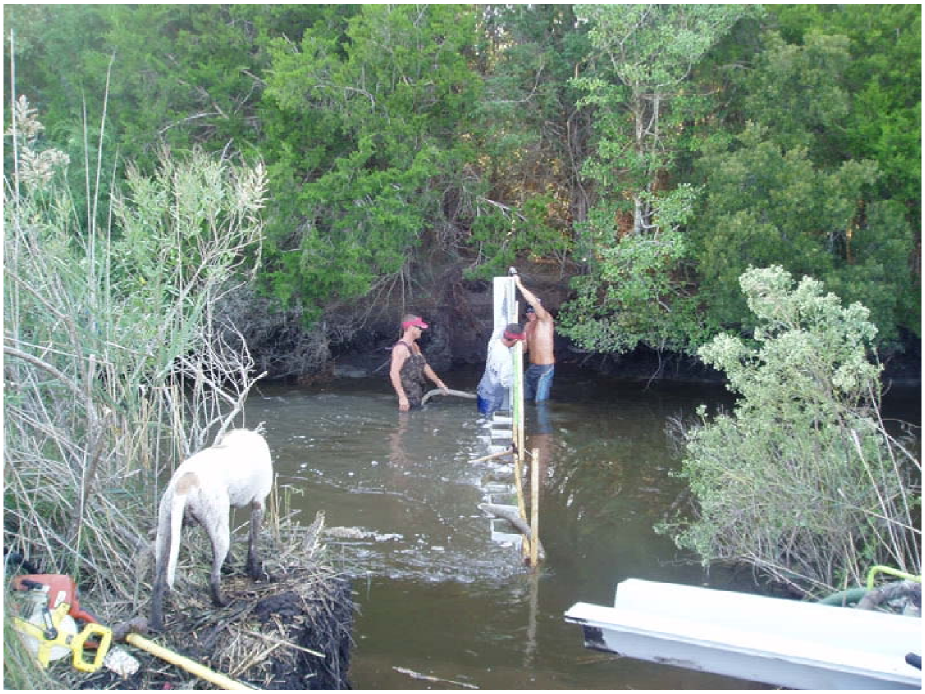


Figure 27. Installation of the low rock weir that diverted drainage water into the tidal marsh portion of the restoration (Fall 2007). Sheet piles were jetted into the canal and reinforced by marl. This design allowed for fish passage during incoming tides and during outflow events.

Post-restoration Photos

Figure 28. Tidal marsh just after planting (June 2006)

Figure 29. Tidal marsh 1 year after planting. Note the water quality station in the photo (July 2007)

Figure 30. Upstream portion of tidal marsh (Spring 2008). Note the clear demarcation between the *Spartina alterniflora* near the stream and the darker *Juncus romerianus*

Figure 31. Tidal marsh in the Fall (2008)

Figure 32. Marsh mid-way down the tidal stream at the time of this report (July 2009)

Figure 33. Aerial view of the Phase II marsh (July 2009)

Research

Figure 34. Dr. Steve Broome (center), with undergraduate student Randall Etheridge (left), and graduate students Nick Lindow and Jodi Lindgren, collect soil sample prior to vegetation planting (June 2006)

Figure 35. Planting of research vegetation plots (June 2006)

Figure 36. Close-up view of water quality and flow monitoring station shortly after marsh planting

Figure 37. Extension Associate Kris Bass looks over the vegetation plots in the marsh (June 2006)

Figure 38. Graduate student Evan Corbin (left) and Dr. Mike Burchell collect water table data in the marsh near the tidal stream (January 2008)

Figure 39. "All hands on deck" effort to collect vegetation for research plots (October 2008)

Figure 40. Preparing for a dye tracer study run in the tidal stream (Summer 2008)

Figure 41. Graduate student Evan Corbin taking manual velocity measurements in the tidal stream (Summer 2008)

Figure 42. Larry Eaton (NCDENR) collects aquatic samples from the tidal stream using a kick net (March 2009)

Workshops/tours/student photos

Figure 43. Field tour associated with a coastal stream tour workshop. Participants included staff from agencies such as NCDOT and NCDENR. (Jan 2005)

Figure 44. Image from a field trip sponsored by the ASABE International Conference on Hydrology and Management of Forested Wetlands, held in New Bern, NC (April 2006).

Figure 45. Participants in a workshop on coastal streams plant marsh plants around a tidal finger in the Phase II restoration area. The workshop (River Course) was developed through the BAE Stream Restoration Program (Dr. Greg Jennings) (May 2008).

Figure 46. Dr. Mike Burchell and Dr. Robert Evans assisted Dr. Bill Kirby-Smith with Duke University (pictured far left) in his environmental policy course during this project. The North River project was toured with this class yearly from 2004-2009.

Figure 47. Field tour associated with a BAE sponsored NCEEP workshop on the North River site. Pictured from left in the tidal marsh are Dr. Francois Birgand (BAE), Bill Gilmore (NCEEP), Kris Bass (BAE), and Todd Miller (NCCF) (Sept 2008).