The Ahn Wetland Ecosystem Laboratory
at
George Mason University

Annual Report 2005

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edited by

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As always, Dr. Ahn appreciates Roslyn Cress for her professional assistance with financial management, and the help of other graduate students involved in the monitoring work at North Fork, including Shera Bender, Mike Rivera, Florence Katrivanos, and Brad Petru.

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THE AHN WETLAND ECOSYSTEM LABORATORY: PROGRESS REPORT 2005

Changwoo Ahn

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Summary

This publication offers the summary of research and teaching activities at the Ahn wetland ecosystem laboratory at George Mason University. It covers progress in calendar year 2005. All the activities were conducted at the North Fork Mitigation Bank as part of the first year of ecological monitoring by our team. The North Fork Mitigation Bank is a 5 year-old created wetland complex for mitigation (as of 2005), which has already complied with legal monitoring requirements. However, our monitoring is designed to examine ecological functioning beyond the mandatory five-year monitoring, including hydrology, soil physicochemistry and nutrients, and vegetation patterns.

Two courses currently being taught by Dr. Ahn, EVPP 644 Wetland Ecology and Management and EVPP 650 Ecosystem Analysis and Modeling, use the North Fork Mitigation Bank for field activities and tours. From 2004 through 2005 a dozen graduate students (under the supervision of Dr. Ahn) and two undergraduate students (under the supervision of Mark Krekeler) participated in class tours and class research activities. In addition to the ecological monitoring study, a study on the effects of microtopography on vegetational and biogeochemical patterns of a created wetland is currently being conducted at North Fork. One paper in the annual report describes a preliminary study conducted late fall 2004. We are currently analyzing the data collected on microtopography, vegetation patterns, and soil nutrients in the summer of 2005, which will appear in the annual report for year 2006. A few presentations were made in 2005 about some of the studies conducted at the North Fork in regional/national meetings. Two proposals are pending to further ecological studies at North Fork.

Presentations in 2005

Moser, K.F. and C. Ahn. 2005. Effects of microtopography on vegetation and soil nutrients in a mitigation wetland in Virginia (poster). Society of Wetland Scientists 26th Annual Meeting, Coastal Plain Wetlands: Ecological, Landscape, and Regulatory Transformations,
Charleston, South Carolina.

Moser, K.F. and C. Ahn. 2005. Effects of microtopography on vegetation and soil nutrients in a mitigation wetland in Virginia (poster). Virginia Academy of Science 83rd Annual Meeting, James Madison University, Harrisonburg, Virginia.

Caballero, R.P., Shankle, C.E.N., Krekeler, M., and Ahn, C. 2005 Investigation of soils in a created wetland near Haymarket, Virginia (poster). 2005 Annual Meeting of Geological Society of America, Salt Lake City, Utah.

Publications in 2005

There were four peer-reviewed conference abstracts published in 2005 by Ahn lab.

Caballero, R. P., Shankle, C.E.N., Krekeler, M, and Ahn, C. 2005 Investigation of soils in a created wetland near Haymarket, Virginia, 2005 Annual Meeting of Geological Society of America, Salt Lake City, Utah.

Ahn, C., and K. F. Moser. 2005. "Developing a dynamic model to predict the recruitment and survival of *Salix nigra* (black willow) in response to flooding . Joint Meeting of 90th Annual ESA and IX INTECOL Congress, Montreal, Canada

Moser, K. F. and C. Ahn. 2005. Effects of microtopography on vegetation and soil nutrients in a mitigation wetland in Virginia. Society of Wetland Scientist 26th Annual Meeting, Coastal Plain Wetlands: Ecological, Landscape, and Regulatory Transformations, Charleston, South Carolina.

Moser, K. F. and C. Ahn. 2005. Effects of microtopography on vegetation and soil nutrients in a Mitigation wetland in Virginia. Virginia Academy of Science 83rd Annual Meeting, James Madison University, Harrisonburg, Virginia

Figure 1. Ahn wetland ecosystem laboratory members at the North Fork Mitigation Bank, 2005

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CHARACTERIZATION OF AN ECOSYSTEM DEVELOPMENT IN A CREATED WETLAND IN NORTHERN VIRGINIA: THE CASE OF NORTH FORK MITIGATION BANK

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Rationale

Virginia has lost approximately 42% of its original wetlands, and recent reports have documented continued annual losses of 2,400 to 3,000 acres, mainly due to development (Chesapeake Bay Foundation, 2005). These losses have continued despite Virginia's commitment with its Chesapeake Bay partner states to reach a "no net loss", and ultimately a "net gain" of wetlands in the Bay watershed. Therefore, there is a high demand for creating or restoring wetlands to mitigate the losses.

Since the 1977 amendments to the Clean Water Act, compensatory wetland mitigation has become commonplace in the United States. Most mitigation projects have been created or restored wetlands (National Research Council, 2001). A number of researchers have analyzed the regulatory and ecological success of these systems, and in general, mitigation wetlands have fallen short of replacing natural wetlands in terms of function (Roberts, 1993; Zedler, 1996; Malakoff, 1998; Cole and Shafer, 2002). Mitigation bank agreements stipulate performance standards to be monitored for a defined length of time—generally five years (ELI, 2002). In almost every case, some measure of vegetation is a performance standard, and in many cases, vegetation is the only performance standard. Common vegetation standards include targets for percent cover of hydrophytic vegetation, limits for nuisance species cover, and goals for survival of planted stock. The National Research Council (2001) cautions that vegetation alone is a poor measure of wetland function, but it is seen as a quick and effective surrogate for the biogeochemical condition of the wetland and is commonly used as a measure of success (Breaux and Serefiddin, 1999). Less frequently monitored parameters include hydrologic regime, non-native species, and soil development (Breaux and Serefiddin, 1999). There is a need to monitor created or restored wetlands for mitigation for a longer period of time (Mitsch and Wilson, 1996; Zedler and Callaway, 2000) with more parameters to be certain of that ecosystem dynamics are developed as found in natural wetlands.

Statement of results or benefits

The main goal of this project is to examine the dynamics of hydrology, vegetation and soil physicochemistry of a wetland created for mitigation beyond the mandatory five-year monitoring period. We will use less frequently used ecological indicators to monitor the maturation of a created wetland in a northern Virginia, which include site hydroperiod, plant communities (percent cover, species richness, and non-native species), soil and water physicochemistry, and nutrient dynamics. We will also compare the biogeochemical parameters measured with those published in the studies of other natural and created wetlands of the same type to determine how the mitigation wetland compares in terms of functional "success".

The study will result in a better understanding of the functional progress of a created wetland after early development. The outcome of the study will also provide useful information on how vegetation development relates to soil physicochemical patterns that simultaneously evolve. The study will try to answer whether the short length of time (5 yrs) currently used for monitoring is appropriate or not to diagnose the functional "success" of mitigation wetlands. The study will also produce potentially valuable information for developing a long-term ecological monitoring plan and criteria that can be used to monitor mitigation wetlands. Moreover, this study will provide the opportunity for training of graduate and undergraduate students in wetland science and technology, and potentially lead to more in-depth, scientific investigations on the ecological functioning of mitigation wetlands. The North Fork mitigation wetland will remain an important research and teaching facility beyond the end of the study, providing a substrate for (1) further studies in wetland ecology, (2) wetland education programs, and (3) comparative analysis with other created wetlands.

Nature, scope, and objectives of the research

The number of compensatory mitigation projects permitted under Section 404 of the Clean Water Act has been increasing. While mitigating wetland loss has become a common practice, poor planning and implementation and lack of expertise in wetlands have led to failures or, at least, to the uncertainty of success associated with many mitigation projects. Numerous reviews of past permitted projects were highly critical indicating that few mitigation projects were deemed successfully constructed replacements (Zedler, 1996; Mitsch and Gosselink, 2000; Zedler and Callaway, 2000; Brown and Veneman, 2001).

A literature review of *post hoc* assessment of compensatory wetlands suggests that many wetlands created and restored do not replace the structure or function of lost natural wetlands (NRC, 2001). In 1999, a U. S. Army Corps of Engineers Wetlands Research Program Technical Note (Streever, 1999) found that many Section 404 permits requiring compensatory mitigation did not include performance standards. In some permits the performance standards or success criteria were not "observable or measurable attributes" that could be used to determine whether the replacement project met its objectives (NRC, 2001). Simple (structural) indicators of success with easily measured parameters such as plant lists, animals witnessed, and percent vegetation cover have been used as the overall indicators of success (Mitsch and Wilson, 1996), but they may not indicate whether a wetland is functioning as desired or as designed. Moreover, failures of created wetlands to compare to natural wetlands have been partially attributed to a lack of developed soils in created wetlands (Bishel-Machung et al., 1996; Stolt et al., 2000; Campbell et al., 2002). Soils have been described as "the physical foundation of every wetland ecosystem" (Stolt et al., 2000). They have tremendous importance in wetland function, as most biogeochemical processes and nutrient storage occur in the soil layers (Mitsch and Gosselink, 2000). Nutrient cycling drives the wetland system, especially with regard to vegetation communities, which are often used as indicators to determine wetland "success" (see Mitsch and Wilson, 1996). Therefore, soil physicochemistry and nutrients should be monitored as one of the "measures of performance".

The amount of time required for monitoring to qualify as legal success is usually too short (5 years) to provide significant information on whether replacement wetlands are actually replacing the functions that were lost in the impacted wetland or even whether they are on the right developmental trajectory. The legal and economic necessities for regulators and land developers seem to dictate the ecological patterns of nature, encouraging "quick-fix" wetlands while not allowing for the stochasticity of nature (Mitsch and Wilson 1996). It seems to take longer time for created wetlands to self-design, evolving into something similar with the natural counterparts. Fennessy et al. (1994) point out that several characteristics of the then-7-year-old Des Plaines River Wetlands in northeastern Illinois were less developed than similar characteristics of "natural" reference wetlands nearby. Mitsch and Wilson (1996) recommend long-term monitoring before determining restoration success, e.g., 15-20 years for freshwater marshes and longer for forested and coastal wetlands. Henry et al. (2002) agree with long-term monitoring on riverine systems, even if it is not always feasible or desired, because there is a lack of knowledge about the functional progress of mitigation wetlands. Long-term monitoring and comparison with reference wetlands is necessary to discriminate the effects of "natural" successional dynamics from short-term changes from human impacts. Long-term monitoring beyond the mandatory monitoring period may indicate successional processes and the trajectory the replacement wetlands are following.

The proposed study will examine the ecological functioning of the North Fork mitigation wetland created by Wetland Studies and Solutions Inc. (WSSI), after mandatory five-year monitoring, including hydrology, soil physicochemistry and nutrients, and vegetation patterns. The objectives of our project are: 1) to analyze hydrologic conditions and hydroperiod of the site; 2) to study the physicochemical and nutrient characteristics of soil and water of the site; and 3) to monitor the status of vegetation communities, including non-native species. We will also compare the parameters measured with those found in both natural and created wetlands with varying ages in the scientific literature to evaluate the functional progress of the North Fork mitigation wetland after the early five years of development.

Methods, procedures, and facilities

Study site description

Created from a 125-acre cattle pasture in 2000, the North Fork mitigation wetland in Prince William County, Virginia (Lat. 38°49.4'N Long. 77°40.3'W), is an ecologically diverse system providing 7 acres of open water, 76 acres of wetlands, and 42 acres of upland buffers (WSSI, 1999). The site is only the second private mitigation wetland approved in northern Virginia. The wetland has the unique hydraulic feature of a dam 1,600 feet long and 25 feet tall, designed for the Probable Maximum Flood event with two feet of freeboard in an 800+ acre watershed. The dam impounds the North Fork of Broad Run, forming a seven-acre pond and controlling the hydrology for much of the created wetland area on the site (WSSI, 2005). The vegetation community at North Fork is diverse, including a mixture of forest, shrub, and emergent vegetation with several sub-communities selected by elevation, source of water, and species composition. Upland buffers, submerged and floating aquatic vegetation, and the open water pond complement these wetlands, creating a heterogeneous complex of habitats that support numerous wetland-dependent plant and animal species (WSSI, 2004a). Our study will focus on North Fork's "Main Pod" (Figure 1). Twenty vegetation and ground well monitoring locations are distributed throughout the Main Pod (Figure 1), nine of which are chosen for soil and water physicochemistry study (locations 6, 10, 11, 12, 34, 35, 37, 40, and 41 in Figure 1).

Figure 1. A map of North Fork mitigation wetland showing twenty locations for vegetation and groundwater monitoring in the Main Pod

Hydrologic patterns

Understanding the hydrologic processes of mitigation wetlands is fundamental to effective ecosystem restoration and creation (Mitsch and Gosselink, 2000). One indicator of success for created wetlands is the fulfillment of the hydrologic criteria (National Research Council, 1995). Hydrologic budgets and hydroperiod, therefore, provide valuable information to meet mitigation goals. The following equation will be used in our attempts to determine hydrologic budgets for the main pod of the North Fork wetland.

$$\Delta V/\Delta t = Q_{in} - Q_{out} + G_{in/out} + P_{reci} - ET \qquad (1)$$

where

$\Delta V/\Delta t$ = Change of water volume in wetland over time

Q_{in} = Surface Inflow

Q_{out} = Surface outflow

$G_{in/out}$ = Groundwater exchange

P_{reci} = Precipitation

ET = Evapotranspiration

We will obtain proper instrumentation to estimate the hydrologic budget of the Main Pod. Currently, the site is equipped with inflow/outflow pressure transducer. We will purchase more pressure transducers to quantify the flow patterns at several locations in the Main Pod. We will additionally place a Stevens Type F water level recorder near the inlet of the main pod to record water depth change. Outflow will be measured by downloading flow data detected by the existing pressure transducer through a weir structure built at the outlet. Daily precipitation and evapotranspiration data will be obtained from a weather station located at the site (Campbell Scientific ET-106). There are a number of groundwater monitoring wells located along each location established for annual vegetation survey (WSSI, 2004b). These groundwater monitoring wells monitoring will be used during the year to monitor groundwater concurrently with surface hydrology to examine the hydrologic functioning of the Main Pod. We will also utilize two soil moisture probes (Campbell Scientific model CS-615) currently located in the Main Pod to conduct more of a qualitative assessment of the moisture level when there is no standing water on the ground to assist our study on the hydrologic pattern of the Pod. Hydroperiods both for the intermittent stream feeding the Main Pod and for several locations of the Pod will be constructed.

Biogeochemical and nutrient patterns

Surface water samples (inflow and outflow) will be collected bi-weekly and/or during storm events for physicochemical and nutrient analyses during the growing season (June through August) at several locations (locations 6, 10, 11, 12, 34, 35, 37, 40, and 41 in Figure 1) throughout the Main Pod along with the hydrologic monitoring. A YSI Multiparameter Water Quality Data Probe will used to measure temperature, dissolved oxygen, pH, conductivity, and redox potential on-site at every water sampling station. The YSI probe will be calibrated weekly during the study. Water samples collected will be transported to the Wetland Ecosystem Laboratory at George Mason University in a cooler and kept in a refrigerator at 4°C until analysis. One subsample will be filtered through a 0.45 μm filter and placed in a freezer for later soluble reactive phosphorus (SRP) analysis. Filters will be soaked for approximately 24 hr in distilled water to remove contamination. Unfiltered subsamples will be preserved by acidification with 2 mL 36 N H_2SO_4 per L of sample (to pH < 2) immediately upon return to the lab for total phosphorus (TP) analysis. Analyses for TP (APHA, 1992 4500-PF), SRP (APHA, 1992 4500-PF) and nitrates (NO_3+NO_2-N) (APHA, 1992 4500-NO3E) will be performed by spectrophotometry.

The soil study will observe soil color and measure physicochemical parameters, including bulk density, soil organic matter and soil total carbon, total nitrogen and total phosphorus. We will take a total of 45 soil cores in the nine locations of the Main Pod. From each location, 5 replicate samples will be collected [at two depths (0-8 cm and 8-16 cm)] by use of a soil auger, visually characterized excluding surface litter, field-stored in polyethylene bags on ice, then stored in the lab field-moist at 4°C. Soil coloration is an indicator of soil type, and the determination of soil hue, value, and chroma is standard practice in wetland delineations. The value and chroma for each soil sample will be determined on-site using a Munsell Soil Color Chart (Kollmorgen Instruments Corporation, Baltimore, MD). Mottling of soils, an indicator of oxidized materials, will also be noted. Soil samples will be homogenized by hand prior to analysis, with roots, recognizable plant material, and coarse gravel removed, then oven-dried at 105°C for 48 hours or until constant mass is achieved. Samples will be weighed and bulk density will be calculated from the initial sample volume. Subsoil samples will be weighed, combusted in a muffle furnace at 550 °C for 1 hr, and re-weighed to determine soil organic matter. Total carbon and nitrogen for the soil samples will also be determined using a Perkin-Elmer 2400 Series II CHNS/O Analyzer. Another portion of the soil samples will be freeze dried and analyzed for total phosphorus with the nitric acid (HNO3) and the hydrochloric acid digestion method (White et al., 2000), using a Technicon II Autoanalyzer and method number 692-82W (Bran and Luebbe Inc., 1989).

Vegetation community patterns

Table 1 shows a partial species list for the Main Pod of North Fork mitigation wetland, cumulative for all previous vegetation survey years within the mandatory monitoring period (WSSI, 2004a). We will conduct growing season monitoring of plant diversity and community establishment through twenty survey locations in the Main Pod that have been previously used during the five-year legal monitoring (WSSI, 2004a). All vegetation along these locations will be identified, including non-native species. The data will be collected and analyzed for prevalence of wetland vegetation (Wentworth et al. 1988), the pervasiveness of non-native species (Kartesz and Meacham, 1999), and plant species richness (Ugland et al. 2003). Vegetation data will be analyzed for any relations with hydrologic and soil physiochemical parameters.

Table 1. Species list for the main pod of North Fork mitigation wetland for the proposed study, cumulative for all vegetation survey years (2000-2004). Species marked with an asterisk are volunteer species. Site locations (6, 10, 11, 12, 35, and 41) are shown in Figure 1.

Site 6	Site 10	Site 11	Site 12	Site 35	Site 41
Agrostis alba	Agrostis alba	Agrostis alba	Agrostis alba	Agrostis alba	Agrostis alba
Carex frankii*	Alisma plantago-aquatica*	Alisma plantago-aquatica*	Carex frankii*	Bidens cernua	Arthraxon hispidus*
Carex vulpinoidea	Carex frankii*	Carex frankii*	Carex sp.	Carex sp.	Carex frankii*
Echinochloa crusgalli*	Echinochloa crusgalli*	Carex lurida	Carex vulpinoidea	Echinochloa crusgalli*	Carex lurida
Eleocharis obtusa*	Eleocharis obtusa*	Carex vulpinoidea	Cyperus strigosus*	Eleocharis obtusa*	Carex sp.
Juncus effusus	Lolium multiflorum	Cyperus strigosus*	Echinochloa crusgalli*	Juncus effusus	Carex vulpinoidea
Ludwigia palustris*		Echinochloa crusgalli*	Eleocharis obtusa*	Ludwigia palustris*	Cyperus strigosus*
		Eleocharis obtusa*	Juncus effusus	Polygonum lapathifolium*	Echinochloa crusgalli*
		Juncus effusus	Juncus tenuis*	Rotala ramosior*	Eleocharis obtusa*
		Leersia oryzoides	Ludwigia alternifolia*	Scirpus atrovirens	Juncus effusus
		Lemna minor*	Ludwigia palustris*		Leersia oryzoides
		Ludwigia palustris*	Panicum dichotomiflorum		Ludwigia palustris*
		Panicum dichotomiflorum	Scirpus cyperinus		Polygonum hydropiper*
			Verbena hastata		Polygonum hydropiperoides*
					Polygonum punctatum*
					Rotala ramosior*
					Scirpus atrovirens

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HYDROLOGICAL MONITORING AND INSTRUMENTATION AT NORTH FORK MITIGATION WETLAND

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During the summer of 2005, Wetland Studies and Solutions staff greatly assisted the George Mason wetland ecology team under Dr. Changwoo Ahn in setting the foundations for the determination of the North Fork Wetland Remediation Bank's water budget. On June 1, 2005, the following instrumentation was installed:

(1) **Global Water WL15X water level recorder/stream gauge**, located in-stream between Tiers 1 and 2, adjacent to the Over Bank Flow area. An L-shaped PVC pipe structure was erected and placed in a trench perpendicular to the stream. The water level recorder was placed on a cable and fed down the pipe so that it sat at the end within the stream, which was capped and had perpendicular cuts sawed into the sides. The submerged end was held under the water by large rocks. The exposed, aboveground end was capped and later secured with a well lock. The trench holding the PVC was filled with dirt to ground level. A **staff gauge** was later attached to a wooden post located on the stream bank opposite the Global Water gauge, and a stream channel profile was surveyed by WSSI staff in October.

(2) **Three V-notch weirs** at overland flow sites leading to the Main Pod. These are located southeast of the Overbank Flow Area and Tier 2 and southwest of Tier 3, in the northwest corner of the Main Pod. Trenches were dug roughly-perpendicular to the overland flow and 2"x12" wooden boards were hinged together and placed in the trenches to form a short wall. The V-shaped cuts were positioned so that the center of the outflow would correspond with the previous location of maximum surface flow. L-shaped metal pieces were fitted to the bases of the cuts to set the conditions required for the weir equation. The height of the walls was adjusted so that water flow would cascade through the weir during surface flow conditions. Bentonite clay was applied to the trenches and in-curved wall ends in order to water-seal the structures. **Staff gauges** were attached to the walls of the weirs immediately adjacent to the cuts to measure water level during flow events.

(3) **Monitoring well** for the **HOBO water level/pressure dataloggers** a short distance back from the weir (toward the Main Pod) by Tier 3. This was made from PVC pipe dug vertically into the ground and exposed several feet aboveground. Holes were drilled into the exposed tops of the wells and fitted with metal hooks, from which small-linked steel chains were used to hang the HOBOs. The steel chains were later replaced by stainless steel cable. The opening was secured with a plastic cap prior to an eventual fitting with a metallic well lock.

(4) **Staff gauges** placed at ground level (attached to wooden posts or survey benchmarks) at Wells 6, 34, and 35 such that obscuration by vegetation was minimized and water level could be read through binoculars from nearby paths.

Since then data has been periodically collected from the Global Water gauge and HOBOs by graduate students and digitally stored at the George Mason Wetland Ecology Lab. While the groundwater data from the HOBOs has been recorded without interruption (save for brief sojourns back to the lab for data extraction), Global Water data for much of September-October was lost due to equipment malfunction, which was rectified early November. The dry period of Summer and Fall 2005 provided few opportunities to utilize the weirs and staff gauges, so little overland flow data has been collected so far. Water levels were checked by Solinst water-level detector at observation wells in the Main Pod during early July and data was recorded based on previous WSSI notation; none of the selected wells located on dry land held water at the time and evidence of land subsidence was found at some wells. Finally, a SonTek/YSI FlowTracker Handheld Acoustic Doppler Velocimeter was used in Fall and Winter along the inflow stream by the Global Water station to collect data for establishing a rating curve for the North Fork of Broad Run. Streamflow observations thus far have been under fairly low-flow conditions, so a rating curve has not yet been established. Currently, global water readings are conducted monthly.

A WATER BUDGET FOR THE NORTH FORK MITIGATION WETLAND

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Abstract

Mitigation of wetland loss driven by the Clean Water Act has resulted in a trend from project specific mitigation in small fragments to the establishment of mitigation banks that can issue credits on a proportional scale for development. This concept of creating large acreage wetland cells relies on the potential success of hydrology and vegetation within the created or restored area. Many studies have investigated vegetative distribution and composition of created wetlands as well as hydrologic success of such wetlands. Knowing the input of water into a created system is vital in preliminary design of created wetlands. Controlling the outflow and elevation of water levels on a daily, weekly or annual basis needs to be accounted for, in particular to achieve desired vegetative communities and nutrient retention. Million dollar mitigation agreements impacting existing wetlands take place on a daily basis with the idea that these impacts are going to be replaced in the long term by the process of creation. Poor design and inaccurate speculation of hydrologic inputs and outputs into a created system will end up in failure, either with an arid landscape or a permanently ponded area. This may result in (A) vegetative failure or (B) selection for undesired vegetative community types. This study investigates a water budget for the 2002 (relatively dry) and 2003 (relatively wet) years at the Main Pod of the North Fork Wetlands Bank located in Haymarket, Virginia.

Keywords: water budget, wetlands, hydrology, North Fork of Broad Run, wetlands restoration, wetland mitigation

Introduction

Wetlands are created and restored for a number of purposes, including habitat replacement, water quality enhancement, and flood control (Mitsch and Gosselink, 2000). In recent history, impacts made to wetlands have been mitigated through wetland banks that can sell proportional credits to developers to absolve their impacts. In the early half of the new century over 200 mitigation banks encompassing 50,000 hectares within 29 states existed and the numbers are increasing (Spieles, 2005). Multi-million dollar mitigation agreements have been based on the expectation that damages to habitat will be compensated within 5-10 years (Zedler and Callaway, 1999). Wetlands constructed for stormwater retention or nutrient removal may be required to retain water for extended periods of time. The retention and removal of dissolved elements is one function of vegetative community types (Cole, 2002). Cole identified that storage takes place on the surface for a week or so. Herbaceous plants affecting the roughness will aid in this function, but hardwoods and basin morphology have a greater impact. Different water levels during different times of the year determine the success of desired vegetation within created wetlands.

A dry period in the spring may allow rice cutgrass (*Leersia oryzoides*) or similarly propagating species to take root if that is your desired vegetative type. If this early draw down in a wetland is not controlled or planned for ahead of time, a wetland mitigation cell designed for forested success and planted with three (3) gallon woody species may dry up or be out competed by these opportunistic species, thus failing to meet the permitted success criteria for the mitigated impacts. The hydrodynamics of a wetland has a direct impact on population diversity (i.e. richness and evenness), and if altered can drive vegetative communities towards a monotypic environment (Kercher and Zedler, 2004; Kercher, Carpenter and Zedler, 2004; Bouma et al., 2005). If water levels inundate a wetland for too long during the growing season, woody species recently planted may be stressed by the new hydrologic conditions and die. The constructed wetland may be invaded by opportunistic herbaceous vegetation such as *Typha* spp. that can out-compete native or planned vegetative communities. This situation is very possible when creating wetlands within developing urban watersheds that can convey more water in the future than was anticipated during the design.

Wetland mitigation and restoration that is created to be a closed system trend towards a monotypic community (Reinartz and Warne, 1993). Closed systems do not receive propagules from outside sources unless the method of dispersal is air or animal dependant. Within a short period of time, invasive and opportunistic vegetation will take over. Hydrologically open created wetlands can develop with a diverse assemblage of species even when no propagules existed before if the transport of propagules through flooding takes place (Mitsch et al., 1998). Conversely, Koning (2005), investigated Grassy Pond in New Hampshire to understand the effect that disturbance from hydrology can take on a vegetative community. This study noted intra-annual variation in water levels to be important in maintaining plant diversity. Grassy Pond is a closed system perched above the water table and relies on precipitation as the main source of hydrology. A high variability in the water levels allows diversity to be maintained. Too much or too little water within a wetland can affect the dominant vegetation composition (Pierce, 1993). Comparison of restored and reference wetland meadows recorded different plant communities that correlated with a hydrologic gradient and organic matter content (Ashworth, 1997). Sustained depths of hydrology over lengthy periods of time will drive the vegetative communities to be characterized by facultative to obligate hydrophytic vegetation. In created wetlands, control of hydrology not only serves to meet the hydrologic success but drives vegetative community success.

Determining volumes of water passing through a created wetland and the retention time within that wetland can only be done with a water budget. In some instances, constraints of the surrounding landscapes limit access to a surface or ground water supply and reliance on precipitation as the main source of hydrology is required. Wetlands constructed for stormwater retention or nutrient removal may be required to retain water for extended periods of time. Maintaining an accurate and consistent water level in wetland mitigation sites is a critical component to maintaining and promoting hydrophytic vegetative growth, which in many instances can be the key qualifier of permit success established during the permitting of impacted wetlands. According to the Virginia Water Protection General Permit as implemented by the Virginia Administrative Code (VAC), water levels must be maintained within 30.48 centimeters (12.0 inches) of the surface for 12.5% of the frost free growing season to qualify for successful hydrology in a created wetland (Virginia Administrative Code 9 VAC 25-670, 2005).

Wang and Mitsch (1998), pointed out that the transport and disposition of dissolved and suspended materials and the storage/release of water can only be performed by creating a water budget. Controlling fluctuations such as this can only be done if a water budget is constructed. In order to model a created ecosystem (open or closed), a balance of inputs and outputs into your system must be estimated before construction ever begins. A water budget allows creators of the wetlands to identify what inputs are likely to come during different seasons of the year and when to anticipate potential surplus or deficits in water supply. This paper creates a water budget for the Main Pod of the North Fork Wetlands Bank for 2002 and 2003 using data collected by WSSI.

Methods

Site Description

The North Fork Wetland Mitigation bank was constructed by Wetland Studies and Solutions, Inc. (WSSI) in-line with the North Fork Branch of Broad Run. This created wetland is located northwest of Haymarket, Virginia in northwest Prince William County. The mitigation bank is located north of Interstate 66 and is bound to the west by Thoroughfare Road (State Route 682) and to the east by Antioch Road (State Route 601). To Thoroughfare Road (upstream) the North Fork has a drainage area of approximately 740 acres. This stream originates in the foothills of the Bull Run Mountain. This quartzite based geologic formation created in the Cambrian era contains many natural springs and seeps. The eastern foothills are underlain by components of fragmented Cambrian and Jurassic era meta-sandstone bedrock, red Triassic shales and poorly drained silts and clays associated with the Culpepper Basin formation (www.fobr.org).

Created in 1999 to 2000, the wetland bank includes seven acres of open water, 76 acres of wetlands, and 42 acres of upland buffers. These wetlands contain a diverse mixture of forested, shrub-scrub, submerged aquatic and emergent wetland vegetation. Permit success for the initial five years of monitoring have been met. The design of the wetland bank includes a large central “Main Pod”, four wetland tiers that collect offsite drainage from preserved forested wetlands to the north, an overflow spillway adjacent to North Fork inside the property and a series of “vernal pools” situated in the southwest corner of the property. Drainage from the tiers and overflow corridor have direct surface flow input into the Main Pod where as the vernal pools were built to be isolated wetlands. Initial construction of this wetland bank began with the establishment of an impervious clay liner with materials acquired from the Vulcan Materials Company. These wetlands are a perched system that is disconnected from the hydrologic input of the natural groundwater table. Monitoring for this wetland include a suite of groundwater monitoring wells spread throughout the interior wetland cells. A submersible pressure transducer was installed at the downstream side of the double culvert located at Thoroughfare Road (Figure 1) to accurately measure hydrology input collected from the upstream drainage area. Outflow measurements are recorded at the concrete outfall structure located along the dam embankment of the Main Pod. This outfall structure contains a movable iron riser board that can manipulate the interior water elevation of the Main Pod and can be raised and lowered by hand depending on anticipated water fluctuations.

Channel morphology of the North Fork below the double culvert located at Thoroughfare Road has altered significantly since the construction of the wetland bank. Measurements historically recorded by WSSI at this transducer may contain inaccuracy in the correlation to this channel morphology. Over time, scouring of the banks from storm events and deposition of substrate in the channel provide data that may not be correlated with a known volume of water. This past summer, the Wetland Ecology and Management class of George Mason University

(GMU) set out to install new measurement devices to accurately observe the new existing conditions of this wetland bank. A water level recorder (Global Water WL15X) was installed in the stream between Tiers 1 and 2, adjacent to the overflow spillway. This reach of North Fork was chosen because of the stable channel morphology. Since further input estimations are required for the overflow spillway and Tiers 2 and 3, v-notch weir boards and associated sandbags and bentonite clay were installed to monitor surface flow in these areas (Figure 1) that contribute to the Main Pod. This monitoring program is in the early stages and data collected to this point only depicts several months of hydrologic input in 2005.

Due to the lack of data collected to this point from the recent establishment of this new monitoring program along with faulty data loggers, data collected by WSSI is used in this paper to create a water budget for the main pod (51 acres) based on data collected for the 2002 and 2003 years. 2003 is the wettest year recorded at the Dulles Airport weather station to date.

Figure 1: Base map for the North Fork Wetlands Bank depicting the layout of the wetland cells.

Water Budget

The equation used to calculate the budget for the North Fork Wetlands Bank follows such

$$\Delta S = (P + I + Si - ET - So)$$

Where

- ΔS = Change in Storage (m^3)
- P = Precipitation (m^3)
- I = Inflow Measured at Thoroughfare Road m^3 (m^3)
- S_i = Surface Flow input from Tiers and Overbank Flow Corridor (m^3)
- ET = Potential Evapotranspiration (m^3)
- S_o = Outflow (surface) at Concrete Outfall (m^3)

This budget is modeled after Kirk et al. (2004). The difference being a groundwater attribute that they included. In this study the groundwater inputs and outputs (G_i and G_o) are not a contributing source of hydrology due to the clay liner. Surface flow has two components, inflow (I) measured at a culvert upstream of the property at Thoroughfare Road. Surface flow (S_i) is from the wetlands within the mitigation bank that have a direct input into the main pod. Evapotranspiration (ET) and precipitation (P) are calculated for the main pod only. Outflow (S_o) is measured at the dam outfall structure and reflects what is leaving the main pod.

Similar methods reviewed included Zhang and Mitsch (2005) and Pierce (1993) which is modeled after Carter (1986). In both of these examples, groundwater is factored in as an input or output, which is not the case for the North Fork Wetlands Bank. Wang and Mitsch (2000) include pumped groundwater which in not a factor as well in this study. All of the methods are similar in that they are estimating inputs to be equal to outputs at any one moment in time.

Inflow at Thoroughfare Road (I)

Data were collected between 2001 through 2004 by WSSI at the inflow and outflow stages of the mitigation bank by submersible pressure transducers. The upstream transducer was installed at the downstream side of the culvert at Thoroughfare Road (Figure 1). The transducer collects data at ten-minute intervals. The Hydrologic Engineering Centers River Analysis System (HEC-RAS) flow model developed by the Army Corps of Engineers (Corps) was used to determine flow calculations with the data collected at Thoroughfare Road (WSSI, 1999).

Surface Flow from tiers and overflow spillway (Si)

A second surface flow component is designed to count surface runoff from the four tiers and the overflow corridor (Figure 1) that also contribute to the Main Pod. The vernal pools were not included as by definition these wetlands should be isolated systems that do not contribute to the Main Pod. Multiple significant storm events within a short period of time may raise the water levels within these cells above the overflow weirs and thus contribute to the Main Pod, but this is interpreted not to be a consistently reliable source of hydrology to include in the budget equation.

In 1986, the U.S. Department of Agriculture Soil Conservation Service (now called the Natural Resource Conservation Service) came up with the TR-55 methodology (USDA, 1986) which is a reliable method for predicting peak discharge due to a 24 hour storm event. The data computed for the wetlands onsite utilized this method to estimate potential surface flow that would be introduced to the main pod during (extreme) storm events.

The TR-55 calculation is:
Q = ((P-0.2S)^2C)/(P+0.8S)
Where

- Q = water depth over the watershed (inches)
- P = Precipitation (inches)
- CN = Runoff Curve = 70 (curve number for hydrologic soil group)
- S = (1000/70)-10 (S is related to soil and cover conditions, 4.2857 for this particular wetland)
- C = Slope Coefficient = 1.0 (roughness coefficient)

To understand how this input influences the Main Pod, the value was then divided by the area of the Main Pod.

Ground Water In (G_i) and Groundwater Out (G_o)

As mentioned above in the water budget, groundwater is not included in this budget because of the creation of a compact clay layer after the initial grading of the wetlands. Subsoil permeability is between k = 1 x 10^{-6} cm/sec and k = 1 x 10^{-8} cm/sec (WSSI, 1999). This input/output was not observed by WSSI in creating the Prince William County (PWC) site plan and is not included as an input for this study.

Precipitation (P)

Precipitation data recorded at the Washington Dulles Airport Weather Station located in southeast Loudoun County, Virginia (approximately 32 km to the east of the Main Pod) were converted to metric units and multiplied by the area of the main pod to quantify actual volume of precipitation that is a direct input during storm events. Interception by plants was not considered in the budget calculation due to the relatively young age of the created wetland and associated plant stock. To design the wetland bank, WSSI calculated their precipitation values the same way in the PWC site plan for their comparison of wet, typical, and dry years. Precipitation data was collected from the weather station for daily intervals and then totaled for each month.

Surface Flow Out (S_o)

A second submersible pressure transducer is located at the concrete overflow structure situated along the dam embankment. This measurement was recorded in ten-minute intervals and was provided by WSSI in acre-foot per day values. These values were converted to cubic meters to be compared with other data in the budget. These conversions were done for each day and then totaled for each month.

Evapotranspiration (ET)

The Thornthwaite Equation, an empirical temperature based method was used to determine potential evapotranspiration (Mitsch and Gosselink, 2000). This equation has been utilized for many studies to successfully predict the approximate evapotranspiration (Pierce 1993; Kirtk et al., 2004). This method was followed by WSSI to calculate their water budgets for the North Fork Wetlands Bank as well and therefore was deemed suitable to use for calculating the 2002 and 2003 water budgets. Data is calculated on a monthly basis.

$$\mathbf{ET_i = 1.6\ (10Ti/I)^a}$$

where

ET_i = potential evapotranspiration for the month i (cm per month)

Ti = mean monthly temperature in (°C)

I = local heat index (°C)

I = sum of (Ti/5)^1.5

a = 0.49 + (0.0179)(I)- (0.0000771)(I^2) + (0.000000675)(I^3) (derived from temperature data)

Results and Discussion

Inflow at Thoroughfare Road (I)

Monitoring stations where the inflow is recorded are found just east of Thoroughfare Road (Figure 1). Inflow amounts for January and February 2002 were not available. These values were substituted with the average of the remaining ten month inflow values for that year and do not reflect accurate data. Inflow data for 2003 recorded at Thoroughfare Road is complete and reflect spikes in precipitation for that year.

Figure 2: A southern view of the flood stage conditions of the North Fork at Thoroughfare Road. 10-8-05.

Figure 3: An eastern view of the flood stage conditions of the North Fork looking towards the wetland bank at Thoroughfare Road. 10-8-05.

Further potential error in these budget calculations may exist in this data in regards to the changing geomorphology of the cross section originally profiled at the culvert. The transducer is correlated with a profile of the stream channel immediately downstream of the culvert. The drainage area to this point is approximately 300 hectares (740 acres) (WSSI, 1999). The weather station recorded approximately 17.3 cm (6.9 in) of rain on October 8, 2005. The volume of precipitation from this storm event falls between a 25 to 50 year storm events for Prince William County, Virginia (VDCR, 1999). Observation (Figure 2 and 3) taken during an onsite visit to the culvert at Thoroughfare Road depict North Fork overtopping the roadway. The culvert at this point is not able to convey flow from a storm of this magnitude. The submersible transducer correlated with the channel morphology in this location does not accurately account for this large of a volume of water. The morphology of the channel in this area has altered shape since the original calibration of the transducer with the channel profile. The widening of the channel and deposition of sand and silts within the channel might have produced an inaccurate reading from the transducer. The volume of water the transducer measures is offset by an unknown area of sediment within the channel. The peak recorded flows are not accurate and underestimate the volume of water during large storm events. The photographs above provide a visual understanding of the volume of water that is not accurately accounted for. Likewise the low flow events are becoming more overestimated with the deposition of more sediment from the roadway into the culvert and downstream channel.

Surface Flow from tiers and overflow spillway (Si)

Surface flow from the three (3) tiers and the overflow spillway did not contribute much hydrology in either year compared to the other inputs to the budget. The Main Pod was never designed to rely on this input solely and because the overflow spillway can be modified by hand, added input from this surface flow can easily be balanced by lowering the overflow spill plate. The maximum values the inflow at Thoroughfare Road are approximately 1200 times the volume of surface flow from the tiers and spillway in 2002, and more than 5000 times the volume calculated for 2003.

This value is an estimate and is not reflective of a weir measurement but based on a roughness coefficient. Pierce's (1993) and Kirk et al. (2004) also use the TR-55 methodology. In Wang and Mitsch (1998) and again in Zhang and Mitsch (2005), surface flow was calculated by measuring the water level and comparing it to the elevation of the weir boxes and the weir crest elevation (Wang and Mitsch, 1998; Zhang and Mitsch, 2005). That is not applicable to the tiers and overflow spillway as no measurement of weirs was available.

Precipitation (P)

The PWC site plan (WSSI, 1999) uses annual precipitation to determine the driest year to be 1965 (73.30 cm/yr), typical to be 1982 (97.94 cm/yr), and the most wet to be 1983 (117.29 cm/yr) using data recorded at the Washington Dulles Airport Weather Station. The total annual precipitation at the weather station was 96.82 cm/yr in 2002, and163.90 cm/yr in 2003, making 2003 the wettest year to date recorded at the station. Both years depict a spring wet period, followed by a moderately dry summer which is then followed by a wet period in fall Precipitation falling directly into the main pod is a small component of the overall input for the water budget compared to the inflow received from the watershed above Thoroughfare Road (740 acres). In many months, the inflow recorded at Thoroughfare Road is more than three (3) times the volume of precipitation that falls directly onto the main pod.

Evapotranspiration (ET)

The potential evapotranspiration calculated for 2002 and 2003 are very similar. January and February of 2002 both had a potential loss of water where in 2003 there was none. Predictions of the potential evapotranspiration using the Thornthwaite Equation are readily used, but are based on an average monthly temperature and do not depict daily fluctuations very well. These averages may be offset by a few hot or cold days versus many days that were within little variance of each other and therefore may hide actual peak evapotranspiration values that may occur on a daily basis in particularly during dry months.

This equation also does not account for the ability of vegetation to retain or release moisture through various physiological adaptations. As the vegetative composition changes over time, fluctuations in evapotranspiration due to plant surface area or consumption may draw more water than anticipated from the budget calculated. Czikowsky and Fitzjarrald (2004) investigated the effects of evapotranspiration on the water table and stream fluctuations within eastern hardwood forests. They suggest that the consumption of water by the hardwoods and subsequent evapotranspiration can have a diurnal effect on river water level fluctuations. As the forested wetlands of the Main Pod mature over time, the North Fork may encounter a similar diurnal pattern with full grown vegetative communities. This effect can be offset by the ability to manipulate the outfall elevation of the weir along the dam.

Surface Flow Out (S_o)

Some portion of outflow data collected for 2002 were not available. January, February, July, August, September and October all had missing data. Monthly surface flow out values for the

Main Pod were estimated by averaging the existing six (6) months of data together. 2003 outflow spikes somewhat mimic the inflow data.

Outflow values for August, 2003 are approximately 123 m^3 which is barely a trickle compared to the amount of precipitation and inflow recorded for that same month. Evapotranspiration data does not differ greatly in the peak discharge values between 2002 and 2003. The potential draw down in August may be a resultant of lowering the outfall structure. Year 2003 being the wettest year on record, should have a large output for the month of August. It appears that there is a gradual draw down before and after August which may have been attributed to a gradual lowering of the outfall structure to a desired minimal elevation to absorb the volume of water that year.

Change in Storage (ΔS)

The collective inputs and outputs for 2002 and 2003 are depicted on the Water Budget graphs (Figures 4 and 5). Four months in 2002 had a negative balance between inputs and outputs and may be flawed due to substitution of half the data for outflow numbers with averages for year. Potentially the summer and early fall months during a typical year may experience lower discharge values from the wetland as the inputs decrease (WSSI PWC site plan). The main pod of the North Fork Wetlands Bank is reliant on inflow from the North Fork of Broad Run as the primary source of hydrology. Precipitation directly on the Main Pod provides supplemental hydrology but is not a primary input. The change in the water budget for year 2002 is approximately 7.79×10^4 m^3 (Table 1). A surplus of water was discharged from the main pod during this typically dry year (using assumed data may exaggerate this value).

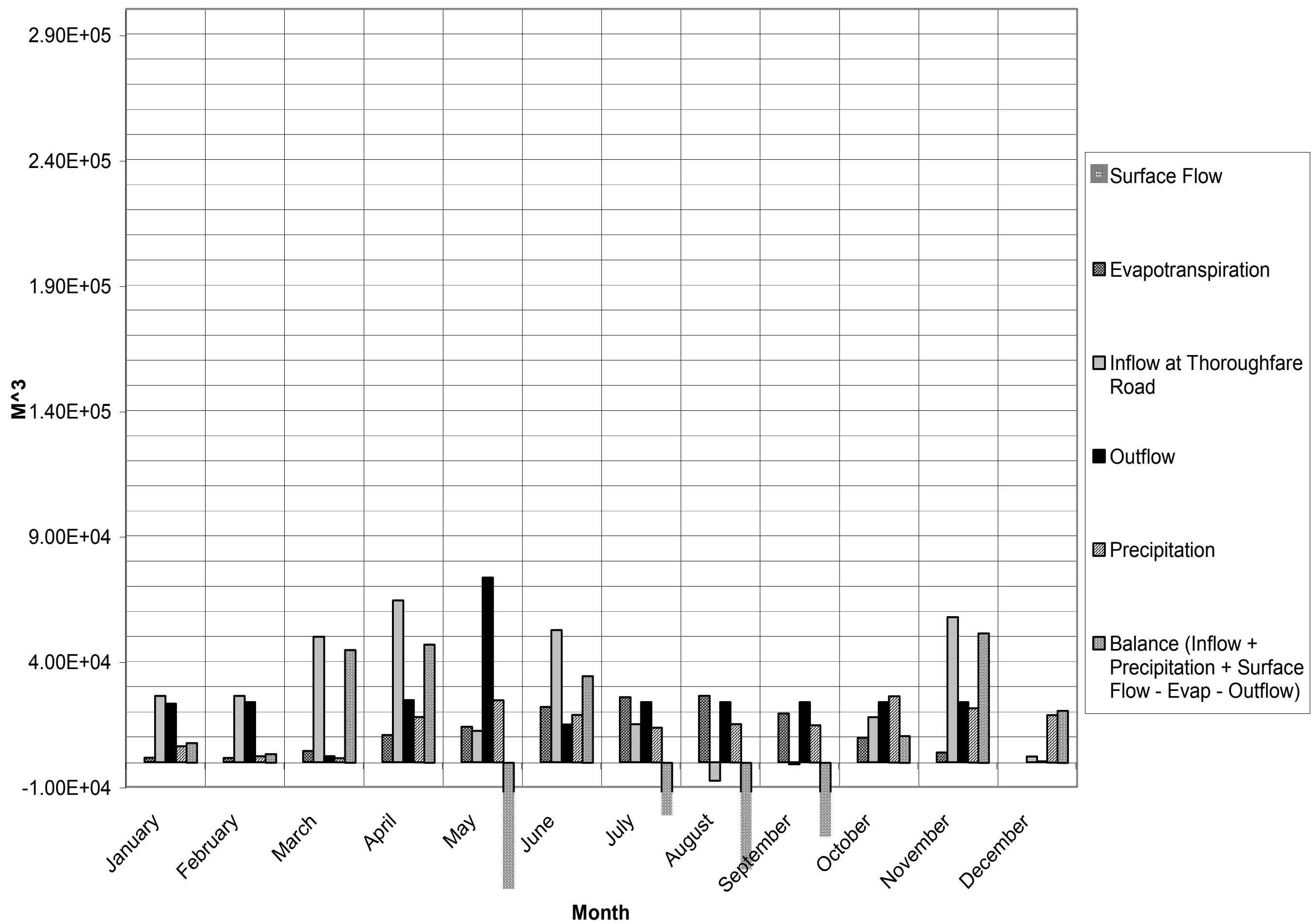

Figure 4: 2002 Water Budget for the Main Pod of the North Fork Wetlands Bank.

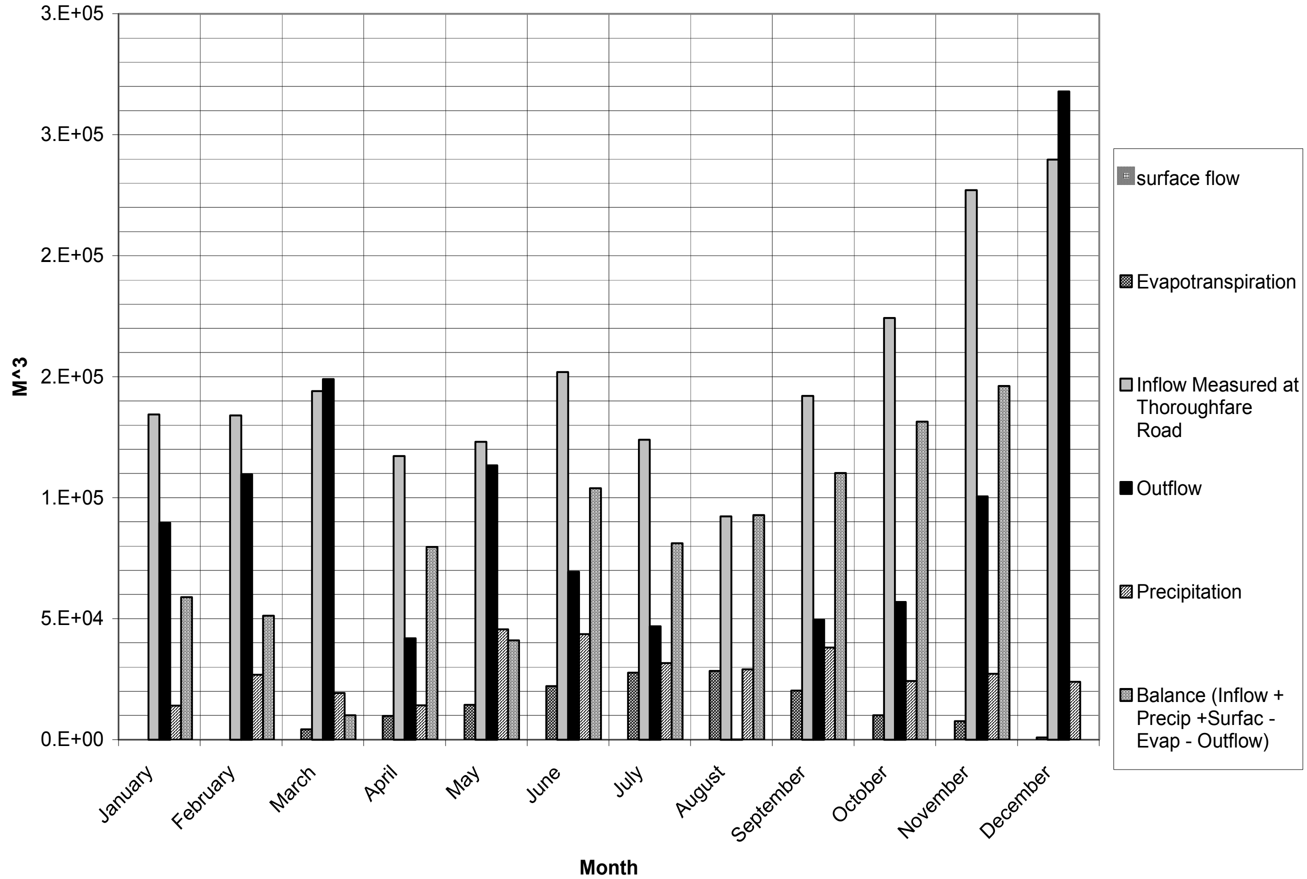

Figure 5: 2003 Water Budget for the Main Pod of the North Fork Wetlands Bank.

Table 1: 2002 Water Budget for the Main Pod of the North Fork Wetlands Bank

month	surface in m^3	ET m^3	inflow m^3	outflow m^3	precip m^3	in-out m^3
Jan	2.54E+01	1.73E+03	2.64E+04	2.33E+04	6.39E+03	7.80E+03
Feb	1.92E+01	1.58E+03	2.64E+04	2.40E+04	2.41E+03	3.35E+03
Mar	2.67E+01	4.37E+03	5.00E+04	2.34E+03	1.68E+03	4.49E+04
Apr	3.25E+01	1.07E+04	6.45E+04	2.48E+04	1.81E+04	4.71E+04
May	3.27E+01	1.40E+04	1.25E+04	7.35E+04	2.48E+04	-5.03E+04
June	2.31E+01	2.20E+04	5.27E+04	1.50E+04	1.89E+04	3.46E+04
July	2.07E+01	2.58E+04	1.52E+04	2.40E+04	1.38E+04	-2.07E+04
Aug	2.47E+01	2.65E+04	-7.40E+03	2.40E+04	1.52E+04	-4.26E+04
Sept	1.25E+01	1.93E+04	-8.63E+02	2.40E+04	1.49E+04	-2.93E+04
Oct	2.41E+01	9.81E+03	1.80E+04	2.40E+04	2.64E+04	1.06E+04
Nov	2.75E+01	3.86E+03	5.78E+04	2.40E+04	2.16E+04	5.16E+04
Dec	7.71E+00	5.52E+00	2.25E+03	3.70E+02	1.89E+04	2.08E+04
					2002 Total =	7.79E+04

2002 Water Budget for the Main Pod of the North Fork Wetlands Bank * Inflow values for January and February are missing and were substituted with averages of remaining ten (10) months = 26449.256 m^3. Outflow values for January, February, July, August, September, October and November are missing and were substituted with averages of remaining seven (7) months = 23950.955m^3.

Although precipitation data for 2003 is higher in value, the measured inflow at Thoroughfare Road in 2003 is between three to six times the inputs of precipitation. Strong inputs for 2003, particularly during the fall seasons can be attributed to a hurricane that affected the region, discharging large volumes of water within the watershed late in the year. The change in the water budget for year 2003 is approximately 9.02×10^5 m^3 (Table 2).

Table 2: 2003 Water Budget for the Main Pod of the North Fork Wetlands Bank

month	surface in m^3	ET m^3	inflow m^3	outflow m^3	Precip m^3	in-out
Jan	3.35E+01	0.00E+00	1.34E+05	8.97E+04	1.41E+04	5.89E+04
Feb	1.81E+01	0.00E+00	1.34E+05	1.10E+05	2.69E+04	5.13E+04
Mar	4.44E+01	4.29E+03	1.44E+05	1.49E+05	1.93E+04	1.02E+04
Apr	4.00E+01	9.87E+03	1.17E+05	4.19E+04	1.42E+04	7.97E+04
May	3.27E+01	1.44E+04	1.23E+05	1.13E+05	4.56E+04	4.10E+04
June	3.51E+01	2.22E+04	1.52E+05	6.94E+04	4.36E+04	1.04E+05
July	2.48E+01	2.77E+04	1.24E+05	4.69E+04	3.17E+04	8.12E+04
Aug	3.00E+01	2.85E+04	9.23E+04	1.23E+02	2.91E+04	9.28E+04
Sept	1.60E+01	2.03E+04	1.42E+05	4.96E+04	3.80E+04	1.10E+05
Oct	4.32E+01	1.01E+04	1.74E+05	5.70E+04	2.42E+04	1.31E+05
Nov	3.97E+01	7.66E+03	2.27E+05	1.01E+05	2.72E+04	1.46E+05
Dec	1.32E+01	8.51E+02	2.40E+05	2.68E+05	2.39E+04	-5.05E+03
					2003 Total =	9.02E+05

A surplus of water was discharged from the main pod during this wet year. Monthly differences between input and output sources collectively are depicted for 2002 and 2003 in Figures 6 and 7 respectively. In 2002 (Figure 6), a relationship between a positive spike in inflow is mimicked by a negative spike in outflow. The balance between the two values reflects the change in storage on a monthly basis. This graph also shows that when inputs and outputs are approximately equal, that there is no change in storage. During the summer months, as the input sources decline, the output catches up from previous storage values and a decline in storage is evident. Overall, the 2002 input and output values have a relatively tight amplitude that reflects a slight lag time between input and discharge with storage following expected trends. Noticeably for the first half of the year in 2003, as inflow spikes in a positive or negative direction the outflow also spikes in the same direction. Around June 2003 a decline in output continues when a consistent or increase in input occurs. This positive spike in the late summer and fall months for storage values while output values are considerably lower throughout summer may be a result from the lowering of the outfall weir level in anticipation of higher than normal climatic inputs.

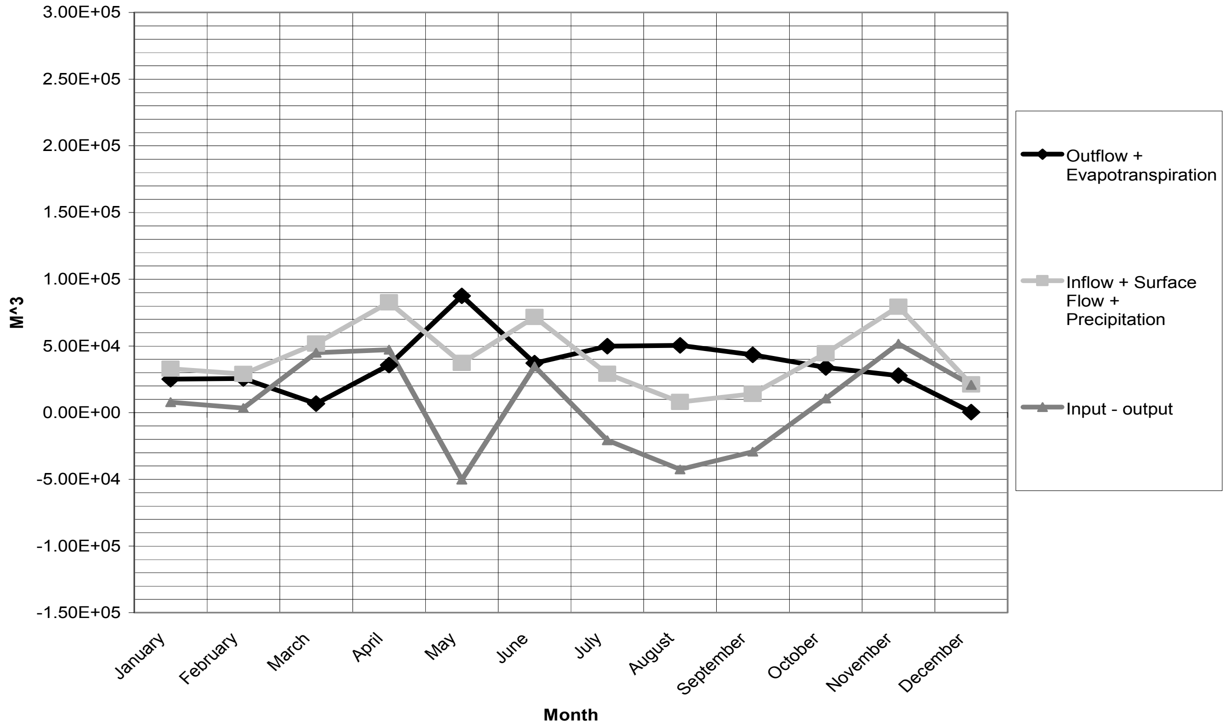

Figure 6: 2002 Comparison of Hydrologic Inputs and Outputs from the Main Pod of the North Fork Wetlands Bank.

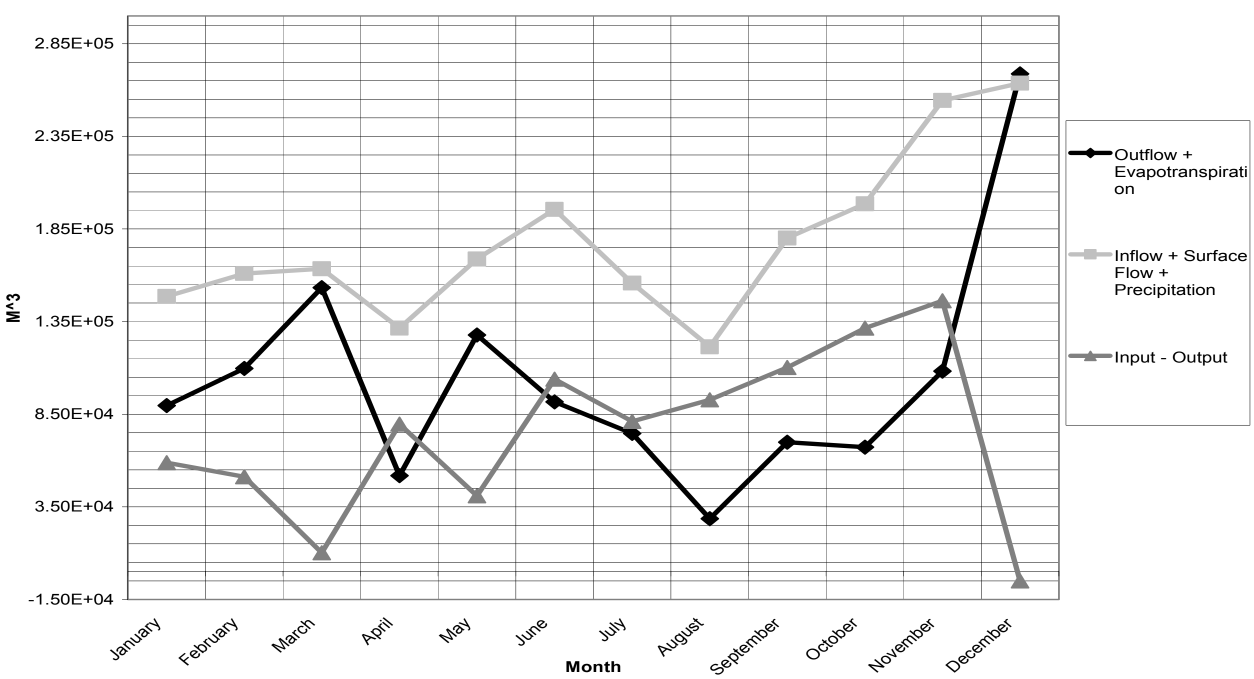

Figure 7: 2003 Comparison of Hydrologic Inputs and Outputs from the Main Pod of the North Fork Wetlands Bank.

The difference in water storage for the Main Pod of the North Fork Wetlands Bank is much larger in the 2003 year compared to the 2002 year (Figure 8a and 8b). Surface inputs and outputs are an order of magnitude larger in 2003 versus 2002 (Tables 3 and 4). This is expected as 2003 is the wettest year to date recorded at the weather station. The large value for the change in storage reflects a manipulation to an output, namely the volume of water passing through the adjustable weir. The change in storage should balance the inputs and outputs with each other, Output values recorded suggest that an overwhelming amount of water is retained within the wetland and not discharged.

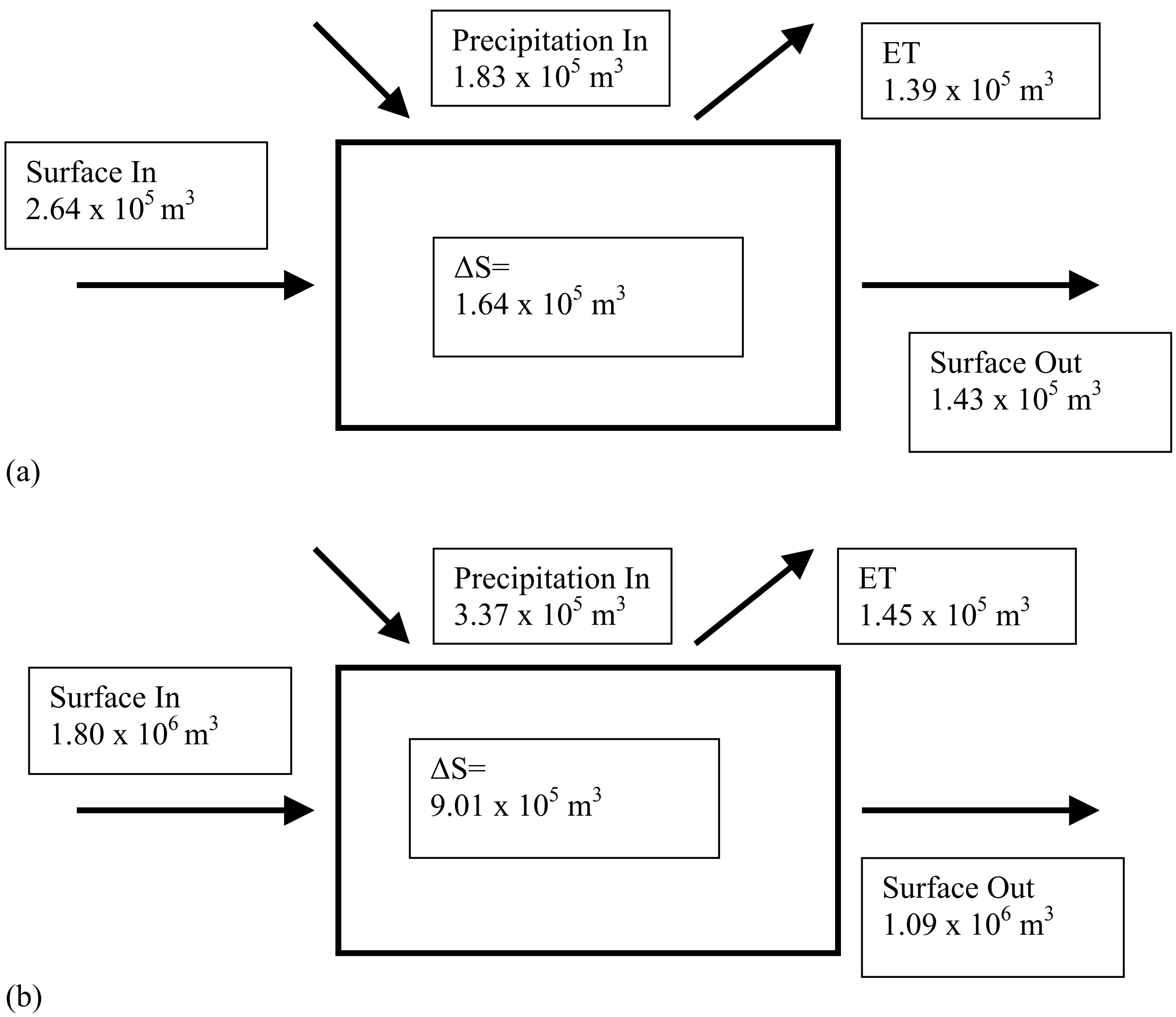

Figure 8: Water budget depicting hydrologic inputs and outputs for the Main Pod of the North Fork Wetlands Bank in 2002 (a) and 2003 (b).

Table 3: 2002 Comparison of Hydrologic Inputs and Outputs for the Main Pod of the North Fork Wetlands Bank

Month	Output (M^3)	Input (M^3)	Input - Output (M^3)
Jan	2.51E+04	3.29E+04	7.80E+03
Feb	2.55E+04	2.89E+04	3.35E+03
Mar	6.71E+03	5.17E+04	4.49E+04
Apr	3.55E+04	8.26E+04	4.71E+04
May	8.76E+04	3.73E+04	-5.03E+04
June	3.70E+04	7.16E+04	3.46E+04
July	4.98E+04	2.90E+04	-2.07E+04
Aug	5.04E+04	7.86E+03	-4.26E+04
Sept	4.33E+04	1.40E+04	-2.93E+04
Oct	3.38E+04	4.44E+04	1.06E+04
Nov	2.78E+04	7.94E+04	5.16E+04
Dec	3.76E+02	2.12E+04	2.08E+04
Total	4.23E+05	5.01E+05	7.79E+04

Table 4: 2003 Comparison of Hydrologic Inputs and Outputs for the Main Pod of the North Fork Wetlands Bank

Month	Output (M^3)	Input (M^3)	Input - Output
Jan	8.97E+04	1.49E+05	5.89E+04
Feb	1.10E+05	1.61E+05	5.13E+04
Mar	1.53E+05	1.63E+05	1.02E+04
Apr	5.18E+04	1.31E+05	7.97E+04
May	1.28E+05	1.69E+05	4.10E+04
June	9.17E+04	1.96E+05	1.04E+05
July	2.86E+04	1.21E+05	9.28E+04
Sept	6.99E+04	1.80E+05	1.10E+05
Oct	6.71E+04	1.99E+05	1.31E+05
Nov	1.08E+05	2.54E+05	1.46E+05
Dec	2.69E+05	2.64E+05	-5.05E+03
Total	1.24E+06	2.14E+06	9.02E+05

Conclusion

This paper created a water budget for the 2002 and 2003 years at the North Fork Wetlands Bank. Insufficient data sets restrict the accuracy of the monitoring to date and do not provide an accurate account of the hydrologic inputs and outputs that influence this created wetland system. Further investigations are needed to accurately depict long term performance of the wetland. As the watershed develops and climatic influences change creating a multi-year baseline of data will help to interpret future anomalies.

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WATER QUALITY MONITORING OF THE NORTH FORK MITIGATION WETLAND AUGUST TO NOVEMBER 2005:

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Abstract
Created wetlands serve to replace the functions of natural, impacted wetlands. Functions such as nutrient retention and water quality improvements have been studied intensively in recent years. In order to explore nutrient dynamics in a created wetland, water samples from five sites at the North Fork mitigation bank, Haymarket Va, were collected and analyzed from August to November 2005. Net reductions in nitrate-nitrogen (NO_3-N) and soluble reactive phosphorous (SRP) were observed from several sampling sites within the wetland with reductions of 15.6% NO_3-N and 59.4% SRP. An increase of more than 600% in ammonium-nitrogen (NH_4-N) occurred from sampling sites throughout the period. These results were attributed to the seasonal transition from growing to non-growing seasons which was documented by decreases in temperatures, dissolved oxygen (DO) and pH. Biological and physical differences between sites also contributed to observed variations in chemical and nutrient parameters measured. High surface inflow resulting from a storm event produced the highest levels of nutrient loadings at the inflow site and the highest reduction in SRP (82.8%) and NO_3-N (~100%) and significant exports of NH_4-N when compared to the other sampling dates. Physicochemical factors are useful indicators of wetland function and nutrient dynamics, but further study on vegetation, soil and hydrology need also to be considered.

Keywords: Nitrate-nitrogen, soluble reactive phosphorus, storm event, mitigation

Introduction
Water quality improvement is one of the most important functions of wetlands (Whigham, 1999). Wetlands are now currently being used to reduce concentration of nutrients in through-flowing water (Verhoeven et al., 2006). The process involves the removal of nutrients, such as nitrogen and phosphorous, that may be present in surface waters. Wetland mitigation, which is the replacement of wetland functions through the creation or restoration of wetlands, is one way in which water quality can be enhanced within watersheds (Nairn and Mitsch, 2000), (Bruland et al., 2003). However the efficiency of wetlands to improve water quality depends on several factors among which include the hydrology of the basin, macrophyte cover and wetland substrate (Bruland et al., 2003). Removal of nutrients from surface flow means that the wetland has the ability to retain or transform these nutrients so as to render the water exiting the system at a higher quality. Bruland et al. (2001) has reported 30%, 97% and 19% reductions of soluble reactive phosphorous (SRP), nitrate-nitrogen (NO_3-N) and total nitrogen (TN) in created wetland systems. The percentage of nutrient retention can be used to indicate the efficiency of the wetland. By analyzing the quality of water moving through the wetland, one can monitor and document the progress of water quality improvements by a wetland system. The goal of this

study is to measure the amount nutrients: nitrogen and phosphorus interacting with the created wetland and determine the efficiency of water quality improvements by the wetland.

Study Site

The North Fork mitigation site, located in Haymarket, Virginia is a mitigation bank created in 1999 by Wetland Studies and Solutions Inc. (WSSI) to provide mitigation for several projects. The North Fork wetlands bank features a diverse mixture of forested, shrub-scrub and emergent vegetation with a source of hydrology, and diverse species composition. Upland buffers, submerged and floating aquatic vegetation and the open water of the ponds complement these wetlands, creating a heterogeneous complex of habitats that support numerous wetland-dependent plant and animal species. There were five sampling sites at this wetland (Fig 1). Site 1 represents in inflow site of channelized flow into the wetland. Site 2 was a location further downstream from site 1 that leads to a created pond (site 3). Site 4 was taken to be the entrance to the main pond created by the dam and site 5 represents samples collected at the dam. Sites 1-5 were used to represent the general flow of surface water through the wetland so as to model water quality treatment processes. The description of each site is given in Table 1 and Figure 1.

Table 1. Brief sampling site descriptions

Location	Description
Site 1	Narrow channelized intermittent stream, lined with rocks and vegetation that accounts for a source of surface inflow for the wetland system. The stream feeds the main pond.
Site 2	Located further downstream from site 1 and is accessed via a constructed boardwalk. Channel is wider than site 1 with dense vegetation cover along the bank at this point.
Site 3	Location formerly a cattle farm pond and has a somewhat rectangular shape with standing water for the majority of the sampling period. Large and thriving community of submerged and floating aquatics. Floating vegetation coverage consists mainly of water lilies (Nymphaea odorata), (H Aiton) and varies from sparse to dense cover.
Site 4	Location where stream converges with the large holding area of the dam. Deep standing water levels with higher water velocities then site 3. Thriving community of submerged and floating aquatics. Back flow from the dam area occurs often at this location
Site 5	Dam. Large open water with moderate coverage by floating aquatics. Greatest depth of approximately of approximately 9ft. Odor of H_2S most prevalent here. Modest to rapid flow through dam weir.

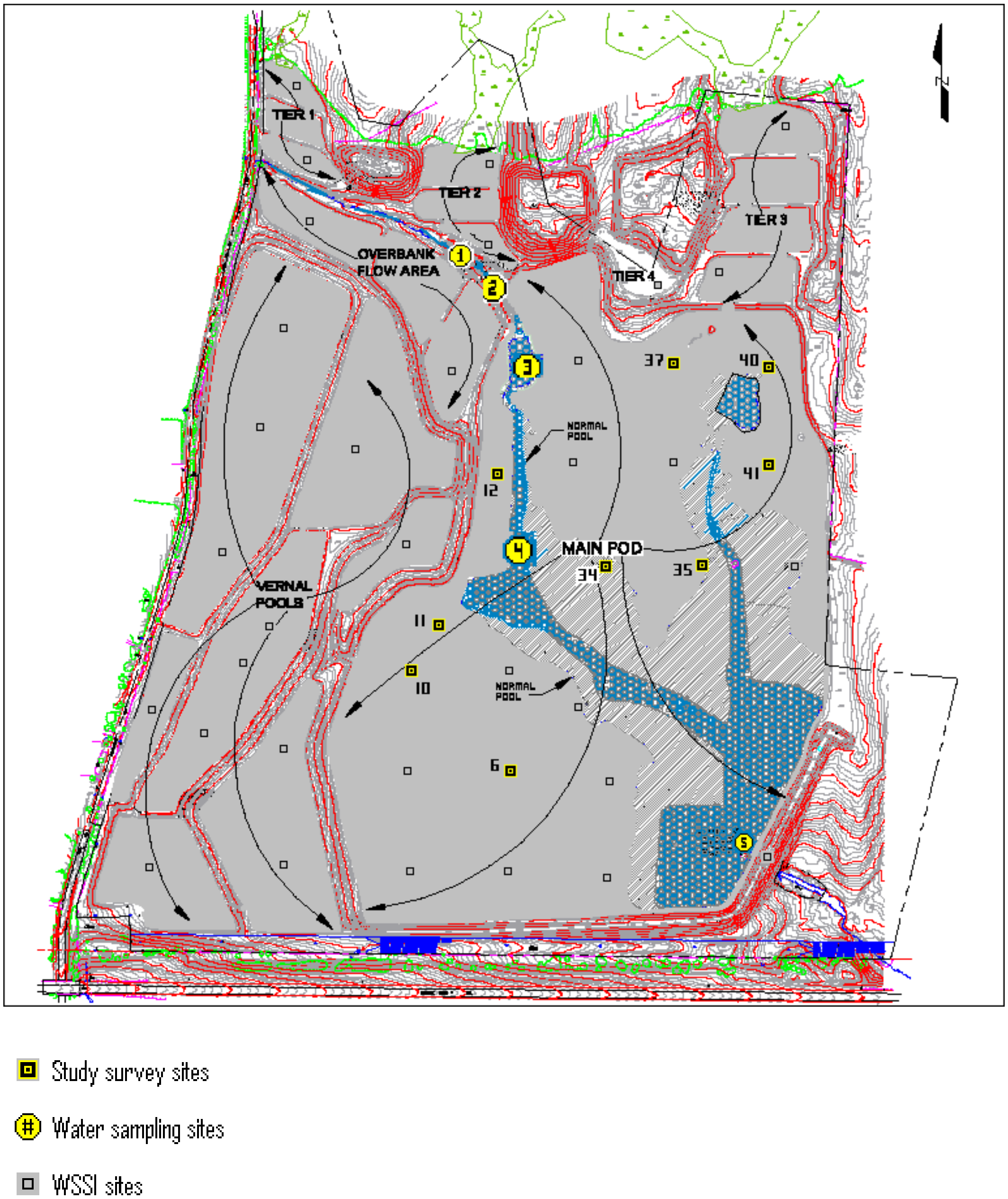

Figure 1. Map of North Fork Mitigation Bank, Haymarket, Virginia.

Hydrology

Hydrology is one of the essential components of wetland function (Zedler, 2000). Hydrological inputs of the North Fork wetland are primarily provided by direct precipitation and surface runoff from the nearby Broad Run stream and overland flow. Surface flow occurs mainly in channelized streams on the site which feed into several ponds that are connected to a large dam impoundment (Fig 1). Constructed on-site weirs monitor and control the flow of surface water and several shallow wells monitor water volumes. The large dam also controls and monitors outflow from the site.

Hydrologic factors are important in the ability of created and natural wetlands to improve water quality, even though studies have disregarded hydrologic data when assessing water quality improvements according to Nairn and Mitsch (2000).

Water Chemistry

Specific parameters were used to analyze water quality. These include pH, turbidity, redox potential, soluble reactive phosphorous (SRP), nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) concentrations. These parameters provide useful information about nutrient dynamics in wetlands.

Nutrients

Phosphorous

Phosphorus (P) enters wetlands either as particulate phosphorus or dissolved phosphorus. Both forms of phosphorus are interchangeable, from particulate phosphorus to dissolved phosphorus, or dissolved phosphorus to particulate phosphorus in the wetland water column and sediments (Wang and Mitsch, 1999). Biological activity, especially in the water column, has been shown to influence phosphorous retention in wetlands through biological uptakes by algae. This is responsible for changes in concentration of soluble reactive phosphorous (SRP). Wu and Mitsch (1998) have documented that algal uptakes of SRP may account for 66% of SRP removed from the water column. Bruland et al. (2002) have found that 60% of total phosphorous consists of SRP. The decomposition of organic matter also contributes to the P concentrations in the water column since phosphorous is release by the detritus. 50-54% of phosphorous release by detritus has been documented by Wang and Mitsch (1999).

Phosphorous may also co-precipitate with $CaCO_3$ and be removed from the water column by this pathway (Nairn and Mitch, 2000). P solubility is regulated by the solid phases of Ca-P compounds (Ann et al., 1998). That is, P concentrations in the water column are affected by the rates of Ca-P binding in the soil. Up to 30-44% of SRP concentration decreased when Ca compounds such as $CaCO_3$ and $Ca(OH)_2$ were present in wetland soil (Ann et al., 1998). Ann et al. (1998) also found that the SRP concentration increased due to the release of P from reducible Fe compounds. Conversely, SRP and dissolved Fe concentrations decreased at about 200 mV. This indicated that P concentrations increase under reduced conditions and that Fe is also an important factor in P solubility.

In some studies, it has been shown that phosphorus retention increases in wetland systems as phosphorous loading increases (Wang and Mitsch, 1999) (Nairn and Mitsch, 2000). Phosphorous loading may be attributed to increased P concentration inflow via high precipitation and surface runoff. Large flooding events have also seen peaked concentrations P. P reductions of 54%-70% have been recorded for storm event periods (Kohler et al., 2004). Overall, wetlands have become widely known to effectively reduce P concentrations in surface flow waters. For example, Norwegian authorities encourage farmers to build such wetlands by covering 70% of the construction costs in order to maximize P retention (Braskerud, 2002).

Nitrogen

Nitrogen cycling in wetlands is complex, involving conversions between different N species and transfers between different storage mechanisms (Kadlec et al., 2005). Spieles and Mitsch (2000) have noted that there are several major pathways from which nitrogen (N) can be retained in wetlands. These include denitrification, adsorption of ammonium onto soil matter, uptake by biomass and mineralization of organic nitrogen (Spieles and Mitsch, 2000) (Hefting et al., 2005). Of these, denitrification is believed to be the primary pathway for nitrogen removal (60-95%). Denitirfication rates ranged from 0 and 3.46 mg N m^{-2} d^{-1} which represented between 0 and 12% of inflow N (Comin et al., 1998). Denitrification involves the transformation of nitrate into nitrogen gas by microorganisms under anaerobic conditions (Mitsch and Gosselink, 2000). However, denitrification is apparently limited by the C:N ratio, with ratios >5:1 resulting in >90% nitrate removal efficiencies (Baker, 1998). Similarly, Mitsch (2005) have suggested that organic carbon availability influences bacterial denitrification rates. That is, systems with high carbon contents can support larger communities of bacteria that enhance denitrification. A point interesting to note is that it has also been observed that more denitrification occurs in unplanted wetlands (Kadlec et al, 2005).

Previous studies of created wetlands have shown evidence of low N retention in wetlands. These results have been attributed to the young age of these sites (Spieles and Mitsch, 2000), where young wetlands are not able to retain as much N as their older counterparts. Braskerud (2002) however found contradicting results in his study where N retention decreased with age. Accumulation of organic material in mitigated wetlands to facilitate nitrogen removal agents require significant time to occur. N uptake by vegetation accounts for only 1–21 % of the annual nitrogen retention, and the effect of microorganisms on N-retention is regarded as being more important than vegetation assimilation of N (Braskerud, 2002)(Kadlec et al., 2005). The nitrogen retention efficiency of such organisms was close to 100% of input according to Comin et al. (1998).

Retention time can also influence the retention of nitrogen in the wetland system. Slow times increase the removal of nitrogen from the water column, while faster times will conversely decrease the amount nitrogen that can be removed (Spieles and Mitsch, 2000). This is especially true for nitrate-nitrogen where reduction occurs at slower flows through wetlands (Wang and Mitsch, 1999). It is interesting to note that Kadlec et al. (2005) have reported that nitrogen detention time (time spent stored in vegetation etc) is far greater than water retention time. Similarly, high inflow may also influence the amount of nitrogen that can effectively be removed. Braskerud (2002) has shown that N retention decreased with increased hydraulic load (3-15% retention). In a study investigating the spiraling time of N in wetlands, N processing in wetlands involves interaction between water, sediment, biofilm solids and vegetation storage (Kadlec et al., 2005). Changes in the nitrate content of inflows are also important for wetland N content and removal, because nitrate is the dominant N-species (Braskerud, 2002) (Lane et al., 2003)

Turbidity

Turbidity reflects the amount of solid particles that are suspended in the water column and low turbidity readings have been found to correlate to small amounts of suspended matter. Inflow generally has higher turbidity readings that outflow (Nairn and Mitsch, 2000).

pH and Dissolved Oxygen

Mitsch and Wang (1999) in their study of the Olentangy river wetland reported that high pH levels meant that their was high macrophyte productivity in the wetland which in turn leads to increased dissolved oxygen (DO) concentrations (Nairn and Mitsch, 2000). Nairn and Mitsch (2000) also obtained average wetland pH values of 7.5 which supported their findings. High biological activities, as indicated with high DO and pH readings can also influence phosphorus and nitrogen retention in wetlands. This is because biological activity is the major pathways for N and P cycling.

Conductivity and Redox Potential

Dissolved ion concentrations in the water column are greater in inflow than outflow. This is due to precipitation with other minerals, which removes the ions from the water column (Nairn and Mitsch, 2000). However, ion concentration is significantly influenced by dilution that may be caused by precipitation (Mitsch and Gosselink, 2000). The presence of dissolved oxygen in the water column influences the redox potential. Low redox (± 100mV) indicates the removal of oxygen and the occurrence of reduction reactions within the water column (Mitsch and Gosselink, 2000).

Temperature

Microbial activity and redox reactions are all influenced by changes in temperature with cooler temperatures resulting in reduced activity. Thus, nitrogen and phosphorous removal from the water column fluctuate with fluctuating temperatures (Wang and Mitsch, 1999)

Methods

Sampling

Grab sampling was conducted once a month for the period August through November 2005. 1000 ml samples were taken at each of the five sites located in Fig. 1 and collected in pre-washed 1000 ml nalgene bottles. On site reading of pH, dissolved oxygen, conductivity, redox potential and temperature were taken with the YSI probe. The samples were transported under ice to the wetland ecology and management laboratory in David King Hall for further analysis. 125 ml nalgene bottles were used to take samples for turbidity analysis.

Sample Preparation

Sub samples were filtered with pre-moistened filter paper (0.45 microns) and frozen for analysis of SRP, NH_4^+-N and NO_3-N. Any unused water samples were kept frozen until further analysis.

Sample analysis

On site readings were taken with the YSI probe (model 600XL-S-5). Water samples measured for turbidity were analyzed using the turbidimeter 2100N. Concentrations of N and P were determined using calibration curves (R^2= 0.995-0.999) from prepared standards using the UV-Vis spectrophotometer-Perking Elmer Lambda 35. Averages were taken of multiple runs and simple statistical tests were performed. Both TP and SRP methods were carried out according to the ascorbic acid and molybdate color reagent method (US EPA Method #365.3, 1979). NH_4^+-N was measured using the phenate method (APHA, 1999, 4500-NH_3 F). NO_3^--N was determined using the cadmium reduction method (Hach Method 8192, Hach DR 2000).

Results

Physicochemistry

Dissolved oxygen (DO) concentrations generally decreased from site 1 through to site 5 with a slight increase in overall concentrations from August 2nd to October 26th. Sites 1 and 2 usually held the highest DO concentrations with sites 4 and 5 recording the lowest. August 2nd readings had the most variance with a range of values between 8.22 mg/L and 1.15 mg/L. This may have been due to YSI probe membrane malfunction. Average DO concentrations show that September 2nd had the lowest concentrations (0.78 ± 0.32 mg/L) while October 26th sampling at the highest (7.31 ± 0.31 mg/L). Mean site 1 inflow concentration for the sample period was 5.54 ± 1.26 mg/L, while mean site 5 outflow was 3.60 ± 1.0 mg/L. The large storm events (Oct 8th and Oct 26th) recorded the high concentrations of DO from sites 1 through 5.

The average pH values show that August 2nd and September 2nd recorded the highest values while the storm events recorded the lowest. However these values were only slightly higher as pH had little fluctuations throughout the sampling period and between sites. There was an average decrease in pH between site 1 and site 5: 7.19 ± 0.24 and 6.97± 0.13 respectively. However, this decrease was also minimal. The temperature of the wetland exhibited seasonal patterns with colder temperatures collected in November (10.4 ± 0.36 ^{o}C) than in August (24.5 ± 0.49 ^{o}C). Temperature readings collected were all from open water locations and did not experience the shading effect of temperatures under water lilies or other aquatic vegetation cover. Conductivities for the sampling period exhibited no significant fluctuations between sites. The storm events recorded the lowest conductivities and September 2nd sampling the highest. There was no significant difference between mean site 1 inflow and site 5 outflow conductivities.

There was a general decrease in turbidity from site 1 to site 5. Site 1 inflow turbidity averaged 16.16 ± 6.07 NTU while site 5 outflow averaged 8.42 ± 1.66 NTU corresponding to a 47.9% decrease. The October 8th storm event recorded the highest turbidity readings with site 1 being most turbid. November 12th sampling however had the highest turbidity readings at site 5 and the lowest at site 1, but this month had the overall lowest recordings for the sampling period. Site 5 generally had the lowest reading of turbidity.

Redox potentials between site 1 inflow (178.71 ± 28.0 mV) and site 5 outflow (136.7 ± 13.4 mV) decreased on average by 23.5% for the sampling period. Site 4 generally had the lowest redox potential reading, with the lowest recorded being -21.9 mV at site 4 on September 2nd. The October 8th storm event had on average the greatest redox potential recorded. However, excluding that storm event, the lowest recorded mean conductivity was recorded for August 2nd. Also, October 26th and November 12th had the greatest redox potentials at site 5 while August and September 2nd recorded the highest redox potentials at sites 1 and 2.

Table 2.
Water quality parameters collected over sampling period including mean ± std. error (n)

Site	1	2	3	4	5	
2-Aug						Mean
Temperature, ^{o}C	23.51	24.01	23.88	24.94	27.04	24.7 ± 0.57 (5)
pH	7.71	7.74	6.93	6.93	7.14	7.29 ± 0.16 (5)
Conductivit,y µS/cm	136	137	149	155	100	135 ± 8.53 (5)
Redox potential, mV	165	180.6	37.1	6.1	112.8	100 ± 30.7 (5)
Dissolved oxygen, mg/L	8.16	8.22	1.87	1.29	2.18	4.34 ± 1.41(5)
Turbidity, NTU	NA	NA	NA	NA	NA	
2-Sep						
Temperature, ^{o}C	24.97	23.84	24.44	23.2	25.61	24.4 ± 0.38(5)
pH	7.82	8.2	7.81	6.85	7.27	7.59 ± 0.21(5)
Conductivity, µS/cm	171	162	177	186	112	162 ± 11.6(5)
Redox potential, mV	263.7	165.1	56.5	-21.9	107.8	114 ± 43.2(5)
Dissolved oxygen, mg/L	1.5	1.4	0.2	0.1	0.7	0.78 ± 0.26(5)
Turbidity, NTU	12.5	15.7	49.6	15.1	3.5	19.3 ± 7.04(5)
SRP, µg P/L	>12000	>1200	164.3	37.9	42.8	81.7 ± 26.1(3)
NH_4-N, µg N/L	52.8	6.6	0	0.46	21.2	16.2 ± 8.85(5)
NO_3-N, µg N/L	178.7	0	0	0	49.8	45.7 ± 30.9(5)
[a] 8-Oct						
Temperature, ^{o}C	20.62	20.64	20.72	20.8	20.9	20.7 ± 0.05(5)
pH	6.6	6.8	6.8	6.7	6.7	6.72 ± 0.03(5)
Conductivity, µS/cm	88	90	93	96	116	96.6 ± 4.50(5)
Redox potential, mV	220.8	200.5	207.2	201.6	181.1	202 ± 5.72(5)
Dissolved oxygen, mg/L	6.63	6.2	5.36	5.67	4.49	5.67 ± 0.33(5)
Turbidity, NTU	35.5	25.3	34.3	16.5	12.6	24.8 ± 4.10(5)
SRP, µg P/L	199.8	70.3	143.4	71.8	34.3	104 ± 26.6(5)
NH_4-N, µg N/L	5.1	4.3	3.5	2.8	433.5	89.8 ± 76.7(5)
NO_3-N, µg N/L	208.2	211.7	0	112.8	0	107 ± 41.9(5)
[b]26-Oct						
Temperature, ^{o}C	10.26	10.17	10.42	10.69	9.53	10.2 ± 0.17(5)
pH	6.99	6.87	6.79	6.72	6.7	6.81 ± 0.05(5)
Conductivity, µS/cm	91	86	92	102	130	100 ± 7.04(5)
Redox potential, mV	115.8	119.5	121.7	114.1	132.1	121 ± 2.82(5)
Dissolved oxygen, mg/L	7.56	8.03	7.48	7.06	6.41	7.31 ± 0.24(5)
Turbidity, NTU	14.6	14.8	12.5	20.4	9.82	14.4 ± 1.56(5)
SRP, µg P/L	61.5	44.3	45.6	44.8	43	47.8 ± 3.07(5)
NH_4-N, µg N/L	0	0	0	0	44.3	8.86 ± 7.91(5)
NO_3-N, µg N/L	99.5	88.6	57.4	144.8	103.9	98.8 ± 12.6(5)

12-Nov						
Temperature, °C	10.23	10.42	8.98	11.38	10.95	10.4 ± 0.36(5)
pH	6.8	6.64	6.98	7.08	7.11	6.92 ± 0.08(5)
Conductivity, μS/cm	137	138	137	136	119	133 ± 3.23(5)
Redox potential, mV	128.2	148.2	132	75.2	149.8	127 ± 12.1(5)
Dissolved oxygen, mg/L	3.88	4.23	3.93	3.8	4.25	4.02 ± 0.08(5)
Turbidity, NTU	2.04	2.22	3.78	4.98	7.75	4.15 ± 0.94(5)
SRP, μg P/L	35.1	36.4	35.8	38.5	42.9	37.7 ± 1.26(5)
NH_4-N, μg N/L	0	0	0	0	66.6	13.3 ± 11.9(5)
NO_3-N, μg N/L	105.3	135	191.6	178.7	345.3	191 ± 37.1(5)

[a] Storm event ~6.29" precipitation October 7th-8th (National Weather Forecast Office)
[b] Storm event <1.5" precipitation October 24th -26th (National Weather Forecast Office)

Nutrient Analysis

Nitrogen

September recorded the highest concentration of NH_4-N and NO_3-N at sites 1. Sites 2, 3 and 4 had the lowest recorded concentration of both forms of nitrogen with zero amounts recorded at site 3 for NH_4-N and at sites 2, 3 and 4 for NO_3-N. Site 5 recorded somewhat considerable amounts of both forms of nitrogen with a 59.8% decrease in NH_4-N and a 72.1% decrease in NO_3-N between site 1 and 5. The October 8th storm event had highest average concentration of NH_4-N recorded with site 5 having the highest. October 26th and November 12th dates both at the lowest concentration of NH_4-N with no detectable concentration at all but site 5.

Once again, the October 8th storm event had high concentrations of NO_3-N with site 1 recording the highest concentrations. Site 3 and 5 on this date had no detectable amounts of nitrogen. The lowest observed mean concentration of NO_3-N were obtained on September 2nd, (43.7 ± 34.6 μg N/L) with no detectable amounts of nitrogen found at sites 2- 4. November 12th produced the highest concentration of NO_3-N (191.2 ± 41.5 μg N/L) with site 5 recording the highest concentrations and site 1 the lowest.

For the sampling period, there was a general increase in NH_4-N at site 5 with a peak in concentration during the storm event. There was also a general decrease in NH_4-N amounts found at site 1-4. Conversely, there was an increase in NO_3-N concentrations at site 5 and a decrease in concentration at site 1. During the storm event however, NO_3-N at site 1 peaked while at site 5 there was no detectable nitrogen concentrations.

Phosphorus

Soluble reactive phosphorus measured for September 2nd at sites 1 and 2 had concentrations of P so high that the samples could not be quantified by the method used, since the sample concentration exceeded the 1200 μg P/L limit of the method. As a result, SRP data for these sites are recorded as exceeding 1200 μg P/L. Site 4 on this sampling date had the lowest SRP concentration, with a small increase at site 5. Site 3 had considerable amounts of SRP with more than a 250% difference between sites 4 and 5.

For the storm events October 8th and 26th, there were both high concentrations of SRP at site 1 and the lowest concentrations at site 5. Site 3 on these days also had higher concentrations of SRP compared to sites 2 and 4. There was no considerable difference in the SRP concentrations from site 1-5 on November 12^{th}.

Discussion

Physicochemistry

The period of sampling for this study (August – November 2005) started during the peak of the growing season and ended during the non-growing season. D.O. concentrations measured at sites 1 and 2 were the highest among the sites measured for the sampling period, with the highest recorded on August 2^{nd}. High D.O. concentrations are indicative of high biological activity as rates of photosynthesis by aquatic plants increase in the growing season (Wang and Mitsch, 1999) (Nairn and Mitsch, 2000). Sites 1 and 2 were free of vegetation cover which allowed direct sunlight to penetrate the water column, increasing the rates of photosynthesis by the aquatic vegetation. According to Nairn and Mitsch (2000) sites dominated by vegetation on the surface of the water, such as algal mats, have supersaturated DO concentration as a result of the high rates of photosynthesis. However sites, 3 and 4 which had thick water lily coverage for August 2nd and moderate coverage for September 2nd, did not have the highest DO concentration as predicted by literature. This may be attributed to the fact that water lily cover prevented sunlight needed for photosynthesis from reaching the lower levels of the water column, thereby slightly reducing photosynthesis rates of submerged aquatic plants. This lack of sunlight at the lower strata of the water column is also evidenced by the lower temperature recorded at these sites (3 & 4) when compared to the other sites. Sites 5 generally had the lowest DO concentration since this area was deep, open water where fewer vegetative activity occurred compared to the other sites.

DO concentration recorded in November, which corresponded to non-growing season generally recorded lower temperatures at all sites when compared to those taken in August. The storm events recorded considerable concentrations of DO. These concentrations varied little from site to site, which can be expected as high intensity rainfall resulted in a mixing and transfer of DO amounts from site to site. However, sites 1 and 2 followed the trend of having the highest DO concentration. September 2^{nd} results deviated greatly from literature results for DO for the growing season. This can possibly be attributed to the sensitive DO membrane of the YSI probe which malfunctioned during this sample date. The membrane was subsequently replaced.

pH, which is also an indicator for biological activity, where high pHs are as a result of large amounts of dissolved CO_2 (carbonate) being consumed aquatic vegetation in the water column (Nairn and Mitsch, 2000). The highest pHs were recorded in the months August and September, which corresponds to the high productivity levels at the peak of the growing during the summer months. pH values of 7.82 and 8.20 are within the range as those found in similar studies which reported pH as high as 8.18 and 9.8-10 for created wetlands (Nairn and Mitsch, 2000)(Wang and Mitsch,1999). There was also little fluctuation in pH values throughout the sampling period with values remaining in the 6.6-7.8 range for the study period, but a general decrease was evident towards November. This slight change in pH occurs simultaneously with the decrease in biological activity towards the end of the growing season.

The low redox readings for August and September, and even November, are indicators of reduced conditions in the wetland. Sites 4 generally had the lowest recorded redox potentials. With the exception of site 5, site 4 had the deepest standing water levels of the sampled sites. This perpetuated flooding condition resulted in low redox potentials. Conversely, sites 1 and 2 which experienced extreme dry drawdown conditions in August and September had the highest redox potentials. Redox potential increases as oxidizing conditions develop, such as exposure of mud flats to the atmosphere (Mitsch and Gosselink, 2000) increase. The redox potentials during the storm events were relatively high with little fluctuations between sites. This may be attributed to the effect of high rainfall volumes.

The low conductivity values obtained during the storm events can be attributed to dilution effects from the rainwater (Wang and Mitsch, 1999). Excluding the storm events, there was a general decrease in conductivities from site 1 to site 5, with the highest decrease occurring in September with 34.5%. According to Olentangy wetland studies, decreases in conductivities from the inflow can be due to precipitation of $CaCO_3$ and other minerals caused by high pH as a result of high water column activity (Wang and Mitsch, 1999). This study found evidence for such when pH and conductivity values were compared for August and September. Higher pH and conductivity values were recorded at site 1 compared with those at site 5.

Turbidity for the October storm event was highest for the sampling period which was attributed to the high water turbulence that induced re-suspension of sediment particles within the water column. Excluding this event, there was a decrease in mean turbidity of wetland waters from September to November. The decrease in turbidity was comparable to those found by Wang and Mitsch, (1999), and Nairn and Mitsch, (2000).

Nutrient Analysis

P dynamics

During September, site 1 contained more than 1200 μg P/L SRP. Because the system was undergoing a significant drawdown during this period, the primary source of inflow may have occurred from the upstream cattle farm whose runoff may have been contaminated with considerable amounts of nutrients. The low water levels would have resulted in a very concentrated P containing water samples. At site 4 and 5, the SRP concentration had reduced considerably. The decreases in SRP concentrations from Site 1 to 5 are probably as a result of heightened biological activity, where P is assimilated by the biota and removed from the water column (Nairn and Mitsch, 2000). Wu and Mitsch (1998) have documented that algal uptakes of SRP may account for 66% of SRP removed from the water column. November concentrations of SRP portrayed the opposite trend where SRP concentration generally increased from site 1 to site 5 (Table 2). This may be attributed to decreased rates of P assimilation as the growing season came to an end.

During the storm event at site 1 there was a high P load measured. However, SRP reduction was the highest on this sampling day with an 82.8% decrease at site 5 (Table 3). P reductions of 54%-70% have been recorded for storm event periods (Kohler et al., 2004). However, this high reduction in P concentration may also be due to dilution effects by high channel volumes. Ann et al., (1998) have found that SRP concentration increased due to the release of P from reducible Fe compounds, which is indicated by low redox potentials. Interestingly in this study, the highest P concentrations measured over the course of the study, with the exception of the high loading of P during the storm event, were observed when redox potentials were also low. It would be of interest to analyze the concentrations of Fe in the soils at these sample sites for further investigation.

Table 3.
Percent water chemistry changes from Site 1 to Site 5 from August to November 2005 with mean ± std. err (n)

	% Change from Site 1 to Site 5					
	Aug 2	Sept 2	Oct 8	Oct 26	Nov 12	Mean
Temperature. ^{o}C	+15.0	+2.56	+1.36	-7.12	+7.04	3.77 ± 3.62 (5)
pH	-7.39	-7.03	+1.52	-4.15	+4.56	-2.50 ±2.37 (5)
Conductivity, µS/cm	-26.5	-34.5	+31.8	+42.9	-13.0	0.11 ± 15.6 (5)
Redox potential, mV	-31.6	-59.1	-18.0	+14.1	+16.8	-15.6 ± 14.3 (5)
Dissolved oxygen, mg/L	-73.3	-53.3	-32.3	-15.2	+9.54	-32.9 ± 14.4 (5)
Turbidity, NTU		-72.0	-64.5	-32.7	+280	27.7 ± 84.5 (4)
SRP, µg P/L		NA	-82.8	-30.1	+22.2	-30.2 ± 30.4 (3)
NH_4-N, µg N/L		-59.8	+8400	NA	NA	~
NO_3-N, µg N/L		-72.1	-100	+4.42	+228	15.1 ± 74.3 (4)

N dynamics

From September to November the mean concentration of nitrate-nitrogen increased in the wetland system. In September, there was a 72% reduction in NO_3-N from site 1 to site 5, with no detectable amounts found at sites 2-4 (Table 3). The high removal of nitrogen on this sampling date corresponded to the high biological activity as indicated by high pH and DO, as N is either assimilated by the biota and/ or high rates of denitrification. 72% reduction of N in September is comparable to previous studies which have reported 60-95% reduction of N (Bruland et al., 2002) (Spieles and Mitsch, 2000). NO_3-N was generally in the lowest concentration at site 3, the water lily pond. Reduction in N can be attributed to plant cover which may increase retention times and increase N removal, as well as the accumulation of organic material that increases the rate of denitrification (Fink and Mitsch, 2004). At site 3 there was significant plant organic material that may have contributed to the factors leading to the reduction of N.

In November, NO_3-N concentrations were observed to be increasing from site 1 to site 5 (Figure 2). This may be as a result of a decrease in biological activity and lowered rates of denitrification. This is also supported by the lower temperature readings recorded in November which limits the chemical reactions regulating denitrification (Spieles and Mitsch, 2004). During the storm event, there was a high amount of N loading at site 1 and with no detectable amounts measured at site 5 (Table 2). The high influent N load from storm event may have lead to an increased removal of N from the system. Spieles and Mitsch (2004) have cited that high nitrate concentrations were found to significantly increase nitrate removal rates. While this may be true, the effect of dilution also contributes to the N levels found at site 5.

Ammonium-nitrate was always in significant amounts at site 5, with the highest concentration of NH_4-N measured during the October storm event. A general increase in NH_4-N from September to November indicates that more partially decomposed organic matter was being exported from the system. This is probably the result of decreasing rates of denitrification and biota assimilation of N as the growing season came to an end. Hefting et al. (2005) believed that denitrification is the primary pathway for nitrogen removal with removal rates between 60-95% of inflow N. Thus, once denitrification is limited by colder temperatures at the end of the growing season, N in the form of ammonia would remain undecomposed in the system. Studies have shown that water temperatures below 15^{o}C (which were recorded in November) drastically reduce that growth rate of nitrifying bacteria, thus leading to a decrease in the rate of denitrification (Spieles and Mitsch, 2004). The higher concentrations consistently found at site 5 (Figure 2) would mean that as surface flow moves through the system, organic material containing NH_4-N is deposited near site 5.

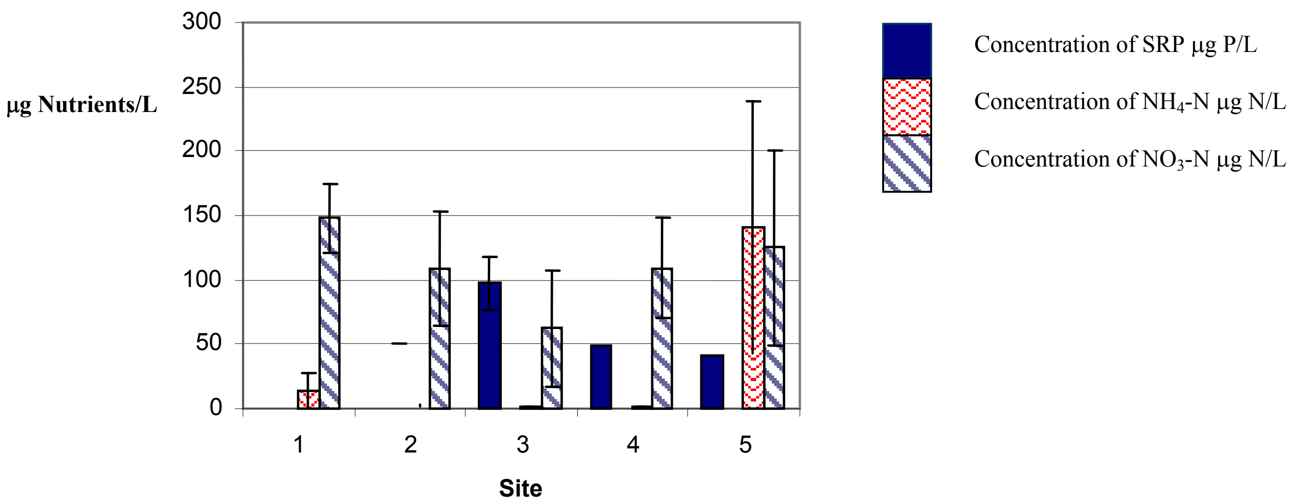

Figure 2. Graph showing the relationship between nutrients and site location

Conclusion

The seasonal dynamics in a mitigated wetland were documented in this study. The wetland exhibited high biological activity during the peak summer months of the growing season as was documented by high DO, temperature and pH. Storm events were also shown to have significant impacts on wetland dynamics. High flows increase N and P loadings at inflow sites from nutrient rich runoff. This influences the removal capacities of the wetland. SRP and NO_3-N concentrations were considerably reduced while NH_4-N concentrations increased during the storm event. N and P interact with the wetland system via different mechanisms (Speiles and Mitsch, 2000). N can be removed via biological factors while the primary removal of P may be sedimentation. The effect of vegetation, soil and hydrology were not addressed in this study, however they are also important factors to consider when examining nutrient dynamics in a wetland. Further long term study need to be completed to increase the significance and validity of the results obtained in this study.

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SOIL PROPERTIES IN A BEAVER-CREATED WETLAND AND THE NORTH FORK MITIGATION WETLAND, 2005

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Abstract

The most important parameters which define a wetland are its hydrology, the vegetation that it supports, and the presence of hydric soils. Considerable interest has been recently focused on the functional assessments of wetlands especially those created as mitigation sites. Soil properties, unlike hydrology are more difficult to restore and are usually not monitored in the years immediately following creation. Two properties that could be very useful in measuring wetland success are hydrogeomorphic features and organic matter content of the soil.

Hydric soils are used in the identification of wetland soils because they indicate saturated or flooded soil conditions were present in the soil long enough to form anaerobic conditions during the growing season. Organic matter content can be used as an indicator of wetland soil because the accumulation of organic matter in wetland soil is an indicator of the soil maturity. This study compared two wetland sites in northern Virginia. Huntley Meadows wetland in Alexandria, VA, is a natural wetland and North Fork Mitigation Bank in Haymarket, VA, is a created wetland. The properties that were studied were soil color, texture, bulk density, pH, organic matter, soil carbon and nitrogen content. When the two wetlands were compared significant differences were found in soil color, soil composition, pH, percent carbon and percent nitrogen.

Key Words: bulk density, created wetlands, mitigation, natural wetlands, redoximorphic features, soil organic matter, C:N ratio

Introduction

The most important parameters which define a wetland are its hydrology, the vegetation that it supports, and the presence of hydric soils (Deshmukh and Mitsch, 1998). Considerable interest has been recently focused on the functional assessment of wetlands (Smith et al., 1995) especially those sites created as mitigation projects (Wilson and Mitsch, 1996, Cole and Brooks, 1999). Soil properties, unlike hydrology, are more difficult to restore, less often considered in restoration plans, and rarely monitored in the years immediately following creation (Shaffer and Ernst 1999).

Soil properties are not traditionally used as a measure of wetland success. Whited et al. (1999) stated that in addition to hydrology, plant communities and wildlife use, some soil properties could be used as criteria for measuring wetland success. One soil parameter that could be used as an indicator of wetland soil is whether or not the soil is hydric. Hydric soils are soils that are formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Mitsch and Gosselink 2000). When soils undergo flooding conditions the soils become highly reduced and the soil acquires over time redoximorphic features. Redoximorphic features are characteristic of soils that have had periodic flooding with anaerobic conditions prevailing in the soil for a period of time and are indicative of wetlands. Studies have shown that the estimates on the time required to form redoximorphic features within hydric soils can vary from one year to more than 100 years (McCullough, 1998). Redoximorphic features of soils include (1) gleying of soils which is a condition resulting from prolonged flooding and is indicated by a presence of bluish or greenish colors throughout the soil. This distinctive color is the result of the reduction of iron and manganese (Mitsch and Gosselink, 2000). (2) mottling of the soil, these are spots or streaks through the soil mass which are also the result of gleying of the soil. (3) low chroma matrix, soil samples are compared to a Munsell® Soil Color Chart. Soil colors are described by a number indicting their hue, value, and chroma. Chromas of 2 or less generally indicate hydric soils (Tiner, 1999, Mitsch and Gosselink, 2000). Soil colors become darker as reduced Fe and Mn are transported out of the soil column during flooded conditions (Anderson et al., 2005).

Another possible indicator of wetland soil is organic matter content. The accumulation of organic matter has been identified as an indicator of soil maturity in created wetlands because of the time required to develop it (Nair et al., 2001). Organic matter can be considered a critical component of soil because of its role in physical, chemical and biological processes including 1) soil structure, with the high cation exchange properties of organic matter which allow the organic matter particles to bind to soil particles forming a more stable structure, 2) nutrient contributions, organic matter is a substantial reservoir for carbon, phosphorus, nitrogen and sulfur, 3) water holding capacity, soil with a high level of organic matter can hold more plant available water than lower organic content soils, 4) pH of the soil influences organic matter decomposition. Very high or low pH will influence the rate of organic matter decomposition (Agvis, 2005).

The objective of this study was to compare the physical and chemical properties of two wetlands soils; one a beaver created natural wetland in existence for at least 50 years, Huntley Meadows wetland and the other a created wetland constructed in 1999 and 2000, North Fork mitigation bank, and to determine if soils of the created wetland closely resembled the soils of the natural wetland. The soil properties of interest in this study were color, if redoximorphic features were present, soil texture, bulk density, total organic matter content, pH, carbon, and nitrogen contents. The underlying assumption was that the soils of Huntley Meadows will be considerably higher in organic matter content, carbon and nitrogen content and considerably lower in bulk density and pH than North Fork.

Methods

Site description

Huntley Meadows wetland

Huntley Meadows wetland is located in Huntley Meadows Park in Alexandria, VA, USA. The park is a total 1,424 acres and is composed predominantly of freshwater wetland and forested wetland (Figure 1). Huntley Meadows supports a wide variety of wetland plants and trees. These plants and trees in turn support a wide array of wildlife.

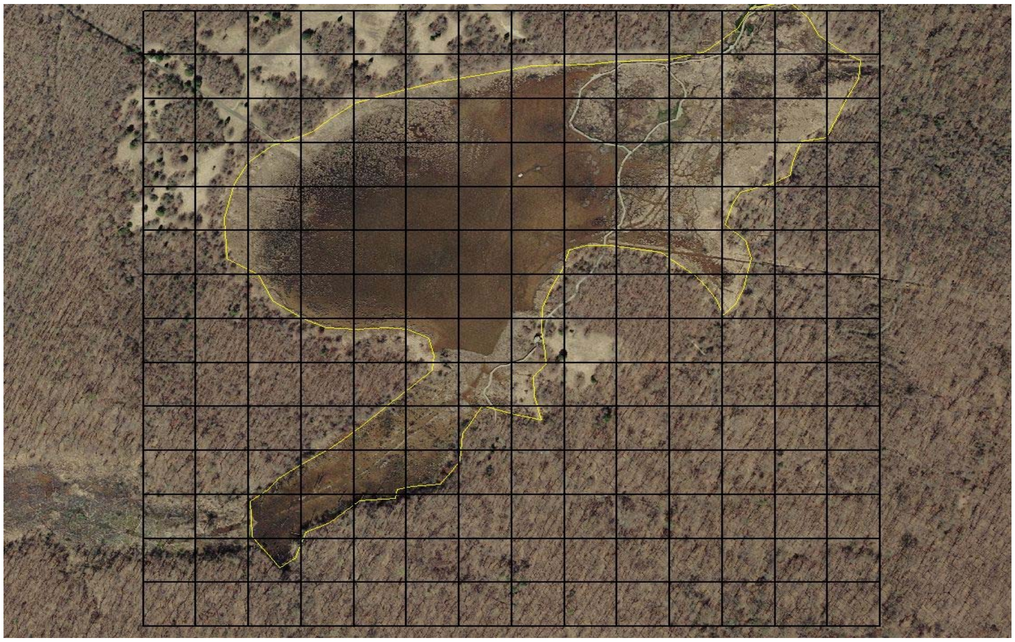


Figure 1. The beaver-created central wetland at Huntley Meadow

The wetland used for this study was the central wetland in Huntley Meadows Park. The central wetland of Huntley Meadows was formed by the damming of Barnyard Run by beavers (Nickelsburg, 1994). The hydrology of Huntley Meadows wetland (HM) has been altered by these beaver created dams. The dams have been responsible for increasing the volume of water that resides within the wetland. This increasing of the water level has altered the hydrology and increased the wetland environment. The beavers have now exhausted the food supply in the central impoundment area and have subsequently moved out of the area (Rosium 2005).

North Fork wetlands mitigation bank

North Fork is a 125 acres wetland mitigation site located in Haymarket, Virginia, USA (Figure 2). North Fork provides mitigation for wetland impacts for more than 40 projects (Wetland Studies and Solutions, Inc., 2000). The site contains 7 acres of open water, 76 acres of wetland, and 42 acres of upland buffers. Before becoming a wetland mitigation site, North Fork was a pasture used for the gazing of cattle.

Figure 2. North Fork mitigation bank and soil sampling sites

The North Fork (NF) site was constructed by Wetland Studies and Solutions Inc. in 1999 and 2000 and it is an ecologically diverse system having open water, wetlands and uplands. The wetland is perched and has a high clay content in the soil which limits the upflow of water. The main source of hydrology is in the form of precipitation. The topography of the area has been modified to promote flooding and deter channeling.

Sampling and soil color

A total of 9 designated samples areas were selected for each site, Huntley Meadows and North Fork. Huntley Meadows soil samples locations were selected from a grid map (Figure 1), each section is 50 m^2. Using a GPS system to locate the designated plots, soil samples were extracted at a randomly selected point with the designated plot coordinates. Soil samples were chosen at points that were north, south, east or west of the randomly selected point. At North Fork each sampling location is indicated on the map (Figure 2) and is a groundwater monitoring well site. At each monitoring well site a random point was selected, from this point a sample was taken to the north, south, east or west and all within 2 m of the well. A total of 3 soil samples were taken using a handheld soil probe with an inner diameter of 2 cm, length of 30 cm and one bulk density sample was collected from each sample location.

All soil samples were evaluated in the field for gleying, mottling, oxidized rhizopheres and were compared with the Munsell® Color Chart, to select a satisfactory match for color, value, and chroma. All information was noted and the cores were immediately placed in a ziplock plastic bag, labeled and placed in a cooler for transport to the laboratory for later processing and evaluation.

Soil texture

One soil sample from each sampling location was tested for texture using the Journal of Agronomic Education method for determining soil texture (University of Arizona, 2003).

Bulk density

Bulk density tins were pre-weighed and were used to gather one sample per designated sampling site; a total of 18 were collected. Soil samples were weighed before placing them into an oven at 105°C for 48 hours. After drying, all samples were placed in a desiccator for 24 hours then weighed. The bulk density was calculated by dividing the mass of solids (dry mass) by the total tin volume (Blake, 1986).

Sample preparation for pH, total organic matter content and CHN analysis

The soil samples were air dried for 48 hours. After drying samples, using a mortar and pestle the dried samples were ground into a fine powder and passed through a 2 mm sieve (Nelson and Summers, 1986). Samples were placed in a dry glass vial with a screw on cap, labeled and stored at room temperature until processed for pH, organic matter and CHN analysis. Due to such a large organic matter content result of the first protocol, another set of organic matter samples were prepared in the same manner as the above samples expect before analysis the samples were dried at 105°C for 24 hours to remove any possible excess water that may be trapped in the soil.

pH

A 1:1 ratio of water to soil was used and stirred continuously for 5 minutes. The sample was allowed to stand for 1 hour. pH was measured with an Accumet 950 pH Ion Meter and results were recorded (Black, 1973).

Total organic matter content

Total organic matter (OM) content was estimated by loss on ignition at 550°C (Nelson, 1982). Crucibles were weighed, 5-7 g of sample was added to the crucibles and the weight was recorded. The crucibles were placed in a muffle furnace at 550°C for 2 hours. Samples were cooled and weighed again. The loss in mass as a percentage of the initial mass is the total OM content of the sample (Deshmukh and Mitsch, 1998). These percentages were averaged for each sampling site to estimate the percent organic matter of the soil. Due to such a large OM percentage result of the above protocol, another analysis was performed for OM content (total of 45 samples), the procedure followed the above stated protocol except the soil samples after being air dried, were then dried at 105°C for 24 hours to remove any possible water that may be trapped in the soil. Percent OM and averages were obtained for each sampling location.

Soil carbon and nitrogen analysis

Total carbon, hydrogen and nitrogen analysis was conducted on the Perkin-Elmer 2400 Series II CHNS/O Analyzer for all soil samples.

Data analysis

Sample data for all sites for bulk density, pH, total OM, carbon and nitrogen analysis were averaged, the standard deviation and standard error was calculated. The data was compared using the two-tailed Students t-test at a confidence level of 0.05.

Results and Discussion

Soil color / redoximorphic features

All soil samples from HM when compared to Munsell® Color Chart were observed to be hydric with a chroma of 2 or less (Table 1).

Table 1. Munsell Chart Data (Mean) of soil samples

Huntley Meadow	Hue	Value	Chroma	Gleying	Oxidized rhizosphere	Mottling
1	2.5Y	5	2	Yes	Yes	Yes
2	2.5Y	4	1	Yes	Yes	Yes
3	2.5Y	6	2	Yes	Yes	Yes
4	2.5Y	5	2	Yes	Yes	Yes
5	2.5Y	6	2	Yes	Yes	Yes
6	2.5Y	5	2	Yes	Yes	Yes
7	2.5Y	6	1	Yes	Yes	Yes
8	2.5Y	6	2	Yes	Yes	Yes
9	2.5Y	5	2	Yes	Yes	Yes

North Fork	Hue	Value	Chroma	Gleying	Oxidized rhizosphere	Mottling
6	10YR	5	3	Yes	Yes	Yes
10	10YR	5	3	Yes	Yes	Yes
11	10YR	5	3	Yes	Yes	Yes
12	10YR	5	4	No	No	No
34	10YR	5	4	Yes	No	No
35	10YR	5	4	No	No	No
37	10YR	4	3	No	No	No
40	10YR	4	3	No	No	No
41	10YR	5	4	Yes	No	No
6	10YR	5	3	Yes	Yes	Yes

All but one of the soil samples for NF recorded a chroma of 3 or higher, indicating these are not hydric soils. This is consistent with other created wetlands, Bishel-Machung et at. (1996) and Confer and Neiring (1996) found soil chroma values with created freshwater marshes to be comparatively higher that those of naturally occurring reference wetlands even after eight years of flooding. Both studies attributed the higher chroma values for created wetlands to low organic matter content. Low organic matter content is expected in newly created wetlands but is not expected in a natural wetland such as HM. It was therefore surprising that HM results for organic matter contents were so low. There are several possible reasons for these results, one is sampling error and the others are discussed in the organic matter section.

All of HM and about 70% of NF showed redoximorphic features. This would be consistent with other created wetlands that redoximorphic features found in created wetlands are far less when compared to natural wetlands (Bishel-Machung et al., 1996).

Soil texture

Soil texture for HM was silty clay, clay loam or silty clay loam and for NF it was sandy clay or sandy clay loam (Table 2). Soils with high clay content usually have a higher OM content due to the slower decomposition of OM. Soils with a high sandy content usually have a higher bulk density than that of mainly clay (Nair et al., 2001). Bishel (1994) reported that created sites had a high percentage of sand which is typical of wetlands developed from excavating upland substrates as such, created wetland soils were classified as sandy clay loams. Reference sites had much less sand and more silt and were classified at clay loam. These results are consistent with our findings.

Table 2. Soil Texture Data

Huntley Meadow	Soil Texture
1	Silty Clay
2	Clay Loam
3	Silty Clay
4	Clay
5	Clay Loam
6	Silty Clay Loam
7	Silty Clay
8	Silty Clay
9	Silty Clay Loam
North Fork	
6	Sand Clay Loam
10	Sandy Clay
11	Sandy Clay
12	Sandy Clay Loam
34	Sandy Clay
35	Sandy Clay
40	Sandy Clay Loam
41	Sandy Clay Loam

Bulk density

Bulk densities for HM ranged from 0.144 to 1.039 g/cm^3, mean of 0.648 $\pm$ 0.095 g/cm^3 and were consistently higher at NF which ranged from 0.759 to 1.119 g/cm^3, mean of 0.872 $\pm$ 0.1 g/cm^3 (Figure 3, Table 3). The bulk density results for HM were comparative to the results found in other studies but the results from NF are considerably lower than expected. Results recorded by Bishel-Machung et at. (1996) in 44 created wetland constructed between 1985 and 1991. Bulk densities averaged between 1.15 $\pm$ 0.2 g/cm^3 in constructed wetlands and in natural wetlands it was considerably lower, averaging 0.60 $\pm$ 0.35 g/cm^3. The natural wetland sites lower bulk densities were attributed to the higher OM content in these soils. The lower bulk density at NF can probably be attributed to sampling error. The NF samples were collected during a rain event in October, 2005. Approximately 10-20 cm of standing water was at each of the sampling locations, making it difficult remove excess plant debris from the sampling area and also difficult to extract the sample. In a comparative study completed by Katrivanos in 2004, the bulk density for NF ranged from 1.66 g/cm^3 to 1.87 g/cm^3. The lower bulk densities at NF can probably be attributed to high water content and large quantity of plant debris in the sample, not to high organic matter content in the soil. Sampling errors could be minimized if a larger number of samples (minimum of 10) per site where collected and analyzed (Bishel-Machung et al., 1996). Another way to possibly avoid sampling errors in bulk density sampling is to sample the entire population not just from selected units (Peterson and Calvin, 1986).

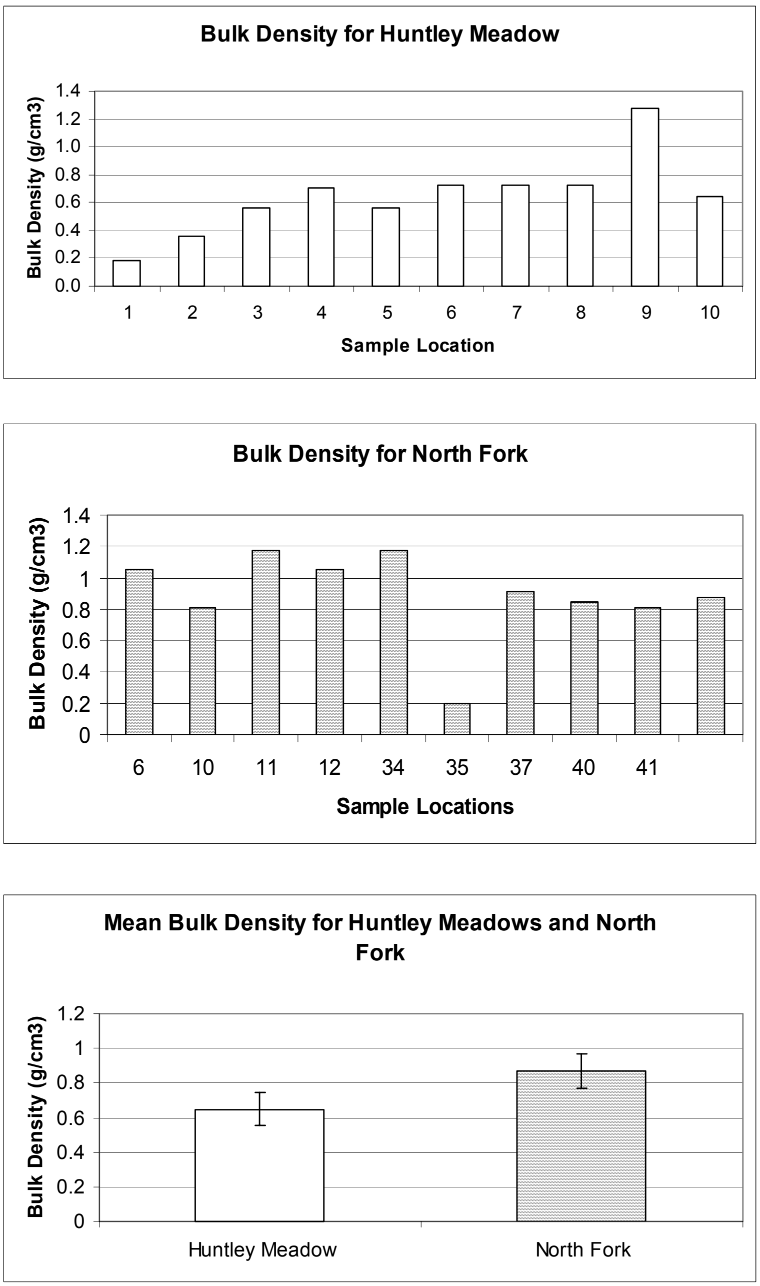


Figure 3. Bulk density of soils

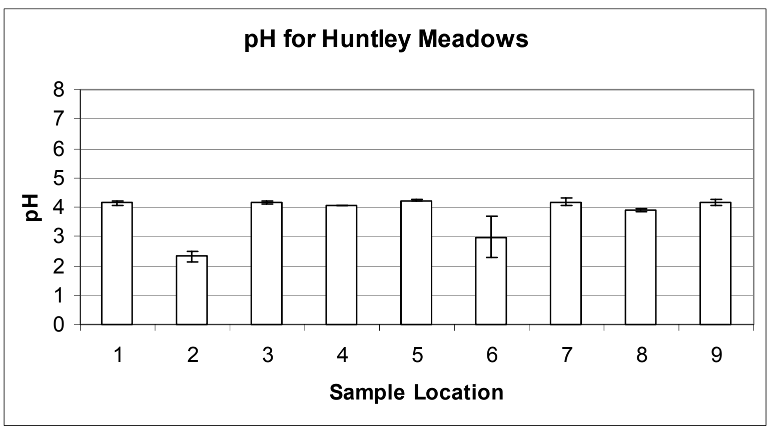
Table 3. Means for selected physicochemical soil properties

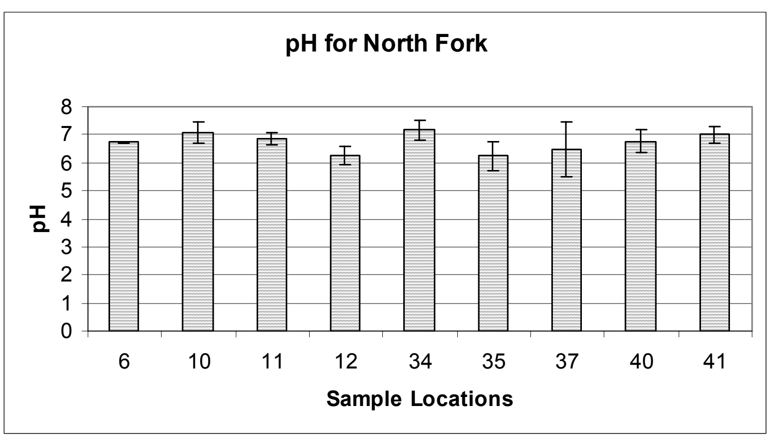
	Huntley Meadows	North Fork	Results of t-test
Bulk density (g/cm^3) (n=18)	0.648 $\pm$ 0.95	0.872 $\pm$ 0.1	NS
pH (n=54)	4.07 $\pm$ 0.06	6.73 $\pm$ 0.11	*
% Organic Matter (n=45)	5.90 $\pm$ 0.46	5.51 $\pm$ 0.5	NS
% Carbon (n=108)	2.07 $\pm$ 0.313	1.262 $\pm$ 0.08	*
% Nitrogen (n=108)	0.171 $\pm$ 0.025	0.110 $\pm$ 0.01	*

NS: no significant difference.
*: significant difference at α = 0.05.

pH

The pH of HM was extremely acidic with an average of 4.1. Extremely acid soils suggest a significant amount of exchangeable hydrogen and aluminum present (Thomas, 1986). The soil at HM is a hydric soil and this result is consistent with the palustrine reference wetlands studied in Virginia whose values ranged from 4.4-5.9 (Stolt et al., 2000). The pH at NF was circumneutral with an average of 6.7 (Figure 4, Table 3). The median pH was 6.5 in creation projects in Pennsylvania (Bishel-Machung, 1996).





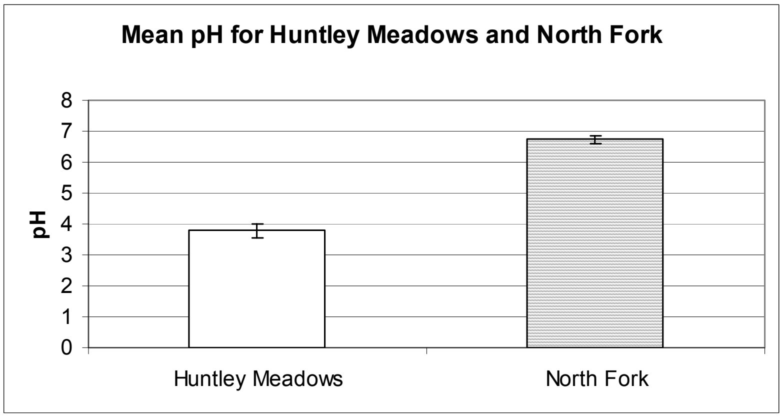
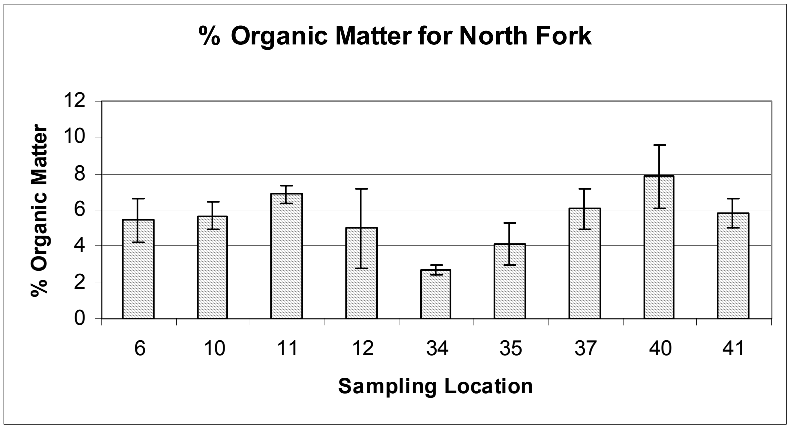


Figure 4. pH of soils from Huntley Meadow and North Fork mitigation bank

The acidic pH for HM can probably be attributed to and organic acid production that occurs during the decomposition of organic matter (Nair et al. 2001). A circumneutral pH is very common in newly created wetland and the almost neutral pH of NF can be attributed to the recent disturbances to the native soil and to subsoil material not being exposed to the same level of organic acids and the intensity of weathering processes as the natural wetland soils. Therefore, constructed wetland soils have more basic cations such as Ca and Mg, on their exchange sites and also have a higher pH (Stolt et al., 2000).

Organic matter

For the first protocol the % OM ranged from 4.0 to 17.0 for HM and 5.5 to 13.1 for NF. The second protocol generated reduced organic matter figures, for HM percentages were between 3.0 to 11.6 and for NF, 2.7 to 10.3 (Figure 5, Table 3). The mean calculated for % OM at HM was 5.90 $\pm$ 0.46 and for NF 5.51 $\pm$ 0.5. For this study the second protocol results will be used for data analysis and interpretation. It is apparent from the data of the first protocol that there is a significant amount of water left in the soil if the soil is only air dried and not oven dried for 24 hours. Results for OM were only slightly higher for HM than NF. Longer term changes in soil condition are influenced by OM. This is inconsistent with other findings, particularly the % carbon results. The inflated results for North Fork may be because of high aluminosilicates in the soil. The ignition method used can be compromised due to loss of water of hydration from aluminosilicates at high temperature which could result in an overestimation of organic matter content (Deshmukh and Mitsch , 1998). Sampling error due to improper clearing of the plant debris from the sample area before taking the sample may have also contributed to the inflated figures for NF.



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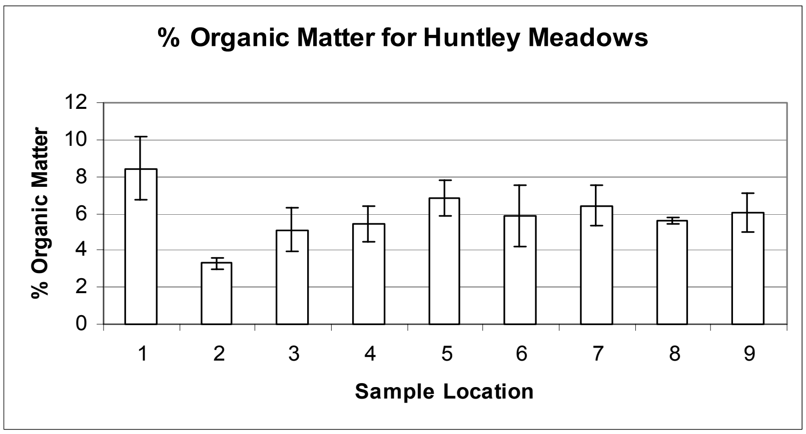


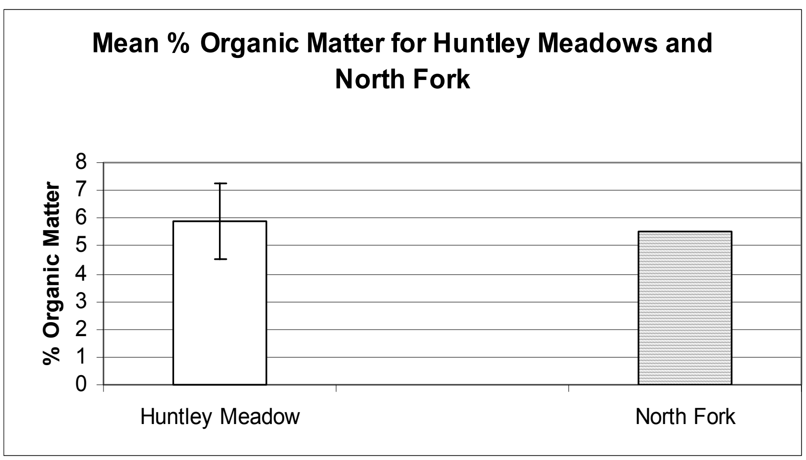


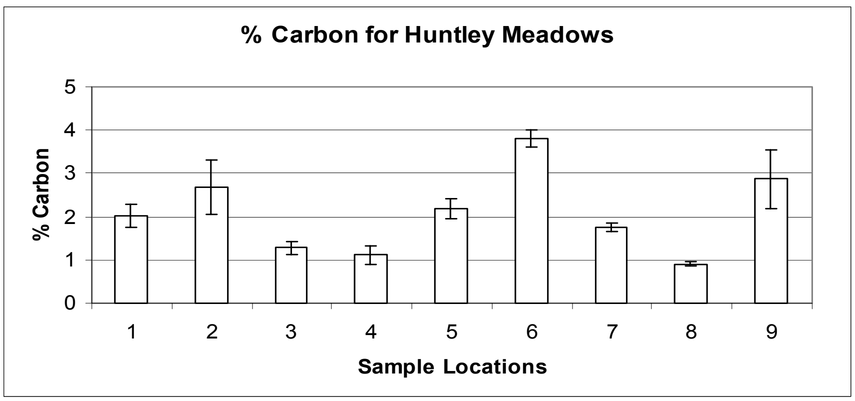
Figure 5. Organic matter content of soil samples

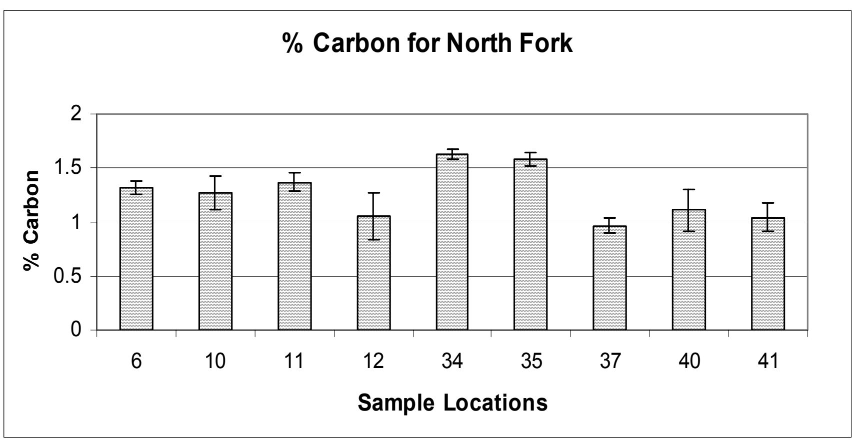
Huntley Meadows results for OM were expected to be much higher because of the age of the wetland . Organic matter is concentrated on the top portion of the soil. When collecting the samples, the whole 30 cm sample was placed into the ziplock bag. The lower OM result for HM could have been the result of the mixing of the entire sample in essence, reducing the organic matter. Another possibility may be due to the drawdown state the wetland was in for the summer and fall of 2005. When water table levels reach the surface only during brief periods of flooding and thus, the accumulation of organic matter is limited by high decomposition rates (high organic acid production) and the constant addition of mineral material as a result of flooding.

Organic carbon contents are very similar between reference and constructed wetlands (Stolt et al., 2000).

Percent carbon and nitrogen

The mean percent of carbon (C) for HM was 2.070 $\pm$ 0.313 and for NF was 1.262 $\pm$ 0.080 (Figure 6, Table 3). The difference between HM and NF is 40 %, this is a significant difference. The average percent nitrogen (N) for HM was 0.171 $\pm$ 0.010 for NF the average was 0.11 $\pm$ 0.025 (Figure 7, Table 3). The difference in nitrogen content is significant also. Even though there is a significant difference between the wetlands, the carbon and nitrogen content for HM is low when compared to other referenced wetlands. Stolt et al. (2000) found that levels of carbon and nitrogen are very similar between reference and constructed wetlands when the reference wetland surface experiences only brief periods of flooding. HM at the time of collection was experiencing a drawdown, this could explain the lack of carbon and nitrogen available in the soil.





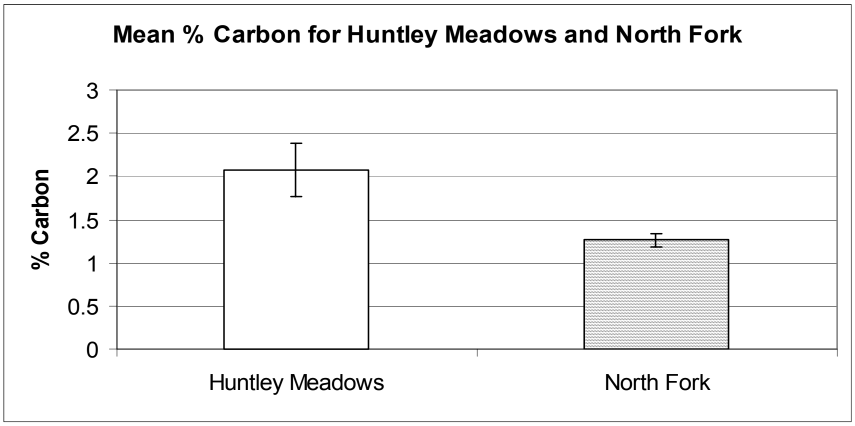
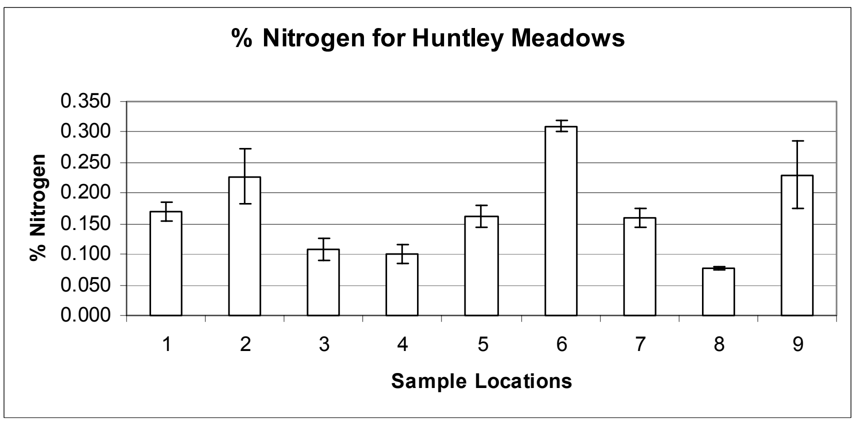
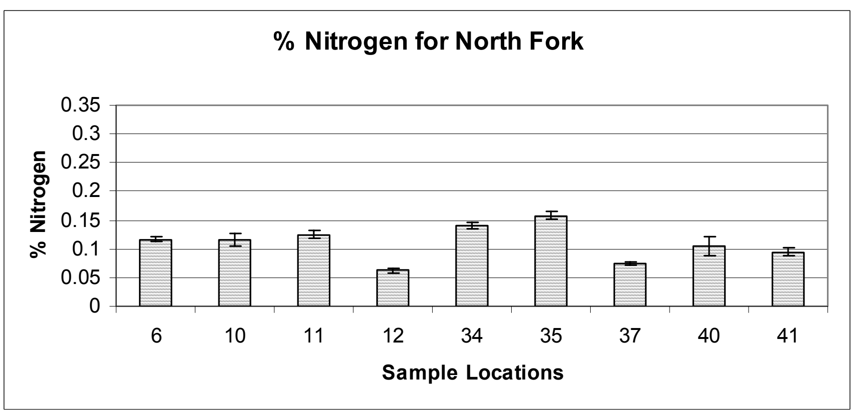


Figure 6. Percent carbon content (%) of soil samples





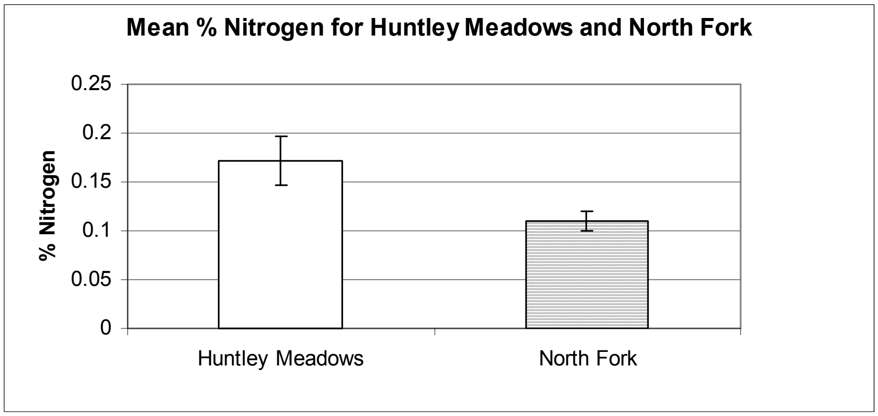


Figure 7. Nitrogen content (%) of soil samples

When using the above figures both HM and NF have an average C:N Ratio of 12. The C:N ratio indicates that there is a sufficient N is available to meet microbial needs. The average C:N ratio for a wetland has been found to be 12-18 (Craft and Chian 2002).

Conclusion

Using the soil parameters of color, texture, bulk density, percent organic matter and C:N ratios the results indicate that when comparing Huntley Meadows to North Fork there are significant differences recorded in soil color, soil texture, pH, carbon and nitrogen contents. It is very short sighted to make any determinations from this data. More soil parameters should be taken into consideration such as determining if aluminosilicates are part of the soil; what are the exact contents of the soil. Weather conditions should be noted such as is this a drought year or a wet year. For bulk density analysis more representative samples should be taken of the wetland area. Incorporation of hydrology data would be beneficial in helping to analyze organic matter data. In order to draw any comprehensive comparison, it is suggested that this study be repeated over a 3-5 year time frame or longer if results are to be a reliable predictor of the success of North Fork as a wetland.

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Effects of artificially-induced microtopography on plant community structure in created wetlands: an on-going study

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ABSTRACT

Microtopography, or small-scale topographic variation, may influence wetland hydrology, physicochemistry, seed germination, and plant community development, but the microtopographic variation found in natural settings is rarely found in newly constructed wetlands. In addition, there may be differences in microtopographic patterns depending on construction practices (i.e., absence or presence of disking) even among created wetlands. This study focuses on the effects of microtopography on hydrology, soil nutrients, and vegetation in freshwater wetlands.

Microtopography will be quantified at two created (disked and undisked) and one natural freshwater wetlands in northern Virginia using elevation data taken at a regular interval (10 or 20 cm) along multi-scale (0.5m-, 1m-, 2m-, and 4m-diameter) nested circular transects. Rusting of steel rods will be used to assess water table/reducing zone depth for a subset of the transect elevation points, with depth data collected monthly during the growing season. Soil core samples for a subset of the transect elevation points will be analyzed for total carbon, nitrogen, and phosphorus. Transect vegetation surveys at the end of growing season will be conducted to assess species richness and spatial distribution of macrophytes, and relate those to elevation, soil nutrient contents, and water table/reducing zone depth, as affected by microtopographic variability. The study is expected to suggest wetland creation methods that might increase ecosystem function and the probability of mitigation success.

Keywords: microtopography; microrelief; species richness; constructed wetlands; soil nutrients; volunteer species

INTRODUCTION

Microtopography, defined as topographic variability on the scale of individual plants (Huenneke and Sharitz, 1986; Titus 1990; Bledsoe and Shear, 2000), may influence wetland hydrology, physicochemistry, seed germination, and plant community composition. The use of heavy machinery for grading during the construction process for wetlands, however, tends to reduce or eliminate the microtopographic heterogeneity commonly found in natural settings (Stolt et al. 2000). Since the plant community plays an important role in ecological functions of wetlands, including nutrient cycling (Grubb, 1977; Ehrenfeld, 1986; Boerner and Koslowsky, 1989; Stoeckel and Miller-Goodman, 2001), the manipulation of microtopographical heterogeneity to enhance plant community development has implications for wetland creation/restoration in Virginia.

Hydrology

Microrelief affects the proximate hydrologic conditions experienced by an individual seed or plant, and it may also affect wetland hydrology in a broader sense. Under conditions of standing water, microtopographical features may cause surface flow paths to become increasingly sinuous as water levels drop; resistance to flow thus increases, affecting water budget and water quality (Harvey et al., 2003). The implication that microtopographic features may enhance water retention in a wetland is supported by field experiments in which disked wetland restoration plots were found to have higher water retention and higher water table levels than plots receiving standard agricultural tillage, whether under standing water or water table conditions (Tweedy et al., 2001). Thus, roughing the surface (as by disking) may be helpful in restoring wetland hydrology to agricultural lands. Moreover, it is suggested as a way to reduce the amount of seeding necessary (Bledsoe and Shear, 2000).

Physicochemistry and soil nutrients

Microtopography also influences soil chemistry and nutrient cycling. A gradient was found in substrate chemistry (pH and exchangeable Ca and Mg) and moisture, tied to locations categorized as hummock, low hummock, and hollow microsites (Karlin and Bliss, 1984). Microtopographic relief has also been shown to affect the flux of nutrients (Mn, Fe, P) in permafrost-affected wetland soils of polygonal tundra (Fiedler et al., 2004). Under the differing redox regimes of “microlow” polygon centers and “microhigh” polygon rims manganese and iron accumulated above the water table in the well-drained microhigh soils, as did phosphorus complexed to soluble iron. The results suggested that manganese, iron, and phosphorus are mobilized at the microlows and subsequently oxidized and immobilized at the microhighs, leading to a net upward translocation. A related study compared sites within a single tundra polygon, characterized as either low center or high rim edge (Kutzbach et al., 2004). Vegetation surveys established that the species composition differed significantly between these two microsite types, though *Carex aquatilis* was the dominant species at both. Methane emission was found to be significantly higher at the polygon center, and plant-mediated (*C. aquatilis*) transport was of higher importance as well. The authors proposed two effects of microtopography upon methane emission from the results: the first, a direct effect of microtopography, was the variance in water table position relative to the surface, determining the extent of anoxic conditions required for methanogenesis; the second, an indirect effect, was the vegetation pattern, which supported plant-mediated methane transport.

Vegetation

In forested uplands, microtopography is often characterized by treefall mounds and pits. A study of forest soil microsites in eastern New York compared physical and chemical properties of such mounds and pits against those of undisturbed soil, and the corresponding plant distributions (Beatty, 1984). Compared to pits, mounds tended to be lower in moisture, more acidic, lower in organic content, and lower in cation exchange capacity, as well as warmer in summer and colder in winter. Though pits generally had more favorable growing environments, with deeper litter and organic soil layers, they had no higher species richness or cover than did mounds. Nonetheless, the differing pit-mound conditions were reflected in the patchy nature of the understory cover and appeared to contribute to greater species richness overall.

The influence of microtopography in differential seed germination has been demonstrated in a series of prepared-bed and pot experiments manipulating soil surface heterogeneity using box frames, glass sheets, and holes of varying depths in seed beds, and varying soil textures in pots (Harper et al., 1965). Differential germination between plant species was explained as a combination of factors, in particular: 1) exposure of the soil to the atmosphere; 2) protection of seeds from water loss; and 3) favorable interaction between seed structure and soil structure. Microtopographic variation has also been shown to promote species richness and abundance, independent of propagule source (Vivian-Smith, 1997).

Vegetation surveys also support the importance of microtopography in determining wetland plant species distribution. A study of the distribution of woody seedlings in natural and disturbed cypress-tupelo swamps found that not only were seedlings disproportionately distributed with regard to microsite type, but so were growth forms (tree, shrub, vine) and species; these distributions were similar in both disturbed and natural swamp conditions (Huenneke and Sharitz, 1986). The authors suggest that microsite effects specific to wetlands include: 1) the "trapping" of water-dispersed seeds; 2) the role played by elevation and inundation in seed germination; 3) chemical and microclimatic effects; and 4) protection from erosion/deposition. A similar study examining the distribution of woody vegetation in a central Ohio fen documented the invasion of hummocks by arbor vitae (Collins et al., 1982), noting that seedling establishment was correlated with higher microsite elevation. Furthermore, a study of woody seedling distribution in a Florida hardwood floodplain swamp found that species were distributed more frequently than expected on small tip-up mounds, which have both higher microelevation and mineral soil substrate, as opposed to microsite substrates characterized by living or dead wood (Titus, 1990).

A study concerning the result of urban runoff sedimentation on species diversity in a sedge meadow tied species loss to loss of microtopographical features created by *Carex stricta* tussock growth (Werner and Zedler, 2002). Species richness decreased with the loss of microtopographic relief due to sediment infilling of hollows among *Carex* hummocks. Disturbance by fire has also been associated with loss of microtopographic relief and higher numbers of *Chamaecyparis thyoides* seedlings in Atlantic white cedar swamps (Ehrenfeld, 1995b). Microtopographic variation treated simply as elevation, however, was shown insufficient for predicting moisture content, redox potential, bulk density, and fiber content in the same cedar swamps (Ehrenfeld, 1995a).

Scale considerations and quantifying microtopography

Because ecological phenomena may only be apparent at certain scales, it is important to recognize the significance of scale in designing experiments; the notion of "micro"-topography itself demands that scale be considered. A proper investigation takes into account the *extent* (overall area of study) and *grain* (unit size of individual study plot) of study, and it attempts to ensure that experimental results are not skewed by these scale-determining factors (Wiens, 1989; Stohlgren et al., 1997). In vegetation surveys, for instance, as grain size increases, rare species are increasingly underrepresented if there are minimal coverage criteria, or overrepresented if presence is the criterion; as extent is increased the between-grain variance is increased. As a result, any characterization of species diversity, for instance, is very scale-sensitive. While a multi-scale upland field study suggested that environmental factors are more important in determining spatial vegetation patterns when considered at larger grain size (Reed et al., 1993), at smaller grain sizes, plant-plant competitive interactions and morphological factors are expected to dictate species composition. The use of multiple scales to examine microtopographic heterogeneity and vegetation patterns has also been used in salt marshes (Morzaria-Luna et al., 2004), though this study found that microtopographic heterogeneity and species richness were not necessarily associated.

The quantification of microtopography presents a challenge because the concept encompasses both elevational relief and surface roughness. While the former is readily measured and its variance quantified (Allmaras et al., 1966), it is an incomplete characterization of surface irregularity; quantification of roughness may depend on the scale of irregularity of interest (Hobson 1972). Most ecological studies have treated microtopography in a general way using descriptive categories (Huenneke and Sharitz, 1986; Paratley and Fahey, 1986; Titus, 1990; Fiedler et al., 2004; Kutzbach et al., 2004; Morzaria-Luna et al., 2004). Studies of agricultural tillage, however, tend to approach the quantification of surface roughness more formally, often in the context of effects with regard to erosion or depression storage (Romkens and Wang, 1986; 1987; Potter and Zobeck, 1990; Potter et al., 1990; Saleh, 1993; Hansen et al., 1999; Kamphorst et al., 2000). Some methodologies employ the "bump" or elevation frequency distribution or compare the distribution and orientation of approximated planar (or linear) surfaces as sampled (Harper et al., 1965; Currence and Lovely, 1970; Hobson, 1972). Romkens and Wang (1986,1987) developed a roughness index which considered the area under the curve between a transect line and its least-squares regression line, as well as the peak frequency factor (number of elevation maxima per distance). Potter and Zobeck (1990) used the cumulative shelter angle distribution (with shelter angle defined as the maximum angle between adjacent surface elevations) as a roughness index patterned on wind erosion dynamics.

A method for quantifying microtopography which strikes a balance between ease of field measurement and ease of subsequent data manipulation compares a given surface area to a corresponding planar area (Hobson, 1972; Helming et al., 1993). For a two-dimensional path, such as a cross-sectional elevation profile, this method compares the overall surface profile length to the corresponding straight-line path, and has been referred to as the "tortuosity" of a surface (Kamphorst et al., 2000). Elevation data can be used to assess the tortuosity of a transect (Werner and Zedler, 2002), or tortuosity may be directly measured, as by means of a roller chain (Saleh, 1993).

OBJECTIVES

The primary goal of this study is to examine the effects of microtopography on hydrology, soil nutrients, and vegetation in freshwater wetlands in northern Virginia. We will quantify microtopography at two created wetlands (one disked and the other undisked during the construction) and one natural wetland as a reference using elevation data taken at a regular (10 or 20 cm) interval along multi-scale (0.5m-, 1m-, 2m-, and 4m-diameter) nested circular transects. We will also investigate soil nutrients and macrophyte species richness, and relate those to the quantified microtopographic variability. The study will test the following hypotheses:

Hypothesis 1

- Microtopography affects the spatial distribution and species richness of macrophytes.

Hypothesis 2

- Microtopographical variability influences nutrients and hydrologic/redox properties of soil that may help explain species distribution and richness.

PROCEDURES

Sites and transect method

Research will be carried out at two created wetlands, North Fork (disked) and Cedar Run (undisked) wetland banks in Prince William County, Virginia, and at a natural "reference" wetland.

Created from a 125-acre cattle pasture in 2000, the North Fork mitigation wetland is an ecologically diverse system providing 7 acres of open water, 76 acres of wetlands, and 42 acres of upland buffers (WSSI, 2005). The vegetation community at North Fork is diverse, including a

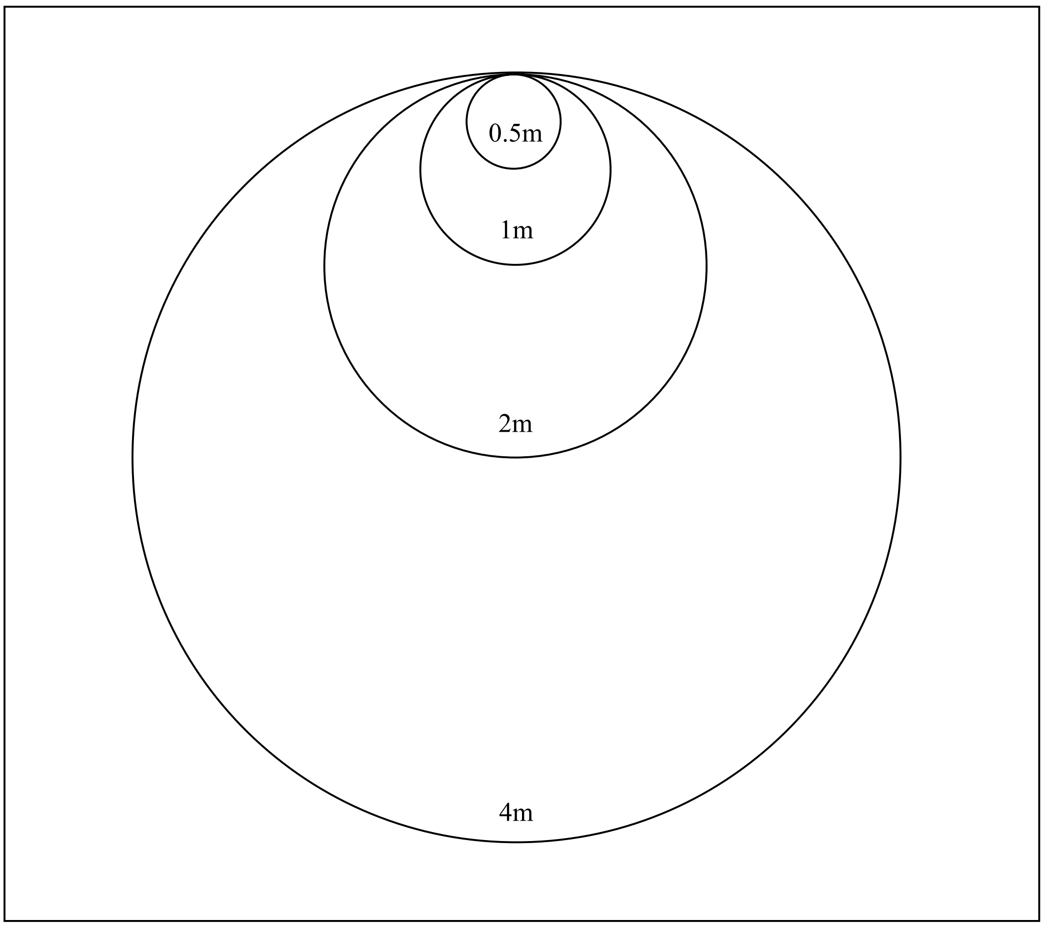

Figure 1. Nested circular transect layout. Hoop diameters indicated.

mixture of forest, shrub, and emergent vegetation with several sub-communities selected by elevation, source of water, and species composition. Located immediately adjacent to Cedar Run itself, the 63-acre Cedar Run wetland was constructed in 2000. The location includes preserved or reforested upland buffers, including mature bottomland forest along Cedar Run. It was also constructed so as to preserve most of the previously existing emergent wetlands by incorporating them into the construction design and enhancing them through the planting of trees and shrubs (WSSI, 2005). A natural reference wetland location is currently being sought.

Two field survey sites will be used at each location, and field data will be collected throughout the growing season (May-October). All field measurements will be taken to correspond to positions along a set of nested circular transects (Figure 1). The circular transect is an approach designed to be directionally-unbiased. Multiple scales will be used to aid in identifying scale-dependent effects; transects will be laid out as 0.5m-, 1m-, 2m-, and 4m-diameter circles using crosslinked polyethylene (PEX) tubing hoops. Data will be collected along the circular paths, as opposed to within the enclosed areas. All transects will share a common point to facilitate meaningful comparison.

Microtopography

Microtopographical variation will be determined from transect elevation measurements taken using survey equipment, with elevations surveyed in to benchmarks where practical. At the beginning of the growing season, elevations will be measured for each transect layout at 10 cm intervals along the 0.5m-, 1m-, and 2m-diameter transects (a total of 111 measurements) and at 20cm intervals for the 4m-diameter transect (63 measurements). The microrelief index based on tortuosity will be calculated for each location/transect from the elevation data and validated against measurements taken using the chain method (Saleh, 1993). The ultimate index value will be unitless (m/m), similar to the microrelief index used by Werner and Zedler (2002).

Hydrology

Depth to water table and the reducing zone will be assessed for each transect layout using steel rust rods (Bridgham et al., 1991) driven to a depth of approximately 80 cm, spaced at 80 cm intervals along all transects (total 30 measurements per transect layout), left in place for 4-week periods, then removed and exchanged with new rods, for a total of six deployments throughout the duration of the growing season in each site. Where available, groundwater wells or other hydrological data will be used to validate the field data.

Soil nutrient analysis

Soil sampling will take place at 40 cm intervals along all transects (60 measurements per transect layout) in the middle of growing season. Soil cores will be collected to a depth of 10cm, excluding surface litter, field-stored in polyethylene bags on ice, then stored in the lab field-moist at 4°C. Soil samples will be homogenized by hand prior to analysis, with roots, recognizable plant material, and coarse gravel removed, then oven-dried at 100°C for 48 hours and ground with a mortar and pestle. Total carbon (C) and nitrogen (N) for the soil samples will be determined using a Perkin-Elmer 2400 Series II CHNS/O Analyzer. Total phosphorus will be analyzed with the nitric acid (HNO3) and the hydrochloric acid digestion method, using a Technicon II Autoanalyzer.

Vegetation

Macrophyte species will be field-identified and individually counted along transects at peak growth. Position along each transect (relative to the elevation measurement intervals) will also be recorded for relation to other study data. Taxon-sampling curves (Colwell and Coddington, 1994) will be used to assess species richness, and Shannon's index (Karlin and Bliss, 1984) will be used to assess plant species diversity. The data will also be analyzed for prevalence of wetland vegetation and the pervasiveness of non-native species (Wentworth et al., 1988).

WORK TO DATE

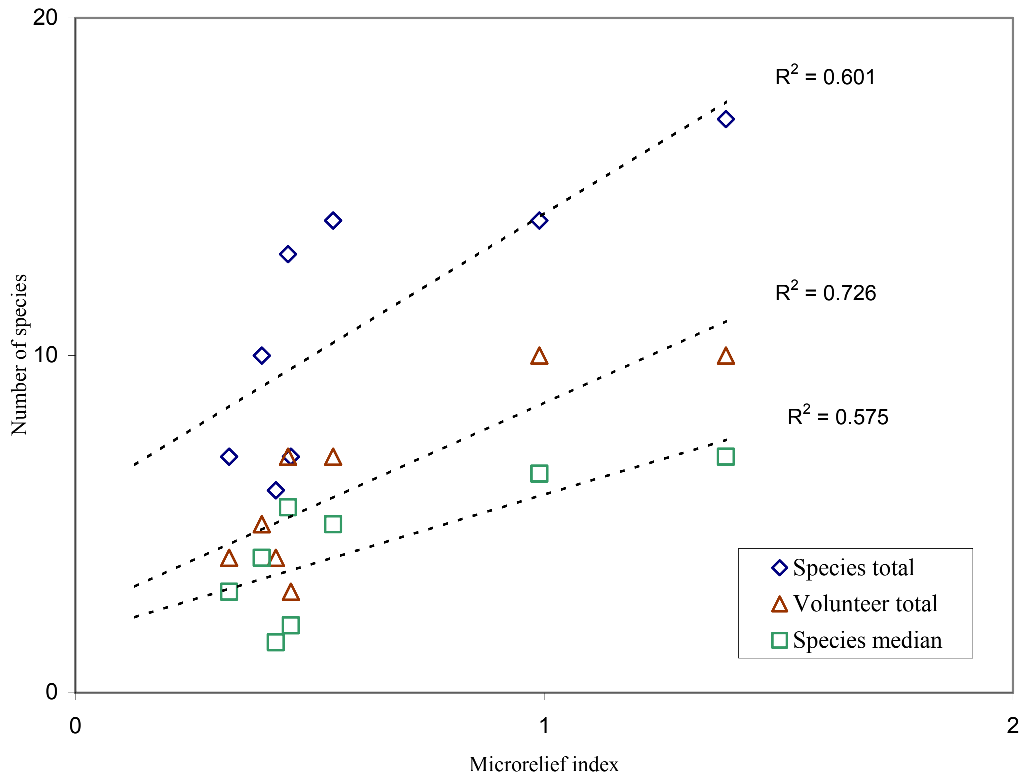

Figure 2. Microrelief index vs. total number of species for all years, total number of volunteer species for all years, and annual median species richness, with linear regression

A preliminary study was conducted at the North Fork mitigation wetland in fall 2004, investigating the effects of microtopographic relief created by initial disking for site preparation on macrophyte species richness and soil nutrient content. Microtopography was characterized for eight sites using a microrelief index[1], using data from 8 m-diameter circular elevation transects. End-of-growing-season vegetation surveys for four of the first five post-construction years were used to determine species richness for each site, as well as relative abundance of naturally-induced versus seeded species. Plant species richness increased with microrelief, particularly with respect to naturally-induced species (volunteer species) (Figure 2). A small number of soil samples from microtopo- high and microtopo-low positions at each site were collected and analyzed for C and N content. Based on the limited soil data, higher contents of carbon and nitrogen were observed consistently in microtopo-highs compared to microtopo-lows

[1] The microrelief index was computed for each transect by summing the absolute values of the horizontal component values (understood as the degree to which the transect surface is sideways-facing, as opposed to upward-facing). For the preliminary study, the index was calculated for the transect in units of m/25.14-m transect, but for comparison with other transect distances, all such values would be divided by the transect length to obtain units of m/m; the ultimate index value is therefore unitless.

(Figure 3). However, the number of soil samples per site was insufficient to relate soil nutrient content either to microrelief index or to macrophyte species richness at each survey site.

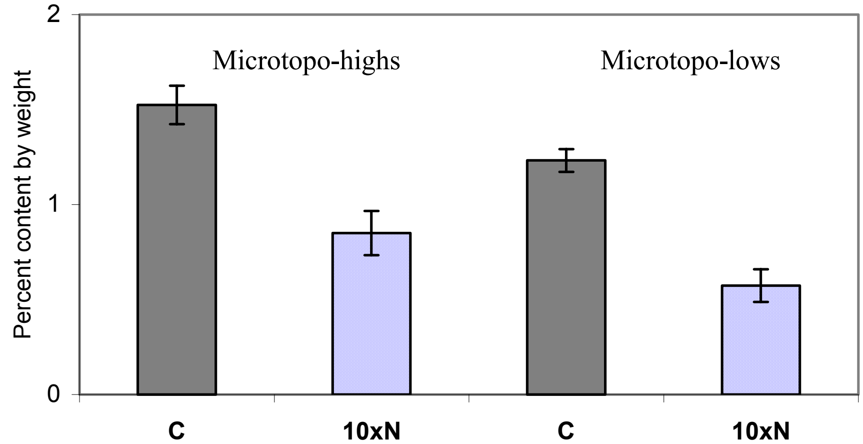

Figure 3. Soil carbon and nitrogen contents (% ± standard error) for microhigh (Hi) and microlow (Lo) samples. Nitrogen values are multiplied by 10 to facilitate comparison at the graph scale

The proposed study will result in a better understanding of the role of the microtopography, either induced or naturally-formed, in the developments of vegetation community and soil characteristics of wetlands. The outcomes of the study may include implications as to the need for initial disking as site preparation, the extent of necessary seeding or planting, the establishment of naturally-induced vegetation (including invasive species), and overall ecosystem development in created wetlands. The outcome will also suggest the microtopographic conditions that may be optimal for created/restored wetlands.

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