ABSTRACT

BALDWIN, ALEXANDER E. Changes to Soil Properties in a Forested Wetland Following 8 Years of Restoration. (Under the direction of Michael J. Vepraskas).

Mitigation credits are awarded to land developers who successfully create or restore wetlands. Because some wetland plant communities adapt slowly to changes in hydrology, restoration may require 15 to 20 years before they can be judged as a success or failure based on vegetation. We hypothesized that restoration success can be evaluated in shorter periods of time if soil properties are used to measure restoration success. The objectives of this study were to: 1) compare soil morphological, physical, and chemical properties in a restored wetland for two time periods – before restoration and 8 years after restoration, and 2) to compare these properties between the restored site and a natural wetland. The study sites are located in the lower Coastal Plain of North Carolina near Aurora. Soils in the restored site were described in 1995, prior to restoration, and all classified as Roanoke sandy loam (clayey, mixed, thermic Typic Endoaquults). The natural wetland was adjacent to the restoration site and was classified as a non-riverine wet hardwood (NRWH). In 2003, 30 soil pedons were sampled, 26 in the restored site and four in the reference, to evaluate changes in soil properties. All sampling occurred in the same sample plots sampled in 1995. It was found that redoximorphic (redox) concentrations increased significantly ($p<0.05$) in the upper 45 cm after 8 years of restoration. The reference site had less redox concentrations than the restored site in the upper 45 cm. Plant available P, and Ca, and CEC, and the percent base saturation had decreased significantly ($p<0.05$) in the restored site since 1995, but each of these properties was still higher than in the natural wetland. Total organic Carbon (TOC) in the upper 15 cm had not increased in the restoration site and was approximately 20% of the amount of TOC found in the reference. Both sites met the hydric soil technical standard, which indicated that the soils in the restored site functioned as hydric soils. The mature trees in the NRWH shaded the soil surface resulting in lower temperatures that reduced the rate of organic matter oxidation during the summer months. The water table in the reference site was 50 cm lower during the growing season than in the restored site. This caused redox concentrations to form 45 cm below the soil surface in the reference wetland, but they accumulated within 45 cm of the soil surface in the restored site. Evaluation of

hydric soil restoration success could be done through use of the hydric soil technical standard, and possibly through changes in redoximorphic features. Most other soil physical and chemical properties changed too slowly to be of value in evaluating restoration success within an 8 year period.

Changes to Soil Properties in a Forested Wetland Following 8 Years of Restoration

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
In partial fulfillment of the
Requirements for the degree of
Master of Science

Soil Science

Raleigh, North Carolina

October 31, 2008

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BIOGRAPHY

Alexander Edwin Baldwin was born in Kilmarnock, Virginia on March 20, 1980. He moved to Pineville, Louisiana in 1981 where his sister was born, and then moved to Wilmington, North Carolina in 1984 where his brother was born. He graduated from E.A. Laney High School in 1998, and then moved to Raleigh, North Carolina to attend North Carolina State University.

His freshman year he met his future wife Michelle Alaina Matern in Chemistry 101. After, spending his first year and a half in First Year College, he decided to follow in his father's footsteps to focus on soil and environmental studies. He began working as a research technician for the Juniper Bay Project, which focused on wetland restoration, in the summer of 2001. He graduated in 2002 with a Bachelor of Science degree in Natural Resources – Soil and Water Systems. In 2003, Alex entered the Master's program in the Soil Science Department at North Carolina State University under the direction of Dr. Michael J. Vepraskas.

Alex took a job with Central Carolina Soil Consulting in the late spring of 2005. He mapped soil in the piedmont region surrounding Raleigh, NC for on-site wastewater systems. On May 12, 2006 Alex married his extremely patient girlfriend, Michelle Alaina Baldwin, and settled in Raleigh, NC. In the fall of 2007, Alex fulfilled the requirements to become a NC Licensed Soil Scientist. Alex currently resides in Raleigh, NC with his wife, Michelle, and two dogs, Ben and Baxter.

ACKNOWLEDGMENTS

I wish to thank my wife, Michelle, who has always listened and provided advice that I could have not gone without. Her support, confidence, and love were the catalyst that has enabled me to complete this manuscript. Without her none of this would have been possible, and for that I will always be in her debt. I would also like to thank my family: Larry Baldwin, Beth Baldwin, Cameron Baldwin and Lawrence Baldwin. All of you have been behind me from the start and provided endless support that will be impossible to repay. From the bottom of my heart, thank you.

I would like to thank my committee members Dr. Stephen W. Broome and Dr. Robert O. Evans for all their guidance and support during my stay. I would like to especially thank Dr. Michael J. Vepraskas who inspired me, in his wetland soils class, to further pursue my education in Soil Science. His energetic personality made the program exceptionally appealing. I would like to thank him for providing me with the opportunity to conduct this research. His patience throughout this process has been incredible, and I could not have asked for a better advisor. Thank you for all your advice during my stay as your graduate student.

Finally, I would like to dedicate this manuscript to those close to me that have passed during its progress: Martha Dixon Baldwin, Thelma Louise Cameron, and Marie Winifred Matern.

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1. INTRODUCTION

In 1977 an amendment was made to the Federal Water Pollution Control Act of 1972, entitled the Clean Water Act (CWA). Under section 404 of the CWA the discharge of dredged and fill material into waters of the United States including wetlands, became regulated. Many activities are regulated in waters of the United States under the CWA including: residential land development, water resources development, infrastructure development, and the drainage of wetlands for agriculture and sivilculture (USEPA, undated). The primary reason for wetland loss and degradation was agriculture. Despite the CWA amendment much agricultural activity is exempted from the Section 404 program. This exemption continued to allow the alteration and drainage of many wetlands for agriculture, until the Farm Bills of 1985 and 1990 (Turner and Gannon, undated).

The Swampbuster provision of the 1985 Food Security Act (Farm Bill), and amendments in the Food, Agriculture, Conservation, and Trade Act (Farm Bill) of 1990, were designed to discourage further conversion of wetlands for agricultural commodity production. Disincentives (i.e. loss of commodity supports, crop insurance, and disaster payments) were put into place to deter farmers from degrading or draining a wetland for agricultural production (Turner and Gannon, undated). Currently there is a federal "no net loss policy" for wetlands authorized by the Clean Water Act (Findley and Farber, 1992; National Research Council, 1995; Gutrich and Hitzhusen, 2003). The "no net loss policy" allows permits to be issued that allow wetland impacts provided that the losses to the wetland are offset by the parties with compensatory mitigation.

Understanding wetland mitigation first requires knowing what a wetland is and why wetland mitigation is necessary. Wetlands defined by 15A NCAC .0202(59) "are "waters" as defined by G.S. 143-212(6) and are areas inundated or saturated by an accumulation of surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support a prevalence of vegetation typically adapted for life in saturated soil conditions." The frequency and duration for a jurisdictional wetland identified by the U.S. Army Corps of Engineers is when the water table is within 30 cm of the soil surface for 5 % or more of the growing season in at least half the years. At some point during the processes of land development a wetland will impede the progress of development. When this occurs land developers have two options: 1) Avoid impact to the wetland by building around it or redesigning the development project, or 2) Apply for a permit from the United States Army Corps of Engineers (USACE) to drain or fill the wetland. If the developer decides to apply for a permit he/she must give a detailed description of how the impacted wetland will be mitigated. Mitigation is often referred to as compensatory mitigation, compensatory mitigation. It is the restoration, creation, enhancement, or in exceptional circumstances, preservation of wetlands and/or other aquatic resources for the purpose of compensating for unavoidable adverse impacts that remain after all appropriate and practicable avoidance and minimization measures have been achieved as defined by (60 Federal Register 228, pp. 58605-58614, "Federal Guidance for the Establishment, Use and Operation of Mitigation Banks," 28Nov95)**.** If the permit application is accepted by the USACE then the developer may destroy one wetland as long as his plan for the compensatory mitigation wetland is carried out concurrently (2003 Wilmington, NC District Regulatory Division). The permit application indicates how the wetland will be mitigated, the size of the mitigation project, and the timeline for completion of the mitigation project.

The type of wetland being destroyed optimally should be the same type of wetland that is mitigated. For example, for this research project the phosphate mining operation by PCS Phosphate Co. destroyed a non-riverine wet hardwood (NRWH) wetland. The design for their compensatory mitigation projects had to be restored or created NRWH wetlands. Additionally, the mitigation project optimally should be located in the vicinity of the wetland being drained. This allows a similar hydrogeomorphic and ecological landscape and climate for the mitigation project, and increases the chances that the mitigation will replace the wetland that was drained (USACE, 2002). Regardless of the type of wetland being restored, three essential characteristics of all wetland types must be restored: hydrology (water table within 30 cm of the soil surface for 14 days or 5% of the growing season), hydrophytic vegetation (plants that are adapted to living in saturated and/or seasonally saturated conditions) and hydric soils. A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part(USDA, NRCS HSTS Tech. Note No.11), Once these criteria are restored the wetland should begin to function as a natural wetland. Functions vary between wetland types, some common functions are: wildlife habitat, floodwater storage, carbon sequestration, and denitrification.

The size (area) of the wetland to be mitigated depends on the amount of wetlands that are being drained or filled, and is specified in the Corps permit. The United States is operating under a “No net loss policy” which means all wetlands that are permitted to be drained or filled will be mitigated, acre for acre. However, some small drained wetlands can contain a significant function in the niche of that wetland ecosystem. Therefore, mitigating that function will be very difficult so a larger area will need to be mitigated even though the wetland drained has a smaller surface area. The Wilmington Regulatory Division (WRD) has gone beyond the “no net loss policy” and has set ratios for the acreage to be mitigated depending on the chosen mitigation method (2003 Wilmington, NC District Regulatory Division). Mitigation ratios relate the area to be replaced to that been lost. A mitigation ratio expressed as 4:1 means that 4 acres of new wetland are required to replace each acre of existing wetland that is lost. WRD mitigation ratios are as follows: Restoration 2:1, Creation 3:1, Enhancement 4:1, and Preservation 10:1 (In combination with appropriate restoration, enhancement or creation). This standard is set to help attain the goal of no net loss of wetlands. From the ratios it is obvious that restoration is the preferred method by the USACE because it has the best chance of replacing wetland functions lost during land development. Of course the current goal now is to develop a wetland functional assessment methodology that can be tested and approved to determine the necessary amount of compensatory mitigation for destroying a wetland.

A timeline of the compensatory mitigation project is also included in the application permit. This timeline includes a section that describes how the site will be monitored in the time following the completion of the compensatory mitigation project. Under regulatory guidance letter number 02-2 from the USACE, monitoring plans must have a reporting frequency sufficient to determine performance standards have been met. An adequate period of monitoring time of 5 to 10 years is suggested to ensure the project meets performance standards. If a violation occurs after the monitoring time has ended, then enforcement will still be taken.

Enforcement is necessary to determine that compensatory mitigation projects are in compliance with the performance standards agreed upon in the permit application. Furthermore, it holds land developers responsible for their mitigation projects after the completion of the project. A failed mitigation project requires the land developer to fix the problem so the mitigation project meets the set performance standards. Without enforcement mitigation projects could fail and the mitigation credits awarded would be meaningless because there would be a loss of wetlands. Most often hydrology is the determining factor in mitigation successes and failures. If hydrology is met then hydric soils will develop and hydrophytic vegetation will become established. Consequently, compensatory mitigation project failures are difficult to monitor and enforce after the initial required monitoring time. Mitigation projects are very common and permits are constantly being submitted to USACE for approval. Therefore, USACE is constantly monitoring new projects and applications, and this leaves little time to check past mitigation projects. For this reason, many violations cited by the District are a result of contacts from concerned citizens (personal communication – Jennifer Burdette). However, mitigation projects are often found in rural areas and along agricultural fields. These areas are often not seen by the public, and if no signs are posted indicating the area is a mitigation project then it may go unnoticed until/if USACE checks the site. Also, if the failure does not affect a surrounding land owner then it will most likely go unnoticed as well.

Compensatory mitigation projects need to be monitored and evaluated to ensure they have restored wetland functions. Currently projects are monitored for a 5-year period to ensure that the wetland vegetation has become established. This "5-year" waiting period is expensive to maintain. If researchers can predict when restoration a project will be successful in less than 5 years, this could significantly help decrease the number of failures or at least correct them before the vegetation is lost. Predicting successful restorations might be done by looking at soil properties. This would require gathering baseline data before the mitigation project and then collecting data during the required monitoring period. Sampling a nearby (local) reference wetland in order to provide target soil properties that the soils of the mitigation should resemble. After the data are collected see if the mitigation soil data is following a trajectory towards the reference soil data. The specific objectives for this project were to: 1) compare soil morphological, physical, and chemical properties in a restored wetland for two time periods – before restoration and 8 years after restoration, and 2) to compare these properties between the restored site and a natural wetland.

2. LITERATURE REVIEW

2.1 Non-riverine wet hardwood (NRWH)

History

Non-riverine wet hardwood wetlands are older mature hardwood forest that are seasonally wet from precipitation. Non-riverine wet hardwood wetlands were rare in North Carolina, because before European settlement, forest fires from lightning occurred often enough to prevent a complete forest succession to a hardwood dominated forest (Ware et al. 1993, Rheinhardt et al. 1997). After the Europeans settled North Carolina, forest succession began to take place on land that was not being farmed or logged, and NRWH wetlands began to form adjacent to large peatlands (Ashe 1894, Pinchot and Ashe 1897, Rheinhardt et al. 1997). Currently the NRWH wetlands are as rare today as they were before the settlement by the Europeans (Quarterman and Keever 1962, Christensen 1988, Rheinhardt et al. 1997). The NRWH wetlands were easy to drain and made excellent farmland. When used to grow loblolly pine, the succession to a hardwood forest was prevented (Schafale and Weakley 1990, Rheinhardt et al. 1997). Although these wetlands are rare, the functions of NRWH serve an important niche in the today's Coastal Plain and should be restored and preserved. To effectively restore a NRWH, the hydrology, vegetation, soils, and functions of a natural NRWH must be observed and characterized to increase the trajectory towards a fully functional wetland.

Hydrology

NRWH are sometimes called precipitation flats because precipitation is the primary hydrologic input to the wetland. These wetlands have wet soils during winter with some ponding of water as a result of poor drainage (Schafale and Weakley 1990). Water loss from the wetland is mainly a result of evapotranspiration; secondary losses include overland flow and gradual, year-round seepage to the underlying aquifer (Heath 1975, Skaggs et al. 1980, Daniel 1981, Rheinhardt et al. 1997). During summer months a mature hardwood stand can lower the water table to more than 2 m below the soil surface. Cowardin (1979) classifies this wetland as Palustrine. Palustrine hydrology includes all non-tidal wetlands that are substantially covered with emergent vegetation--trees, shrubs, and/or moss.

Vegetation

Schafale and Weakley (1990) give a general overall description of the vegetation found in NRWH (Table 2.1). Plants of a NRWH must be able to withstand prolonged periods of both drought and saturation (surface ponding) as the wetlands are seasonally saturated.

Table 2.1. List of the common species of a natural non-riverine wet hardwood forest and the types of species that should eventually thrive in wetland restoration/mitigation projects.

Plant Layer	Plant Species
Trees – Overstory	*Quercus michauxii* (Swamp Chestnut Oak), *Q. laurifolia* (Diamond Lead Oak), *Q. pagoda (falcata var. pagodaefolia)* (Cherrybark Oak), *Liriodendron tulipifera* (Tulip/Yellow Poplar, *Liquidambar styraciflua* (Sweetgum), *Ulmus Americana* (American Elm), *Acer rubrum* (Red Maple), and *Nyssa biflora* (Swamp Tupelo)
Trees – Understory	*Carpinus caroliniana* (Ironwood), *Acer rubrum* (Red Maple), *Ilex opaca* (American Holly), and *Asimina triloba* (Pawpaw)
Shrub layer	*Lindera benzoin* (Spicebush), *Persea palustris* (Swamp Bay), *Leucothoe axillaries* (Fetter-bush), *Clethra alnifolia* (Sweet-pepper bush), *Vaccinium corymbosum* (Highbush Blueberry), *Myrica cerifera* (Southern Wax Myrtle), *Arundinaria gigantean* (Giant Cane), *Sabal minor* (Dwarf Palmetto), and *Callicarpa Americana* (American Beautyberry)
Vines	*Bignonia (Anisostichus) capreolata* (Crossvine), *Toxicodendron (Rhus) radicans* (Poison Ivy), *Campsis radicans* (Trumpet Creeper), *Berchemia scandens* (Supplejack), and *Vitis spp.* (Wild Grape)
Herb layer	*Carex spp.* (Sedges), *Saururus cernuus* (Lizard's-tail), *Boehmeria cylindrical* (False Nettle), *Woodwardia areolata* (Netted Chain Fern), *Athyrium filix-femina var. asplenioides* (Southern Lady Fern), and *Mitchella repens* (Parttridge Berry)
Rare Plant Species	Vascular -- *Listera australis* (Southern Twayblade), *Trillium pusillum var. pusillum* Nonvascular -- Cheilolejeunea rigidula

Soils

Soils of a NRWH are poorly or very poorly drained Alfisols, Ultisols, and Inceptisols (Schafale and Weakley, 1990; Rheinhardt and Rheinhardt, 2000; Morris 2005). They are mineral soils with little organic accumulation on the surface. Deciduous hardwoods provide an annual input of organic matter. However, NRWH are mineral soils that may contain a thin organic horizon, at the surface. Morris' (2005) data shows that soil texture ranges from sandy loam to clay loam in the upper 90 cm of soil from six NRWH's sampled in eastern North Carolina. Fine soil particles begin to accumulate at approximately 45 cm, and this slows the movement of water infiltrating into the clay enriched subsoil. Therefore, surface ponding will occur if the storage capacity of the soil is quickly exceeded during a heavy rain event. When this situation occurs it allows the soil to develop features representative of hydric soils. The longer periods of continuous saturated and anaerobic conditions are usually present during the winter and spring (Rheinhardt and Rheinhardt, 2000; Morris 2005).

Microtopography

Hurricanes and other severe weather are common to the Coastal Plain region of North Carolina. Often during these severe weather events trees are blown over in NRWH leaving a depression where the tree was uprooted with the root wad next to the depression. The fallen tree creates a microtopographic feature on the soil surface. These microtopographic features can also be formed by logging operations where the roads and skidder trails used by the loggers would create parallel depressions of compacted soil (Scherrer 2000).

Diversity and patterns of plant communities along with characteristics of NRWH soils are a result of surface microtopography (Lutz 1940, Stephens 1956, Bratton 1976, Ehrenfeld 1995, Scherrer 2000). The gradient from micro highs (mounds) to the micro lows (pits) creates a variety of microsites that serve hosts as to a diversity of plants over a small distance. As the root wad exposes subsoil and mixes organic surface soil with mineral subsoil, plants can become established and survive (Lutz 1940, Veneman et al. 1984, Scherrer 2000). The micro lows also serve as a method to collect and store surface runoff from precipitation.

NRWH Functions

Wetlands are functioning ecosystems that provide habitat with an array of plant and animal niches. Wetlands are associated with approximately 70% of North Carolina's rare and endangered plants and animals (Rader and Babcock, 1989). Since NRWH wetlands are rare, an animal survey could not be located. However, based on personal observations the following have been seen in a natural NRWH located south of Aurora, NC: box turtle, white tail deer, rabbit, eastern black bear, water moccasin, black water snake, woodpecker, and mosquitoe. These wetlands can also act as sink for sequestration of carbon if organic matter is available. Denitrification can also occur if nitrate (NO_3^-) is available (Richardson and Vepraskas, 2001).

2.2 Soil Morphology

Soil morphology allows one to qualitatively describe the physical features of the soil which includes texture, structure, color, consistence, biological, chemical, and mineral properties of the soil horizons, as well as the thickness and arrangement of these horizons (Soil Survey staff, 1999, Buol et al., 2003). Horizons form parallel to the soil surface and each horizon has distinguishable characteristics from the horizons above and below it. Differences in horizons are a result of soil forming processes. The layers are divided upon change of any morphological feature, such as change in texture or color from the above or below horizon. Morphology is best examined in the field by use of a large pit in which all the horizons are exposed along a vertical face, which extends into the parent material (generally 2 m deep). Morphology provides a useful tool to record changes to a soil.

Chemical reactions within a horizon can cause visual differences to the matrix color and produce redoximorphic features or mottles in the soil. With matrix being the dominant color of the horizon, redoximorphic features represent the minor colors that are in contrast to the matrix color (Buol, et al., 2003).

Soil Color

Soil color has three quantitative variables: hue, value, and chroma (Buol et. al., 2003). Hue is the dominant color related to the wavelength of light. Value is a measure of degree of light reflected of color. Chroma is a measure of the purity or strength of the dominant wavelength of light reflected.

Since the description of color is subjective, a standardized measurement system, in the form of the Munsell Color Charts (Gregtag Macbeth, Munsell Corporation), has been created that contains color charts. Each chart contains 29 to 42 color chips enabling the user to best fit the soil color to a particular chip. All chips on a given page have the same spectral color, or hue. Every chip corresponds to a given color. These variables of color are designated in the Munsell notation, for example a notation of 10 YR 3/2 is a soil with a color of 10YR hue, value of 3, and a chroma of 2. This would indicate a very dark grayish brown color.

Several components control soil color. Humified organic matter coating mineral grains controls dark colors in surface horizons (Vepraskas, 2000, Buol et al., 2003). The red to yellow colors of the subsoil are due to iron oxide coatings on mineral grains. Even in low amounts, these iron oxides have high pigmenting power (Schwertmann and Taylor, 1977). Since organic matter usually decreases with depth, subsoil color is controlled either by parent material and/or iron oxides. However, organic matter in association with iron and aluminum compounds controls subsurface horizon color in spodic horizons (Buol et al., 2003). Soil color can also be a function of its redox status.

Oxidation of iron occurs during periods of aeration. Hydrolysis and oxidation reactions release reduced (Fe^{2+}) iron bound in primary silicate minerals. Iron (Fe^{3+}) that is released precipitates as iron oxides (Fe_2O_3) or hydroxides ($FeOOH$) due to its low solubility (Schwertmann and Taylor, 1977). The precipitated iron oxides are then uniformly distributed throughout the matrix in aerated soils, or can be segregated into concentrations and depletions in soils with a fluctuating water table.

Redoximorphic Features

Vepraskas (2000) found seasonally saturated soils developed redoximorphic features formed as a result of redox reactions manganese (Mn) and iron (Fe). These features form from the reduction, movement, and reoxidation of these compounds. The reaction of each element is related to its own feature of soil wetness; (i) Mn-based features and (ii) Fe-based features. Mn-based features are visible as black masses, and gray depletions. The Fe-based feature occurs as red masses or gray depletions.

Oxidation-reduction reactions are the catalyst for forming iron based redoximorphic features (Soil Survey Staff, 1999; Vepraskas, 2000). They are formed by changes in redox conditions in seasonally saturated soil. They are identified in the field by their loss (depletion) or gain (concentration) of Fe/Mn compared with the matrix color. This pigmentation is due to the reduction, translocation and oxidation of Fe oxides. The concentrations usually have high chroma (4 or higher in Munsell notation), while depletions are low chroma colors (≤ 2). These features generally form near organic matter sources (Vepraskas, 2000). Factors that affect redox reactions can include type and amount of organic matter, slope and water movement, and temperature.

Redox concentrations were defined as an apparent accumulation of oxidized iron (Schoenberg et al., 1998). They were noted by a higher iron oxide content and chroma than the surrounding matrix. They form by iron moving, oxidizing and reprecipitating. Typical mineral composition of concentrations includes goethite, ferrihydrite, and lepidicrocite (Schwertmann and Taylor, 1989), which produce red, orange, yellow and brown colors. There are three types of redox concentrations: iron masses, iron in pore linings and nodules, and concretions. Iron masses are soft, non-cemented, easily crushed accumulations of iron oxides within peds, away from cracks or root channels. The size of these masses depends on the size of the structural aggregate.

Pore linings are iron accumulations around ped surfaces, cracks, and root channels. These can occur at any depth within the profile, and do not need live roots to form. Oxidized rhizospheres are iron oxidized around an active root bringing oxygen into a saturated environment. Nodules and concretions are usually round, cemented iron that is not easily crushed. They are not a reliable indicator of current redox processes because the uncertainty of their origin (Vepraskas, 2000). They were thought to have either formed in place or been deposited.

Areas of iron loss in the soil are termed redox depletions. They are defined as bodies of low chroma ≤2 and value of 4 or more, where Fe, Mn, and perhaps clay have been stripped out of the area (Soil Survey Staff 1999; Vepraskas, 1999). Depletions can occur along pore linings, root channels, ped surfaces, or ped interiors. Evidence of iron reduction is readily identifiable in the field. In many cases, the iron has been reduced for "significant" periods (Hayes and Vepraskas, 2000; Veneman et al., 1998).

2.3 Wetland Soil Indicators

Saturation and reduction are two of the three variables that affect wetland soil morphology. When soils are saturated, reduced, and have soil microbes present there is a potential for soil morphological properties to form that are unique to hydric soils (Richardson and Vepraskas, 2001). The soil morphological properties have been divided into physical and chemical indicators. Chemical indicators are soil properties that require test to analyze representative soil samples. These indicators are usually more quantitative where as physical indicators are qualitative. Results for chemical features cannot be determined in-situ. Physical indicators are soil features that can be determined or reasonably estimated by eye or hand. These indicators are commonly used when describing soil profiles in the field. They are inexpensive, time efficient, easily replicable, and effective for describing the visual characteristics of soils.

Chemical - Reduction chemistry and morphology

In order to understand the chemical reactions that occur in saturated soil we must first understand what occurs when the soil is not saturated. Soil microbes produce electrons as they consume and digest organic matter (dead roots, leaves, wood, etc.) (Vepraskas, 1995). As this happens in an unsaturated soil, the electrons are accepted by oxygen (O_2) (Mitsch and Gosselink, 1993). The chemical reaction would be:

$$\mathbf{O_2 + 4e^- + 4H^+ \rightarrow 2H_2O} \qquad \mathbf{(2.3.1)}$$

Once the soil becomes saturated, microbes use the dissolved O_2 in the water as an electron acceptor until it is depleted and the soil becomes anaerobic (McBride, 1994). After the soil becomes saturated and dissolved (O_2) levels are approximately 10^{-6} M, aerobic microbes die and anaerobic microbes continue to decompose organic matter (Faulkner and Patrick, 1992; McBride, 1994). After the microbes begin to reduce dissolved O_2 the soil redox potential has decreased and is approximately between 300 and 600 mV depending on pH (McBride, 1994). After the dissolved O_2 is depleted the microbes continue to decompose organic matter and produce electrons that are accepted by other oxidized soil components which in turn become reduced.

Electron acceptors in the soil usually follow this order with increasing reduction:

1) Denitrification

$$\mathbf{2NO_3^- + 10e^- + 12H^+ \longrightarrow N_2 + 2H_2O} \qquad \mathbf{(2.3.2)}$$

2) Manganese Reduction

$$\mathbf{MnO_2 + 2e^- + 4H^+ \longrightarrow Mn_2^+ + 2H_2O} \qquad \mathbf{(2.3.3)}$$

3) Iron Reduction

$$\mathbf{Fe_2O_3 + 2e^- + 6H^+ \longrightarrow 2Fe(II) + 3H_2O} \qquad \mathbf{(2.3.4)}$$

4) Sulfate Reduction

$$\mathbf{SO_4^- + 8e^- + 10H^+ \longrightarrow H_2S + 4H_2O} \qquad \mathbf{(2.3.5)}$$

5) Carbon Dioxide Reduction

$$\mathbf{CO_2 + 8e^- + 8H^+ \longrightarrow CH_4 + 2H_2O} \qquad \mathbf{(2.3.6)}$$

(adapted from McBride, 1994, and Mitsch and Gosselink, 1993)

The typical reduction sequence in soils is a result of the lack of air in soil pores. Oxygen is reduced first-making the soil anaerobic- followed by nitrate, manganese oxides, then iron oxides, sulphur and lastly carbon. Each element acts as an electron acceptor until it is fully consumed. By its virtue of position in the reduction sequence, iron must occur when oxygen, nitrate, and Mn oxides have been first reduced. Once the soil drains and oxygen enters the pores, aerobic microbes dominate and oxygen once again becomes the primary electron acceptor.

Four conditions must be satisfied simultaneously for iron reduction to occur (Faulkner and Patrick, 1992, Menongial et. al., 1996 Vepraskas, 1999): (i) dissolved oxygen removal; (ii) a source of oxidizable organic matter (electron source); (iii) active bacteria to decompose organic matter with, soil temperatures must be above biological zero (5 ˚C); and (iv) saturated soils. Reduction of Fe(III) can only occur if it is present in the soil. Iron reduction is inhibited or stopped when any of these components are absent. When all factors are present and occurring, bacteria decomposing the soluble organic matter will reduce Fe(III) to Fe(II). Reduction of iron may not occur, if any of the requirements in the above sequence cease. The lag time between soil saturation and iron reduction can be around three weeks or 21-days (Hayes, 1998, He et. al., 2002).

Measuring Redox Potential

Redox potential is theoretically based on the quantity of e^- available in the soil solution, which is measured as potential electron activity pe which can be converted into redox potential Eh (mv):

$$\mathbf{Eh = .059\ pe} \qquad \mathbf{(2.3.7)}$$

Recent soil hydromorphology studies employ redox electrodes with monitoring wells to assess soil redox potential by measuring Eh (Hayes, 1998, Karthenasis, et. al., 2003, D'Amore, et. al., 2004). Field measurements of voltage are converted to Eh by adding a correction factor of 200 mv. The presence of reduced iron in soil solution is determined by the use of an Eh-Ph diagram (Vepraskas, 2000) calculated by:

$$\mathbf{Eh = 595 - 60pH \quad (ph< 7.5)} \qquad \mathbf{(2.3.8)}$$

Magnitude and sign of voltage must be recorded and pH of soil solution must be known. Redox potential measurements are highly variable; therefore measurements should include at least 5 separate probes at a given depth in the soil and should be no more than 6 inches apart within the same horizon. Potentials range from +1 volt to –1 volt (+1000 mv to –1000 mv). Aerated soils tend to have higher Eh values (1000 to 500mv) while soils with reduced iron have lower potentials ($\leq$500 mv).

Physical - Redoximorphic Feature Formation

Reduced iron (Fe^{2+}) is soluble, which allows it to move with the soil water and eventually oxidize in unsaturated/aerobic conditions forming Fe-based redox features. Iron oxides coat soil mineral surfaces, giving a reddish, yellow, or brownish characteristic color to the soil. When saturation occurs, oxygen diffusion into the soil is reduced by orders of magnitude, and is depleted by microbes decomposing organic matter (Menongial, et. al., 1996). The microbes then deplete any remaining NO_3^- and Mn, and the next element in the sequence of reduction, Fe. Iron oxides dissolve and become colorless, gray color remains because that is the color of most mineral grains without the Fe oxide coating. Mobile Fe^{2+} ions then move to points of oxidation, concentrate and re-oxidize upon soil drying or are leached from the system. Points of oxidation include entrapped oxygen within peds, root channels and cracks, or anywhere oxygen reenters the soil (Vepraskas, 2000).

Oxidized rhizospheres, pore linings, form in flooded soils where living plant roots bring oxygen into the root zone, thus causing Fe^{2+} to oxidize and precipitate as Fe^{3+} around the root channels. Pore linings can develop at any depth in the soil profile. Once the soil is saturated and reduced, the ferrous iron is mobile in soil solution. As the soil drains, the soluble iron can move to points of oxidation (Vepraskas 2000, Evans and Franzmeier, 1986). These points are either within peds (masses), caused by larger pores or voids; or along ped faces

Redox depletions of chromas greater than 2 can occur if they are formed by the same process of iron loss seen in chroma 2 depletions. Iron-oxides may remain on the particle surfaces if chroma 3 colors are present (Vepraskas 1999). These soils can be reduced for short periods, but may be waterlogged for long periods (Vepraskas and Wilding, 1983). Chroma $\geq$3 depletions are associated with saturation, but have been found to be saturated and reduced for a lesser time period than chroma $\leq$2 depletions (Franzmeier, et. al. 1983).

Hayes and Vepraskas (2000) found duration of saturation in soils on a broad inter-stream divide of the Lower Coastal Plain in NC varied slightly with distance away from an individual drainage ditch. However, within 30m of the ditch, water tables were lower and fluctuated more often and redox potential was lower (<500mv) for a shorter period than those soils further away from the ditch. Reduced iron (Fe II) was discharged into the argillic horizons soils adjacent to the ditch from upslope soils and was oxidized when water tables fell, thus creating more oxidized iron (Fe III) masses closer to the ditch.

2.4 Wetland Restoration Projects Studied

The purpose of wetland restoration research is to increase the probability of success. We are just beginning to understand the dynamic functions within wetlands and how to restore the jurisdictional wetland criteria in hopes that the natural functions of the wetland will eventually come back. Therefore, when looking at changes in soil properties we must consider all wetland types and not just limit the research to restored NRWH. Specific characteristics of interest changes in: redoximorphic feature abundance, organic carbon, A horizon thickness, and soil nutrients (P, Mn, Ca, pH, BS%). Baseline data for these soil characteristics should be gathered at the restoration site before wetland hydrology is restored. Ultimately this data needs to be correlated to a reference wetland to determine what the initial state of the soil was before being drained.

Stolt et al., (2000) compared three constructed wetlands in Virginia, 4 to 7 years old, to paired adjacent Palustrine forested and scrub-shrub reference wetlands. They examined differences in topography, hydrology, and soil properties as well as redox potential. They found seasonal fluctuations in water-table levels to be similar between the paired constructed and reference wetland. Redox potentials were also similar in reference and constructed wetlands. Levels of organic carbon (C) and nitrogen (N) were 5 to 10 times greater in the reference wetlands. Since most of the N was in the organic form, the N levels followed the elevated C levels in the reference. Similar results were found for C and N by Bishel-Manchung et al. (1996) in a pooled study of 20 reference and 44 constructed wetlands in Pennsylvania. The constructed wetlands studied by Bishel-Manchung et al. (1996) ranged in age from 1 to 8 years and they found no relationship between the age of a wetland and organic C content. Stolt et al. concluded that levels of C and N in the constructed wetland would increase as hydrophytic vegetation added organic matter to the soil surface. In time the levels of C and N should begin to approach levels found in the reference.

Hanks (1971) studied old field succession on the inner Coastal Plain of New Jersey. He studied 22 sites that had been abandoned from 1 year to 40 years and six stands of forest that showed little disturbance over 50 years. Hanks found that soil pH, organic matter, phosphorus and calcium differed among successional age-groups. The content of plant available calcium and phosphorus decreased from younger through older age groups. It was noted that calcium dropped about 180 mg/L during the first 15 – 20 years and more slowly afterwards. The pH increased in acidity by 1 unit from the 1-2 year old fields compared to the 10-15 year old fields. The decrease in phosphorus was most evident from the 1-2 year old fields to the 10-15 year old fields. The loss of phosphorus was thought to be attributed to the complexing of phosphorus with iron and aluminum. Meanwhile, Odum (1960) found a tendency for phosphorus, calcium, and organic matter to leach downward in old field soils. Base saturation and pH levels were found to be higher in the constructed wetlands as compared to the associated adjacent reference wetland (Stolt et al., 2000). They also noted the constructed wetland soils had more basic cations, such as Ca and Mg, on their exchange sites and also had a higher pH. The effects of the addition of lime and fertilizers may persist for a considerable time after abandonment and may be reflected in given soil parameters during old field succession. The restoration of wetland hydrology could lessen the time to restore native wetland soils, but the effects still buffer the process of change to the soil properties.

Several studies were found that compared differences in soil properties after a period of time for a restored wetland. However, most studies removed the A horizon as a method to restore wetland hydrology. The removal of the A horizon would restore hydrology with the use of the natural water table, and eliminated the need for ditches, dikes, and dams. A study by Vepraskas et al. (2006) found in a created riverine wetland soil that redox concentrations increased by approximately 10% after nine ponding events that ranged in length from 4 to 44 days. Also, abundance of redoximorphic features increases with the number of ponding events. This study focused more on redox depletions than redox concentrations.

3. Materials and Methods

3.1 Site Locations

This project evaluated two sites in the lower Coastal Plain of North Carolina. The sites consisted of a restored non-riverine wet hardwood forest (NRWHF), and a natural NRWHF that was used as a reference for this study. Both sites are located south of Aurora, N.C. (N 35° 15.24', W 76° 48.31') in Beaufort County (Figure 3.1). The sites will be referred to as the restored site and the reference site. The restored site was on the western edge of an agricultural field under production, and the reference site was located directly adjacent to the west side of the restored site (Figure 3.2). Second-growth Palustrine forest surrounds the eastern, southern, and northern boundary of the restored site (Figure 3.3) (Scherrer 2000).

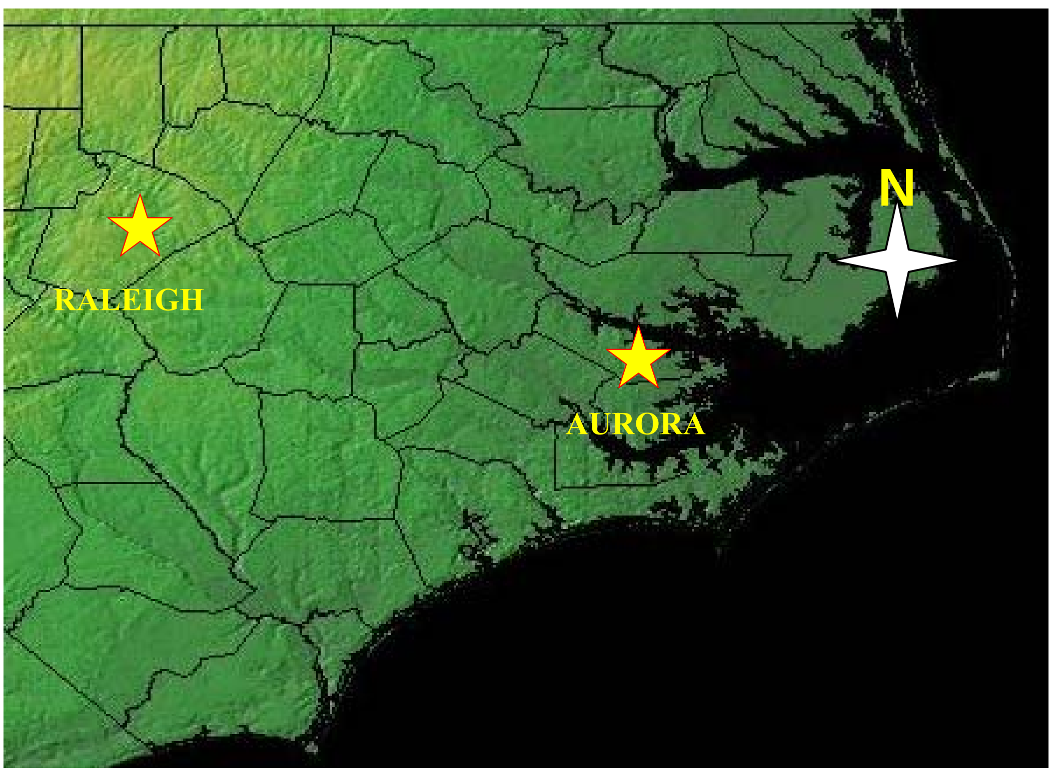


Figure 3.1. Map of North Carolina's lower Piedmont and Coastal Plain regions showing location of research site (Beaufort, Co.) relative to Raleigh, NC.

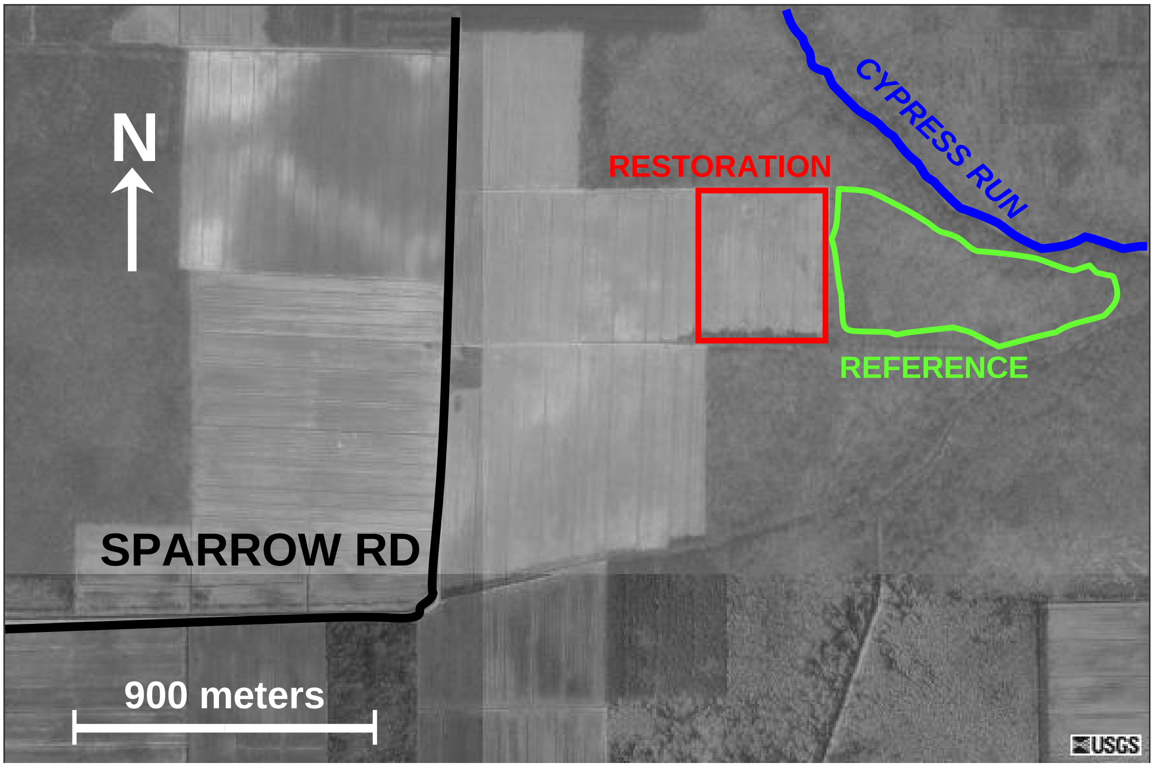
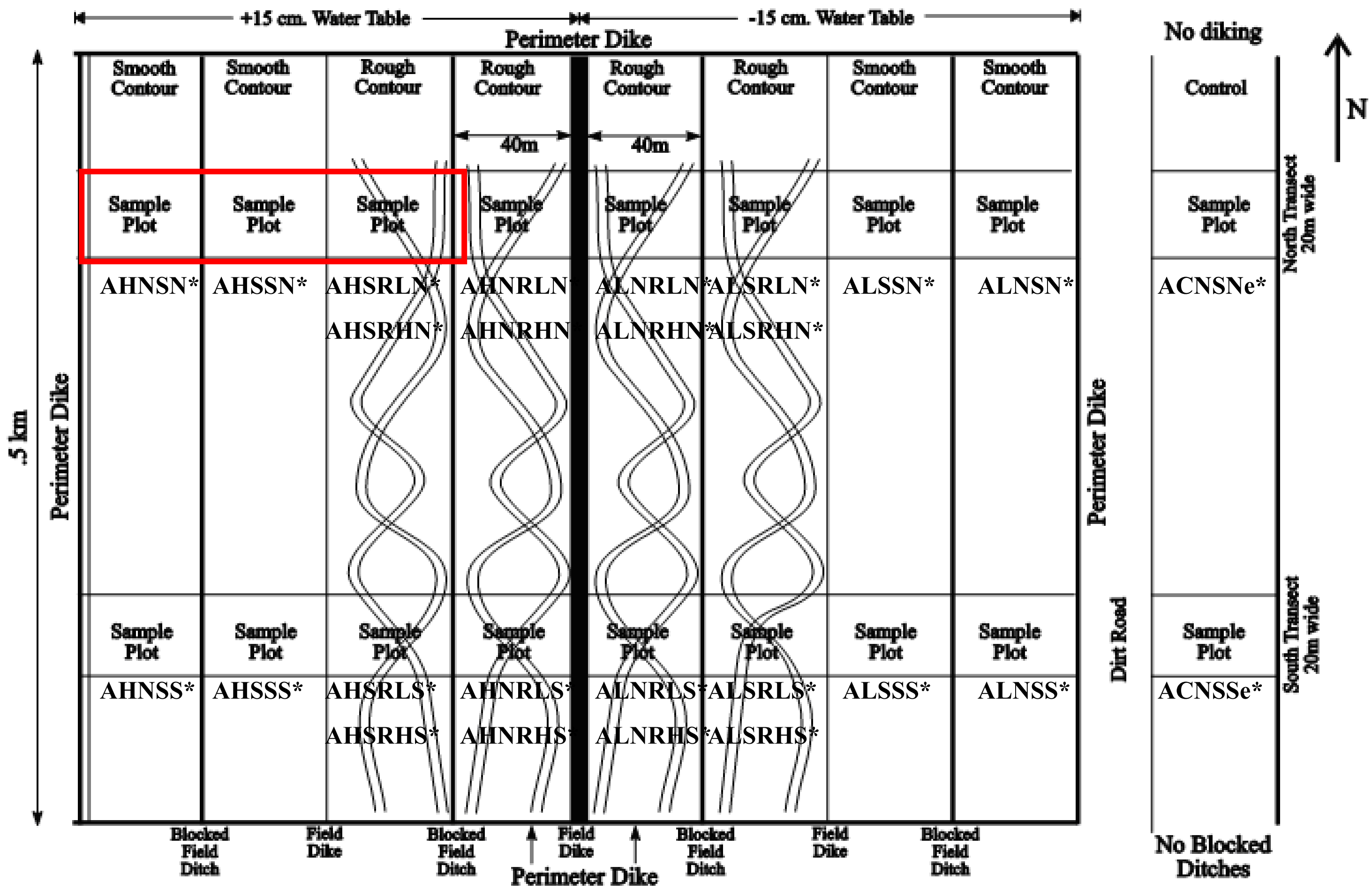


Figure 3.2. Aerial photo of restored and reference site. Picture was taken March 6, 1994. Picture was obtained from the TerraServer website (http://www.terraserver.com).

Figure 3.3. Generalized plan view of restored site. The rough treatments are in the middle with smooth treatments to each side. The entire study area is surrounded by a perimeter dike except for the control where existing agricultural drainage was maintained. Sample plot labels are indicated to the right of the sample plot. The four sample plots highlighted in red were sampled by bucket auger. All data was collected within the two transects at the sample plots (Smith, 1998).
* The abbreviations describe the treatments to the sample plots. Table 3.1 is a key for the abbreviations.


+15 cm. Water Table
-15 cm. Water Table
Perimeter Dike
No diking
N
Smooth Contour
Smooth Contour
Rough Contour
Rough Contour
Rough Contour
Rough Contour
Smooth Contour
Smooth Contour
Control
40m
40m
Sample Plot
AHNSN*
AHSSN*
AHSRLN*
AHNRLN*
ALNRLN*
ALSRLN*
ALSSN*
ALNSN*
ACNSNe*
AHSRHN*
AHNRHN*
ALNRHN*
ALSRHN*
North Transect 20m wide
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Perimeter Dike
Perimeter Dike
Dirt Road
South Transect 20m wide
AHNSS*
AHSSS*
AHSRLS*
AHNRLS*
ALNRLS*
ALSRLS*
ALSSS*
ALNSS*
ACNSSe*
AHSRHS*
AHNRHS*
ALNRHS*
ALSRHS*
Blocked Field Ditch
Field Dike
Blocked Field Ditch
Field Dike
Blocked Field Ditch
Field Dike
Blocked Field Ditch
Perimeter Dike
No Blocked Ditches

The reference site is confined by Cypress Run Creek to the north and an agricultural main collection ditch to the south. The restored site was a prior converted wetland, and the reference site may have been timbered at some point in the past. However, the mature hardwood forest indicates the reference site has fully recovered even if it had been altered. The restored site was owned by PCS Phosphate and served as one of their mitigation sites. The restored site is approximately 10 ha in size and the reference site is approximately 18 ha in size.

3.2 Site Development for Restoration

Restoration began in April of 1995 and included alterations that prevented precipitation from leaving the site as NRWH wetlands are precipitation driven. In order to prevent surface runoff, an earthen dike was built around the perimeter of the site. The restored site had four parallel field ditches spaced 80 m apart that had the outlets blocked. The ditches were not filled in as the study wanted to maintain two different water table treatments. All sampling in the restored site occurred within two transects located approximately 100 m from the field edges. Both transects ran from east to west and crossed the field ditches in a perpendicular manner. These transects were used to collect all data for the restored site. The reference plots were located by extending the southern transect from the restored site into the reference site. Two plots were identified in the reference, one at 50 m and the other at 180 m into the reference site.

3.3 Treatment Design

The four field ditches were left open and in place, however, V-notch weirs were placed at the outlet of each ditch. The weirs of the two eastern field ditches were set so that the water table would reach 15 cm below the average land surface before water would flow over the weir. The weirs of the two western field ditches were set at 15 cm above the average land surface so that the water would only leave the outlet when the water table reached 15 cm above the average land surface. An earthen dike was placed in the middle of the site running from north to south, to keep the surface runoff of the two controlled drainage treatments independent.

The site was tilled in February and March 1995 to suppress native annual vegetation. Within the two water table treatments, two surface treatments were imposed to include a smooth treatment and a rough contoured treatment (Figure 3.3). Smooth treatments were located on the eastern and western edge of the restoration site (Figure 3.4). The surface of the smooth treatment was not manipulated, but was left as it had existed under agricultural production. Rough treatments consisted of micro highs and micro lows, which were intended to simulate microtopographic relief characteristic of NRWH. A farm tractor pulled a modified disk-plow that left behind a furrow and mound that simulated the micro highs and micro lows found in NRWH. The tractor driver was left to create the contouring in a random, haphazard manner by moving back and forth across the middle (either side of the interior field ditches) of the site in the north/south direction (Smith 1998). Dikes were built equidistant from each field ditch, after contouring, to make each treatment independent from the adjacent treatment.

The target wetland community is a NRWH and hardwood saplings were planted to facilitate a quicker trajectory towards the climax community of a hardwood forest. These saplings included a variety of indigenous hardwood tree saplings which included *Liriodendron tulipifera* (yellow-poplar), *Quercus nigra* (water oak), *Quercus pagoda* Raf. (cherrybark oak), and *Nyssa biflora* Walt. (swamp blackgum). The vegetation layout had natural and planted plots alternating across the site from the east to west. The density of saplings planted was approximately 250 trees per hectare (Scherrer 2000). Additionally, these plantings were intended to enhance the establishment of heavy-seeded species that otherwise might not appear for many years (Scherrer 2000). There were two vegetation treatments for this restoration project, natural and planted. Natural blocks were left unaltered and represented a normal succession sequence from old field to forest. Planted blocks included the aforementioned tree species in a 6 m by 6 m grid.

A control plot was located between the eastern boundary of the restored site and the western boundary of the reference site. This area was under agricultural production but it ceased after restoration. The control plots still had a drainage ditch approximately 10 m away that effectively drained the control area.

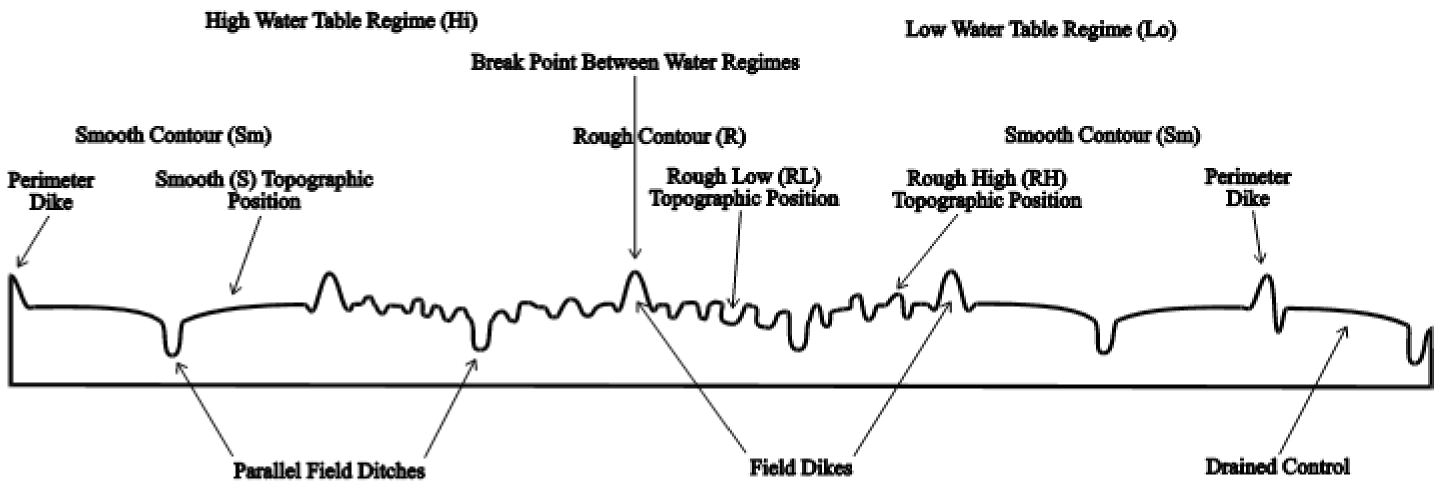

Figure 3.4. Cross-sectional view of treatment layout for the entire study site (Smith, 1998).

3.4 Sampling Locations

Smith (1998) established sampling locations within the two identified transects. The smooth contour treatment had one sampling location in each sample cell. The rough contour treatment had two sampling locations in each sample cell, one in the representative micro-high and one in the representative micro-low. The same cells that were sampled in 1995 were sampled again in 2003. These sample cells are bordered by at least one field dike and one ditch. As these cells extended from a field dike to a field ditch, sampling locations were chosen to be close to the middle of the sample plot to limit influence from either side. The rough contour sampling locations were kept as close to the middle as possible, but importance was placed on identifying a micro-high and micro-low.

3.5 Initial Site Conditions

Restored - 1995

Land elevation is less than 20 m and the predominant soil series is Roanoke sandy loam (Fine, mixed, thermic Typic Endoaquult) (Smith 1998). The USDA classifies the soil as hydric, with precipitation being the main hydrological driving force. Lilly (1981) found agricultural land preparation included extensive ditching and draining, forest clearing, and smoothing and grading of the surface to enhance runoff for parcels of land similar to the Aurora wetland restoration site. The soil was then fertilized and cropped with corn, wheat, and soybeans for many years, time is unknown (Scherrer 2000).

Smith (1998) determined initial soil conditions after surface treatments were imposed. This included a completed profile description and obtaining soil samples from a soil pit in each sampling location. Samples were collected by Smith (1998) from the 0 to 15 cm depth and were analyzed by the North Carolina Department of Agriculture Soil Testing Laboratory. Smith completed 26 profile descriptions.

Restored – 2003

The restoration site was re-sampled in August 2003. Soil profile descriptions were completed and samples collected in the same sampling locations used by Smith in 1995. A backhoe was used to excavate soil pits in most plots. A 2" open bucket soil auger was used to sample four plots (AHSRHN, AHSRLN, AHSSN, AHNSN) in the restored site and all plots in the reference as the areas were inaccessible with the backhoe (Figure 3.3 and Table 3.1). Profile descriptions were made of each pit face using standard soil survey criteria and nomenclature (Soil Surv. Div. Staff, 1999) to a depth of approximately 1 m. Some sampling plots in the restoration site had a water table above 1 m, in these pedons the bottom of the description was determined by the depth to the water table. Auger borings were completed during a dry portion of the summer in all plots to determine the depth to the parent material (C horizon). Morphological features such as horizonation and visual estimation of aerial extent of redoximorphic features were made. Pit sampling provided a large lateral and vertical view of the soil profile in place, allowing for accurate description of percent redoximorphic features, horizon boundaries, and soil structure. Soil pits also allowed photographs to be taken to further analyze and represent the visual observations made in the field.

Table 3.1. Key to identify treatments for the sample plots.

Key	Location and Treatment
Site	A = Aurora
Water Table Treatment	H = +15 cm above the soil surface L = -15 cm below the soil surface C = Control
Vegetation Treatment	S = Selected Plantings N = Natural Succession
Surface Treatment	RH = Rough High RL = Rough Low S = Smooth
Transect	N = North Ne = Northeast S = South Se = Southeast

A total of 30 soil profile descriptions were completed. Four profile descriptions were made in the reference, 24 profile descriptions were made in the restored site, and two control plots were described. Control and smooth surface treatments plots included one profile description per soil pit. Reference and contoured surface treatment plots contained two profile descriptions per pit, one described the micro high and the other described the micro low. Therefore, in contoured surface treatments the soil pits were dug perpendicular to the microtopography (Figure 3.5).

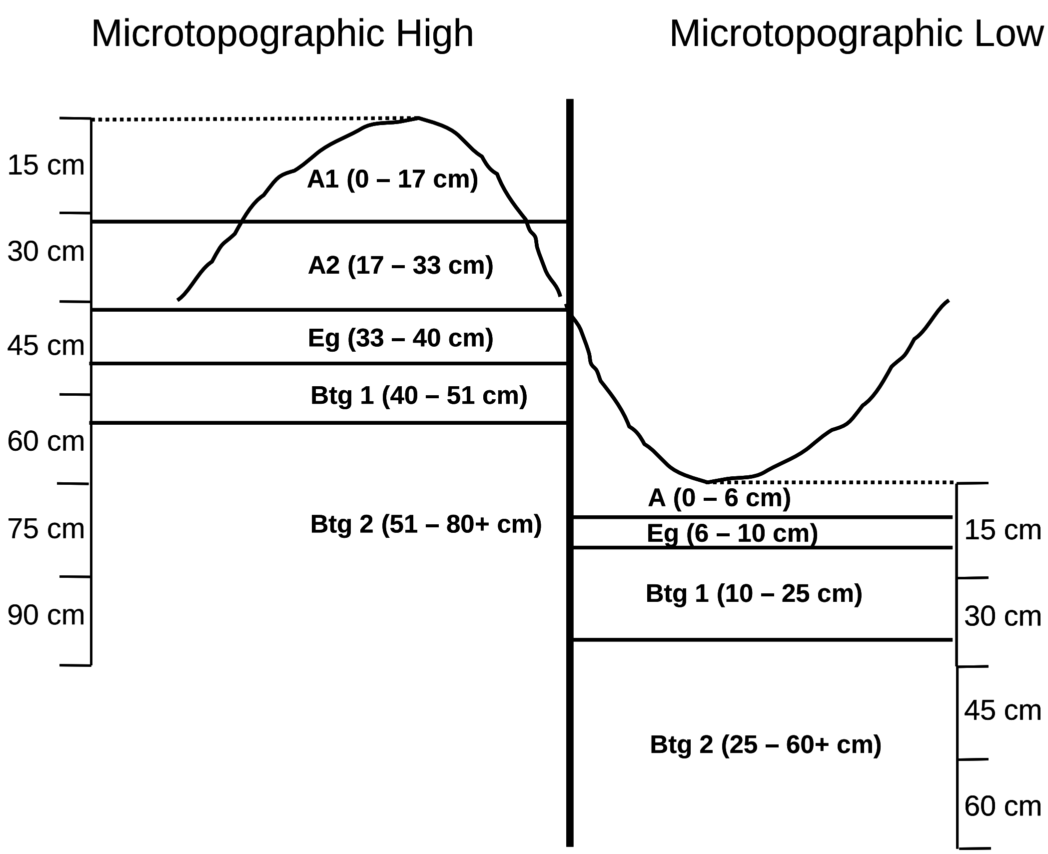

Figure 3.5. Example of how one soil pit was used to perform two profile descriptions. One description characterized the micro-topographic high and the other characterized the micro-topographic low.

Two undisturbed soil cores (7.6 cm diameter by 7.6 cm height) were collected for the upper 15 cm of each profile description to determine bulk density. This was done using an Uhland core sampler (Uhland, 1950) made of a hammer to drive the cores buffered by a ring adapter within a cutting head sleeve into the soil. The cores were brought back to the lab and oven dried in the lab at 100 ˚C for 24 hours and then weighed to determine bulk density.

Grab samples from all horizons of the reference and restoration site were dried and ground with an electric grinder to pass through a 2 mm mesh sieve. Percent organic carbon and total nitrogen were determined through dry combustion with a Perkin-Elmer PE2400

CHN Elemental Analyzer (Culmo, 1988). Extractable K, Ca, Na, Mg, Mn, Zn, and Cu were determined by running Mehlich III extract (Mehlich, 1984) through an inductively coupled plasma emission spectrograph. Cation exchange capacity and sum of base cations were also determined (Mehlich, 1976). These samples were sent to the North Carolina Department of Agriculture, Soil Testing Services, Raleigh, North Carolina for nutrient analysis.

Reference Site - 2003

Wetland restoration often occurs in areas where a similar natural wetland is located. These reference wetlands can provide useful information to how the restored wetland once functioned and how they would appear if left unaltered. As mentioned before a hardwood forest surrounds three sides of the restoration site, and is an active functioning NRWH. This natural wetland is a second-growth hardwood forest with an overstory of *Quercus michauxii* (swamp chestnut oak), *Quercus laurifolia* (laurel oak), *Quercus nigra* (water oak), *Liquidambar styraciflua* (yellow-poplar), and *Fraxinus pennsylvanica* (white ash) among other species (Scherrer 2000). Precipitation is also the main hydrological input to this specific NRWH. Water infiltrates slowly as the restrictive clay layer begins at about 30 cm, the soil is classified as Roanoke sandy loam (Fine, mixed, thermic Typic Endoaquult). The reference site contains the microtopographic features that were simulated in the restored wetland. Two soil sampling/monitoring plots were established in the reference wetland with each plot having a micro high and a micro low.

3.6 Sampling Methods and Equipment

The hydric soil technical standard (HSTS) was tested and all data was gathered weekly from December 2003 to December 2004, for 1 year. This is the minimum recommended monitoring time by the National Technical Committee for Hydric Soils (NTCHS) (USDA, NRCS HSTS Tech. Note No.11). A 1 year period is set so that a full dry-wet-dry cycle can be observed. During this period a soil is said to have met the HSTS if it is saturated and anaerobic in the upper 25 cm for 13 days. When instruments are measured weekly the 13 day requirement is met when conditions are observed in 3 consecutive weeks. This period of anaerobic and saturated conditions must be met during a period of normal or below normal rainfall.

Rainfall

The HSTS can only be met during periods of normal or below normal rainfall. Normal rainfall falls between the 30th and 70th percentile of the weather station closest to the site. This limits the number of wetlands that meet the standard so that heavy rain events do not cause a marginal area or upland to be counted as a wetland during periods of above normal rainfall.

Rainfall was monitored on site using a Davis Rain Collector II tipping bucket recording rain gauge. A HOBO Event data logger (Onset Computer Corp. PO Box 3450 Pocasset, MA 02559-3450) was integrated to the tipping-bucket rain gauge and recorded the time and date of each tip (0.2 mm). Once a month a HOBO data logger shuttle was used to download the data from the rain gauge, the data was then interpreted using BoxCar Pro4.3 software. Additionally, a manual rain gauge (Ben Meadows Co., PO Box 5277 Janesville WI USA 53547-5277) was installed adjacent to the recording rain gauge as a back up and to ensure the data quality of the recording rain gauge. Both gauges were placed on a wooden platform in an open area of the restored site where no trees would interfere with the rainfall observation data.

Saturation

To meet the standards requirement for saturation, free standing water must exist in two piezometers at a depth of 25 cm below the soil surface. Two piezometers at a depth of 100 cm below the soil surface are also required to provide an advance notice of when the water table might rise to within 25 cm of the soil surface. In addition, an open screen well to a depth of 2 m is recommended to monitor and confirm site hydrology (Figure 3.6).

Piezometers were only open at the bottom and determined if the soil was saturated at a specific depth. Wells had slits cut the entire length of the soil profile and measure the water table across a range of depths. An open screen well at a depth of 2 m is required for each plot to record local hydrological patterns. Wells and piezometers were installed by augering a hole and backfilling with a coarse sand and sealing the remaining with a 10 cm thick bentonite cap.

Water table levels were measured using three different types of wells: BAE floating device in polyvinylchloride (PVC) recording wells (2 m depth), RDS WL-40 (1 m depth) (Remote Data Systems, Inc. 163 Brunswick Electric Road, Suite 1B Whiteville, North Carolina 28472), and manually read PVC pipe wells (1.5 m). The BAE floating wells were installed in each plot on the southern transect in 1996, 1 year after restoration. These wells were working and in place so they were used for data collection for this study (Dec 2003 to Dec 2004). The control plot and reference area were not previously instrumented so RDS WL-40 wells were installed in each plot in December 2003. During the summer of 2004 the water table in the reference wetland dropped below 104 cm, which is the lower limit of the RDS WL-40 wells. Manually read open screen wells were installed during September 2004 to a depth of 150 cm. Sloughing of coarse sediments below 150 cm made it impossible to install the well to 2 m.

The restored site was instrumented with 26 piezometers at a depth of 25 cm, 26 piezometers at a depth of 100 cm, and nine open screen wells. The control plot was instrumented with two piezometers at 25 cm, two piezometers at 100 cm, and one open screen well. The reference site was instrumented with 4 piezometers at 25 cm, 4 piezometers at 100 cm, two automated wells (1 m depth) and two manual open screen wells (1.5 m depth).

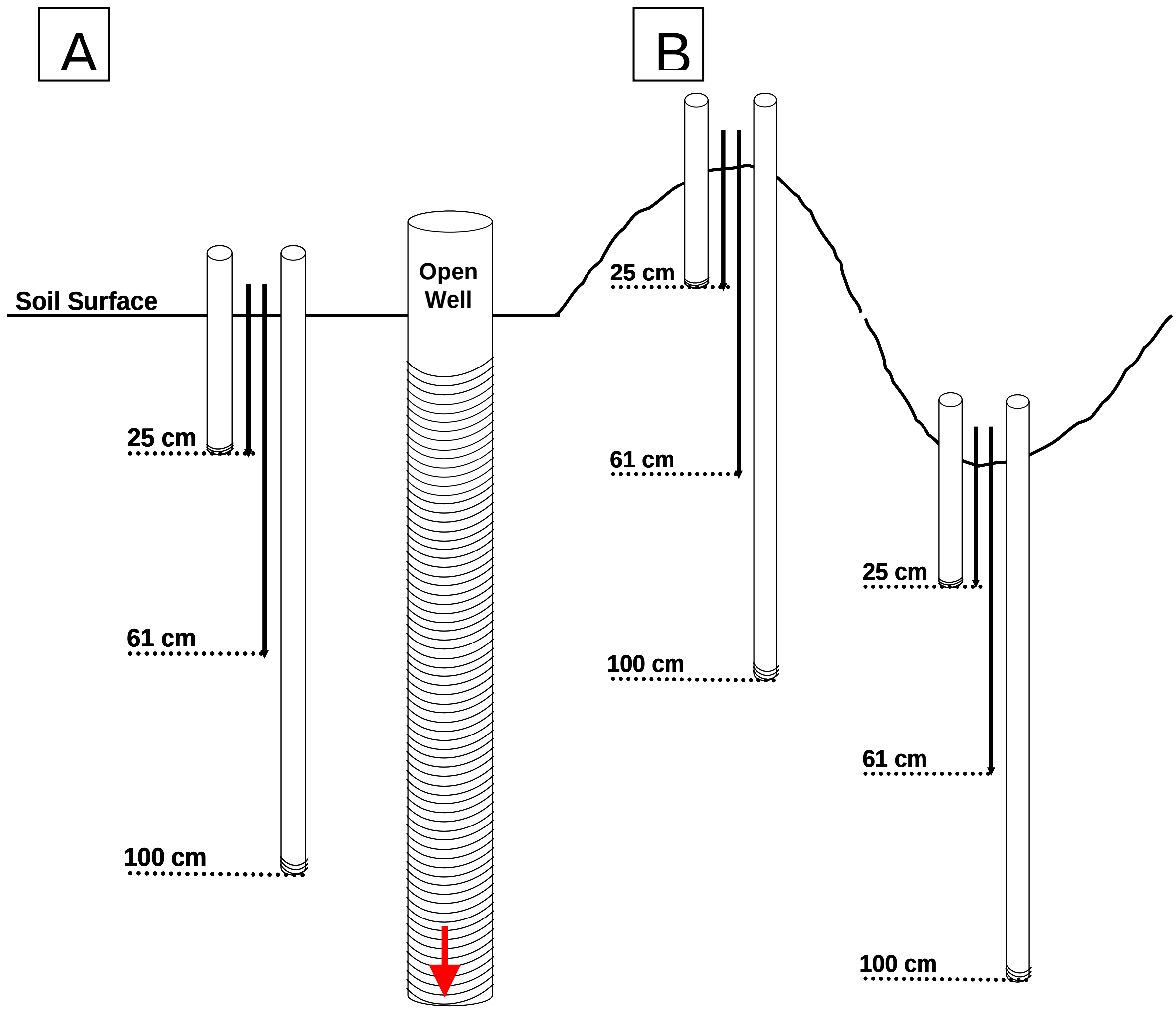

Figure 3.6. Hydric soil technical standard instrumentation for a smooth (A) and microtopographic (B) plot. Each HSTS monitoring station includes: two piezometers and five redox electrodes at 25 cm, five redox electrodes at 61 cm, two piezometers at 100 cm, and an open screen well to 200 cm. The contoured treatments include a HSTS monitoring

station in the micro-high and the micro-low. The open screen wells in the contoured treatments were positioned on unaltered land surfaces within the treatment plots.

Anaerobic Conditions

All plots were instrumented with five redox electrodes at two depths (25 cm and 61 cm). A detailed construction method was given by Smith (1998). The smooth plots in the restored site had only one sampling location (Figure 3.6A). Reference plots and contoured plots in the restored site had the two sets of redox electrodes instrumented in both the micro high and the micro low (Figure 3.6B). There were a total of 130 electrodes in the restored site, 40 electrodes in the reference site, and 10 electrodes in the control plot. A detailed construction method for the electrodes is given by Smith (1998). Voltage was measured in the field weekly at each depth for each plot using an Accument AP60 Series Portable Meters Fisher Scientific Co (Pittsburgh, PA) and an Ag/AgCl, KCL saturated reference electrode from Jensen Instruments (Tacoma, WA). The field readings were concerted to Eh values by adding a conversion factor of 200 mV.

Soil pH was measured at each sampling location where a bank of redox electrodes existed. Soil samples were collected from both depths where redox electrodes were located (25 cm and 61 cm) for each set of redox electrodes. Each time pH was measured 38 soil samples (reference n=4; restoration n=32, control n=2) were individually analyzed for pH. Samples were placed in plastic tubes and sealed to be brought back to the lab for pH analysis. Soil pH was determined by making a soil slurry consisting of 10 g of soil mixed with 20 g of distilled water. An AR series bench top pH meter from Fisher was then used to measure the pH of the soil slurry. Soil pH was measured at three times: during a saturated and anaerobic period, a wet to dry transitional period, and an unsaturated and aerobic period.

Soil pH values were used in the following equation [$Eh = 595 - (60 * pH)$] to determine when soils became aerobic and anaerobic. This equation is used for the HSTS (USDA, NRCS HSTS Tech. Note No.11).

3.7 Statistics

The treatments were compared using statistical analysis software from SAS. The characteristics of the A horizon, redox concentration percentage, total-organic carbon, total kjeldahl-nitrogen, and NCDA soil test results were analyzed using the Mixed (SAS, 2000) procedure, with a compound symmetry covariance structure to compare surface treatments from 1995 to 2003. The Tukey-Kramer method was used to compare surface treatments within a given year. The model statement included the year, treatment, plot, and a year*treatment interaction term.

4. RESULTS and DISCUSSION

4.1 Impact of Restoration on Soil Properties

4.1.1 Soil Morphological Properties

<u>Profile Descriptions</u>

Soil profile descriptions are reported in Tables 4.1, 4.2, and 4.3 to illustrate major horizon properties. Table 4.1 and 4.2 represent profile descriptions of a micro-high and micro-low, respectively. The micro-highs had multiple A horizons from the addition of the surface layer from the micro-lows to create the micro-topographic high. As a result, the A horizon in the micro-lows was not as thick as the micro-high or the micro-low. All the treatments still reflect a typical plowed A horizon with a depth of 15 cm, with the exception of the micro-high which was topped with the cut made from the micro-low.

Tables 4.3 and 4.4 are representative profile descriptions of a micro-high and micro-low, respectively, for the reference. An obvious difference between the reference and restored site is the presence of an organic horizon in the reference. Aside from that horizon, the soils in the restored site generally have the same horizon types and properties observed in the reference. An A horizon followed by an E horizon that had signs of gleying and Btg horizon below the E that had developed redoximorphic features overtime.

It should also be noted that backhoe access was limited to the reference plots, so profile descriptions were recorded from hand auger borings compared to the restored site which was described with soil pits.

Table 4.1: Profile description for a restored micro-high sample plot in 2003 (ALSRHS).

Horizon	Depth (cm)	Matrix Color	Redox Conc. (%)	Texture	Structure
A1	0-17	10YR 4/1	7.5YR 4/6 (20%)	Sandy Loam	Sub-angular Blocky
A2	17-33	10 YR 4/1	7.5YR 4/6 (20%)	Sandy Loam	Sub-angular Blocky
Eg	33-40	2.5Y 6/2	none	Sandy Loam	Sub-angular Blocky
Btg1	40-51	2.5Y 6/1	10YR 5/8 (45%)	Sandy Clay	Prismatic
Btg2	51-88+	2.5Y 5/1	10 YR 6/8 (20%)	Sandy Clay	Prismatic

Table 4.2: Profile description for a restored micro-low sample plot in 2003 (ALSRLS).

Horizon	Depth (cm)	Matrix Color	Redox Conc. (%)	Texture	Structure
A	0-6	2.5Y 4/1	none	Sandy Loam	Sub-angular Blocky
Eg	6-10	2.5Y 6/2	none	Sandy Loam	Sub-angular Blocky
Btg1	10-25	2.5Y 6/1	10YR 5/8 (30%)	Sandy Clay	Prismatic
Btg2	25-60+	2.5Y 5/1	10YR 6/8 (50%)	Sandy Clay	Prismatic

Table 4.3: Profile description for a reference micro-high sample plot in 2003 (AHR2).

Horizon	Depth (cm)	Matrix Color	Redox Conc. (%)	Texture	Structure
Oa	0-1	10YR 2/2	none	n/a	n/a
A	1-9	10YR 2/1	none	Loam	Granular
Eg	9-28	10YR 5/1	none	Sandy Loam	n/a
Btg1	28-63	10YR 4/1	10YR 5/6 (20%)	Sandy Clay Loam	n/a
Btg2	63-90+	10YR 5/1	10YR 6/8 (5%)	Sandy Clay Loam	n/a

Table 4.4: Profile description for a reference micro-low sample plot in 2003 (ALR2).

Horizon	Depth (cm)	Matrix Color	Redox Conc. (%)	Texture	Structure
Oa	0-1	10YR 2/2	none	n/a	n/a
A	1-23	10YR 3/2	none	Sandy Loam	Granular
Btg1	23-60	10YR 5/1	10YR 5/8 (5%)	Sandy Clay	n/a
Btg2	60-98+	10YR 5/1	10YR 6/8 (30%)	Sandy Clay	n/a

A Horizon

Very little change in thickness and color of the A horizon occurred over 8 years since the wetland has been restored (Table 4.5). The thickness of the A horizons in micro-highs had significantly decreased ($p = 0.02$) from 1995 to 2003. This may have occurred as the micro-high settled or compacted over time. In addition some soil may have eroded off the micro-highs and into the micro-lows. The difference in the thickness of the micro-lows was not significant ($p = 0.14$), after 8 years, there was still a noticeable thickening of the A horizon.

The matrix color of the A horizon showed almost no change within most restored site surface treatments from 1995 to 2003 (Table 4.5). The Munsell values of the smooth surface treatment increased by one unit and was significant at the $p = 0.10$ level. This may have indicated that carbon was being oxidized and produced a lighter color in the soil.

Table 4.5. Summary of A horizon thickness and color for the restored and reference sites.

Soil Feature	Year	Surface Treatments			
		Control n = 2	Smooth n = 8	Micro-High n = 8	Micro-Low n = 8
		---------------------Average Percentage---------------------			
Thickness (cm)	1995	18	21	31	10
	2003	14	21	27	13
	Statistical Difference	nd	p = 0.91	p = 0.02	p = 0.14
Matrix Munsell Value	1995	4	4	4	4
	2003	5	5	4	4
	Statistical Difference	nd	p = 0.10	p = 1.0000	p = 0.33
Matrix Munsell Chroma	1995	1	1	1	1
	2003	1	1	1	1
	Statistical Difference	nd	p = 0.02	p = 0.23	p = 0.11

* P-values are given for comparison of treatments vertically from 1995 to 2003. The control plots were too few for statistical analysis, nd = not determined.

Table 4.6: Comparison of A horizon thickness and color between the reference and restored site (2003).

Year and Soil Feature	Surface Treatments			
	Control	Smooth	Micro-High	Micro-Low
2003	n = 2	n = 8	n = 8	n = 8
Thickness (cm)	14	21	27	13
Matrix Value	5	5	4	4
Matrix Chroma	1	1	1	1
Reference (n = 2)				
Thickness (cm)	n/a	n/a	10	16
Matrix Value	n/a	n/a	2	3
Matrix Chroma	n/a	n/a	1	2

A statistical comparison could not be completed between the reference and restored site, but trends were apparent (Table 4.6). The reference site had a lower Munsell value in the matrix indicating a darker A horizon. The A horizon of the micro-high in the reference is much thinner, about half, than in the restored site. Micro-highs are typically caused in natural wetlands by fallen trees that expose their root ball. These root balls often become the micro-high, in such cases it should be expected that the soil will settle and decrease the height of the micro-high over time. The A horizon of the micro-low was noticeably thicker after 8 years (Table 4.6). This most likely is a result of the micro-low being a small depressional area and collecting different organics and the sloughing of surrounding micro-highs. A similar process may have been occurring in the micro-lows of the restored site.

<u>Redoximorphic Features</u>

From 1995 to 2003, mean percentages of redox concentration increased in almost all treatments in the 0 to 45 cm depth range (Table 4.7). The micro-low did not show a significant difference at the 0 to 15 cm depth range as the mean percentage of redox concentrations did not change from 1995 to 2003. The percentage of redox concentrations appeared to increase in the smooth surface treatment for the 15 to 30 cm depth, but was not significant ($p = 0.29$). All three surface treatments showed a significant ($p<0.05$) increase in the percentage of redox concentrations. There were too few control sample locations for statistical analysis, but there appears to be an increase in redox concentration percentage at the 0 to 45 cm depth range as well.

Table 4.7: Summary of redox concentration percentage by depth.

Depth (cm)	Year	Surface Treatments			
		Control n = 2	Smooth n = 8	Micro-High n = 8	Micro-Low n = 8
		---Average Percentage---			
0 - 15	1995	11	3[a]	1[b]	12[c]
	2003	23	18	11	12
	Statistical Difference	nd	p = 0.001	p = 0.02	p = 0.85
15 - 30	1995	20	19[a]	8[b]	22[c]
	2003	32	23[a]	16[b]	32[c]
	Statistical Difference	nd	p = 0.30	p = 0.04	p = 0.01
30 - 45	1995	23	29	19	27
	2003	47	40	31	38
	Statistical Difference	nd	p = 0.03	p = 0.02	p = 0.02

*Statistics are presented below the values being compared, a statistical difference is represented by a P-value < 0.10. Different lower case letters beside the value represent a statistical difference between surface treatments within the given year.

Table 4.8: Comparison of redox concentration percentage by depth between the restored (2003) and the reference sites. Statistical analysis was not applicable to this comparison.

Year and Depth (cm)	Surface Treatments			
	Control	Smooth	Micro-High	Micro-Low
	---Average Percentage---			
2003	n = 2	n = 8	n = 8	n = 8
0 - 15	23	18	11	12
15 - 30	32	23	16	32
30 - 45	47	40	31	38
Reference (n=2)				
“	n/a	n/a	1	0
“	n/a	n/a	6	6
“	n/a	n/a	21	27

A comparison of the restored data from 2003 to the reference data revealed a large apparent difference in the mean percentage of redox concentrations for the 0 to 45 cm depth (Table 4.8). Most of the depths for both surface treatments showed the restored site with approximately 10% more redox concentrations compared to the reference. The largest difference occurred in the micro-low where the percentage of redox concentrations was three times higher in the restored site at the 0 to 30 cm depth range. Percentage of redox concentrations in the reference more closely resemble the values identified by Smith in 1995 for the 0 to 45 cm depth range.

4.1.2 Soil Physical Properties

Soil Texture

Soil textural classes are summarized for all treatments in both the restored site and reference site in Table 4.9. Soil textural classes were identical across all treatments for the 0 to 15 cm depth range, and depths below 30 cm. The major difference among treatments occurred for the 15 to 30 cm depth range. In both the restored and reference site, the micro-low treatments had a sandy clay loam textural class. The other treatments had a sandy loam textural class. This indicated that the Bt horizon was closer to the surface in the micro-lows in both the reference and restored sites. This indicates the surface contouring of the restoration site did an excellent job in producing similar textural classes at similar depths as compared to the target reference wetland.

Table 4.9: Mean soil textural classes by depth for the restoration and reference sites.

	Restored Site 2003			Reference Site	
Depth (cm)	Smooth (n=8)	Micro-High (n=8)	Micro-Low (n=8)	Micro-High (n=2)	Micro-Low (n=2)
0 - 15	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
15 - 30	Sandy Loam	Sandy Loam	Sandy Clay Loam	Sandy Loam	Sandy Clay Loam
30 - 45	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam
45 - 60	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy Clay Loam

Bulk Density

Bulk density values are reported in Table 4.10. Statistics were not applicable to this measurement and are not available to analyze the differences these data represent. However, it is noted that the micro-highs in both the reference and restoration site tend to have lower bulk densities than the micro-lows. This is most likely due to the micro-lows having had their original surface removed to a depth of approximately 20 cm, with the tillage pan, below the original A horizon, being brought to within 15 cm of the new surface. Tillage pans typically have bulk densities >1.65 g cm $^{-3}$ (Vepraskas, 1988).

Table 4.10: Mean bulk density for the upper 15 cm of the surface treatments of the 8 year old restored site and the reference site. The number of plots sampled is shown in parentheses. Measurements were not made in 1995.

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

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

Mean bulk density values were higher across all treatments for the restoration site than compared to the reference site. Root limiting bulk density values have been found to vary with soil texture (Daddow and Warrington, 1983). As shown in Fig. 4.1, a bulk density value greater than 1.65 g cm^{-3} is high enough to slow root growth and prevent roots from growing below the layer in sandy loam and sandy clay loam soils. In general, only the micro-low treatments in the restored site were found to have root limiting bulk densities in the A horizon. Loosening of this layer with tillage may benefit plant growth, and should be practiced as part of the restoration plan. Eight years of restoration did not restore bulk density values to those found in the reference site.

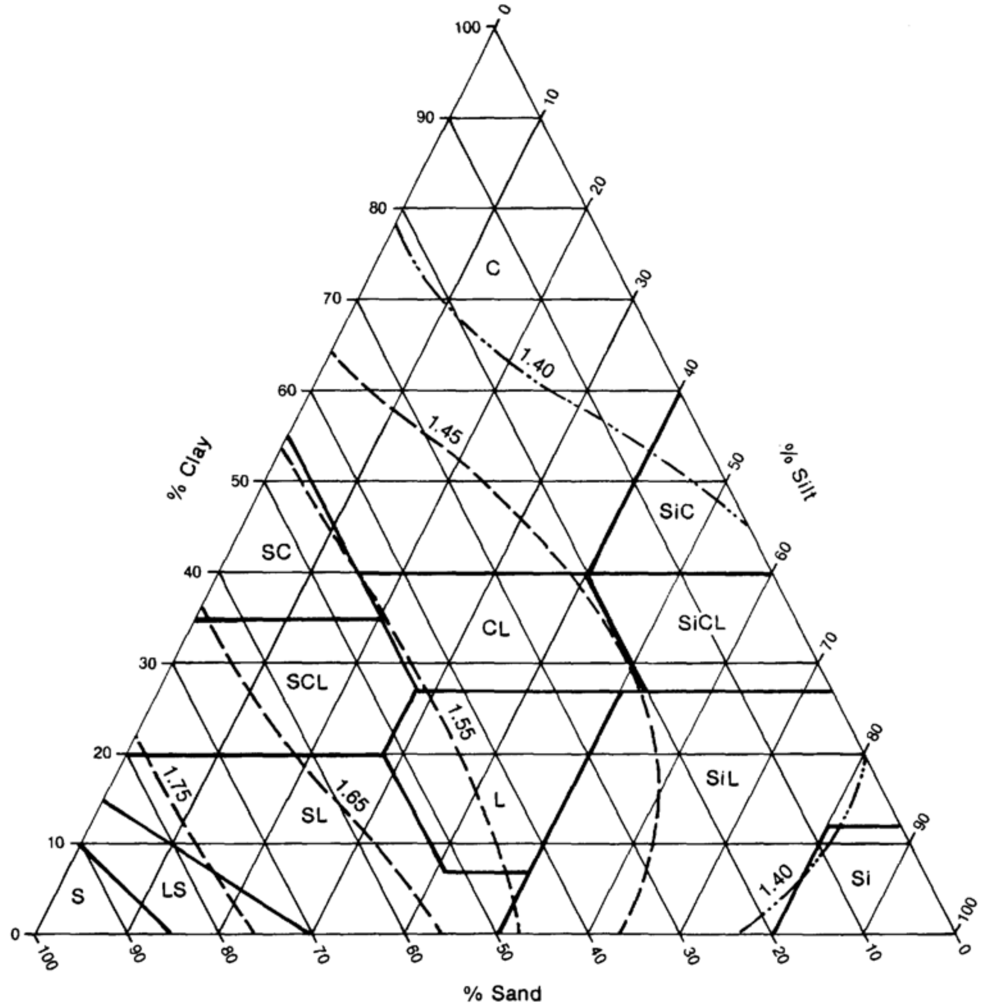

Figure 4.1: Bulk density values (g cm^{-3}) that restrict root growth for different textural classes. Data were developed by Daddow and Warrington (1983).

4.1.3. Soil Chemical Properties

Total-organic Carbon and Total Kjeldahl-Nitrogen

The mean total-organic Carbon (TOC) and mean total kjeldahl-nitrogen (TKN) have decreased significantly ($p<0.01$) since 1995 for both the smooth surface and micro-high surface treatments (4.11). The mean for the micro-lows follows the same trends as the other two treatments but was not significantly different between 1995 and 2003. None of the C:N ratios were significantly different when comparing 2003 to 1995.

Hanks (1971) found similar findings for soil sampled in various ages of old field succession. While not being significantly different he found there was a decrease in organic matter percent from the 1-2 year age group relative to the 10-15 year age group. The age group of 25-40 years represented the closest levels that resembled a natural forest. It should also be noted the data from the control showed the same patterns as the restored site after 8 years for TOC, TKN, and C:N ratio. The smooth surface treatment showed the largest decrease in TOC, which correlates with a slightly lighter color observed in the A horizon for the smooth surface treatment.

Table 4.11 Summary of mean Total-Organic Carbon, Total Kjeldahl-Nitrogen, and C:N ratios for the upper 15 cm of soil.

Element	Year and Depth (cm)	Surface Treatments			
		Control n = 2	Smooth n = 8	Micro-High n = 8	Micro-Low n = 8
TOC (%)	1995	1.11	1.14 [a]	1.17 [b]	0.72 [c]
	2003	0.67	0.74[a]	0.88[b]	0.63
	Statistical Difference	nd	p = 0.001	p = 0.01	p = 0.40
TKN (%)	1995	0.09	0.10 [a]	0.10 [b]	0.06 [c]
	2003	0.05	0.06	0.07	0.05
	Statistical Difference	nd	p = 0.004	p = 0.02	p = 0.14
C:N	1995	12.3	11.9	11.5	11.3
	2003	12.5	12.0	11.9	12.3
	Statistical Difference	nd	p = 0.89	p = 0.55	p = 0.16

*Statistics are presented below the values being compared, a statistical difference is represented by a P-value < 0.10. Different lower case letters beside the value represent a statistical difference between surface treatments within a given year. Statistics could not be applied to the control plots as the sample number was too small (nd = not determined).

Table 4.12 Summary of mean Total-Organic Carbon, Total Kjeldahl-Nitrogen, and C:N ratios for the upper 15 cm of soil of the restored (2003) and reference sites. Statistical analysis was not applicable to this comparison.

Year and Depth (cm)	Surface Treatments			
	Control	Smooth	Micro-High	Micro-Low
2003	n = 2	n = 8	n = 8	n = 8
TOC	0.67	0.74	0.88	0.63
TKN	0.05	0.06	0.07	0.05
C:N	12.5	12.0	11.9	12.3
Reference (n=2)				
TOC	n/a	n/a	3.26	3.80
TKN	n/a	n/a	0.17	0.21
C:N	n/a	n/a	19.7	18.5

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

The C:N ratios gave an indication of nutrient immobilization. The values in the reference were close to 20:1, where the microbes immobilize soil nitrogen and allow less nitrogen for plants. An ideal C:N ratio for a healthy and active microbial population is closer to 10:1, similar to the C:N values found in the restored site in 2003.

NCDA Nutrient Analysis

Levels of phosphorus (P) decreased by approximately one-half across all treatments from 1995 to 2003 in the restored site (Table 4.13). Decreased P levels are mainly lost as a result of plant uptake, but there may have been some secondary loss from erosion of the soil surface, this amount is most likely negligible. While runoff from the site has been prevented by dikes and berms, it is possible that sediments are being moved within the site. However, loss of P from this method is most likely negligible. Phosphorus is released from iron and aluminum compounds once the soil becomes reduced. It is possible that P is moving with the soil water after saturation and reduction, and depending on how much fluctuation occurred in the water table, could determine the amount of P removed from the soil. Phosphorus in the micro-lows did decrease, but not significantly. This change is most likely a result of the uptake by plants. Initial low levels of phosphorus in the micro-low treatments were probably due to the removal of topsoil from these areas during wetland construction.

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

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

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

Table 4.13: Summary of selected mean results from the NCDA soil testing for the upper 15 cm of soil in the restored site. Values with the same letter indicate a significant difference at $p < 0.01$.

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

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

Table 4.14: Summary of selected mean results from the NCDA soil testing for the upper 15 cm of soil in the restored (2003) and reference sites. Statistical analysis was not available for this comparison.

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

It was noted earlier that all the selected NCDA soil nutrient properties had decreased from 1995 to 2003 at the 0 to 15 cm depth. When the restored values were compared to the upper 15 cm of the reference soil, it showed the restored levels were still all above conditions in the reference. Phosphorus in the restored micro-highs needs to be reduced by approximately half before reference phosphorus levels are reached. The micro-lows only need 1 mg kg^{-1} less of phosphorus to reach levels found in the reference. Phosphorus in the micro-low of the restored site appeared to eventually be one of the initial values to reach the values found in the reference.

Manganese (Mn) increased after 8 years, but it would need to decrease to resemble the soils found in the reference non-riverine wet hardwood forest. The restored micro-high still contain approximately three times the amount of Mn found in the reference micro-highs. The restored micro-lows have approximately four times the amount of Mn found in the reference micro-lows. There is a possibility that this may take an extremely long period of time. The hydrology of the restored site has not provided an outlet for Mn to leave the soil. The flux of the water table during transitional periods between saturated/anaerobic and unsaturated/aerobic conditions are believed to cause the Mn to accumulate in the upper 15 cm of the restored soil.

Calcium needs to decrease in the restored micro-highs by about a third to reach levels found in the reference micro-highs. The micro-lows appear to have done a better job at removing Ca as the restored micro-low only need to drop about 25% to meet levels found in the reference micro-lows. Base saturation is almost four times the amount in the restored micro-highs as compared to the micro-highs. The micro-lows of the restored site need to diminish by half to reach levels found in the reference micro-lows. This correlates with the findings in Ca, and we expect Ca levels in the restored soil to reflect the natural soil before BS. pH followed the same declining trends as Ca and BS; however there was little difference between the two surface treatments as both restored site treatments need to increase in acidity by approximately 1.2 pH units.

The wetter hydrology of the restored site may have facilitated a quicker loss of these soil properties. This would cause soil properties in the restored site to reflect a natural wetland soil sooner. However, it could also diminish the nutrients below levels found in the reference wetland and influence the restoration of the vegetation.

Table 4.15: Summary of selected mean results from the NCDA soil testing analysis for three different depths: 0-15 cm, 15-30 cm, and 30-45 cm relative to the soil surface in the restored (2003) and reference sites. Statistical analysis was not available for this comparison.

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

The same selected NCDA nutrients were compared by depth for the micro-highs and micro-lows between the restored and reference site in Table 4.15. Statistical analysis was not applicable to this comparison, as the sample size for the reference was too small. However, this table does provide useful information that allowed us to speculate about how and why phosphorus, manganese, calcium, base saturation, and pH are changing in the soil of the restored site.

Phosphorus is most abundant in the upper 15 cm of the soil for both micro treatments. Amounts of P diminish with depth in both the micro-highs and micro-lows of both sites. Only the restored micro-highs had detectable amounts of P at the 30-45 cm depth range. Phosphorus decreased the least from the 0-15 cm depth to the 15-30 cm depth in the restored micro-highs. Most likely a result of this soil being the last to become saturated and anaerobic, and allowing mire P to remained bound to Fe and Al oxides and hydroxides. Phosphorus decreased the most from 0-15 cm depth to the 15-30 cm depth in the micro-lows of the restored site. This resulted from this depth being saturated and reduced longer and having the presence of P, thereby allowing the Fe and Al oxides to become reduced and release P into the soil water. This has caused P levels at the 15-30 cm depth in the micro-lows of the restored site to drop below levels found at the same depth in the micro-lows of the reference. This should not have a negative impact on the status of the restored site.

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

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

Both of these soils would be considered acid soils, as the pH values ranged from 3.98 to 6.12. In general the pH of these acid soils would increase towards 7 under anaerobic conditions. This was seen as the pH of the 30-45 cm depth range was always higher than the pH at the 0-15 cm depth range. The pH of the micro-lows in the restored site decreased at the 15-30 cm depth before it rebounded to a higher value at the 30-45 cm depth. The difference was small and believed to not be a significant change.

4.2 Precipitation, Saturation, and Anaerobic Conditions

Since the goal of all wetland restoration projects is to restore functions of the target wetland, identical soil measurements of saturation and anaerobic conditions were made in two plots in the adjacent reference Non-riverine Wet Hardwood (NRWH) wetland. Each plot contained a micro-topographic high and micro-topographic low. There were no sampling locations in the reference that reflected the smooth surface treatment in the restoration site.

4.2.1 Precipitation

On-site precipitation data were used to determine whether the saturation and redox data were collected during a period of normal precipitation (Table 4.15). For this study, normal rainfall is defined based on monthly values, and the range of rainfall between the 30^{th} and 70^{th} percentile precipitation probability.

The automated rain gauge did not function perfectly throughout the study. Manual rain gauge data were used to compensate for missing rainfall data. It has been noted that the tipping bucket mechanism in the automated rain gauge can over count the measuring unit in particularly heavy precipitation events. Also, when using the manual rainfall data nine months fall at or below the 70^{th} percentile compared to only seven months when the HOBO data was used.

The discrepancies between the two precipitation sampling units were adjusted for in the third column of Table 4.16. The most limiting values were used, for the adjusted precipitation values. This allowed a hydric soil status and restoration success to be determined in the most adverse conditions. If the restored or reference status had not been met, further analysis could have been completed to possibly include the months of April and August where one device recorded normal or drier rainfall and one did not.

Table 4.16: Summary of rainfall data relative to the 30th and 70th percentile. Highlighted measurements reflect months that site precipitation was at or below the 70th percentile.

Month	**Percentiles**		**Measured Rainfall**		
	30th	**70th**	**Automated**	**Manual**	**Adjusted**
			---centimeters---		
DEC-2003	5.94	11.1	24.6	17.9	24.6
JAN-2004	8.18	12.9	4.09	1.40	4.09
FEB-2004	5.41	8.99	14.0	11.9	14.0
MAR-2004	8.03	12.5	7.98	6.31	7.98
APR-2004	5.44	10.4	9.34	11.1	11.1
MAY-2004	6.76	12.5	0	7.32	7.32
JUN-2004	8.59	14.2	12.6	12.6	12.6
JUL-2004	9.42	16.4	19.9	20.1	20.1
AUG-2004	11.6	19.7	24.0	10.8	24.0
SEPT-2004	7.39	16.1	16.5	16.1	16.5
OCT-2004	4.37	10.1	14.3	8.55	14.3
NOV-2004	4.78	8.74	2.23	5.68	5.68
DEC-2004	5.94	11.1	0.08	10.5	10.5

4.2.2 Anaerobic Conditions

The soil is anaerobic when confirmed by redox potential (Eh) data or verified by reduced iron (Fe^{2+}). In-situ pH data is also required to determine when the redox potential values are reflecting anaerobic conditions. There were five electrodes in each plot at 10 cm and five electrodes in each plot at 61 cm. The deeper electrodes were installed to provide data to evaluate soil morphology in the B horizon (clay layers) and helped to determine if the site was epi-saturated (perched water table).

All the treatments followed similar trends of reduction and oxidation (Figure 4.2). All treatments were anaerobic from the beginning of the study until about mid-May. From May to the end of August the restored site stayed aerobic. After August the redox data became erratic until the end of October. The erratic patterns are a result of erratic rain events and attributed to the time it takes to effectively rewet the site after a dry summer. After October the results showed that all surface treatments were once again anaerobic.

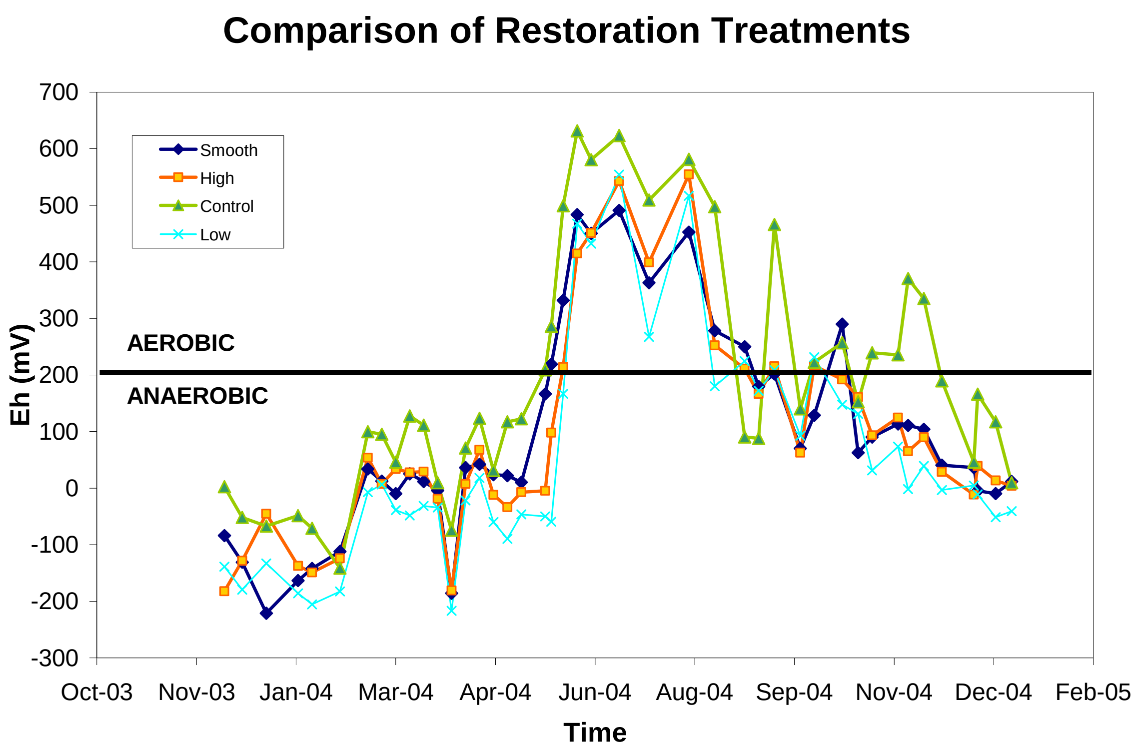

Figure 4.2: Mean redox potential of both depths (25 and 61 cm) for each surface treatment in the restored site 2003.

Shallow redox electrodes (25 cm) in the restored site mimicked the same trends found in the reference (Figure 4.3). From December 2003 to September 2004 the soil went from anaerobic to aerobic and then went into a transitional state before becoming completely anaerobic. During the transitional period (September 2004 to December 2004) the degree of reduction varied more in the restored site than the reference site (Figure 4.3). This is most likely a result of the controlled hydrology in the restored site which kept the restored site wetter than the reference site.

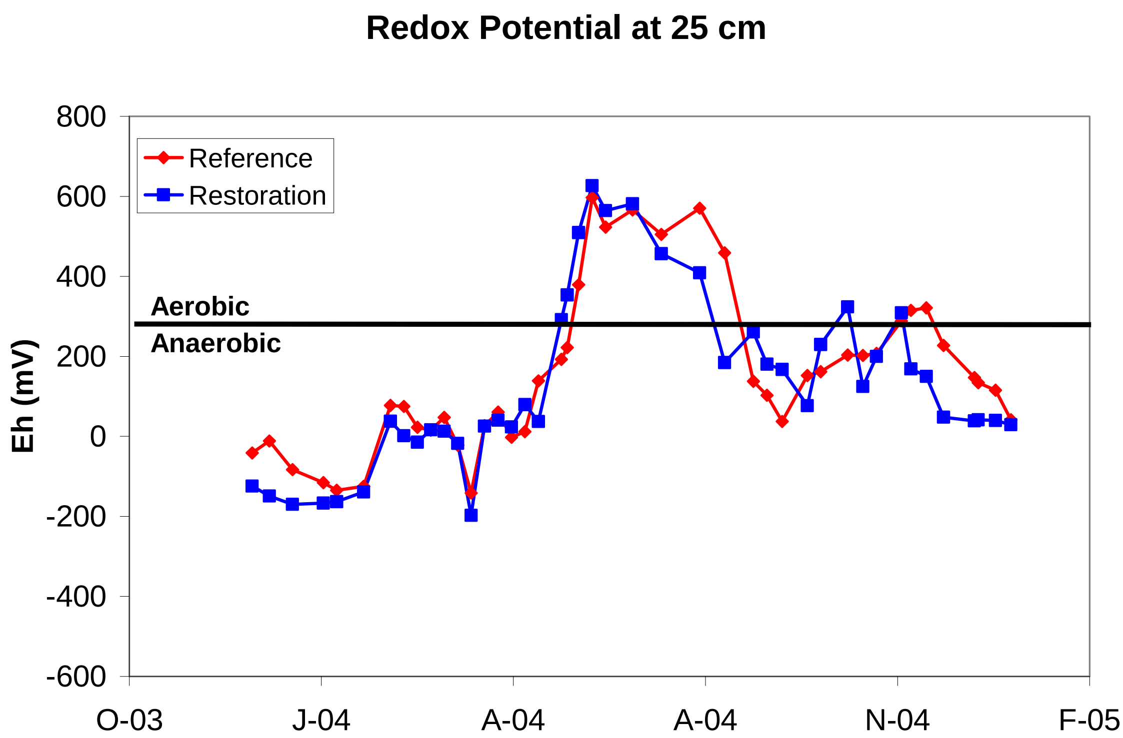

Figure 4.3: Composite redox potential for the restored and reference site at a depth of 25 cm.

Much like the shallow electrodes the electrodes at 61 cm showed a similar reduction-oxidation period from the winter to the summer (Figure 4.4). The reference was again slightly less reduced than the restored site from December 2003 to September 2004. Once the transitional period started, the reference electrodes were more erratic than the reference electrodes. This is most likely attributed to the controlled drainage of the restored site. During the transitional period the water table in the restored site is at a depth where it consistently stayed saturated and reduced.

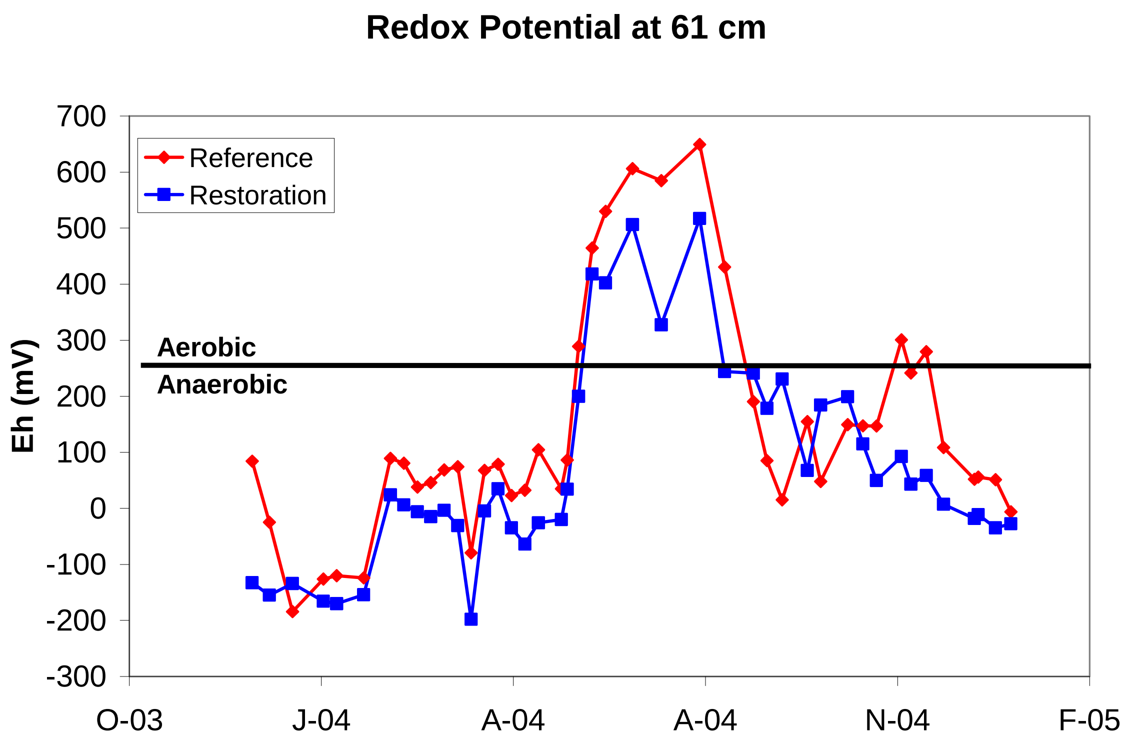

Figure 4.4: Composite redox potential for the restored and reference site at a depth of 61 cm

4.2.3 Saturation

Saturation is determined by four piezometers in each plot, two piezometers at 25 cm, and two piezometers at 100 cm. The piezometer data were verified by an open well at a depth of 2 m in each plot (Figure 4.5). Saturated conditions have occurred when free water was in the shallowest (25 cm) piezometer. The 100 cm piezometers were in place to determine whether or not a perched water table was present.

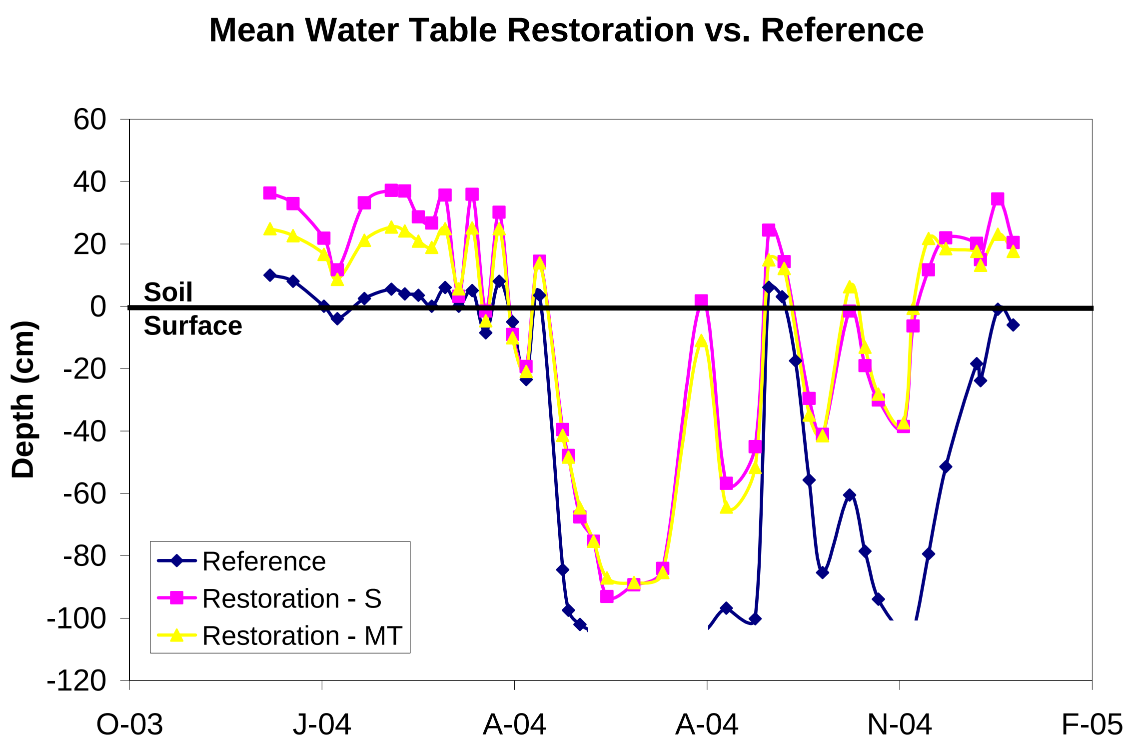

Figure 4.5. Water table fluctuations during the study period recorded by automated wells installed at a depth of 200 cm for the restored and reference site

The piezometer data showed on average all of the surface treatments in the restored site were saturated at least 200 days or more (Table 4.16). The control plot was also saturated for more than 200 days. The reference site which did not have controlled hydrology was saturated for 150 days on average in the micro-highs and 183 days on average in the micro-lows. The micro-lows were expected to be saturated longer as the purpose of them is to collect and retain precipitation. The restored site was saturated longer than the reference site for the study period.

Table 4.17. Total number of days each surface treatment was saturated at the 25 cm depth during the study period for the restored site and the reference site.

Site – Surface Treatment	Dates	Total No. of Days
Restored 2003 - Smooth	12/9/2003 to 5/6/2004 (150 days)	257
	9/2/2004 to 9/23/2004 (21 days)	
	10/14/2004 to 1/7/2005 (86 days)	
Restored 2003 – Micro-high	12/9/2003 to 5/27/2004 (171 days)	224
	11/16/2004 to 1/7/2005 (53 days)	
Restored 2003 – Micro-low	12/9/2003 to 5/18/2004 (162 days)	325
	7/29/2004 to 1/7/2005 (163 days)	
Reference – Micro-high	12/9/2003 to 5/6/2004 (150 days)	150
Reference – Micro-low	12/9/2003 to 5/18/2004 (162 days)	183
	12/18/2004 to 1/7/2005 (21 days)	

*The control plot was saturated for 171 days from 12/9/2003 to 5/27/2004 and 92 days from 6/24/2004 to 9/23/2004, for a total of 263 days being saturated.

The piezometers did not reflect a perched water table in the restored or reference site. Even after the water table dropped to summer levels approximately 94 cm in the restored site and more than 120 cm in the reference site the water table rebounded to the surface in both sites on July 29, 2004. The piezometer data matched the same water table fluctuations in both sites.

Well data confirmed the findings in the piezometers for both restoration and the reference site. The well data also showed that the water table in the reference site drops to a much deeper depth than the water table in the restoration site. Tweedy (1998) also studied this restored site and ran a DRAINMOD simulation that accurately predicted this finding.

This is important because it may reflect why certain soil redoximorphic features form in certain depths of the soil and if we can expect the soil in the restoration site to reflect a successful restoration project.

The primary difference in water tables was only seen during the summer months. During periods of saturation, redox and water table data correlate very well between the reference and restoration site. This indicated that soil features will eventually form in the restoration to mimic the reference site, but the features will take an unknown amount of time to develop.

4.2.4 Meeting the HSTS

The smooth (Fig. 4.6), micro-high (Fig. 4.7), and micro-low (Fig. 4.8) in the restored site met the HSTS for approximately the same time at three different 3 week intervals during the study period. There were three 3 week periods when the soil was saturated and anaerobic within 25 cm of the soil surface and occurred during a time of normal rainfall. As only one 3 week period is required to meet the HSTS, therefore all of the treatments produced a hydric soil as defined by the HSTS. The control (Fig. 4.9) plot also met the HSTS in January 2004 and March 2004 to the end of May 2004. This could indicate that a different control plot location may have been necessary. One alternate location would have been to the east of the restored site in the agriculture field.

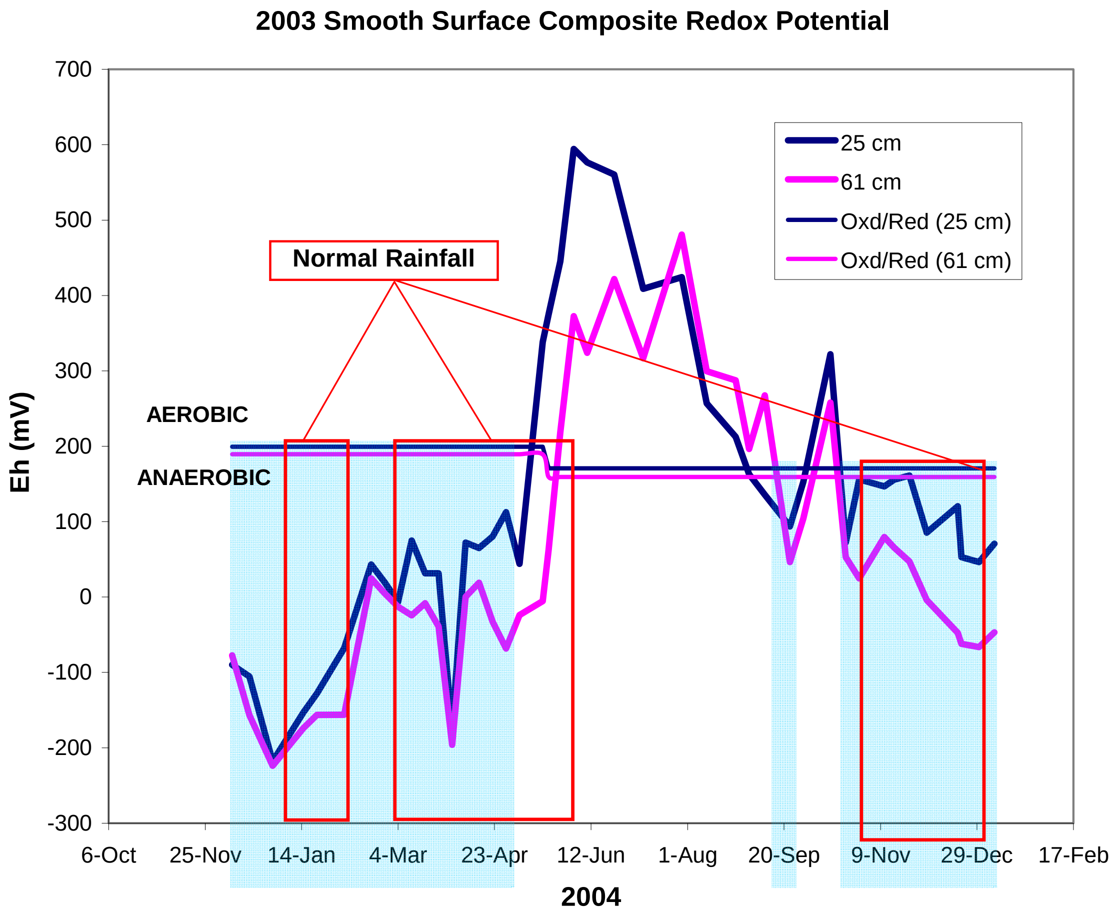

Figure 4.6. Redox potential for the restored (2003) smooth surface treatment at the 25 and 61 cm depths. The shaded areas represent periods of saturation. The HSTS is met when there is saturation and reduction during periods of normal rainfall.

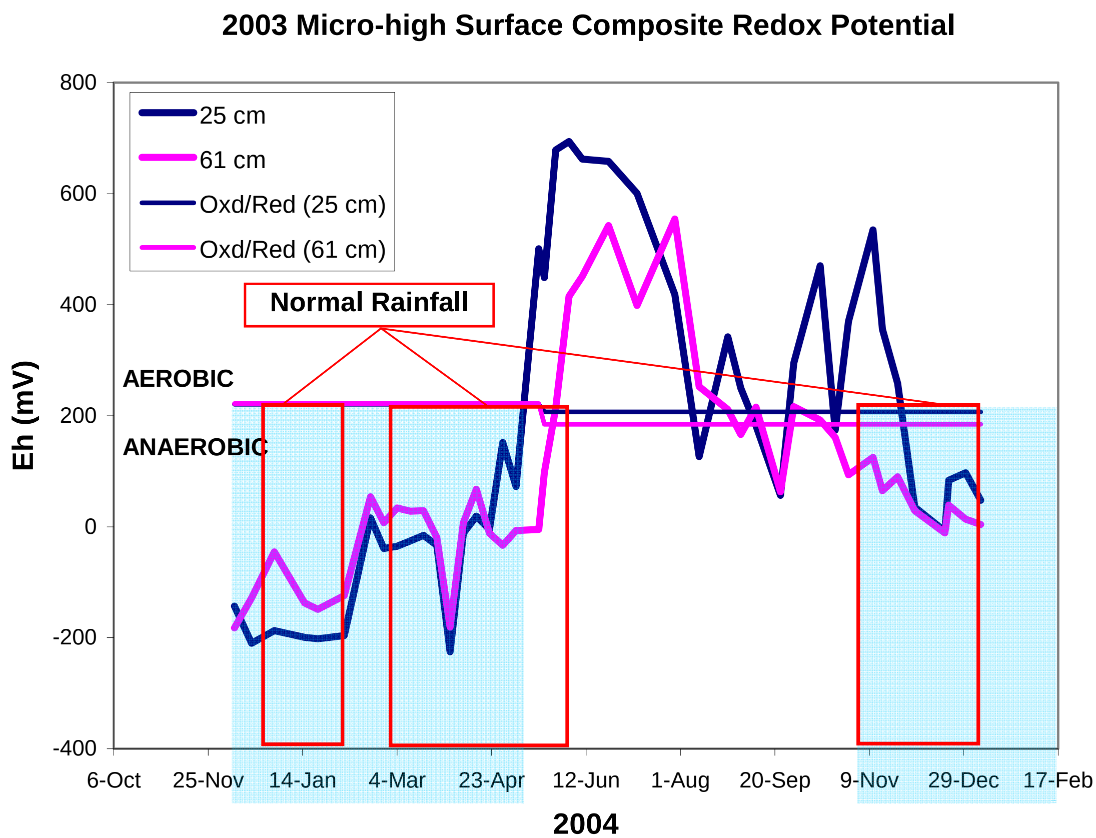

Figure 4.7. Redox potential for the restored (2003) micro-high surface treatment at the 25 and 61 cm depths. The shaded areas represent periods of saturation. The HSTS is met when there is saturation and reduction during periods of normal rainfall.

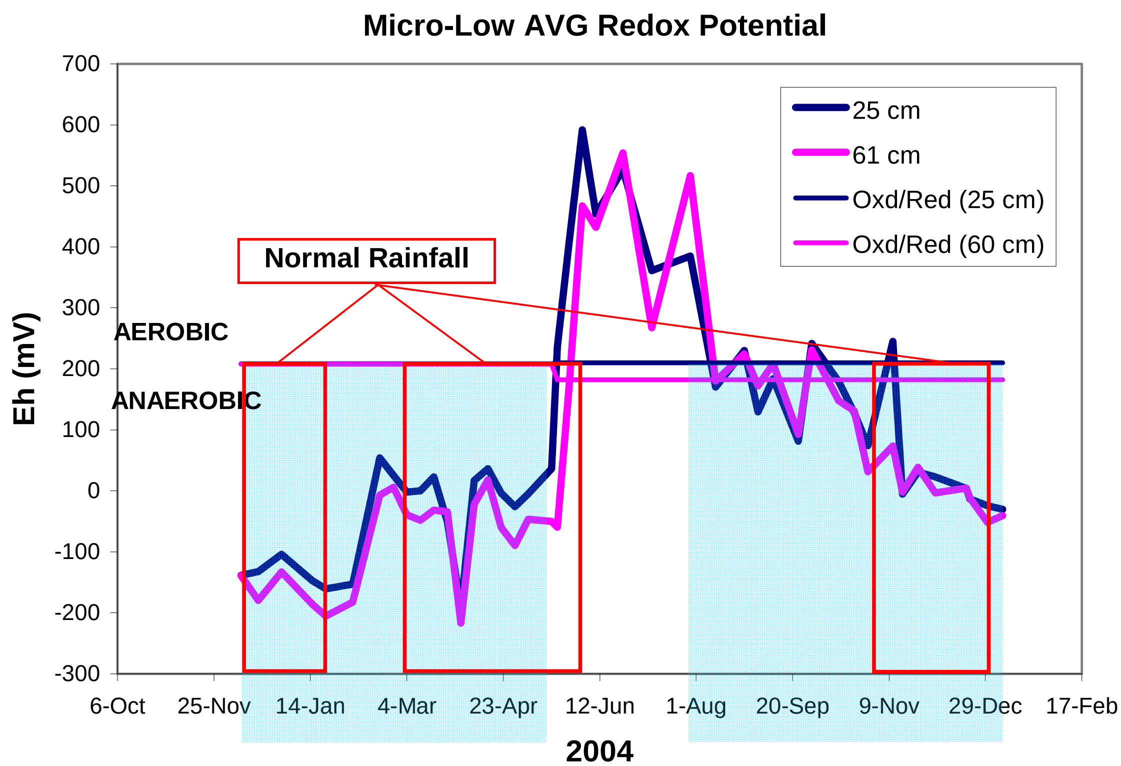

Figure 4.8. Redox potential for the restored (2003) micro-low surface treatment at the 25 and 61 cm depths. The shaded areas represent periods of saturation. The HSTS is met when there is saturation and reduction during periods of normal rainfall.

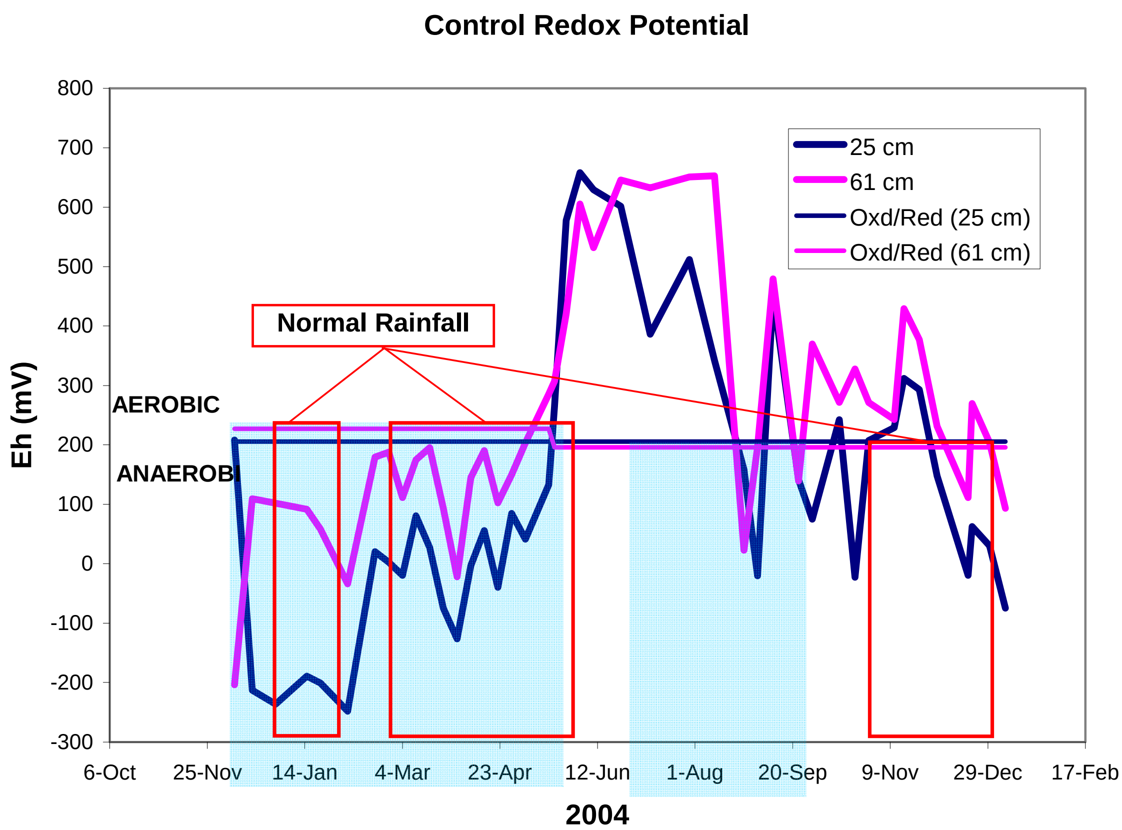

Figure 4.9. Redox potential for the control surface treatment at the 25 and 61 cm depths. The shaded areas represent periods of saturation. The HSTS is met when there is saturation and reduction during periods of normal rainfall.

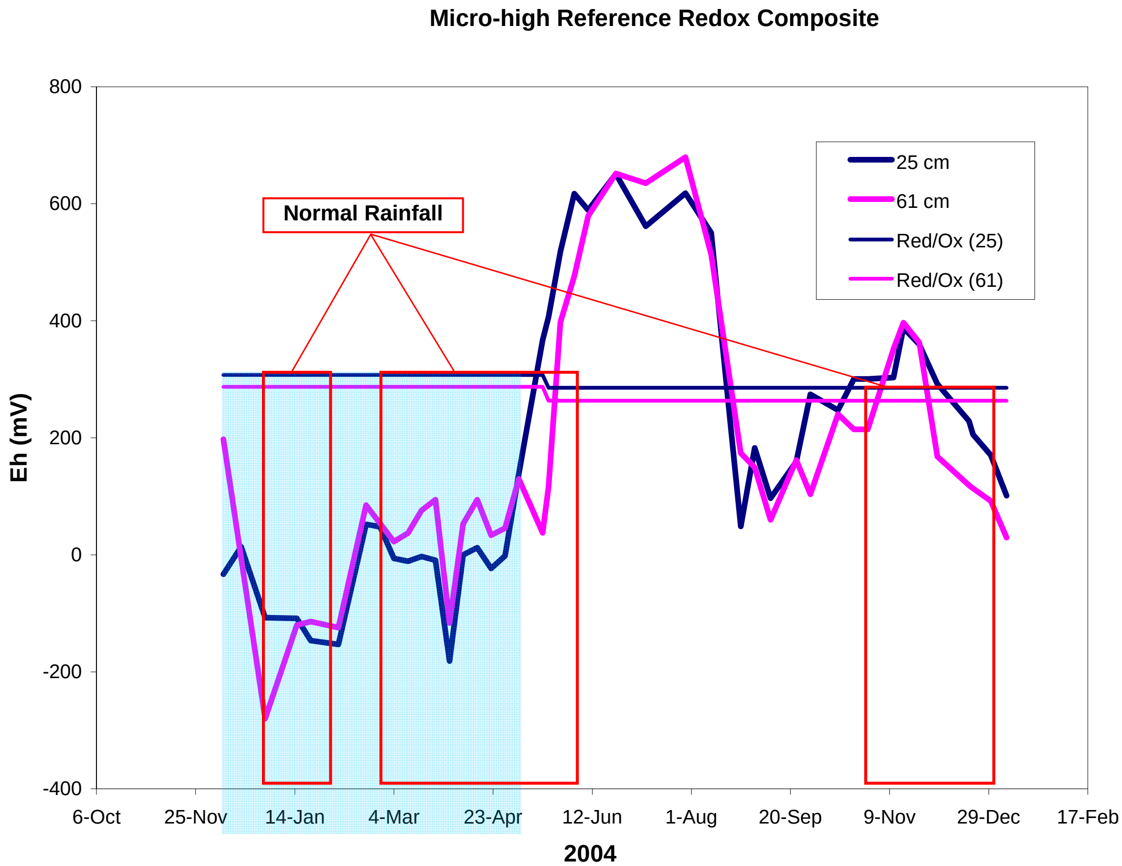

Figure 4.10. Redox potential for the micro-high in the reference site at the 25 and 61 cm depths. The shaded areas represent periods of saturation. The HSTS is met when there is saturation and reduction during periods of normal rainfall.

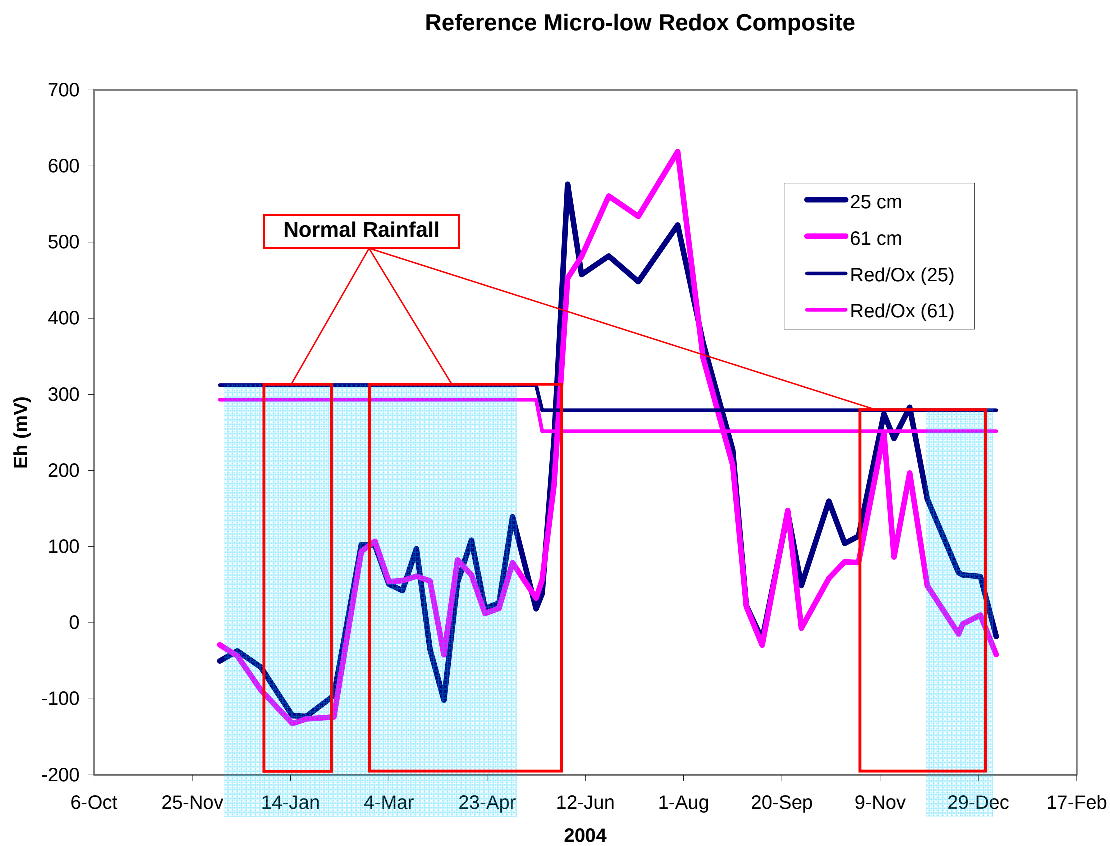

Figure 4.11. Redox potential for the micro-low in the reference site at the 25 and 61 cm depths. The shaded areas represent periods of saturation. The HSTS is met when there is saturation and reduction during periods of normal rainfall.

The micro-highs (Figure 4.10) and micro-lows (Figure 4.11) in the reference also met the HSTS. The reference soil met the HSTS during the first two periods of normal rainfall, just as the restored site did. The reference site had not yet become anaerobic and saturated during the third period of normal rainfall. This indicated that the restored site wets up faster than the reference site. This is most likely a result of the water table dropping deeper in the ground in the reference site and takes longer to rebound to the 25 cm depth than the restored site does, as the restored water table only drops to about 90 cm during the summer. As a result, the soil in the reference met the HSTS fewer days than the soil in the restored site (see Figure 4.12).

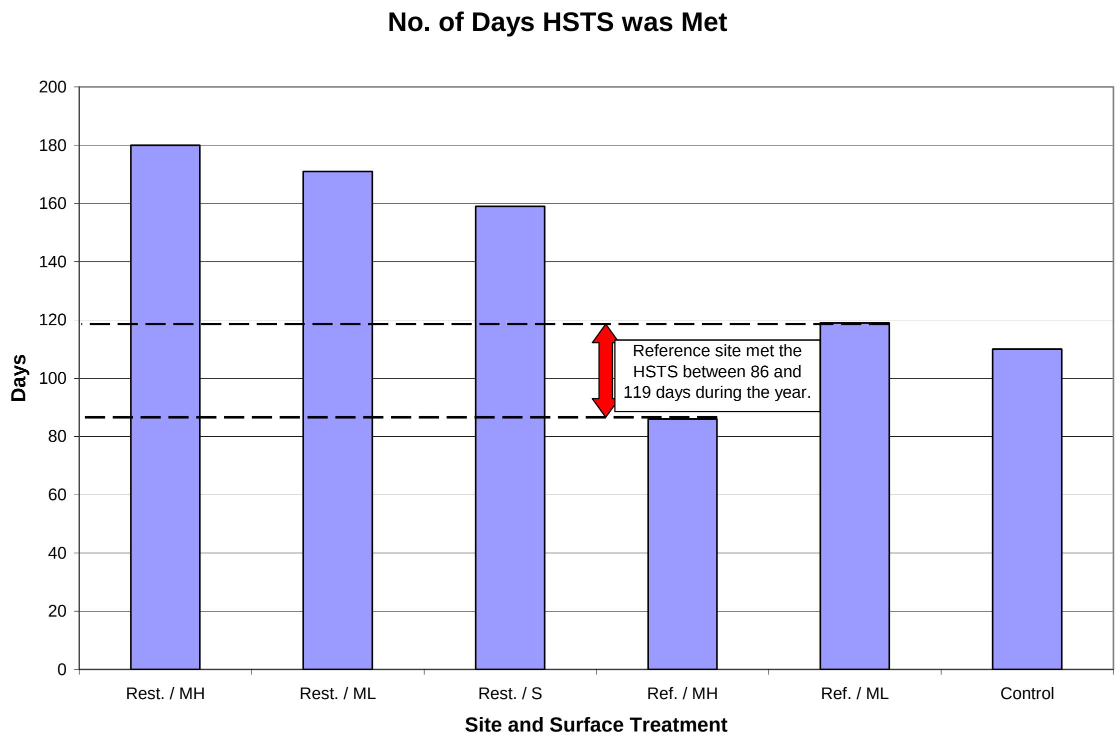

Figure 4.12. Total number of days each surface treatment successfully met all requirements for the HSTS.

The reference wetland had a slightly less erratic redox graph compared to the restored wetland. This is do to the fact that there were eight plots representing each of the surface treatment plots in the restoration and only two plots that represented the surface treatments in the reference. However, it also reflected a mature established functioning NRWHF. The restored wetland having been only eight years into restoration is expected to still be going under transformations to become a functioning wetland.

The micro highs in the reference wetland did not become saturated after the dry period during the summer, even though redox potentials become anaerobic. This may be a result of the broad flat nature of the forest floor, the microtopographic highs are very small compared to the rest of the area.

5. CONCLUSIONS

This study found that soil morphology, soil physical, and soil chemical properties change within 8 years following restoration of wetland hydrology in a former agricultural field. The restored soil visually, physically, and chemically matched the soil found in the reference wetland. Altering the soil surface to represent a natural non-riverine wet hardwood forest (NRWHF), prevented losing precipitation via runoff. This was very effective in aiding development of hydric soil characteristics.

Twenty-six profile descriptions were used to compare the restored site to initial conditions in 1995 and to the reference wetland. In 2003, it was found that the restored soils maintained the same hydric soil field indicator (depleted matrix, F3) that was observed in 1995. There was very little change in the thickness and matrix color of the A horizon. The only significant (P=0.02) difference was that the thickness of the A horizon in the micro-high of the restored site, decreased in thickness by 4 cm. The A horizon in the reference was darker in color (10YR 2/1) than the A horizon (10YR 4/1) in the restored site. Redox concentrations significantly (P=0.05) increase from 0 to 45 cm in the restored site after 8 years for all three surface treatments. The largest significant (P=0.05) increase was 10% at the 30 to 45 cm depth in all three surface treatments from 1995 to 2003. Redox concentrations in the reference were less abundant than in the restored site in 2003, but the difference was not significant. The primary difference for redox concentrations between the reference and restored site was from 0 to 30 cm, where the mean for the micro-low in the reference had as little 0%, compared to the restored micro-low that had as many as 32%.

The measured physical characteristics of the soil, were the soil texture and soil bulk density. Soil texture was a sandy loam for surface horizons in both sites, and a sandy clay loam for the clay layer in both sites. The data revealed the upper 15 cm of the micro-lows in both sites was a sandy loam and 15 to 60 cm was a sandy clay loam. This indicated the micro-lows in the restored site were cut to a similar depth that was found in the reference. Bulk densities were collected from the upper 15 cm of all surface treatments in the restored and reference site. Bulk densities were found to be higher in the restored site as a result of plowing when the soil was under agricultural production. The micro-lows in the reference had a mean bulk density of 1.72 gcm^{-3}, which could restricted root growth. Light tillage of the micro-lows to loosen the soil could benefit plant growth.

Total-organic carbon (TOC) and total kjeldahl-nitrogen (TKN) along with plant available nutrients were measured in the restored site, in 1995 and 2003, and the reference site. TOC and TKN both decreased after 8 years. Values found in the reference were close to three times higher than the values found in the restored site. Therefore, TOC and TKN are not ideal measurements to establish success of a wetland restoration project after 8 years. Phosphorus (P), calcium (Ca), and base saturation (BS) all decreased significantly after 8 years in all three surface treatments. The reference values for these nutrients were all below the values sampled from the reference. The decline of these values indicated a trend of the restored soil eventually meeting the levels found in the reference. The time for this to occur is unknown. Manganese (Mn) increased in the upper 15 cm much like how the Fe-rich redox concentrations increased in the restored site after 8 years. The reference site had much lower amounts of Mn in the upper 15 cm than the restored soil. Therefore, the increasing amounts of Mn will eventually begin to decrease in the restored site but the time is unknown.

The hydric soil technical standard (HSTS) was in eight smooth surface treatments, eight micro-high surface treatments, and eight micro-low surface treatments in the restored site. The HSTS was also set-up in one control location and the reference site contained two micro-highs and two micro-lows that were tested. The HSTS tested the soil for anaerobic and saturated conditions. The standard was met if the soil was anaerobic and saturated for three consecutive weeks, during a period of normal rainfall. All treatments at both sites, including the control, met the HSTS. However, the restored site met the standard 40 to 90 days longer than the reference. The hydrology at the restored site appeared to be superfluous and could affect restoration of NRWHF vegetation.

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

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7. APPENDICIES

APPENDIX A. Soil Profile Descriptions

Plot location: ACNSSe
Date: 8/11/2003
Describer: Vepraskas
Vegetative Cover: Trees and Shrubs

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-15	10YR 5/1	10YR 5/6 (20%)	n/a	n/a	n/a	n/a	Sandy Loam	Moderate	1	Sub-angular blocky
Eg	15-23	10YR 6/1	7.5YR 5/8 (20%) 2.5YR 3/6 (10%)	n/a	n/a	n/a	n/a	Sandy Clay Loam	Moderate	3	Sub-angular blocky
Btg1	23-41	10YR 5/1	10YR 5/8 (45%)	n/a	2.5Y 3/6 (2%)	n/a	n/a	Clay	Strong	10	Prismatic
Btg2	41-65	2.5Y 5/1	10YR 5/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg3	65-80+	2.5Y 5/1	10YR 6/8 (25%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	5	Sub-angular blocky

Plot location: ALNSS
Date: 8/11/2003
Describer: Vepraskas
Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
Ap	0-21	2.5Y 4/2	7.5YR 4/6 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Moderate	1	Sub-angular blocky
Eg	21-25	2.5Y 6/2	10YR 5/6 (30%)	n/a	n/a	n/a	n/a	Sandy Loam	Moderate	1	Sub-angular blocky
Btg1	25-40	10YR 5/1	10YR 5/8 (45%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg2	40-55	2.5Y 5/1	10YR 6/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg3	55-65	N 6/0	10YR 6/8 (70%)	n/a	n/a	n/a	n/a	Clay	Strong	25	Sub-angular blocky
Btg4	65-90	2.5Y 5/1	10YR 6/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Moderate	20	Sub-angular blocky
Btg5	90-119+	2.5Y 6/1	10YR 6/8 (80%)					Sandy Loam	Moderate	30	Sub-angular blocky

Plot location: ALSSS
Date: 8/11/2003
Describer: Vepraskas
Vegetative Cover: Selected Plantings

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
Ap	0-20	10YR 4/2	7.5YR 4/6 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	20-27	2.5Y 6/2		n/a	n/a	n/a	n/a	Sandy Loam	Weak	2	Sub-angular blocky
Btg1	27-45	2.5Y 6/1	10YR 5/8 (45%)	n/a	n/a	n/a	Present on linings	Sandy Clay	Strong	25	Prismatic
Btg2	45-67	2.5Y 5/1	10YR 5/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg3	67-95+	2.5Y 5/1	10YR 5/8 (75%)	n/a	n/a	n/a	n/a	Sandy Clay Loam	Moderate parting to Moderate	10 3	Prismatic Sub-angular blocky

Plot location: ALSRLS Describer: Vepraskas
Date: 8/11/2003 Vegetative Cover: Selected Plantings

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-6	2.5Y 4/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	6-10	2.5Y 6/2	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	10-25	2.5Y 6/1	10YR 5/8 (30%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Strong	18	Prismatic
Btg2	25-60+	2.5Y 5/1	10YR 6/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic

Plot location: ALSRHS Describer: Vepraskas
Date: 8/11/2003 Vegetative Cover: Selected Plantings

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-17	10YR 4/1	7.5YR 4/6 (20%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	17-33	10YR 4/1	7.5YR 4/6 (20%) (more distinct than A1)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	33-40	2.5Y 6/2	none	n/a	n/a	n/a	n/a	Sandy Loam	V. Weak	2	Sub-angular blocky
Btg1	40-51	2.5Y 6/1	10YR 5/8 (45%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg2	51-88+	2.5Y 5/1	10YR 6/8 (20%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic

Plot location: ALNRLS Describer: Vepraskas
Date: 8/11/2003 Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-11	10YR 4/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	11-17	2.5Y 6/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	17-27	2.5Y 6/1	10YR 5/8 (50%) 7.5YR 4/6 (5%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	18	Prismatic
Btg2	27-40	10YR 5/1	10YR 5/6 (40%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg3	40-60+	10YR 5/1	10YR 6/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic

Plot location: ALNRHS | Describer: Vepraskas
Date: 8/11/2003 | Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-16	10YR 4/1	7.5YR 4/4 (10%)	n/a	n/a	n/a	n/a	Sandy Loam	Moderate	1	Sub-angular blocky
A2	16-27	10YR 5/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Moderate	1	Sub-angular blocky
Eg	27-31	2.5Y 6/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Strong	1	Sub-angular blocky
E/Btg	31-44	2.5Y 6/1	10YR 5/8 (45%)	n/a	n/a	n/a	n/a	E - SL Btg - C	Strong	18	Prismatic
Btg1	44-67+	10YR 5/1	10YR 6/8 (25%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	25	Prismatic

Plot location: AHNRLS | Describer: Vepraskas
Date: 8/11/2003 | Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-12	10YR 4/1	7.5YR 4/4 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	20-Dec	10YR 5/1	7.5YR 4/4 (15%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	20-40	10YR 5/1	10YR 5/6 (45-50%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay Loam	Moderate	3	Sub-angular blocky
Btg2	40-70	10YR 5/1	10YR 5/6 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	18	Prismatic

Plot location: AHNRHS | Describer: Vepraskas
Date: 8/11/2003 | Vegetative Cover: Trees and Shrubs

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-18	10YR 4/1	7.5YR 4/6 (5%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	18-28	10YR 5/1	7.5YR 4/6 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A3	28-34	10YR 5/1	10YR 5/8 (20%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	34-50	10YR 5/1	10YR 5/8 (40%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay Loam	Moderate	3	Sub-angular blocky
Btg2	50-86	2.5Y 5/1	10YR 6/8 (45%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Strong	18	Prismatic

Plot location: AHSRLS   Describer: Vepraskas
Date: 8/12/2003   Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-13	10YR 5/1	10YR 4/6 (15%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	13-25	2.5Y 5/1	10YR 5/8 (25%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Strong	18	Prismatic
Btg2	25-50	10YR 4/1	10YR 5/8 (40%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Strong	25	Prismatic

Plot location: AHSRHS   Describer: Vepraskas
Date: 8/12/2003   Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-12	10YR 5/1	10YR 4/6 (20%) Faint	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	12-24	10YR 4/1	none	n/a	5YR 4/6 (30%) Distinct	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	24-35	2.5Y 5/1	10YR 5/8 (35%) Distinct	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Moderate	3	Sub-angular blocky
Btg2	35-64+	10YR 4/1	10YR 5/8 (45%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Strong	25	Prismatic

Plot location: AHSSS   Describer: Vepraskas
Date: 8/12/2003   Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-7	2.5Y 5/2	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	7-21	2.5Y 5/1	none	n/a	10YR 5/6 (20%)	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	21-34	10YR 5/1	10YR 5/8 (25%)	n/a	7.5YR 4/4 (5%)	n/a	n/a	Sandy Clay	Strong	4	Prismatic
Btg2	34-60	2.5Y 5/1	10YR 5/6 (45%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong parting to	18	Prismatic
									Strong	4	Angular Blocky
Btg3	60-75+	10YR 7/1 (45%) 10YR 5/1 (15%)	10YR 6/8 (40%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong	6	Angular Blocky

Plot location: AHNSS   Describer: Vepraskas
Date: 8/12/2003   Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-8	10YR 5/2	7.5YR 4/6 (15%) Faint	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
AE	8-20	10YR 5/1	10YR 4/6 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	20-31	2.5Y 5/1	7.5YR 5/8 (25%)	n/a	2.5YR 4/8 (5%)	n/a	n/a	Sandy Clay	Strong	4	Sub-angular blocky
Btg2	31-50	10YR 4/1	10YR 5/8 (35%)	n/a	2.5YR 4/8 (5%)	n/a	n/a	Sandy Clay	Strong	25	Prismatic
Btg3	50-75+	10YR 6/8	10YR 5/1 (40%)	n/a	2.5YR 4/8 (5%)	n/a	n/a	Sandy Clay	Moderate	5	Prismatic

Plot location: ACNSNe   Describer: Vepraskas
Date: 8/12/2003   Vegetative Cover: Trees and Shrubs

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-13	10YR 5/1	10YR 5/8 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	13-19	10YR 6/1	10YR 5/8 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	19-26	2.5Y 5/2	10YR 5/8 (15%)	n/a	n/a	n/a	n/a	Sandy Clay Loam	Weak	4	Sub-angular blocky
Btg2	26-64+	2.5Y 5/1	10YR 5/8 (40%)	n/a	10YR 5/8 (5%)	n/a	n/a	Sandy Clay	Moderate	18	Prismatic

Plot location: ALNSN   Describer: Vepraskas
Date: 8/12/2003   Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-14	10YR 4/1	10YR 3/6 (10%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	14-18	10YR 6/1	10YR 5/8 (20%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	18-30	10YR 5/1	10YR 6/8 (30%)	n/a	n/a	n/a	n/a	Sandy Clay	Moderate	4	Sub-angular blocky
Btg2	30-70	10YR 5/1	10YR 6/8 (50%)	n/a	n/a	n/a	n/a	Sandy Clay	Strong parting to	18	Prismatic
									Strong	4	Sub-angular blocky
Btg3	70-95+	2.5Y 5/1	10YR 6/8 (50%)	n/a	n/a	n/a	n/a	Sandy Loam	Moderate	4	Sub-angular blocky

Plot location: ALSSN | Describer: Vepraskas
Date: 8/13/2003 | Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-18	10YR 4/1	10YR 4/6 (35%) Faint	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	18-22	10YR 6/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	4	Sub-angular blocky
Btg1	22-43	10YR 4/1	10YR 5/6 (25%)	n/a	5YR 3/4 (5%)	n/a	n/a	Sandy Clay	Moderate parting to Strong	18 5	Prismatic Angular Blocky
Btg2	43-70	2.5Y 5/1	10YR 6/8 (45%)	n/a	5YR 3/4 (5%)	n/a	n/a	Sandy Clay	Moderate	25	Prismatic

*Depth of rooting was 70cm.

Plot location: ALSRHN | Describer: Vepraskas
Date: 8/13/2003 | Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-12	10YR 3/2	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	23-Dec	10YR 3/1	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	23-47	10YR 4/1	10YR 4/6 (25%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Moderate	5	Sub-angular blocky
Btg2	47-70	10YR 4/1	10YR 6/8 (40%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Moderate parting to Strong	18 13	Prismatic Angular Blocky

*Only northern sample plot with HSTS monitoring equipment.

Plot location: ALSRLN | Describer: Vepraskas
Date: 8/13/2003 | Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-16	10YR 3/2	none	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Btg1	16-43	10YR 4/1	10YR 4/6 (25%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Moderate	5	Sub-angular blocky
Btg2	43-64+	10YR 4/1	10YR 6/8 (40%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay	Moderate	18	Prismatic

*Only northern sample plot with HSTS monitoring equipment.

Plot location: ALNRHN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-22	10YR 3/2	10YR 4/4 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	22-30	2.5Y 4/1	10YR 5/6 (10%)	n/a	2.5YR 3/6 (2%)	n/a	n/a	Sandy Clay Loam	Moderate	3	Sub-angular blocky
Btg1	30-44	10YR 4/1	10YR 5/6 (25%)	n/a	2.5YR 3/6 (5%)	n/a	n/a	Sandy Clay	Moderate	18	Prismatic
Btg2	44-62+	10YR 4/1	10YR 5/6 (25%)	n/a	2.5YR 3/6 (5%)	n/a	n/a	Sandy Clay	Moderate	18	Prismatic

Plot location: ALNRLN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-19	10YR 3/2	10YR 4/4 (15%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
Eg	19-23	2.5Y 4/1	none	n/a	2.5YR 3/6 (2%)	n/a	n/a	Sandy Clay Loam	Moderate	3	Sub-angular blocky
Btg1	23-48	10YR 4/1	10YR 5/6 (25%)	n/a	2.5YR 3/6 (5%)	n/a	n/a	Sandy Clay	Strong	18	Prismatic
Btg2	48-62+	10YR 4/1	10YR 5/6 (45%)	n/a	2.5YR 3/6 (5%)	n/a	n/a	Sandy Clay	Moderate	18	Prismatic

Plot location: AHNRHN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-16	10YR 5/1	7.5YR 4/6 (5%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
A2	16-27	10YR 5/1	7.5YR 4/6 (20%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
E/Bg	27-36	10YR 6/1	10YR 5/8 (20%)	n/a	n/a	n/a	n/a	Sandy Clay Loam	Moderate	18	Prismatic
									parting to		
									Strong	3	Sub-angular blocky
Btg1	36-58	10YR 6/1	10YR 6/8 (30%)	n/a	n/a	n/a	n/a	Sandy Clay	Moderate	18	Prismatic
									parting to		
									Moderate	6	Sub-angular blocky

Plot location: AHNRLN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-10	10YR 4/1	10YR 4/6 (25%)	n/a	n/a	n/a	n/a	Sandy Loam	Weak	1	Sub-angular blocky
E/Bg	10-18	10YR 6/1	10YR 5/8 (25%)	n/a	5YR 4/6 (5%)	n/a	n/a	Sandy Clay Loam	Moderate	5	Sub-angular blocky
Btg1	18-42	10YR 5/1	10YR 6/8 (35%)	n/a	n/a	n/a	n/a	Sandy Clay	Moderate	18	Prismatic
									parting to		
									Moderate	6	Sub-angular blocky
Btg2	42-52+	10YR 5/1	10YR 6/6 (40%)	n/a	n/a	n/a	n/a	Sandy Clay Loam	Moderate	18	Prismatic
									parting to		
									Moderate	6	Sub-angular blocky

Plot location: AHSRHN Describer: Vepraskas
Date: 8/11/2003 Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-10	10YR 4/1	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
A2	10-21	10YR 4/1	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
A3	21-36	10YR 4/1	none	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg1	36-66	10YR 4/1	10YR 5/8 (10%)	n/a	2.5Y 3/6 (2%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	66-86+	10YR 6/1	7.5YR 5/8 (20%)	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a

*Sample by hand auger

Plot location: AHSRLN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-10	10YR 5/1	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	10-27	10YR 5/1	10YR 5/8 (5%)	n/a	2.5YR 3/6 (10%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	27-50	10YR 4/1	10YR 5/8 (5%)	n/a	2.5YR 3/6 (10%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg3	50-70	2.5Y 6/2	10YR 5/8 (25%)	n/a	2.5YR 4/8 (10%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg4	70+	2.5Y 6/2	10YR 6/8 (30%)	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a

Plot location: AHSSN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Selected

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-15	10YR 5/1	7.5YR 4/6 (5%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
AB	15-33	10YR 5/1	7.5YR 5/8 (10%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	33-66	10YR 5/1	7.5YR 5/8 (40%)	n/a	2.5YR 4/8 (5%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	66-88+	2.5Y 5/1	7.5YR 5/8 (40%)	n/a	2.5YR 4/8 (5%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a

Plot location: AHNSN Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Natural

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-15	10YR 5/1	7.5YR 4/6 (10%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
A2	15-23	10YR 5/1	7.5YR 4/6 (15%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Eg	23-35	10YR 6/1	10YR 5/8 (10%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	35-50	2.5Y 6/2	7.5YR 5/8 (30%)	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	50-80+	10YR 4/1	10YR 6/8 (40%)	n/a	7.5YR 5/8 (5%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a

Plot location: ALR1 Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Mature Hardwood Stand. Thin understory, mostly open.

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A1	0-6	10YR 2/2	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
A2	6-11	10YR 3/1	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Eg	11-34	10YR 6/1		n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	34-63	10YR 5/1	10YR 5/8 (40%)	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	63-95+	2.5Y 6/1	10YR 6/8 (10%)	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a

Plot location: AHR1 Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Mature Hardwood Stand. Thin understory, mostly open.

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
A	0-12	10YR 2/1	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
E1	12-25	2.5Y 6/2	10YR 5/6 (10%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
E2	25-40	10YR 6/1	10YR 5/6 (5%)	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	40-63	10YR 5/1	10YR 5/8 (30%)	n/a	5YR 4/6 (10%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	63-94+	10YR 5/1	10YR 5/6 (30%)	n/a	n/a	n/a	n/a	Sandy Clay	n/a	n/a	n/a

Plot location: ALR2 Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Mature Hardwood Stand. Thin understory, mostly open.

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
Oa	0-1	10YR 2/2	none	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
A	1-23	10YR 3/2	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	23-60	10YR 5/1	10YR 5/8 (5%)	n/a	5YR 4/6 (20%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a
Btg2	60-98+	10YR 5/1	10YR 5/8 (30%)	n/a	5YR 4/6 (10%)	n/a	n/a	Sandy Clay	n/a	n/a	n/a

Plot location: AHR2 Describer: Vepraskas
Date: 8/13/2003 Vegetative Cover: Mature Hardwood Stand. Thin understory, mostly open.

Horizon	Depth (cm)	Matrix Color	Redox concentrations			Redox depletions		Texture	Structure		
			Fe Masses	Nodules	Pore Linings	Matrix	Coatings		Grade	Size (cm)	Shape
Oa	0-1	10YR 2/2	none	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
A	1-9	10YR 2/1	none	n/a	n/a	n/a	n/a	Loam	n/a	n/a	n/a
Eg	9-28	10YR 5/1	none	n/a	n/a	n/a	n/a	Sandy Loam	n/a	n/a	n/a
Btg1	28-63	10YR 4/1	10YR 5/6 (20%)	n/a	5YR 3/4 (5%)	n/a	n/a	Sandy Clay Loam	n/a	n/a	n/a
Btg2	63-90+	10YR 5/1	10YR 6/8 (5%)	n/a	5YR 4/6 (20%)	n/a	n/a	Sandy Clay Loam	n/a	n/a	n/a

APPENDIX B. Soil Nutrient Data

Restored Site (2003) - South Transect

Plot	Horizon	Depth	Wt/Vol	pH	BS	TOC	TKN	Al	K	Ca	Mg	CEC	P	Mn	Zn	Cu
		(cm)	(g/cm^3)		---------- % ----------			---------- ($cmol_c\ kg^{-1}$) ----------					--------- ($mg\ kg^{-1}$) ----------			
ACNSSe	A	15	1.24	5.30	73.0	0.79	0.06	0.39	0.05	1.18	0.27	1.9	37.18	5.97	5.81	0.48
	Eg	23	1.21	6.10	89.0	0.53	0.03	0.21	0.04	1.79	0.45	2.5	6.28	2.07	0.50	0.17
	Btg1	41	1.15	6.00	93.0			0.26	0.10	4.12	0.80	5.3	0.00	0.26	0.26	0.00
	Btg2	65	1.23	6.20	93.0			0.20	0.11	3.50	0.38	4.2	0.00	0.49	0.08	0.08
	Btg3	80+	1.19	6.20	95.0			0.16	0.17	3.93	0.45	4.7	0.00	1.18	0.34	0.08
ALNSS	Ap	21	1.24	5.80	88.0	0.73	0.06	0.25	0.06	2.11	0.43	2.8	16.61	6.94	3.79	0.16
	Eg	25	1.21	6.30	92.0	0.30	0.02	0.19	0.06	2.71	0.54	3.5	0.00	1.82	0.25	0.08
	Btg1	40	1.17	6.60	96.0			0.17	0.10	4.96	0.76	6.0	0.00	0.34	0.09	0.09
	Btg2	55	1.19	6.80	97.0			0.10	0.11	4.94	0.57	5.7	0.00	1.09	0.00	0.08
	Btg3	65	1.19	6.90	97.0			0.11	0.12	5.13	0.54	5.9	0.00	2.10	0.08	0.17
	Btg4	90	1.20	6.90	98.0			0.07	0.13	4.63	0.41	5.2	0.00	7.33	0.17	0.17
	Btg5	119+	1.25	6.90	98.0			0.06	0.13	3.00	0.28	3.5	0.00	15.04	0.32	0.16
ALSSS	Ap	20	1.25	5.50	79.0	0.80	0.07	0.26	0.05	1.22	0.28	1.8	32.64	7.68	5.20	0.40
	Eg	27	1.30	6.30	90.0	0.40	0.03	0.12	0.04	1.37	0.31	1.8	13.31	2.69	0.38	0.31
	Btg1	45	1.17	6.40	95.0			0.17	0.11	4.41	0.87	5.6	0.00	0.17	0.09	0.00
	Btg2	67	1.19	6.00	95.0			0.10	0.11	4.61	0.52	5.3	0.00	1.09	0.08	0.00
	Btg3	95+	1.21	6.30	96.0			0.10	0.11	3.95	0.35	4.5	0.00	9.09	0.17	0.17
ALSRLS	A	6	1.27	5.60	84.0	0.57	0.05	0.20	0.05	1.33	0.27	1.9	9.13	5.67	2.13	0.39
	Eg	10	1.23	6.10	90.0	0.30	0.02	0.18	0.06	2.22	0.46	2.9	0.00	2.11	0.24	0.08
	Btg1	25	1.21	5.90	93.0			0.25	0.10	3.85	0.68	4.9	0.00	0.41	0.17	0.00
	Btg2	60+	1.20	6.20	96.0			0.17	0.11	4.78	0.50	5.6	0.00	0.50	0.08	0.08
ALSRHS	A1	17	1.30	5.20	71.0	0.92	0.08	0.36	0.03	1.08	0.24	1.7	29.15	8.08	5.54	0.38
	A2	33	1.30	5.60	77.0	0.72	0.06	0.27	0.04	1.19	0.22	1.7	34.38	5.85	5.38	0.69
	Eg	40	1.30	6.30	88.0	0.18	0.01	0.11	0.03	0.92	0.17	1.2	4.77	2.31	0.69	0.08
	Btg1	51	1.18	6.20	94.0			0.21	0.11	4.17	0.75	5.2	0.00	0.34	0.08	0.00
	Btg2	88+	1.17	6.10	94.0			0.25	0.12	4.94	0.65	6.0	0.00	0.17	0.09	0.00
ALNRLS	A	11	1.22	5.30	77.0	0.68	0.06	0.29	0.05	1.10	0.25	1.7	20.82	5.57	0.25	0.16
	Eg	17	1.29	6.40	91.0	0.30	0.02	0.09	0.03	1.33	0.23	1.7	0.78	2.17	0.16	0.08
	Btg1	27	1.18	6.50	94.0			0.18	0.08	3.38	0.51	4.1	0.00	0.59	0.08	0.00
	Btg2	40	1.18	6.60	95.0			0.18	0.10	4.59	0.56	5.4	0.00	0.17	0.17	0.00
	Btg3	60	1.19	6.50	96.0			0.15	0.10	4.45	0.40	5.1	0.00	1.60	4.96	0.00
ALNRHS	A1	16	1.25	5.00	64.0	0.88	0.07	0.43	0.05	0.91	0.22	1.6	23.60	9.92	4.72	0.24
	A2	27	1.27	5.10	65.0	0.69	0.06	0.38	0.06	0.80	0.19	1.4	19.69	3.62	0.39	0.79
	Eg	31	1.34	6.20	88.0	0.21	0.02	0.12	0.04	1.13	0.26	1.6	0.37	2.99	0.22	0.07
	E/Btg (E)	44	1.26	6.50	93.0			0.19	0.07	3.06	0.63	3.9	0.00	1.90	0.08	0.00
	E/Btg (Btg)		1.13	6.80	95.0			0.17	0.11	4.86	0.72	5.9	0.00	0.35	0.09	0.00
	Btg1	67	1.23	6.70	97.0			0.12	0.14	5.03	0.50	5.8	0.00	4.31	2.28	0.08
AHNRLS	A1	12	1.32	5.90	80.0	0.66	0.05	0.26	0.04	1.25	0.27	1.8	22.95	5.38	0.23	0.15
	A2	20	1.26	6.10	88.0	0.31	0.02	0.26	0.06	2.16	0.63	3.1	0.00	1.19	0.08	0.00
	Btg1	40	1.15	5.20	78.0			0.68	0.10	2.97	0.78	4.5	0.00	0.26	0.17	0.00
	Btg2	70	1.18	5.00	82.0			0.59	0.13	3.53	0.48	4.7	0.00	0.25	5.76	0.08
AHNRHS	A1	18	1.22	5.50	76.0	0.76	0.06	0.33	0.04	1.26	0.31	1.9	34.43	7.21	0.82	0.41
	A2	28	1.31	6.10	86.0	0.56	0.04	0.20	0.05	1.46	0.44	2.1	20.31	2.67	0.15	0.23
	A3	34	1.27	6.40	91.0	0.39	0.02	0.14	0.06	1.51	0.49	2.2	4.88	1.50	0.08	0.08
	Btg1	50	1.13	5.40	85.0			0.45	0.11	2.89	0.77	4.2	0.00	0.18	0.27	0.00
	Btg2	86	1.17	5.40	89.0			0.35	0.13	3.41	0.53	4.4	0.00	0.51	5.98	0.17
AHSRLS	A	13	1.24	5.60	81.0	0.64	0.05	0.32	0.06	1.62	0.46	2.5	23.95	6.37	0.16	0.16
	Btg1	25	1.21	6.20	94.0	0.64	0.05	0.24	0.11	4.13	1.41	5.9	0.00	1.16	0.08	0.08
	Btg2	50	1.18	5.10	86.0			0.44	0.11	3.02	0.77	4.3	0.00	0.25	6.02	0.00
AHSRHS	A1	12	1.24	5.50	74.0	0.88	0.07	0.40	0.05	1.31	0.37	2.1	26.53	8.23	5.81	0.16
	A2	24	1.23	5.80	84.0	0.72	0.07	0.28	0.06	1.65	0.46	2.5	23.01	6.50	0.24	0.33
	Btg1	35	1.14	6.20	91.0	0.42	0.05	0.24	0.09	2.81	0.86	4.0	0.00	1.84	0.09	0.09
	Btg2	64	1.13	5.20	88.0			0.45	0.13	4.07	0.73	5.4	0.00	0.27	7.26	0.09
AHSSS	A1	7	1.19	5.50	80.0	0.72	0.06	0.34	0.05	1.54	0.44	2.4	42.27	9.33	4.79	0.25
	A2	21	1.23	6.60	93.0	0.47	0.04	0.13	0.06	2.01	0.61	2.8	28.21	5.61	0.16	0.33
	Btg1	34	1.16	6.40	94.0			0.20	0.09	3.57	0.78	4.6	0.00	0.69	0.09	0.00
	Btg2	60	1.13	6.40	96.0			0.17	0.12	5.15	0.77	6.2	0.00	0.09	0.09	0.00
	Btg3	75	1.19	6.60	98.0			0.09	0.12	5.08	0.52	5.8	0.00	0.08	0.08	0.08
AHNSS	A	8	1.21	5.20	74.0	0.76	0.08	0.31	0.05	1.02	0.24	1.6	19.09	1.32	1.74	0.17
	AE	20	1.23	6.00	89.0	0.48	0.04	0.17	0.05	1.73	0.31	2.3	16.50	3.17	0.57	0.24
	Btg1	31	1.19	6.50	94.0			0.13	0.06	2.53	0.47	3.2	4.20	3.28	0.08	0.08
	Btg2	50	1.16	6.80	98.0			0.10	0.13	5.54	0.67	6.4	0.00	0.60	0.09	0.09
	Btg3	75	1.21	7.10	99.0			0.05	0.15	5.78	0.56	6.5	0.00	0.25	0.00	0.17

Restored Site (2003) - North Transect

Plot	Horizon	Depth	Wt/Vol	pH	BS	TOC	TKN	Al	K	Ca	Mg	CEC	P	Mn	Zn	Cu
		(cm)	(g/cm^{-3})		---------- % ----------			----------- ($cmol_c\ kg^{-1}$) -----------					--------- ($mg\ kg^{-1}$) ----------			
ACNSNe	A	13	1.25	5.70	86.0	0.60	0.05	0.20	0.03	1.41	0.31	2.0	27.76	3.52	4.96	0.40
	Eg	19	1.26	6.60	95.0	0.18	0.02	0.10	0.06	2.16	0.69	3.0	0.00	2.06	0.24	0.08
	Btg1	26	1.20	6.80	96.0			0.12	0.08	3.22	0.94	4.4	0.00	0.75	0.17	0.00
	Btg2	64	1.19	7.20	98.0			0.09	0.13	5.79	0.73	6.7	0.00	1.01	0.08	0.08
ALNSN	A	14	1.22	5.70	79.0	0.70	0.06	0.29	0.03	1.42	0.26	2.0	29.75	4.67	3.28	0.25
	Eg	18	1.28	6.20	90.0	0.30	0.03	0.16	0.04	1.70	0.34	2.2	9.92	2.27	0.63	0.23
	Btg1	30	1.21	6.60	95.0			0.14	0.07	3.34	0.67	4.2	0.00	1.24	0.08	0.08
	Btg2	70	1.27	7.20	97.0			0.10	0.09	4.33	0.35	4.9	0.00	4.88	0.00	0.08
	Btg3	95+	1.24	7.20	97.0	0.12	0.01	0.09	0.11	3.99	0.30	4.5	0.00	0.97	0.00	0.08
	Crotovinas in Btg2		1.28	6.90	96.0			0.12	0.08	3.41	0.39	4.0	0.00	4.61	0.00	0.08
ALSSN	A	18	1.23	5.70	84.0	0.82	0.06	0.26	0.05	1.75	0.44	2.5	21.14	5.45	3.17	0.16
	E	22	1.23	6.50	91.0	0.61	0.05	0.23	0.06	2.48	0.68	3.5	0.00	1.14	0.00	0.00
	Btg1	43	1.17	6.50	93.0			0.23	0.11	3.91	0.82	5.1	0.00	0.34	0.00	0.00
	Btg2	70	1.21	6.60	95.0			0.17	0.13	4.13	0.67	5.1	0.00	0.74	0.00	0.08
ALSRHN	A1	12	1.20	5.40	75.0	1.13	0.1	0.45	0.06	1.55	0.41	2.5	27.67	4.92	3.08	0.25
	A2	23	1.25	5.90	83.0	0.87	0.07	0.31	0.05	1.79	0.48	2.6	17.84	5.20	2.16	0.64
	Btg1	47	1.14	5.40	80.0	0.49	0.05	0.61	0.09	2.80	0.89	4.4	0.00	0.61	0.09	0.00
	Btg2	70	1.15	4.80	83.0			0.53	0.12	3.24	0.55	4.4	0.00	0.52	0.09	0.09
ALSRLN	A	16	1.18	5.40	79.0	1.15	0.09	0.39	0.07	1.75	0.44	2.6	29.58	5.00	3.14	0.25
	Btg1	43	1.16	4.90	73.0	0.56	0.06	0.86	0.09	2.71	0.69	4.4	0.00	0.78	0.09	0.00
	Btg2	64	1.16	4.90	79.0			0.72	0.13	3.34	0.56	4.7	0.00	0.34	0.00	0.00
ALNRLN	A	19	1.23	5.30	76.0	0.69	0.06	0.32	0.04	1.29	0.29	1.9	22.76	7.89	3.17	0.24
	Eg	23	1.34	6.10	88.0	0.50	0.04	0.24	0.04	1.91	0.44	2.6	0.60	3.28	0.22	0.07
	Btg1	48	1.24	6.00	91.0			0.25	0.08	2.88	0.62	3.8	0.00	0.56	0.00	0.00
	Btg2	62+	1.23	6.30	95.0			0.18	0.11	4.52	0.64	5.5	0.00	0.33	0.00	0.00
ALNRHN	A	22	1.27	5.20	74.0	0.76	0.07	0.37	0.04	1.27	0.24	1.9	22.83	5.28	5.12	0.31
	Eg	30	1.30	6.40	90.0	0.49	0.05	0.22	0.05	2.40	0.58	3.3	0.00	3.31	0.08	0.00
	Btg1	44	1.21	6.60	94.0	0.37	0.05	0.21	0.11	4.16	0.81	5.3	0.00	0.41	0.00	0.00
	Btg2	62	1.20	6.60	96.0			0.17	0.13	4.82	0.78	5.9	0.00	0.75	0.00	0.08
AHNRLN	A	10	1.25	5.80	82.0	0.50	0.04	0.22	0.02	1.18	0.24	1.7	14.64	2.72	1.12	0.16
	E/Bg	18	1.23	6.30	92.0	0.40	0.04	0.21	0.08	3.09	0.75	4.1	0.00	5.12	0.24	0.00
	Btg1	42	1.14	7.10	98.0			0.08	0.10	4.46	0.72	5.4	0.00	1.67	0.00	0.00
	Btg2	52+	1.18	7.20	98.0			0.09	0.12	4.69	0.54	5.4	0.00	6.69	0.00	0.08
AHNRHN	A1	16	1.35	5.00	84.0	1.00	0.08	0.19	0.04	1.31	0.25	1.8	14.52	5.04	1.56	0.07
	A2	27	1.28	6.00	84.0	0.59	0.05	0.27	0.03	1.66	0.31	2.3	14.69	3.59	2.03	0.31
	E/Bg	36	1.18	6.60	95.0	0.19	0.02	0.17	0.11	4.51	0.78	5.6	0.00	1.95	0.00	0.00
	Btg1	58	1.18	6.90	96.0			0.12	0.08	4.12	0.48	4.8	0.00	2.63	0.00	0.00
AHSRLN	A	10	1.16	5.20	74.0	0.78	0.06	0.42	0.07	1.45	0.34	2.3	9.31	4.05	1.47	0.00
	Btg1	27	1.16	5.40	88.0	0.48	0.05	0.29	0.08	2.40	0.62	3.4	0.00	1.38	0.09	0.00
	Btg2	50	1.19	5.20	84.0			0.46	0.09	3.02	0.58	4.1	0.00	0.42	0.00	0.08
	Btg3	70	1.27	6.10	94.0			0.18	0.13	3.56	0.47	4.3	0.00	0.39	0.00	0.08
	Btg4	70+	1.18	6.80	96.0			0.14	0.16	4.36	0.49	5.1	0.00	2.71	0.08	0.42
AHSRHN	A1	10	1.14	5.40	73.0	1.65	0.14	0.41	0.06	1.25	0.35	2.1	38.51	8.33	5.61	0.09
	A2	21	1.19	5.80	83.0	0.84	0.08	0.25	0.04	1.42	0.37	2.1	35.55	5.13	4.29	0.08
	A3	36	1.21	5.70	82.0	0.55	0.05	0.33	0.06	1.69	0.51	2.6	10.58	2.81	1.74	0.25
	Btg1	66	1.11	5.40	80.0			0.57	0.11	2.75	0.66	4.1	0.00	0.72	0.18	0.09
	Btg2	86+	1.17	5.90	90.0			0.30	0.15	3.35	0.48	4.3	0.00	0.68	0.17	0.09
AHSSN	A	15	1.18	5.10	66.0	1.59	0.13	0.57	0.08	1.28	0.32	2.3	59.15	5.34	2.97	0.34
	AB	33	1.20	5.70	58.0	0.86	0.06	0.95	0.05	1.50	0.38	2.9	33.17	4.83	0.92	0.67
	Btg1	66	1.18	6.10	89.0			0.33	0.12	3.62	0.53	4.6	0.00	0.68	0.00	0.17
	Btg2	88+	1.17	6.00	92.0			0.26	0.15	3.77	0.46	4.6	0.00	0.68	0.09	0.17
AHNSN	A1	15	1.14	5.30	76.0	0.87	0.07	0.41	0.07	1.50	0.39	2.4	58.16	5.88	3.77	0.18
	A2	23	1.22	6.00	81.0	0.51	0.04	0.33	0.05	1.61	0.45	2.4	36.23	4.10	1.15	0.33
	Eg	35	1.19	6.20	88.0			0.21	0.06	1.85	0.53	2.7	20.50	3.28	0.50	0.34
	Btg1	50	1.18	6.40	91.0			0.19	0.08	2.44	0.63	3.3	0.00	1.10	0.17	0.17
	Btg2	80	1.17	6.80	96.0			0.15	0.16	4.24	0.58	5.1	0.00	1.97	0.17	0.17

Reference Site (2003)

Plot	Horizon	Depth	Wt/Vol	pH	BS	TOC	TKN	Al	K	Ca	Mg	CEC	P	Mn	Zn	Cu
		(cm)	(g/cm^3)		---------- % -----------			----------- ($cmol_c\ kg^{-1}$) ------------					--------- ($mg\ kg^{-1}$) -----------			
ALR1	Oe	1				21.85	1.07									
	A1	6	0.93	4.30	47.0	4.63	0.28	1.54	0.18	1.60	0.35	3.7	30.75	4.19	2.26	0.65
	A2	11	1.15	4.80	49.0	0.66	0.04	1.52	0.06	1.83	0.25	3.7	0.00	0.43	0.17	0.00
	Eg	34	1.18	5.30	83.0			0.52	0.10	3.46	0.29	4.4	0.00	0.25	0.00	0.08
	Btg1	63	1.24	5.80	90.0			0.26	0.14	3.28	0.26	3.9	0.00	1.05	0.00	0.16
	Btg2	95+														
AHR1	Oe	1				19.01	0.9									
	A1	12	0.99	3.90	29.0	2.58	0.14	1.17	0.11	0.54	0.12	1.9	13.03	3.03	0.51	0.10
	E1	25	1.20	4.40	17.0	1.08	0.05	0.82	0.03	0.17	0.05	1.1	3.00	0.67	0.17	0.00
	E2	40	1.22	4.60	29.0	0.44	0.03	0.88	0.03	0.41	0.11	1.4	0.00	0.33	0.16	0.00
	Btg1	63	1.17	5.00	81.0			0.56	0.10	3.15	0.35	4.2	0.00	0.09	0.00	0.00
	Btg2	94+	1.18	5.80	82.0			0.26	0.14	4.08	0.37	4.9	0.00	1.02	0.08	0.08
ALR2	Oa	1				20.59	1.03									
	A	23	1.05	4.20	19.0	1.77	0.09	1.09	0.06	0.27	0.07	1.5	17.24	0.38	1.05	0.10
	Btg1	60	1.11	4.20	11.0	0.65	0.05	1.86	0.07	0.20	0.13	2.3	0.00	0.18	0.18	0.00
	Btg2	98+	1.11	4.50	29.0			1.57	0.09	0.52	0.14	2.3	0.00	0.18	0.18	0.18
AHR2	Oa	1				7.38	0.41									
	A	9	0.84	3.80	18.0	3.64	0.18	2.45	0.21	0.58	0.17	3.4	25.83	2.26	2.26	0.48
	Eg	28	1.18	4.20	11.0	1.09	0.05	0.94	0.04	0.10	0.03	1.1	3.81	0.42	0.34	0.17
	Btg1	63	1.15	4.30	14.0	0.61	0.05	1.81	0.08	0.29	0.13	2.3	0.00	0.35	0.17	0.00
	Btg2	90+	1.09	4.30	23.0			1.36	0.07	0.40	0.14	2.0	0.00	0.37	0.18	0.09