Abstract

Title of Thesis: HYDROMORPHOLOGY OF PIEDMONT FLOODPLAIN SOILS

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Alluvial soils situated on middle locations along Mid-Atlantic Piedmont floodplains lack characteristic redoximorphic features that allow them to meet a current field indicator of hydric soil. Although these soils appear to be located in wetlands based on their hydrologic, vegetative, and electrochemical status; there is no hydric soil indicator that accurately includes soils on these landscapes. Two research sites in Maryland and one in Delaware were instrumented along a hydrosequence. Depth to water table, redox potential, and soil temperature were measured. Redox potential measurements of the hydric and possible hydric soil conclude that Fe(III) is predicted to be reduced to Fe(II) for a significant period of time during the growing season. Based on data collected over three years, the possible hydric soil was confirmed hydric. An alternate hydric soil indicator has been proposed for these landscapes.

HYDROMORPHOLOGY OF PIEDMONT FLOODPLAIN SOIL

by

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Dedication

I began this research in September, 2001, the same month that my mother, Carol, lost her fight against pancreatic cancer. She battled the disease for one year; six months longer than doctors had predicted. Throughout my mom's last year, she encouraged me to be strong, laugh often, and above all, live my life to the fullest. I am grateful for that as well as having a wonderful and loving childhood together with my father, Rich, and sister, Cathy. I dedicate this work to my family – thank you for helping me become who I am today and everyday.

"Everything I am or ever hope to be, I owe to my angel mother."

~ Abraham Lincoln

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I sincerely thank all who have contributed to my success:

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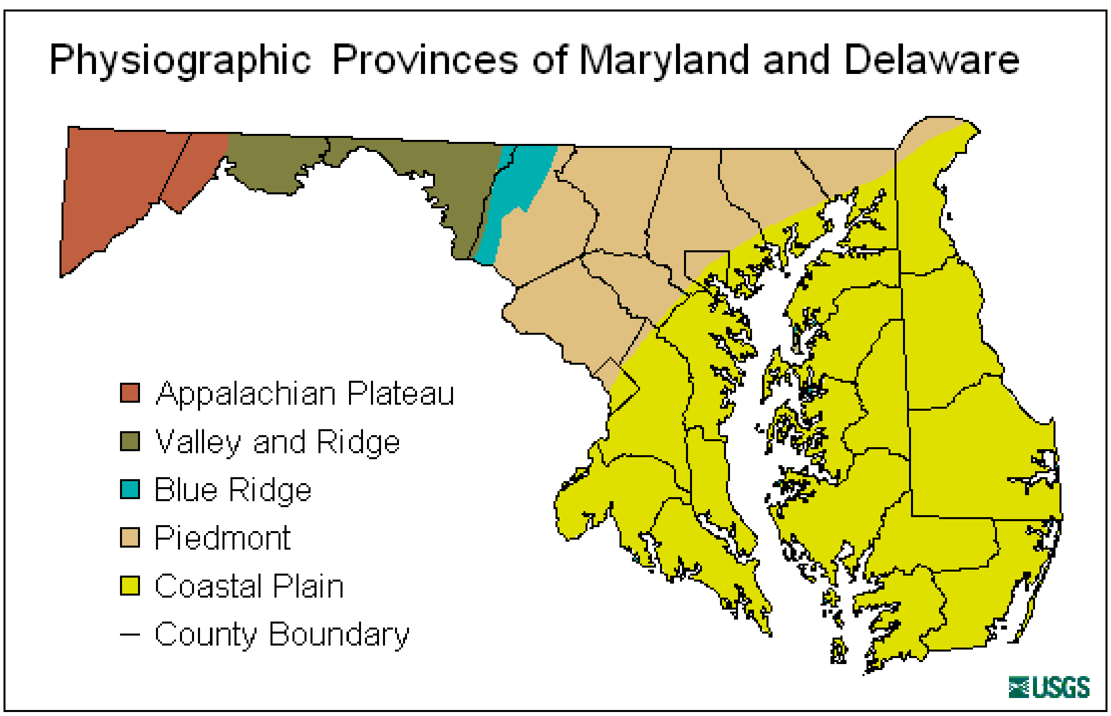
I. Introduction

As development pressures continue along the eastern United States, accurate identification of soil and landscape features is essential. The Piedmont physiographic province extends from southeastern New York to northeastern Alabama. Both Maryland and Delaware contain part of the Mid-Atlantic Piedmont physiographic province shown in figure 1-1. The Interstate 95 corridor from northern Delaware, south through Washington DC is located towards the eastern boundary of the Piedmont province and is experiencing a great deal of population growth due to the location of major cities and employment opportunities that attract people to the area.

Figure 1-1: Physiographic Provinces of Maryland and Delaware. The Piedmont physiographic province, shaded in tan, is surrounded by the Coastal Plain province, in yellow, to the east and the Blue Ridge province, in blue, to the west.

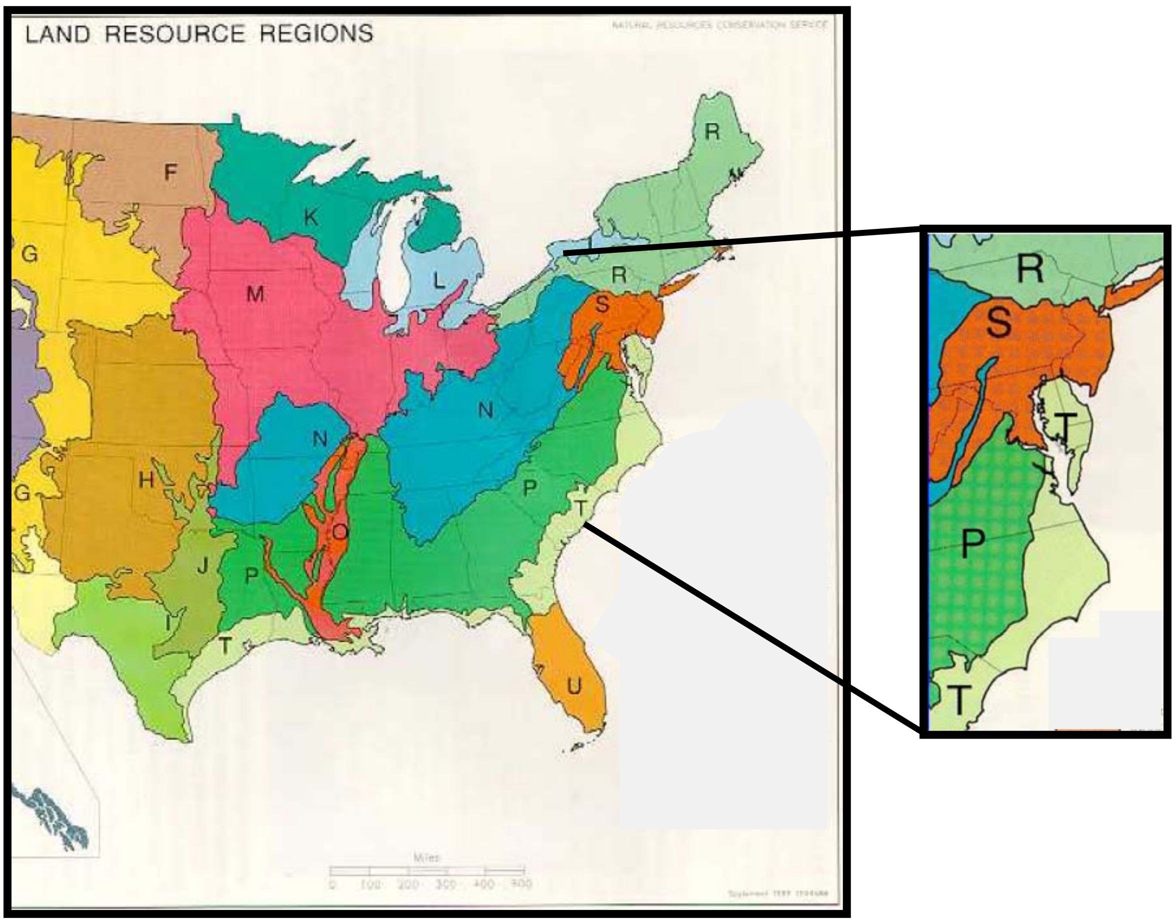


Soils on floodplains of this area are agriculturally important because of their location in fertile, highly cultivated floodplains (Fanning and Fanning, 1989). Some locations along these floodplains however, are wetlands; that is they are saturated seasonally with water for a sufficient amount of time to maintain hydrophytic vegetation, wetland hydrology, and hydric soils. Wetlands are "…those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (Federal Register, 1980).

Certain soil morphological features, indicative of a wetland soil, form due to the onset of reducing conditions brought about by saturation. Low chroma, gley colors are indicative of the removal of reduced iron in an anaerobic soil environment. Thick, dark organic rich surface horizons signify slow organic matter decomposition which results from saturated soil conditions with little or no oxygen. A hydric soil is defined as "…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" (Federal Register, 1994). The anaerobic conditions in these soils promote the growth of hydrophytic vegetation.

A set of field indicators of hydric soil were developed by the National Technical Committee for Hydric Soils in order to positively identify hydric soils using specific morphological features. These field indicators of hydric soil are used throughout the Unites States. The indicators are intended to be "proof positive", which means that if an indicator is met, the soil is definitely hydric. Each region in the country uses a subset of the indicators that can be applied to that area. The Piedmont Region in Maryland and Delaware is located in Land Resource Region S (Fig. 1-2).

Figure 1-2: Land Resource Regions (LRR) for the Eastern United States. The close view on the right details LRR S which encompasses the Piedmont in Maryland and Delaware (USDA-NRCS, 2002). LRR P is the South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region, LRR R is the Northeastern Forage and Forest Region, LRR S is the Northern Atlantic Slope Diversified Farming Region, and LRR T is the Atlantic and Gulf Coast Lowland Forest and Crop Region.

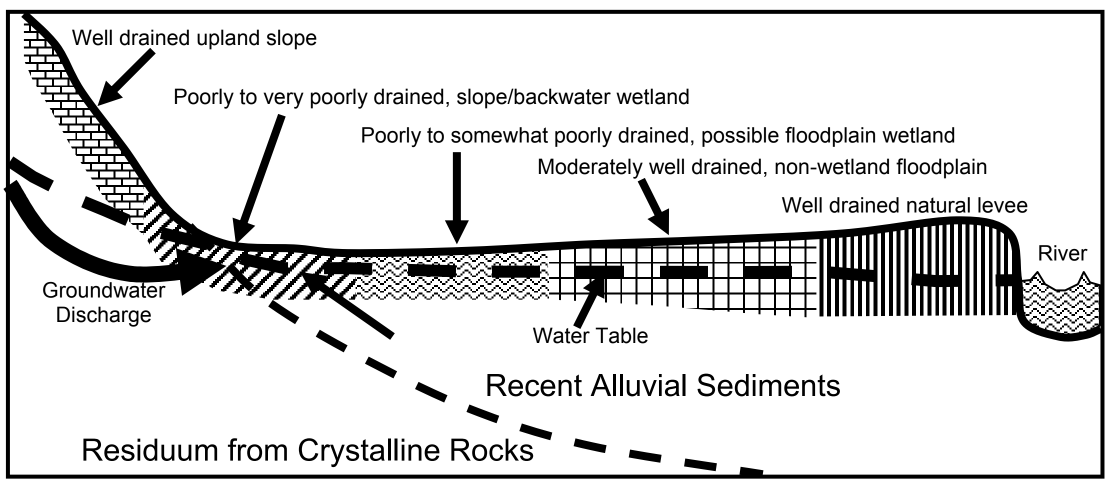


Although the hydrology of these floodplain sites indicates hydric soils are present, the observed soil morphology in some of these wetlands is different from what one would expect to see; therefore, accurate hydric soil (and wetland) determinations are hindered.

A greater understanding of the hydrological dynamics in these soils and subsequent formation of redoximorphic features, would help to alleviate the difficulty of wetland delineations on these floodplains.

Figure 1-3 depicts a schematized cross-section of a Piedmont floodplain. Cassel et al. (2002) state that soil water movement in the Piedmont is complex and gives rise to both extremely wet and droughty conditions depending on landscape position. The poorly to very poorly drained, slope/backwater wetlands exhibit soil morphology that is typically found in hydric soils. Such features include a depleted matrix and in most circumstances, dark, organic rich surface layers that enable them to be accurately identified as hydric soils.

Figure 1-3: Schematic of a Piedmont Floodplain (Rabenhorst, M.C., 2001).



The poorly to somewhat poorly drained soils in the possible floodplain wetlands do not demonstrate classic hydric soil morphology. The dominant matrix in the upper part displays 3 chroma colors with many redox concentrations of iron and manganese. Due to the absence of a depleted matrix or thick, dark surface horizons indicative of more substantial wetness, the soils in these portions of the landscape do not meet a current field indicator of hydric soil. This is true even though portions of the floodplain have hydrophytic vegetation and wetland hydrology.

The moderately well drained soils closer to the stream and levee may or may not display redox concentrations, but not the redox depletions or other features normally found in wetter environments. This area along the floodplain does not maintain typical wetland hydrology or hydrophytic vegetation and therefore is clearly not a wetland.

As is typical on floodplains, these soils exhibit a buried surface horizon 1.5 to 2 m below the existing surface. The age of the upper portions of the soil unit (above the buried surface) range between 250 and 3000 years. The large sediment load deposited on these floodplains is thought to be attributed to European colonization after extensive clear-cutting and farming during times when little or no thought was given to erosion prevention. The formation of soil crusts and destabilization of soil aggregates were caused by direct impact of rain on newly exposed soil. This reduced infiltration, increased runoff, and caused water to entrain more soil particles (Jacobson and Coleman, 1986) that would be carried to nearby rivers. When rivers overflowed their banks, water and sediment were conducted over the floodplain and a slowed velocity resulted in large accumulations of sediments.

Hypotheses

In most hydric soils, morphological field indicators have formed in response to hydrological conditions which have persisted for extended periods of time. In Piedmont floodplains, it is generally assumed that the upper portion of the soil has formed in materials that have accumulated following post colonial settlement, and therefore are relatively young. It is postulated, therefore, that the youthful nature of the soils formed in alluvial sediments of Piedmont floodplains has inhibited the development of soil morphological features that are normally diagnostic for hydric soils.

There are two research hypotheses to be evaluated. 1) There are soils within Piedmont flooplains that, despite their lack of an approved field indicator, are hydric soils, and based on water table and redox potential data can be identified as hydric using the technical standard for hydric soils (USDA-NRCS, 2002). 2) There are redoximorphic features associated with these hydric soils that can be used to develop a new field indicator for identifying and delineating hydric soils in these particular settings.

Objectives

1. To document the water table and redox potential dynamics of Mid-Atlantic Piedmont floodplain soils.

2. To understand the hydrological significance of redoximorphic features in these alluvial soils.

3. To evaluate whether the present field indicators of hydric soil are adequate to identify hydric soils in Mid-Atlantic Piedmont floodplains.

4. If needed, to propose new or alternate field indicators for identifying hydric soils in the Mid-Atlantic Piedmont floodplain landscapes.

II. Background

Piedmont Floodplains

The Piedmont physiographic province stretches from southeastern New York through northeastern Alabama. The terrain of the Piedmont is gently rolling to hilly, quite contrasting from low relief of the Coastal Plain province to the east and the more mountainous Ridge and Valley province to the west. Figure 1-1 shows the location of the Piedmont province in Maryland and Delaware. Seven counties in Maryland and one county in Delaware are included in this province.

Geology

A variety of geologic materials compose the framework of the Piedmont physiographic province, but essentially all are metamorphic crystalline rocks of Late Pre-Cambrian to Paleozoic age (300-900 Ma). A few such groups include Precambrian Baltimore Gneiss which consists of biotite-quartz-feldspar gneiss and biotite-hornblende gneiss. The Precambrian Lower Pelitic Schist also underlays this region and is made up of medium to coarse grained biotite-oligoclase-muscovite-quartz schist with garnet, staurolite, and kyanite (Edwards, 1991).

Soil along the upland slope in the Piedmont formed in a variety of materials including local alluvium over residuum from acid crystalline rocks (Baile); material weathered from Gneiss (Brandywine); materials weathered from micaceous schist (Chester, Glenelg, Manor); colluvium and residuum weathered from phyllite, micaceous schist, gniess and other acid crystalline rocks (Glenville). These soils represent the source of the sediment that has been deposited along the floodplains.

Sedimentary Units

Two distinct stratigraphic units on Piedmont floodplains reflect the different responses to land use change (Jacobson and Coleman, 1986). Jacobson and Coleman (1986) state that the history of land use in Maryland allows for approximate quantitative estimates of the changes in upland hydrology and sediment supply that is responsible for the observed stratigraphy. The various floodplain strata act as evidence of the response of the stream to land use changes in the surrounding watershed.

There are three marked disturbance periods in the Mid-Atlantic Piedmont. The latest period is considered to account for the upper stratigraphic unit on the floodplain. The first disturbance period occurred prior to European settlement in 1730. This phase consisted of natural disturbance including forest fires and drought (Jacobson and Coleman, 1986). It is recognized that Native Americans set forest fires as a means to clear land for agriculture as well as provide more diverse game habitat (Maxwell, 1910). This stage of human disturbance was most likely not extensive and is considered as part of the natural condition (Jacobson and Coleman, 1986).

Poor land use practices during the 1730's through 1930's resulted in erosion and loss of farmland efficiency due to the depletion of nutrients from surface horizons of former forest soils. Throughout the early period of European settlement, only the most successful land was kept in cultivation. The sediment from the Piedmont uplands between the 1730's and 1830's only increased moderately above natural background levels (Jacobson and Coleman, 1986). Around the mid 1800's, land use records became available with the implementation of the agricultural census. Records indicate a steep increase in cropland which can be attributed to newly introduced farming techniques, urban market growth, use of fertilizers, use of mechanical farm equipment, and the development of the railroad (Craven, 1925; U.S.Census Office Reports, 1840-1978). During the agricultural peak, 1900 through 1910, an average of 67% of land in five Piedmont counties was designated cropland compared with approximately 26% today (Economic Research Service, 2003). Subsequent years led into the decline in acreage due to economic decay of the 1930's (Jacobson and Coleman, 1986). This second disturbance period was responsible for the greatest amount of sediment supplied to the streams. The buried surface found on the floodplain is thought to separate the pre-settlement and agricultural periods.

The final disturbance period, post-1930, was determined by the significant decline in acreage designated as cropland as well as the implementation of soil conservation practices. The year 1930 is used as the minimum date to identify the very recent deposits on Piedmont floodplains (Jacobson and Coleman, 1986). The accumulation from this period is much less significant than that built up during the agricultural period, therefore this smaller sediment load is coupled with the previous deposition.

Soils of Piedmont Floodplains

A number of soil series are mapped on Mid-Atlantic Piedmont floodplains. The series range from poorly drained to well drained soils. The Hatboro series is a very deep, poorly drained soil formed in alluvium derived from soils formed in residuum from metamorphic and crystalline rock. This soil classifies as fine-loamy, mixed, active, nonacid, mesic Fluvaquentic Endoaquepts. This soil series is often found adjacent to the hillslope, in the backswamp area of the floodplain, and encompasses hydric soils that typically meet field indicator F3, *depleted matrix* (USDA-NRCS, 2002).

The Codorus series consists of very deep, moderately well drained and somewhat poorly drained soils formed in recently deposited alluvial materials derived from upland soil materials weathered from mostly metamorphic and crystalline rocks. This soil classifies as fine-loamy, mixed, active, mesic Fluvaquentic Dystrudepts. This soil series is located between the back swamp area and the natural levee.

The Comus series consists of very deep, well drained soils formed in alluvium high in mica. This soil classifies as coarse-loamy, mixed, active, mesic Fluventic Dystrudepts. This soil series is situated adjacent to the river on the natural levee.

From the descriptions of the above series, it is evident that a variety of soil wetness conditions exist on Piedmont floodplains that range from very poorly drained backswamp areas to well drained non-wetland areas. Figure 1-3 displays the cross-section of a Piedmont floodplain and the different soil wetness conditions that exist there. The wettest areas are generally located furthest from the river adjacent to the hillslope. The driest area lies on the natural levee adjacent to the river.

Hydric Soil

The term hydric soil was proposed by Cowardin et al. (1979) and is technically defined as "…a soil formed under conditions of saturation, ponding, or flooding, long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register, 1994). This definition does not indicate the exact amount of time that saturation is required, nor does it define growing season or the upper part. Much debate is given to these topics throughout the scientific community. *Long enough* is usually referred to as a two week period (Vepraskas and Sprecher, 1997). The concept of *growing season* is highly controversial and is defined as the portion of the year when the soil temperature at 50 cm below the surface is greater than $5^{o}C$ (USDA-NRCS, 2002). The term *upper part* is interpreted to be the upper 30 cm of the soil for textures finer than loamy fine sand and the upper 15 cm for coarser textured soil (USDA-NRCS, 2002).

Field identification of hydric soil became necessary with the implementation of section 404 of the Clean Water Act (Public Law 92-500, 33 U.S. Congress 1251). Under regulation of the Clean Water Act, jurisdictional wetlands (wetland protected by law) can only be altered (filled or drained) through permit from the U.S. Army Corps of Engineers (COE)(Soil Conservation Service, 1994). Enforcement of the Act by the COE concentrated on protecting jurisdictional wetlands that sustain three basic parameters: hydrophytic vegetation, wetland hydrology, and hydric soils (Vepraskas and Sprecher, 1997). The three parameter approach of the COE was reaffirmed when the Environmental Protection Agency (EPA), Soil Conservation Service (SCS), and Fish and Wildlife Service (FWS) joined the COE in developing a national standard that identified and delineated jurisdictional wetlands based on the same three parameters (Federal Interagency Committee for Wetland Delineation, 1989).

The identification of hydrophytic vegetation is useful in the delineation process, however, the herbaceous layer of plants does not persist through all seasons. Also, deciduous trees and shrubs shed their leaves in the fall making plant classification more difficult. In some locations, the vegetation has been altered or removed, therefore, it would not be possible to correctly identify the naturally occurring plant species.

Hydrology is also a distinctive factor, yet, without long term record of water table data, one is unable to confirm normal position of the water table at a particular time of year. During the wet season, while the water table is at or close to the surface, wetland hydrology is evident. During the dry season, however, the water table may be more than a meter below the soil surface, and thus, not observable during regular field observation. The installation and monitoring of wells can be time consuming and costly. Often, immediate wetland determination is necessary and seasonal monitoring is seldom practical.

A hydric soil maintains morphological features indicative of a reduced soil environment. Oxidation-reduction reactions occur in the soil that alter the electrochemical status of iron oxyhydroxides and other minerals, causing iron to exist in either reduced Fe(II) or oxidized Fe(III) forms. The iron coated mineral grains are depleted of iron via reduction and resultant removal of iron, or they may develop the red or orange color indicative an accumulation of oxidized iron. These features persist throughout the year; consequently, field observation and identification is possible at times of the year when reduction is not occurring.

Quantification of Redoximorphic Features

Periods of saturation and subsequent reduction are essential to the formation of redoximorphic features. West et al. (1998), Daniels et al (1971), and Franzmeier et al. (1983), performed studies that quantified the amount of time soil horizons were saturated before the observation of various redox features. Redox concentrations are described in soil horizons that are saturated for approximately 20% of the time (West et al., 1998). Low chroma (2 or less) depletions were identified in soil horizons that were saturated on average 40% of the time, and depleted matrices were found in soils that were saturated approximately 50% of the time (Daniels et al., 1971; Franzmeier et al., 1983, & West et al., 1998).

Oxidation-Reduction Reactions

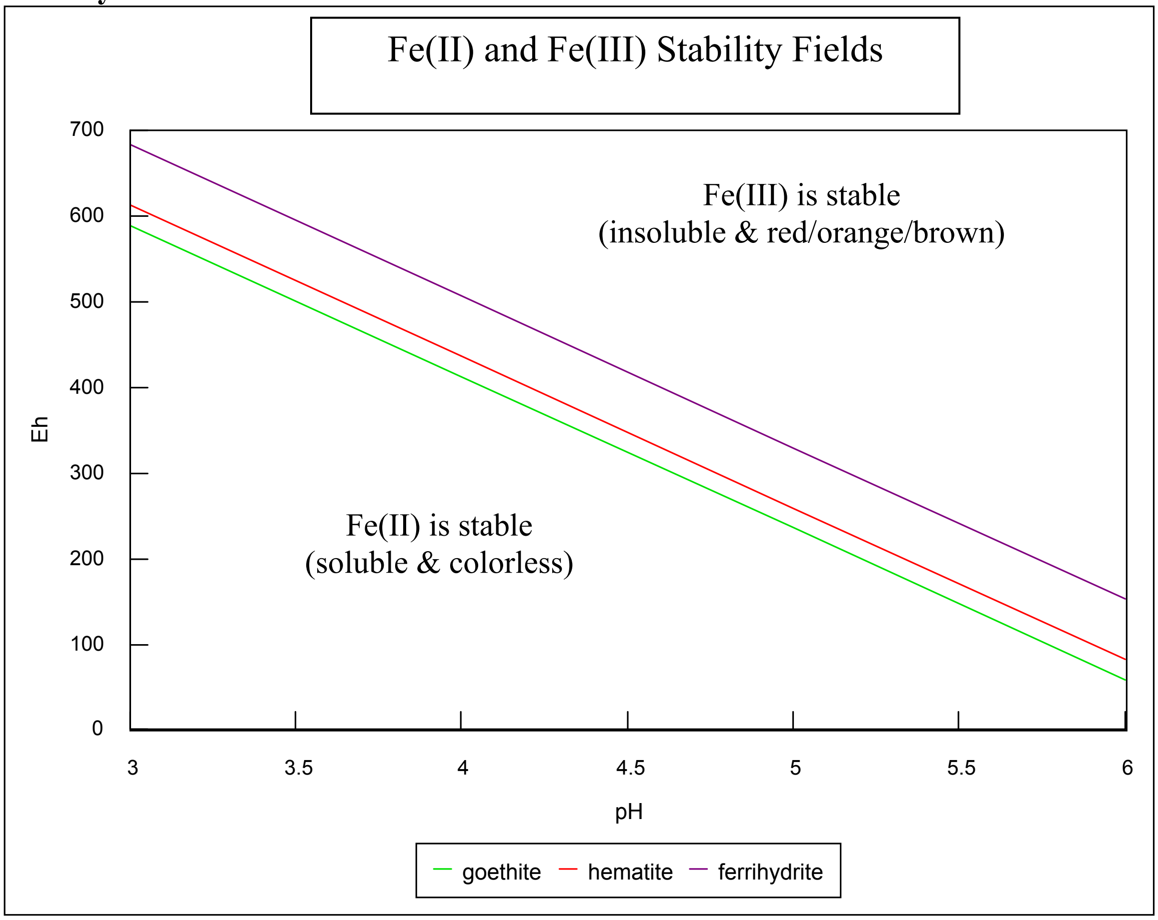
One of the most accurate methods for establishing hydric conditions involves monitoring the oxidation-reduction (redox) potential in the soil. This practice is not always feasible for standard wetland determinations (Vepraskas and Wilding, 1983; Faulkner et al., 1989) due to time and cost constraints. Fortunately, the result of these redox reactions can be visually assessed through soil morphological features.

In the soil, heterotrophic microbes oxidize a carbon source, such as organic matter, to obtain energy, and also require a chemical compound to act as an electron acceptor. In an aerobic environment, this electron acceptor is typically O_2. In an anaerobic setting (once O_2 has been depleted), microbial respiration and organic matter decomposition continue to occur despite soil saturation. While the soil is saturated, the transport of O_2 into the soil system is minimal, so, other compounds must be used as the electron acceptors. After O_2, NO_3^{-2} is used as an electron acceptor, followed by $Mn^{+3,+4}$, Fe(III), SO_4^{-2}, and CO_2^- (Mitsch and Gosselink, 1993).

The redox potential at the point at which Fe(III) becomes reduced is pH dependent and can be determined from an Eh-pH diagram such as the one in Figure 2-1. Eh-pH diagrams are useful to predict the stability of the particular state of a chemical compound in a system. These diagrams assume a standard temperature and pressure and are developed for equilibrium conditions. The stability fields of these diagrams are for pure compounds and impurities in structure will change field boundaries. Although there are a number of assumptions that go into the formation of Eh-pH diagrams, they are useful in the prediction of stable chemical species.

In figure 2-1, common iron bearing minerals are shown to illustrate the redox potential at which these species are expected to reduce to Fe(II). Ferrihydrite is an amorphous iron hydroxide that is slightly more reducible than the more crystalline hematite and goethite minerals. The activity of these iron bearing minerals in figure 2-1 is 10^{-6} M, a typical activity (concentration) observed in soils.

Figure 2-1: Eh/pH diagram showing the stabilities of goethite, hematite, and ferrihydrite. Standard temperature and pressure were assumed in the development of this graph. The activity of the iron was assumed at 10^{-6} M. Oxidized iron (Fe(III)) is predicted to be stable above the stability lines for the various iron oxyhydroxides, while reduced iron (Fe(II)) is predicted to be stable below the stability lines.



Additional Methods to Detect Reduction

A direct chemical technique to identify Fe reduction in soils is the use of α, α'dipyridyl dye (Childs, 1981). When this dye solution is applied to a fresh soil surface, the presence of Fe(II) is revealed when the dye turns a pinkish-red color. Erroneous positive readings are possible when the dye is applied in excessive direct sunlight (Childs, 1981).

A new method to identify a reduced soil environment is the use of Indicator of Reduction In Soil (IRIS) tubes. Jenkinson (2003) developed this approach in an effort to demonstrate iron is either reduced or oxidized in the soil. Polyvinyl chloride (PVC) tubes coated with ferrihydrite "paint" are installed in the soil. After some prescribed interval, the tubes are removed and analyzed for the dissolution of iron from the tube. Clean areas of the tube appear devoid of Fe(III) and therefore are thought to represent a reduced environment. Jenkinson (2003) studied nine sites in Indiana and concluded that the tubes located in saturated soils had significant removal of iron. The tubes located in unsaturated soils were not altered while in an oxidized soil environment (Jenkinson, 2003).

Redoximorphic Features

Oxidation-reduction reactions in soil create chemical and mineralogical changes that are observable in the field. Nearly all indicators of reduction are produced by O, C, Mn, Fe, and S (Vepraskas and Sprecher, 1997). Indicators related to C, Mn, Fe, and S affect soil color. Yellow, red, brown, and orange colors are related to oxidized Fe. While in an aerobic environment, oxidized Fe maintains these bright colors, however, gray and gleyed colors occur while the colorless and soluble reduced Fe is present. The low chroma colors are the result of uncoated mineral grains. Black colors are produced by C, Mn, and monosulfides (Fanning et al., 1993).

The most important reduction reaction for the formation of hydromorphological features in soil is Fe(III) to Fe(II). The majority of redoximorphic features that form in soil are the outcome of this reaction since iron is widely prevalent and is the key coloring agent in most soils. Subsoil horizons that are occasionally or never reduced demonstrate an assortment of colors ranging from red or brown to yellow. These colors are the result of FeOOH or related Fe(III) oxide and hydroxide minerals that coat particle surfaces.

Redox concentrations occur in areas where Fe(II) has accumulated through the process discussed above. When oxygen is introduced to these locations, the Fe(II) oxidizes to Fe(III) and displays a reddish color. These features are identified as iron masses and pore linings.

The reduction of Fe(III) oxide or hydroxide causes reddish colored soils to reveal the gray and white colors of the natural uncoated sand, silt, and clay particles. This gray color, often mediated by quartz and kaolinite, results from the removal of Fe(III) compounds from the surfaces of these minerals grains. Once the Fe oxide coatings have been removed from the mineral grains, the gray color persists whether the soil is oxidized or reduced. When reduction occurs in soils for short amounts of time (two weeks), redox depletions are likely to form along root channels and ped faces. When soils are reduced for extended periods, they often develop low chroma (gray) matrix colors.

Field Indicators of Hydric Soil

Soil morphological features formed under reduced conditions may be indicative of a hydric soil. The *Corps of Engineers Wetland Delineation Manual* (Environmental Laboratory, 1987) provided a set of morphological field indicators to be used in identifying hydric soils. Another set of field indicators has been published by the National Technical Committee for Hydric Soils (NTCHS) (USDA-NRCS, 2002).

Hydric soil indicators are used to infer saturation and a reduced environment in the upper part of the soil. These indicators have been regionalized for use throughout the United States and can be modified for application in individual land resource regions. Figure 1-2 displays the Piedmont Region of Maryland and northern Delaware located in Land Resource Region S. The NTCHS indicators were designed mainly by scientists engaged in soil survey activities. Extensive field work suggests that these indicators correlate well with the occurrence of hydric soils (Vepraskas and Sprecher, 1997). The indicators were created to accurately identify a hydric soil as "proof positive". Therefore, if a soil meets an indicator, it is hydric, however, if a soil does not meet an indicator, it is not necessarily non-hydric.

Technical Standard for Hydric Soil

A hydric soil technical standard was developed by the National Technical Committee for Hydric Soils (USDA-NRCS, 1998). This standard was established to evaluate the function of restored or created wetlands, evaluate the current functionality of a hydric soil onsite, and to modify, evaluate, validate, or adopt hydric soil field indicators in a particular region. The main requirements in this technical standard, are 1) anaerobic and, 2) saturated conditions.

In order to satisfy the criteria for anaerobic conditions, a soil must satisfy either the specified redox potential based on pH, or provide a or positive reaction to α, α'dipyridyl dye. Redox potential must be measured using five platinum electrodes at 25 cm for loamy soils, 12.5 cm for sandy soils, or 10 cm for soils that inundate but do not saturate to a significant depth. One pH measurement must also be made at the corresponding depth. A soil would meet the anaerobic conditions portion of the technical standard if the redox potential measured on three out of five electrodes is less than or equal to 175 mV at pH 7. The redox potential measurements may be adjusted based on pH using the equation: $Eh = 595 - 60\ (pH)$. This Eh/pH line was developed for soils with pH values of 3 through 9.

The redox criterion can also be documented by using α, α'dipyridyl dye if a positive reaction is observed (a pinkish-red color appears) in two out of three samples when the dye is applied to three freshly opened peds. These samples must represent at least 10 of the upper 30 cm for most loamy and clayey soils, half of 12.5 cm for sandy soils, or 5 cm of the upper 10 cm for soils that inundate but do not saturate to a significant depth.

The second requirement, saturated conditions, can be documented using piezometer data that are verified by open well data. An open well must be installed and measured daily capturing at least one dry – wet – dry cycle. Piezometers are recommended to be installed at depths of 25 cm and 100 cm. The soil must be saturated to within 30 cm for most loamy and clayey soils, and within 15 cm for sandy soils.

Simultaneous anaerobic and saturated conditions are required for at least 14 consecutive days. The annual frequency of these measurements must be more than 50% or more than one out of two years. This frequency requirement is assumed to be met if the data are collected during a period within the 30th to 70th percentile probability of normal rainfall.

Problem Hydric Soils

SSSA Special Publication Number 50 (1997) discusses numerous examples of soils that may be hydric but do not meet any of the hydric soil indicators currently on the list. For example, Bell and Richardson (1997) discuss the problems with defining soil morphologies associated with seasonally saturated and reduced conditions in Mollisols. Within the upper 30 cm, redox depletions were typically absent due to the high organic matter content and the accumulation of material that has eroded away from other organic rich surfaces. As another example, Kuehl et al. (1997) discuss various obstacles to making hydric soil determinations in sandy soils. They observed very few redox features in sandy soils, possibly because they contain low amounts of Fe (Kuehl et al., 1997).

Another group of soils where there have been difficulties in the application of standardized hydric soil indicators, is the wet Andisols of the Northwestern United States. McDaniel et al. (1997) demonstrated that redox features formed in Andisols are more subtle than features in equally wet and reduced soils formed from different parent materials. Another case presented itself in a set of seasonally ponded depressions, termed vernal pools. Clausnitzer et al. (2003) evaluated current field indicators to determine their relevance in such settings. They found the hydric soils described in their study were not identifiable based on the existing indicators of hydric soil. This circumstance exemplifies the need for continuous modification of the indicators (Clausnitzer et al., 2003).

Similar to the cases described above, hydric soils on Mid-Atlantic Piedmont floodplains may also present problems in accurate delineation. Some of the hydric soils in these settings do not meet an approved field indicator of hydric soil. Research is needed to be conducted to demonstrate if these soils are hydric and to formulate a field indicator specific for soils in these settings.

Additions or changes to the current list of hydric soil indicators can be done following proper research and documentation. Proposed changes are usually initiated as test indicators that are reviewed by soil scientists in the field. Once the test indicator has been reviewed and deemed accurate, its provisional status may be eliminated and the indicator accepted for use.

III. Oxidation-Reduction Potential and Saturation Relationship in Mid-Atlantic Piedmont Floodplain Soils

Introduction

The measurement of soil oxidation-reduction potential, or redox potential, is used to predict the stability of various mineral species. The potential is measured between a platinum (Pt) tipped electrode and a reference electrode that are both placed in contact with the soil. Soils with reduced conditions transfer a relatively negative charge to the Pt electrode, while soils with oxidized conditions transfer a relatively positive charge to the Pt electrode. The voltage developed between the reference electrode and the soil solution is typically measured with a voltmeter that is designed to measure to the nearest mV.

Redox potential is influenced by a number of factors including oxygen content, temperature, microbial activity, and the presence of various electron acceptors, such as iron and manganese. Soils with oxygen present will have relatively high redox potentials. When oxygen is depleted from the soil environment, microbes will act on alternate electron acceptors as they decompose organic matter. These microbially mediated reactions will occur much at slower rates in cooler temperatures. Each of these factors have a profound impact on the redox potential measured in the soil, and therefore, must be considered when collecting these data.

The NTCHS established a technical standard for hydric soils that is used to document or identify soils the hydric soil definition. This is done through field measurements of saturation and reduction. A hydric soil in defined as "… a soil that formed under conditions of saturation, ponding, or flooding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register, 1994). "Conditions of saturation, ponding, or flooding" basically imply that the pores are filled with water. "Long enough during the growing season" communicates the length of time necessary for the saturated conditions to persist. This is commonly 5% of the growing season, or 14 days (Vepraskas and Sprecher, 1997). "Anaerobic conditions" occur when all of the oxygen has been depleted from the system (USDA-NRCS, 2002). Soil microbes must then use an alternate electron sink such as Fe(III). Finally, "the upper part" refers to the upper 30 cm of soil for loamy soils, or the upper 15 cm for sandy soils (USDA-NRCS, 2002). Therefore, the technical standard requires that for a soil to be hydric, there must be saturation and evidence of Fe(II) reduction within the upper 30 cm for loamy soils and 15 cm for sandy soils, for at least 14 days.

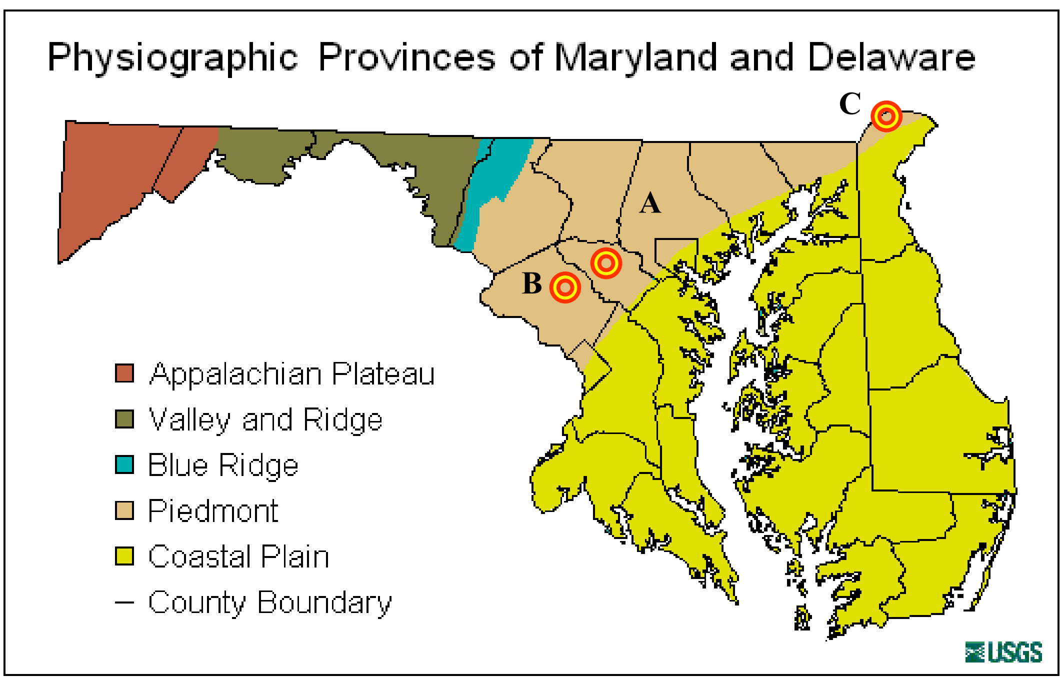
Because the collection of soil redox potential is time consuming, must be taken at least every other week in order to document soil reduction, and requires equipment that is often unavailable or costly to obtain, an alternate method using water table data is being developed to determine the time necessary for saturation to occur before the onset or reduced conditions. Measuring depth to water table involves either and automated recording well or a simple open well and takes little time to record. Past water table data is often available at study sites, whereas redox potential data rarely is. The objectives of this research were to document the height and duration of water tables and the redox potentials in Mid-Atlantic Piedmont floodplain soils, and to better understand the impact of water tables on soil redox potentials in these systems.

Materials and Methods

Site Locations

Three representative floodplains were selected within the Mid-Atlantic Piedmont physiographic province for this study (Fig. 3-1). These sites were chosen based on their low likelihood of human disturbance as well the presence of characteristic floodplain features, including a backswamp wetland and a natural levee.

Figure 3-1: Physiographic Provinces of Maryland and Delaware. Site A is the Middle Patuxent River in Howard County, Maryland; Site B is Rock Creek in Montgomery County, Maryland; and Site C is White Clay Creek in New Castle County, Delaware.

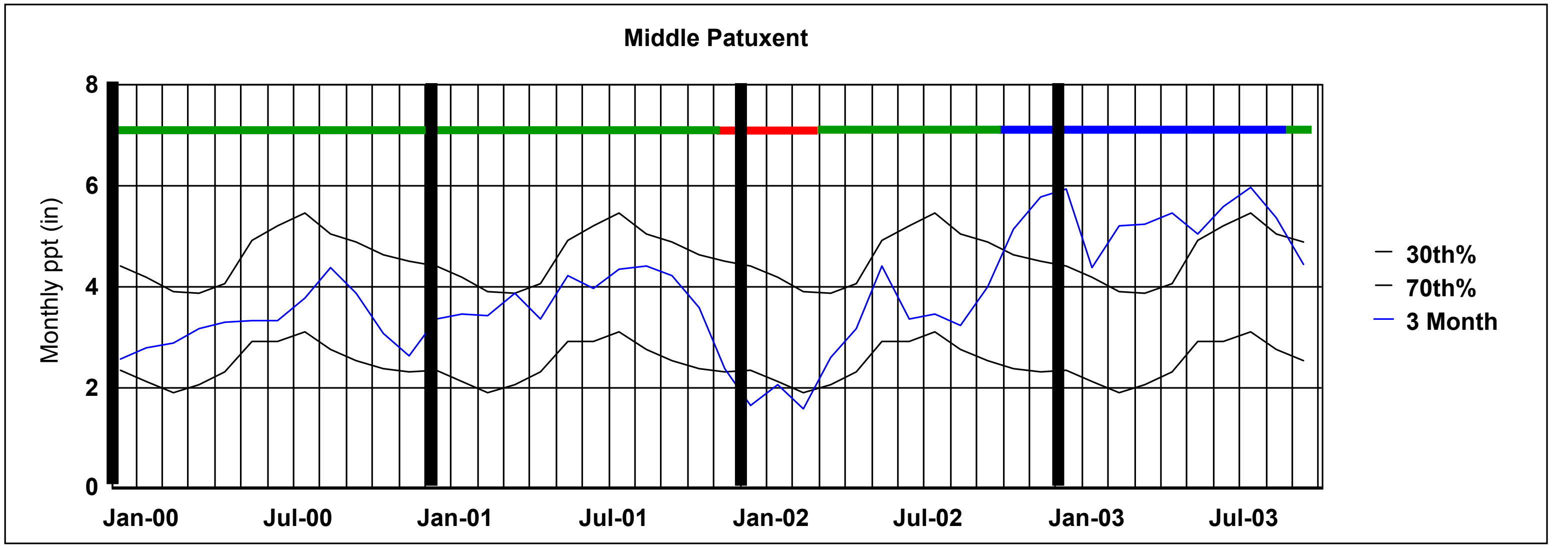


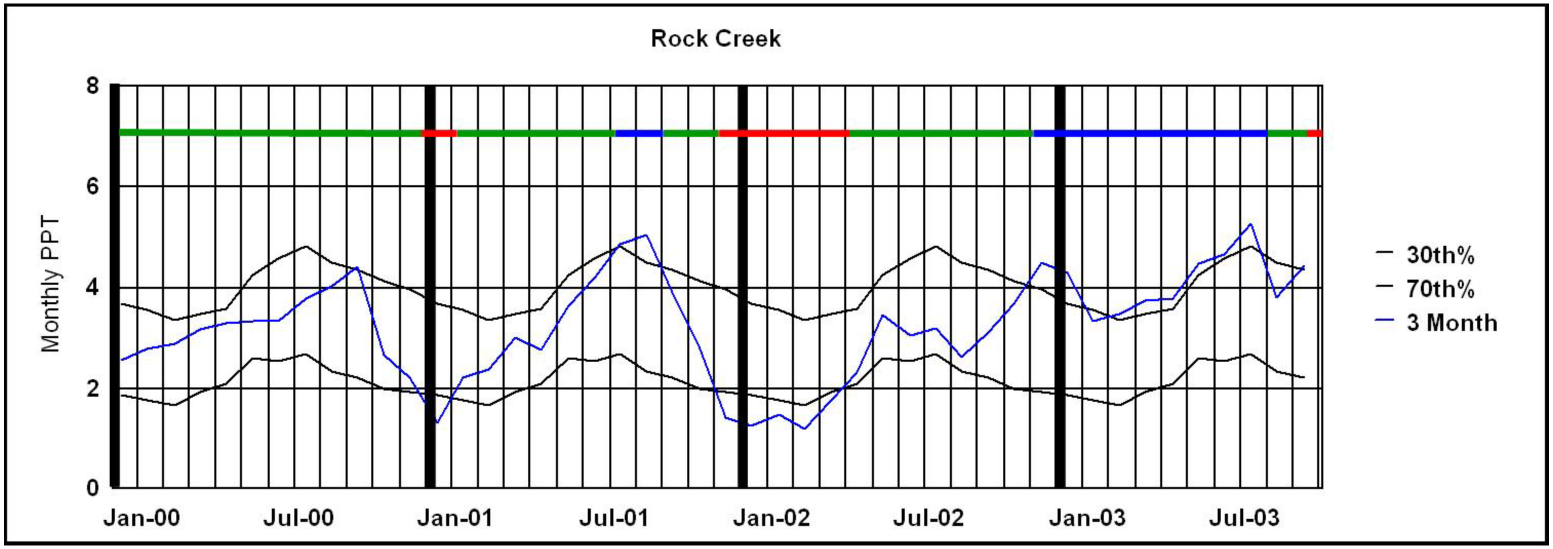
On each of these floodplains, up to four monitoring stations were set up along a transect. Soils on this transect ranged from very wet to drier soils. Figure 1-3 displays a schematic depiction of the transects used for this study and illustrates the various soil wetness classes occurring on the floodplains. A total of ten monitoring stations were established on the three floodplain sites: four of these stations were located on poorly to very poorly drained soils adjacent to the backswamp area; three monitoring stations were located in somewhat poorly to poorly drained soils, centrally located on the transect and were possible wetland areas; the remaining three stations were located on moderately well drained soils found closer to the natural levee of the river.

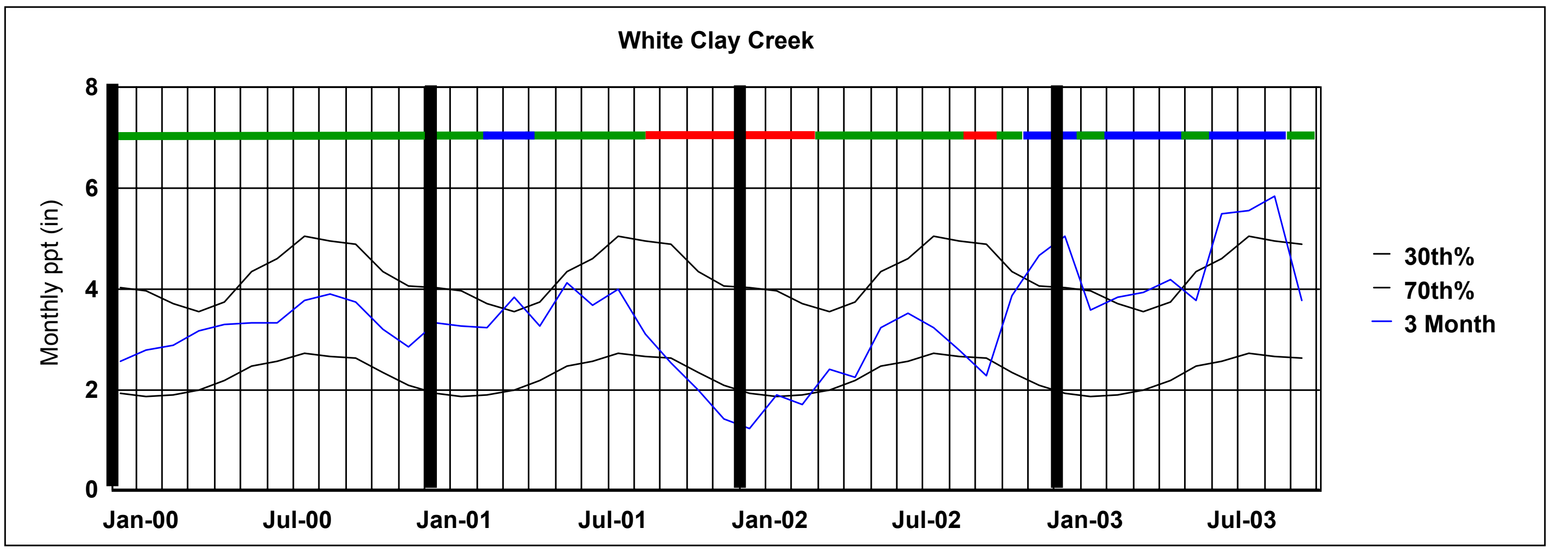
Rainfall

Rainfall during the period of study varied dramatically between 2002 and 2003. Figure 3-2 shows the precipitation data obtained from near to the Middle Patuxent River, Rock Creek, and White Clay Creek sites. The precipitation totals during 2001 were close to the 50 year average of rainfall in this area. The black lines indicate the 30% and 70% percentiles for precipitation. During 2002, rainfall appeared below normal (30^{th} percentile) and during 2003, rainfall was well above normal (70^{th} percentile). Figure 3-2 shows the yearly averages of precipitation from 2001 and 2002 fell within the 30^{th} and 70^{th} percentile, while 2003 was above the 70^{th} percentile.

Figure 3-2: Precipitation Data from the Middle Patuxent River, Rock Creek, and White Clay Creek. The blue line represents the three month running average of precipitation. Colored bar across the top of the graphs illustrates whether the precipitation was below (red), average (green), or above (blue) the normal precipitation range (30th through 70th percentile).




Rock Creek
Monthly PPT
0
2
4
6
8
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
30th%
70th%
3 Month


White Clay Creek
Monthly ppt (in)
0
2
4
6
8
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
30th%
70th%
3 Month

Water Table Measurement

Depth to the water table was logged twice daily using automated recording wells installed to a maximum depth was 1.5 m. The data stored in these wells were offloaded approximately every three months.

Redox Potential Measurement

Soil oxidation-reduction potential was measured at 10, 20, 30, 40, and 50 cm depths at each of the ten monitoring stations. Redox potentials were measured adjacent to the wells bi-weekly during the wet season (February-June) and monthly during the dry season (July through January). Six Pt electrodes were installed to each depth in order to ascertain accurate redox potential measurements. Calomel reference electrodes were used and a correction of 244 mV was applied to adjust the reading to Eh.

pH

pH was also measured adjacent to the wells at the same intervals and depths as redox potential. A 5/8-in soil corer was used to extract a small soil sample at each depth. This soil was made into a 1:1 slurry with deionized water and set aside for 15 min. A pH meter was used to record the pH of this mixture in the field.

Results and Discussion

Water Table Data

The four soils located in the wettest locations containing poorly to very poorly drained soils were saturated to the surface with ground water for much of the year (Fig. 3-3). One soil was located at the Middle Patuxent River, one at Rock Creek, and the remaining two were at White Clay Creek (low and low/mid). The water table at the low well at the Middle Patuxent River and White Clay did not drop below 50 cm, while the water table at the low well at Rock Creek and low/mid well at White Clay Creek remained above 80 cm for the entire study period. The water tables were at or above the soil surface for 55-92% of the time, and were at or above 30 cm for 80-100% of the time. Among the wet sites, the soil at the low well at White Clay Creek was clearly wettest; the soil at the low well at Forage Farm and low/mid well at White Clay were comparable and in the middle; and the soil at Rock Creek was (relatively speaking) the least wet.

The three soils in the middle locations along the transects, underwent more dramatic seasonal fluctuations in ground water levels than did the wet sites (Fig. 3-4). The water table at these three sites stayed at or above 30 cm for long periods of time during the growing season. The water table was at or above 30 cm at the Middle Patuxent River for 58% of the time, at Rock Creek for 52% of the time, and at White Clay Creek for 71% of the time. Figure 3-3 shows that the water table was often above 30 cm for a continuous amount of time so that saturation occurred for months at a time. From the middle of May to October of 2002, the water table at the middle wells dropped below 60 cm, while during 2003, the water tables remained above 60 cm for the majority of the year. This demonstrates the extreme difference in precipitation amounts in 2002 and 2003.

The three soils in the driest locations experienced significant periods when the seasonal water table was between 30 and 50 cm below the surface (Fig. 3-5). The water table at these sites fluctuated between 25 and 100 cm for most of the year. The water table was at or above 30 cm for 27% of the time at the Middle Patuxent River, 4% of the time at Rock Creek, and 30% of the time at White Clay Creek.

Figure 3-3: Water Table Data from the wet sites between December 2001 and October 2003. The water table from the low well at White Clay Creek is shown by the red line, the low/mid well at White Clay is shown by the orange line, the low well at the Middle Patuxent River is shown by the blue line, and the low well at Rock Creek is shown by the green line.

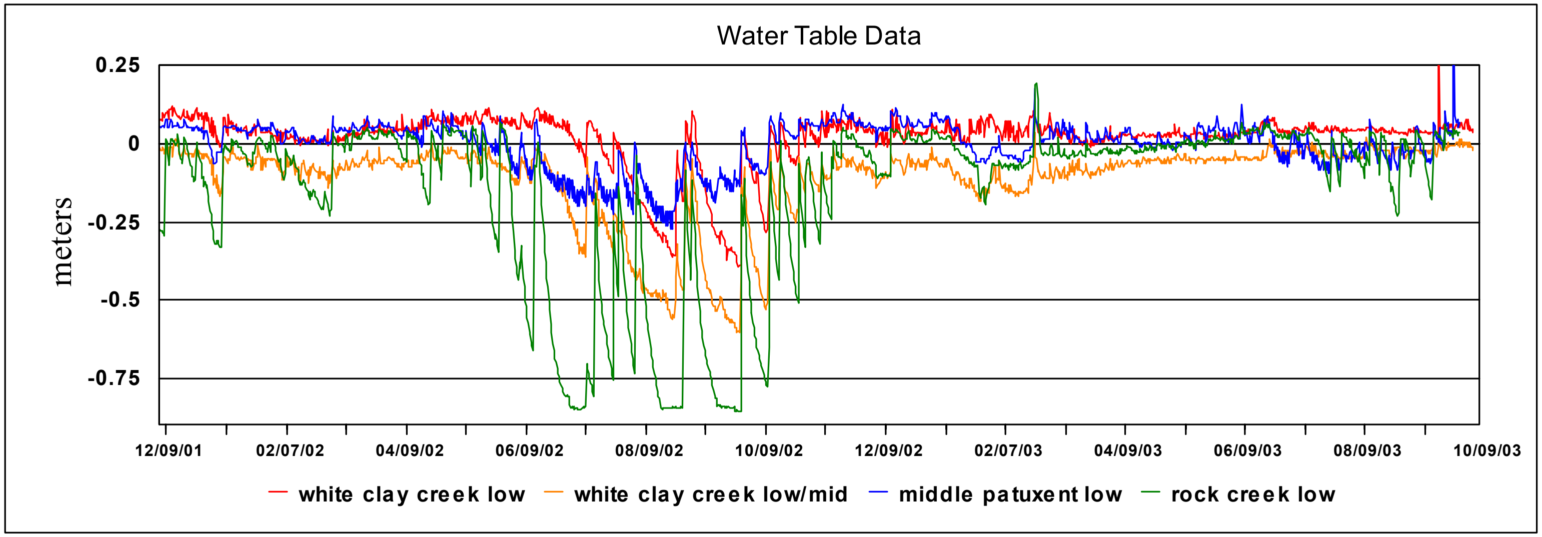


Figure 3-4: Water Table Data from the middle sites between December 2001 and October 2003. The water table from the middle well at White Clay Creek is shown by the red line, the middle well at the Middle Patuxent River is shown by the blue line, and the middle well at Rock Creek is shown by the green line.

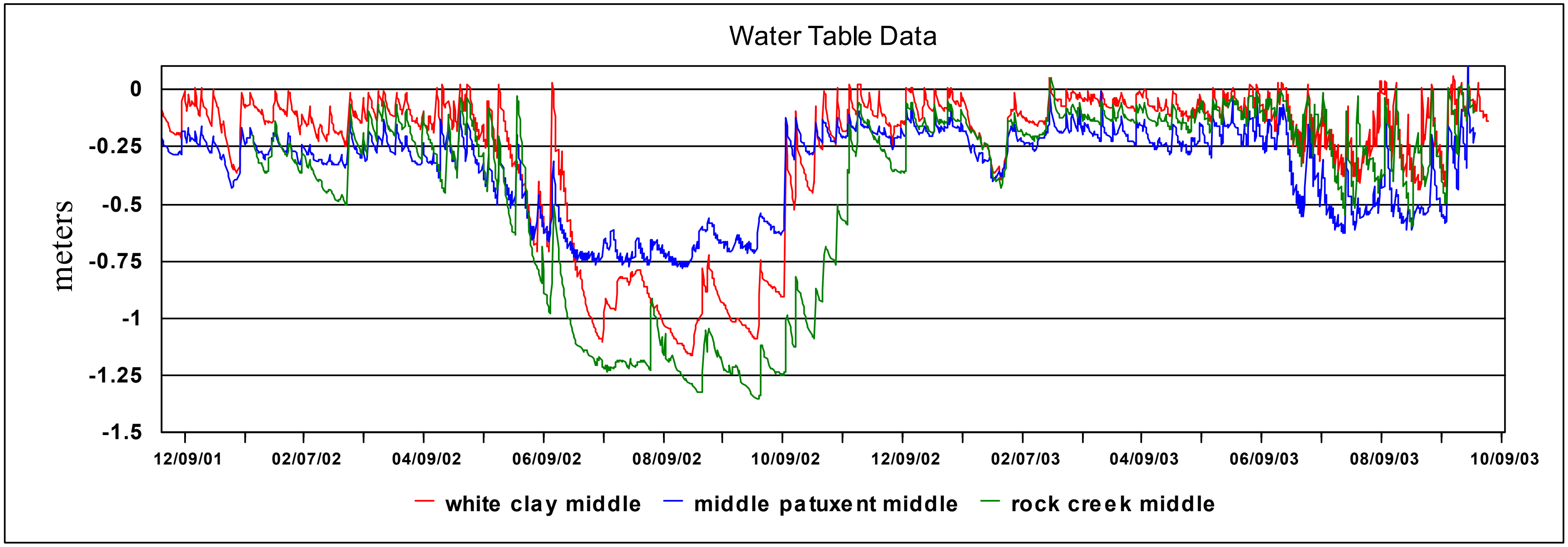
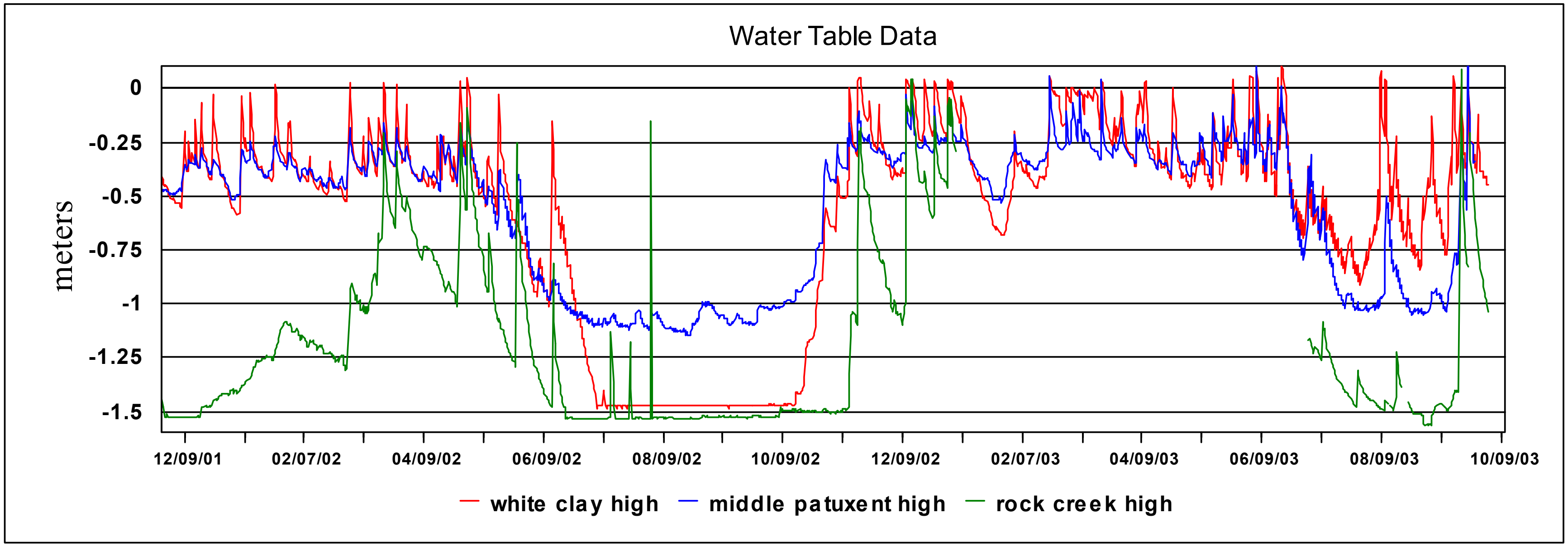


Figure 3-5: Water Table Data from the driest sites between December 2001 and October 2003. The water table from the high well at White Clay Creek is shown by the red line, the high well at the Middle Patuxent River is shown by the blue line, and the high well at Rock Creek is shown by the green line.



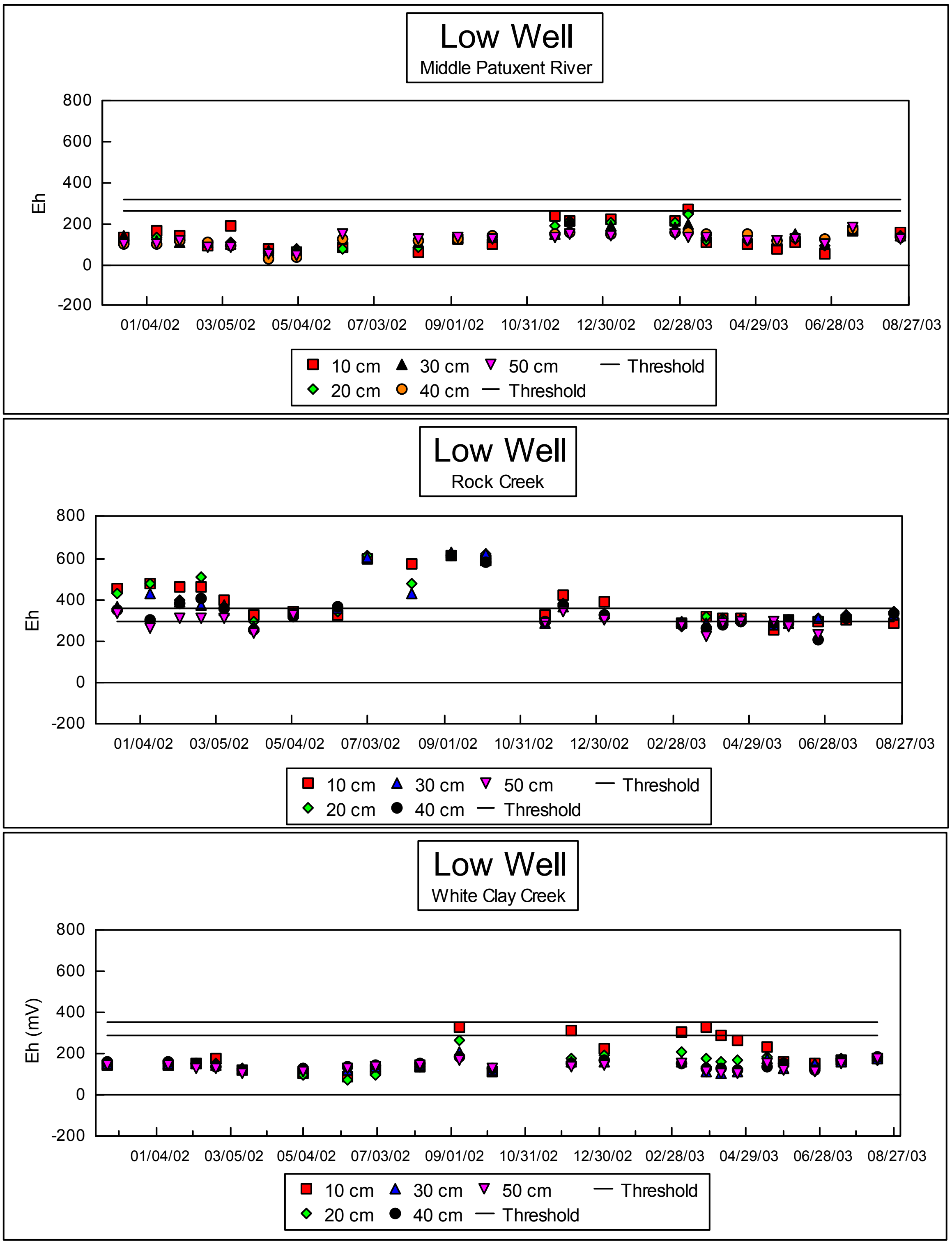
Redox Potential and pH

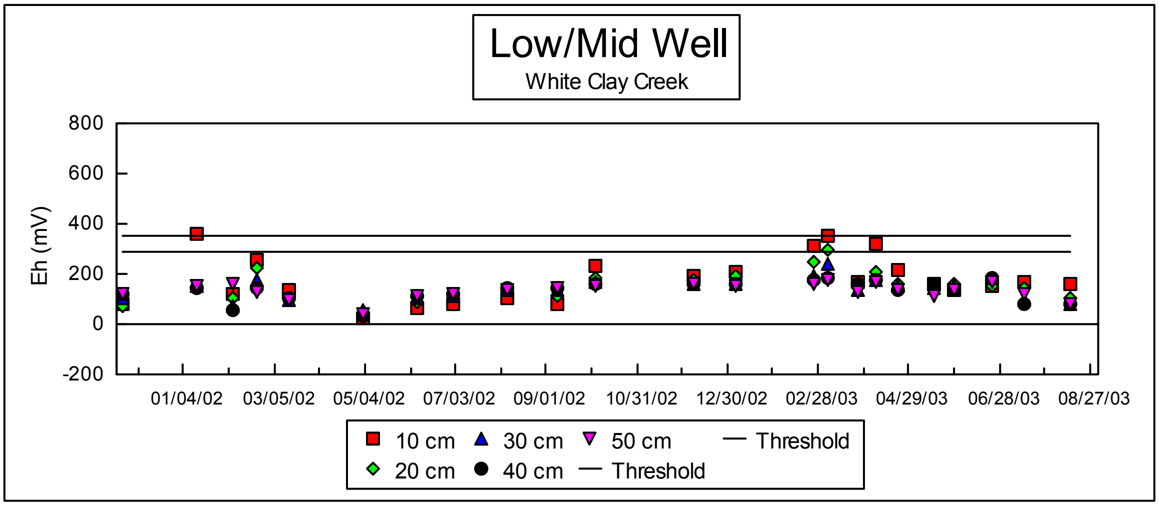
In order to determine whether or not iron is reduced in a soil system, redox potential must be measured and compared using Eh-pH stability diagrams or to the Eh plot of the technical standard. Using the technical standard for hydric soils, a soil with a pH of 4 is expected to be reducing with respect to iron when the redox potential is at or below 355 mV. In a soil with a pH of 5, Fe(III) may be reduced to Fe(II) at a redox potential of 295 mV or less. The pH of all the soils in this study ranged from 4 to 5.5. The two parallel lines on the graphs of redox potential versus time are based upon the iron stability equation of the technical standard, using two pH values representing the range measured in the soil. Therefore, at Eh values below these the lines, it is expected that Fe(III) would be reduced and Fe(II) would be the stable phase.

Wettest sites

The redox potential at the wettest locations remained below the threshold for reduction of Fe(III) to Fe(II) for more than six months per year. Figure 3-6 displays the redox potential of the soil at the low sites, showing the redox potential rarely rising above 300 mV for much of the two years during which redox potentials were measured. Based on the technical standard for hydric soils, the soils at all four low locations meet the criteria for reduced soil conditions.

Figure 3-6: Redox potential data from the soil in the wettest sites. Points represent the mean of six replicate Eh measurements at 10, 20, 30, 40, and 50 cm below the soil surface. Solid black lines represent the values below which the iron present in the soil is predicted to be reduced and are based on the equation for the technical standard using pH values representing the range measured in the soil.

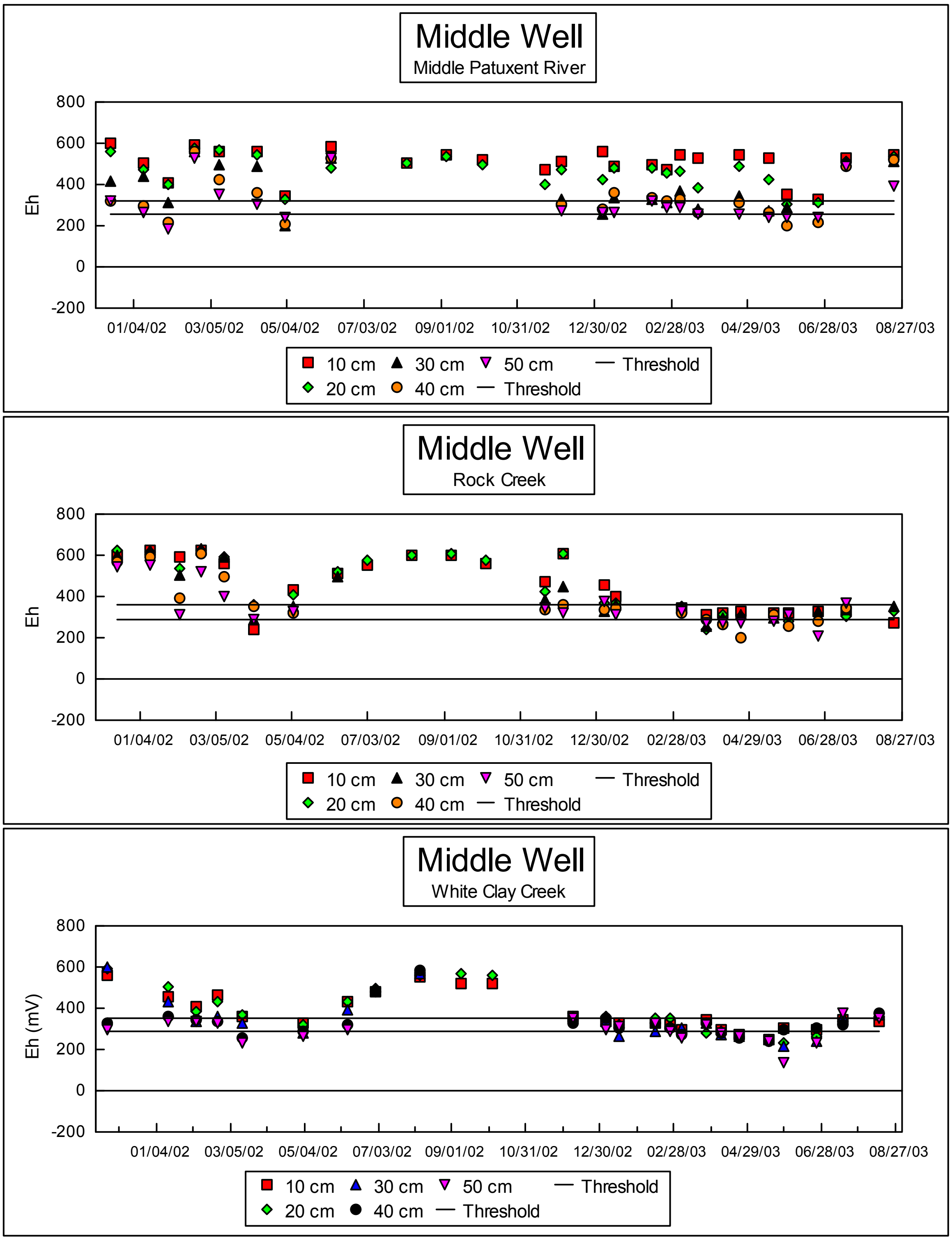




Middle sites

There was far greater fluctuation in redox potential at these locations than with the wetter and drier soils. Not surprisingly, seasonal water table fluctuation appeared to play a large role in the redox status of these soils. Figure 3-7 demonstrates the various soil redox potential measured and the seasonal trends observed in the soils in the intermediate location along the transects. At the Middle Patuxent River site during 2002, the redox potential of the soil in the middle location was below the technical standard for reduced iron for two non-consecutive measurements at 30, 40, and 50 cm depths. During 2003, the redox potential was below this standard for more than four consecutive months. During 2002 at Rock Creek, the redox potential of the soil at the middle location was below the technical standard for reduced iron at 30, 40 and 50 cm depths for more than one month, and in 2003, at all depths for more than five consecutive months. At White Clay Creek during 2002, the soil at 30, 40, and 50 cm depths was below the technical standard for approximately two consecutive months, and during 2003, and at all depths for more than six months.

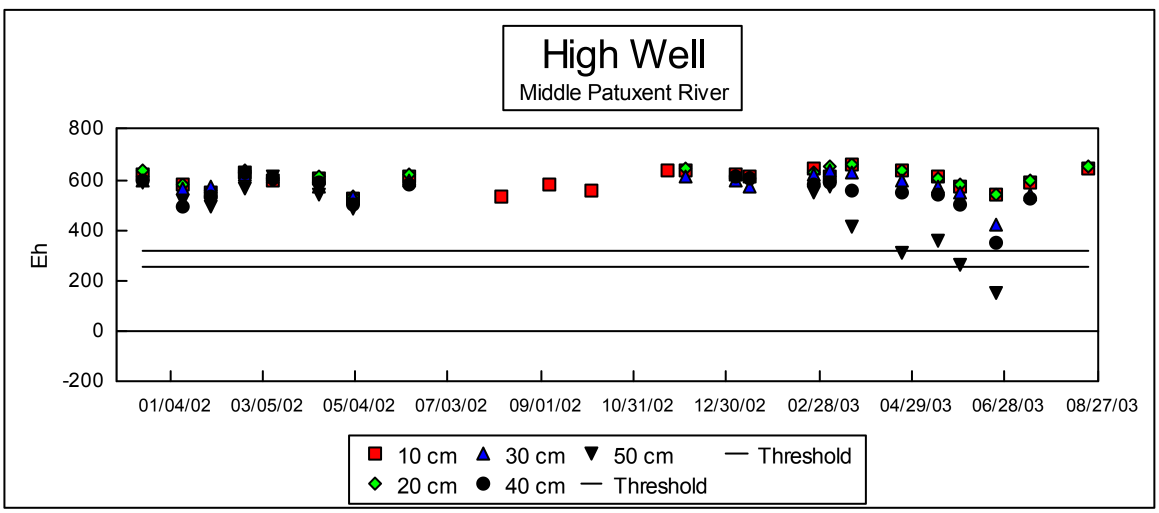
Figure 3-7: Redox potential data from the soil in the middle sites. Points represent means of six replicate Eh measurements at 10, 20, 30, 40, and 50 cm below the soil surface. Solid black lines represent the values below which the iron present in the soil is predicted to be reduced and are based on the equation for the technical standard using pH values representing the range measured in the soil.

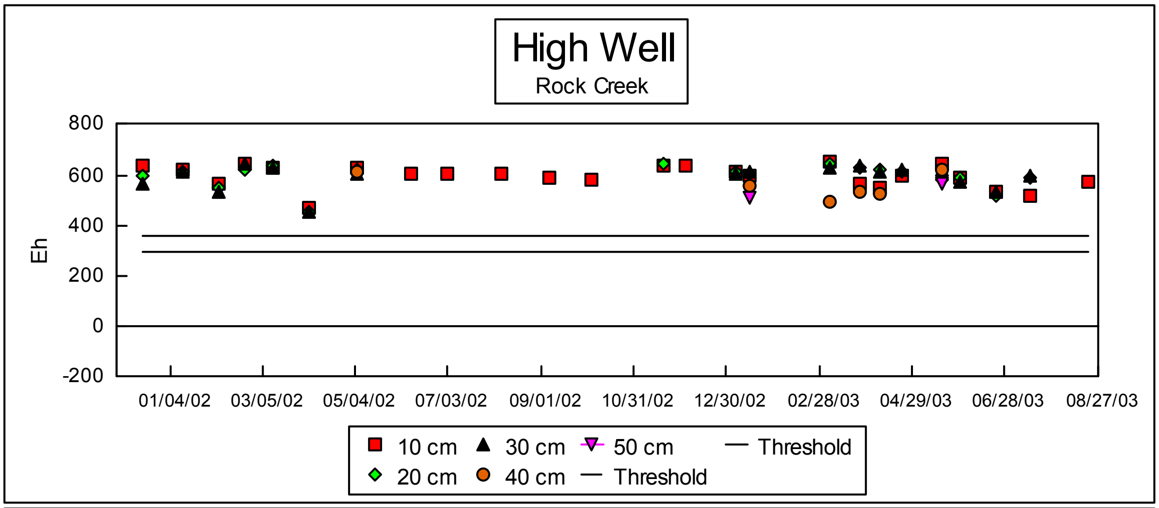


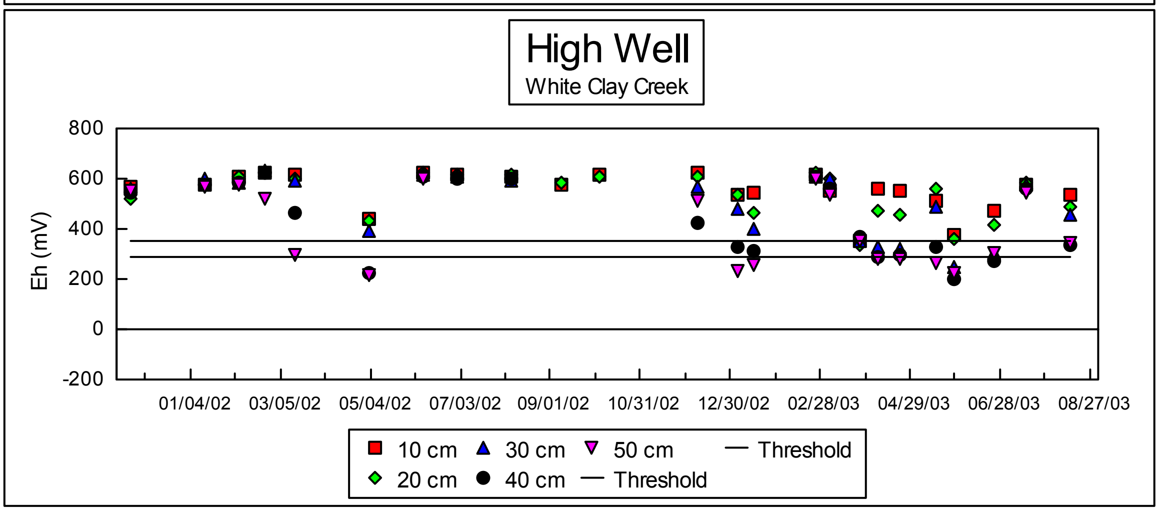
Driest sites

The locations containing better drained soils (high wells) had redox potentials that largely remained in the oxidized zone, with respect to iron, for all depths (Fig. 3-8). During extremely wet conditions in 2003, the redox potential of soil at 50 cm at the Middle Patuxent River was below the technical standard for reduced iron. During 2002 at White Clay Creek, the redox potential of the soil at 40 and 50 cm depths was below the technical standard, while in 2003, on two separate occasions, the soil at 40 and 50 cm was below the technical standard for reduced iron for one month and three months. At all three sites, the redox potential at 30 cm and shallower, were not recorded below the technical standard for reduced iron except for single measurements at White Clay Creek during the excessively wet year, 2003.

Figure 3-8: Redox potential data from the soil in the drier sites. Points represent the mean of six replicate Eh measurements at 10, 20, 30, 40, and 50 cm below the soil surface. Solid black lines represent the values below which the iron present in the soil is predicted to be reduced and are based on the equation for the technical standard using pH values representing the range measured in the soil.







Effect of Saturation on Redox Potential

Because redox potential measurements are difficult and time consuming to obtain, and because historical water table records often exist where there is no record of redox measurements, the ability to infer redox conditions from water table data would be most useful. Therefore, an attempt was made to determine how long a soil must be saturated in order to become reduced. Comparisons were made between periods of saturation and redox potential (Fig. 3-11, 3-12), and Eh values were plotted against the amount of time the soil was saturated at a particular depth.

In order to minimize error and outliers, attempts were made to limit the effects of low soil temperature, prolonged saturation (greater than 120 days), and insufficient active organic carbon on microbial processes. Soil temperature has a profound effect on microbial activity. Cool temperatures inhibit activity, moderate temperatures sustain normal levels of microbial activity, and warmer temperatures appear to promote activity. Between December and February, soil temperatures (at 30 cm) at all three sites fluctuated between approximately 2^{o} and $10^{o}C$ with the average temperature being $5^{o}C$ (Figure 3-9). Because such low soil temperatures would be expected to dramatically decrease rates of microbial activity, data from months with the lowest soil temperatures were removed and only the data collected between March and November were used (Fig. 3-11).

Prolonged saturation to the surface occurred at many of the low sites in this study. Redox potentials of the soil at these sites were often reduced for an entire season or year. Incorporating these data (approximately 200 to 300 days of saturation) into a model to predict the amount of time a soil must be saturated before the onset of reduced conditions would unnecessarily complicate the analysis. Soils at these sites are not regularly or seasonally oxidized. Therefore, the time necessary to reduce these soils upon saturation can not be reliably calculated and should not be applied to other soils. Therefore, these data were omitted from the analysis (Fig. 3-11).

The soils on Mid-Atlantic Piedmont floodplains generally contained a sufficient amount of organic carbon in the upper part to sustain microbial activity (Fig. 3-10). The upper part is defined as 30 cm, and the carbon levels at 40 and 50 cm were often lower than those at the 20 and 30 cm depths. To avoid discrepancies due to the possibility the carbon levels at these lower depths may have been a limiting factor in the onset of reducing conditions, these data (40 and 50 cm) were not included in the development of this model.

Under similar pretense, the soil at 10 cm often contained a greater amount of carbon, apparently skewing the model developed for the soils at depths with questionable reduction (20 and 30 cm). Consequently, these data at 10 cm were also not used in the development of the model.

Eh values measured between March and November, from the middle and high sites, at 20 and 30 cm, were plotted against the number of days of continuous saturation at the specific depths of redox potential measurement (Fig. 3-11). This graph was used to estimate the amount of time saturated conditions must exist before the onset or reducing conditions.

Figure 3-9: Soil Temperature from March 2001 through January 2003 at 30 cm. Rock Creek is shown in red, White Clay Creek is shown in green, and the Middle Patuxent River is shown in blue.

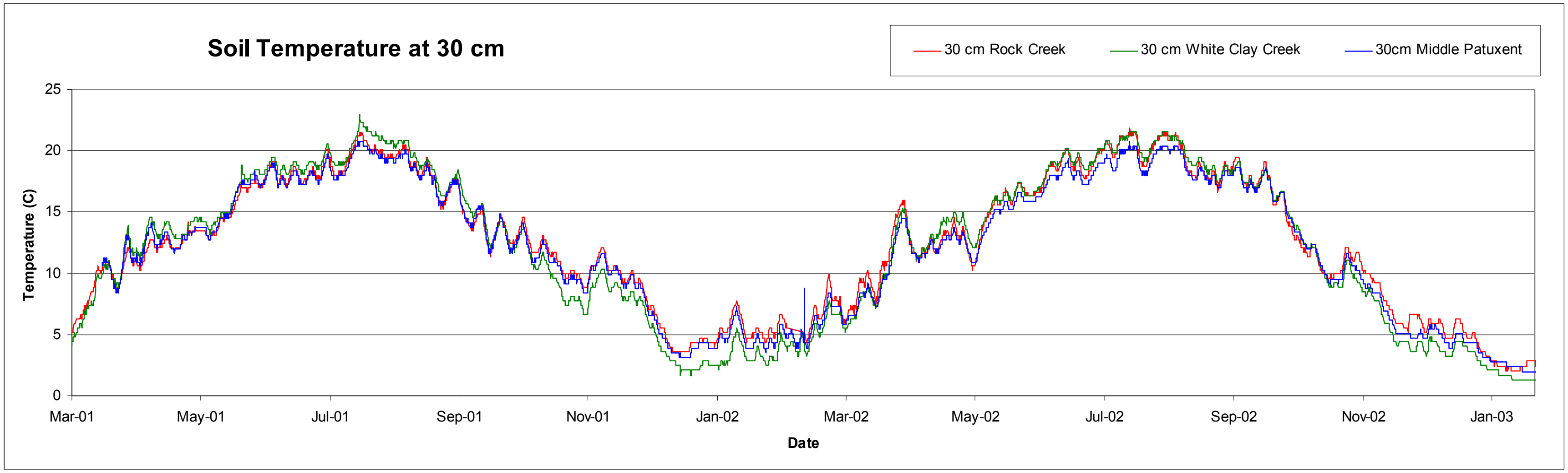


Figure 3-10: Total carbon percentage for all soils (0 to 50 cm) at the middle and high sites. Data from the entire pedons can be found in Appendix B.

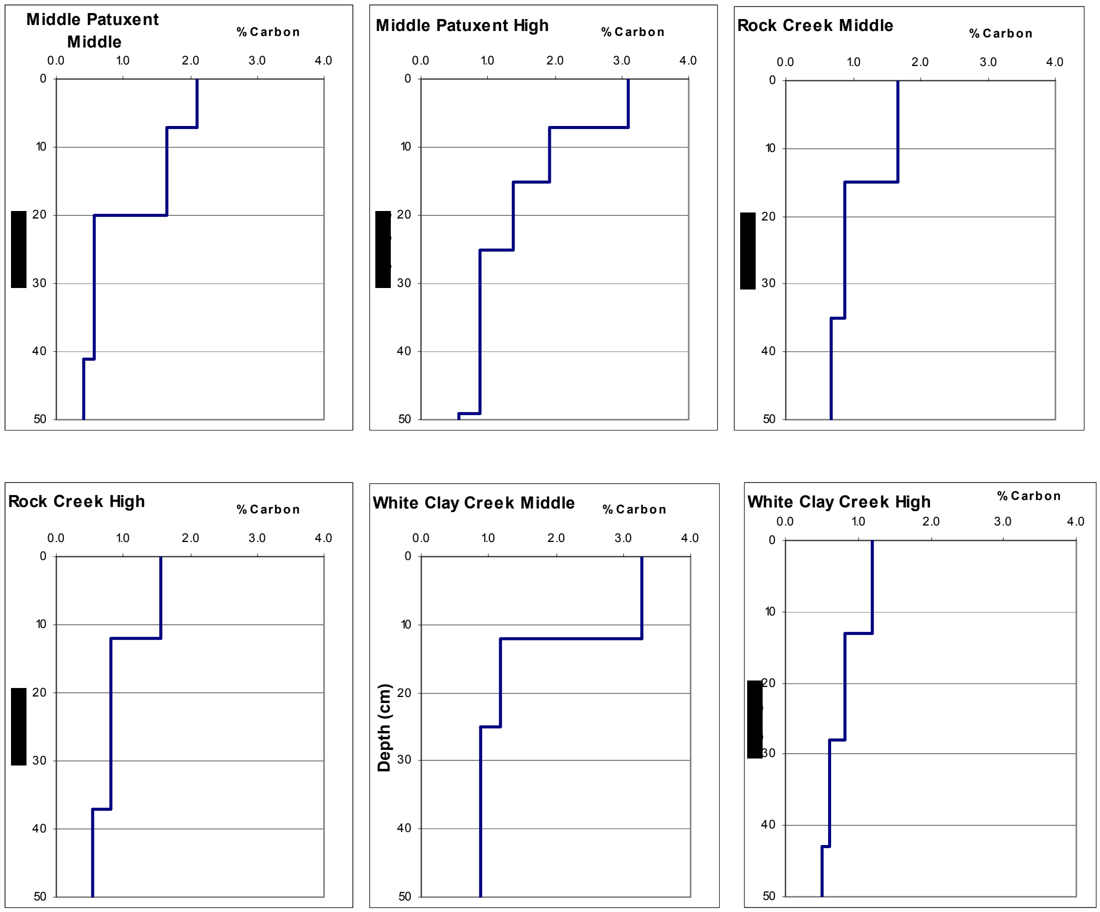


Figure 3-11: Redox potential versus the number of days of continuous saturation within the upper 30 cm at the middle and high wells from March through November. The average of six replicate Eh measurements at a particular depth is plotted against the number of days the soil at that depth was saturated. Blue vertical lines estimate the length of time saturation is necessary in order for the redox potential to fall below the Eh threshold at which iron is predicted to be reduced based on a pH of 4.1 (350 mV) and 4.5 (325 mV)(Based on the technical standard).

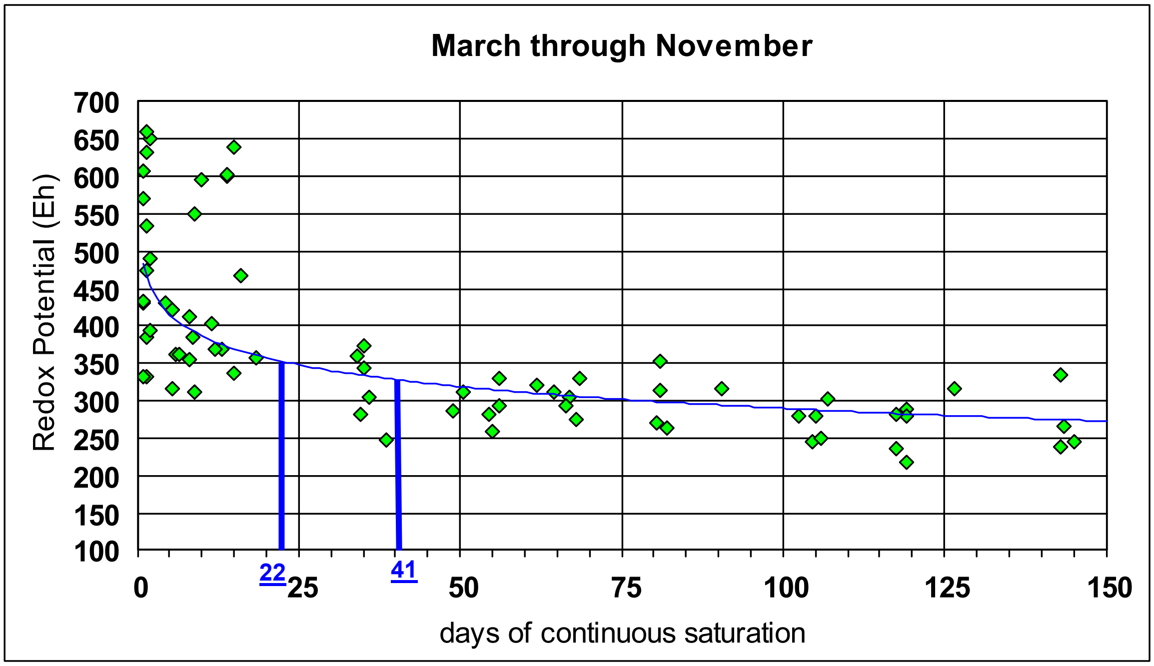
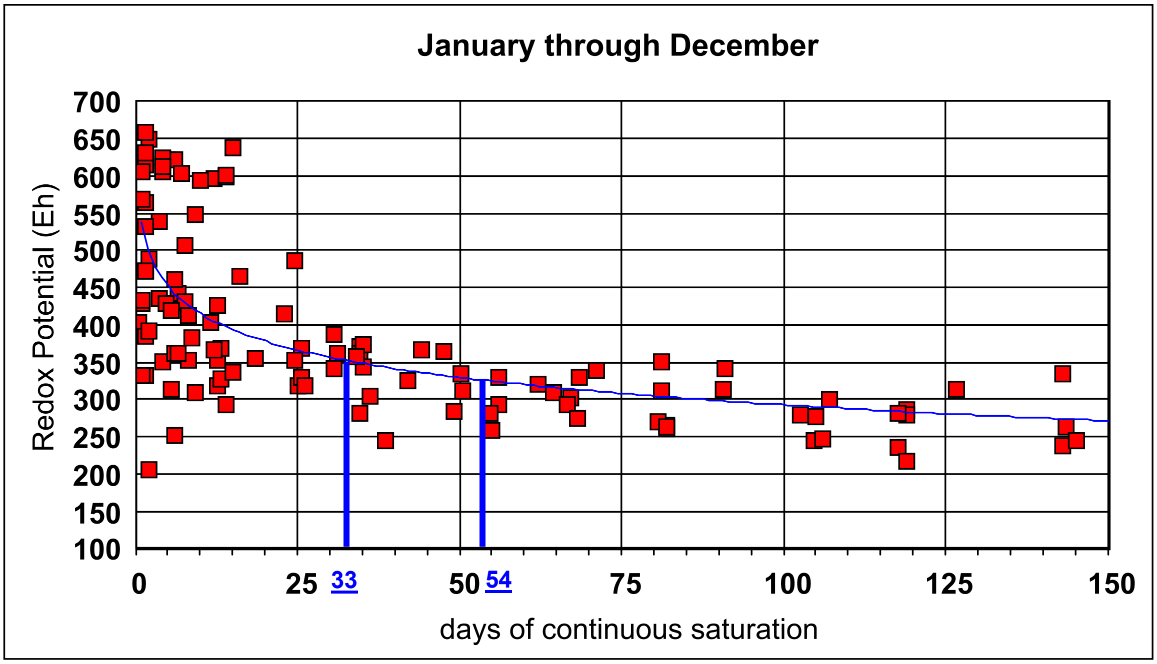


Figure 3-12: Redox potential versus the number of days of continuous saturation within the upper 30 cm at the middle and high wells for the entire year. The average of six replicate Eh measurements at a particular depth is plotted against the number of days the soil at that depth was saturated. Blue vertical lines estimate the length of time saturation is necessary in order for the redox potential to fall below the Eh threshold at which iron is predicted to be reduced based on a pH of 4.1 (350 mV) and 4.5 (325 mV)(Based on the technical standard).

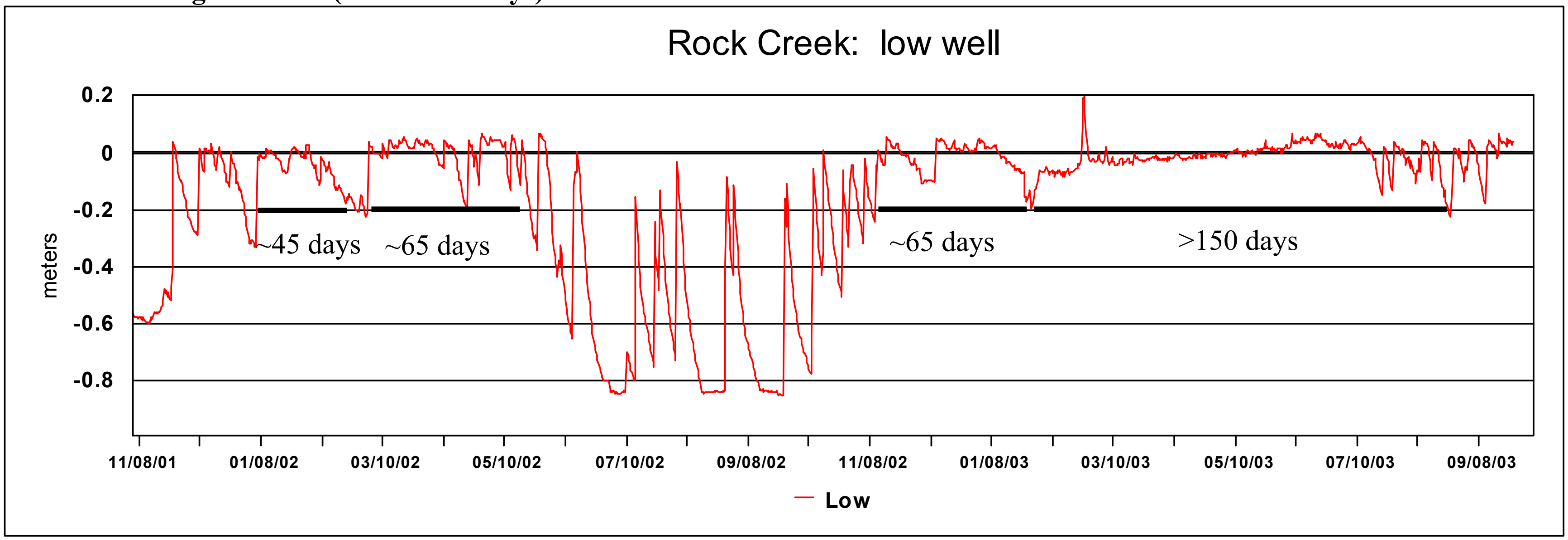


A least squares line was fit to the data set from the middle and high sites for the data collected between March and November (Fig. 3-11). Based on this function, the soil redox potential will drop to 350 mV after 22 days of continuous saturation and a redox potential of 325 mV will be reached after 41 days of continuous saturation. Therefore, based on the pH conditions documented in these soils, approximately 22 to 41 days of saturation are required for the Eh to drop to a point where Fe is reduced. Based on these estimates, previous (more comprehensive) water table data sets can be used to estimate the development of reducing conditions when Eh measurements were not available.

For comparison, a least squares line was fit to the data collected during the entire year (including low temperatures) (Fig. 3-11). The soil redox potential was predicted to drop to 350 mV after 33 days of continuous saturation and a redox potential of 325 mV will be reached after 54 days of continuous saturation. These values vary considerably from the number of days estimated from the previous data set (March through November). A much longer period of time is estimated to be necessary for saturation to produce reducing conditions. These estimates were not considered applicable for these research sites.

This approach was applied to the wet site at Rock Creek (data not used in the construction of this model) to evaluate at the reliability of the relationship between saturation time and redox potential. During the winter and spring of 2002, the soil at 20 cm was saturated for approximately 45 days and 65 days (Fig. 3-13). The redox potential at 20 cm at this site was between 329 and 294 mV, and (based on measured pH) met the technical standard for reduced iron. From January through August 2003, the soil at 20 cm was saturated for roughly 65 days and again for more than 150 days (Fig. 3-13). At this depth, the redox potential of the soil ranged from 344 to 274 mV, also below the technical standard for reduced iron.

Figure 3-13: Water Table Data from wet site at Rock Creek between November 2001 and September 2003. Black lines indicate the length of time (number of days) the soil was saturated at or above 20 cm below the surface.



The National Technical Committee for Hydric Soils established that a soil must be saturated and anaerobic for 14 days during one out of two years assuming the data are collected during a year with 30^{th} to 70^{th} percentile precipitation probability (normal year). During the two years that redox data were collected, 2002 and 2003, the rainfall was significantly different than normal (one year average to below the 30^{th} percentile and one year average to above the 70^{th} percentile) (Fig. 3-2). Using the model shown in figure 3-11, water table data collected during a year that fell within the normal precipitation range (Fig. 3-14) at the middle well at the Middle Patuxent River was used to better estimate the redox conditions within the soil. During the typical year, August 2000 through August 2001, the water table was continuously above 30 cm for two distinct periods, one for 50 days and one for 65 days (Fig. 3-15). Based on the saturation time and redox potential model, this appears to be adequate time for reduced conditions to develop in the soil at this depth.

For comparison, during the dry year, 2002, the water table was above 30 cm for 25, 20, and 15 days (Fig. 3-16). The redox potentials measured at these times indicate that the soil was reduced at one instance during late April (Fig. 3-7). This one measurement is not sufficient to infer reduced conditions existed for 14 days. The following wet year, 2003, the soil at 30 cm was saturated for 90 days and 140 days (Fig. 3-17). Redox potentials measured during these times conclusively illustrate that the soil was reduced much longer than 14 days (Fig. 3-7).

Figure 3-14: Precipitation Data from the Middle Patuxent River during a more typical year. The black lines display the 30th and 70th percentile for precipitation and the blue line shows the actual precipitation. The blue line falls within the two black lines indicating that this year had normal precipitation levels.

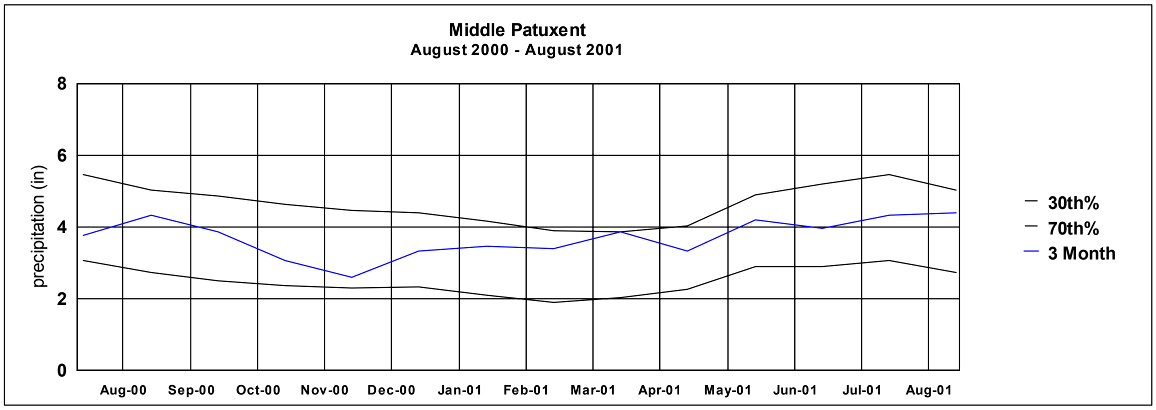


Figure 3-15: Water Table Data from the middle location at the Middle Patuxent River during a year with normal rainfall levels. Black lines indicate the length of time (number of days) the soil was saturated at or above 30 cm below the surface.

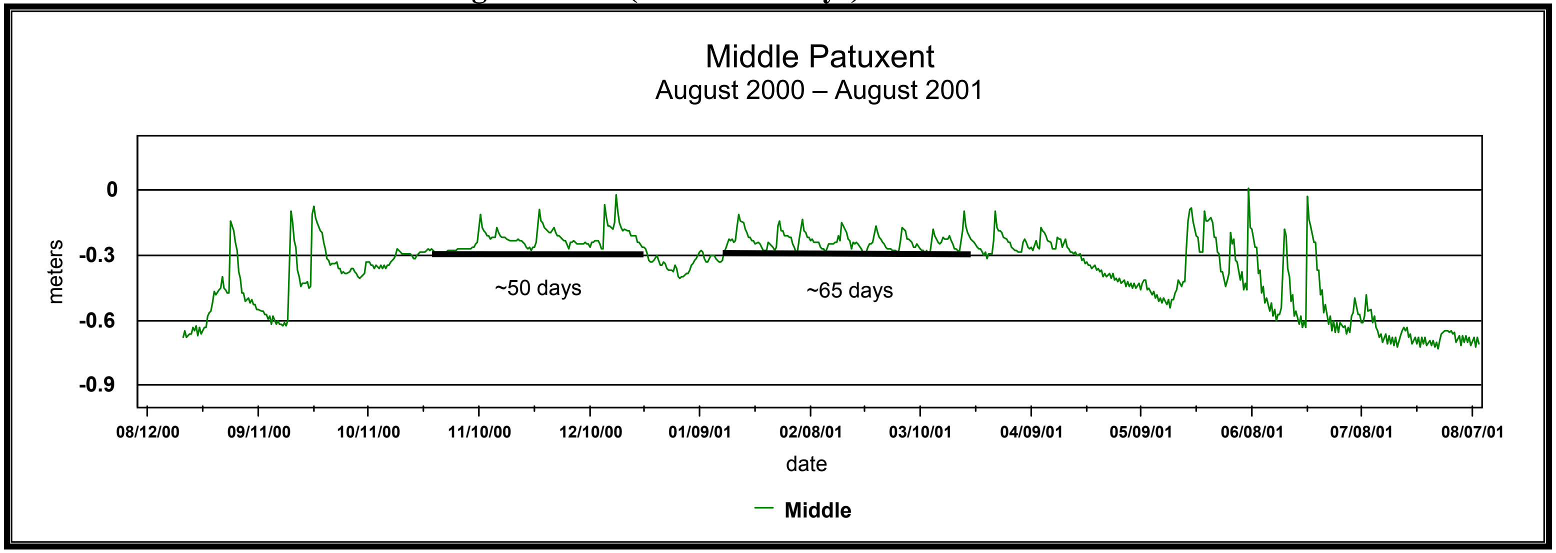


Figure 3-16: Water Table Data from the middle location at the Middle Patuxent River during a year with droughty conditions. Black lines indicate the length of time (number of days) the soil was saturated at or above 30 cm below the surface.

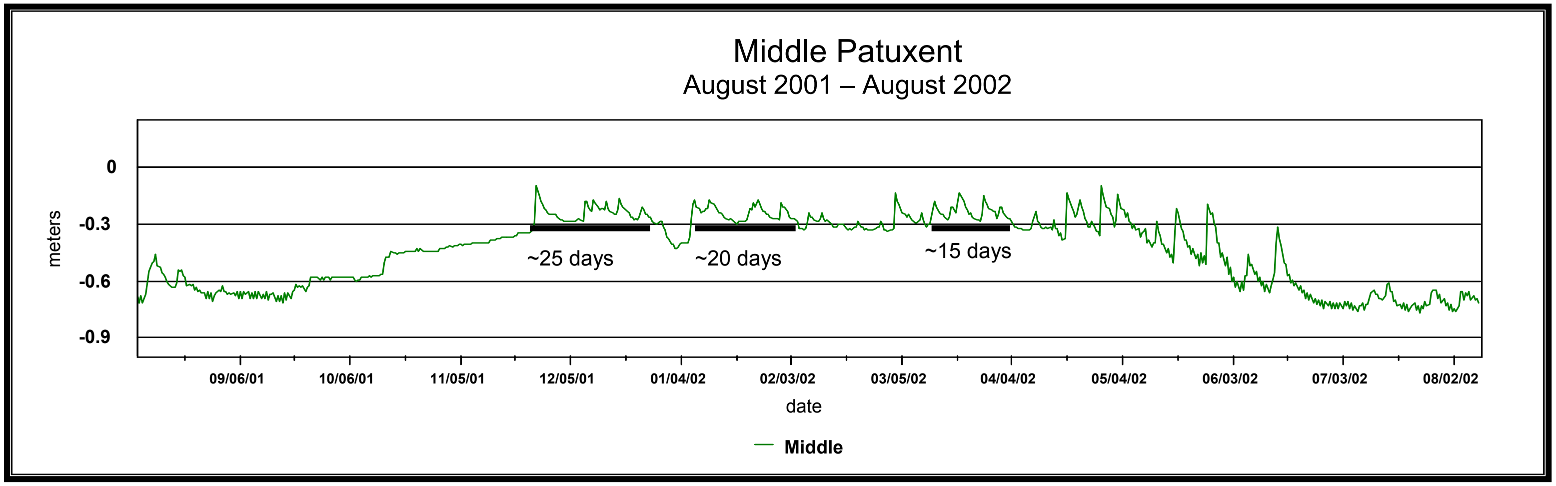
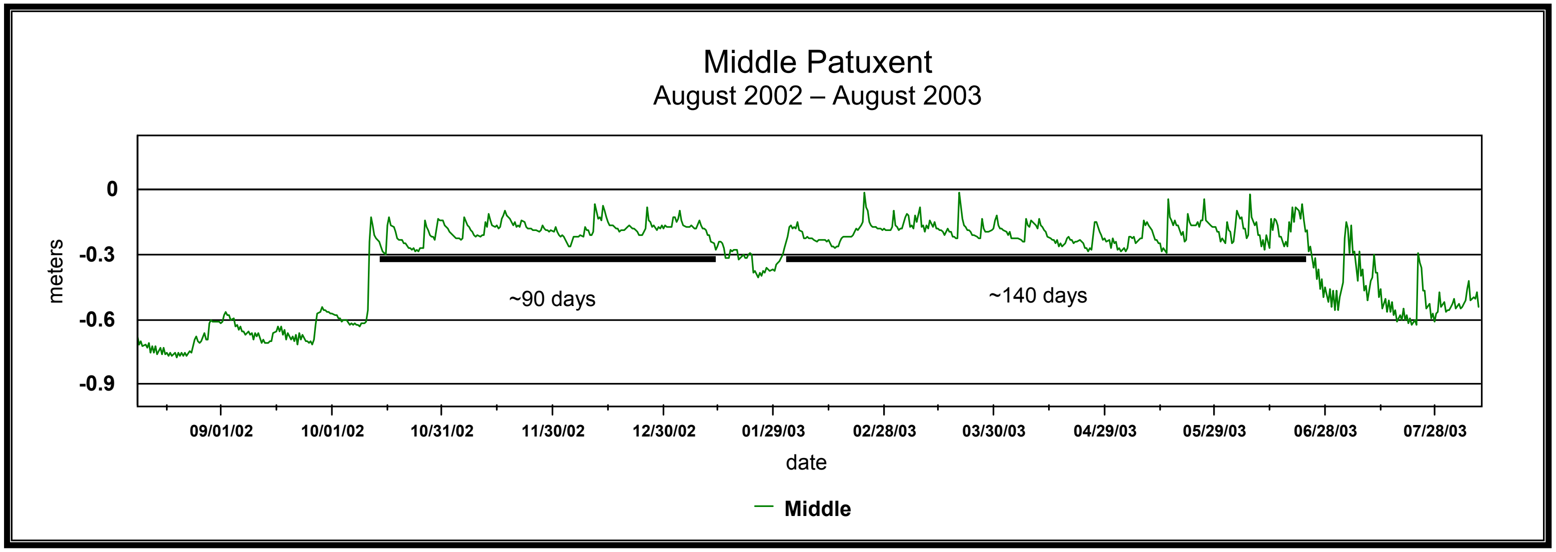


Figure 3-17: Water Table Data from the middle location at the Middle Patuxent River during a year with excessively wet conditions. Black lines indicate the length of time (number of days) the soil was saturated at or above 30 cm below the surface.



Conclusions

The soil at the low locations along the floodplains maintained high water tables and low redox potentials for most of the study period. Redox potentials only became oxidizing with respect to iron when the water tables dropped during a few of the drier months in 2002.

At the middle and high locations, the relationship between water table and redox potential was examined. Using data collected throughout the year, the redox potential of a soil is predicted to drop to the point where iron is reduced following 33 to 54 days of continuous saturation. When winter data (Dec – Feb) is excluded, the redox potential of a soil is predicted to drop to the point where iron is reduced following 22 to 41 days of continuous saturation. This model was then applied to predict the onset of reducing conditions in soils based upon the technical standard for hydric soils, using water table data from a year with normal precipitation. Because this model describing the relationship between water table duration and the onset of reducing conditions has been developed using data from soils on Piedmont flood plains, it may not be applicable to other soil settings. Future work should address this question and compare this model to similar ones developed for other soils.

IV. Effects of Water Tables on the Formation of Redoximorphic Features in Mid-Atlantic Piedmont Floodplain Soils

Introduction

The observation of depth to particular types of redoximorphic features in soils is used to access the depth and duration of the seasonally high water table (Simonson and Boersma, 1972; Franzmeier et al., 1983; Elless et al., 1996). Certain soils appear to have greater affinity than others to develop these characteristic redox features. Soil horizons that maintain high water tables for long durations typically show redoximorphic features such as 2 chroma depletions or a low chroma soil matrix. Other soil horizons where seasonally high water tables persist for a lesser amount of time may exhibit redox concentrations of oxidized iron and or manganese. In soils where water tables rise for only brief periods, redoximorphic features may not form at all.

Studies have been conducted in an attempt to relate the presence of redoximorphic features with the percent of time that a horizon is saturated (West et al., 1998). West et al. (1998) studied soils on the Georgia Coastal Plain and confirmed the presence of redox concentrations in soil horizons that were saturated for 20% of the time, redox depletions (2 chroma or less) in horizons that were saturated for approximately 40% of the time, and a depleted matrix in horizons that were saturated for about 50% of the time. Daniels et al. (1971) documented that soil horizons with gleyed matrices were saturated between 25% and 50% of the time, and soils with 3 chroma matrix colors (value of 6 or 7) were saturated for 25% of the time. Research by Franzmeier et al. (1983) supports the findings that soils with 3 chroma colors are wetter than suggested in *Soil Taxonomy* (1999).

The relationship between saturation time and the formation of redoximorphic features appears to vary widely throughout the geographic region, landscape position, soil type, and climate. Soils on Piedmont floodplains do not appear to have developed redoximorphic features in equilibrium with water table levels. These features cannot be related to the previous work comparing the formation of redoximorphic features to water table levels. Therefore, the objective of this study was to assess the relationship between the formation of redoximorphic features and the depth and duration of high water tables in soils located on Mid-Atlantic Piedmont floodplains.

Methods

Sites were established on three floodplains, with minimal slope (less than 1%), in the Mid-Atlantic Piedmont physiographic province (Fig. 3-1). The sites are located on floodplains near the Middle Patuxent River in Howard County, Maryland, the North Branch of the Rock Creek in Montgomery County, Maryland, and the White Clay Creek in New Castle County, Delaware. These sites were selected based on a few criteria, including the length of the floodplain extending between 50 and 100 m from river to backswamp area, the remoteness of the sites to prevent human disturbance of equipment, and a flooding frequency of one in two years.

Each site was instrumented with three or four automated recording wells along a transect similar to that shown in figure 1-3. At the Middle Patuxent River and Rock Creek, one well was installed in the wettest area of the floodplain, adjacent to the hillslope, in the groundwater discharge wetland (low). At White Clay Creek, two wells were installed in this wetland area (low and low/mid). At all three sites, another well was installed towards the middle area of the floodplain and a third in the drier area nearer to the natural levee (high). Depth to water table was measured twice daily to a maximum depth of 1.5 m.

During March 2002 at Rock Creek and August 2002 at the Middle Patuxent River and White Clay Creek, soil pits were excavated at the locations along the transects within 2 m of where the wells were positioned. Soil morphological descriptions were made at these locations (Soil Survey Staff, 1993). Special consideration was given to the identification and description of redoximorphic features in these soils.

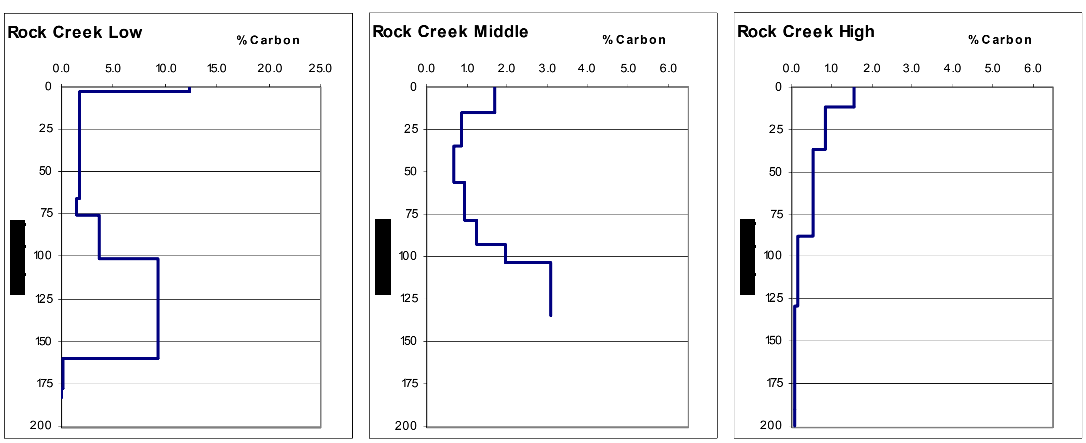
Results and Discussion

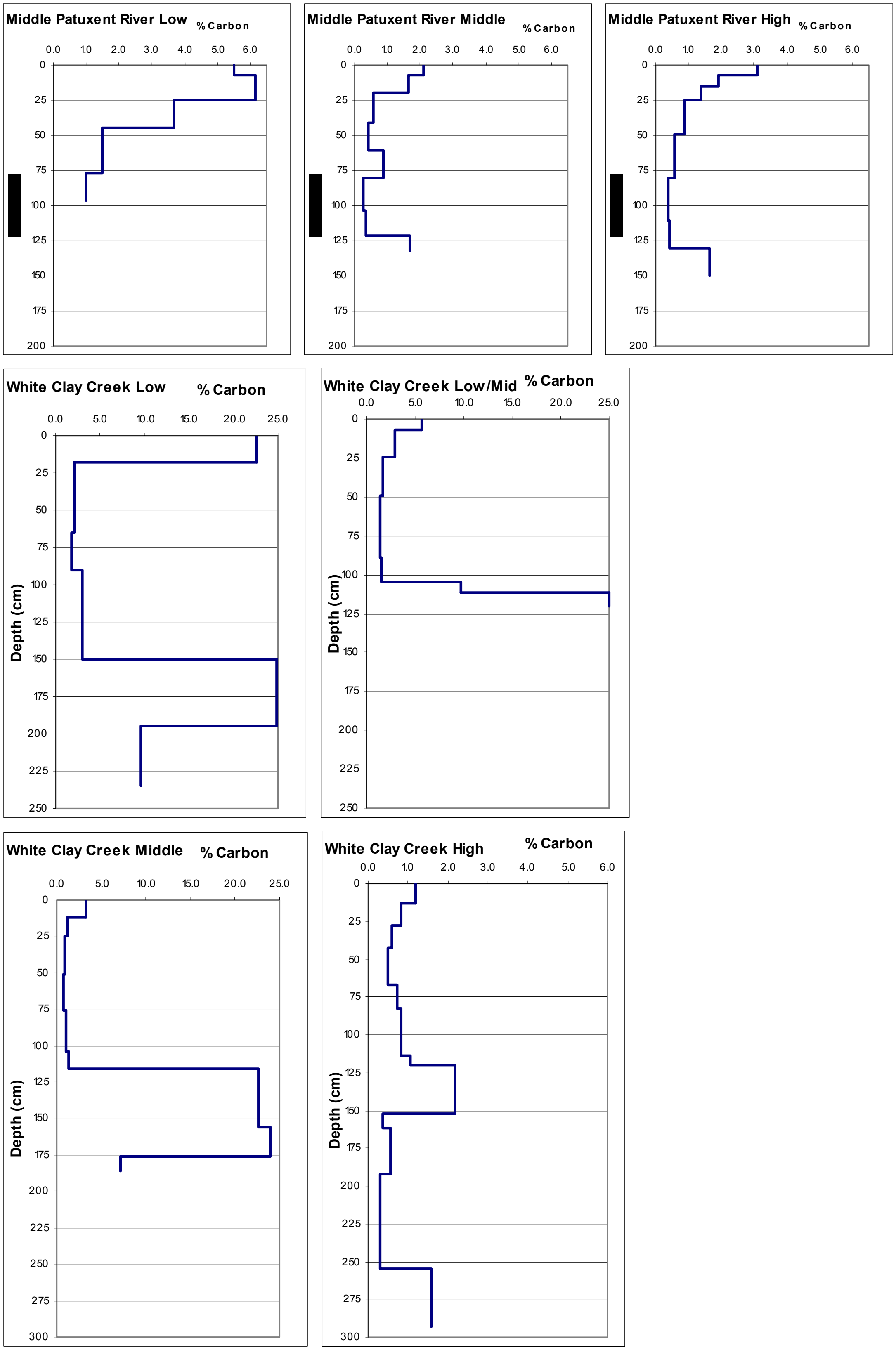
Soil Properties

The soils located in the low areas along the floodplains exhibited a variety of morphological features indicative of extreme wetness, including, low chroma matrix colors, redox concentrations, and thick, dark, organic rich surface horizons. The soils in the middle locations displayed redoximorphic features such as redox concentrations and depletions, but lacked features of extreme wetness as seen in the low sites. Most of the horizons in the soils located towards the middle of the floodplain had horizons with 3 chroma matrix colors rather than the 2 chroma colors that are typically associated with longer periods of saturation. The soils in the high locations along the floodplain transects showed some redox concentrations and depletions within the soil profile, but generally at a greater depth.

Soil organic carbon percentages appear to be sufficient for microbial activity to occur. Figure 4-1 shows the total carbon percentages in all horizons sampled. The dithionite citrate bicarbonate (DCB) extractable iron content in the soil was also sufficient to form redox concentrations and depletions, ranging between 2.3% and 0.85% in the upper 50 cm of the three middle profiles (see Appendix M for values).

Figure 4-1: Organic carbon percentage for all soils sampled at the Middle Patuxent River, Rock Creek, and White Clay Creek. Scales vary between each site.




Middle Patuxent River Low
% Carbon
Middle Patuxent River Middle
% Carbon
Middle Patuxent River High
% Carbon
White Clay Creek Low
% Carbon
Depth (cm)
White Clay Creek Low/Mid
% Carbon
Depth (cm)
White Clay Creek Middle
% Carbon
Depth (cm)
White Clay Creek High
% Carbon
Depth (cm)

As reflected in the water table data for each site, the Mid-Atlantic region experienced droughty conditions during 2002, while in 2003, the region received above average levels of precipitation (Fig. 3-2). Figure 4-2 is a hydrograph from the wells in the wettest location on the floodplains. For the majority of the time, the water table remained above 25 cm at each of these four low sites. Figure 4-3 shows the water table at the middle sites remained above 25 cm between December and June (wet season), and above 130 cm for the remainder of the year. Figure 4-4 displays the water table data from the drier locations along the floodplains. The water table fluctuated between 0 and 50 cm during the wet season and ranged between 75 cm and 150 cm during the drier months (July through November).

Figure 4-2: Water table data from the wet sites between December 2001 and October 2003. The water table from the low well at White Clay Creek is shown by the red line, the low/mid well at White Clay is shown by the orange line, the low well at the Middle Patuxent River is shown by the blue line, and the low well at Rock Creek is shown by the green line.

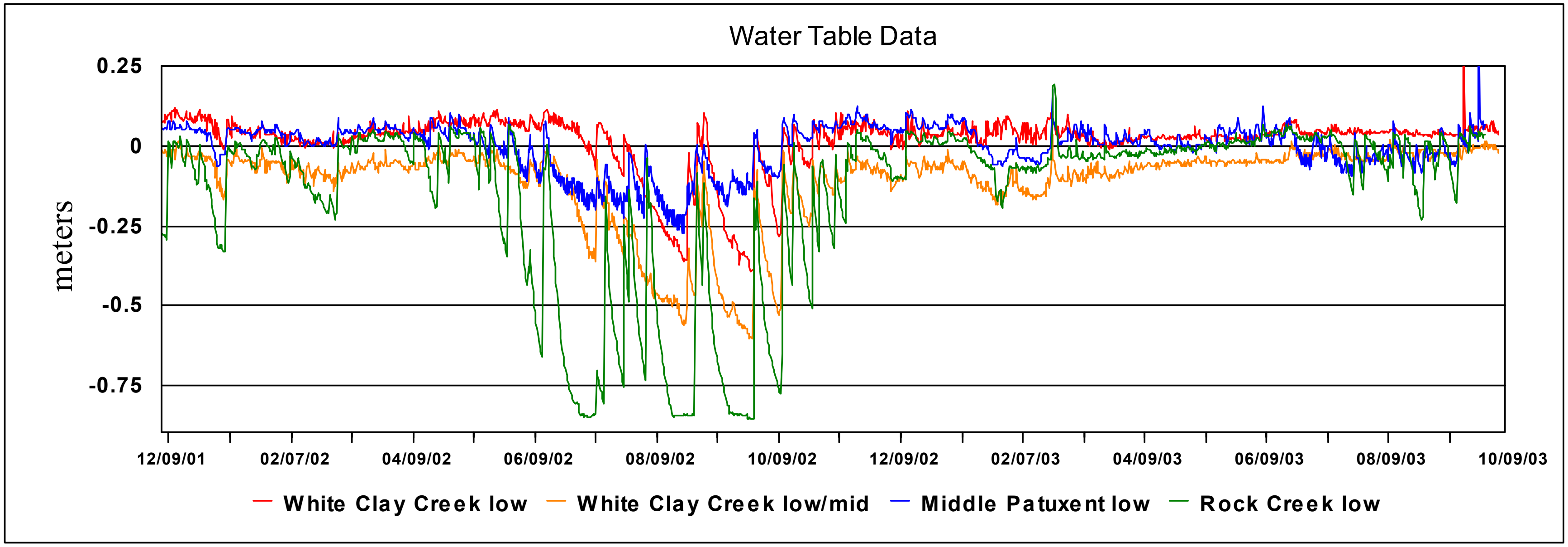


Figure 4-3: Water table data from the middle sites between December 2001 and October 2003. The water table from the middle well at White Clay Creek is shown by the red line, the middle well at the Middle Patuxent River is shown by the blue line, and the middle well at Rock Creek is shown by the green line.

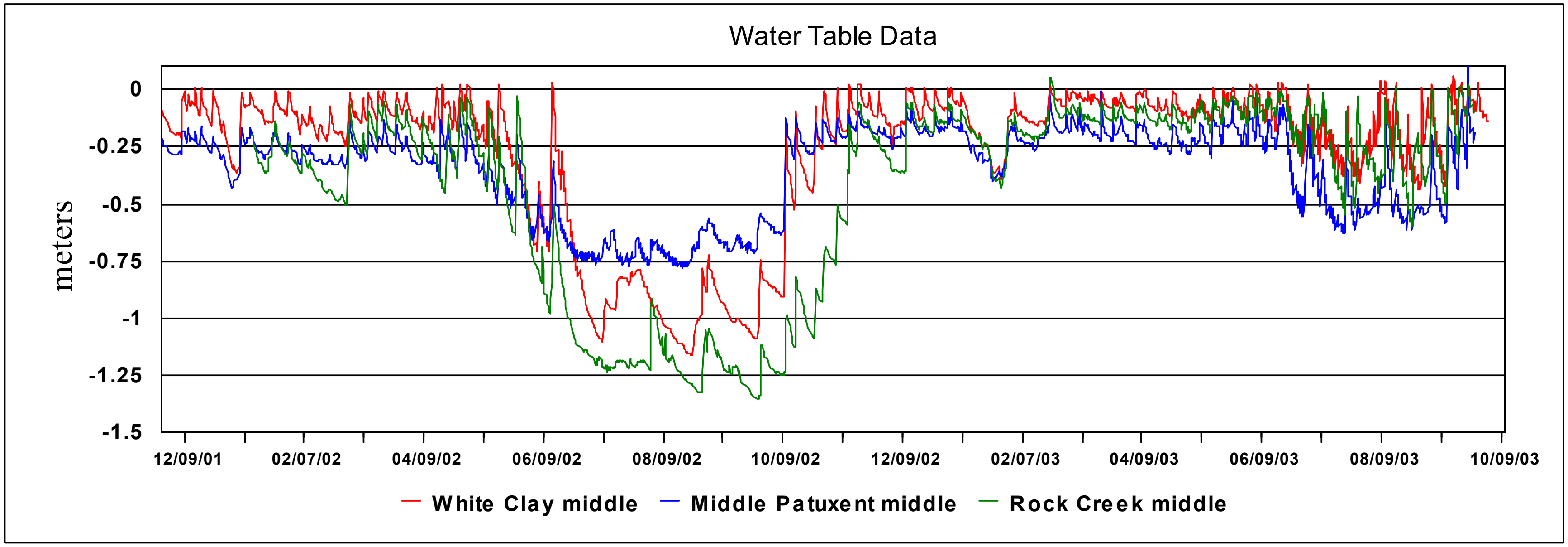
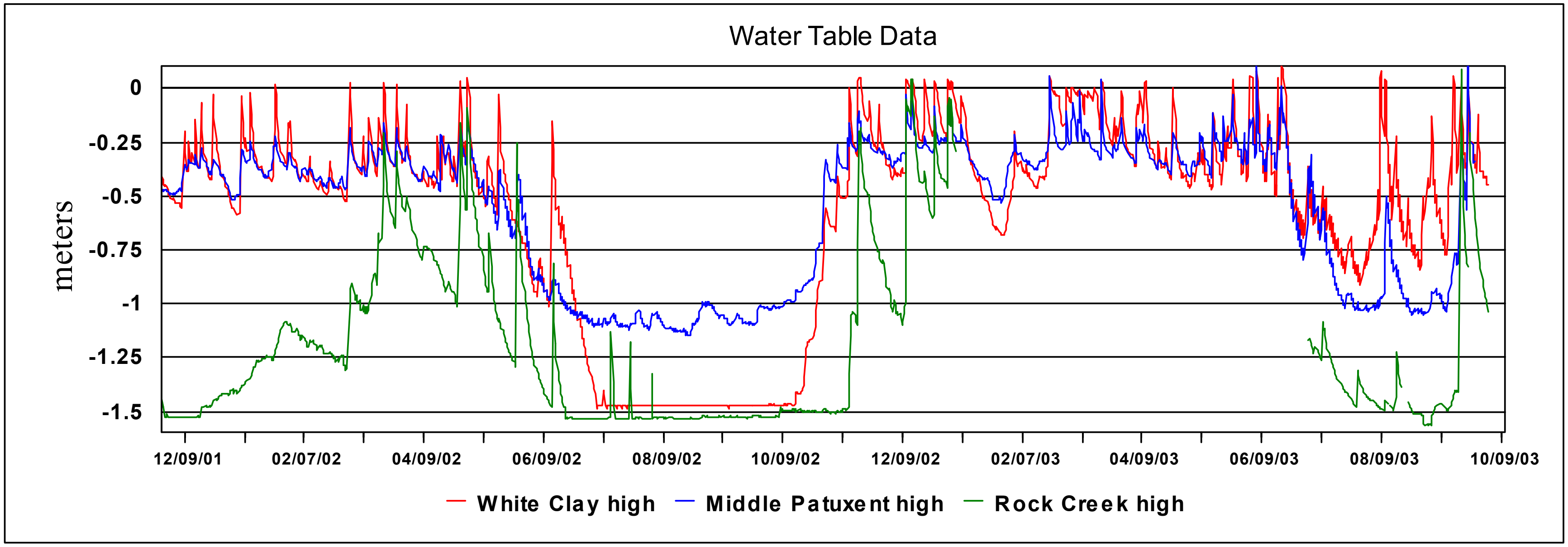


Figure 4-4: Water table data from the driest sites between December 2001 and October 2003. The water table from the high well at White Clay Creek is shown by the red line, the high well at the Middle Patuxent is shown by the blue line, and the high well at Rock Creek is shown by the green line. A missing line indicates data missing due to well malfunction.



Cumulative Frequency Distribution of the Water Table

The wettest (low) soils along the floodplain are saturated to the surface for between 50% and 93% of the time, and water tables are at or above 30 cm for 80% to 100% of the time. The morphological features at these sites reflect extremely wet conditions. Thick, dark, organic-rich surface horizons and thick low chroma, depleted matrix colors are common near the soil surface.

The soils situated in the middle location along the floodplain also have water tables that occur within the upper horizons for long periods of time throughout the year. These soils are saturated to the surface for between 0% and 13% of the time, and they are saturated at or above 30 cm for between 50% and 72% of the time. While redoximorphic features such as concentrations and 2 chroma depletions occur between depths of 0 and 30 cm, these soils lack a depleted matrix in the upper 30 cm.

The drier (high) locations along the floodplains exhibit high water tables to the surface for only brief periods, between 0% and 7% of the time. The water table is at or above 30 cm for between 6% and 32% of the time. The redox features observed in these soils, such as concentrations and 2 chroma depletions, tend to develop more strongly below 30 cm where the water table is present for longer periods of time.

Figure 4-5: Cumulative frequency distribution of the water table at the low (blue), middle (green), and high (red) wells at the Middle Patuxent River.

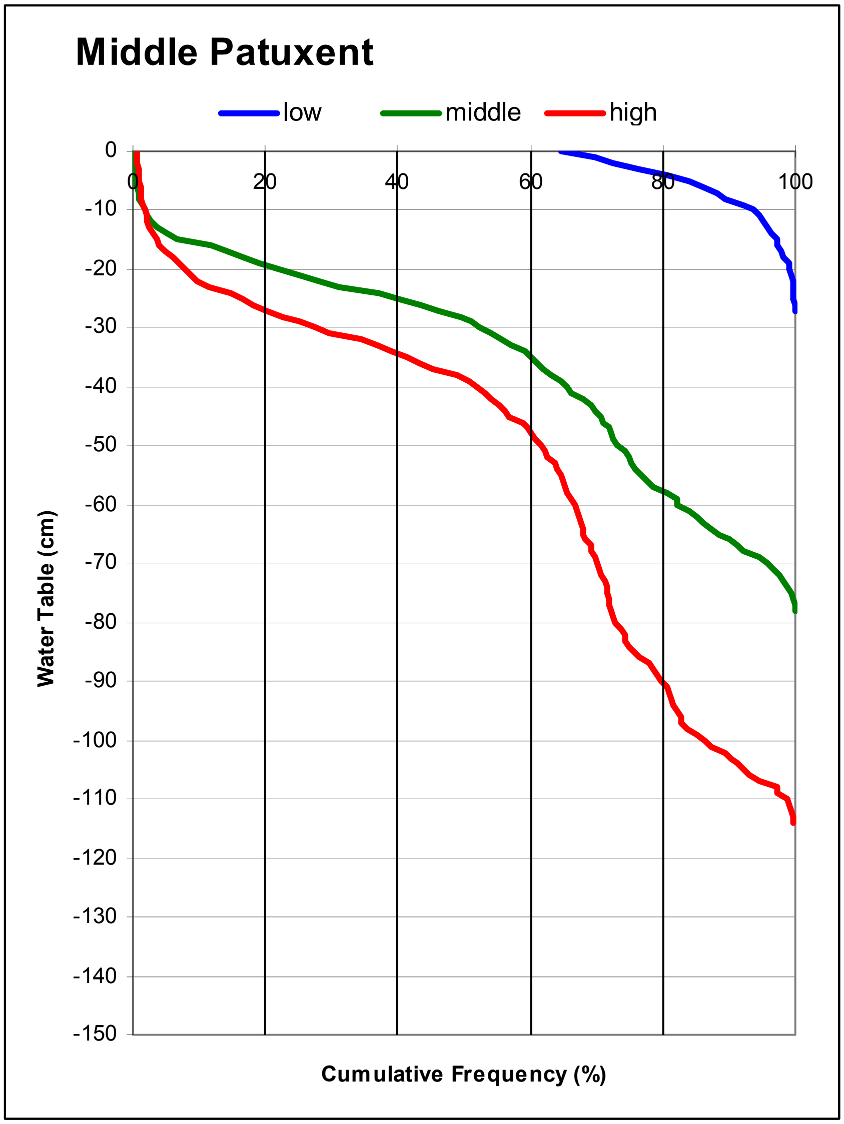


Figure 4-6: Cumulative frequency distribution of the water table at the low (blue), middle (green), and high (red) wells at the Rock Creek.

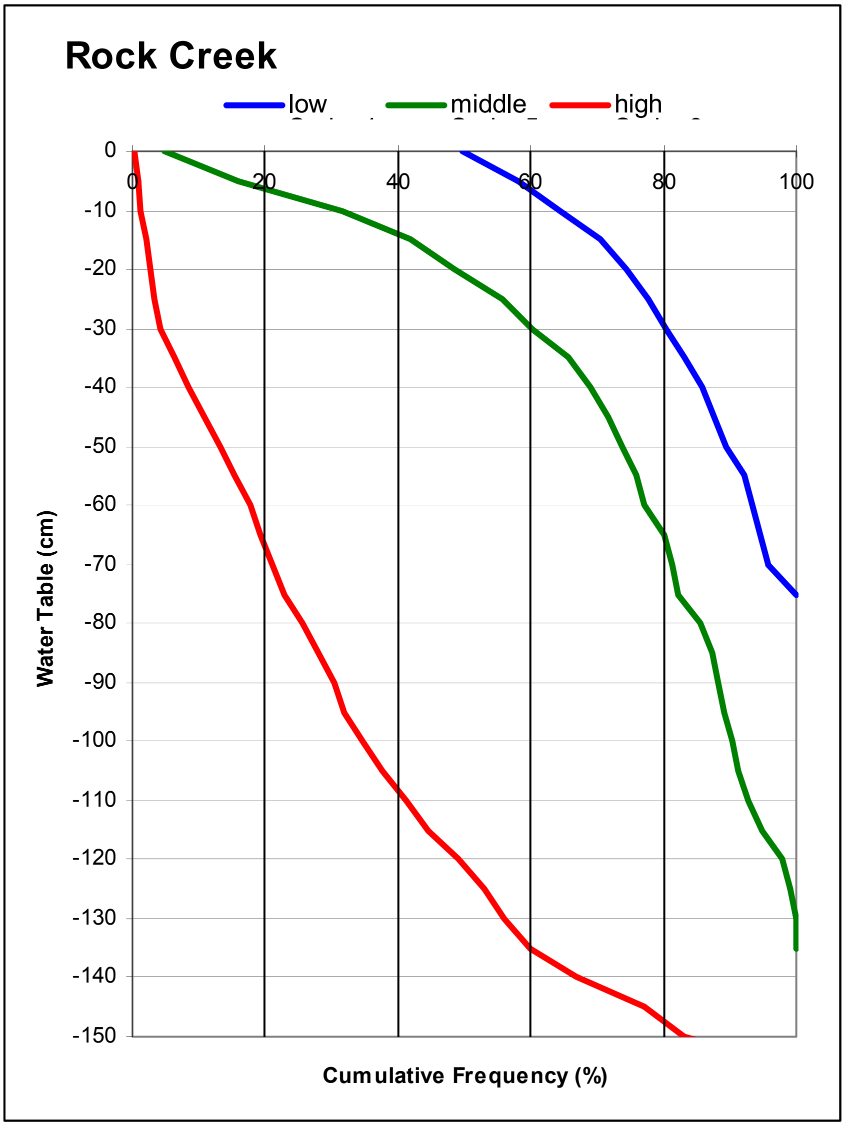
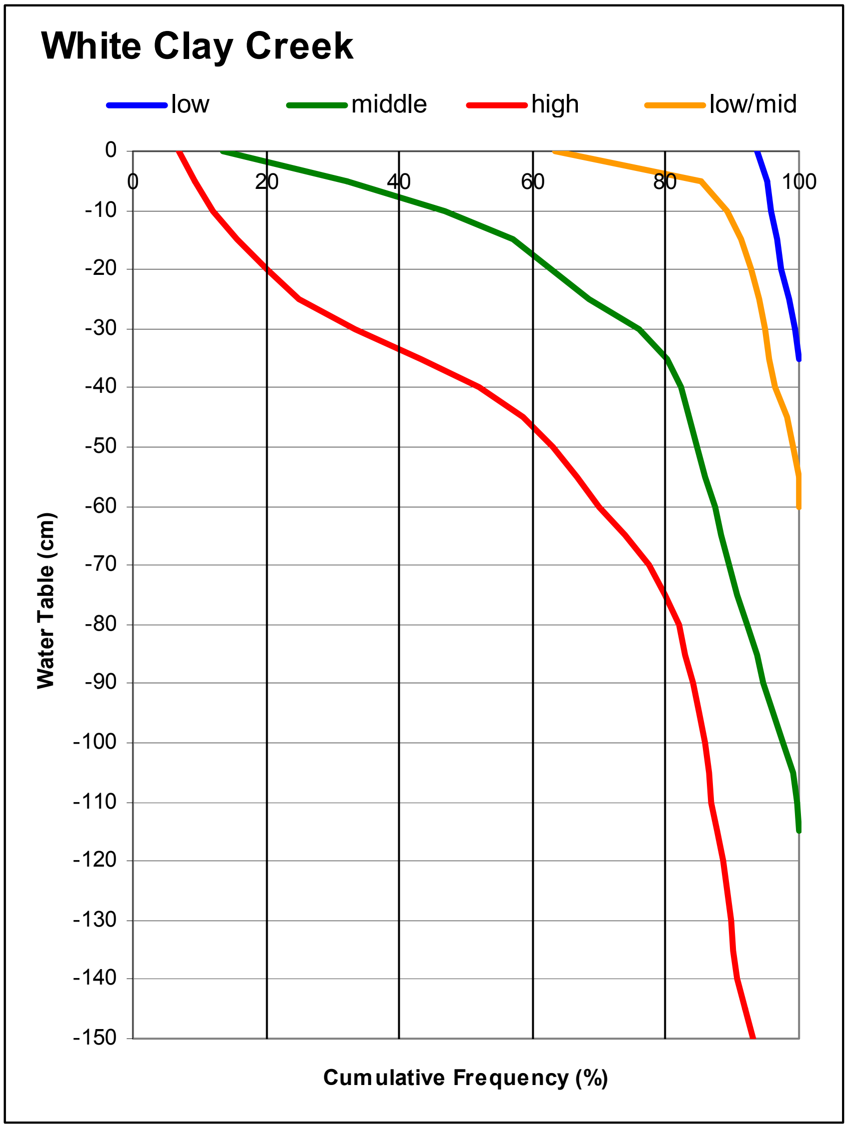


Figure 4-7: Cumulative frequency distribution of the water table at the low (blue), low/mid (orange), middle (green), and high (red) wells at the White Clay Creek.



Relationship Between Redoximorphic Features and Percent of Time Saturated

Figure 4-8 shows the relationship between the quantities of distinct or prominent redox concentrations of iron and manganese described in various soil horizons and the percentage of time that a soil horizon was saturated (using figures 4-5, 4-6, and 4-7 at the midpoint of each horizon). When a soil horizon is saturated between 0% and 50% of the time, the percent of concentrations observed increases linearly from 0 to 30% concentrations. When the soil is saturated for more than 50% of the time, there is essentially no change in the quantity of redox concentrations observed.

Figure 4-8: Quantity of distinct or prominent concentrations described in soil horizons as related to percentage of time the horizon was saturated (note percent of time saturated reflects mean of the horizon).

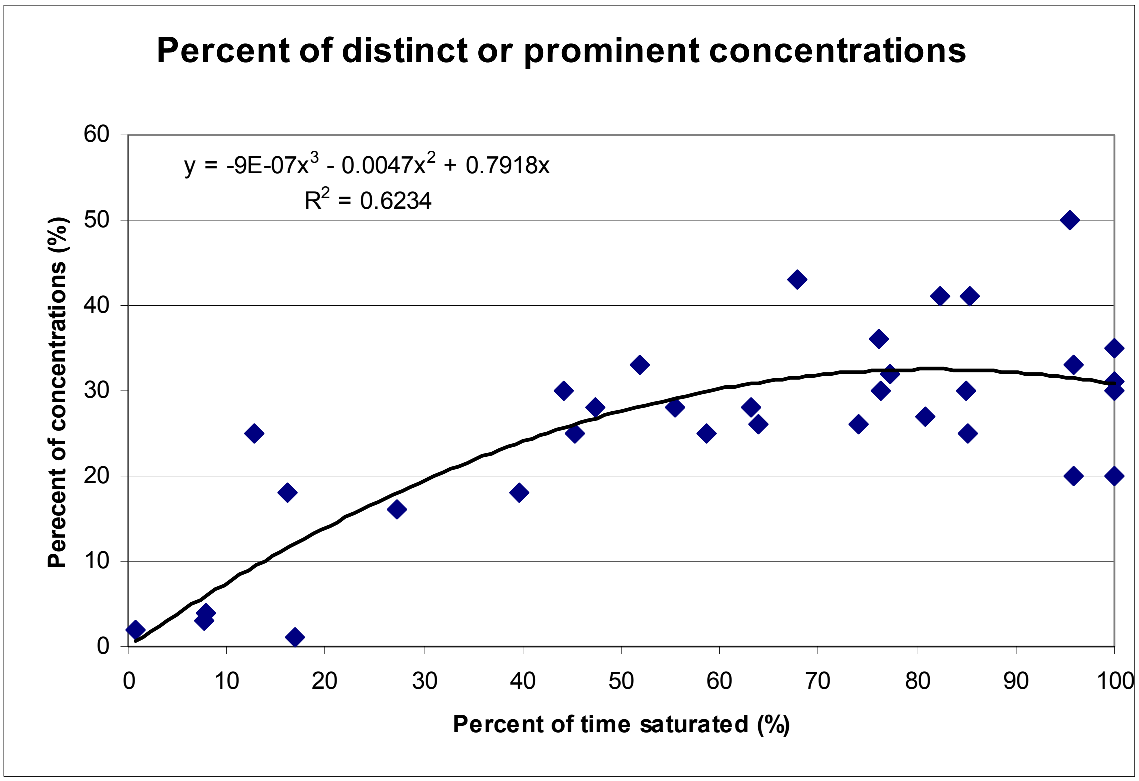


Figure 4-9 shows the quantity of 2 chroma (or less) redox depletions in Piedmont soil horizons in relation to the percentage of time saturated. Two chroma depletions do not appear to form until the soil is saturated for at least 27% of the time, and generally the horizons must be saturated for 45% of the time in order for there to be 5% or more depletions. Redox depletions occurred in soils in the Coastal Plain of Georgia after being saturated for at least 10% of the time with an average of 40% of the time (West et al., 1998). In both the Piedmont and Georgia Coastal Plain soils, the percentage of depletions increased as the percent of time the soil is saturated increased.

Soil horizons saturated between 27% and 75% of the time generally formed less than 10% depletions, while soils saturated for more than 75% of the time typically formed between 46% and 100% depletions. These horizons with longer percentages of saturation were identified as depleted matrices when the percentage of concentrations was greater than 60%. Figure 4-11 illustrates that the soils on floodplains located in the Mid-Atlantic Piedmont formed redox depletions only after substantially longer periods of saturation than did the soils in the study by West et al. (1998).

Figure 4-9: Proportion of the soil horizon that has a Munsell chroma of 2 or less (and value 4 or more) in relation to the percentage of time the horizon was saturated (note percent of time saturated reflects mean of the horizon and data is for all sites).

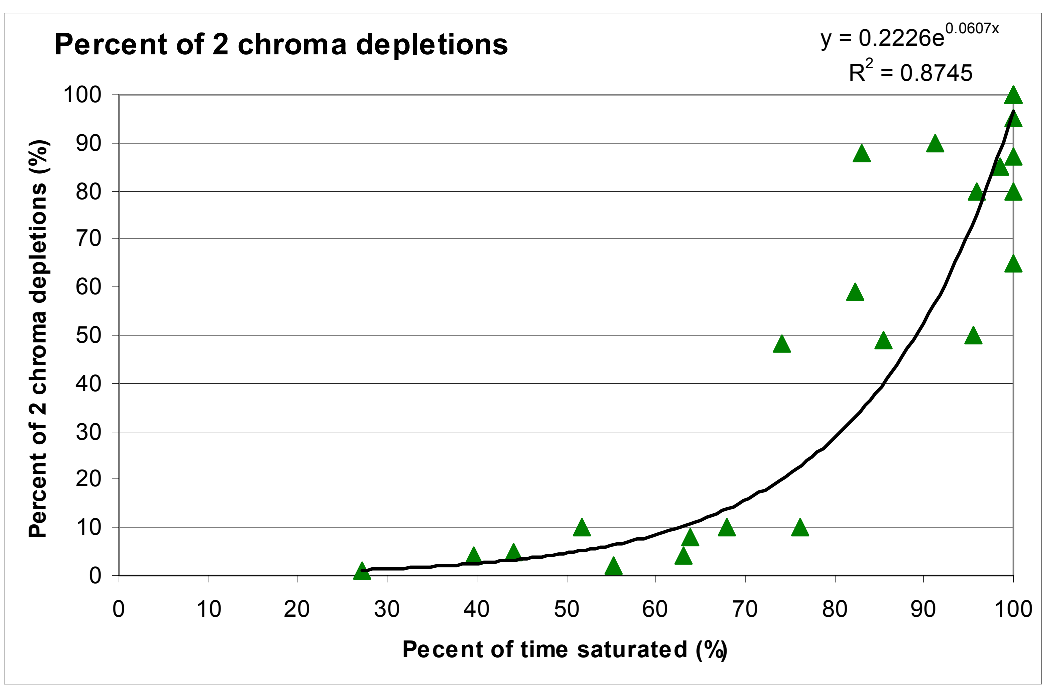


Figure 4-10 illustrates that in Piedmont floodplain soils, a depleted matrix is observed only when a soil horizon is saturated for more than 80% of the time. West et al. (1998) reported that low chroma matrices formed in horizons that had the water table present for an average of 51% of the time. This estimation for the amount of time saturated is far shorter than the amount of time necessary to form low chroma matrices in these alluvial soils.

Figure 4-10: The occurrence of a depleted matrix versus the percentage of time saturated (note percent of time saturated reflects mean of the horizon).

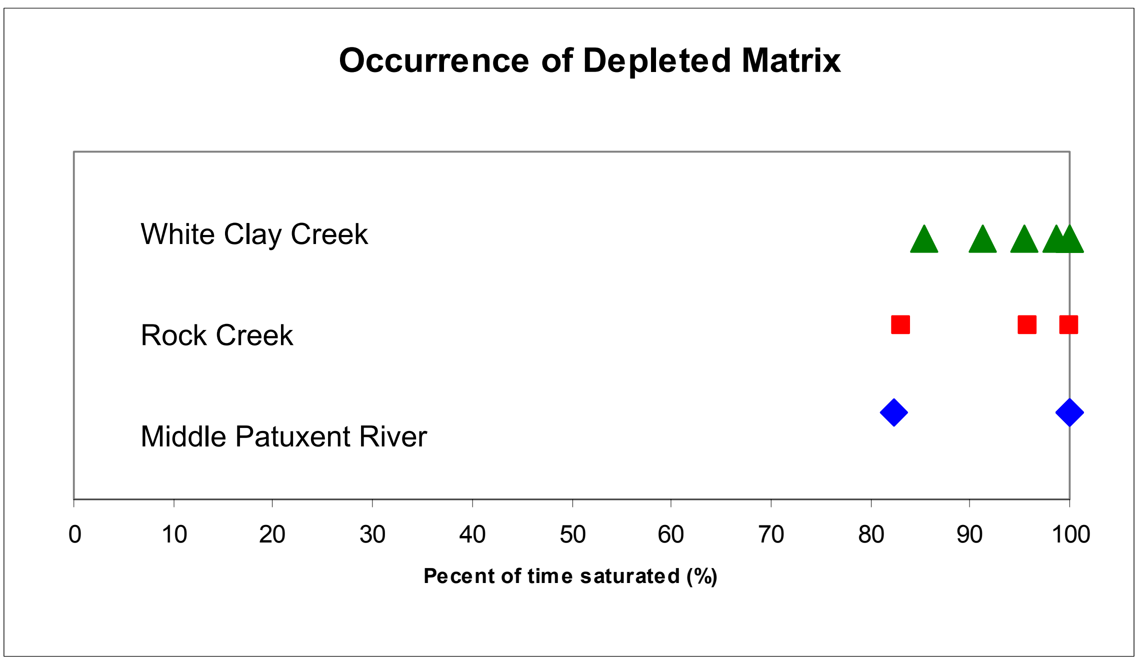
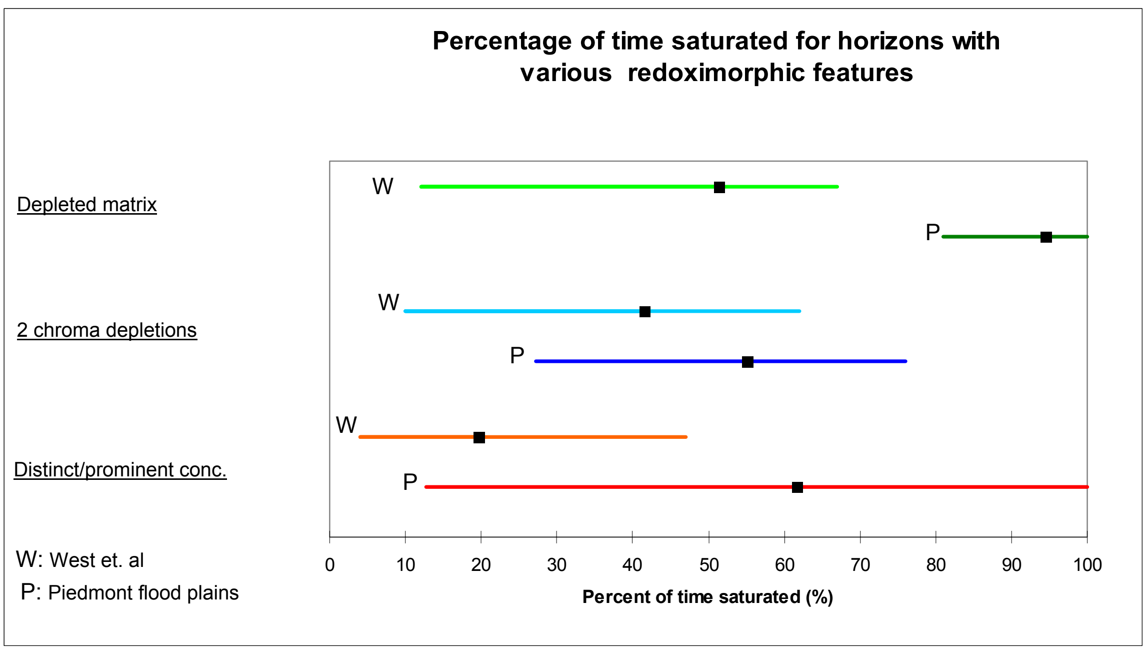


Figure 4-11 compares the necessary time saturated for the formation of various redoximorphic features in this study with those reported by West et al. for soils on the Georgia Coastal Plain. West et al. (1998) state that their observations were similar to results from other studies in a variety of settings (Daniels et al., 1971; Coventry and Williams, 1984; Evans and Franzmeier, 1986; Elless et al., 1996). In contrast to these published findings, Piedmont floodplain soils show soil horizons with comparable redoximorphic features were saturated for substantially longer periods that those reported in other studies.

Figure 4-11: Percentage of time saturated for horizons with a depleted matrix (greater than 60% depletions), 2 chroma depletions, and distinct or prominent concentrations for soils on Mid-Atlantic Piedmont floodplains and on the Georgia Coastal Plain (West et al., 1998). Black squares are averages. Lines with P are soils on the Piedmont and W are soils on the Georgia Coastal Plain.



Conclusions

Redoximorphic features form under saturated soil conditions, as a result of reducing conditions. Distinct and prominent redox concentrations of iron oxyhydroxides begin to form in Mid-Atlantic Piedmont floodplain soils when they are saturated for more than

15% of the time. Depleted zones (less than 2 chroma) occur in soil horizons that are saturated for periods greater than 25% or 30% of the time. A depleted soil matrix (chroma less and or equal to 2) appears in Piedmont floodplain soils that are saturated for greater than 75% of the time.

Thus, increased percentage of time saturated is generally associated with the occurrence of iron oxide concentrations, redox depletions, and depleted matrices. In comparison to other groups of soils that contain redoximorphic features, Piedmont floodplain soils are generally saturated for a greater percentage of time than other soils showing similar amounts and types of redoximorphic features. This can easily lead to an incorrect hydrological interpretation from soil morphology.

One possible explanation for this occurrence is the age of the alluvial sediments on the floodplains. The upper 1 to 2 m is thought to have been deposited after colonial settlement; therefore these soils may not have had sufficient time to reach equilibrium with the present hydrology. Thus, longer periods of saturation are required in Piedmont floodplain soils to form redoximorphic features that are found in other soils of greater age.

V. Assessment of Hydric Soil Indicators for Mid-Atlantic Piedmont Floodplains

Introduction

Identification of wetlands became necessary with the implementation of section 404 of the Clean Water Act (Public Law 92-500, 33 U.S. Congress 1251). Under regulation of this Act, jurisdictional wetlands (wetland protected by law) can only be impacted (drained or filled) through permit from the U.S. Army Corps of Engineers (COE) (Soil Conservation Service, 1994). Wetlands are defined as habitats that maintain hydrophytic vegetation, wetland hydrology, and hydric soils (Cowardin et al., 1979; Tiner and Burke, 1995; Environmental Laboratory, 1987; Hamner, 1992). In order to identify an area as a wetland, these criteria must be observed (Environmental Laboratory, 1987; U.S. Department of Agriculture, 1994).

Certain soil morphological features, brought about by reduced conditions, can indicate the presence of a hydric soil. The *Corps of Engineers Wetland Delineation Manual* (Environmental Laboratory, 1987) placed technical limits on wetland hydrology, established protocols to identify hydrophytic plant communities, and provided a set of field indicators of hydric soils. Another set of field indicators has been developed by the National Technical Committee for Hydric Soils (NTCHS) (USDA-NRCS, 2002). The NTCHS indicators were designed mainly by scientists engaged in soil survey activities. Extensive field work suggests that these indicators correlate well with the occurrence of hydric soils (Vepraskas and Sprecher, 1997).

Hydric soil indicators are used to infer saturation and anaerobic conditions by the presence of a reduced soil environment. These USDA indicators have been regionalized for specialized use throughout the United States and can be modified for application in individual Land Resource Regions (LRR). Figure 1-2 shows that the Piedmont region of Maryland and northern Delaware are located in LRR S.

Soil scientists working in Maryland and Delaware have experienced some uncertainty while mapping soils on Mid-Atlantic Piedmont floodplains. Soil profiles described near the middle of the floodplain often appear drier than would be expected. The water table was repeatedly near the surface while the soil was being described, yet 2 chroma depletions and gleyed matrices were lower in the soil profile. Hydrophytic vegetation, such as skunk cabbage, was also covering the soils in question.

Many of the alluvial parent materials in the Piedmont physiographic province were deposited within the past 2,000 years and the upper portions of soil profiles may be much younger. Therefore, they may not have had sufficient time to form diagnostic redoximorphic features. Figure 1-3 shows a schematic of the cross section of a Piedmont floodplain. Soils located in the middle area on the floodplain are possible hydric soils, however redox features that have formed in these soils are not diagnostic in terms of identifying these soils as hydric. Three chroma matrix colors exist rather than depleted matrix colors that would be expected under the observed wetness conditions.

There is need to monitor the water table levels and redox potential in these areas in order to accurately delineate the wetland boundary on these floodplains while defining these soils as hydric or non-hydric. The objectives of the study were: 1) to evaluate the utility of the present field indicators in delineating hydric soils found on floodplains in the Mid-Atlantic Piedmont physiographic region and if necessary 2) to develop an alternate field indicator for hydric soils in these particular settings.

Materials and Methods

Study Area

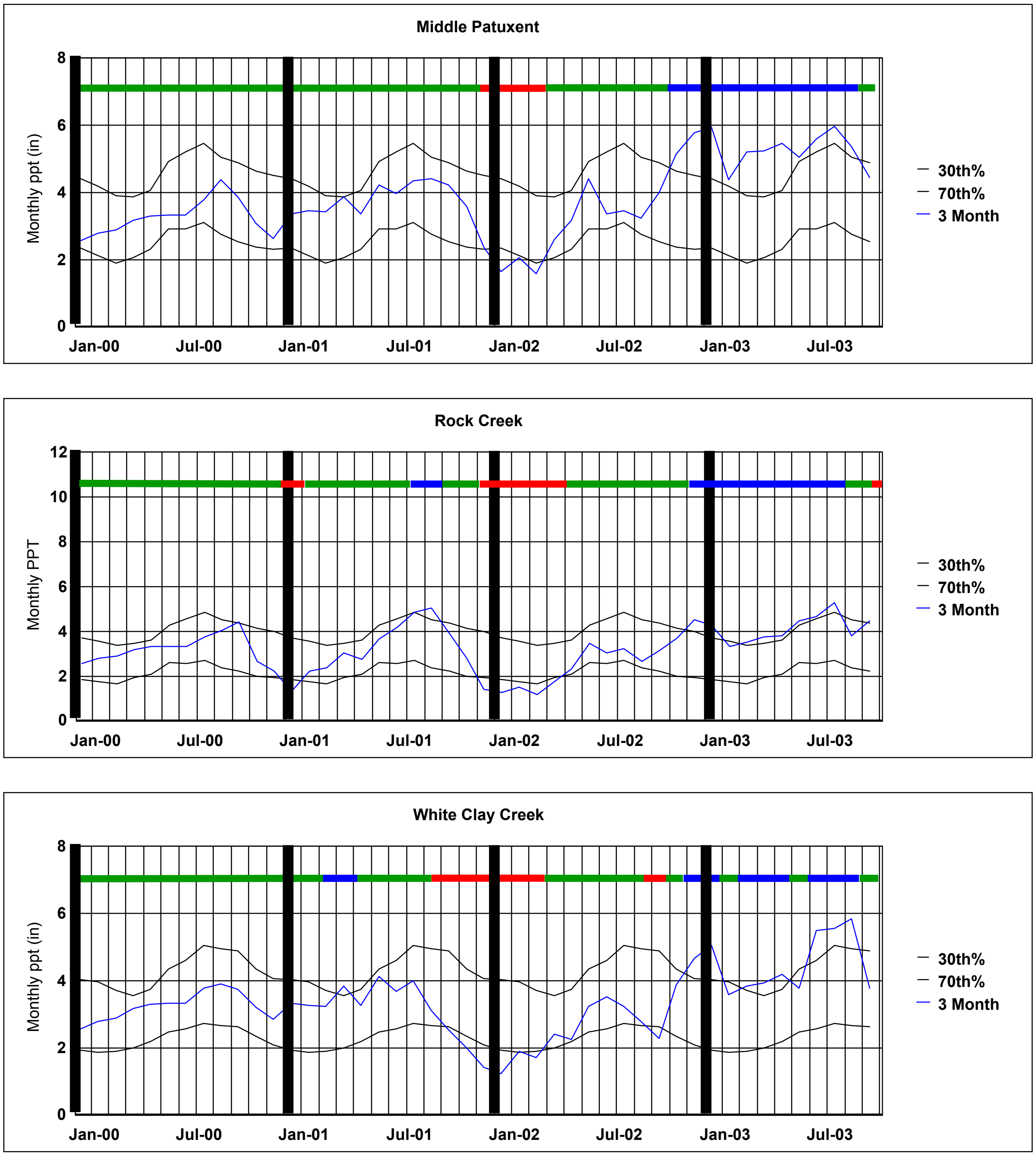
Three sites chosen for this study were situated in Montgomery and Howard Counties in Maryland and New Castle County in Delaware (Fig. 3-1). The site located in Montgomery County was along the North Branch of the Rock Creek. The site in Howard County was along the Middle Patuxent River, and the site in New Castle County was along White Clay Creek. These representative sites were selected based on a number of characteristics, including the low likelihood of human disturbance as well the presence of characteristic floodplain features, including a backswamp wetland and a natural levee.

A number of soil series are mapped on Mid-Atlantic Piedmont floodplains, spanning the full range of drainage conditions from poorly drained through well drained soils. The poorly drained Hatboro soils (fine-loamy, mixed, active, nonacid, mesic Fluvaquentic Endoaquepts) are often found adjacent to hillslopes, in the wet, backswamp area of the floodplain furthest from the stream, where groundwater discharges from the upland slope into the floodplain system. The moderately well drained Codorus soils (fine-loamy, mixed, active, mesic Fluvaquentic Dystrudepts) are generally located between the back swamp area and the natural levee. The well drained Comus soils (coarse-loamy, mixed, active, mesic Fluventic Dystrudepts) are commonly situated adjacent to the river on the natural levee.

In this study we examined soils along hydrosequence transects from wetter soils to drier soils, at each site (Fig. 1-3). The Middle Patuxent River and Rock Creek sites, in Maryland, each contained three monitoring stations, with one in the backswamp wetland (low position), another towards the middle of the floodplain (middle zone), and the third, closer to the river, nearer to, but not on, the natural levee (high zone). White Clay Creek, in Delaware, was similar but also contained an additional monitoring station in the backswamp wetland (low position).

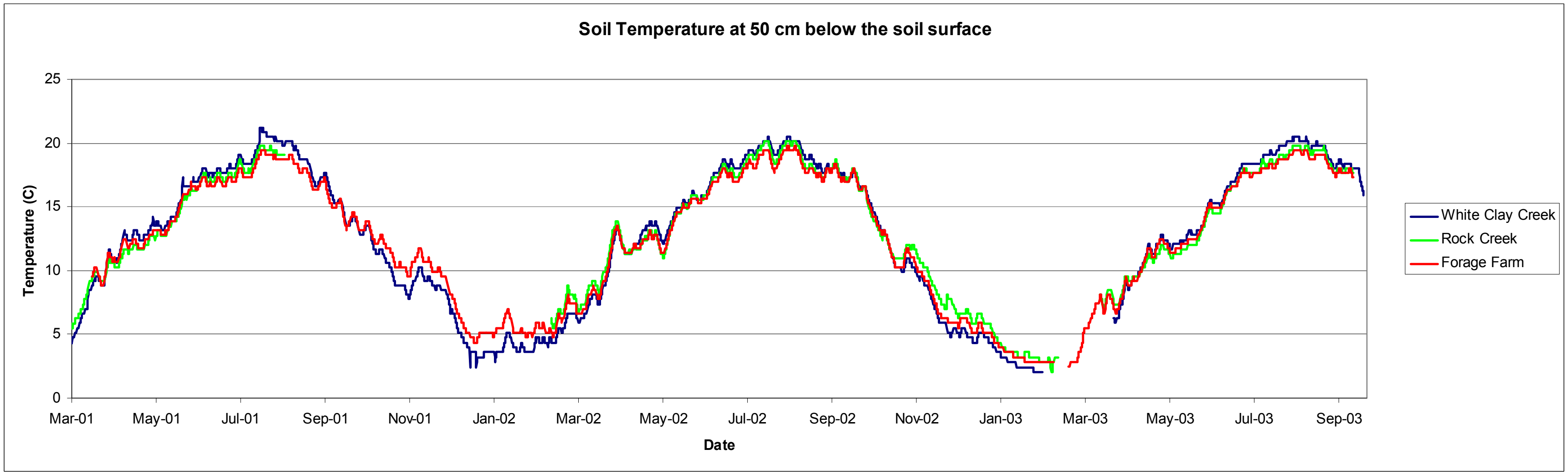
The average annual precipitation for the three study sites is approximately 42 in. (105 cm). The monthly average from October 2001 through March 2002 was generally below the 30th percentile and from April through September 2002 was within the average range (Fig. 5-1)(USGS, 2004). From October 2002 through December 2002 the rainfall was above the 70th percentile and in February, March, May, June, and July the rainfall was above the 70th percentile. January and April 2003 were within the average range. Figure 5-1 shows the deviation of these amounts in comparison to the 50 year average at the Middle Patuxent River, Rock Creek, and White Clay Creek.

Figure 5-1: Precipitation Data from the Middle Patuxent, Rock Creek, and White Clay Creek from January 2002 through August 2003. Annual gridlines are shown by black vertical lines. Thin black lines show the 30th and 70th percentile for normal precipitation. The blue lines indicate the running average of three months of data. The line across the top of the graph shows normal (green), below average (red), and above average (blue) precipitation.



The sites have a mesic temperature regime with an average air temperature of 12^{o}C, and soil temperatures at 50 cm below the surface drops near to or below 5^{o}C for about two months during the winter (Fig. 5-2).

Figure 5-2: Soil temperature measurements at 50 cm below the soil surface at the Middle Patuxent River (red), Rock Creek (green), and White Clay Creek (blue).



Field Procedures

Water table levels were monitored twice daily to a depth of 1.5 m at each of the ten monitoring stations using automatic monitoring wells. The water table data were collected from January 2000 through October 2003. Open auger holes were positioned adjacent to the automatic wells to ensure the automated wells were calibrated accurately throughout the year.

The station used for precipitation data at the Middle Patuxent River, was located 0.5 mi from the site at the University of Maryland Agricultural Research Forage Farm, Clarksville, Maryland. Precipitation data for Rock Creek, was measured in Rockville, Maryland, approximately 5 mi from the site. The precipitation data for White Clay Creek was obtained from the University of Delaware Farm, located 4 mi from the site.

Soil temperature was measured at the middle well along each transect. Loggers were used to record temperature five times daily at depths of 10, 30, and 50 cm below the soil surface. Batteries were changed and loggers were downloaded in March of each year.

Soil oxidation-reduction (redox) potential was measured adjacent to each well using platinum (Pt) electrodes inserted to depths of 10, 20, 30, 40, and 50 cm. A pilot hole was made with a thin steel rod to ensure the Pt tip was not damaged by inserting into soil. The Pt tip was inserted into the hole and pressed to make solid contact with the soil. Six electrodes were placed in a semi-circle around the calomel reference electrodes maintaining less than 30 cm between the Pt and reference electrodes. Redox potentials at each depth were measured with a digital multimeter combined with a KCl saturated calomel reference electrode. Redox measurements were converted to Eh values by adding a reference electrode conversion factor of 244 mV.

In order to predict the stability of Fe phases, pH measurements were also made at the same depths and intervals as redox measurements. pH was measured in the field on a 1:1 soil/water slurry using a pH meter. Redox potential and pH were recorded at each well, approximately every two weeks during the wet season and monthly during the dry season. These measurements were made December 2001 through August 2003 in order to obtain a data set for two entire dry-wet-dry cycles.

Soil pits were excavated at each site near the well location, and soil profiles were described and sampled by horizon (Soil Survey Staff, 1993). Samples were taken to the University of Maryland Pedology Lab to be air dried and crushed prior to physiochemical analyses.

Laboratory Analyses

Particle size analysis was performed on soil samples using the pipette method and the percentage of various sand sizes was measured by sieving (Gee and Bauder, 1986). pH was measured in the laboratory using 1:1 soil and water ratio (Thomas, 1996). Ten grams of air dried soil was added to 10 ml of distilled water, stirred, and let stand for 15 min. The pH meter was calibrated and used to measure pH. Soil organic carbon was determined via dry combustion with a LECO CHN-600 analyzer. Analysis for pH and organic carbon were run in duplicate.

Total “free” iron oxide content was measured using the citrate-bicarbonate-dithionite procedure (Loeppert and Inskeep, 1996). Samples were diluted 1:101 and analyzed by direct aspiration on the Atomic Absorption Spectrophotometer (Jenne et al., 1974).

Results and Discussion

Site and Soil Morphological Characteristics

Middle Patuxent River

The Middle Patuxent River site is located on the University of Maryland’s Research Forage Farm in Howard County, MD. The transect at this site is the shortest of the three sites, running 35 m in length from the Middle Branch of the Patuxent River to the wettest monitoring location (Fig. 5-3). The soil at the low well meets field indicator, F6, *redox dark surface* (USDA-NRCS, 2002)(Table 5-1). The soil at the middle location did not meet any of the field indicators of hydric soil. This soil possessed a considerable amount of redox concentrations, had a matrix color with chroma 3 to 4, and had no depletions in the upper 30 cm. The high well at this site also did not meet an indicator, having 4 chroma matrix colors and a small percentage of redox concentrations in the upper 30 cm.

Figure 5-3: Map showing the location of monitoring wells and sampling points near the Middle Patuxent River. Monitoring wells are indicated by small circles. Light blue lines indicate a subtle drainage system at the site, which carries water only during heavy rains.

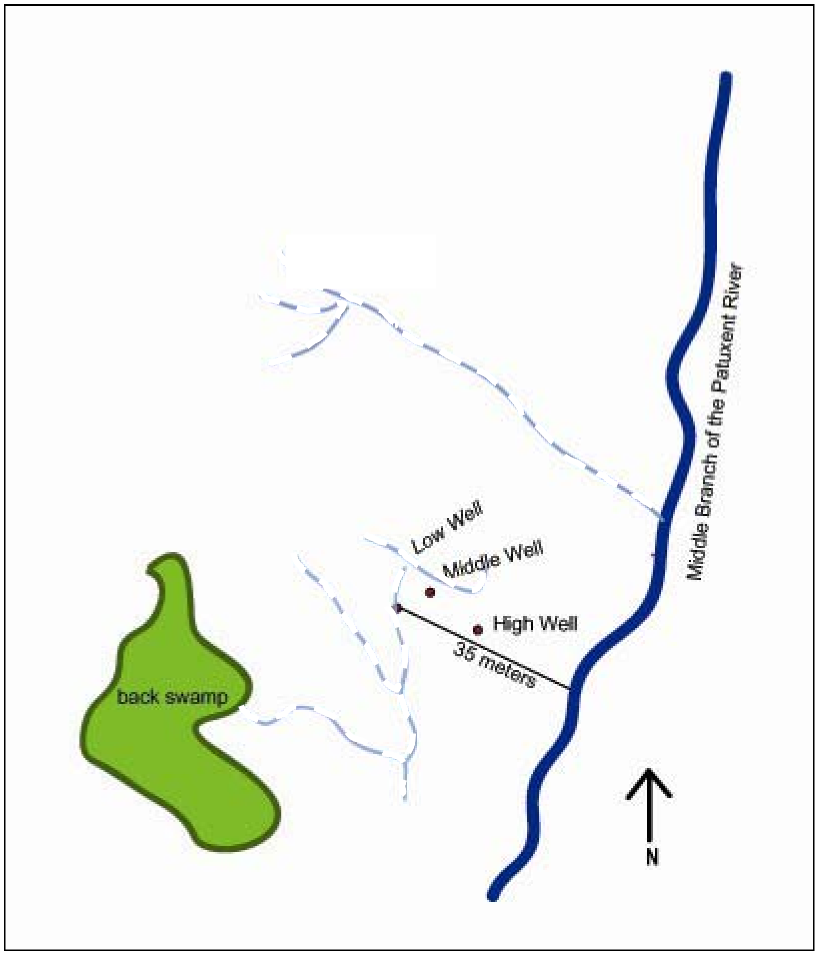


Table 5-1: Soil description of the low well at the Middle Patuxent River.

						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
Middle Patuxent Low (FF1)														
A1	0-7	cs	10YR 3/3	sil	12	30	2-3D	7.5YR 4/6	-	-	-	5.50	1F-MSbk	5.09
A2	7-25	as	5Y 3/2	sil	12	8	2P	5YR 4/6	-	-	-	6.17	1MSbk	4.63
Cg1	25-45	cs	5Y4/2	sil	10	-	-	-	-	-	-	3.66	0Ma	5.05
Cg2	45-77	cs	5Y 4/1	sil	14	-	-	-	-	-	-	1.48	0Ma	5.43
Cg3	77-96+	-	5Y 4/1	fsl	8	-	-	-	-	-	-	1.01	0Ma	5.70

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.
Soil classification: Coarse-loamy, mixed, active, mesic, Typic Fluvaquent

North Branch of the Rock Creek

The transect at Rock Creek runs 88 m in length from the North Branch of the Rock Creek to the wettest monitoring location (Fig. 5-4). The soil at the wettest location (low) at this site met hydric soil indicator F3, *depleted matrix* (USDA-NRCS, 2002)(Table 5-2) and was saturated to the surface for 50% of the year. The soil at the middle location did not meet a hydric soil field indicator, although it did exhibit many soft masses of Fe and Mn oxyhydroxides in the upper 30 cm and had 3 chroma matrix colors in the upper horizons. The soil at the driest (high) location along the transect did not meet an indicator of hydric soil, nor did hydrological measurements or vegetation suggest that this soil might be hydric. It maintained 4 chroma matrix colors and lacked significant redox concentrations within the upper 30 cm.

Figure 5-4: Map showing the location of monitoring wells and sampling points near the North Branch of the Rock Creek. Monitoring wells are indicated by small circles. Light blue lines indicate a subtle drainage system at the site, which carries water only during heavy rains.

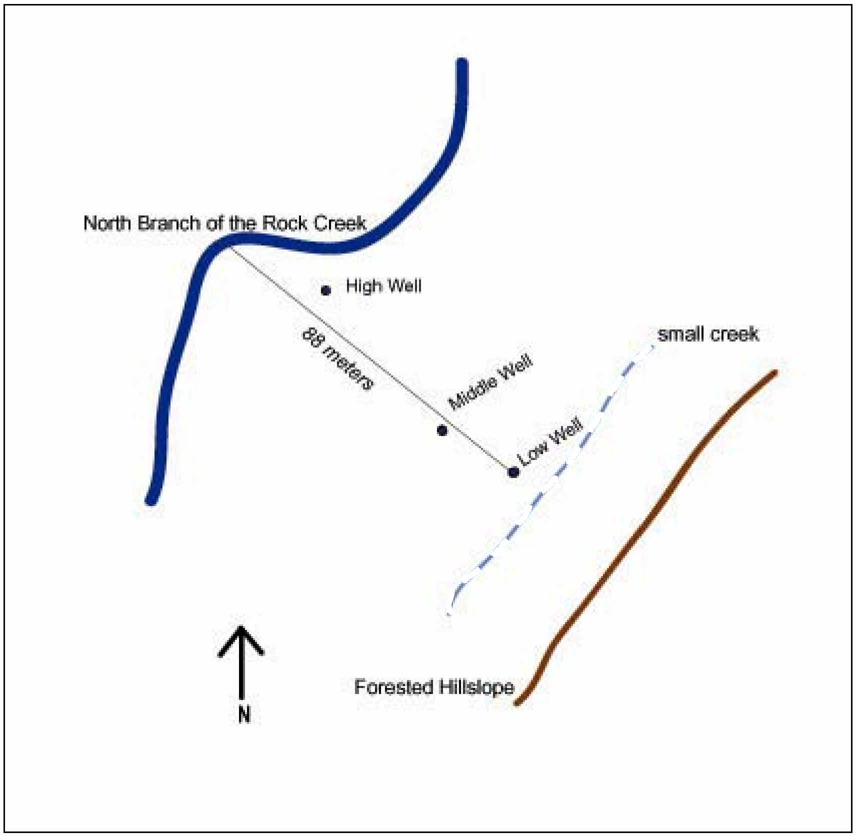


Table 5-2: Soil description* of the low well at Rock Creek.

						Redox features								
						Concentrations			Depletions					
Horizon*	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
Site 2-1 Rock Creek Low (RC1)														
Oe	2.5	as	7.5YR 4/3	-					-	-	-		-	-
Bg	66	cs	2.5Y 4/2	sil	26	10	2P	7.5YR 4,5/6	-	-	-		1-2M-CSbk	4.73
						2	2D	2.5YR 3/4						
Cg1	76	cs	2.5Y 4/1	sil	26	20	2P	7.5YR 4,5/6	-	-	-		1Pl	7.8
Cg2/Ab	102	cs	2.5Y 4/2	sil	26	10	2P	7.5YR 4,5/6	-	-	-		0Ma	5.03
			2.5Y2.5/1			3	2P	2.5YR 3/4						
Ab	160	cs	N 2.5	l	24	-	-	-	-	-	-		0Ma	4.86
Cg2	178	cs	5Y 5/1	fsl	4	10	3P	10YR 4/6	-	-	-		0Ma	5.43
			2.5Y 4/3											
C	183	-	2.5Y 5/3	s	1	4	3P	10YR 4/6	-	-	-		0Ma	5.23

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

*Soil described by Lenore Vasilas and Steve Burch, NRCS.

Soil classification: Fine-loamy, mixed, active, mesic, Typic Fluvaquent

White Clay Creek

The third site is situated in White Clay Creek State Park in New Castle County, Delaware. The floodplain at this site is the widest in this study, stretching approximately 200 m from White Clay Creek to the wettest monitoring well (Fig. 5-5). Rather than three wells, this transect included 4 monitoring wells. The soil at the wettest (low) location along the floodplain meets hydric soil indicator A10, *2cm muck* (USDA-NRCS, 2002)(Table 5-3). The soil at the low/mid well location meets hydric soil indicator F3, *depleted matrix* (USDA-NRCS, 2002)(Table 5-4). The water tables at these two locations persisted at or above the surface for 94% and 63% of the year respectively. The soil at the middle location, however, did not meet a hydric soil indicator even though the water table was near the surface for extended periods. The morphological characteristics in this soil were similar to those found in the soils at the middle well locations at the previous sites, with upper horizons having 3 chroma matrix colors and a substantial percentage of redox concentrations. As in the other two sites, the high well also did not meet an indicator of hydric soil. This soil had 4 chroma matrix colors near the surface.

Figure 5-5: Map showing the location of monitoring wells and sampling points near the White Clay Creek. Monitoring wells are indicated by small circles.

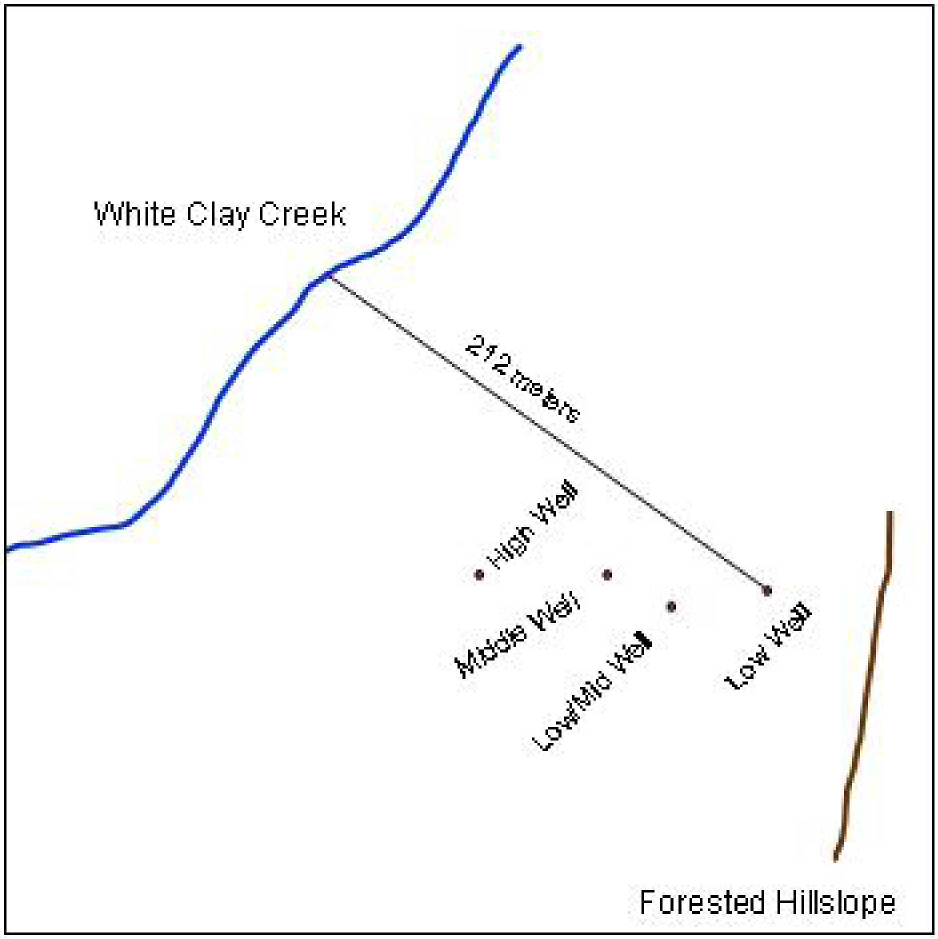


Table 5-3: Soil description of the low well at White Clay Creek.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	Cm				%	%			%			%		
						White Clay Creek Low (WC1)								
Oa	0-18	as	7.5YR 2.5/1	mu	ND	-	-	-	-	-	-	22.64	0Ma	
Cg1	18-65	cs	5Y 3/1	sil	19	-	-	-	-	-	-	2.069	0Ma	4.89
Cg2	65-90	cs	5Y 3/1	sil	19	-	-	-	-	-	-	1.801	0Ma	4.91
Cg3	90-150	-	5Y 3/1	sil	19	-	-	-	-	-	-	2.929	0Ma	4.92
Oab	150-195	-	7.5YR 3/2	mu	ND	-	-	-	-	-	-	24.895	0Ma	
Ab	195-235+	-	7.5YR 2.5/1	mul	ND	-	-	-	-	-	-	9.622	0Ma	4.91

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil Classification: Fine-loamy, mixed, active, mesic, Typic Hydraquent (n-value greater than 0.7)

Table 5-4: Soil description of the low/mid well at White Clay Creek.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
						White Clay Creek Low-Middle (WC2)								
A	0-7	aw	5YR 3/3	sil	15	25	2D	5YR 4/6	15	2-3D	2.5Y 3/1	5.659	1MSbk	4.92
Cg1	7-24	gs	5YR 4/1	l	15	10	2-3P	5YR 4/6	-	-	-	2.983	0Ma	4.58
Cg2	24-49	gs	5YR 4/1	sil	15	25	1-2P	7.5YR 4/6	-	-	-	1.67	0Ma	4.68
						25	1-2P	5YR 4/6						
Cg3	49-89	cs	5YR 4/1	l	10	-	-	-	-	-	-	1.438	0Ma	5
Cg4	89-105	as	5YR 4/1	sil	15	-	-	-	-	-	-	1.57	0Ma	4.69
Ab	105-112	as	N2.5	musil	29	-	-	-	-	-	-	9.69	1FSbk	4.76
Oab	112+	-	7.5YR 2.5/1	mu	ND	-	-	-	-	-	-	25.01	0Ma	

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil Classification: Coarse-loamy, mixed, active, mesic, Typic Fluvaquent

Middle Well Locations

Based on hydrological measurements, the soils at these middle locations along the floodplain appear to be hydric (Fig. 5-6). The graphs in figure 5-7 show the percentage of time that water tables were observed at or above a given depth. Because these are loamy soils, the primary zone of interest is the upper 30 cm. During the period of study, the water tables were within 30 cm of the surface for 59%, 60%, and 76% of the year for the Middle Patuxent River, Rock Creek, and White Clay Creek sites respectively.

Figure 5-7: Cumulative frequency distribution of the water table at the middle well locations at the Middle Patuxent River, Rock Creek, and White Clay Creek.

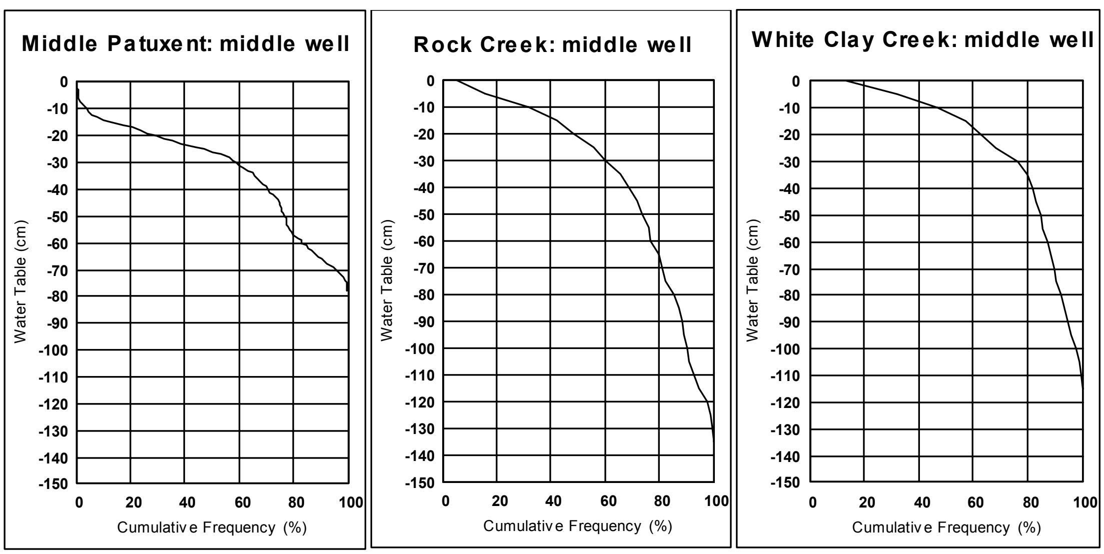
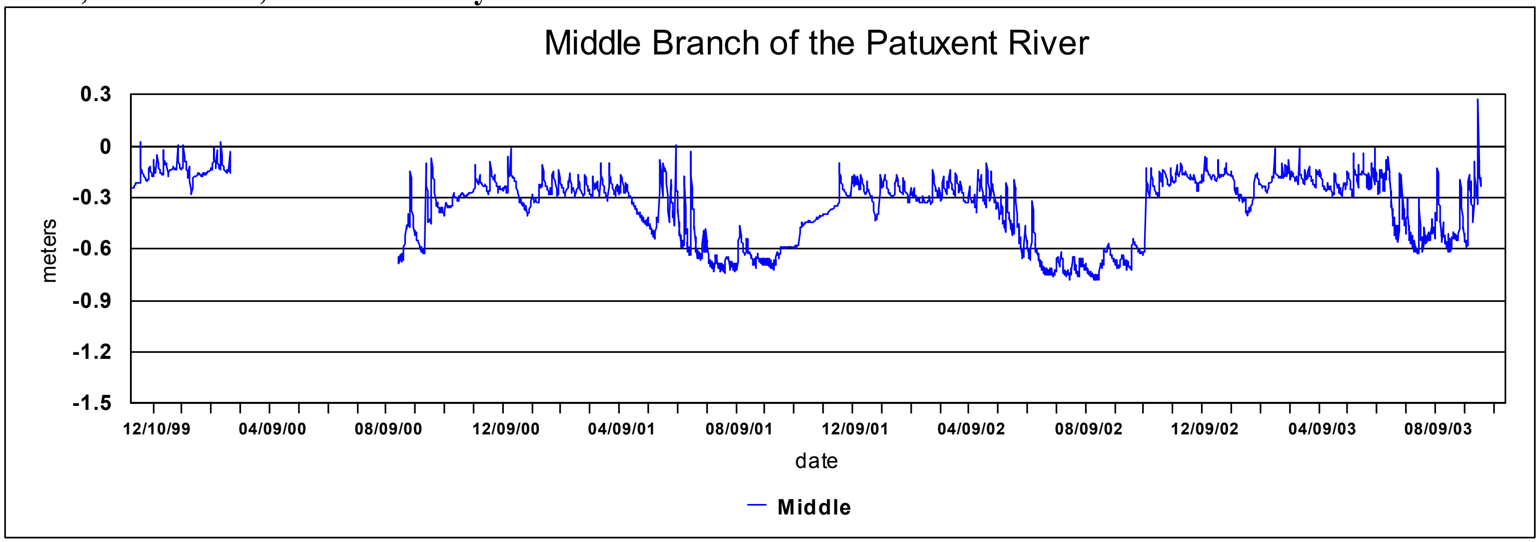
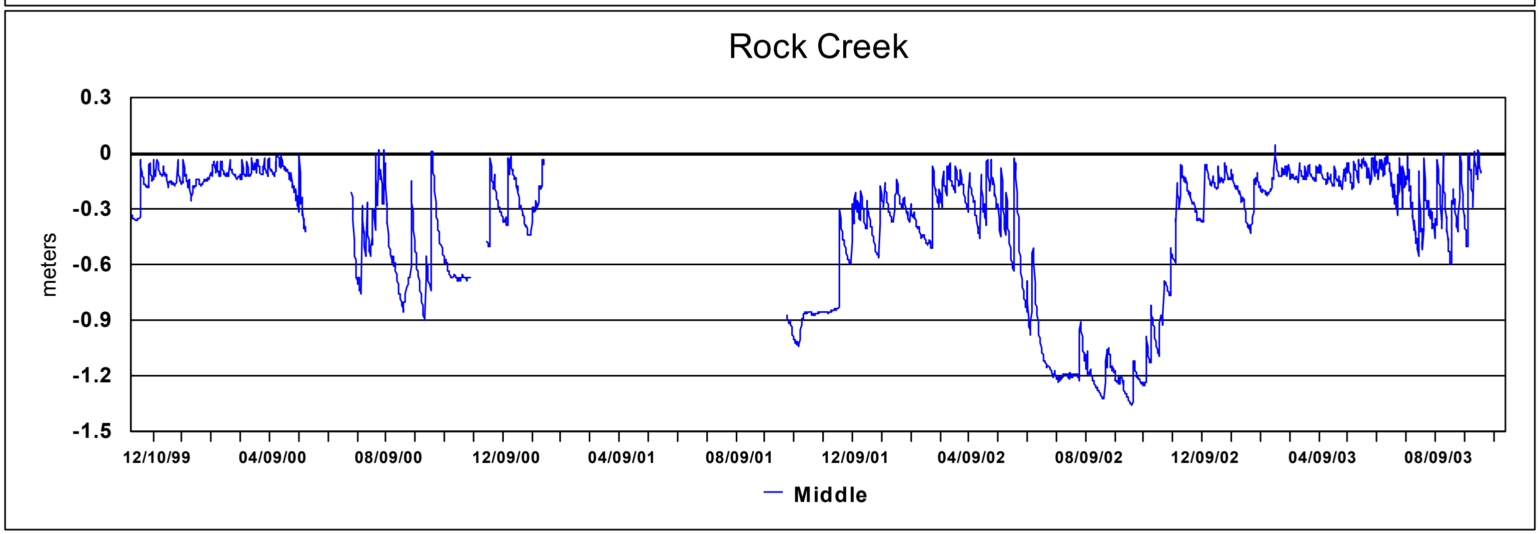
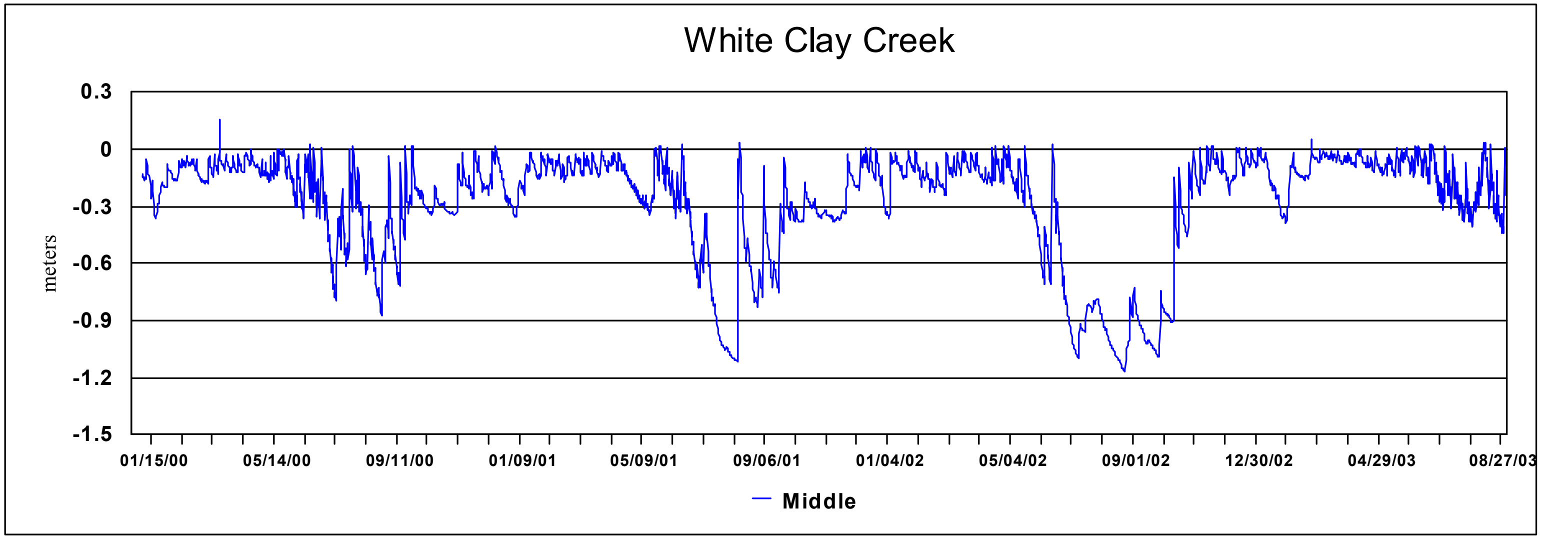


Figure 5-6: Water Table Data between December 1999 and October 2003 at the middle well locations at the Middle Patuxent River, Rock Creek, and White Clay Creek.






White Clay Creek
0.3
0
-0.3
-0.6
-0.9
-1.2
-1.5
meters
01/15/00
05/14/00
09/11/00
01/09/01
05/09/01
09/06/01
01/04/02
05/04/02
09/01/02
12/30/02
04/29/03
08/27/03
Middle

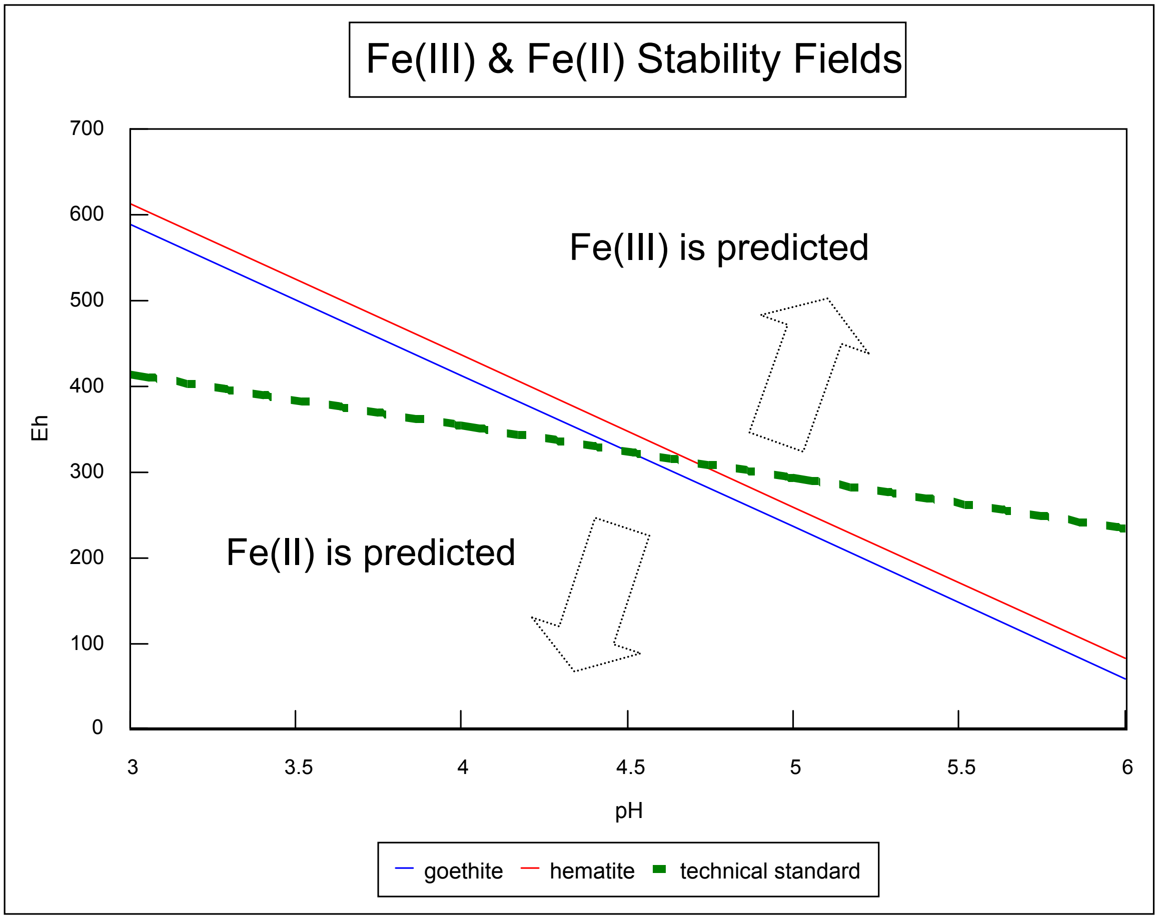
Biogeochemical Characteristics

In order to confirm that a soil meets the technical definition of a hydric soil, a saturated and reduced soil environment must be observed for 14 consecutive days in the upper part (at or above 25 cm for all soils except sand) during the growing season for one out of two years, providing they are normal years (USDA-NRCS, 2002). Normal is characterized as a year with precipitation levels between the 30^{th} and 70^{th} percentile from the average. From October 2001 through November, 2002, the precipitation was generally below the 30^{th} percentile, while from December 2002 through June 2003, the precipitation was above the 70^{th} percentile (Fig 5-1). Therefore, during the wet season in 2002, the precipitation levels were below normal and during the wet season in 2003, the precipitation levels were above normal.

A technical standard was developed by the National Technical Committee for Hydric Soil that can be used to determine whether or not a soil is hydric, in cases where a soil does not meet one of the approved field indicators of hydric soils. It can also be used to evaluate and test new or potential field indicators of hydric soils. This technical standard includes provisions regarding height and duration of water table levels and also values of measured redox potentials (and pH). If Eh and pH of a soil are below the line described by the equation: $Eh = -60\ pH + 595$, then the soil is considered to be reduced.

The soil pH values at the middle well locations generally ranged between 4 and 5. Therefore, based on the above equation, the Eh at which Fe(III) would be reduced to Fe(II) was between 295 and 350 mV (depending on soil pH). Figure 5-8 is an Eh/pH diagram showing the stability fields of two common iron bearing minerals, goethite and hematite. The dotted line shows the line defined by the equation: Eh = -60 pH + 595, for the technical standard.

Figure 5-8: Fe(III) and Fe(II) stability fields for goethite (blue) and hematite (red)(assumed Fe activity of 10^{-6} M). Also shown is the line of the equation from the technical standard (dotted green).



Based on the technical standard, the soils at the wettest location along the floodplains (low and low/mid) were reduced within 10 cm of the surface for the majority of the study (data in Appendix F). The soil morphology, hydrology, and redox potential indicate that these soils are undoubtedly hydric soils.

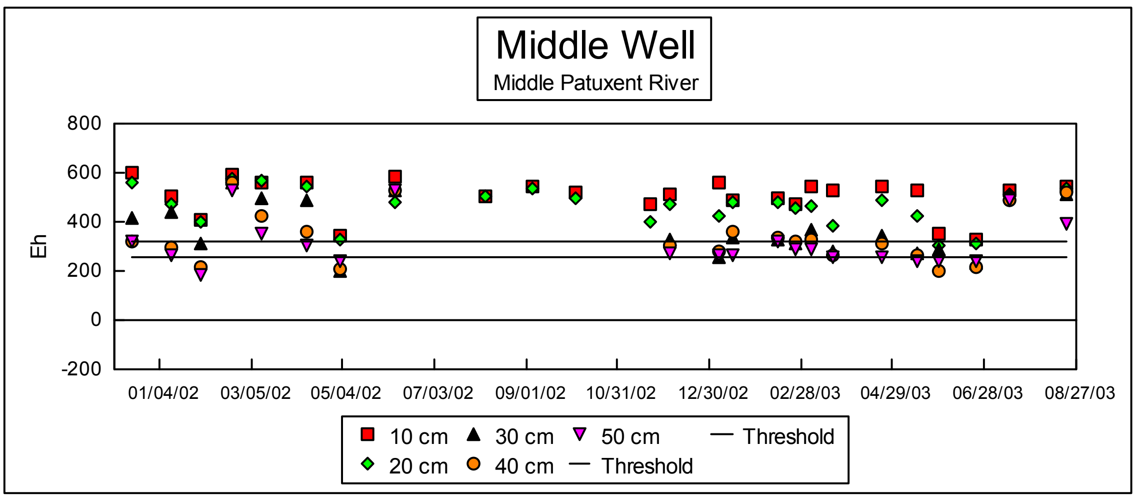
The soils in the driest locations (high) along the floodplain occasionally had Eh values at depths of 40 and 50 cm that plotted below the technical standard line, but that was mainly during the extremely wet year, 2003. Eh measurements within 30 cm of the soil surface never were observed in the Fe(II) stability field throughout the entire monitoring period. Consequently, these soils in the high zones clearly did not meet the technical standard for hydric soils (data in Appendix F). The water table measurements in these soils also confirmed their designation as non-hydric soils.

Soil at Middle Wells

The redox potentials measured in the soils at the middle well locations showed distinct seasonal trends. Measurements in the soil near the middle well at the Middle Patuxent River site indicated that the soil is not reduced at depths of 10 and 20 cm for any significant periods during 2002 or 2003 (Fig. 5-9). During the dry year, 2002, the redox potential at 30 cm was below 295 mV on two separate occasions, but because these were not consecutive measurements, reduced conditions can not be assumed to have persisted for 14 days. During the wet year, 2003, the soil at 30 cm was reduced for approximately 20 days early in the year and again for 55 days, which is much longer than the necessary 14 days based on the technical standard. Since saturated and reduced conditions are required in one out of two years with normal precipitation, we cannot yet conclusively state whether or not this soil met the technical standard without looking more closely at water table data from past years with normal precipitation levels.

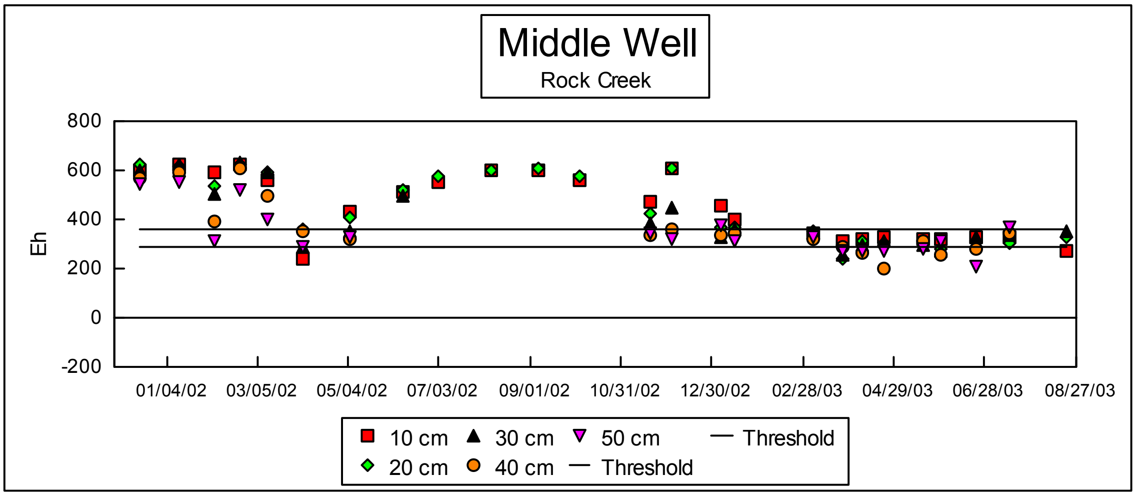
Using the model introduced in the previous chapter (Fig. 3-11), water table data from a year with normal precipitation (Fig. 3-14) was examined for periods of saturation. Number of days saturated at 30 cm was then used to estimate the length of time the soil redox potential was below the technical standard. This site was saturated at or above 30 cm for 50 and 65 day periods. Therefore, this site was reduced, below the technical standard, for greater than the required 14 consecutive days, making it a hydric soil.

Figure 5-9: Soil redox potential from the middle well at the Middle Patuxent River. Points represent the average of six electrodes. Solid black lines represent the values below which the iron present in the soil is predicted to be reduced and are based on the equation for the technical standard using pH values representing the range measured in the soil.



At the middle site at Rock Creek, the soil redox potential measurements were below the stability line at all depths from March through August of 2003, but only in April of 2002, which was the dry year (Fig. 5-10). During 2002, the redox potential at 30 cm was below the technical standard for approximately 45 days, however, during 2003, the soil at 30 cm was below the technical standard for more than 140 days.

Figure 5-10 Soil redox potential from the middle well at Rock Creek. Points represent the average of six electrodes. Solid black lines represent the values below which the iron present in the soil is predicted to be reduced and are based on the equation for the technical standard using pH values representing the range measured in the soil.



To ensure that the redox measurements of the soil were below the technical standard line, data from individual dates were plotted on Eh/pH diagrams (Figure 5-11, 5-12, 5-13). Based on figures 5-11, 5-12, and 5-13, the redox potential at 30 cm was below the technical standard for all measurements, and is reasonably assumed to remain below for the duration between these dates.

Figure 5-11: Eh/pH diagram with data from the middle location at Rock Creek on April 8, 2003. Arrow is pointing to 30 cm.

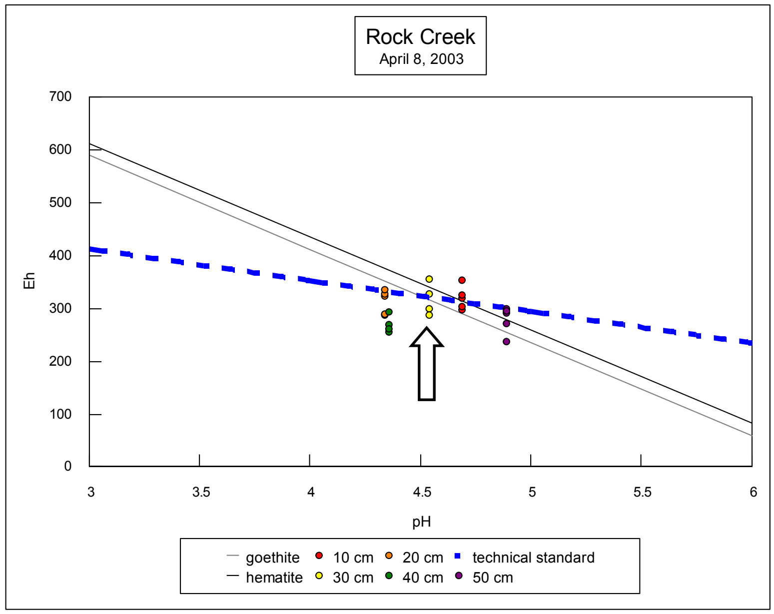


Figure 5-12: Eh/pH diagram with data from the middle location at Rock Creek on May 30, 2003. Arrow is pointing to 30 cm.

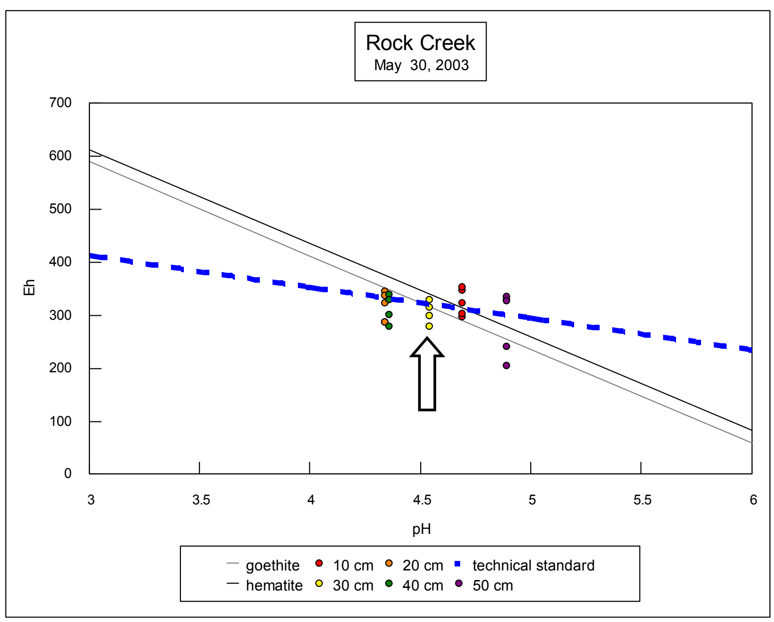
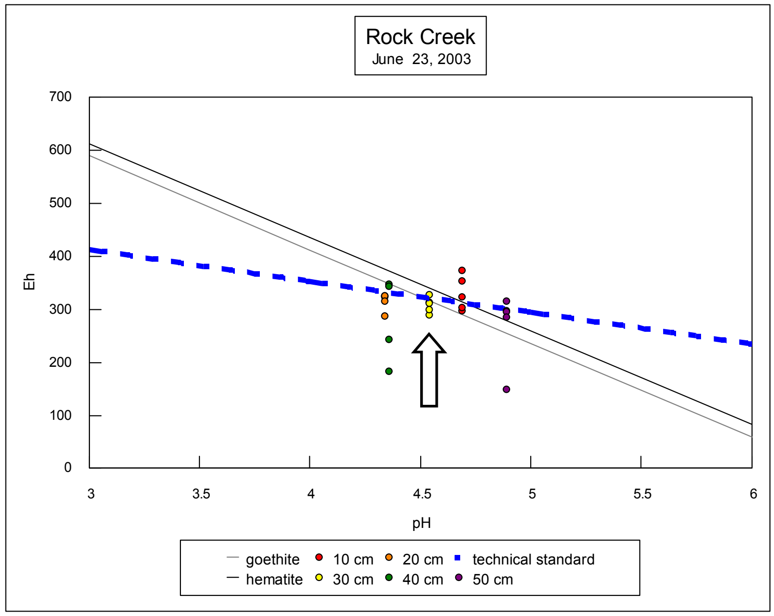
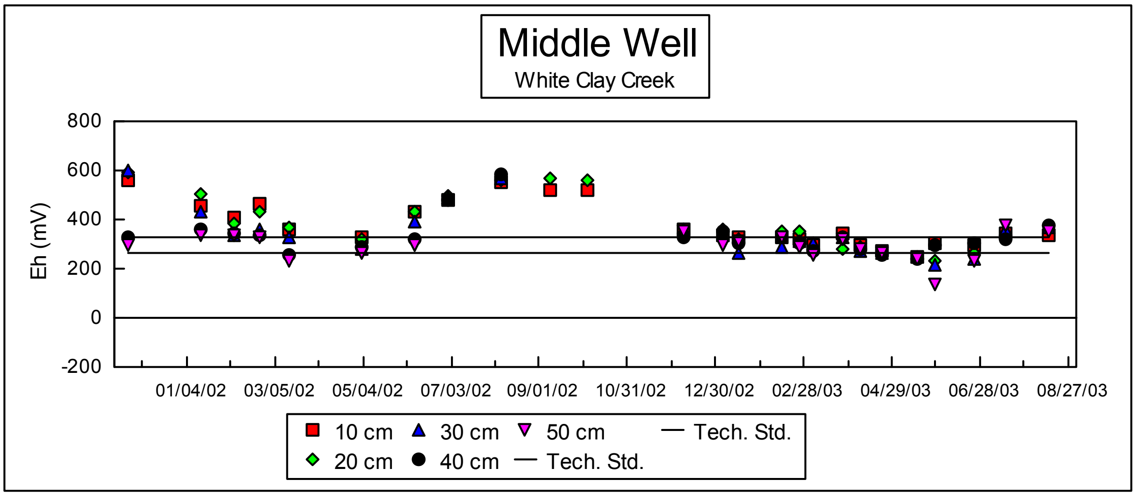


Figure 5-13: Eh/pH diagram with data from the middle location at Rock Creek on June 23, 2003. Arrow is pointing to 30 cm.



The redox potential at the middle well at White Clay Creek shows that the soil was below the technical standard line for reduced iron at 40 and 50 cm for more than 100 days during 2002 and 2003 (Fig. 5-14). At 30 cm, redox potential was below 295 mV for approximately 75 days during 2002. During 2003, the redox potential was below the technical standard at 30 cm for greater than 90 days, which is far longer than the required 14 days.

Figure 5-14: Soil redox potential from the middle location at White Clay Creek. Points represent the average of six electrodes.



Measurements from individual dates were plotted on Eh/pH diagrams to be certain that the redox potential was below the technical standard line. Figure 5-15, 5-16, and 5-17 show that the measured values at 30 cm were in fact below the technical standard line.

Figure 5-15: Eh/pH diagram with data from the middle location at White Clay Creek on April 08, 2003. Arrow is pointing to 30 cm.

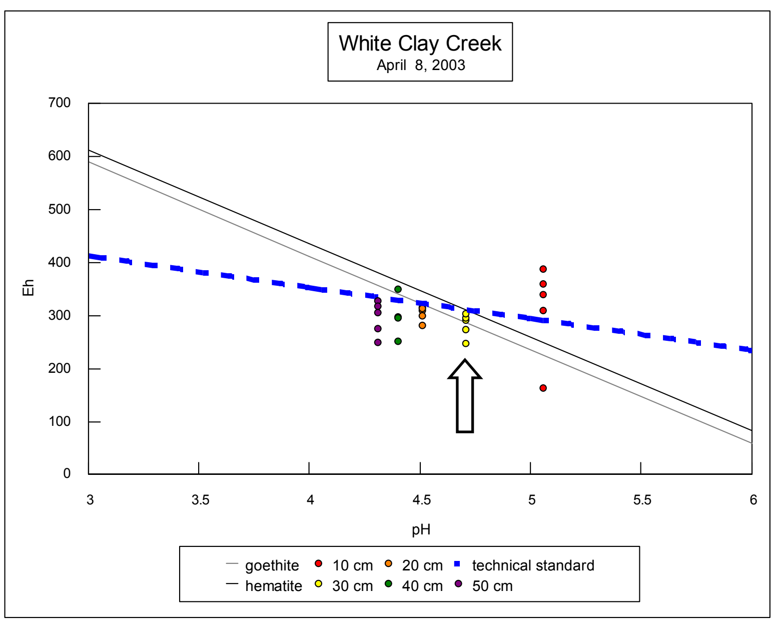


Figure 5-16: Eh/pH diagram with data from the middle location at White Clay Creek on May 29, 2003. Arrow is pointing to 30 cm.

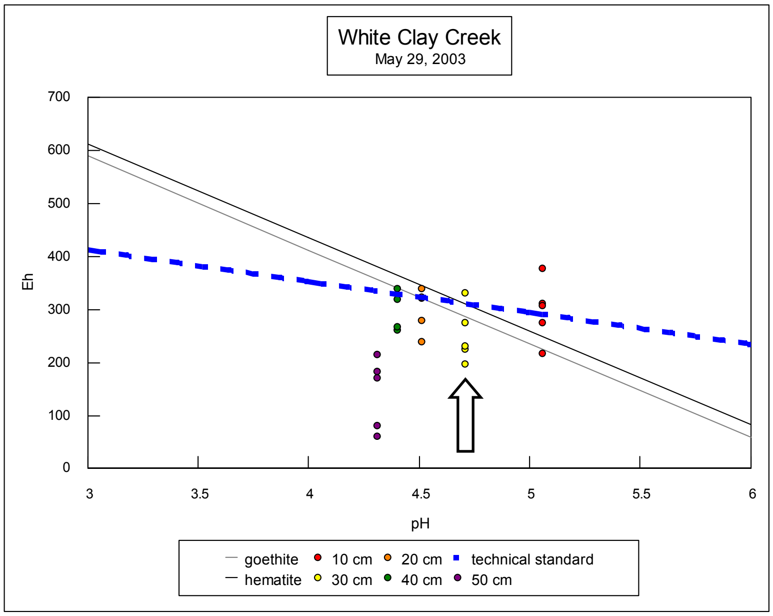
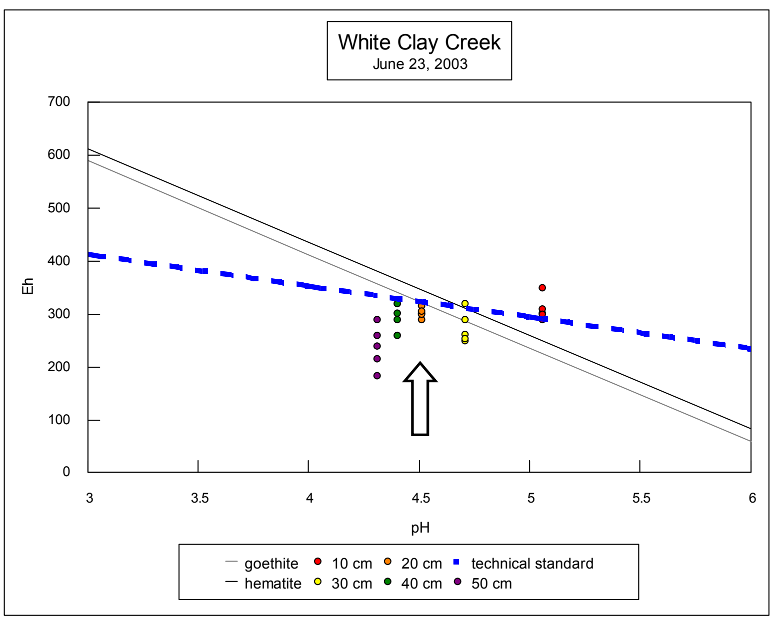


Figure 5-17: Eh/pH diagram with data from the middle location at White Clay Creek on June 24, 2003. Arrow is pointing to 30 cm.



Field Indicator of Hydric Soil

Based upon the data collected, the soils at each of the middle sites along these floodplains met the technical standard, and therefore are hydric. None of these soils, however, meets any of the Field Indicators for Hydric Soil. Therefore, an attempt was made to identify soil morphological features that would be proof positive as a field indicator for these hydric soils located on Piedmont floodplains. Careful examination of the profile description shows that each soil has a horizon within 21 cm of the surface that has 3 chroma matrix colors. In this horizon there is also an abundance (greater than 25%) of distinct and prominent concentrations of iron and manganese oxyhydroxides. Table 5-5 summarizes those features present in each pedon located at the middle locations along the transects.

Table 5-5: Soil descriptions of the upper 50 cm at the middle wells. Based on redox potential and water table data, these soils are hydric. Common redox features among these profiles include 3 chroma matrix colors and an abundance of distinct and prominent redox concentrations.

			Concentrations		
Horizon	**Depth (cm)**	**Color**	**Abundance (%)**	**Contrast***	**Color**
			Middle Patuxent River Middle Well		
A	0-7	10YR 4/3	8	f	7.5YR 4/6
			2	p	N2
BA	7-20	10YR 4/4	10	f	7.5YR 4/4
			3	p	N2
Bw1	20-41	2.5Y 4/3	15	d-p	7.5YR 4/6
			10	d-p	7.5YR 5/8
Bw2	41-61	2.5Y 4/3	15	p	5YR4/6
			15	d	7.5YR 4/6
			2	p	N2
			Rock Creek Middle Well		
A	0-15	10YR 4/3	20	d	7.5YR 4/4
			5	p	5YR 2.5/2
Bw1	15-35	10YR 4/3	20	d	7.5YR 4/6
			5	p	2.5YR 3/6
			3	p	5YR 2.5/2
Bw2	35-56	10YR 4/2.8	10	d	7.5YR 3/4
			15	p	2.5YR 2.5/4
			1	p	5YR 2.5/2
			White Clay Creek Middle Well		
A	0-12	2.5Y 3/3	15	p	7.5YR 4/6
			1	p	5YR 2.5/1
BA	12-25	10YR 4/3	25	d	7.5YR 4/6
			3	p	N2
Bw1	25-51	10YR 4/3	20	p	7.5YR 5/6
			10	d-p	5YR 3/3
			6	p	N2

* Contrast: f, faint; d, distinct; p, prominent

Alternate Field Indicator of Hydric Soil

Because these soils meet the technical standard based on both saturation and redox potential, but do not meet a field indicator of hydric soil, an alternate field indicator is proposed in order to accurately identify these soils as hydric. The following indicator is proposed for use with soils located on frequently flooded floodplains in the Mid-Atlantic Piedmont physiographic province (MLRA S).

> *A zone at least 15 cm thick, starting within 25 cm of the soil surface with 60% or more of the soil with Munsell chroma of 3 or less, containing 20% or more distinct or prominent redox concentrations of Fe and/or Mn oxyhydroxides.*

The soil at the middle location along the floodplain at the Middle Patuxent River has a matrix color of 2.5Y 4/3 starting at 20 cm (Table 5-6). This horizon is 21 cm thick and has a total of 25% distinct and prominent redox concentrations of iron; therefore, it meets this proposed indicator. The soil at the middle location at Rock Creek has a matrix color of 10YR 4/3 starting at the soil surface (Table 5-7). The combined thickness of these 3 chroma horizons is 56 cm and has between 25% and 28% distinct and prominent redox concentrations in each horizon; therefore, this soil also meets the proposed field indicator. The soil at the middle location at White Clay Creek has a matrix color of 10YR 4/3 starting at 12 cm (Table 5-8). This BA horizon, when combined with the Bw1 horizon with the same color, has a combined thickness of 39 cm. These horizons have between 28% and 36% redox concentrations; as a result, this soil also meets the proposed field indicator.

Three chroma matrix colors have not developed in the soil at the high location along the floodplain at the Middle Patuxent until 49 cm below the soil surface (Table 5-9). Consequently, this soil does not meet the proposed indicator. At Rock Creek, the soil at the high location shows 3 chroma matrix colors beginning at 37 cm (Table 5-10). This 40 cm thick horizon only has 18% redox concentrations. Since the horizon fails to occur above 25 cm and does not have more than 20% concentrations, this soil does not meet the proposed field indicator. The soil at the high well at White Clay has 3 chroma colors and 18% redox concentrations beginning at 43 cm below the soil surface (Table 5-11). Because this horizon is not within 25 cm and does not have sufficient redox concentrations, this soil does not meet the proposed field indicator.

The alternate field indicator proposed for soils on Piedmont floodplains include as hydric, those soils in the middle locations, but excludes those soils located in the drier locations. Because this proposed indicator successfully discriminates between soils which did not meet the technical standard, this indicator appears to be proof positive for these landscapes.

Table 5-6: Soil description of the middle well at the Middle Branch of the Patuxent River.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
						Middle Patuxent Middle (MP2)								
A	0-7	cs	10YR 4/3	sil	14	8	3F	7.5YR 4/6	-	-	-	2.10	1MGr	4.71
						2	1P	N2						
BA	7-20	cs	10YR 4/4	sil	15	10	3F	7.5YR 4/4	-	-	-	1.66	1MSbk	3.92
						3	1P	N2						
Bw1	20-41	cs	2.5Y 4/3	l	18	15	2-3P	7.5YR 4/6	-	-	-	0.58	2M-CSbk	5.60
						10	2-3P	7.5YR 5/8						
Bw2	41-61	cs	2.5Y 4/3	sl	12	15	2-3P	5YR4/6	-	-	-	0.41	1CSbk	5.80
						15	2-3D	7.5YR 4/6						
						2	1P	N2						
Bw3	61-80	cs	2.5Y4/3	sil	12	15	2-3P	7.5YR 5/8	5	2-3D	5Y 4/1	0.89	1M-CSbk	5.66
						10	3P	2.5YR 5/8						
						5	3P	5YR 3/3						
						3	1P	N2						
Cg	80-104	cs	10Y 5/1	fsl	10	5	2-3P	7.5YR 5/8	-	-	-	0.26	0Ma	4.82
Ab1	104-121	cs	5GY 3/1	fsl	10	4	1F	7.5YR 4/4	-	-	-	0.34	1CSbk	4.38
Ab2	121-132	-	2.5Y 2.5/1	fsl	10		-	-	-	-	-	1.68	1CSbk	4.33

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil classification: Coarse-loamy, mixed, active, mesic, Fluvaquentic Dystrudept

Table 5-7: Soil description of the middle well at the North Branch of Rock Creek.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
Site 2-2 Rock Creek Middle (RC2)														
A	0-15	cs	10YR 4/3	sil	16	20	1D	7.5YR 4/4	-	-	-	1.67	1-2sbk	5.00
						5	1P	5YR 2.5/2					1-2abk	
Bw1	15-35	cs	10YR 4/3	sil	21	20	1-2D	7.5YR 4/6	-	-	-	0.87	2fsbk	5.02
						5	1P	2.5YR 3/6						
						3	1P	5YR 2.5/2						
Bw2	35-56	gs	10YR 4/2.8	sil	18	10	1D	7.5YR 3/4	8	2D	2.5Y 5/2	0.67	1-2fsbk	4.97
						15	2P	2.5YR 2.5/4						
						1	1P	5YR 2.5/2						
Bg	56-79	cs	2.5Y 5/2	sil	18	14	1-2P	7.5YR 4/6	5	1F	2.5Y 5/1	0.94	1-2fsbk	4.76
						12	1-2P	5YR 3/4						
AB	79-93	cs	10YR 3.5/2	sil	18	10	1P	7.5YR 3/4	-	-	-	1.24	1-2csbk	4.58
						5	2D	10YR 4/4						
Ab1	93-104	cs	10YR 2/1	sil	18	4	1D	7.5YR 3/3	-	-	-	1.94	2fsbk	4.57
Ab2	104-135	+	10YR 2/1	sil	18	4	1D	7.5YR 3/3	-	-	-	3.09	1-2csbk	4.65

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil classification: Fine-loamy, mixed, active, mesic, Fluvaquentic Dystrudept

Table 5-8: Soil description of the middle well at White Clay Creek.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
Site 3-3+A101 White Clay Creek Middle-High (WC3)														
A	0-12	cs	2.5Y 3/3	l	13	15	1-2P	7.5YR 4/6	1	2F	5Y 5/2	3.28	1MSbk	4.73
						1	2P	5YR 2.5/1						
BA	12-25	gs	10YR 4/3	l	13	25	1-2D	7.5YR 4/6	2	2F	2.5Y 4/2	1.18	1MSbk	4.88
						3	1-2P	N2						
Bw1	25-51	cs	10YR 4/3	l	14	20	2P	7.5YR 5/6	10	2F	2.5Y 4/2	0.89	1F-MSbk	4.94
						10	2D	5YR 3/3						
						6	1-2P	N2						
Bw2	51-76	cs	10YR 4/3	l	13	20	3P	7.5YR 4/6	20	2F	2.5Y 4/2	0.81	1F-MSbk	4.89
						10	2P	5YR 3/3						
Bw3	76-104	cs	2.5Y 4/2.5	l	15	25	2P	5YR 4/6	25	2-3F	2.5Y 4/1	1.03	2MSbk	4.61
						5	2P	5YR 3/4						
Bg	104-116	as	2.5Y 4/2	sil	21	15	2-3P	7.5YR 4/6	-	-	-	1.31	2F-MSbk	4.60
			2.5Y 4/1			5	2-3P	5YR 2/1						
Oab1	116-156	as	10YR 2/1	mu	-	-	-	-	-	-	-	22.69	0Ma	
Oab2	156-176		'.5YR 2.5/2	mu	-	-	-	-	-	-	-	23.96	0Ma	
Ab	176-186+		10YR 3/1	sl	21	-	-	-	-	-	-	7.08	1M-CSbk	4.54

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil classification: Coarse-loamy, mixed, active, mesic, Fluvaquentic Dystrudept

Table 5-9: Soil description of the high well at the Middle Branch of the Patuxent River.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
Middle Patuxent High (MP3)														
A	0-7	as	10YR 4/4	sil	14	-	-	-	-	-	-	3.093	1MGr	3.85
BA	7-15	cs	10YR 5/4	sil	14	-	-	-	-	-	-	1.913	1MSbk	3.71
Bw1	15-25	cs	10YR 5/4	sil	17	4	1D	7.5YR 4/6	-	-	-	1.38	2MSbk	3.83
Bw2	25-49	cs	10YR 5/6	sil	17	25	1-2D	7.5YR 4/6	-	-	-	0.89	2MSbk	4.29
Bw3	49-80	cs	10YR 4/3	sil	18	40	2D	7.5YR 4/6	10	2F	2.5Y 5/3	0.56	2M-CSbk	5.30
						3	1P	N2						
Bg1	80-111	cs	2.5Y 5/1	l/sil	20	30	1-2P	2.5YR 3/6	-	-	-	0.37	2M-CSbk	5.45
						10	1-2P	7.5YR 4/6						
						1	1P	N2						
Bg2	111-130	as	5Y4/1	sil	23	20	2P	10YR 4/6	-	-	-	0.41	2M-CSbk	5.46
						10	2P	7.5YR 3/4						
						5	2D	2.5Y 4/3						
2Ab	130-150	as	2.5Y 3/1	sl	10	-	-	-	-	-	-	1.66	1CSbk	4.98
3C	150+	-	ND	vgrlcos	ND	-	-	-	-	-	-	ND	ND	ND

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil classification: Fine-loamy, mixed, active, mesic, Fluvaquentic Dystrudept

Table 5-10: Soil description of the high well at Rock Creek.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
Rock Creek High (RC3)														
A	0-12	gs	10YR 4/4	sil	15	-	-	-	-	-	-	1.56	1-2MSbk	4.07
Bw1	12-37	gs	10YR 4/4	sil	19	-	-	-	-	-	-	0.81	1-2MSbk	4.24
Bw2	37-76	cs	10YR 4/3	sil	15	15	1D	7.5YR 3/4	-	-	-	0.54	1CPr	4.69
						3	1P	N2	-	-	-			
BC	76-88	cs	10YR 4/3	l	15	30	1D	7.5YR 3/4	5	2D	2.5Y 5/2	0.54	1-2CSbk	4.77
2Cg	88-129		2.5Y 5/2	fsl	16	25	2D	10YR 5/4	10	2D	2.5Y 6/1	0.14	1MSbk	4.80
						8	1P	10YR 4/6						
2C	129-160	-	10YR 5/4	sl	4	5	1D	7.5YR 6/4	20	2P	2.5Y 6/1	0.06	-	4.93
2C2	160-190	-	7.5YR 4/3	ls	7	-	-	-	3	1P	2.5Y 6/2	0.08	-	5.19
3C3	190-200+	-	7.5YR 4/6	vgcosl	7	30	1D	7.5YR 5/8	1	1P	5Y 4/3	0.08	-	5.19
						1	1P	5YR 3/4						

Boundary: as, abrupt smooth; aw, abrupt wavy; cs, clear smooth; gs, gradual smooth.

Texture: sil, silt loam; fsl, fine sandy loam; l, loam; sl, sandy loam; vgrlcos, very gravelly loamy coarse sand; ls, loamy sand; mu, muck; mul, mucky loam; musil, mucky silt loam.

Concentration Type: 1, fine; 2, medium; 3, coarse; F, faint; D, distinct; P, prominent.

OC, organic content.

Structure: 0, structureless; 1, weak; 2, moderate; 3, strong; F, fine; M, medium; C, coarse; Gr, granular; sbk, sub-angular blocky; Pr, prismatic; Ma, massive.

Soil classification: Coarse-loamy, mixed, active, mesic, Fluvaquentic Dystrudept

Table 5-11: Soil description of the high well at White Clay Creek.

						Redox features								
						Concentrations			Depletions					
Horizon	Depth	Boundary	Matrix color	Texture	Clay	Abundance	Type	Color	Abundance	Type	Color	OC	Structure	pH
	cm				%	%			%			%		
						White Clay Creek High (WC4)								
A	0-13	cs	10YR 3/3	l	14	-	-	-	-	-	-	1.20	1MGr	4.50
BA	13-28	cs	10YR 4/4	l	14	1	1D	7.5YR 4/6	-	-	-	0.82	1F-MSbk	4.64
Bw1	28-43	as	10YR 4/4	l	15	15	2-3D	7.5YR 4/6	4	2F	10YR 5/3	0.61	1M-CSbk	4.80
						3	1P	N2	-	-	-			
Bw2	43-67	as	2.5Y 4/3	l	15	20	2-3P	7.5YR 4/6	4	3F	2.5Y 4/2	0.51	1MSbk	4.92
						5	3P	5YR 4/6	-	-	-			
						3	1P	N2	-	-	-			
Bw3	67-83	cs	2.5Y 4/3	l	16	20	2P	7.5YR 4/6	5	2-3F	2.5Y 4/2	0.73	1M-CSbk	4.94
						7	2-3P	N2	-	-	-			
Bg1	83-114	cs	2.5Y 4/2	l/sil	19	20	2-3P	7.5YR 4/6	10	2-3F	2.5Y 5/1	0.83	2MSbk	4.73
						20	2-3P	7.5YR 5/8						
						1	1P	N2						
Bg2	114-120	as	2.5Y 4/1 (60%)	sil	21	10	1-2P	2.5YR 3/6	-	-	-	1.06	1MSbk	4.59
			2.5Y 4/2 (25%)			5	1-2P	5YR 4/6						
Ab	120-152	cs	10YR 2/1	sil	23	25	1-2P	2.5YR 3/6	-	-	-	2.18	1F-MSbk	4.60
Bgb	152-162	-	2.5Y 4/1	l	12	15	1-2P	7.5YR 4/6	5	2F	2.5Y5/1	0.37	1M-CSbk	4.66
						10	2D	5YR 4/6						
Bwb	162-192	-	2.5Y 4/3	l	15	35	2-3P	7.5YR 5/8	25	2-3D	5Y 4/1	0.56	1M-CSbk	4.69
Cg	192-255	-	5GY 3/1	fsl	8	-	-	-	-	-	-	0.29	0Ma	4.17
A'b	255-293+	-	10YR 2/1	sl	8	-	-	-	-	-	-	1.60	0Ma	3.90

See Table 5-2 for abbreviations.

Soil classification: Coarse-loamy, mixed, active, mesic, Fluvaquentic Dystrudept

Conclusions

The soils at the low and low/mid well locations are clearly hydric based on hydrological and redox potential measurements. All these soils meet a currently approved field indicator of hydric soils.

The morphology and biogeochemistry of the soil at the high locations suggest that they are not saturated or reduced for long enough during the growing season to be classified as hydric soils. There are brief periods of reduction at the lower depths (40 and 50 cm), but these soils clearly do not show evidence of "anaerobic conditions" in the upper part. Therefore, they are not hydric soils.

The water table data and oxidation-reduction potentials measured in the soils at the middle well locations indicate that these three soils meet the technical standard for hydric soils. For soils located on Mid-Atlantic Piedmont floodplains, a zone at least 15 cm thick, with greater than 60% of the soil Munsell chroma 3 or less starting within 25 cm of the soil surface and containing 20% or more distinct or prominent redox concentrations of Fe and or Mn oxyhydroxides, should be considered to be hydric soils.

VI. Indicator of Reduction in Soil (IRIS): Evaluating a New Approach for Assessing Reduced Conditions in Soil

Introduction

Hydric soils are defined as those that "…formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register, 1994). Anaerobic conditions exist when oxygen has been depleted from the soil, causing heterotrophic microbes to act on alternate electron acceptors in order to oxidize organic material.

Field indicators of hydric soil are used widely throughout the United States as a method of identifying hydric soils (USDA-NRCS, 2002). These indicators describe morphological features in soil that suggest saturation for a sufficient amount of time to maintain reduced conditions. Soil morphological features are a relatively permanent element in wetlands, however, there are particular settings where the soil and or hydrology has been altered or removed. In these cases, it becomes more difficult to determine whether or not a soil is hydric as redoximorphic features indicative of the high water table may not have had sufficient time to form.

The National Technical Committee for Hydric Soils established a technical standard to be able to adopt, modify, or eliminate field indicators of hydric soils. In problematic soil settings, where field indicators may not be applicable, the technical standard can also be used in lieu of field indicators to identify hydric soils in the field. This technical standard includes requirements for saturation and redox potential (USDA-NRCS, 2002). Soil redox potential measurements can be used to determine the electrochemical status of the soil and to predict which mineral species will be theoretically stable. For this method, according to the technical standard, at least five platinum (Pt) electrodes must be installed at a depth of 25 cm (for all soils except sands). Measurements of soil oxidation-reduction (redox) potential can be used to infer reduced conditions in hydric soils. The disadvantages of this method are the time and equipment necessary to make these measurements. Multiple redox potential measurements must be made throughout the year, in order to document that the soil is reduced for 14 or more consecutive days.

The use of α, α'dipyridyl dye can also be used to detect the presence of reduced iron in soil and thus infer that the soil is reduced (USDA-NRCS, 2002). A positive reaction to α, α'dipyridyl dye is indicated by a pinkish-red color that appears in the presence of reduced iron. In order to meet this criteria for the technical standard, there must be a positive reaction in 10 cm of the upper 30 cm for loamy soils in two out of three samples tested. In addition a positive reaction must be observed at regular intervals within a 14 day period to conclude that this soil is reduced for at least 14 days.

A new procedure is being developed to monitor wet soil environments and document soil reduction. Jenkinson (2003) developed and tested indicator of reduction in soil (IRIS) polyvinyl chloride tubes that are coated in ferrihydrite paint. These tubes were installed in saturated and unsaturated soils in Indiana, North Dakota, and Minnesota. A significant correlation was found between depth to water table and removal of Fe(III) from the IRIS tubes. Fe(III) was removed from the tube in locations where the soil was saturated by the seasonally high water table. The Fe(III) coating was left undisturbed in locations where the soil was unsaturated. The assumption was that the iron paint was removed or translocated in soluble (Fe(II)) form from the tube surface due to reducing conditions in the soil. Jenkinson (2003) however, did not make measurements of soil redox potential for direct comparisons with the IRIS tubes.

In this study, IRIS tubes were tested to evaluate their suitability to identify the dissolution of oxidized iron in soils within a young floodplain setting. It was postulated that the IRIS tubes might indicate where iron was being reduced in the profile providing a simpler, less tedious, and time consuming approach than measuring redox potential and water tables. The objective of this study was to compare Fe oxide removal from IRIS tubes with soil redox potential measurements in order to assess the usefulness of IRIS tubes for confirming reduced soil conditions.

Materials and Methods

Study Area

Three floodplains in the Piedmont physiographic region of Maryland and Delaware were instrumented for this study. Figure 3-1 shows the location of two sites in Maryland on the Middle Patuxent River and the North Branch of the Rock Creek, and one site in Delaware on White Clay Creek. The sites were set up along transects from a groundwater discharge wetland, across the floodplain toward drier soil nearer the river

(Fig. 1-3). The sites at the Middle Patuxent River and Rock Creek contained three monitoring stations located in the wet, backswamp area (low), intermediate area (middle), and the drier area (high) of the floodplain. White Clay Creek contained an additional fourth monitoring station (low/mid) in the wet, backswamp area.

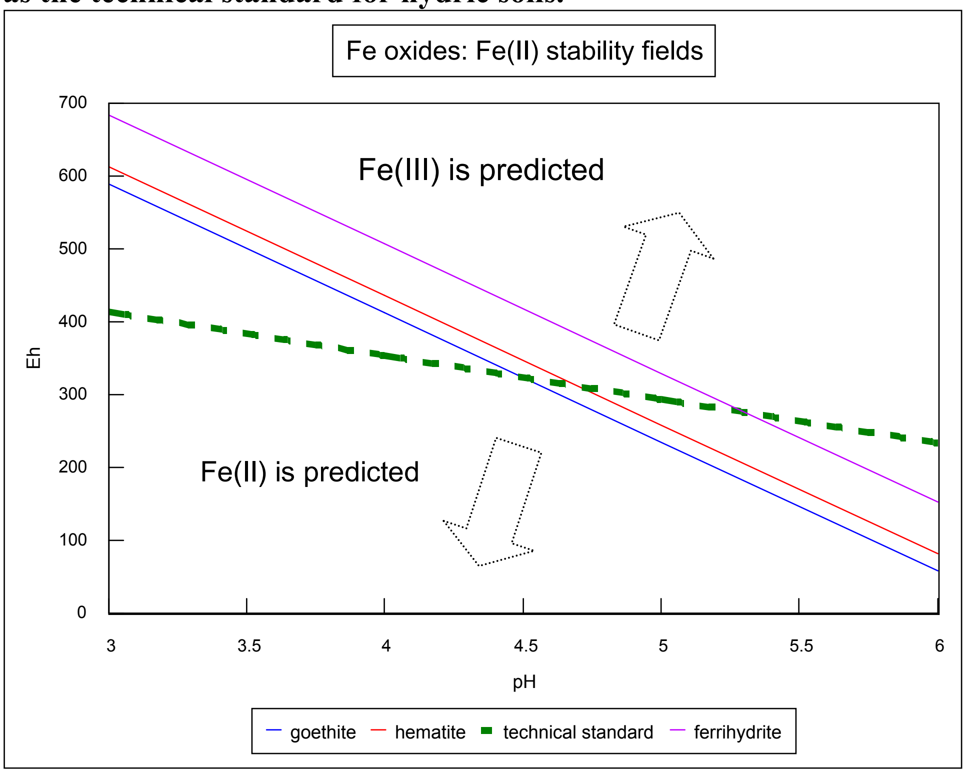
Field Procedures

Water table measurements were made twice daily using automatic monitoring wells. Soil temperature was measured used loggers placed at 10, 30, and 50 cm below the soil surface.

Soil oxidation-reduction (redox) potential was measured at all well locations every two to three weeks. These measurements were made using six Pt electrodes inserted to depths of 10, 20, 30, 40, and 50 cm. A pilot hole was made with a thin steel rod to ensure the Pt tip was not damaged when inserted into the soil. The Pt tip was inserted into the hole and pressed to make solid contact with the soil. The electrodes were placed in a semi-circle around the calomel reference electrodes maintaining less than 30 cm between the Pt and reference electrodes. Redox potentials were measured with a digital multimeter and a calomel saturated KCl reference electrode. Redox measurements were converted to Eh values by adding the reference electrode conversion factor (244 mV).

In order to accurately compare soil conditions with Eh/pH stability diagrams, soil pH measurements were also made at the same intervals and depths as redox measurements. pH was measured in the field on a 1:1 soil/water slurry using a pH meter. Figure 6-1 shows Eh/pH stability diagram for selected iron species (assumed activity of 10^{-6} M). Ferrihydrite is slightly more easily reduced, than hematite, followed by goethite. The dashed line is the technical standard for reduced iron. This is a theoretical line developed by the National Technical Committee for Hydric Soils to relate measured redox potential to the stability of various iron species.

Figure 6-1: Iron stabilty diagram showing Fe(III) - Fe(II) stability fields for goethite, hematite, and ferrihydrite. Also plotted is the Fe(III) - Fe(II) line adopted as the technical standard for hydric soils.



Preparation of IRIS Tubes

IRIS tubes were constructed based on the procedure established by Jenkison (2003). A brief synopsis of the procedure follows with modifications from the original method discussed by Jenkinson.

Ferrihydrite paint was prepared by dissolving ferric chloride salt ($FeCl_3$) in distilled water. One M KOH was added to raise the pH and precipitate the ferrihydrite. This solution was centrifuged and then placed in dialysis tubing to remove the salts. The viscosity of the paint suspension was adjusted by evaporation to that of oil paint. It was stored in an opaque plastic container at room temperature.

The paint was analyzed to determine the mineralogy of the iron oxides present. Samples of the paint were dried and ground for analysis using x-ray diffraction (XRD)(Cu KV). The XRD pattern indicated that goethite and another poorly crystalline iron mineral was present (Appendix N). Two broad peaks, typical of ferrihydrite, were identified (around 2.54 and 1.49 d spacings). Because XRD does not produce quantitative results, samples of the paint were extracted using dithionite-citrate-bicarbonate (DCB) (Loeppert and Inskeep, 1996) and acid ammonium oxalate to determine the dominant iron species (Schwertmann, 1964; McKeague and Day, 1966). The DCB extracts essentially all the secondary Fe oxides while NH_4 oxalate extracts the poorly crystalline Fe oxides, particularly ferrihydrite (Scwertmann and Taylor, 1986). The ratio of NH_4 oxalate Fe to DCB Fe was 0.7, suggesting that most (approximately 70%) of the total iron was in a poorly crystalline form, assumed to be ferrihydrite.

Polyvinyl chloride (PVC) tubes, ¾ in. outside diameter (nominally one half inch PVC tubing), were cut into 60 cm lengths. Fifty cm of the tube were cleaned with acetone and lightly sanded using fine sand paper. Tubes were set on a lathe type device and the prepared ferrihydrite paint was painted onto the sanded portion of the tube. Jenkinson (2003) suggested two coats of paint should be applied to each tube.

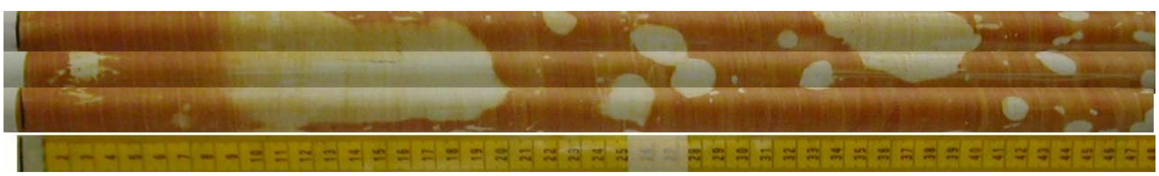
Preliminary data were collected before the beginning of this study. Tubes with two coats of paint were installed in backswamp areas while soil temperatures were low. Upon the removal of these tubes, the amount of iron removed from the tube was not substantial. Therefore, it was decided that the remainder of the study be conducted using tubes painted with a single coat. Thus approximately 25 of the initial tubes were given two coats and the remainder of the 150 tubes received one coat. In hindsight, low soil temperature appeared to be the reason for the lower percentage of iron removal from the initial tubes with two coats of paint, and it is expected that tubes with either one or two coats would have produced similar results.

IRIS Tube Procedures

Beginning in March 2003, duplicate IRIS tubes were installed at each well location. A 5/8 in. diameter push auger was used to make a pilot hole so the tube could be inserted into the soil with minimal scratching yet ensuring soil contact. Tubes remained in the field for 12 to 32 days at a time (averaging 20 days). Redox potential was measured on the dates the tubes were installed and removed. Upon removing a set of tubes, another set was immediately inserted into the original holes. The removed tubes were partially cleaned of soil and returned to the lab for additional cleaning.

All IRIS tubes removed from the soil were labeled and cleaned with tap water to remove any adhering soil material. Three photos were taken of each tube following 120^{o} rotation. These photos were then cropped and joined with a photo of a tape measure (cm) to form one image of the whole surface of the tube. Figure 6-2 shows an image of an IRIS tube removed on June 23 from the middle well at White Clay Creek. These tubes were divided into five, 10 cm sections corresponding to the five depths at which redox potential and pH were measured. Using published figures designed for estimating percentage of aerial coverage for comparison (fig. 4-11, Stoops, 2003), visual estimates were made of the percentage of iron oxide paint that had been removed from the tube in each 10 cm section.

Figure 6-2: Image displaying the reduction of Fe(III) from IRIS tube at White Clay Creek (middle well) removed 6-23-03 (top of tube is on the left). Scale along the bottom is cm.



Results and Discussion

Each 10 cm section of tube was placed into one of four groups based on the soil redox potential at the corresponding depth when the tubes were installed and removed. The technical standard equation for redox potential was used to determine if the soil was reduced or oxidized. These groups were; 1) reduced at installation, reduced upon removal; 2) oxidized at installation, oxidized upon removal; 3) reduced at installation, oxidized upon removal; and 4) oxidized at installation, reduced upon removal.

Figure 6-3 shows the total number of sections that were observed in each of the four groups. The sections in group 3 and 4 were difficult to analyze since reducing conditions were observed on only one of the two dates. The data in figure 6-3 shows there are relatively few instances when the soils were oxidizing on one date and reducing on the other. Because it could not be assumed that these soils were either reduced or oxidized while the tubes were in the soil, these ambiguous data were removed from further analyses (fig. 6-4). If the soil was either reducing or oxidizing on both dates, the soil was considered to be reducing or oxidizing respectively while the tubes were in the soil.

Figure 6-3: Number of 10 cm sections of IRIS tubes observed in the various groups based on redox potential versus the percentage of iron oxide removed from the tube. Green indicates reduced at both installation and removal, blue indicates oxidized at both installation and removal, yellow indicates reduced at installation and oxidized upon removal, and pink indicates oxidized at installation and reduced upon removal.

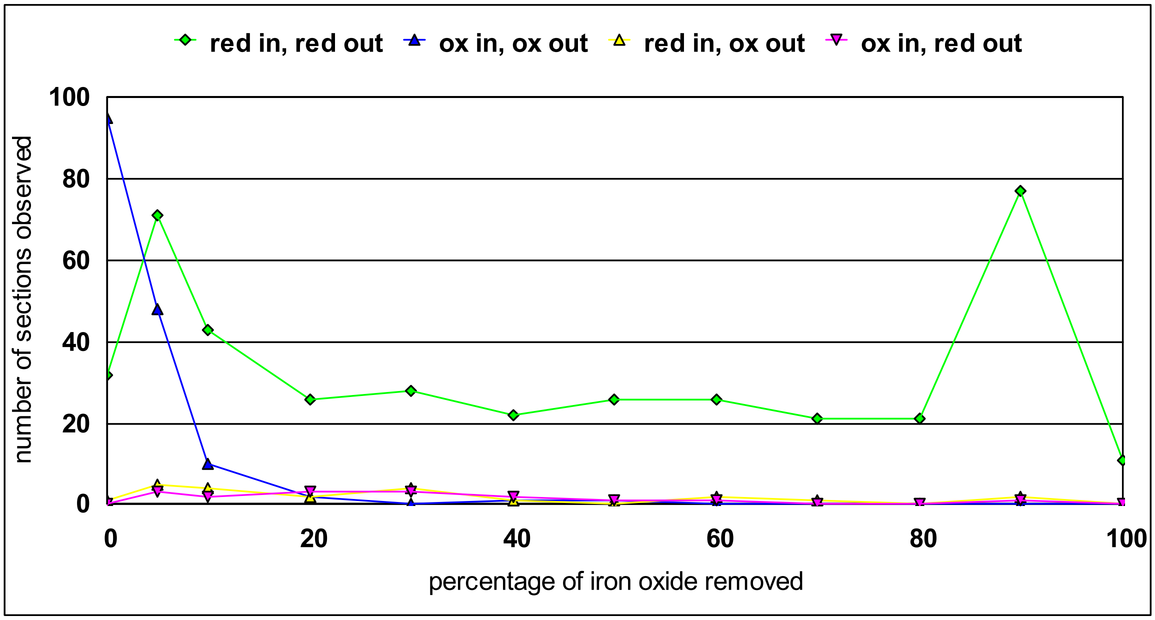
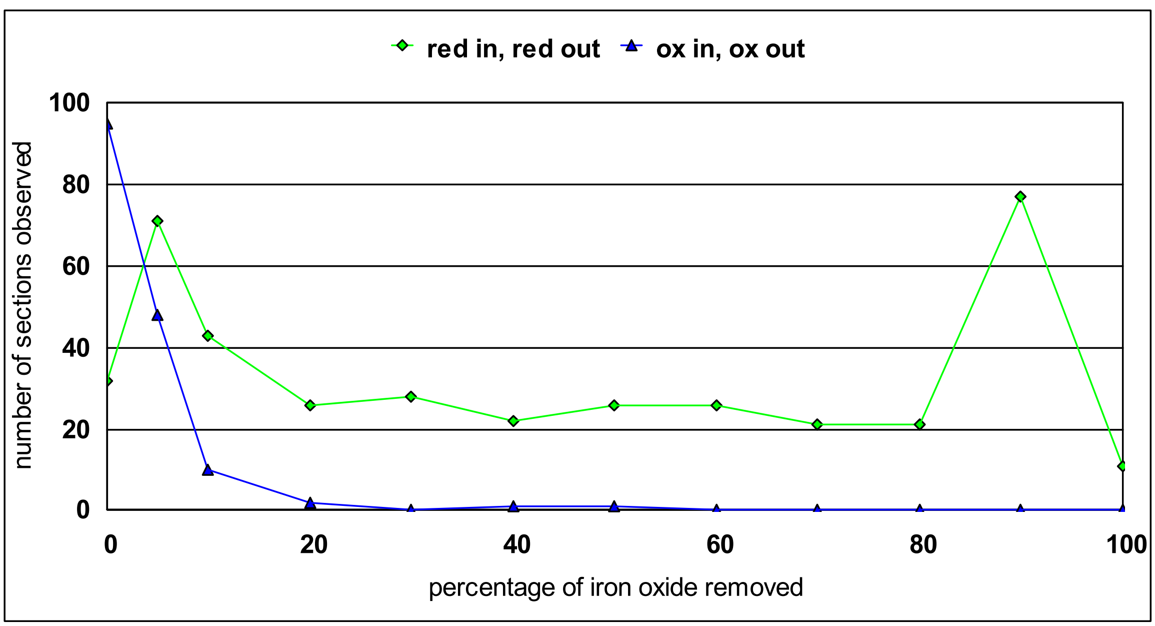
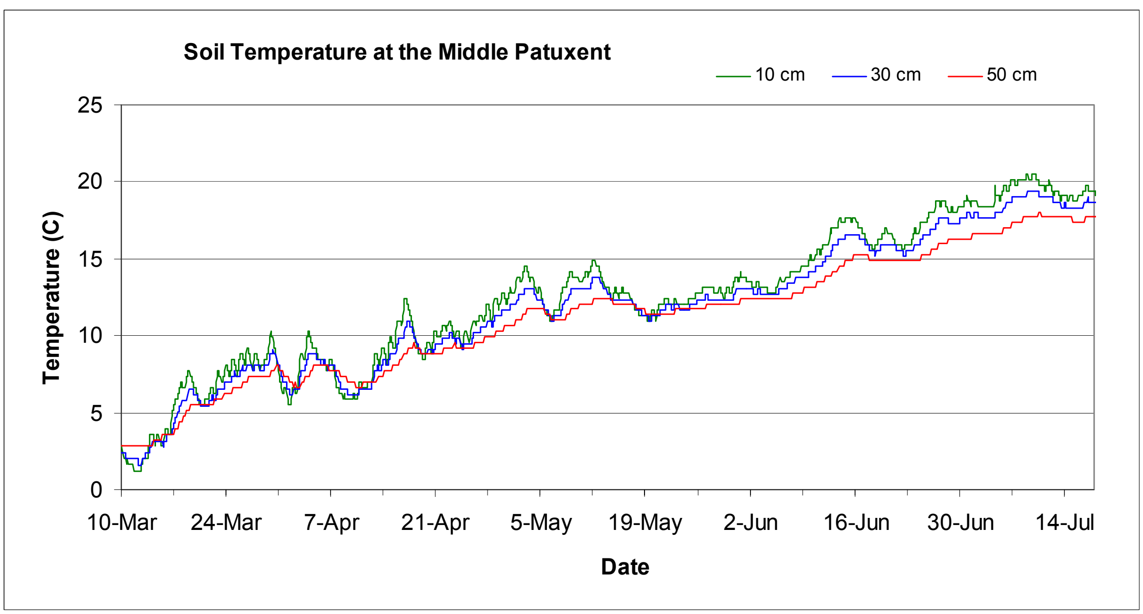


Figure 6-4: Number of 10 cm sections of IRIS tubes observed in two groups based on reduced or oxidized conditions versus the percentage of iron oxide removed from the tube. Green indicates reduced at both installation and removal and blue indicates oxidized at both installation and removal.



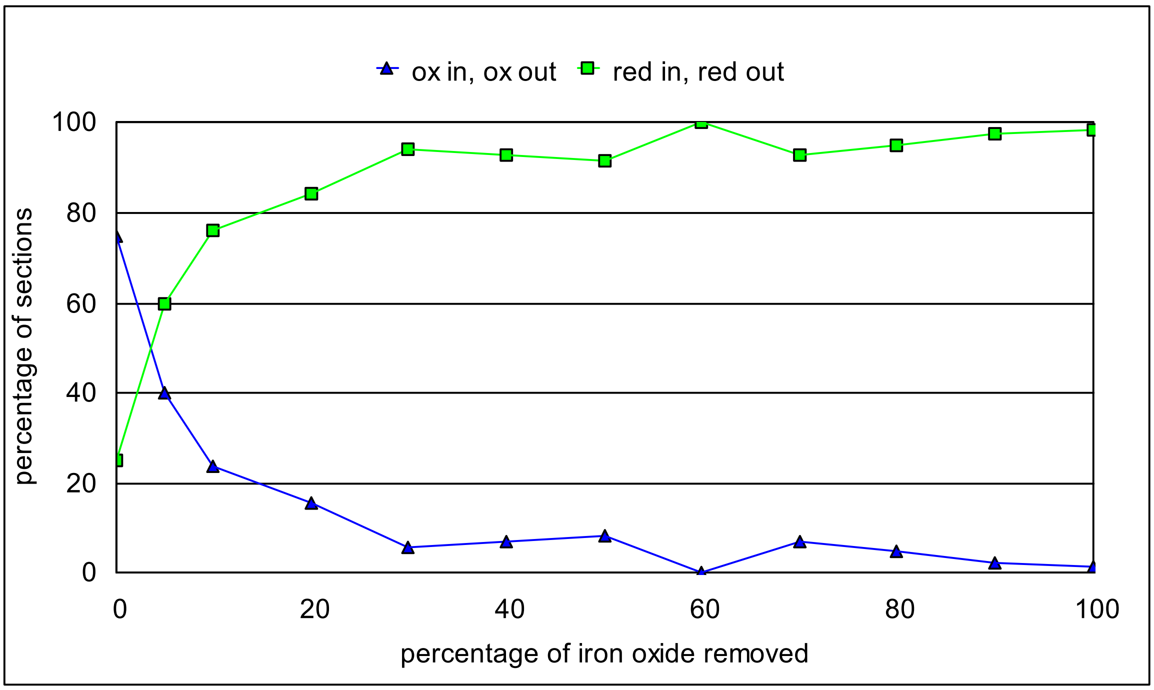
The data in figure 6-4 demonstrates there were times when the soil was reduced for two to three weeks when no iron oxide paint was removed from the tubes. Since organic carbon was not a limiting factor in these soils (fig. 3-10), cool soil temperatures were the likely cause for this occurrence (fig. 6-5). On the contrary, there were times when the soil was oxidizing and up to 10% of the iron oxide paint was removed from a section. The reason for this may have been microsite variability in the soil. Since a Pt redox electrode measures the potential in only a small area of soil, the tube surface may have captured a more representative zone. When 20% or more iron oxide paint was removed from a section of an IRIS tube, there was a high probability that the soil met the technical standard definition of reduction and a low probability that it did not meet the technical standard.

Figure 6-5: Soil temperature at the Middle Patuxent River. This data serves as an example of the soil temperatures observed in each of the three floodplain sites. Early in the study the soil temperatures were between 2^{o} and 10^{o}C.



The data in figure 6-6 shows the observation of the 10 cm sections as a percentage. The soil was reducing in 85% of the sections where 20% of the iron oxide paint was removed, while in less than 15% of the cases, the soil was not reducing. When 30% or greater iron oxide paint was removed from the 10 cm section of tube, an average of 95% of the sections were reduced based on the technical standard.

Figure 6-6: Percentage of 10 cm sections of IRIS tubes observed in the reducing (green) or oxidizing (blue) group versus the various percentage of iron oxide paint removed from the tube.



Conclusions

Indicator of reduction in soil tubes (IRIS) have proved to be a useful tool in the identification of reduced soil conditions. A relationship exists between soil redox potential and the amount of iron oxide paint removed from the tubes. When a tube is installed in a soil that is continually reduced (according to redox measurements and the criteria for the technical standard for hydric soils) for a period of two to three weeks, at least 20% of the iron oxide paint is typically removed from the tube surface. When a tube is installed in an oxidized soil, there is a very low likelihood that even as much as 10% or 20% of the iron oxide coating will be removed. Consequently, tubes that have been installed in the soil may be analyzed for percentage of iron oxide paint removed from the tube, in order to determine whether or not the soil meets the technical standard for reduction.

VII. Conclusions

On Mid-Atlantic Piedmont floodplains, morphological features indicative of reduced conditions form under various degrees of saturation. In order to form greater than 5% redox concentrations of iron or manganese, the soil must be saturated for at least 12% of the year. Formation of redox depletions of iron (2 chroma or less) requires saturation for longer periods of time. Depletions were observed in soil horizons that were saturated for at least 27% of the year. Depleted matrices were detected only when the soil was saturated for at least 74% of the year. The results of this study differed greatly the results of other studies by West et al. (1998) and others. Shorter periods of saturation were necessary to form comparable redox features in older soils in the Georgia Coastal Plain. This is probably related to the age of the soils under investigation in both studies. The soil on Mid-Atlantic Piedmont floodplains are far younger (250 to 2000 years), than the soils of the Georgia Coastal Plain, 11,000 to 23.8 M years old (Miocene to Pleistocene)(West et al., 1998).

Water table levels can be used to interpret the biogeochemical processes responsible for the formation of redoximorphic features in soil. If a soil in saturated during a year with normal precipitation, for 22 to 41 days (based on the model in fig. 3-11), the redox potential is predicted to be below the technical standard for reduced iron. This relationship is useful in circumstances when precipitation levels are abnormal or when redox potential data in not available. In these cases, water table data from a year with normal precipitation can be used to predict the amount of time reduced condition persist in the soil.

The soils at the wettest locations along the floodplain transect were reduced and saturated for prolonged periods of time throughout the year. The soils in the middle locations experienced much variability in both water table levels and redox potential. When the soil was saturated for long periods of time during the wet season, reduced conditions typically occurred within 10 cm of the soil surface. Low soil temperatures negatively impacted the activity of microbes acting on iron as an alternate electron source. Soils in the drier locations maintained reduced conditions in prolonged saturated zones, usually 40 and 50 cm.

The soils located in the middle position along the floodplains in the Mid-Atlantic Piedmont are hydric soils that do not meet a field indicator of hydric soil (USDA-NRCS, 2002). A new indicator is being proposed for soils located on Mid-Atlantic Piedmont floodplains; a zone at least 15 cm thick, starting within 25 cm of the soil surface with 60% or more of the soil with Munsell chroma of 3 or less, containing 20% or more distinct or prominent redox concentrations of Fe and/or Mn oxyhydroxides. The three soils studied in the middle locations on three floodplains in the Mid-Atlantic Piedmont are accurately identified as hydric soils based on this new field indicator of hydric soil. This proposed indicator also effectively discriminates non-hydric soils in the drier locations along the floodplains.

A new method to detect reduced soil conditions was developed by Jenkinson (2003). Indicator of reduction in soil tubes (IRIS) are being compared to in situ soil redox potential measurements. These tubes were constructed using 60 cm long PVC tubing coated in ferrhydrite paint. Ten cm segments of the tubes were analyzed for the amount of iron oxide paint removed from the tube and compared to the measured redox potential at the corresponding depth. Tubes that were installed and removed from the soil while it was reduced showed greater than 20% removal of the iron oxide paint from the tube. Tubes that were installed and removed from the soil while it was oxidized, typically showed less than 10% removal of the iron oxide paint. Therefore, these tubes can be analyzed for percentage of iron oxide paint removed from the tube, in order to determine whether or not the soil meets the technical standard for reduction.

Appendix A: Soil Descriptions

Description of Soil at Middle Patuxent Low Site (MP1)

Horizon	Depth (cm)	Description
A1	0-7	Dark brown (10YR 3/3) loam and silt loam (12% clay) with many medium and coarse distinct strong brown (7.5YR 4/6) hypo coatings, soft masses, and pore linings of iron; weak fine and medium subangular blocky structure; very friable; clear smooth boundary.
A2	7-25	Dark olive gray (5Y 3/2) silt loam and loam (12% clay) with common (8%) medium prominent yellowish red (5YR 4/6) pore linings of iron; weak medium subangular blocky structure; friable; 0.7 n-value; abrupt smooth boundary.
Cg1	25-45	Olive gray (5Y 4/2) silt loam (10% clay); structureless massive; friable; 1.0 n-value; clear smooth boundary.
Cg2	45-77	Dark gray (5Y 4/1) silt loam (14% clay); structureless massive; friable; less than 0.7 n-value; clear smooth boundary.
Cg3	77-96+	Dark gray (5Y 4/1) fine sandy loam (8% clay); structureless massive; 0.7-1.0 n-value.

Classification: Coarse loamy, mixed, mesic, active Typic Fluvaquent

Location: Low site along the Middle Branch of the Patuxent River, University of Maryland, Forage Farm Research Facility. Howard County, Maryland. Shepard Ln. to Folly Quarter Rd., left onto Carroll Mill Dr., cross over bridge/river.

Parent Material: Alluvium

Physiography: Piedmont

Geomorphology: Floodplain

Stoniness: none

Drainage Class: Very poorly

Slope: <1%

Remarks:

Described by: Karen Castenson (UMD), Martin Rabenhorst (UMD), and Robert Vaughan (UMD). July 16, 2002.

Description of Soil at Middle Patuxent Middle Site (MP2)

Horizon	Depth (cm)	Description
A	0-7	Brown (10YR 4/3) silt loam (14% clay) with common (8%) coarse faint strong brown (7.5YR 4/6) soft masses and pore linings of iron and few (2%) fine prominent black (N2) soft masses of manganese; weak medium granualr structure; friable; clear smooth boundary.
BA	7-20	Dark yellowish brown (10YR 4/4) silt loam (15% clay) with common (10%) coarse faint brown (7.5YR 4/4) soft masses and pore linings of iron and common (3%) fine prominent black (N2) soft masses of manganese; weak medium subangular blocky structure; friable; clear smooth boundary.
Bw1	20-41	Olive brown (2.5Y 4/3) loam (18% clay) with common (15%) medium and coarse prominent strong brown (7.5YR 4/6) and common (10%) medium and coarse prominent strong brown (7.5YR 5/8) soft masses and pore linings of iron; moderate medium and coarse subangular blocky structure; friable; clear smooth boundary.
Bw2	41-61	Olive brown (2.5Y 4/3) sandy loam (12% clay) and lower 5cm of coarse sandy loam with common (15%) medium and coarse prominent yellowish red (5YR 4/6) and common (15%) medium and coarse distinct strong brown (7.5YR 4/6) soft masses and pore linings of iron and few (2%) fine prominent black (N2) soft masses of manganese; weak coarse subangular blocky structure; friable; 0.7 n-value; clear smooth boundary.
Bw3	61-80	Olive brown (2.5Y 4/3) silt loam (12%clay) with common (15%) medium and coarse prominent strong brown (7.5YR 5/8), common (10%) coarse prominent red (2.5YR 5/8), and common (5%) coarse prominent dark reddish brown (5YR 3/3) pore linings of iron and common (3%) fine prominent black (N2) soft masses and pore linings of manganese; weak medium and coarse subangular blocky structure; friable; clear smooth boundary.
Cg	80-104	Greenish gray (10Y 5/1) fine sandy loam (10% clay) with common (5%) medium and coarse prominent strong brown (7.5YR 5/8) pore linings of iron; structureless massive; friable; clear smooth boundary
Ab1	104-121	Very dark greenish gray (5GY 3/1) fine sandy loam (10% clay) with common (4%) fine and medium faint brown (7.5YR 4/4) pore linings of iron; weak coarse subangular blocky structure; friable; clear smooth boundary.
Ab2	121-132	Black (2.5Y 2.5/1) fine sandy loam (10% clay); very weak coarse subangular blocky structure; fribable; abrupt smooth boundary.

Classification:	Coarse loamy, mixed, mesic, active Fluvaquentic Dystrudept
Location:	Middle site along the Middle Branch of the Patuxent River, University of Maryland, Forage Farm Research Facility. Howard County, Maryland. Shepard Ln. to Folly Quarter Rd., left onto Carroll Mill Dr., cross over bridge.river.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none above 132cm.
Slope:	<1%
Remarks:	Gravels below 132cm.
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), and Robert Vaughan (UMD). July 16, 2002.

Description of Soil at Middle Patuxent High Site (MP3)

Horizon	Depth (cm)	Description
A	0-7	Dark yellowish brown (10YR 4/4) silt loam (14% clay); moderate medium granular structure; friable; abrupt smooth boundary.
BA	7-15	Yellowish brown (10YR 5/4) silt loam (14% clay); weak medium subangular blocky structure; friable; clear smooth boundary.
Bw1	15-25	Yellowish brown (10YR 5/4) silt loam (17% clay) with common (4%) fine distinct strong brown(7.5YR 4/6) soft masses of iron; weak medium subangular blocky structure; friable; clear smooth boundary.
Bw2	25-49	Yellowish brown (10YR 5/6) silt loam (17% clay) with many (25%) fine and medium distinct strong brown (7.5YR 4/6) soft masses and pore linings of iron; weak medium subangular blocky structure; friable; clear smooth boundary.
Bw3	49-80	Brown (10YR 4/3) silt loam (18% clay) with many (40%) medium distinct strong brown (7.5YR 4/6) soft masses and pore linings of iron, common (3%) fine prominent black (N2) soft masses of maganese, and common (10%) medium faint light olive brown (2.5Y 5/3) depletions of iron; moderate medium and coarse subangular blocky structure; friable; clear smooth boundary.
Bg1	111-130	Gray (2.5Y 5/1) loam and silt loam (20% clay) with many (30%) fine and medium prominent dark red (2.5YR 3/6) and common (10%) fine and medium prominent strong brown (7.5YR 4/6) soft masses and pore linings of iron, few (1%) fine prominent black (N2) soft masses of manganese; moderate medium and coarse subangular blocky structure; friable; clear smooth boundary.
Bg2	130-150	Dark gray (5Y 4/1) silt loam (23% clay) with common (20%) medium prominent dark yellowish brown (10YR 4/6), common (10%) medium prominent dark brown (7.5YR 3/4), common (5%) medium distinct olive brown (2.5Y 4/3) soft masses and pore linings of iron; moderate medium and coarse subangular blocky structure; friable; abrupt smooth boundary.
2Ab	150-160	Very dark gray (2.5Y 3/1) sandy loam (10% clay); weak coarse subangular blocky structure; friable; abrupt smooth boundary.
3C	160+	Very gravelly coarse sand layer begins at this depth. Unable to sample due to influx of ground water.

Classification:	Coarse loamy, mixed, mesic, active Fluventic Dystrudept
Location:	High site along the Middle Branch of the Patuxent River, University of Maryland, Forage Farm Research Facility. Howard County, Maryland. Shepard Ln. to Folly Quarter Rd., left onto Carroll Mill Dr., corss over bridge/river.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none above 160cm.
Slope:	<1%
Remarks:	
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), and Robert Vaughan (UMD). July 16, 2002.

Description of Soil at Rock Creek Low Site (RC1)

Horizon	Depth (cm)	Description
Oe	0-2.5	Brown (7.5YR 4/3) mucky organic horizon with hemic materials; structureless massive, abrupt smooth boundary.
Bg	2.5-66	Brown (2.5Y 4/2) silt loam (26% clay) with common (10%) fine prominent strong brown (7.5YR 4/6, 5/6) and few (2%) medium prominent dark reddish brown (2.5YR 3/4) soft masses and pore linings of iron; weak to moderate medium to coarse subangular blocky; friable; clear smooth boundary.
Cg1	66-76	Dark gray (2.5Y 4/1) silt loam (26% clay) with many (20%) fine and medium prominent dark reddish brown (7.5YR 4/6, 5/6); weak platy structure; friable; clear smooth boundary.
Cg2/Ab	76-101.5	Dark grayish brown (2.5Y 4/2) silt loam (27% clay) with common (10%) medium prominent strong brown (7.5YR 4/6) and common (12%) fine prominent dark reddish brown (2.5YR 3/4) soft masses and pore linings of iron; structureless massive; friable, clear smooth boundary.
Ab	101.5-160	Black (N 2.5) loam (24% clay); structureless massive; clear smooth boundary.
Cg2	160-178	Gray (5Y 5/1) and olive brown (2.5Y 4/3) fine sandy loam (4% clay) with common (10%) medium distinct dark yellowish brown (10YR 4/6) soft masses of iron; structureless massive; clear smooth boundary.
C	178-183	Light olive brown (2.5Y 5/3) sand (1% clay) with common (4%) medium distinct dark yellowish brown (10YR 4/6) soft masses of iron, structureless massive.

Classification:	Fine loamy, mixed, mesic, active Typic Fluvaquent
Location:	Low site along the North Branch of the Rock Creek. Montgomery County, Maryland. From Georgia Ave., left onto Emory Ln., right onto Walking Fern Dr.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none
Slope:	<1%

Remarks:	Samples from this pedon were not analyzed at the University of Maryland Pedology Laboratory.
Described by:	Lenore Vasilas (NRCS) and Steve Burch (UMD).

Description of Soil at Rock Creek Middle Site (RC2)

Horizon	Depth (cm)	Description
A	0-15	Brown (10YR 4/3) silt loam (16% clay) with many (20%) fine distinct brown (7.5YR 4/4) and common (5%) fine prominent dark reddish brown (5YR 2.5/2) soft masses and pore linings of iron; moderate fine subangular blocky parting to moderate fine angular blocky structure; friable; clear smooth boundary.
Bw1	15-35	Brown (10YR 4/3) silt loam (21%) with many (20%) fine and medium distinct strong brown (7.5YR 4/6) soft masses of iron, common (5%) fine prominent dark red (2.5YR 3/6) and common (3%) fine prominent dark reddish brown (5YR 2.5/2) pore linings of iron; moderate fine subangular blokcy structure; friable; clear smooth boundary.
Bw2	35-56	Brown (10YR 4/2.8) silt loam (18% clay) with common (15%) medium prominent dark reddish brown (2.5YR 2.5/4), common (10%) fine distinct dark brown (7.5YR 3/4) and fine prominent dark reddish brown (5YR 2.5/2) softmasses and pore linings of iron, and common (8%) medium distinct grayish brown (2.5Y 5/2) iron depletions; weak to moderate fine subangular blocky structure; friable; gradual smooth boundary.
Bg	56-79	Grayish brown (2.5Y 5/2) silt loam (18% clay) with common (14%) medium prominent strong brown (7.5YR 4/6) and common fine prominent (12%) dark reddish brown (5YR 3/4) soft masses and pore linings of iron, and common (5%) fine faint dark gray (2.5Y 5/1); weak to moderate fine subangular blocky structure; friable, clear smooth boundary.
AB	79-93	Very dark grayish brown/dark brown (10YR 3.5/2) silt loam (18% clay) with common (10%) fine prominent dark brown (7.5YR 3/4) and common (5%) medium distinct dark yellowish brown (10YR 4/4) soft masses and porelinings of iron; weak to moderate coarse subangular blocky structure; friable; clear smooth boundary.
Ab1	93-104	Black (10YR 2/1) silt loam (18% clay) with common (4%) fine distinct dark brown (7.5YR 3/3) soft masses of iron; moderate fine subangular blocky structure; friable; clear smooth boundary.
Ab2	104-135+	Black (10YR 2/1) silt loam (10% clay) with common (4%) fine distinct dark brown (7.5YR 3/3) soft masses of iron; weak to moderate subangular blocky structure; friable.

Classification: Fine loamy, mixed, mesic, active Fluvaquentic Dystrudept

Location:	Middle site along the North Branch of the Rock Creek. Montgomery County, Maryland. From Georgia Ave., left onto Emory Ln., right onto Walking Fern Dr.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none
Slope:	<1%
Remarks:	
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), Robert Vaughan (UMD), Steve Burch (UMD), John Wah (UMD), Suzy Parks (UMD). March 14, 2002.

Description of Soil at Rock Creek High Site (RC3)

Horizon	Depth (cm)	Description
A	0-12	Dark yellowish brown (10YR 4/4) silt loam (15% clay); weak to moderate subangular blocky structure; friable; gradual smooth boundary.
Bw1	12-37	Dark yellowish brown (10YR 4/4) silt loam (19% clay); weak to moderate subangular blocky structure; friable; gradual smooth boundary.
Bw2	37-76	Brown (10YR 4/3) loam and silt loam (15% clay) with common (15%) fine distinct dark brown (7.5YR 3/4) soft masses of iron and common fine prominent black (N2) soft masses of manganese; weak coarse prismatic parting to weak coarse subangular blocky structure; friable; clear smooth boundary.
BC	76-88	Brown (10YR 4/3) loam and sandy loam (15%clay) with many (30%) fine prominent dark brown (7.5YR 3/4) soft masses and pore linings of iron and common (5%) medium distinct grayish brown (2.5Y 5/2) iron depletions; weak to moderate coarse subangular blocky structure; friable; clear smooth boundary.
2Cg	88-129	Grayish brown (2.5Y 5/2) fine sandy loam (15% clay) with many (25%) medium distinct yellowish brown (10YR 5/4) soft masses of iron, common (8%) fine prominent dark yellowish brown (10YR 4/6) pore linings of iron and common (10%) medium distinct gray (2.5Y 6/1) iron depletions; weak medium subangular blocky structure; friable.
2C	129-160	Yellowish brown (10YR 5/4) sandy loam/loamy sand with common (5%) fine distinct light brown (7.5YR 6/4) pore linings of iron and common (20%) medium prominent gray (2.5Y 6/1) depletions of iron; friable.
2C2	160-190	Brown (7.5YR 4/3) loamy sand with common (3%) fine prominent light grayish brown (2.5Y 6/2) depletions of iron; friable.
3C3	200+	Strong brown (7.5YR 4/6) very gravelly coarse sandy loam with many (30%) fine distinct strong brown (7.5YR 5/8), few fine prominent dark reddish brown (5YR 3/4) soft masses and pore linings of iron and few (1%) fine prominent olive (5Y 4/3) depletions of iron; friable.

Classification:	Coarse loamy, mixed, mesic, active Fluventic Dystrudept
Location:	High site along the North Branch of the Rock Creek. Montgomery County, Maryland. From Georgia Ave., left onto Emory Ln., right onto Walking Fern Dr.

Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	None above 190
Slope:	<1%
Remarks:	Auger used below 88 cm.
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), Phil King (NRCS), Robert Vaughan (UMD), Phillip Zurheide (UMD), and Steve Burch (UMD). July 16, 2002.

Description of Soil at White Clay Creek Low Site (WCC1)

Horizon	Depth (cm)	Description
Oa	0-18	Black (7.5YR 2.5/1) mucky organic horizon with sapric materials; structureless massive, abrupt smooth boundary.
Cg1	18-65	Very dark gray (5Y 3/1) silt loam (19% clay); structureless massive; friable; clear smooth boundary.
Cg2	65-90	Very dark gray (5Y 3/1) silt loam (19% clay) with a layer of coarse sandy loam; structureless massive; friable; clear smooth boundary.
Cg3	90-150	Very dark gray (5Y 3/1) silt loam (19% clay); structureless massive; friable; clear smooth boundary; 10% organic fragments.
Oab	150-195	Dark brown (7.5YR 3/2) mucky organic horizon with sapric materials; structureless massive; abrupt smoth boundary.
Ab	195-235+	Black (7.5YR 2.5/1) mucky loam; structureless massive; friable; 35% organic fragments.

Classification:	Fine loamy, mixed, mesic, active Typic Hydraquent
Location:	Low site along White Clay Creek. New Castle County, Delaware. Off of Park Rd., 100m from Ranger's Station.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none
Drainage Class:	Very poorly.
Slope:	<1%
Remarks:	N-value between 18-90 cm is greater than 0.7.
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), Phil King (NRCS), Robert Vaughan (UMD), Phillip Zurheide (UMD), and Steve Burch (UMD). July 16, 2002.

Description of Soil at White Clay Creek Low/Middle Site (WCC2)

Horizon	Depth (cm)	Description
A	0-7	Dark reddish brown (5YR 3/3) loam and silt loam (15% clay) with many (25%) medium distinct yellowish red (5YR 4/6) concentrations and common (15%) distinct medium and coarse very dark gray (2.5Y 3/1) depletions; weak medium subangular blocky parting to weak medium granular structure; friable; abrupt wavy boundary.
Cg1	7-24	Dark gray (5YR 4/1) loam (15% clay) with common (10%) medium and coarse prominent yellowish red (5YR 4/6) concentrations as pore linings; structureless massive; friable; gradual smooth boundary.
Cg2	24-49	Dark gray (5YR 4/1) loam and silt loam (15% clay) with many (25%) fine and medium prominent strong brown (7.5YR 4/6) and many (25%) fine and medium prominent yellowish red (5YR 4/6) concentrations as pore linings; structureless massive; friable; gradual smooth boundary.
Cg3	49-89	Dark gray (5YR 4/1) loam (10 % clay); sturctureless massive; friable; less than 0.7 n-value; clear smooth boundary.
Cg4	89-105	Dark gray (5YR 4/1) silt loam (15% clay); structureless massive; friable; 0.7 n-value; abrupt smooth boundary.
Ab	105-112	Black (N2.5) mucky silt loam; weak fine subangular blocky structure; friable; abrupt smooth boundary.
Oab	112+	Black (7.5YR 2.5/1) mucky organic horizon with sapric materials; structureless massive.

Classification:	Coarse loamy, mixed, mesic, active Typic Fluvaquent
Location:	Low/Middle site along White Clay Creek. New Castle County, Delaware. Off of Park Rd., 100m from Ranger's Station.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none
Drainage Class:	Very poorly
Slope:	<1%

Remarks:

Described by: Karen Castenson (UMD), Martin Rabenhorst (UMD), Phil King (NRCS), Robert Vaughan (UMD), Phillip Zurheide (UMD), and Steve Burch (UMD). July 16, 2002.

Description of Soil at White Clay Creek Middle/High Site (WCC3)

Horizon	Depth (cm)	Description
A	0-12	Dark olive broiwn (2.5Y 3/3) loam (13% clay) with common (15%) fine and medium prominent strong brown (7.5YR 4/6) concentrations as pore linings and soft masses, few (1%) medium prominent black (5YR 2.5/1) concentrations as soft masses, and few (1%) medium faint olive gray (5Y 5/2) depletions; weak medium subangular blocky structure; friable; clear smooth boundary.
BA	12-25	Brown (10YR 4/3) loam (13% clay) with many (25%) fine and medium distinct strong brown (7.5YR 4/6) concentrations as pore linings and soft masses; common (3%) fine and medium prominent black (N2) concentrations as soft masses; few (2%) medium faint dark grayish brown (2.5Y 4/2) depletions; weak medium subangular blocky structure; friable; gradual smooth boundary.
Bw1	25-51	Brown (10YR 4/3) loam (14% clay) with many (20%) medium prominent strong brown (7.5YR 5/6) concentrations as pore linings, common (10%) medium distinct and prominent dark reddish brown (5YR 3/3) concentrations as pore linings, and common (10%) medium faint dark grayish brown (2.5Y 4/2) depletions; weak fine and medium subangular blocky structure; friable; clear smooth boundary.
Bw2	51-76	Brown (10YR 4/3) loam (13% clay) with many (20%) coarse prominent strong brown (7.5YR 4/6) concentrations as pore linings, common (10%) medium prominent dark reddish brown (5YR 3/3) concentrations as pore linings, and many (20%) medium faint dark grayish brown (2.5Y 4/2) depletions; weak fine to medium subangular blocky structure; friable; clear smooth boundary.
Bw3	76-104	Dark grayish brown (2.5Y 4/2.5) loam (15% clay) with many (25%) medium prominent yellowish red (5YR 4/6) concentrations as pore linings, common (5%) medium prominent dark reddish brown (5YR 3/4) concentrations inside pore linings, and many (25%) medium and coarse faint dark gray (2.5Y 4/1) depletions, moderate medium subangular blocky structure, friable; clear smooth boundary.
Bg	104-116	Dark gray (2.5Y 4/1) and dark grayish brown (2.5Y 4/2) silt loam (21% clay) with common (15%) medium and coarse prominent strong brown (7.5YR 4/6) concentrations as pore linings and few (5%) medium and coarse prominent black (5YR 2/1) concentrations as pore linings; moderate fine to medium subangular blocky structure; friable, abrupt smooth boundary.

Oab1	116-156	Black (10YR 2/1) mucky organic horizon with sapric materials; structureless massive; 0.8 n-value; abrupt smooth boundary.
Oab2	156-176	Very dark brown (7.5YR 2.5/2) mucky organic horizon with sapric materials; structureless massive; 0.8 n-value; clear smooth boundary.
Ab	186+	Very dark gray (10YR 3/1) sandy loam high in organic matter; weak medium to coarse subangular blocky structure; friable.

Classification:	Coarse loamy, mixed, mesic, active Fluvaquentic Dystrudept
Location:	Middle/High site along White Clay Creek. New Castle County, Delaware. Off of Park Rd., 100m from Ranger's Station
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none
Slope:	0%
Remarks:	
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), Phil King (NRCS), Robert Vaughan (UMD), Phillip Zurheide (UMD), and Steve Burch (UMD). July 16, 2002.

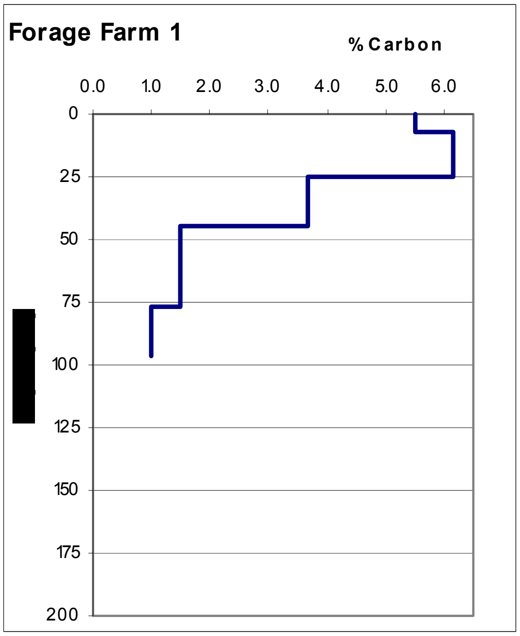
Description of Soil at White Clay Creek High Site (WCC4)

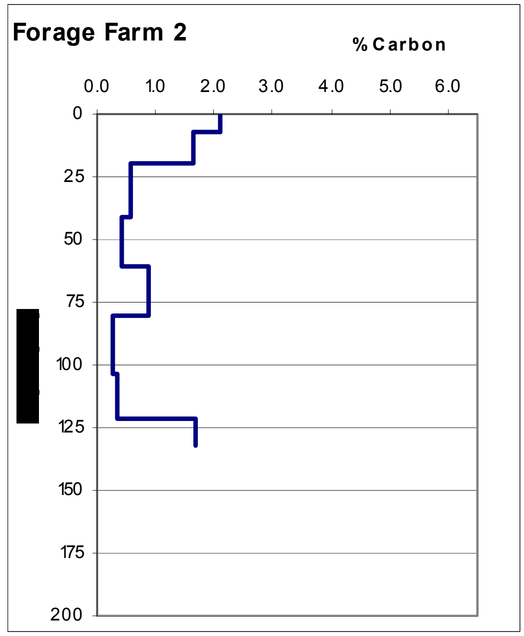
Horizon	Depth (cm)	Description
A	0-13	Dark brown (10YR 3/3) loam (14% clay), weak medium granular structure, very friable, clear smooth boundary.
BA	13-28	Dark yellowish brown (10YR 4/4) loam (14% clay) with few (1%) fine distinct strong brown (7.5YR 4/6) soft masses of iron; weak fine and medium subangular blocky structure, friable, clar smooth boundary.
Bw1	28-43	Dark yellowish brown (10YR 4/6) loam (15% clay) with common (15%) medium and coarse distinct strong brown (7.5YR 4/6) pore linings of iron, common (3%) fine black (N2) soft masses of manganese, and common (4%) medium faint brown (10YR 5/3) iron depletions; weak medium and coarse subangular blocky structure; friable; abrupt smooth boundary.
Bw2	43-67	Olive brown (2.5Y 4/3) loam (15% clay) and three 1-2cm lenses of loamy sand with many medium and coarse prominent strong brown (7.5YR 4/6) soft masses and pore linings of iron, common (5%) coarse prominent yellowish red (5YR 4/6) pore linings of iron, common (3%) fine prominent black (N2) pore linings of manganese, and common (4%) coarse faint dark grayish brown (2.5Y 4/2) iron depletions; weak medium subangular blocky structure; friable; abrupt smooth boundary.
Bw3	67-83	Olive brown (2.5Y 4/3) loam (16% clay) with many (20%) medium prominent strong brown (7.5YR 4/6) soft masses and pore linings of iron, common (7%) medium and coarse prominent black (N2) soft masses and pore linings of manganese; weak medium and coarse subangular blocky structure, friable, clear smooth boundary.
Bg1	83-114	Dark grayish brown (2.5Y 4/2) loam and silt loam (19% clay) with many (20%) medium and coarse prominent strong brown (7.5YR 4/6) and many (20%) medium and coarse prominent strong brown (7.5YR 5/8) soft masses and pore linings of iron, few fine prominent black (N2) soft masses of manganese, and common (10%) medium and coarse faint gray (2.5Y 5/1) iron depletions; moderate medium subangular blocky; friable; clear smooth boundary.
Bg2	114-120	Dark gray (2.5Y 4/1) (60%) and dark grayish brown (2.5Y4/2) (25%) silt loam (21% clay) with common (10%) fine and medium prominent dark red (2.5YR 3/6) and fine and medium prominent yellowish red (5YR 4/6) pore linings of iron; weak medium subangular blocky structure; friable; abrupt smooth boundary.

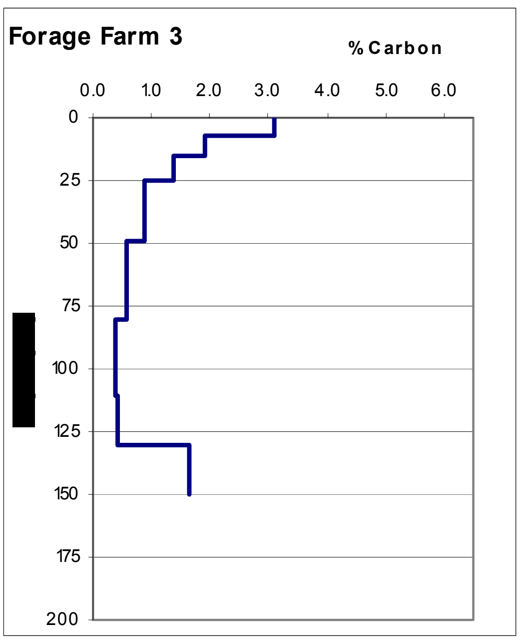
Ab	120-152	Black (10YR 2/1) sil (23% clay) with many (25%) fine and medium prominent dark red (2.5YR 3/6) pore linings and ped faces of iron; moderate fine and medium subangular blocky parting to moderate medium granular structure; friable; clear smooth boundary.
Bgb	152-162	Dark gray (2.5Y 4/1) loam (12%) with common (15%) fine and medium prominent strong brown (7.5YR 4/6) and common (10%) medium distinct yellowish red (5YR 4/6) pore linings of iron, and common (5%) medium faint gray (2.5Y 5/1) iron depletions; weak medium and coarse subangular blocky structure; friable.
Bwb	162-192	Olive brown (2.5Y 5/3) loam (15%) with many (35%) medium and coarse strong brown (7.5YR 5/8) soft masses and pore linings of iron and common (5%) medium and coarse distinct dark gray (5Y 4/1) iron depletions; weak medium and coarse subangilar blocky structure; friable.
Cg	192-255	Very dark greenish gray (5GY 3/1) fine sandy loam (8% clay), structureless massive, friable.
A'b	255-293	Black (10YR 2/1) sandy loam (8% clay); structureless massive, friable.

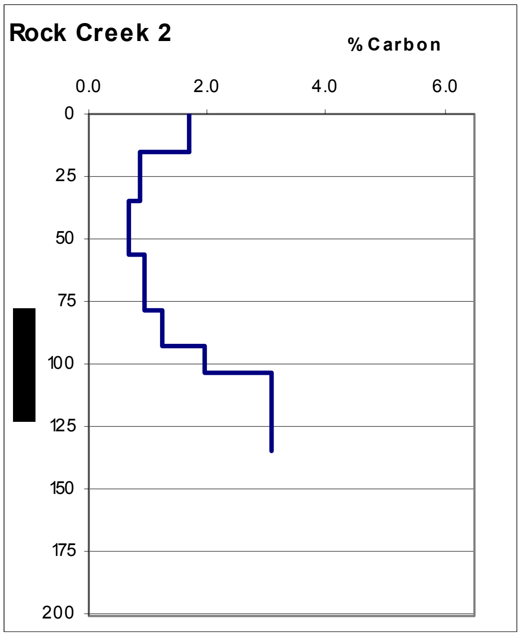
Classification:	Coarse loamy, mixed, mesic, active Fluventic Dystrudept
Location:	High site along White Clay Creek. Off of Park Rd., 100m from Ranger's Station, New Castle County, Delaware.
Parent Material:	Alluvium
Physiography:	Piedmont
Geomorphology:	Floodplain
Stoniness:	none
Slope:	<1%
Remarks:	Augering began at 162cm. Reaction to alpha-alpha dipyridal occurred spotty between 152 and 192cm and positive. below 192cm.
Described by:	Karen Castenson (UMD), Martin Rabenhorst (UMD), Phil King (NRCS), Robert Vaughan (UMD), Phillip Zurheide (UMD), and Steve Burch (UMD). July 16, 2002.

Appendix B: Organic Carbon Data





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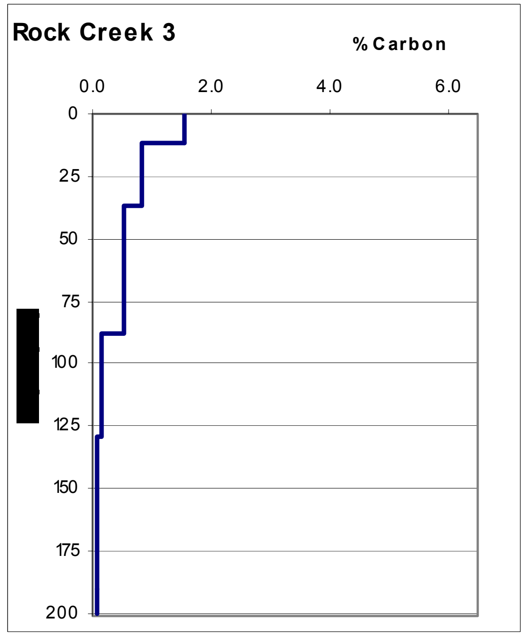
50
75
100
125
150
175
200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% Carbon
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6.0
0
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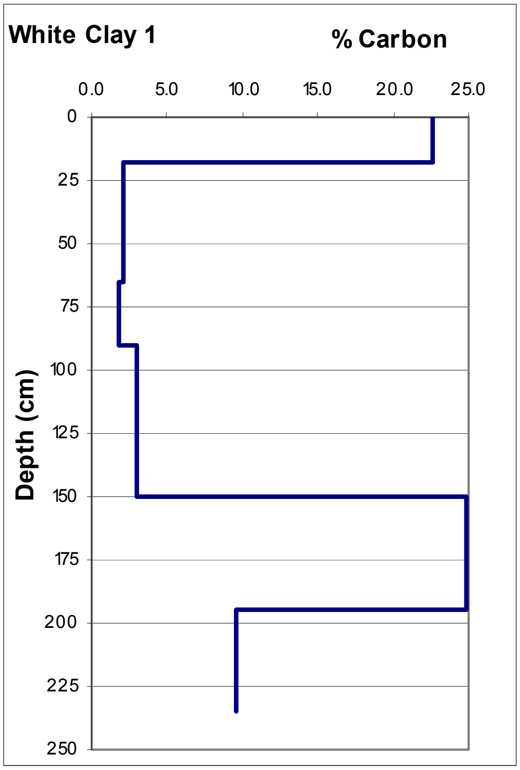
75
100
125
150
175
200


White Clay 1
% Carbon
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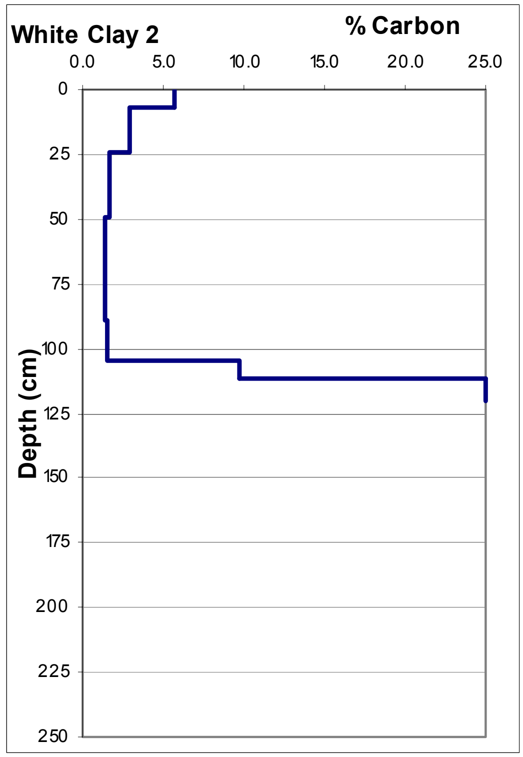
0 25 50 75 100 125 150 175 200 225 250
Depth (cm)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% Carbon
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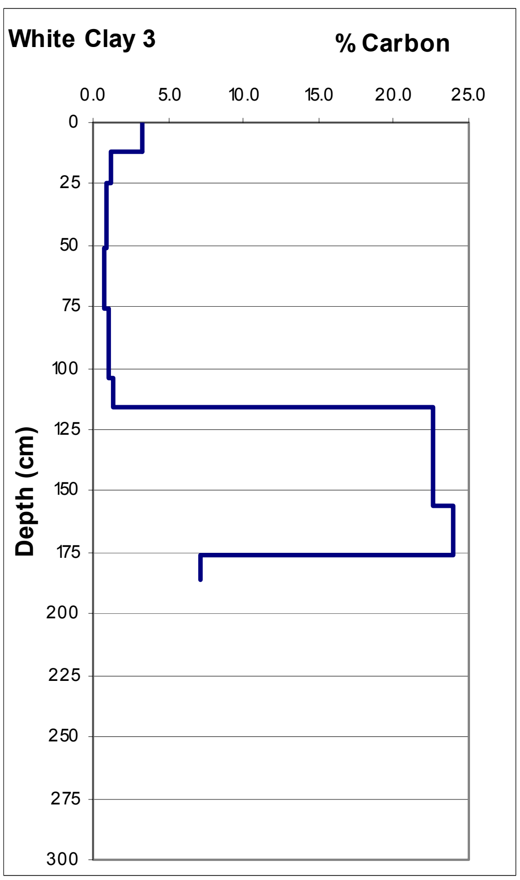
0 25 50 75 100 125 150 175 200 225 250
Depth (cm)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% Carbon
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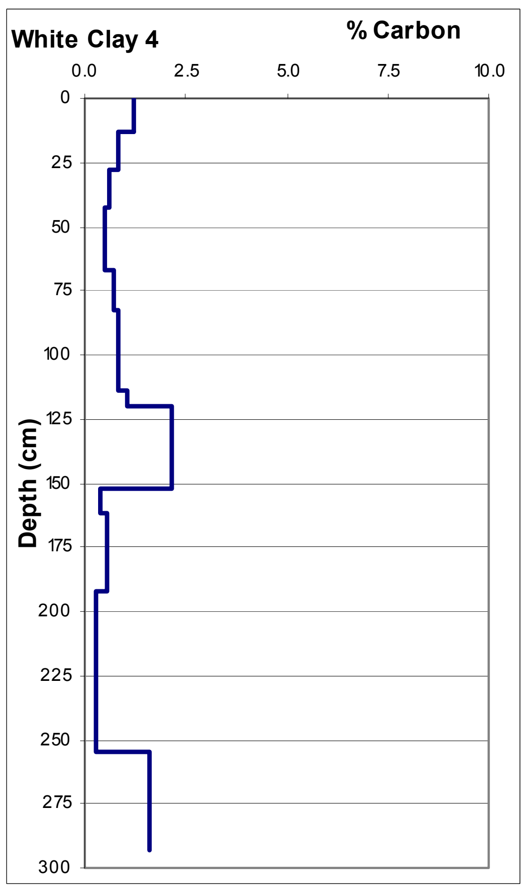
0 25 50 75 100 125 150 175 200 225 250 275 300
Depth (cm)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% Carbon
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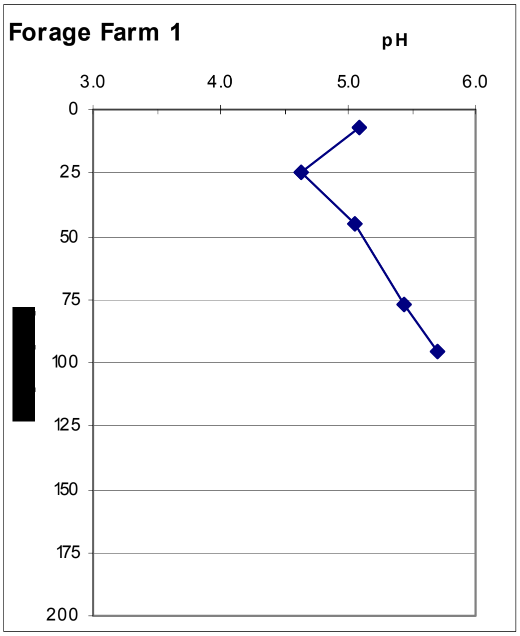
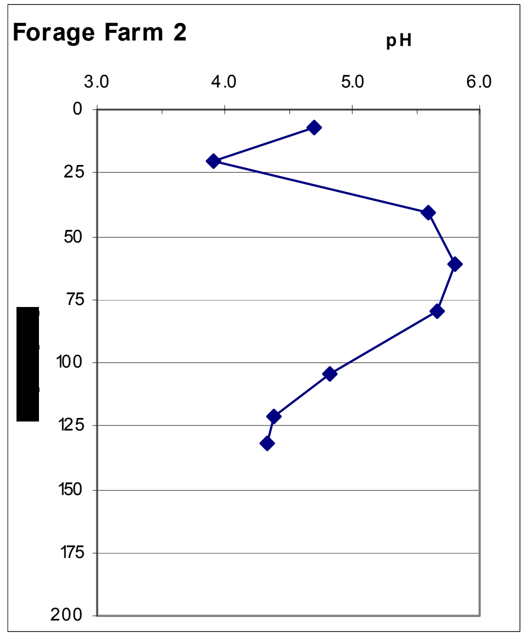
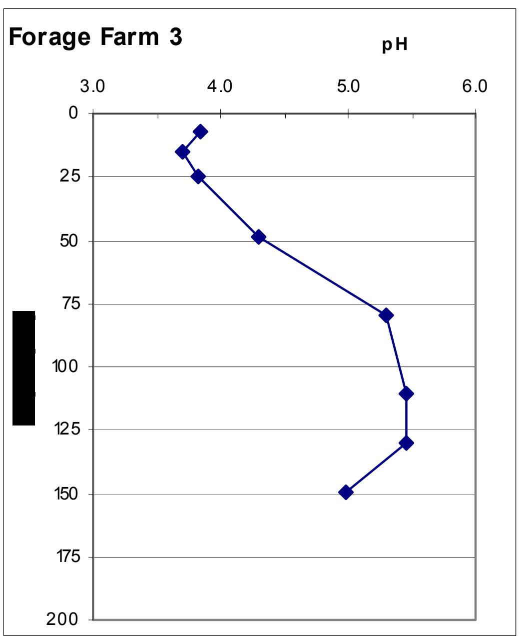
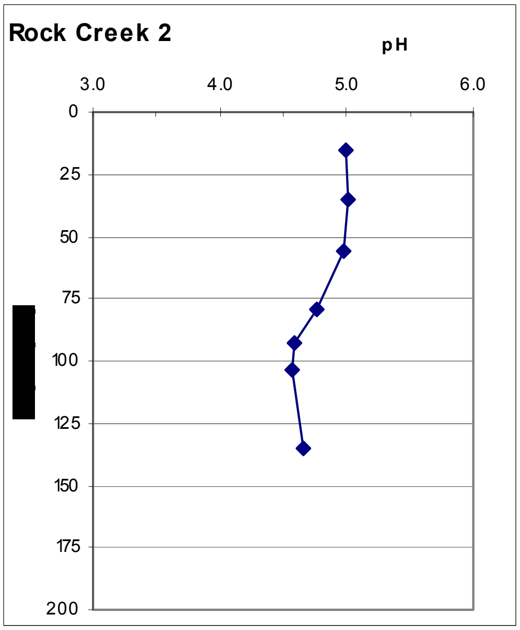
Depth (cm)

Appendix C: pH Data





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6.0
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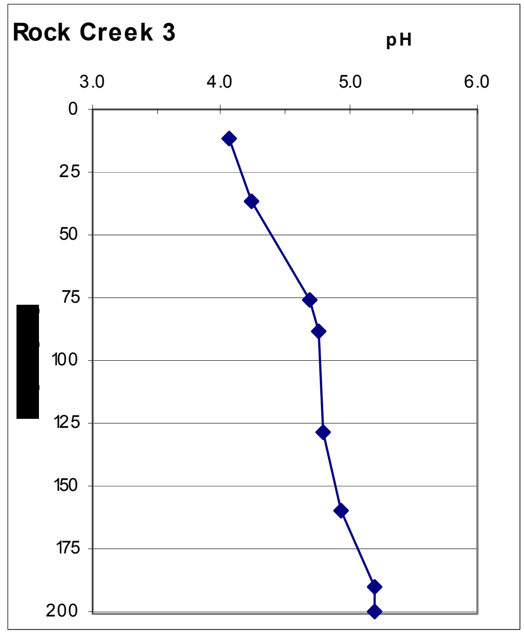
75
100
125
150
175
200
[redacted]


Rock Creek 3
pH
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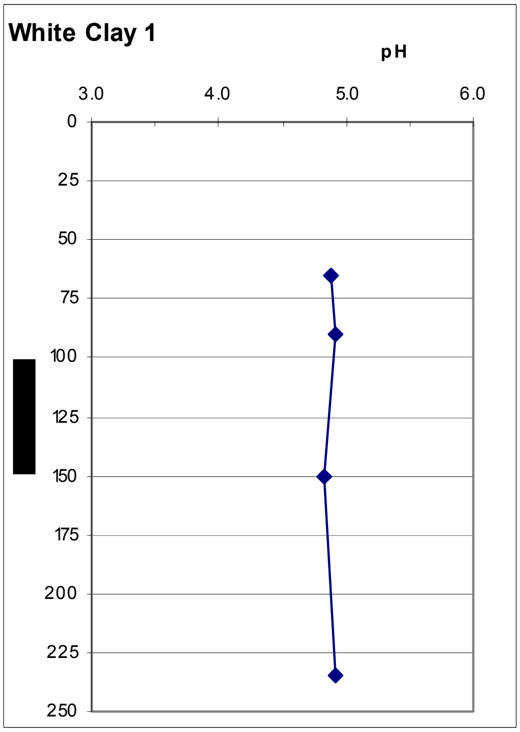
4.0
5.0
6.0
0
25
50
75
100
125
150
175
200
[redacted]


White Clay 1
pH
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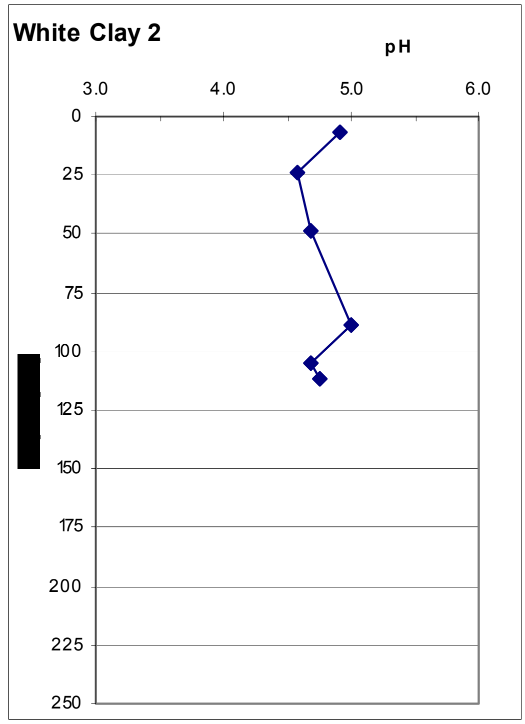
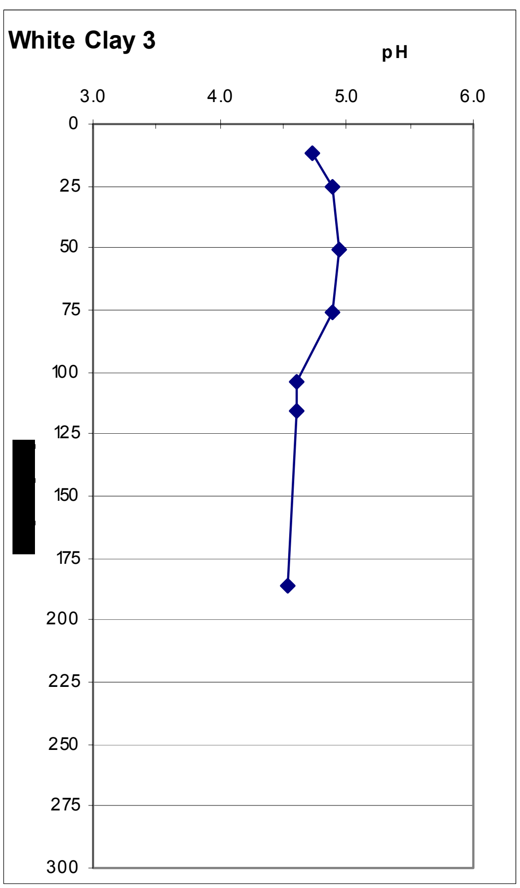
6.0
0
25
50
75
100
125
150
175
200
225
250
[redacted]


White Clay 2
pH
3.0
4.0
5.0
6.0
0
25
50
75
100
125
150
175
200
225
250
[redacted]


White Clay 3
pH
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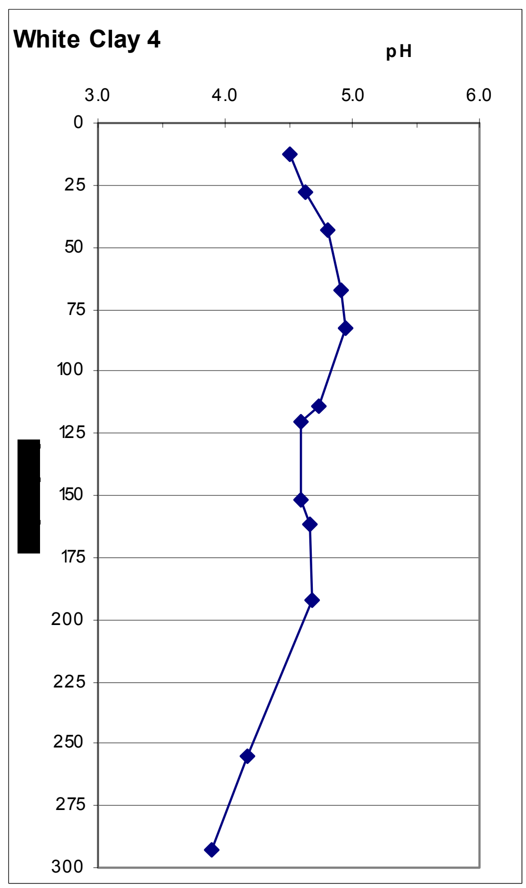
6.0
0
25
50
75
100
125
150
175
200
225
250
275
300
[redacted]


White Clay 4
pH
3.0
4.0
5.0
6.0
0
25
50
75
100
125
150
175
200
225
250
275
300
[redacted]

Appendix D: Particle Size Analysis Data

						---- Sand ----					
Pedon	Sample	% sand	%silt	% clay	% fine clay	% vc	% c	% m	% f	% vf	% CF
FF1	A1 0-7	28.4	49.2	22.4	6.2	0.2	0.9	1.1	10.2	16.0	0.0
FF1	A2 7-25	19.1	52.8	28.1	7.6	0.0	0.9	1.6	7.3	9.3	0.0
FF1	Cg1 25-45	13.2	68.5	18.3	2.5	0.1	1.7	1.1	4.4	5.9	0.0
FF1	Cg2 45-77	23.8	62.6	13.6	2.3	0.7	0.2	1.3	8.0	13.5	0.0
FF1	Cg3 77-96	68.3	25.3	6.4	1.5	0.3	6.6	26.5	22.3	12.6	0.0
FF2	A 0-7	30.5	49.5	20.0	5.9	0.3	1.0	1.4	13.3	14.6	0.0
FF2	BA 7-20	12.5	61.7	25.8	8.3	0.2	0.3	1.0	3.7	7.3	0.0
FF2	Bw1 20-41	52.0	37.6	10.3	2.6	0.9	4.6	10.9	23.8	11.8	0.1
FF2	Bw2 41-61	68.0	24.0	8.0	2.0	1.0	11.7	15.1	28.6	11.7	0.3
FF2	Bw3 61-80	22.6	59.1	18.3	4.0	0.1	1.1	3.2	9.9	8.3	0.1
FF2	Cg 80-104	58.6	29.5	11.9	3.3	0.6	2.0	6.3	18.8	30.9	0.2
FF2	Ab1 104-121	64.7	20.6	14.7	8.9	0.3	4.3	15.1	35.1	9.8	0.1
FF2	Ab2 121-132	70.1	18.6	11.3	5.3	0.4	3.8	18.3	34.1	13.6	0.4
FF3	A 0-7	26.7	50.4	22.9	6.4	0.0	0.3	0.5	9.8	16.0	0.0
FF3	BA 7-15	14.5	59.2	26.3	8.4	0.0	0.2	0.6	2.9	10.8	0.0
FF3	Bw1 15-25	15.3	66.3	18.4	5.7	0.1	0.9	1.3	4.1	8.8	0.0
FF3	Bw2 25-49	16.2	64.2	19.6	5.8	0.1	1.5	1.8	0.4	12.5	0.0
FF3	Bw3 49-80	45.3	43.7	11.0	2.8	0.2	2.0	6.7	22.5	14.0	0.0
FF3	Bg1 80-111	36.8	42.9	20.3	6.7	0.1	1.4	3.3	14.5	17.5	0.0
FF3	Bg2 111-130	44.4	33.7	22.0	10.3	0.3	2.2	4.5	22.2	15.2	0.0
FF3	2Ab 130-150	76.0	14.9	9.0	4.9	0.3	3.8	16.3	43.7	11.9	0.0

						------------------------------ Sand ------------------------------ ---					
						%	%	%	%	%	%
Pedon	Sample	% sand	%silt	% clay	% fine clay	vc	c	m	f	vf	CF
RC2	A 0-15	13.5	64.9	21.6	4.1	0.0	0.4	0.8	3.3	8.9	0.0
RC2	Bw1 15-35	13.4	70.2	16.4	2.6	0.2	1.2	2.1	4.0	5.9	0.0
RC2	Bw2 35-59	12.2	71.4	16.4	5.2	0.2	0.6	1.9	2.4	7.0	0.0
RC2	Bg 59-79	9.0	71.5	19.6	10.4	0.3	0.7	0.9	1.5	5.5	0.0
RC2	AB 79-93	7.7	67.3	24.9	8.0	0.0	0.3	0.5	2.0	4.9	0.0
RC2	Ab1 93-104	26.7	49.9	23.4	8.8	0.2	0.5	3.5	10.7	11.7	0.0
RC2	Ab2 104-135	35.9	42.0	22.1	7.7	0.3	0.9	3.6	17.2	13.8	0.1
RC3	A 0-12	40.3	44.5	15.3	4.5	0.0	0.4	5.1	18.6	16.2	0.1
RC3	Bw1 12-37	26.9	60.3	12.8	1.2	0.2	0.7	2.4	10.6	13.0	0.0
RC3	Bw2 37-76	22.5	62.6	14.9	4.4	0.0	0.7	1.5	7.6	12.6	0.0
RC3	BC 76-88	48.7	40.1	11.1	4.1	0.1	0.7	7.2	25.5	15.3	0.0
RC3	2Cg 88-129	59.0	32.8	8.2	3.0	0.1	1.3	5.8	19.8	32.1	0.0
RC3	2C1 129-160	82.4	13.6	3.9	4.3	0.5	8.0	35.1	29.4	9.3	0.0
RC3	2C2 160-190	81.9	11.2	6.9	3.7	0.4	12.9	27.4	32.6	8.7	0.0
RC3	3C3 190-200	78.3	14.3	7.3	4.1	12.3	17.0	24.1	17.1	7.8	39.0

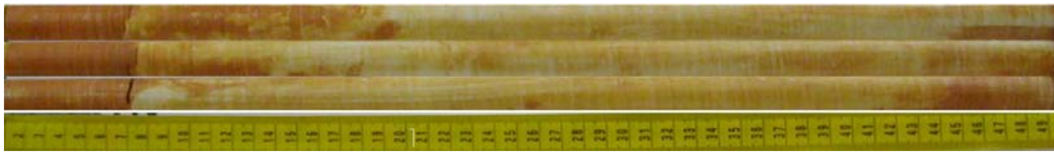
						Sand					
Pedon	Sample	% sand	%silt	% clay	% fine clay	% vc	% c	% m	% f	% vf	% CF
WCC1	Cg1 18-65	21.0	65.1	13.9	2.6	1.3	2.6	2.4	5.1	9.6	1.0
WCC1	Cg2 65-90	17.2	68.6	14.2	2.6	1.3	2.9	1.6	2.5	8.9	0.2
WCC1	lense 65-90	81.2	14.9	3.9	1.1	25.1	33.5	9.4	7.9	5.3	4.8
WCC1	Cg3 90-150	16.9	68.0	15.0	3.2	0.2	0.8	1.3	4.3	10.4	0.0
WCC1	Ab 195-235	54.2	27.8	17.9	7.0	1.1	2.5	13.5	27.6	9.5	0.0
WCC2	A 0-7	21.6	60.4	18.0	5.1	0.0	0.7	1.3	5.2	14.4	0.0
WCC2	Cg1 7-24	21.7	66.4	12.0	2.5	0.2	2.0	1.4	1.8	16.4	0.0
WCC2	Cg2 24-49	18.5	67.6	13.9	3.1	0.0	0.6	0.9	5.6	11.3	0.0
WCC2	Cg3 49-89	12.9	69.8	17.3	3.3	0.1	0.6	0.4	2.4	9.4	0.0
WCC2	Cg4 89-105	3.6	70.5	25.8	6.0	0.2	0.2	0.2	0.7	2.2	0.0
WCC2	Ab 105-112	5.4	65.4	29.3	8.3	0.0	0.5	0.5	1.2	3.1	0.0
WCC3	A 0-12	35.2	47.3	17.5	4.4	0.6	0.9	2.8	12.4	18.5	0.0
WCC3	BA 12-25	29.8	54.3	15.9	4.3	0.1	0.6	1.1	9.5	18.6	0.0
WCC3	Bw1 25-51	28.8	59.2	12.0	3.3	0.1	1.9	1.7	1.9	23.2	0.0
WCC3	Bw2 51-76	37.3	50.5	12.2	3.1	0.3	2.5	4.0	14.0	16.5	0.0
WCC3	Bw3 76-104	6.8	70.4	22.8	5.7	0.1	1.4	0.9	1.8	2.6	0.0
WCC3	Bg 104-116	7.1	71.1	21.8	5.8	0.2	1.2	1.4	1.4	2.8	0.0
WCC3	Ab 176-186	58.1	21.0	20.9	11.4	0.7	5.9	11.5	31.2	8.8	0.0

						------------------------------ Sand ---------------------------- ----					
Pedon	Sample	% sand	%silt	% clay	% fine clay	% vc	% c	% m	% f	% vf	% CF
WCC4	A 0-13	66.6	22.0	11.4	8.3	2.2	9.5	17.4	23.2	14.2	0.0
WCC4	BA 13-28	45.2	39.2	15.6	10.2	0.5	3.6	4.8	1.2	35.1	0.0
WCC4	Bw1 28-43	48.6	42.1	9.3	2.1	3.0	5.5	4.8	17.6	17.8	1.1
WCC4	Bw2 43-67	56.1	35.2	8.7	1.7	2.5	4.3	8.6	21.7	19.0	4.4
WCC4	Bw2 lense	80.7	15.4	3.9	0.7	17.7	20.1	13.8	21.7	7.4	9.6
WCC4	Bw3 67-83	38.9	49.9	11.2	2.4	0.6	3.4	5.9	12.2	16.8	0.2
WCC4	Bg1 83-114	14.9	67.5	17.6	4.4	0.3	1.5	1.2	3.8	8.1	0.0
WCC4	Bg2 114-120	14.1	68.2	17.7	4.8	0.1	0.7	1.2	3.4	8.8	0.0
WCC4	Ab 120-152	31.5	39.0	29.5	15.7	0.2	0.8	1.9	13.8	14.7	0.0
WCC4	Bgb 152-162	47.8	38.6	13.7	2.8	0.3	2.2	3.6	21.7	19.9	0.0
WCC4	Bwb 162-192	40.3	39.7	20.0	6.2	0.8	1.5	2.6	18.4	17.0	0.0
WCC4	A'b 255-293	80.0	8.7	11.3	9.0	0.2	1.9	16.6	46.5	14.8	0.0

Appendix E: IRIS Photos

Middle Patuxent River Low Well (FF1)

Date Out: 3-21-03

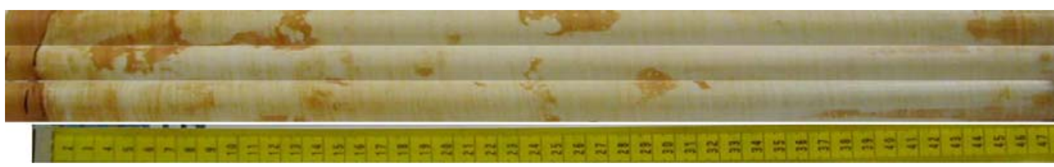


A

B

Date Out: 4-22-03

A



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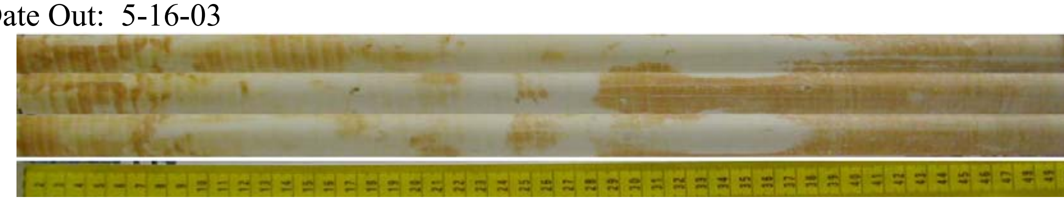
Date Out: 5-16-03



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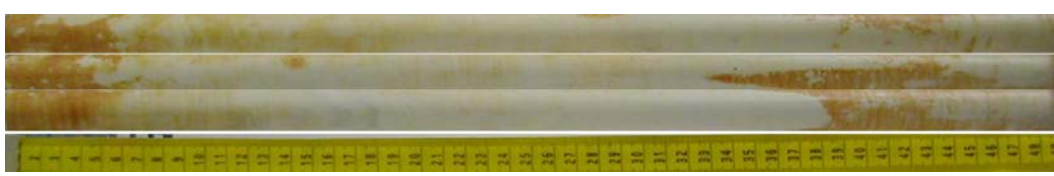

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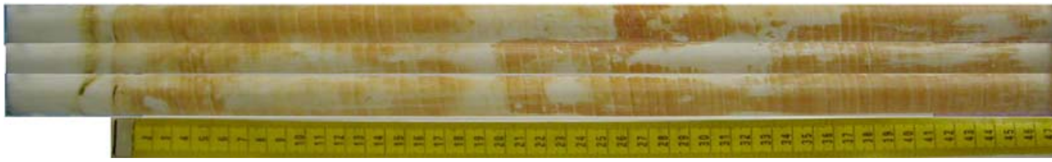
Date Out: 5-29-03



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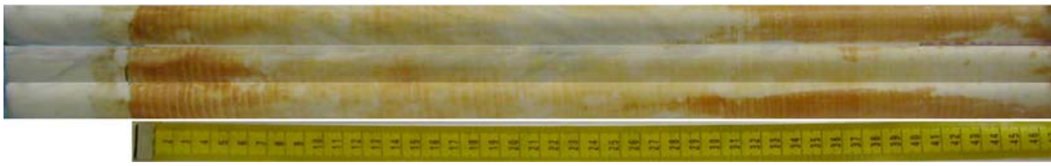

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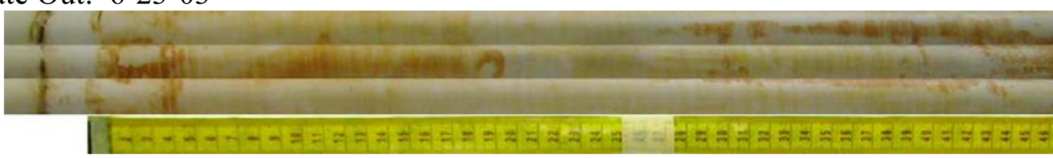
Date Out: 6-23-03



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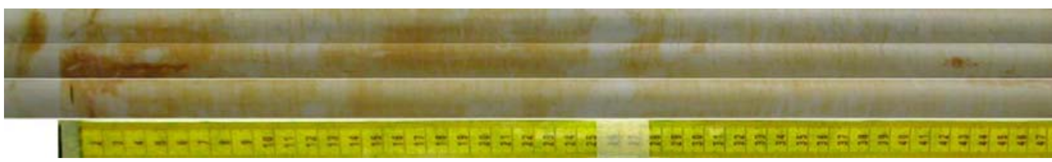

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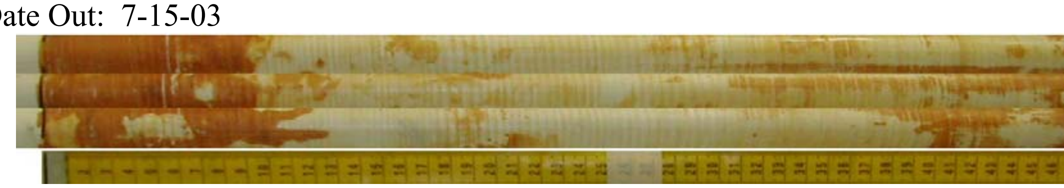
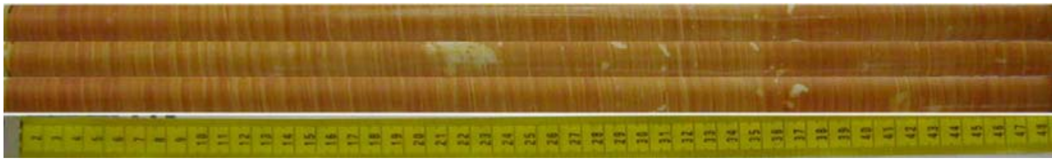
Date Out: 7-15-03



A

Middle Patuxent River Middle Well (FF2)
Date Out: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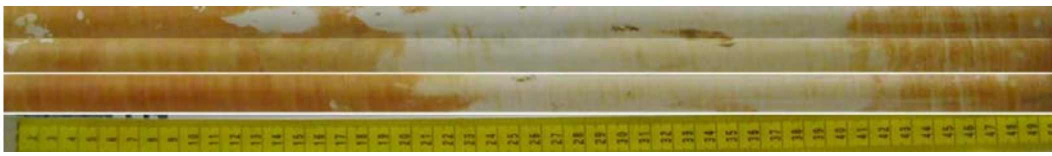
B

Date Out: 4-22-03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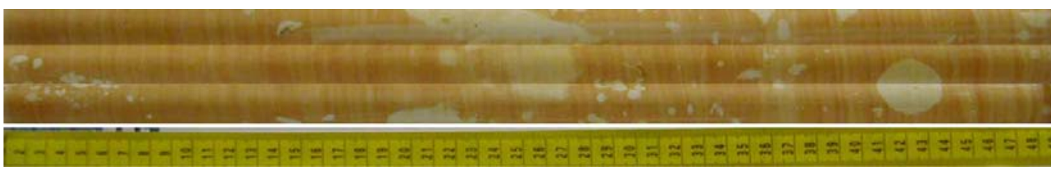
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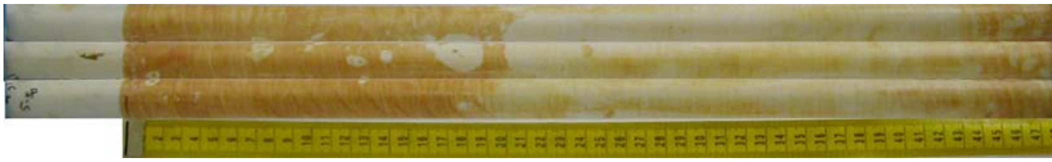
Date Out: 5-16-03


A


B

Date Out: 5-29-03



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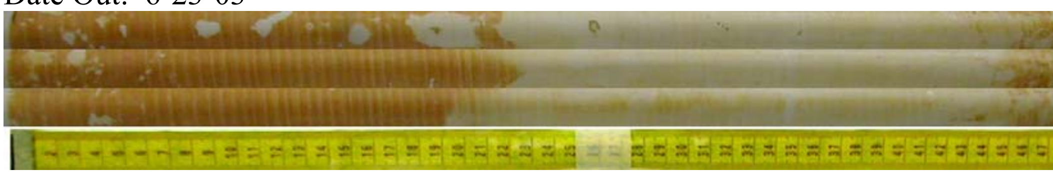
B

Date Out: 6-23-03



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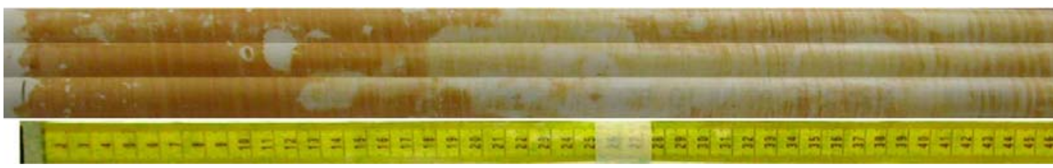

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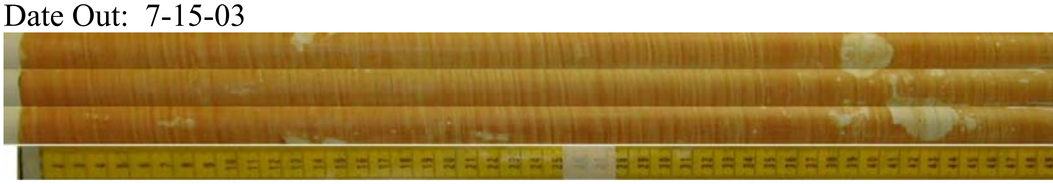
Date Out: 7-15-03



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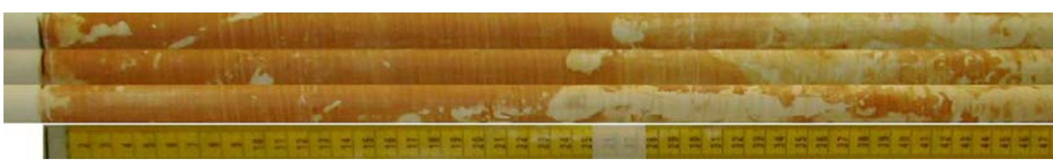
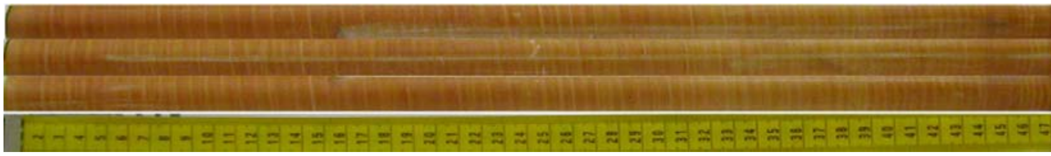


B

Middle Patuxent River High Well (FF3)
Date Out: 3-21-03


A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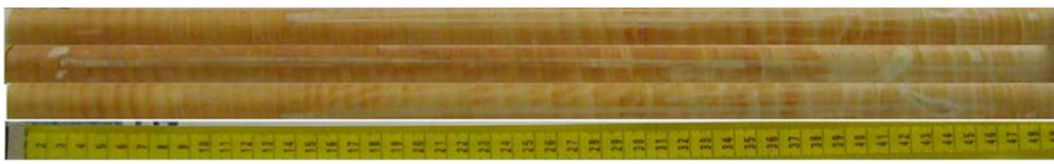
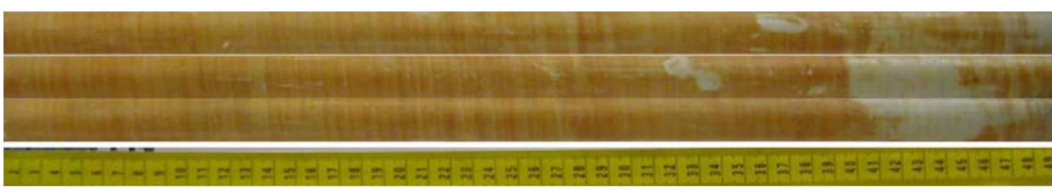
Date Out: 4-22-03


A


B

Date Out: 5-16-03


A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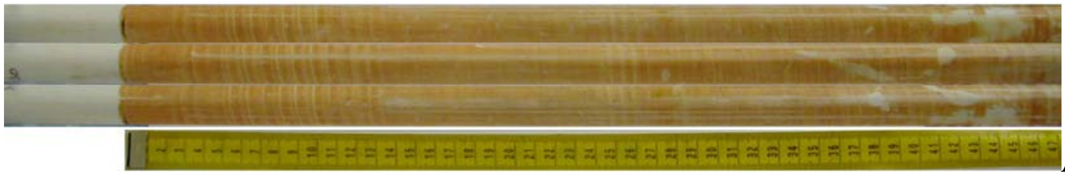
Date Out: 5-29-03



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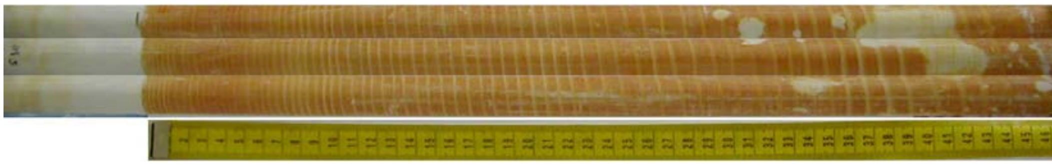


B

Date Out: 6-23-03

A

B

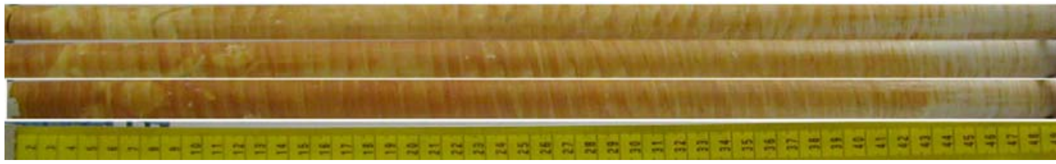
Date Out: 7-15-03

A

B

Rock Creek Low Well (RC1)

Date Out: 4-08-03



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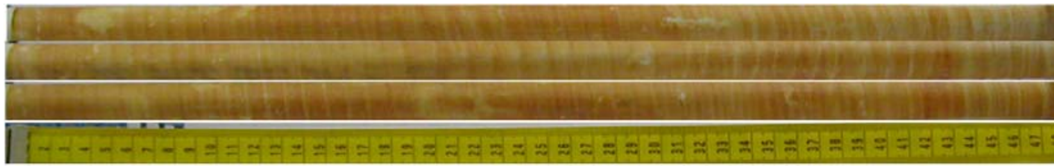


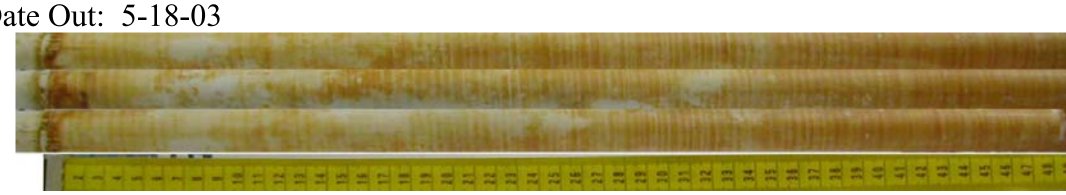
B

Date Out: 4-22-03

A

B

Date Out: 5-18-03



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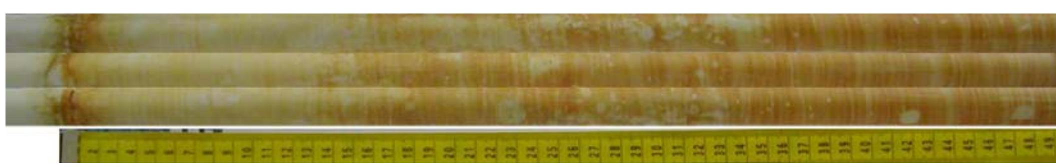
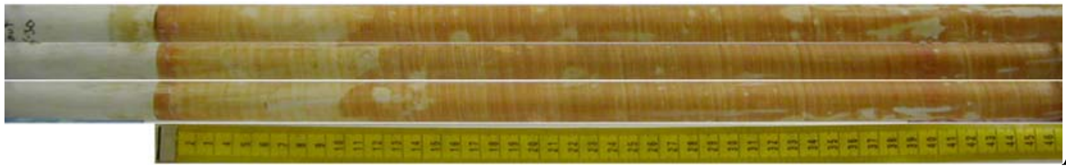


B

Date Out: 5-30-03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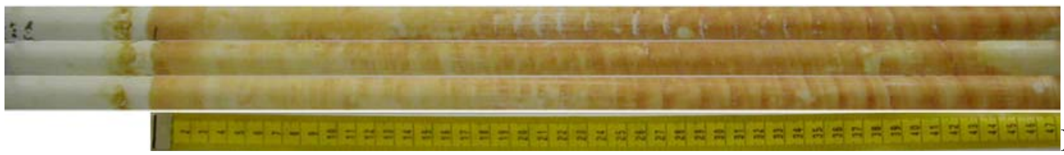
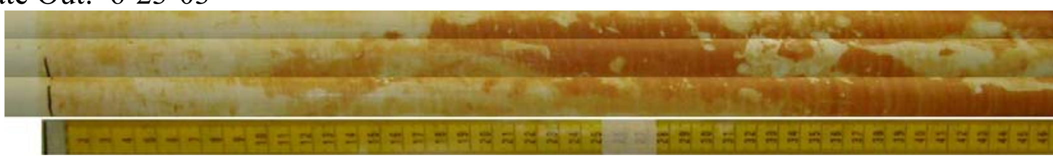

B

Date Out: 6-23-03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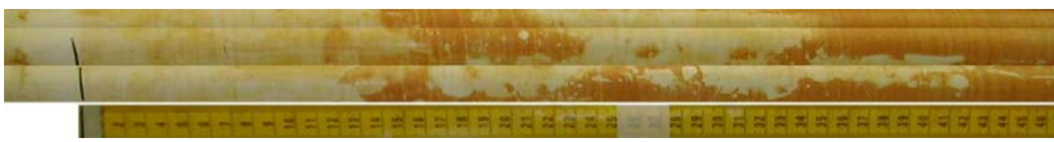
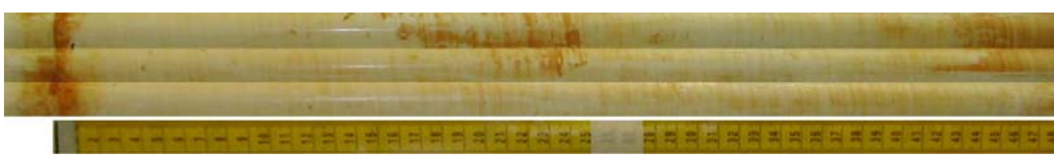

B

Date Out: 7-15-03


A

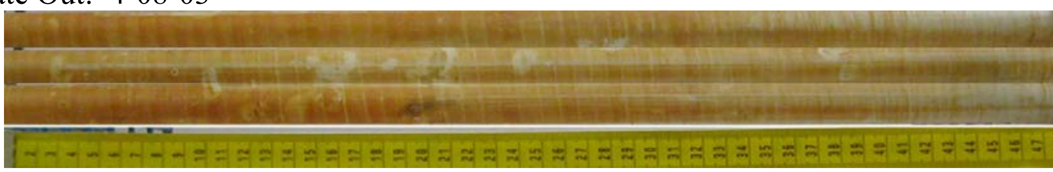

B

Rock Creek Middle Well (RC2)
Date Out: 3-27-03


A


B

Date Out: 4-08-03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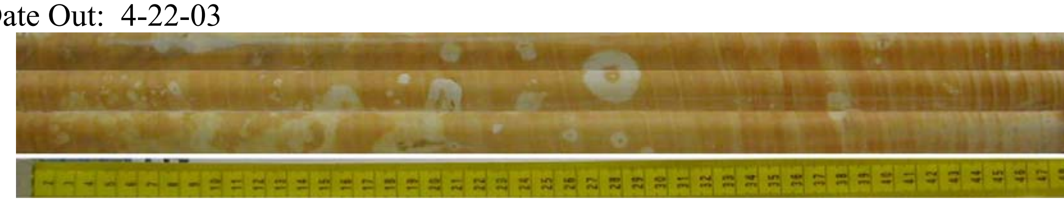
B

Date Out: 4-22-03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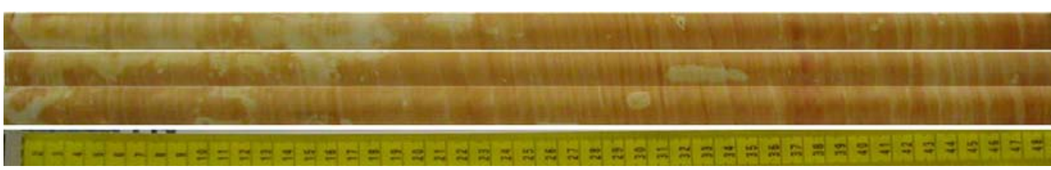
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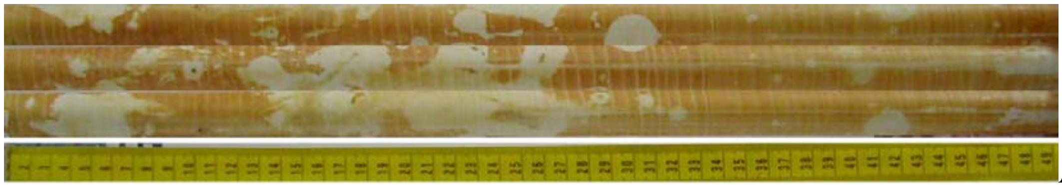
Date Out: 5-18-03



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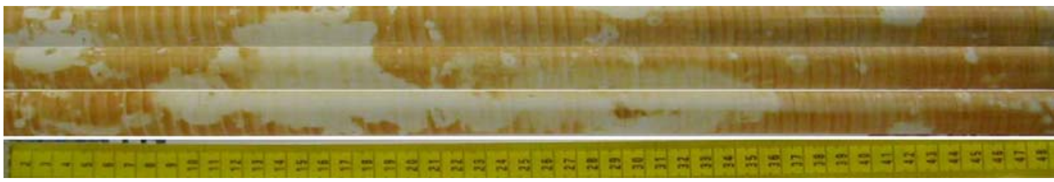


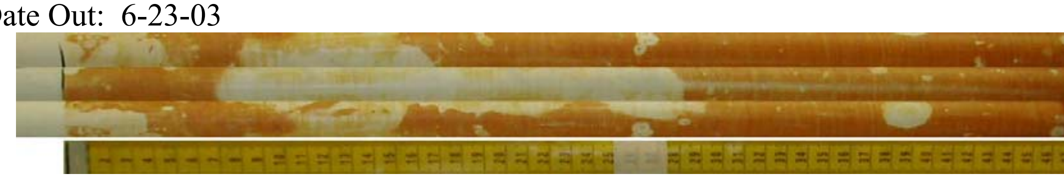
B

Date Out: 5-30-03

A

B

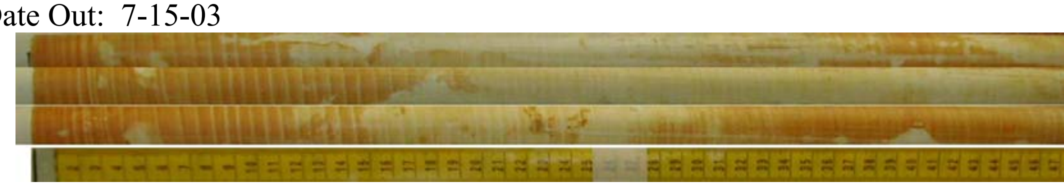
Date Out: 6-23-03



A

B

Date Out: 7-15-03



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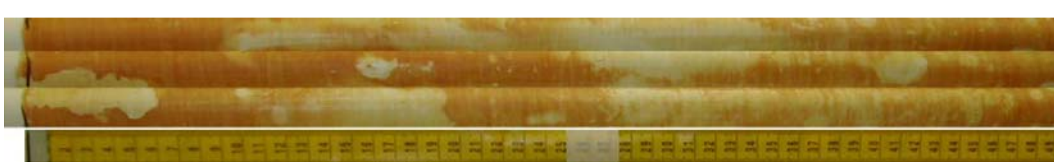
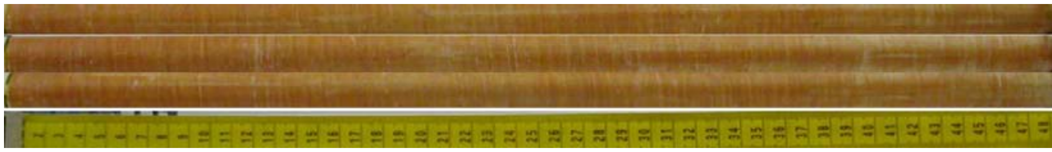


B

Rock Creek High Well (RC3)

Date Out: 3-27-03



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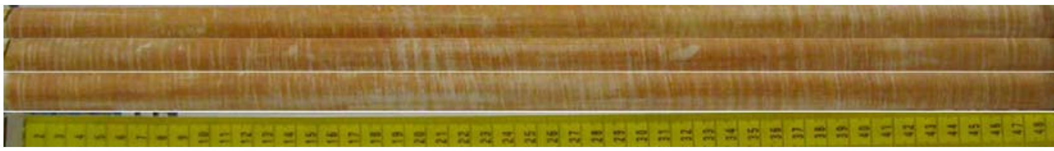
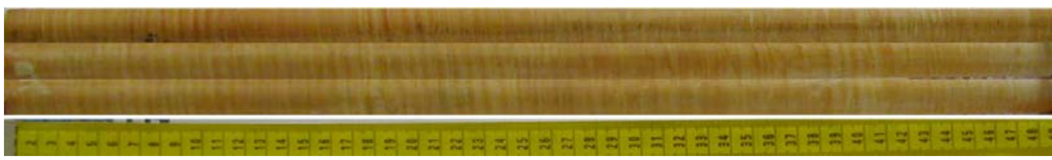


B

Date Out: 4-08-03

A



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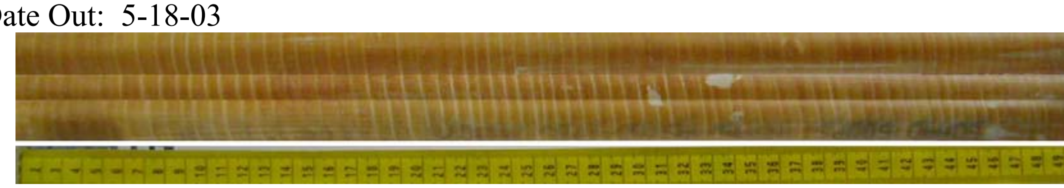
Date Out: 5-18-03



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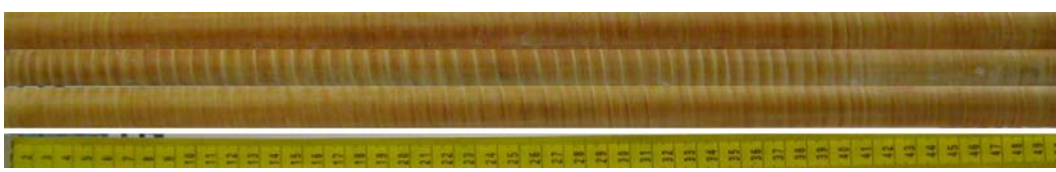

B

Date Out: 5-30-03

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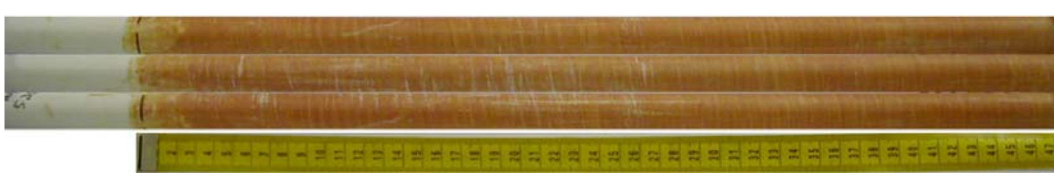

B

Date Out: 6-23-03

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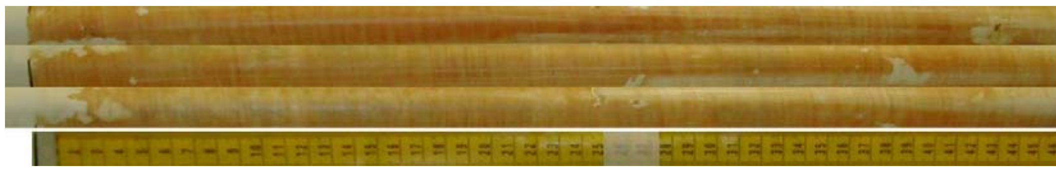


B

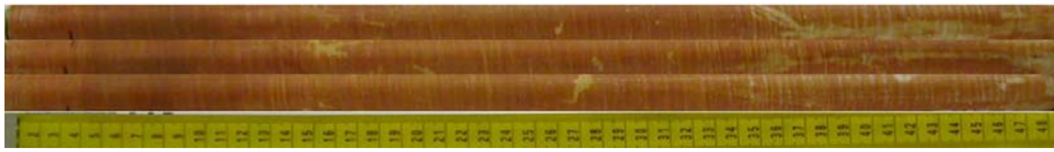
Date Out: 7-15-03

A

B

White Clay Creek Low Well (WC1)
Date Out: 3-27-03

A



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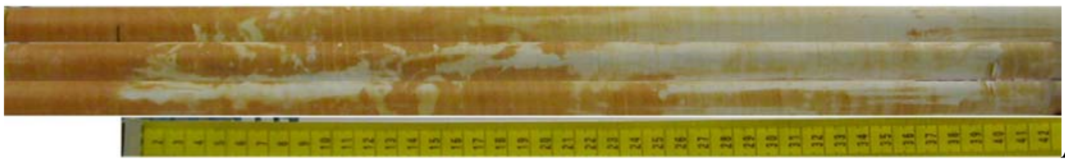
Date Out: 4-08-03



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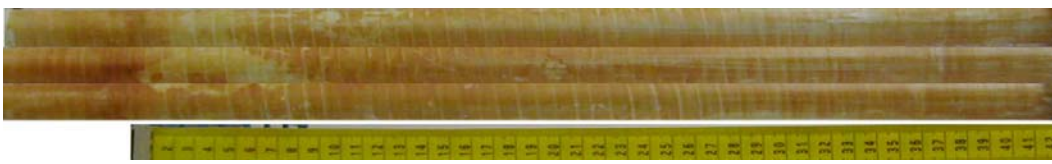
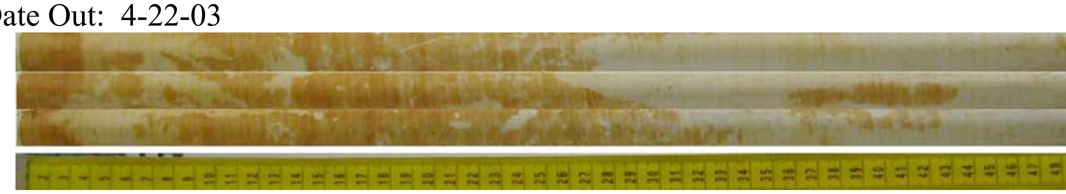


B

Date Out: 4-22-03



A

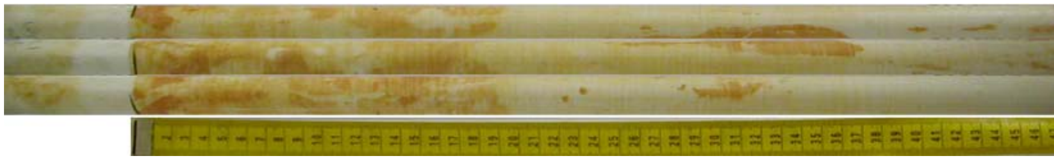
B

Date Out: 5-16-03

A

B

Date Out: 5-29-03



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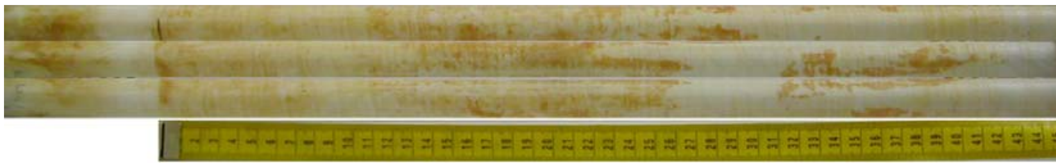

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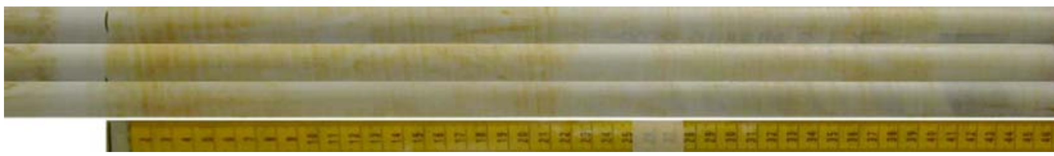
Date Out: 6-23-03



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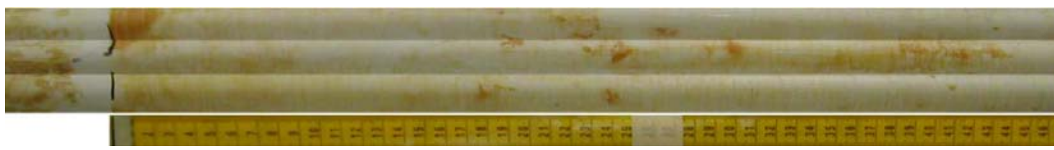

B

Date Out: 7-15-03

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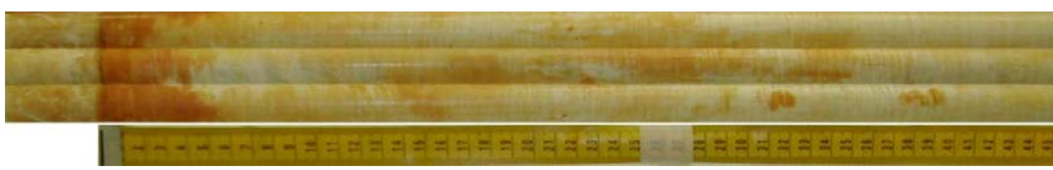
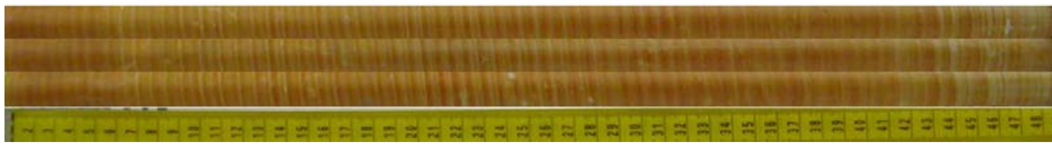


B

White Clay Creek Low-Mid Well (WC2)

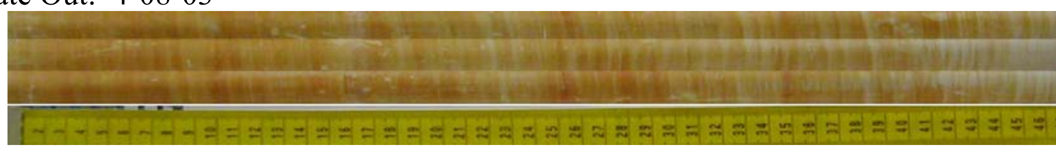
Date Out: 3-27-03

A



B

Date Out: 4-08-03



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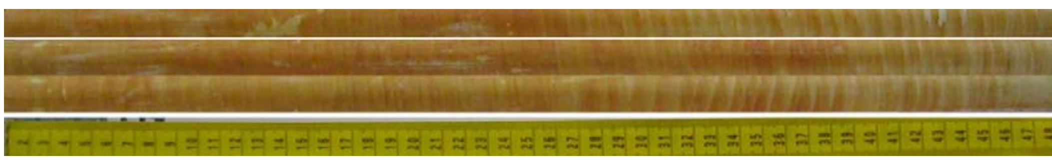


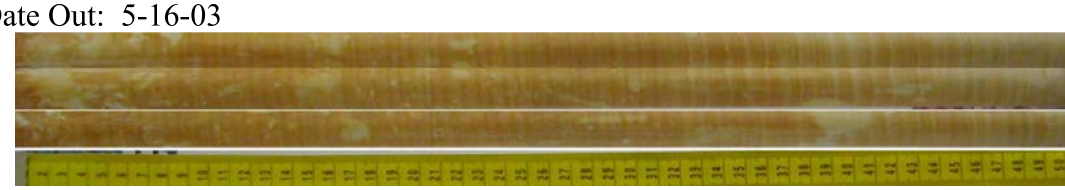
B

Date Out: 4-22-03

A

B

Date Out: 5-16-03



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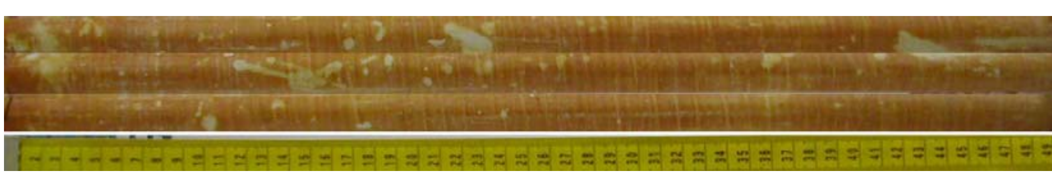
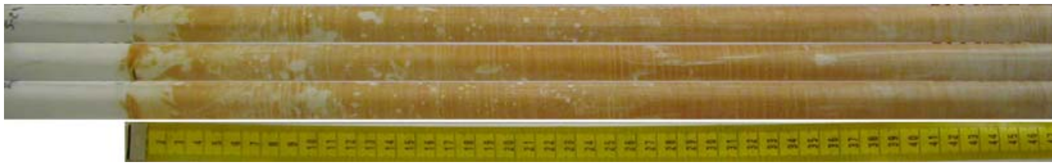


B

Date Out: 5-29-03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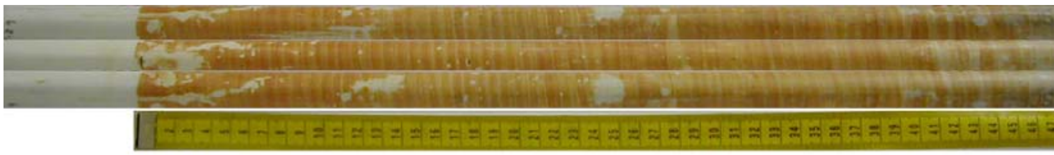
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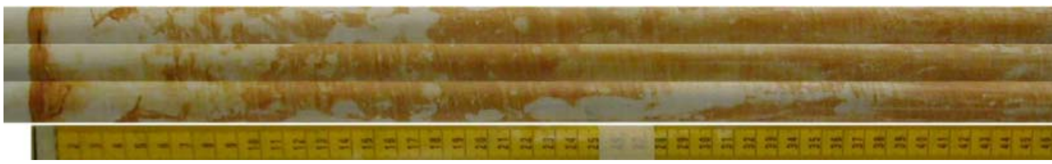
Date Out: 6-23-03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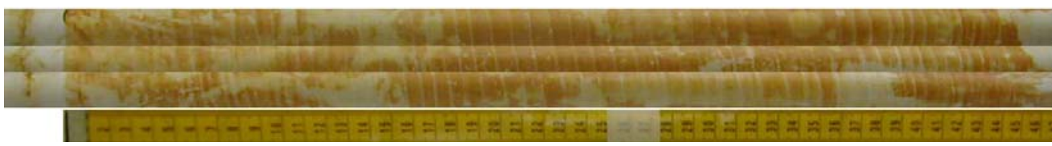
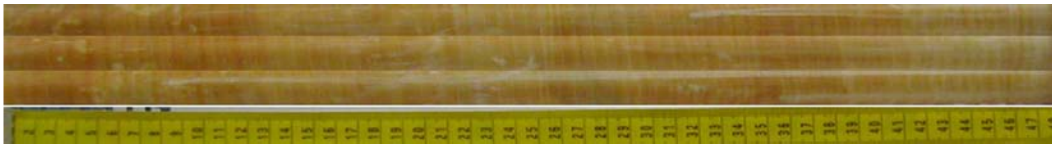

B

Date Out: 7-15-03


A


B

White Clay Creek Middle Well (WC3)
Date Out: 4-08-03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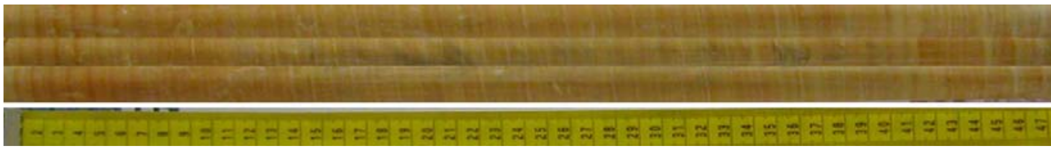
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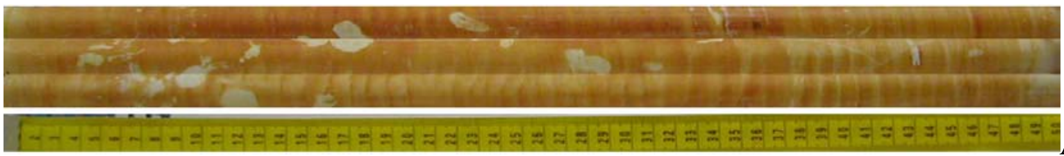
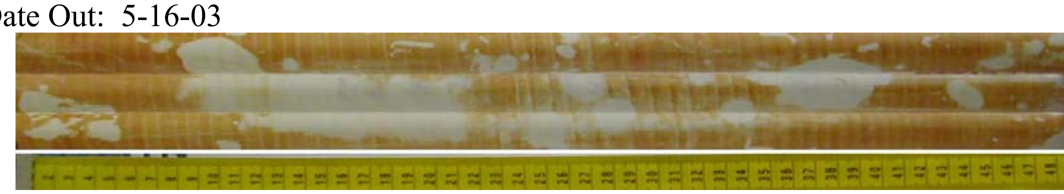
Date Out: 4-22-03


A


B

Date Out: 5-16-03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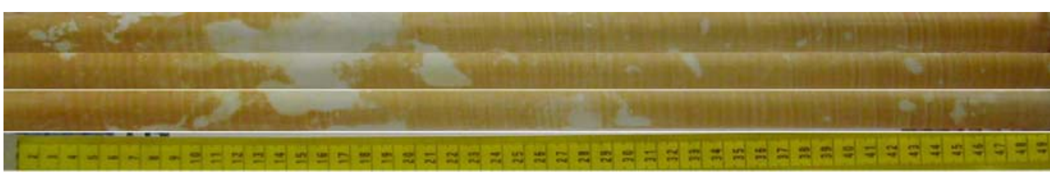
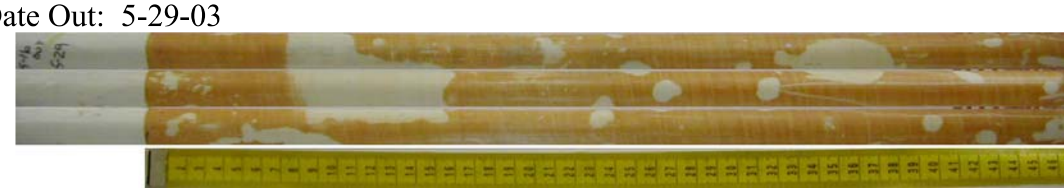
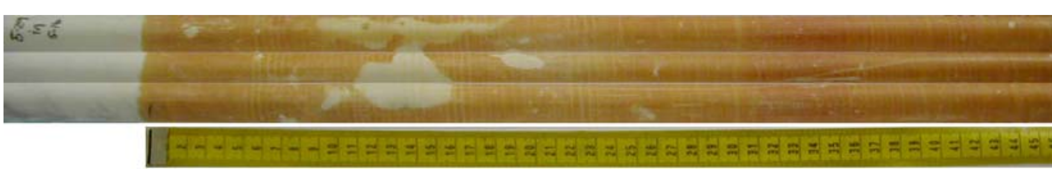
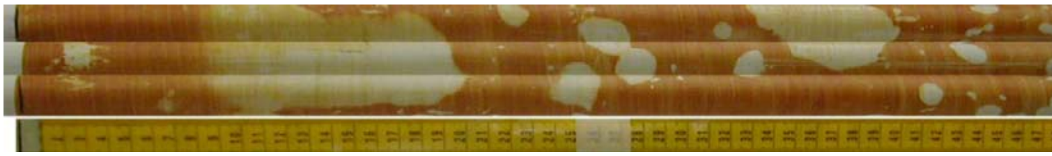

B

Date Out: 5-29-03

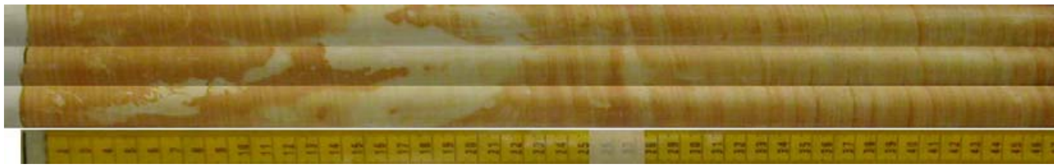

A


B

Date Out: 6-23-03



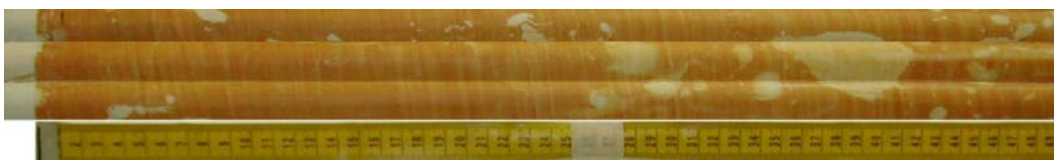
A



B

Date Out: 7-15-03

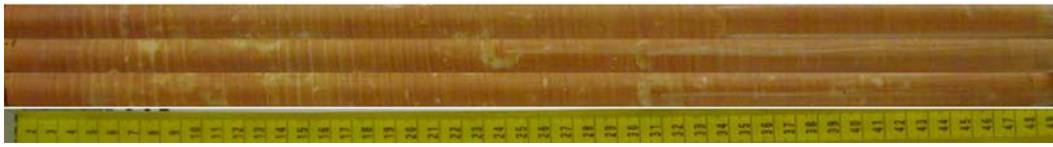
A



B

White Clay Creek High Well (WC4)

Date Out: 3-27-03

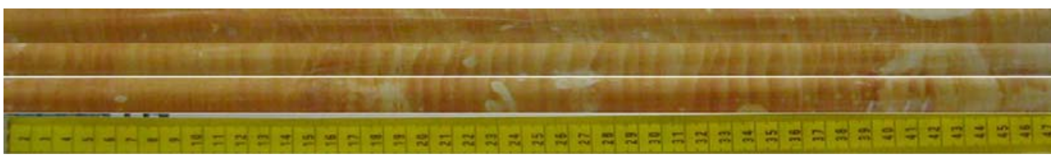


A

B

Date Out: 4-08-03

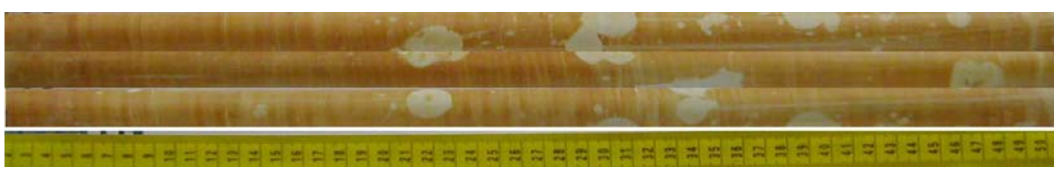
A



B

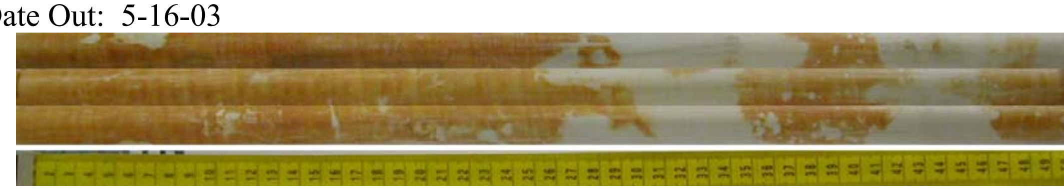
Date Out: 4-22-03

A

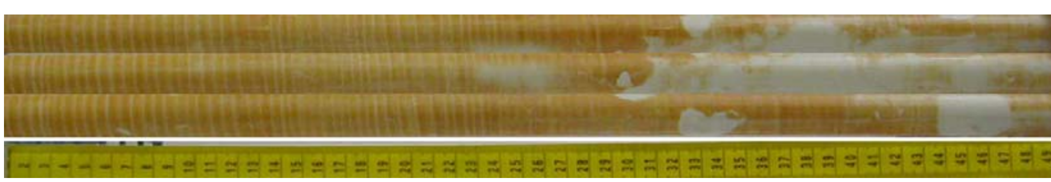


B

Date Out: 5-16-03

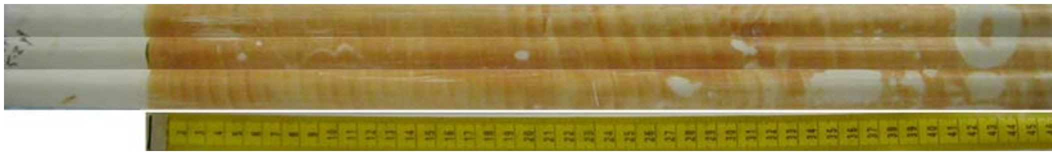


A

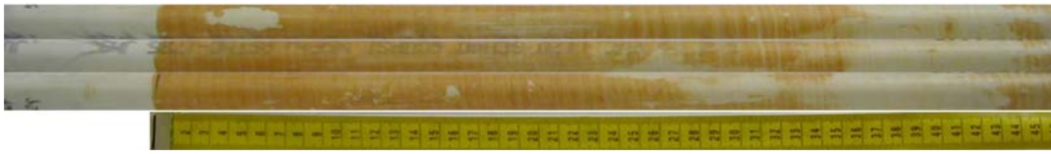


B

Date Out: 5-29-03



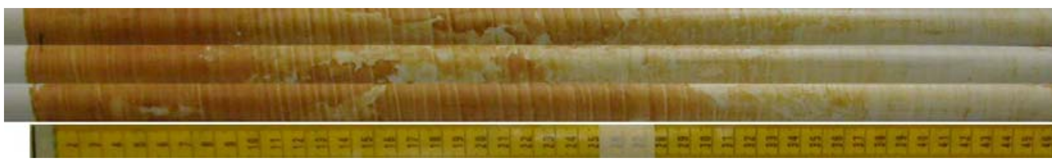
A



B

Date Out: 6-23-03

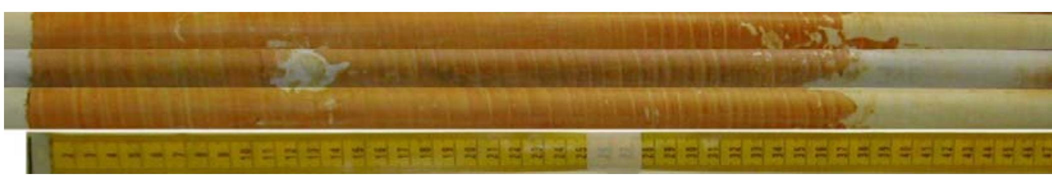
A



B

Date Out: 7-15-03

A

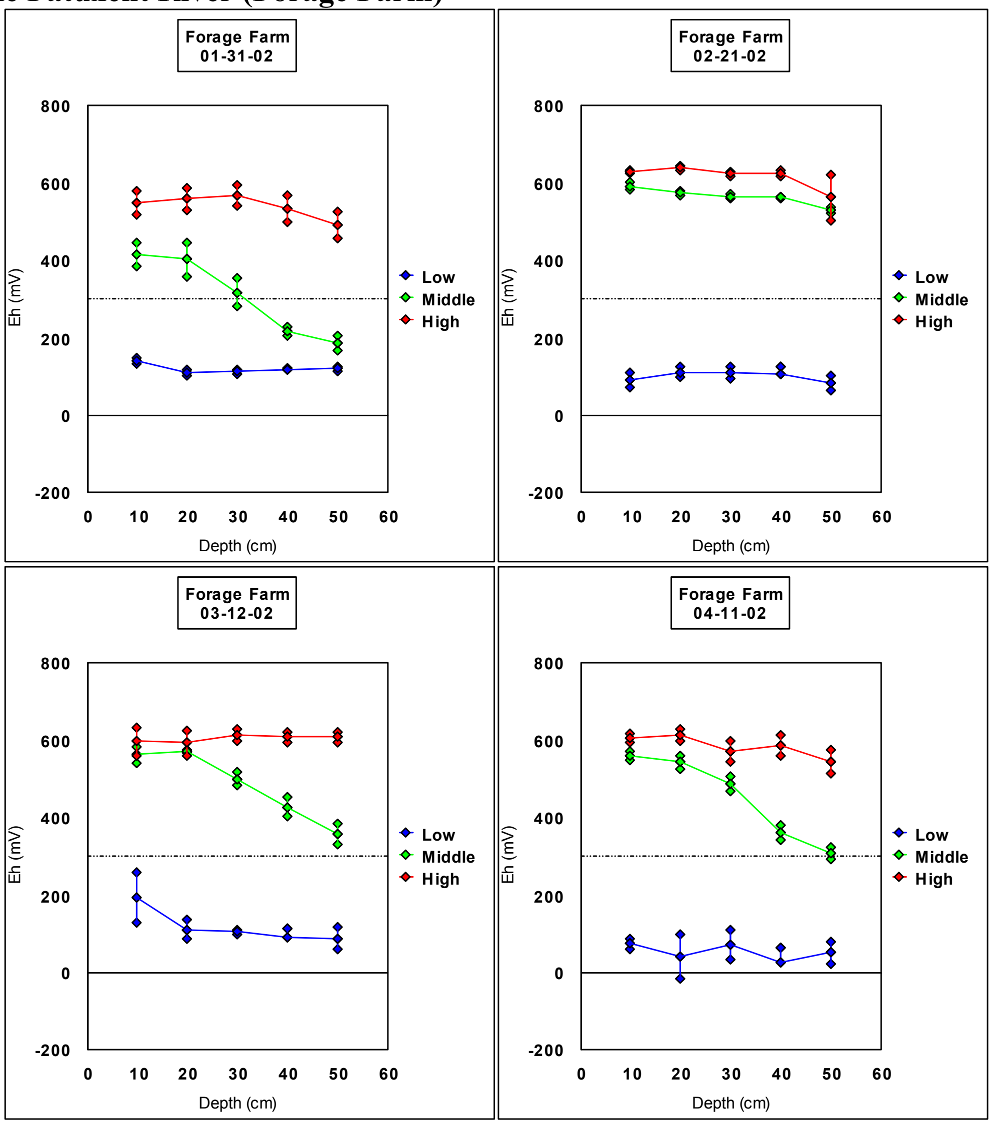


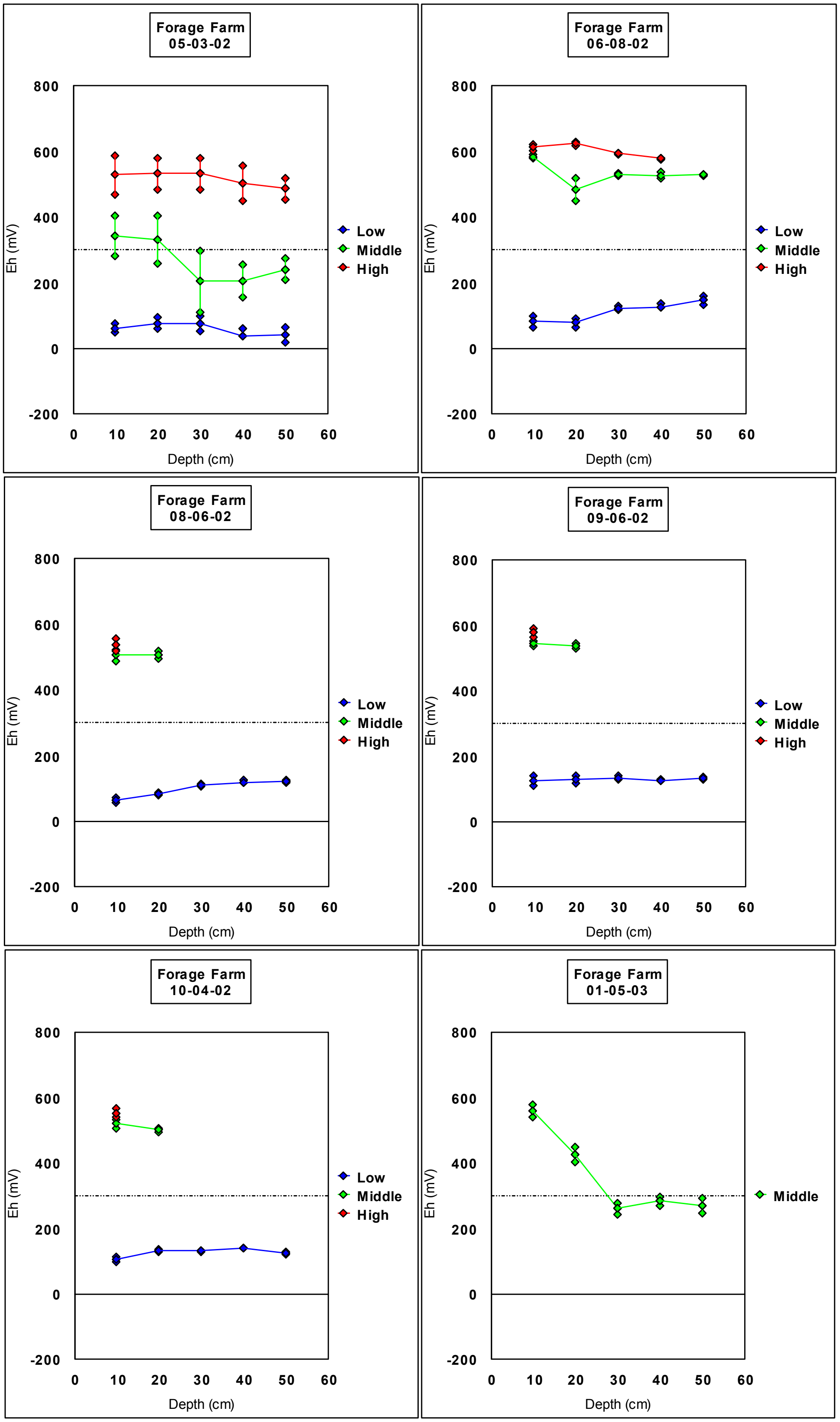
B

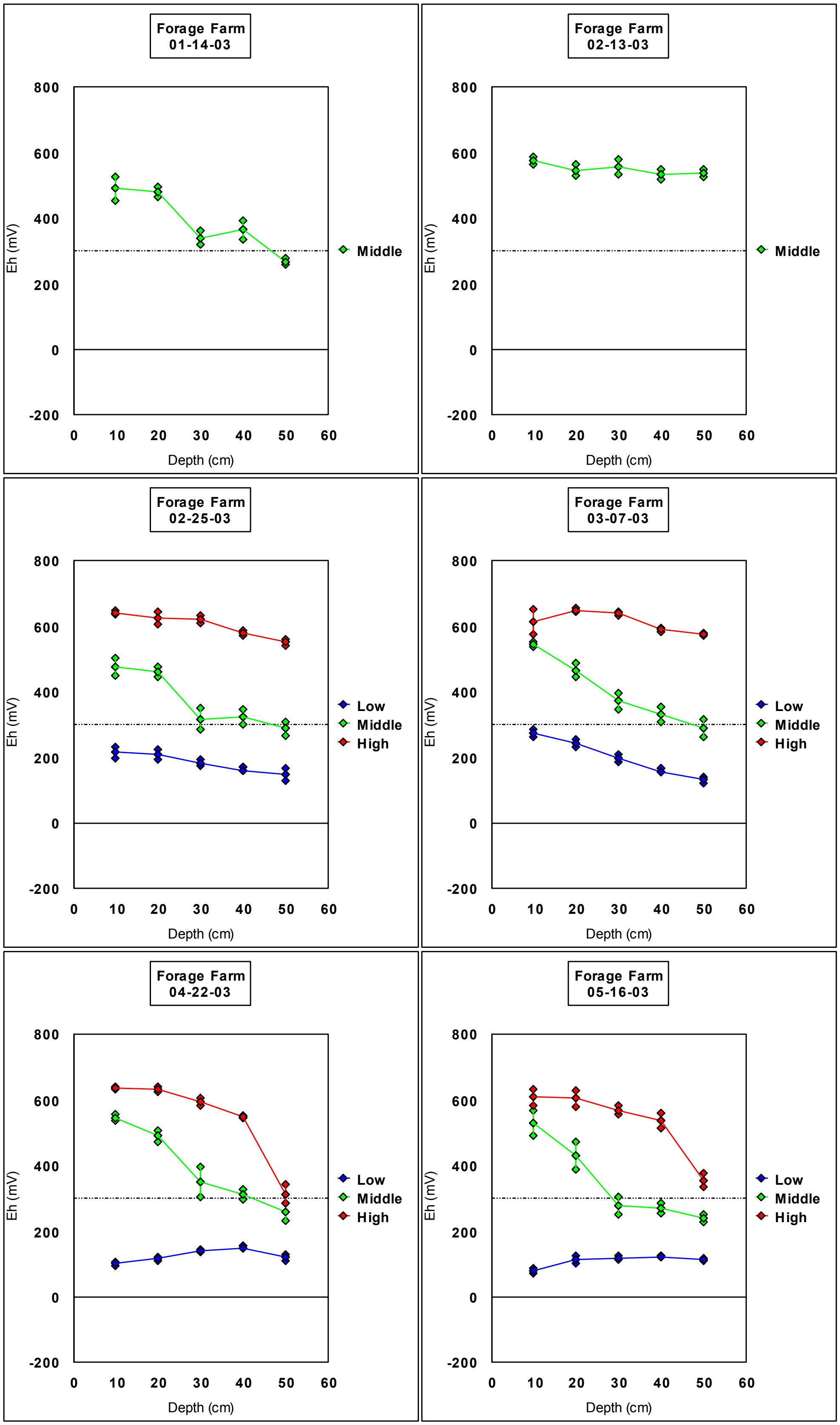
Appendix F: Redox Potential Data

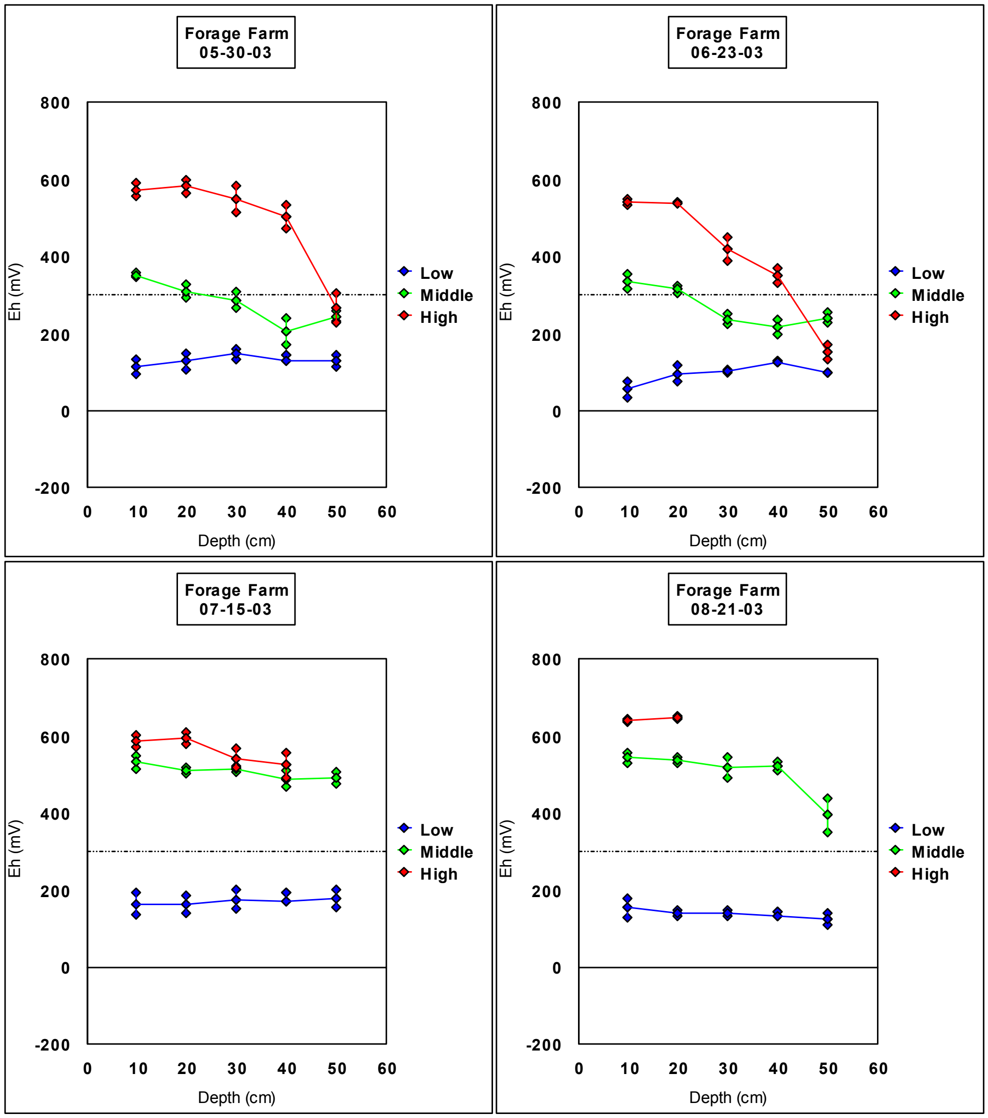
Points above and below each point indicate standard error. The dotted lines are located at 300 mV and can be used as a reference line in all graphs.

Middle Patuxent River (Forage Farm)

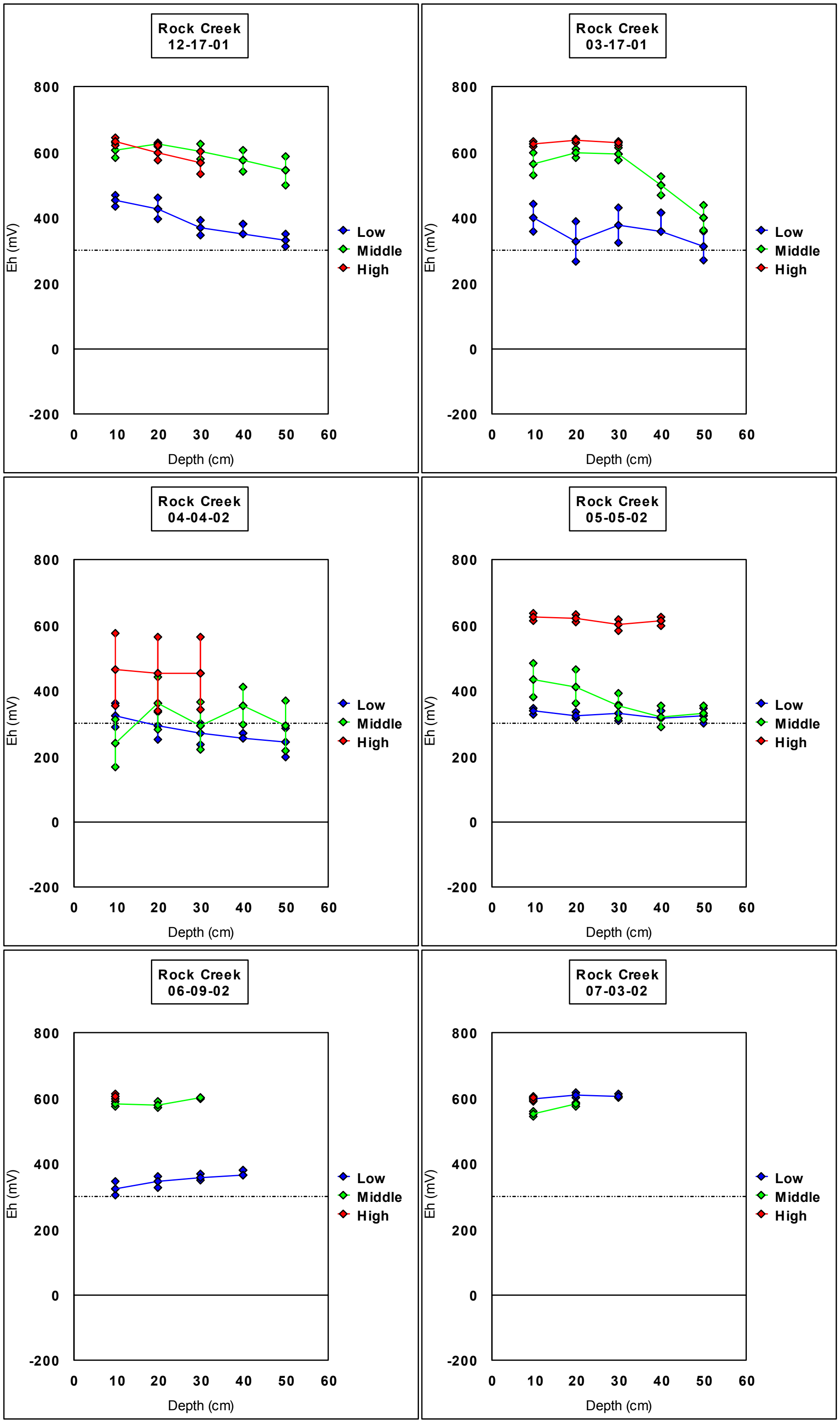


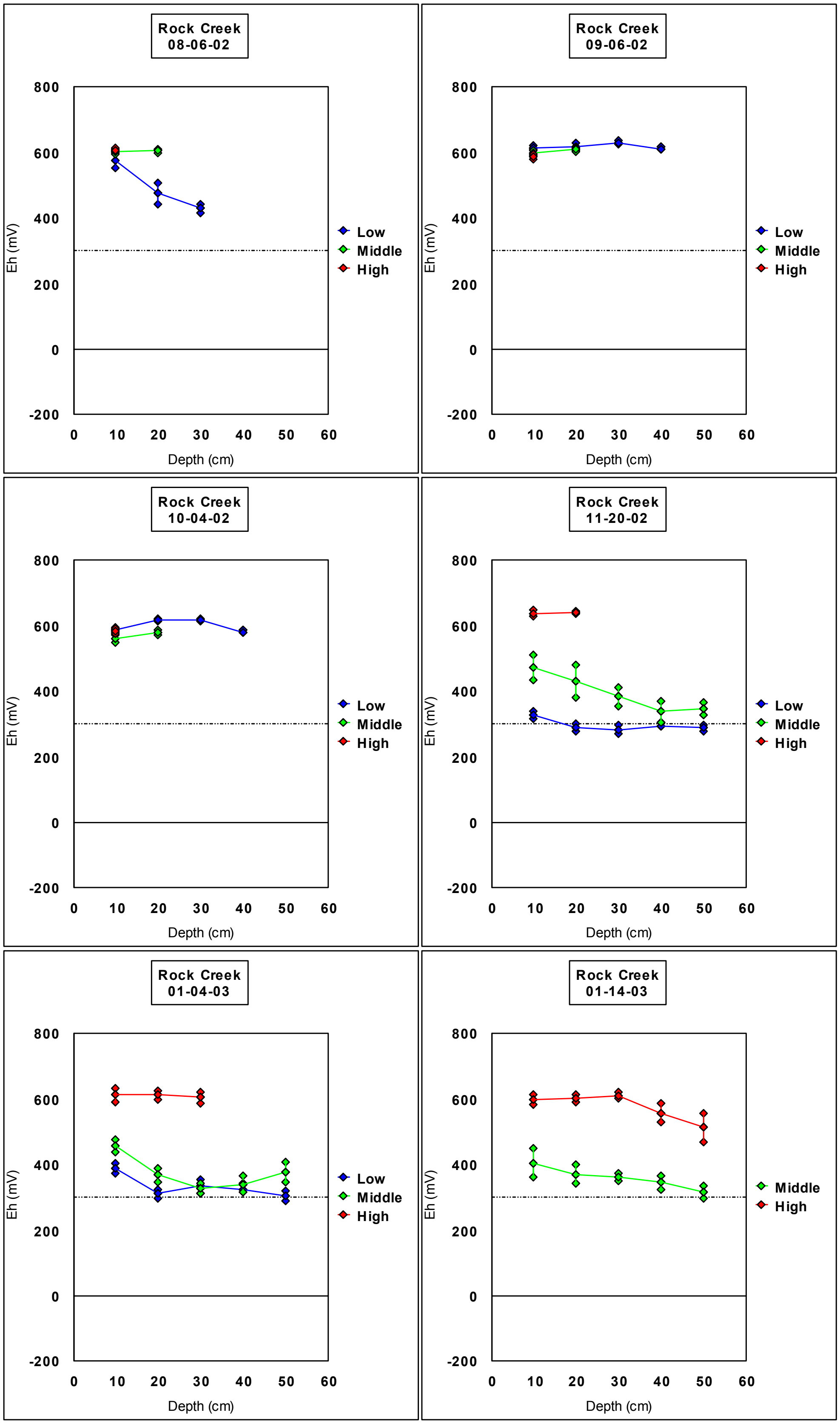

Forage Farm
05-03-02
Forage Farm
06-08-02
Forage Farm
08-06-02
Forage Farm
09-06-02
Forage Farm
10-04-02
Forage Farm
01-05-03
Eh (mV)
Depth (cm)
800
600
400
200
0
-200
0
10
20
30
40
50
60
Low
Middle
High

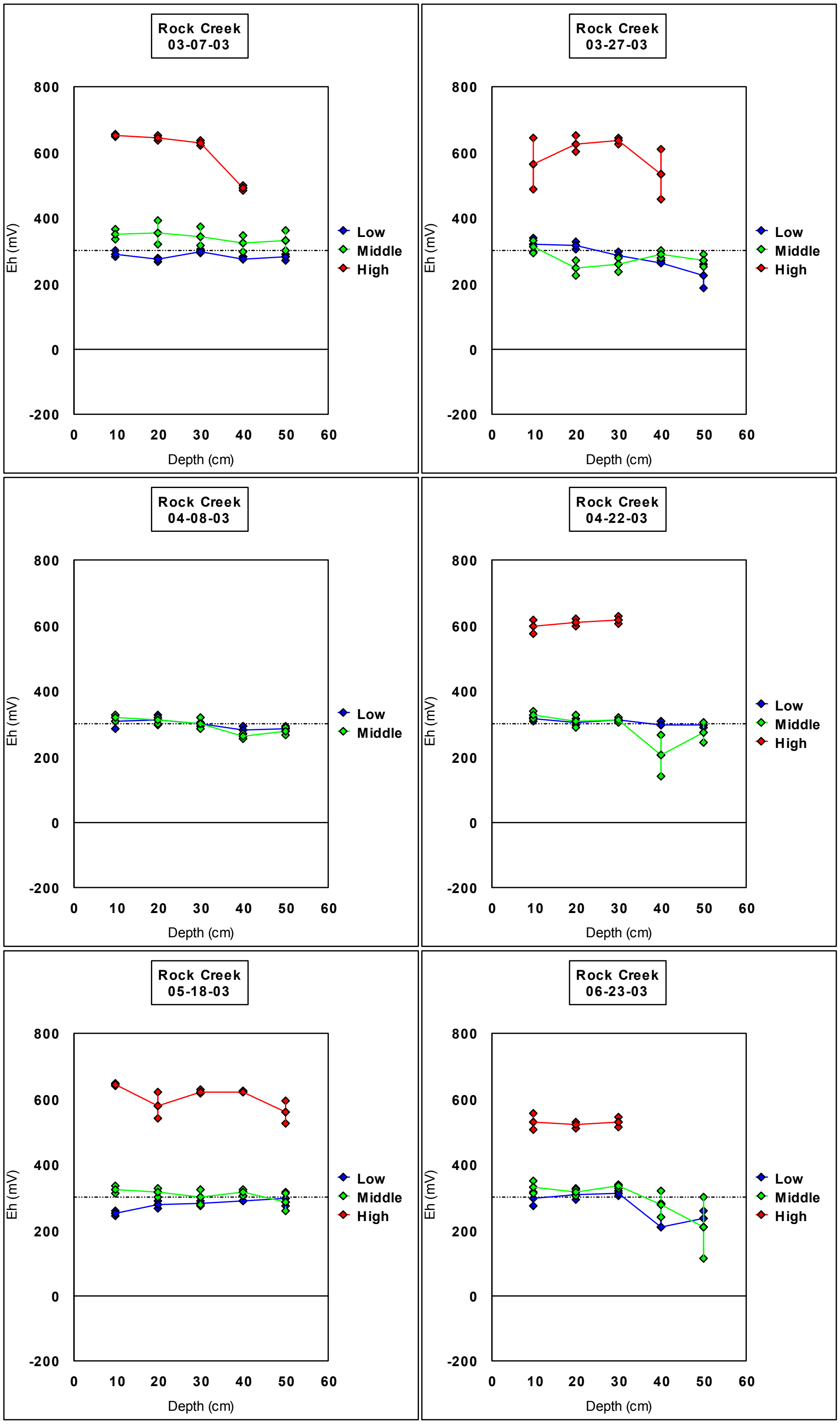

Forage Farm
01-14-03
800
600
400
200
0
-200
Eh (mV)
0 10 20 30 40 50 60
Depth (cm)
Middle
Forage Farm
02-13-03
800
600
400
200
0
-200
Eh (mV)
0 10 20 30 40 50 60
Depth (cm)
Middle
Forage Farm
02-25-03
800
600
400
200
0
-200
Eh (mV)
0 10 20 30 40 50 60
Depth (cm)
Low
Middle
High
Forage Farm
03-07-03
800
600
400
200
0
-200
Eh (mV)
0 10 20 30 40 50 60
Depth (cm)
Low
Middle
High
Forage Farm
04-22-03
800
600
400
200
0
-200
Eh (mV)
0 10 20 30 40 50 60
Depth (cm)
Low
Middle
High
Forage Farm
05-16-03
800
600
400
200
0
-200
Eh (mV)
0 10 20 30 40 50 60
Depth (cm)
Low
Middle
High

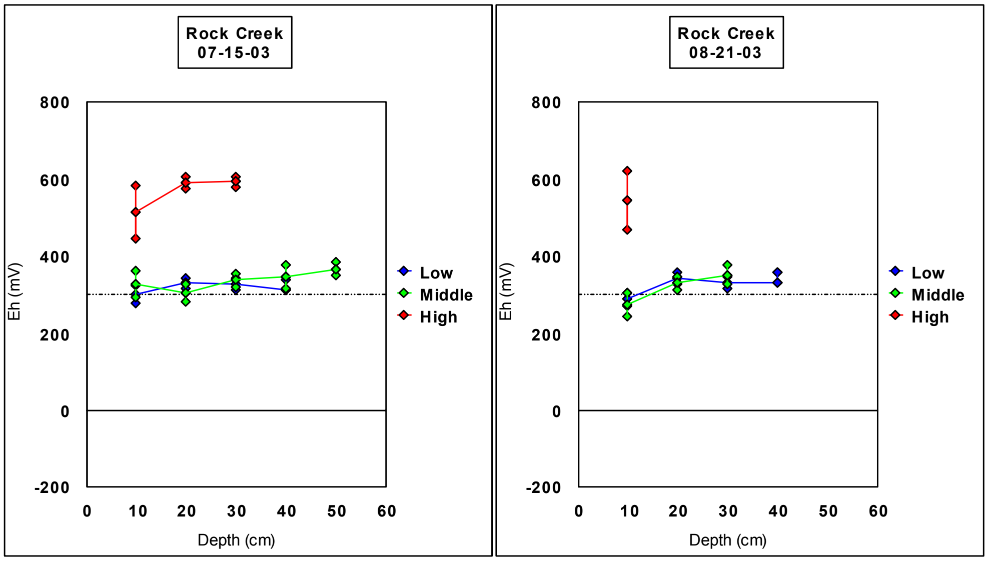

Forage Farm
05-30-03
Forage Farm
06-23-03
Forage Farm
07-15-03
Forage Farm
08-21-03
Eh (mV)
Depth (cm)
Low
Middle
High
800
600
400
200
0
-200
0
10
20
30
40
50
60

Rock Creek

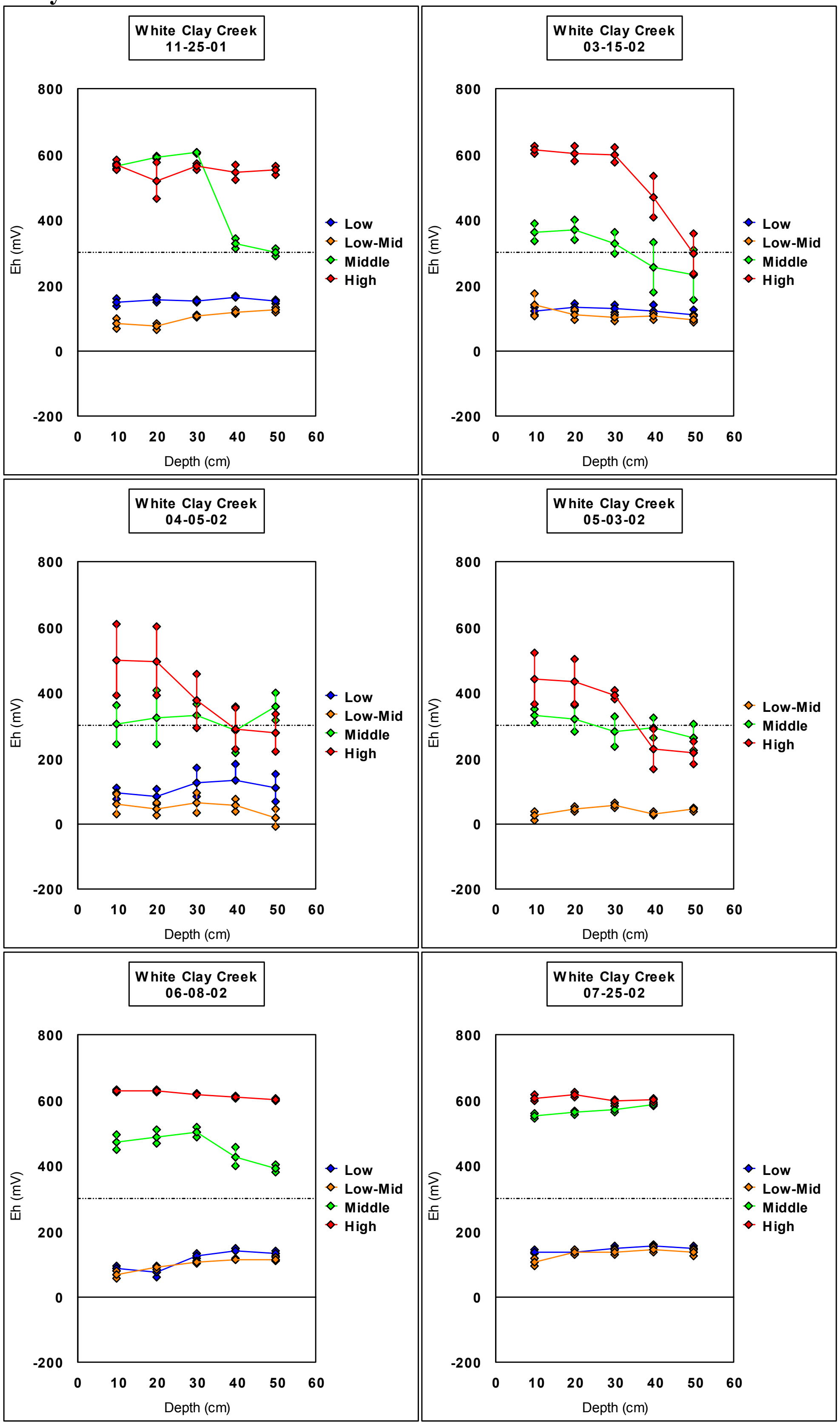

Rock Creek 12-17-01
Rock Creek 03-17-01
Rock Creek 04-04-02
Rock Creek 05-05-02
Rock Creek 06-09-02
Rock Creek 07-03-02
Eh (mV)
Depth (cm)
800
600
400
200
0
-200
0
10
20
30
40
50
60
Low
Middle
High

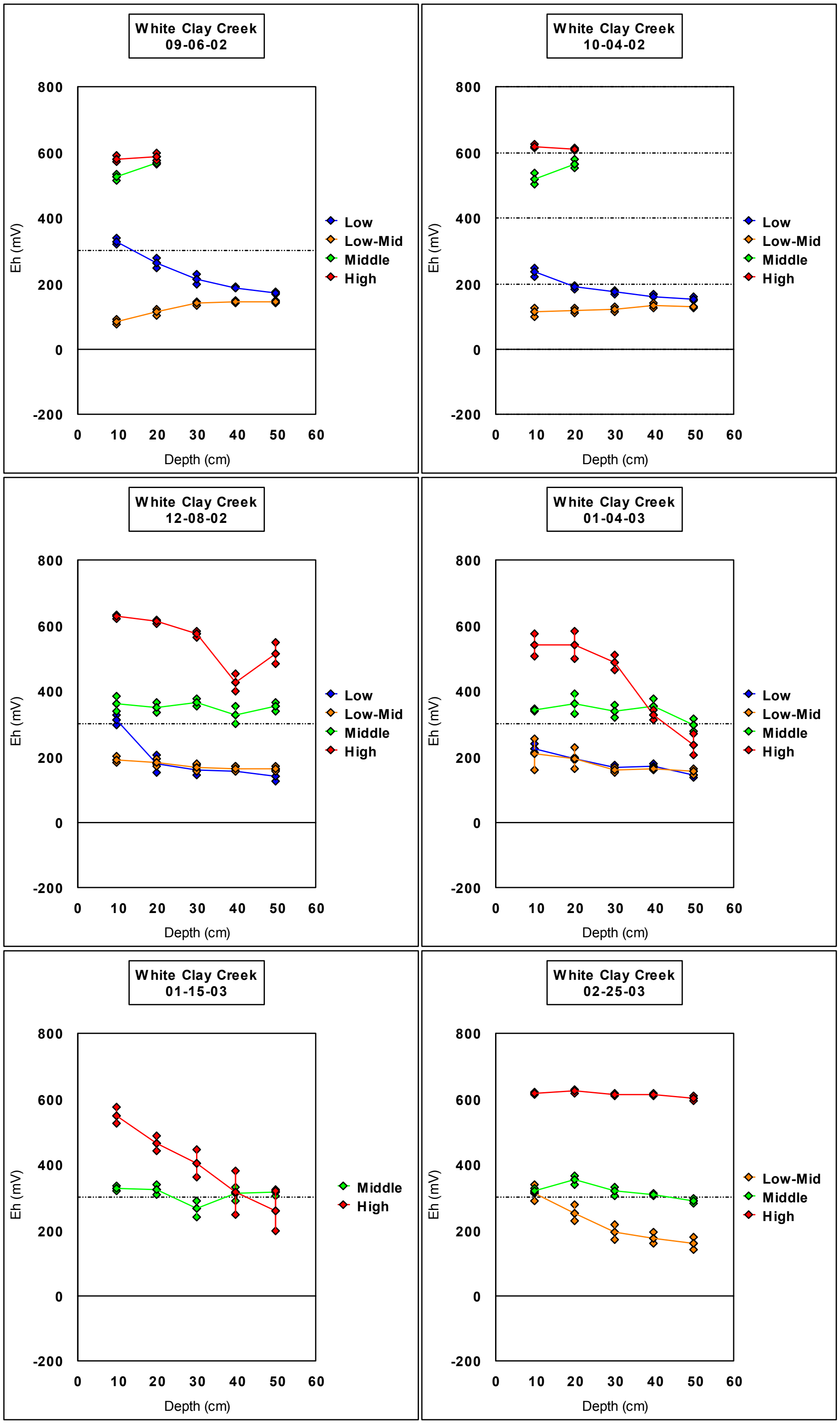

Rock Creek
08-06-02
Rock Creek
09-06-02
Rock Creek
10-04-02
Rock Creek
11-20-02
Rock Creek
01-04-03
Rock Creek
01-14-03
Eh (mV)
Depth (cm)
800
600
400
200
0
-200
0
10
20
30
40
50
60
Low
Middle
High

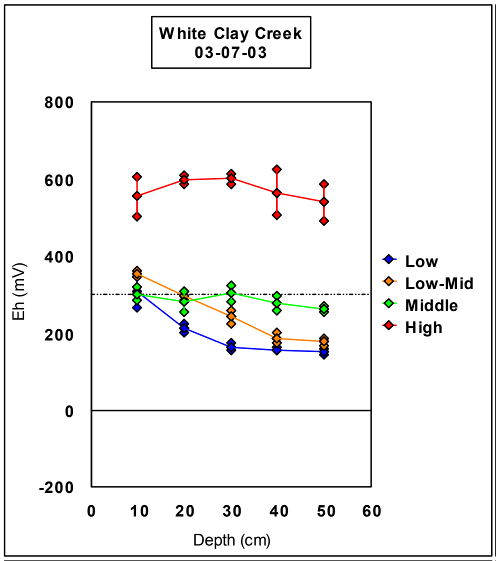

Rock Creek
03-07-03
Rock Creek
03-27-03
Rock Creek
04-08-03
Rock Creek
04-22-03
Rock Creek
05-18-03
Rock Creek
06-23-03
Eh (mV)
800
600
400
200
0
-200
Depth (cm)
0
10
20
30
40
50
60
Low
Middle
High

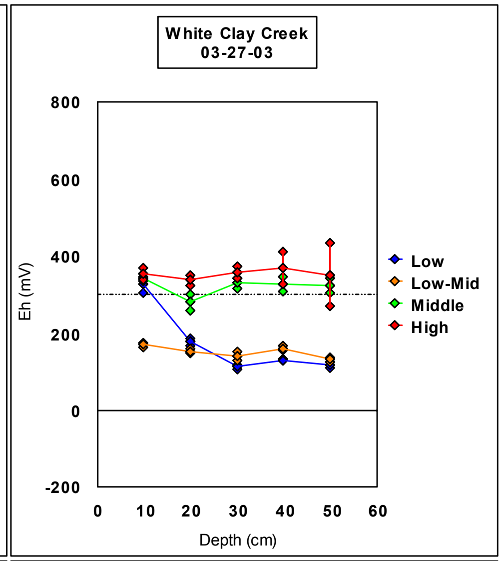

Rock Creek
07-15-03
800
600
400
200
0
-200
Eh (mV)
0
10
20
30
40
50
60
Depth (cm)
Low
Middle
High
Rock Creek
08-21-03
800
600
400
200
0
-200
Eh (mV)
0
10
20
30
40
50
60
Depth (cm)
Low
Middle
High

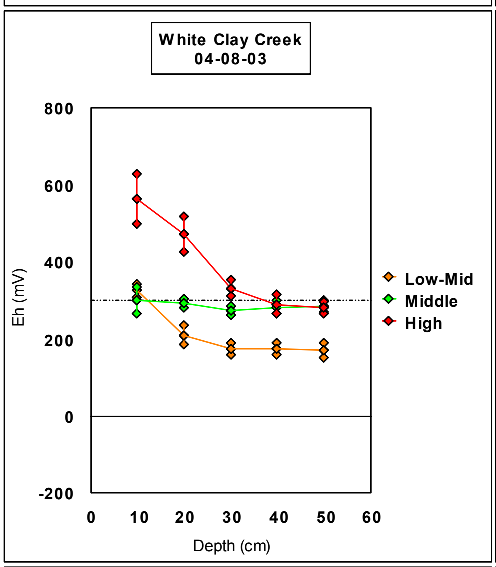
White Clay Creek

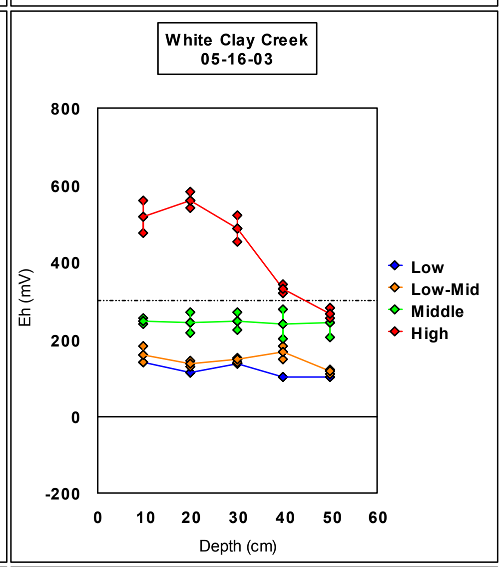


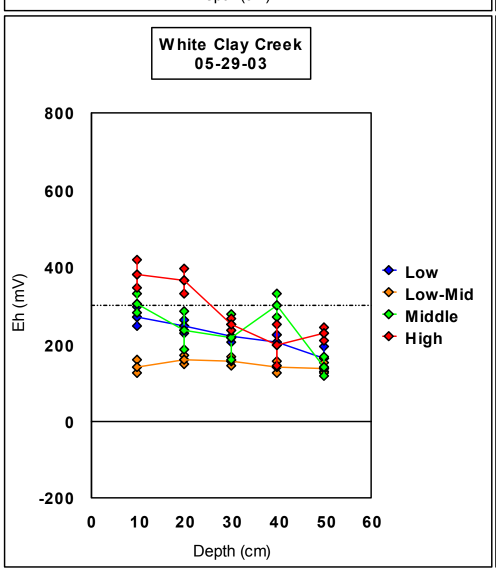

White Clay Creek
09-06-02
White Clay Creek
10-04-02
White Clay Creek
12-08-02
White Clay Creek
01-04-03
White Clay Creek
01-15-03
White Clay Creek
02-25-03
Eh (mV)
Depth (cm)
800
600
400
200
0
-200
0
10
20
30
40
50
60
Low
Low-Mid
Middle
High

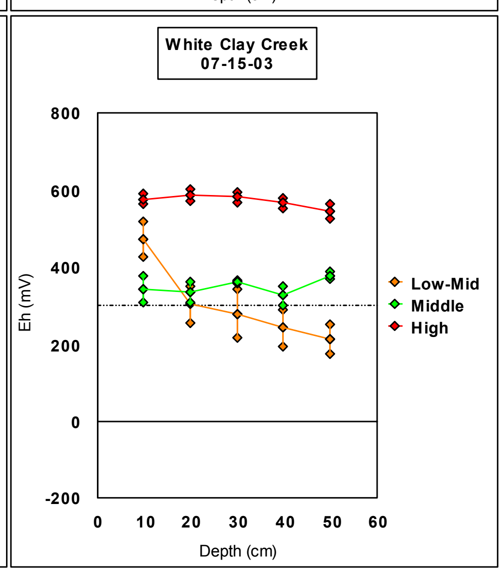

White Clay Creek
03-07-03
Eh (mV)
Depth (cm)
Low
Low-Mid
Middle
High

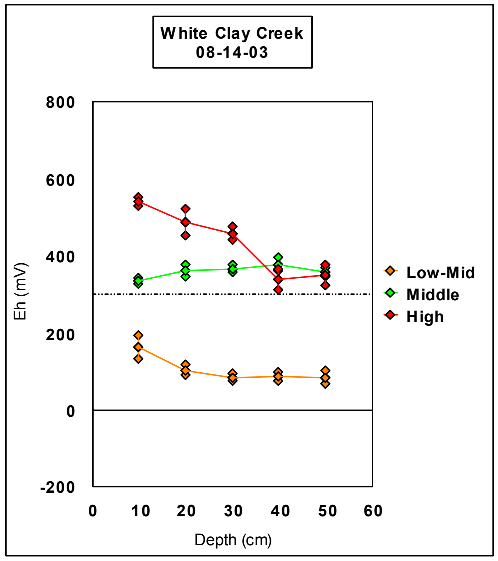

White Clay Creek
03-27-03
Eh (mV)
Depth (cm)
Low
Low-Mid
Middle
High


White Clay Creek
04-08-03
Eh (mV)
Depth (cm)
Low-Mid
Middle
High

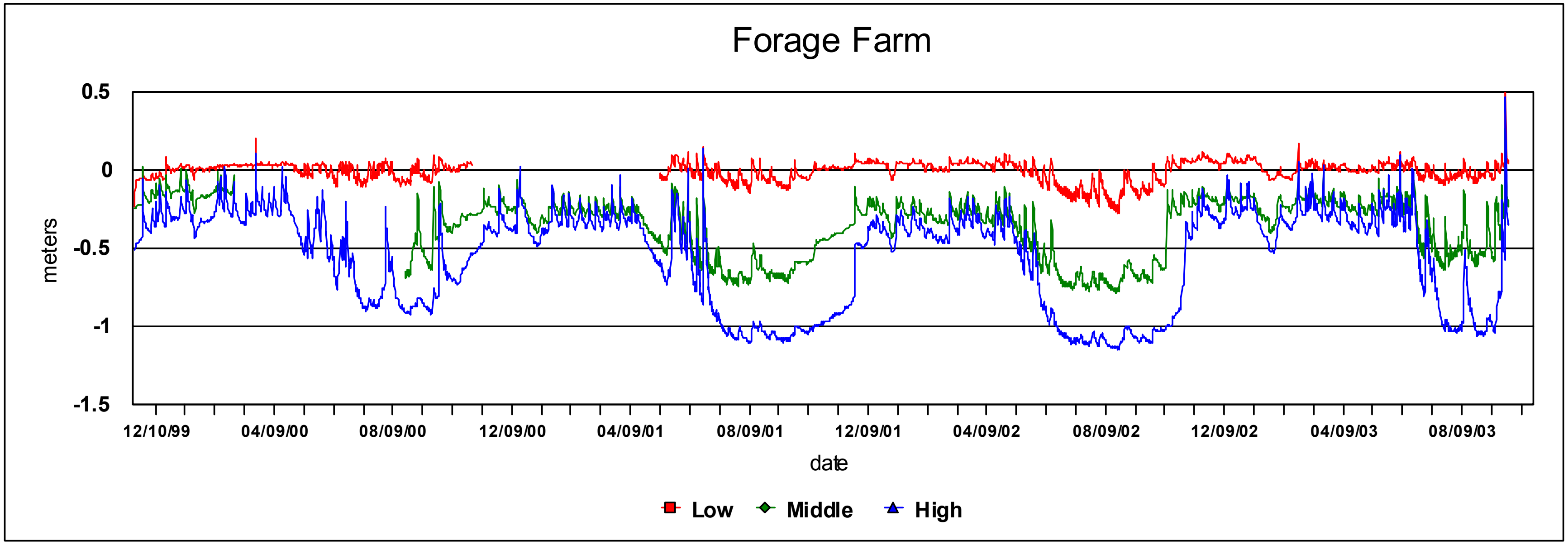

White Clay Creek
05-16-03
Eh (mV)
Depth (cm)
Low
Low-Mid
Middle
High

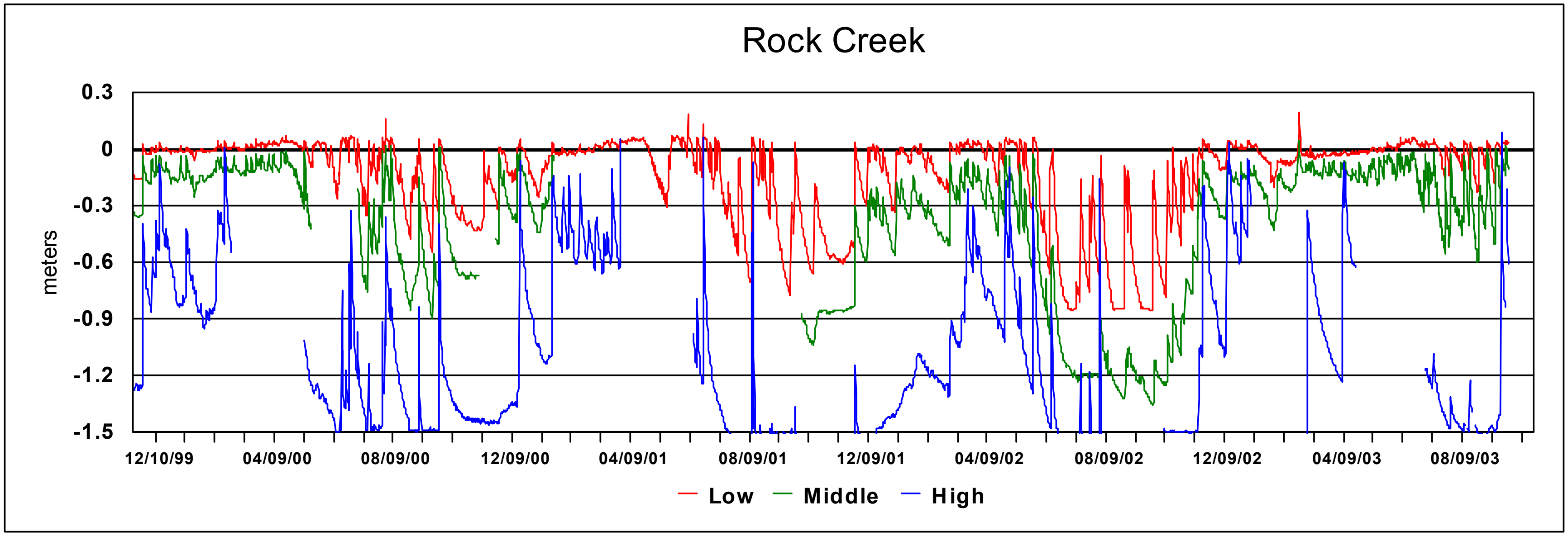

White Clay Creek
05-29-03
Eh (mV)
Depth (cm)
Low
Low-Mid
Middle
High

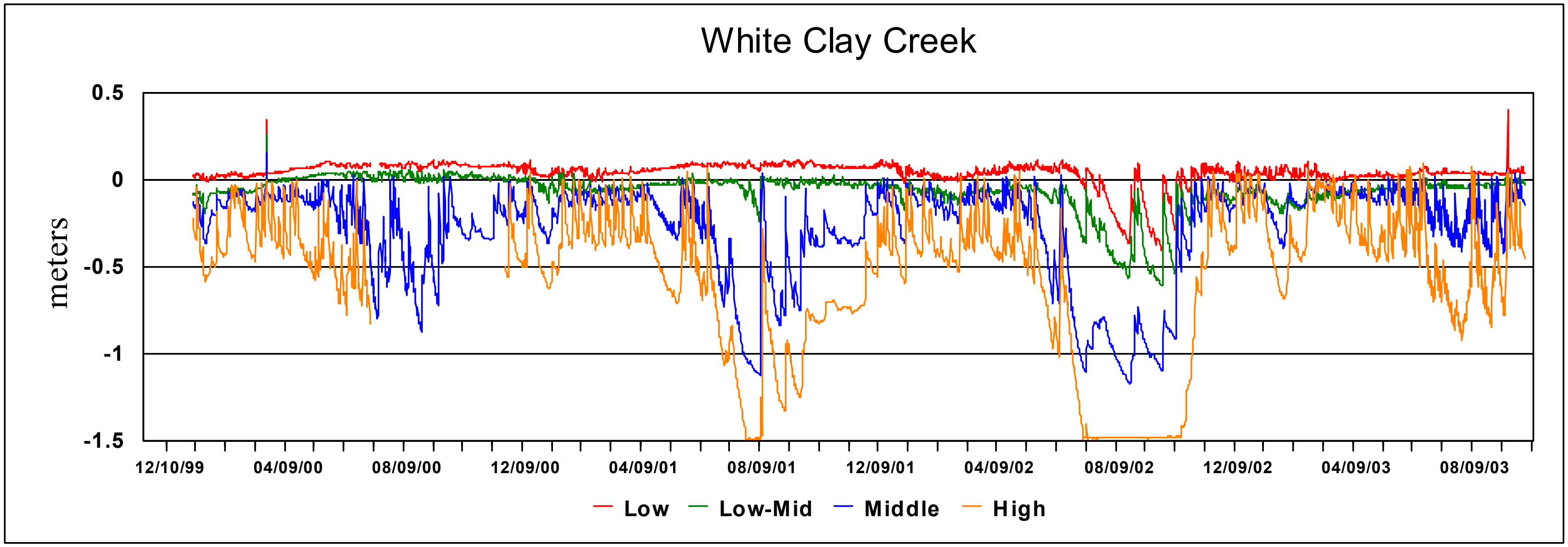

White Clay Creek
07-15-03
Eh (mV)
Depth (cm)
Low-Mid
Middle
High


White Clay Creek
08-14-03
800
600
400
200
0
-200
Eh (mV)
0
10
20
30
40
50
60
Depth (cm)
Low-Mid
Middle
High

Appendix G: Water Table Data

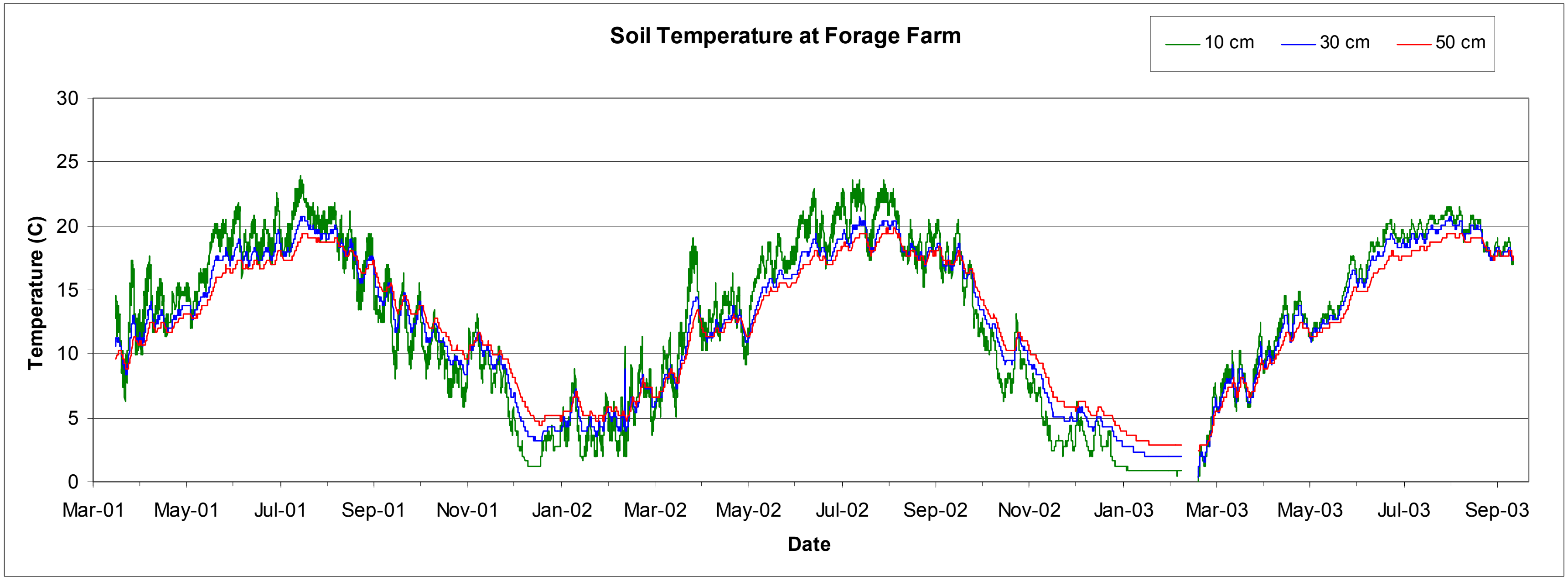


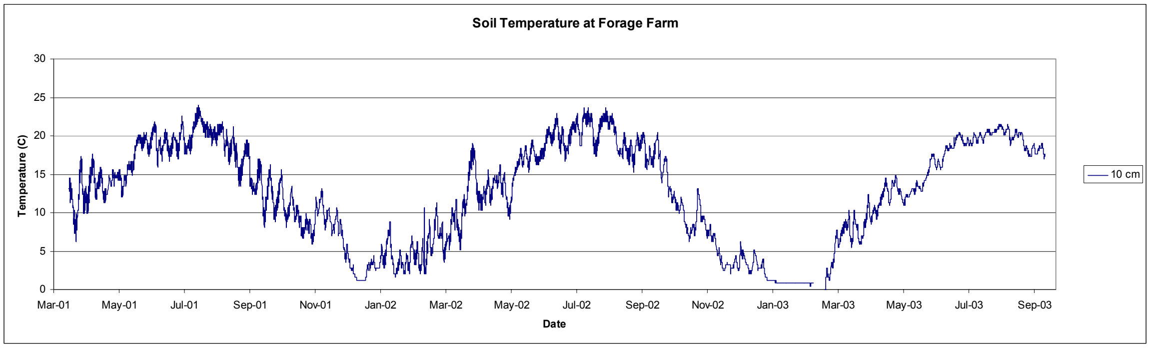

Rock Creek
meters
0.3
0
-0.3
-0.6
-0.9
-1.2
-1.5
12/10/99
04/09/00
08/09/00
12/09/00
04/09/01
08/09/01
12/09/01
04/09/02
08/09/02
12/09/02
04/09/03
08/09/03
Low
Middle
High

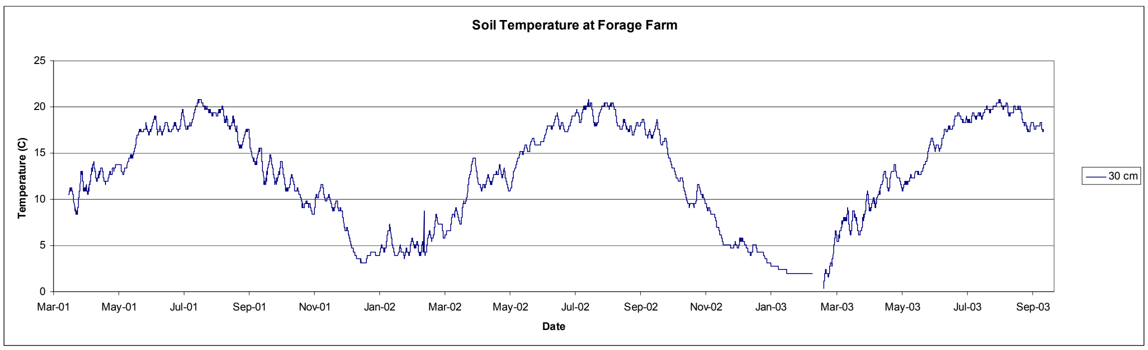

White Clay Creek
meters
0.5
0
-0.5
-1
-1.5
12/10/99
04/09/00
08/09/00
12/09/00
04/09/01
08/09/01
12/09/01
04/09/02
08/09/02
12/09/02
04/09/03
08/09/03
Low
Low-Mid
Middle
High

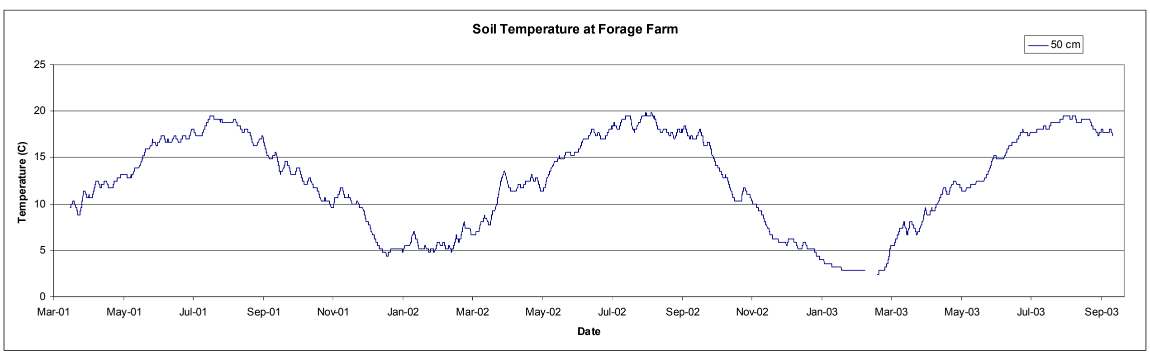
Appendix H: Soil Temperature Data

Middle Patuxent (Forage Farm)

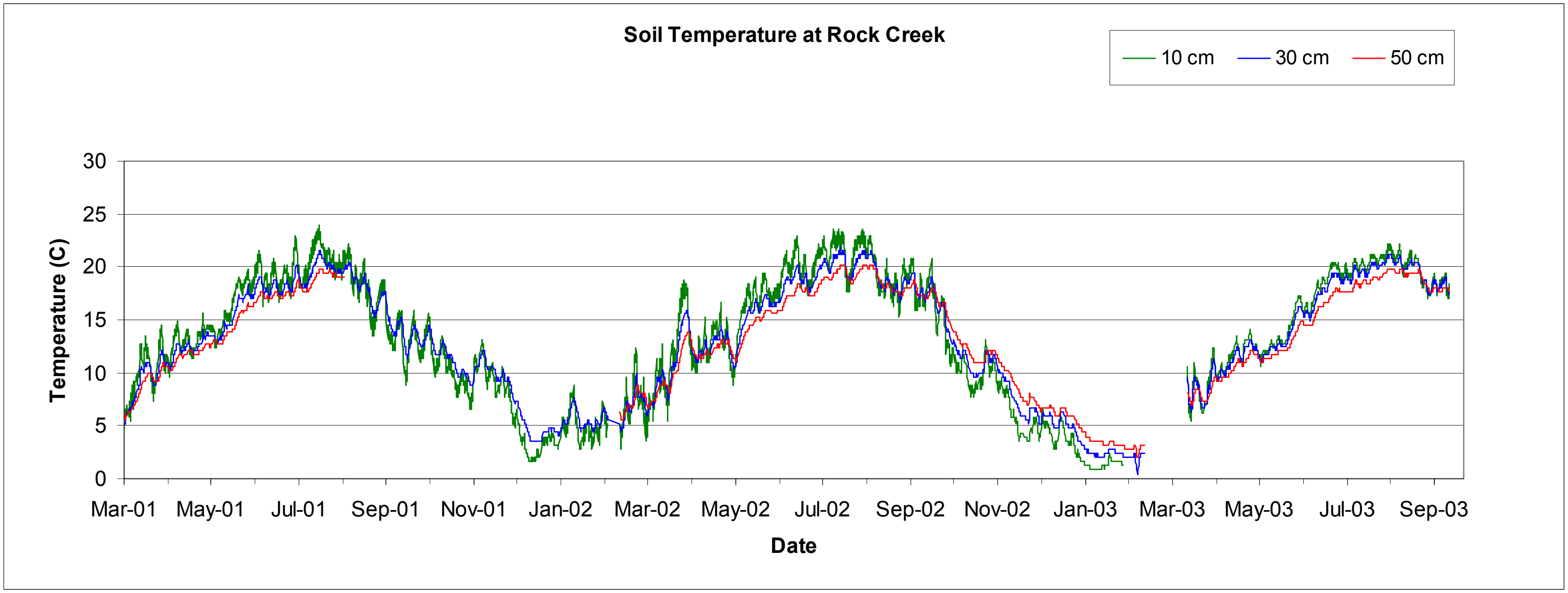



Soil Temperature at Forage Farm
30
25
20
15
10
5
0
Temperature (C)
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date
10 cm

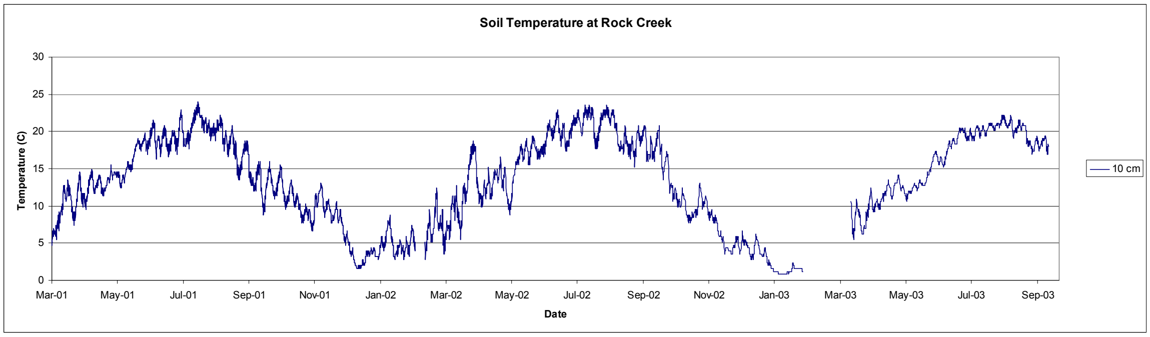

Soil Temperature at Forage Farm
25
20
15
10
5
0
Temperature (C)
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date
30 cm

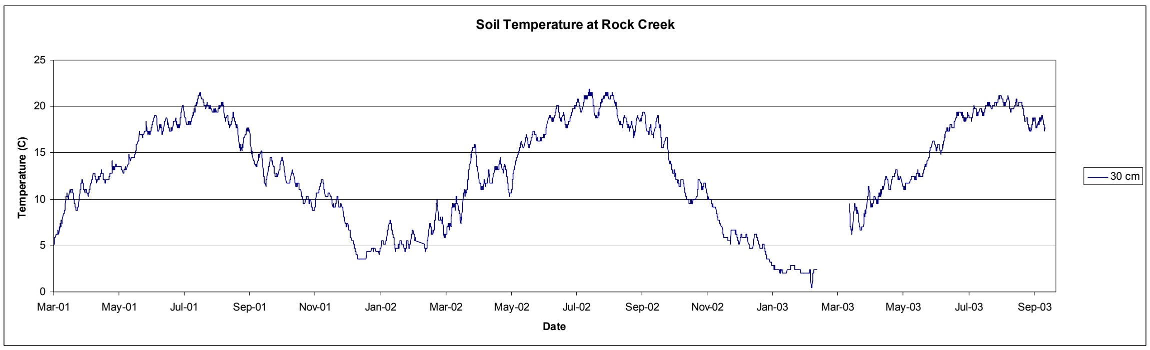

Soil Temperature at Forage Farm
50 cm
25
20
15
10
5
0
Temperature (C)
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date

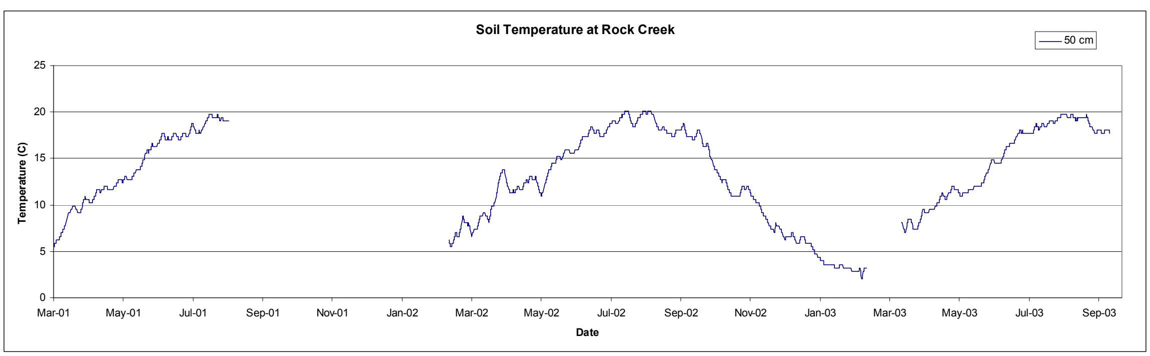
Rock Creek



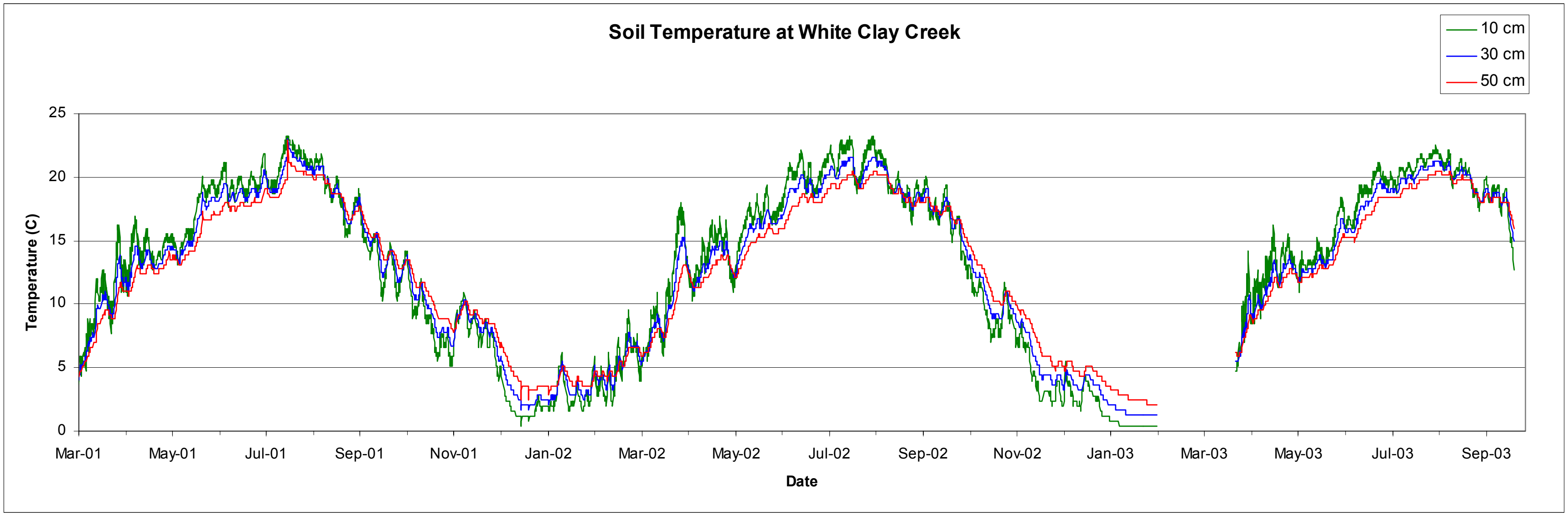
Soil Temperature at Rock Creek
10 cm
30 cm
50 cm
Temperature (C)
30
25
20
15
10
5
0
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date

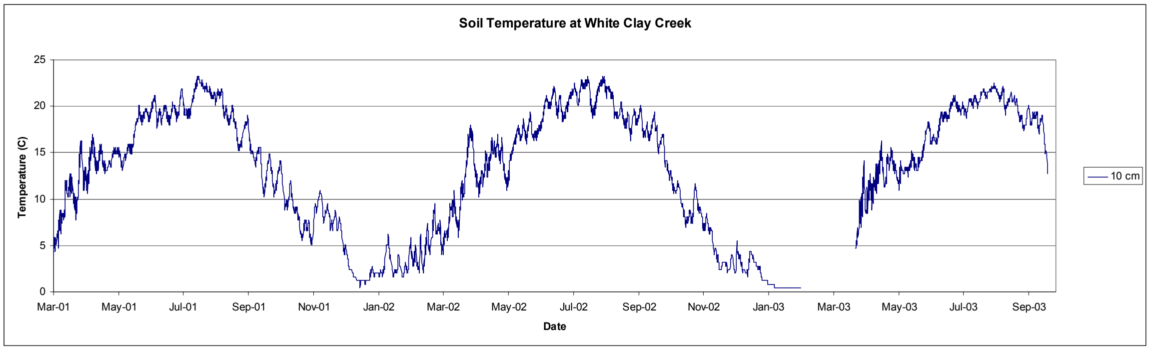

Soil Temperature at Rock Creek
Temperature (C)
Date
10 cm
0
5
10
15
20
25
30
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03

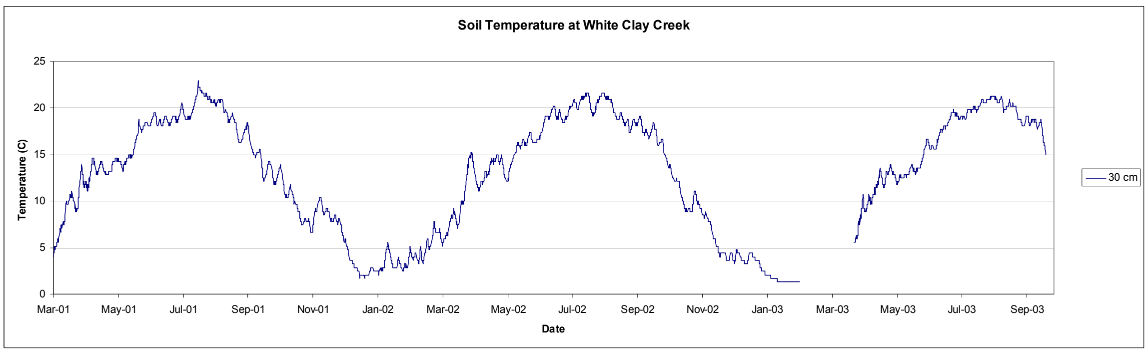

Soil Temperature at Rock Creek
Temperature (C)
Date
30 cm
0
5
10
15
20
25
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03

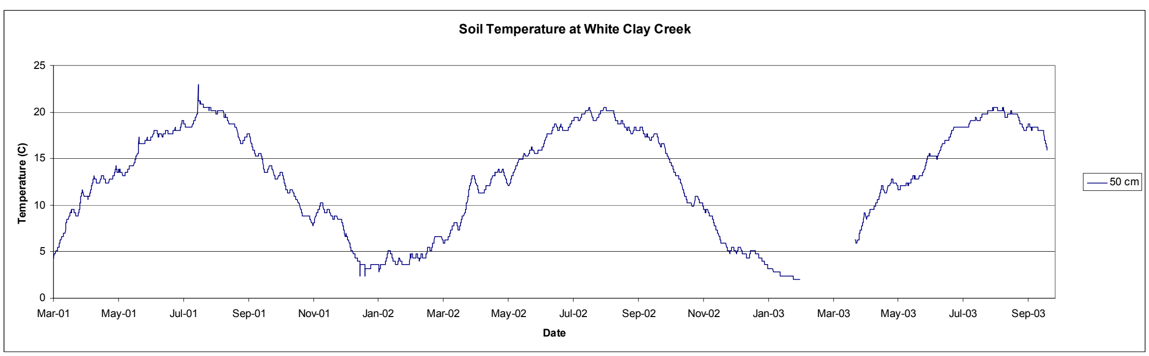

Soil Temperature at Rock Creek
50 cm
Temperature (C)
Date
0
5
10
15
20
25
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03

White Clay Creek

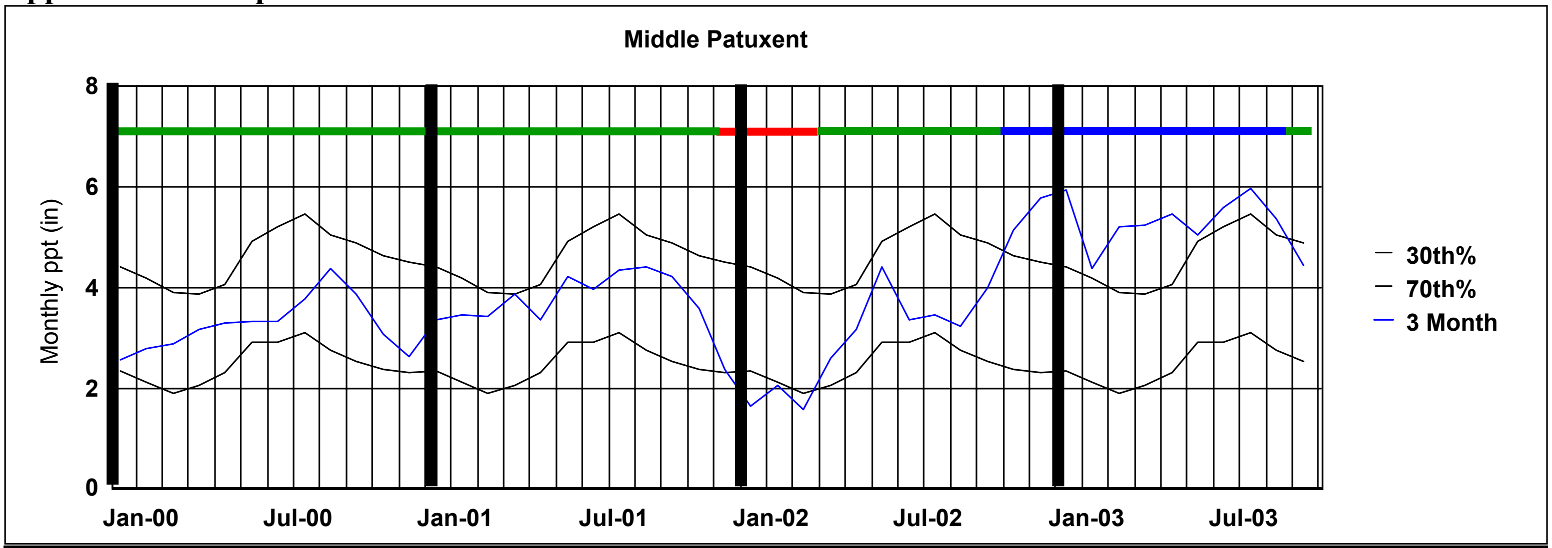


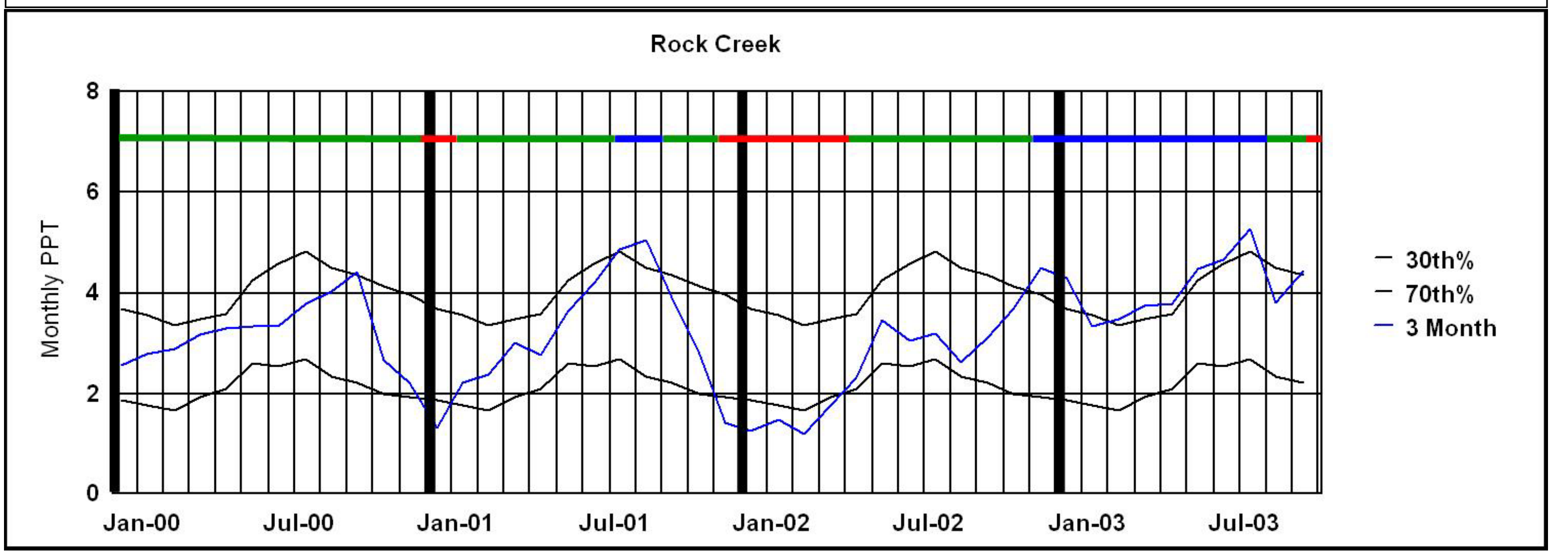

Soil Temperature at White Clay Creek
Temperature (C)
25
20
15
10
5
0
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date
10 cm

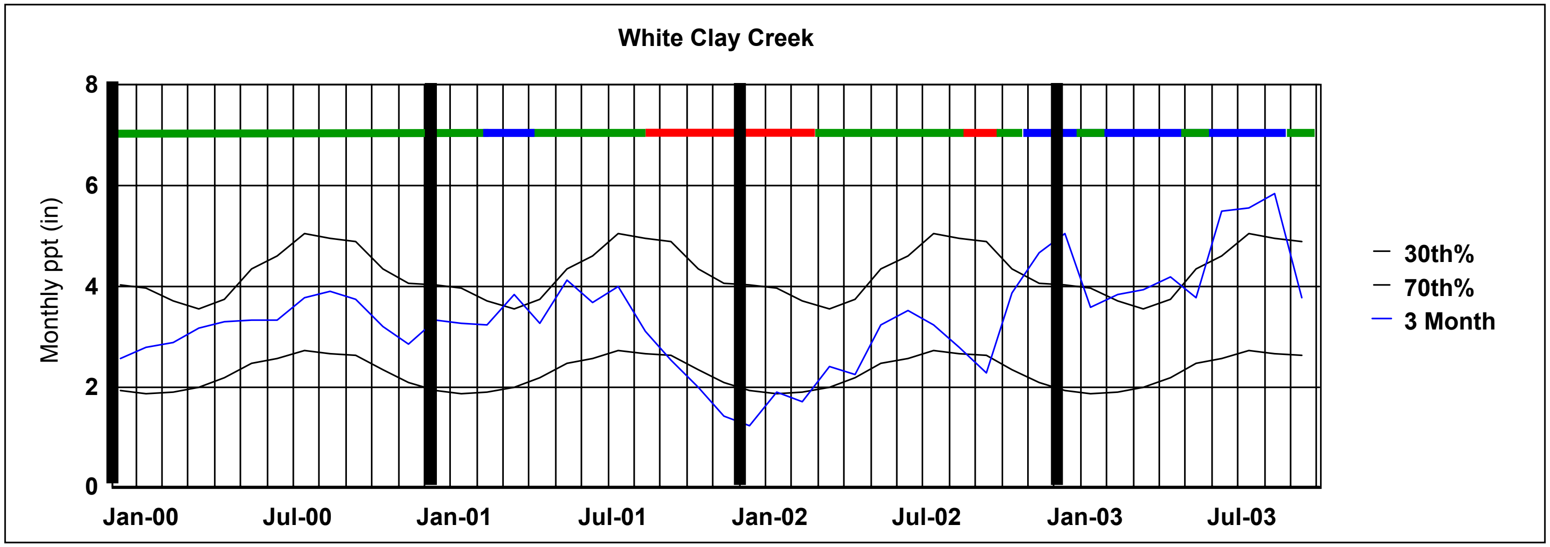

Soil Temperature at White Clay Creek
Temperature (C)
25
20
15
10
5
0
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date
30 cm


Soil Temperature at White Clay Creek
Temperature (C)
25
20
15
10
5
0
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Date
50 cm

Appendix I: Precipitation Data






White Clay Creek
Monthly ppt (in)
0
2
4
6
8
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
30th%
70th%
3 Month

Appendix J: Radiocarbon Dating Results

February 28, 2003

Dr. Martin C. Rabenhorst
University of Maryland
Natural Resource Sciences
H J Patterson Hall, Room 1112
College Park, MD 20742
USA

RE: Radiocarbon Dating Results For Samples WCC3, FF3

Dear Dr. Rabenhorst:

Enclosed are the radiocarbon dating results for two samples recently sent to us. They each provided plenty of carbon for accurate measurements and all the analyses went normally. The report sheet also contains the method used, material type, applied pretreatments and, where applicable, the two sigma calendar calibration range.

As always, this report has been both mailed and sent electronically. All results (excluding some inappropriate material types) which are less than about 20,000 years BP and more than about ~250 BP include this calendar calibration page (also digitally available in Windows metafile (wmf) format upon request). The calibrations are calculated using the newest (1998) calibration database with references quoted on the bottom of each page. Multiple probability ranges may appear in some cases, due to short term variations in the atmospheric 14C contents at certain time periods. Examining the calibration graphs will help you understand this phenomenon. Don't hesitate to contact us if you have questions about calibration.

We analyzed these samples on a sole priority basis. No students or intern researchers who would necessarily be distracted with other obligations and priorities were used in the analyses. We analyzed them with the combined attention of our entire professional staff.

Information pages are also enclosed with the mailed copy of this report. If you have any specific questions about the analyses, please do not hesitate to contact us.

Thank you for prepaying the analyses. A receipt is enclosed. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood

Dr. Martin C. Rabenhorst — Report Date: 2/28/2003

University of Maryland — Material Received: 2/3/2003

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 175680 SAMPLE : WCC3 ANALYSIS : Radiometric-Standard delivery MATERIAL/PRETREATMENT : (wood): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 260 to 560 (Cal BP 1690 to 1390)	1630 +/- 60 BP	-25.0* o/oo	1630 +/- 60* BP
Beta - 175681 SAMPLE : FF3 ANALYSIS : Radiometric-Standard delivery (with extended counting) MATERIAL/PRETREATMENT : (wood): acid/alkali/acid 2 SIGMA CALIBRATION : Cal AD 1240 to 1420 (Cal BP 710 to 540)	670 +/- 70 BP	-25.0* o/oo	670 +/- 70* BP

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: est. C13/C12=-25:lab. mult=1)

Laboratory number: **Beta-175680**

Conventional radiocarbon age[1]: **1630±60 BP**

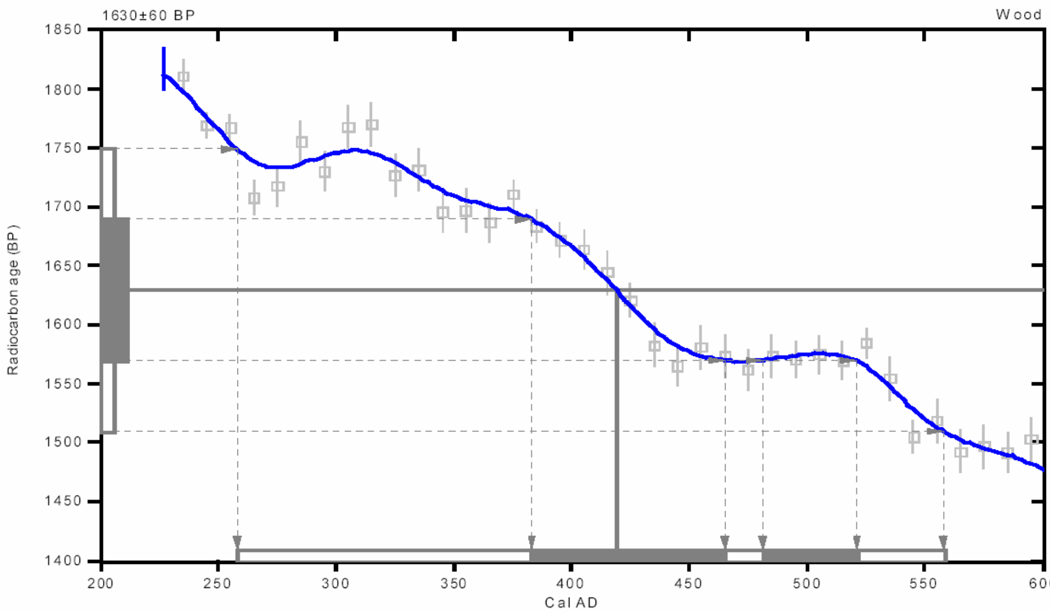
2 Sigma calibrated result: (95% probability) **Cal AD 260 to 560 (Cal BP 1690 to 1390)**

[1] C13/C12 ratio estimated

Intercept data

Intercept of radiocarbon age with calibration curve: Cal AD 420 (Cal BP 1530)

1 Sigma calibrated results: (68% probability) Cal AD 380 to 460 (Cal BP 1570 to 1480) and Cal AD 480 to 520 (Cal BP 1470 to 1430)



References:

Database used

Calibration Database

Editorial Comment

Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii

INTCAL98 Radiocarbon Age Calibration

Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083

Mathematics

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: est. C13/C12=-25:lab. mult=1)

Laboratory number: **Beta-175681**

Conventional radiocarbon age[1]: **670±70 BP**

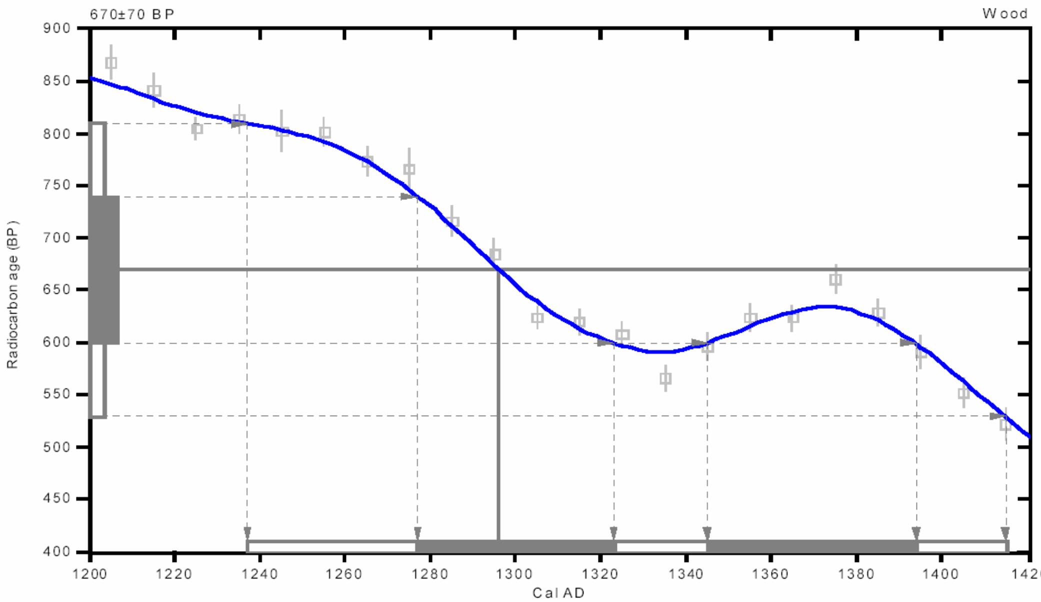
2 Sigma calibrated result: (95% probability) **Cal AD 1240 to 1420 (Cal BP 710 to 540)**

[1] C13/C12 ratio estimated

Intercept data

Intercept of radiocarbon age with calibration curve: Cal AD 1300 (Cal BP 650)

1 Sigma calibrated results: (68% probability) Cal AD 1280 to 1320 (Cal BP 670 to 630) and Cal AD 1340 to 1390 (Cal BP 600 to 560)



References:

Database used

Calibration Database
Editorial Comment
Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii
INTCAL98 Radiocarbon Age Calibration
Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083
Mathematics
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

Appendix K: Vegetation Analysis

Site: Middle Patuxent River 1 - low (FF1)

Tree stratum

		Dominance	Status
Mockernut Hickory	*Carya tomentosa*	D	
Red Maple	*Acer rubrum*		FAC

Sapling stratum

opposite w/ sm leaflets (sample)			

Shrub stratum

Spicebush	*Lindera benzoin*	D	FACW
Common Winterberry	*Ilex verticillata*		FACW+
Cornus (sample)	*Cornus*		

Herbaceous stratum

Spotted Touch-me-not	*Impatiens capensis*	D	FACW
Ground Ivy		D	
Skunk Cabbage	*Symplocarpus foetidus*	D	OBL
Japanese Stilt Grass	*Eunalia*	D	
Moneywort	*Lysimachia numnularia*	D	
Grass (sample)	*Elymus riparius*	D	
Sedge-like (sample)		D	
Mockernut Hickory	*Carya tomentosa*		
Stinging Nettle	*Urtica dioica*		FACU
Spicebush	*Lindera benzoin*		FACW
Northern Earlwood Viburnum	*Viburnum*		
Jack and the Pulpit	*Arisaema triphyllum*		FACW-
Thumb Plant (sample)			
False Nettle	*Boehmeria cylindrica*		FACW+
Rice Cutgrass	*Leersia oryzoides*		OBL
Red Oak	*Quercus rubra*		FACU-
Ground-nut	*Apios americana*		FACW
	Rudbeckia lacinata		
	Agrimonia parviflora		

Woody Vine stratum

Greenbriar	*Smilax rotundifolia*	D	FAC
Poison Ivy	*Toxicodendron radicans*	D	FAC
Multiflora Rose	*Rosa multiflora*	D	FACU
Virginia Creeper	*Parthenocissus quinquefolia*	D	FACU
Japanese Honeysuckle	*Lonicera japonica*		FAC-

notes: woody vines are on hummocks and climbing trees

Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: Middle Patuxent River 2 - mid (FF2)

Tree stratum

		Dominance	Status
Mockernut Hickory	*Carya tomentosa*		
Pin Oak	*Quercus palustris*		FACW
Red Maple	*Acer rubrum*		FAC

Sapling stratum

Shrub stratum

opposite w/ sm leaflets (sample)		D	
Spicebush	*Lindera benzoin*		FACW

Herbaceous stratum

Spicebush	*Lindera benzoin*	D	FACW
Ground Ivy		D	
Garlic Mustard	*Allium*	D	
Jumpseed (Virginia Knotweed)	*Polygonum virginiana*	D	FAC
Moneywort	*Lysimachia numnularia*		
Mockernut Hickory	*Carya tomentosa*		
Common Ragweed	*Ambrosia artemisiifolia*		
Strawberry			
Box Elder	*Acer negundo*		FAC+
	Geum virginianum		
Smartweed (sample)	*Polygonum*		
Skunk Cabbage	*Symplocarpus foetidus*		OBL
opposite w/ sm leaflets (sample)			
Cloverlike (sample)			
Leersia (sample)			
Stinging Nettle	Urtica dioica		FACU

Woody Vine stratum

Greenbriar	*Smilax rotundifolia*	D	FAC
Poison Ivy	*Toxicodendron radicans*	D	FAC
Multiflora Rose	*Rosa multiflora*	D	FACU
Japanese Honeysuckle	*Lonicera japonica*		FAC-

Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: Middle Patuxent River 3 - high (FF3)

Tree stratum

		Dominance	Status
Mockernut Hickory	*Carya tomentosa*	D	
Pin Oak	*Quercus palustris*	D	FACW
Tulip Poplar	*Liriodendron tulipifera*		FACU
Birch/Hophornbeam (sample)			
Red Maple	*Acer rubrum*		FAC

Sapling stratum

opposite w/ sm leaflets (sample)	*Viburnum prunifolium*	D	
	Celtis occidentalis		

Shrub stratum

Armor Maple	*Acer*		
	Celtis occidentalis		

Herbaceous stratum

Spicebush	*Lindera benzoin*	D	FACW
Strawberry		D	
Garlic Mustard	*Allium*	D	
Jumpseed (Virginia Knotweed)	*Polygonum virginiana*		FAC
Japanese stilt grass	*Eunalia*		
Green Ash	*Fraxinus pennsylvanica*		FACW
Jack and the Pulpit	*Arisaema triphyllum*		FACW-
Ground Ivy			
Box Elder	*Acer negundo*		FAC+
Rue (sample)			
Smartweed (sample)	*Polygonum*		
Highbush Blackberry	*Rubus allegheniensis*		
Wood Reed	*Cinna arundinacea*		FACW+
Sedge (sample)			
Multiflora rose	*Rosa multiflora*		FACU

Woody Vine stratum

Japanese Honeysuckle	*Lonicera japonica*	D	FAC-
Greenbriar	*Smilax rotundifolia*	D	FAC
Poison Ivy	*Toxicodendron radicans*		FAC
Virginia Creeper	*Parthenocissus quinquefolia*		FACU

Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: Rock Creek 1 - low (RC1)

Tree stratum

		Dominance	Status
Red Maple*	*Acer rubrum*		FAC

Sapling stratum

Red Maple	*Acer rubrum*		FAC
Box Elder	*Acer negundo*		FAC+

Shrub stratum

Cornus (sample)	*Cornus*		

Herbaceous stratum

Japanese Stilt Grass	*Eunalia*	D	
False Nettle	*Boehmeria cylindrica*	D	OBL
Bailey's Sedge		D	
Arrow-leaved Tearthumb	*Polygonum punctatum*	D	OBL
Ricecut Grass	*Leersia oryzoides*		OBL
Lady Fern	*Athyrium Filix-femina*		
Rush (sample)			
Halberd-leaved Tearthumb	*Polygonum arifolium*		OBL
Big-leaved Arrowhead	*Sagittaria latifolia*		OBL

Woody Vine stratum

Greenbriar*	*Smilax rotundifolia*		FAC
Multiflora Rose*	*Rosa multiflora*		FACU

*on 2ft. hummock

Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: Rock Creek 2 - mid (RC2)

Tree stratum

		Dominance	Status
Red Maple	*Acer rubrum*	D	FAC
Pin Oak	*Quercus palustris*	D	FACW
Green Ash	*Fraxinus pennsylvanica*	D	FACW
Oak (sample)	*Quercus*	D	

Sapling stratum

Red Maple	*Acer rubrum*		FAC
Box Elder	*Acer negundo*		FAC+

Shrub stratum

Flowering Dogwood	*Cornus florida*		

Herbaceous stratum

Japanese Stilt Grass	*Eunalia*	D	
Skunk Cabbage	*Symplocarpus foetidus*	D	OBL
	Geum canadense		
Red Maple	*Acer rubrum*		FACU-
Garlic Mustard	*Allium*		
False Nettle	*Boehmeria cylindrica*		OBL
	Laportea canadensis		
Circle plant (sample)			
Thumb plant (sample)			

Woody Vine stratum

Virginia Creeper	*Parthenocissus quinquefolia*		FACU

notes: sphagnum moss on ground
Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: Rock Creek 3 - high (RC3)

Tree stratum

		Dominance	Status
Shellbark Hickory	*Carya laciniosa*	D	FACW
Red Maple	*Acer rubrum*	D	FAC
Pin Oak	*Quercus palustris*	D	FACW
White Ash	*Fraxinus americana*	D	FACU
Shingle Oak	*Quercus*	D	
Swamp White Oak/Swamp Chesnut Oak		D	

Sapling stratum

Red Maple	*Acer rubrum*	D	FAC
Box Elder	*Acer negundo*		FAC+

Shrub stratum

Japanese Crabapple		D	

Herbaceous stratum

Japanese Stilt Grass	*Eunalia*	D	
Grass (sample)		D	
European Barberry			
Red Oak	*Quercus rubra*		FACU-
Smartweed (sample)	*Polygonum*		
Long Bristle Smartweed	*Polygonum caespitosum*		
Garlic Mustard	*Allium*		
Skunk Cabbage	*Symplocarpus foetidus*		OBL
Strawberry			
Marigold (sample)			

Woody Vine stratum

Virginia Creeper	*Parthenocissus quinquefolia*		FACU
Grape	*Vitis rotundifolia*		

Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: White Clay Creek 1 - low (WCC1)

Tree stratum — Dominance, Status

		Dominance	Status

Sapling stratum

Red maple v. trilobum*	*Acer rubrum v. trilobum*	D	FAC

Shrub stratum

Red maple v. trilobum*	*Acer rubrum v. trilobum*	D	FAC
Spicebush	*Lindera benzoin*		FACW

Herbaceous stratum

Big-leaved Arrowhead	*Sagittaria latifolia*	D	OBL
Tussock Sedge	*Carex stricta*	D	OBL
Japanese stilt grass	*Eunalia*	D	
Halberd-leaved Tearthumb	*Polygonum arifolium*	D	OBL
Broad-leaved Cattail	*Typha latifolia*		OBL
Marsh Fern	*Thelypteris thelpteroides*		OBL
Ground-nut	*Apios americana*		FACW
Multiflora Rose*	*Rosa multiflora*		FACU
Arrow-leaved Tearthumb	*Polygonum punctatum*		OBL
Spotted Touch-me-not	*Impatiens capensis*		FACW
Smartweed (sample)	*Polygonum*		
Dye Bedstraw	*Galium tinctorium*		OBL

Woody Vine stratum

Poison Ivy	*Toxicodendron radicans*		FAC
Virginia Creeper	*Parthenocissus quinquefolia*		FACU

*on hummocks

Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: White Clay Creek 2 - low/mid (WCC2)

Tree stratum

		Dominance	Status
Pin Oak	*Quercus palustris*	D	FACW
Willow Oak	*Quercus phellos*	D	FAC+
Green Ash	*Fraxinus pennsylvanica*	D	FACW
Red Maple	*Acer rubrum*		FAC

Sapling stratum

Willow Oak	*Quercus phellos*	D	FAC+
Red maple	*Acer rubrum*	D	FAC

Shrub stratum

Speckled Alder	*Alnus rugosa*	D	FACW+
Buttonbush	*Cephalanthus occidentalis*	D	OBL
Multiflora rose	*Rosa multiflora*	D	FACU
Silky Dogwood	*Cornus amomum*		FACW
Spicebush	*Lindera benzoin*		FACW

Herbaceous stratum

Spotted Touch-me-not	*Impatiens capensis*	D	FACW
Sensitive Fern	*Onoclea sensibilis*	D	FACW
Japanese stilt grass	*Eunalia*	D	
Skunk Cabbage	*Symplocarpus foetidus*	D	OBL
Grass (sample at 3+4)		D	
Grass (sample at 2)		D	
Halberd-leaved Tearthumb	*Polygonum arifolium*		OBL
Silky Dogwood	*Cornus amomum*		FACW
Goldenrod	*Euthamia*		
Soft Rush	*Junkus effusis*		FACW+
Sweet Flag	*Acorus calamus*		OBL
Arrow-leaved Tearthumb	*Polygonum punctatum*		OBL
Red maple	*Acer rubrum*		FAC
Moneywort	*Lysimachia numnularia*		
False Nettle	*Boehmeria cylindrica*		FACW+
Common Dodder	*Cuscuta gronovii*		FAC*

Woody Vine stratum

Poison Ivy	*Toxicodendron radicans*		FAC
Highbush Blackberry	*Rubus allegeniensis*		
Ground-nut	*Apios americana*		FACW
Virginia Creeper	*Parthenocissus quinquefolia*		FACU

*epiphyte
notes: moss covering ground
Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: White Clay Creek 3 - middle (WCC3)

Tree stratum		Dominance	Status
Mockernut Hickory	*Carya tomentosa*	D	
Pin Oak	*Quercus palustris*		FACW
Red Maple	*Acer rubrum*		FAC

Sapling stratum

Box Elder	*Acer negundo*	D	FAC+

Shrub stratum

Multiflora rose	*Rosa multiflora*	D	FACU
Spicebush	*Lindera benzoin*	D	FACW

Herbaceous stratum

Jumpseed (Virginia Knotweed)	Polygonum virginiana	D	FAC
Sensitive Fern	*Onoclea sensibilis*	D	FACW
Multiflora rose	*Rosa multiflora*	D	FACU
Japanese stilt grass	*Eunalia*		
Skunk Cabbage	*Symplocarpus foetidus*		OBL
Grass (sample at 3+4)			
Spotted Touch-me-not	*Impatiens capensis*		FACW
Columbine	*Aquilegia canadensis*		
	Geum virginianum		
Goldenrod	*Euthamia*		
Jack and the Pulpit	*Arisaema triphyllum*		FACW-
Boxelder	*Acer negundo*		FAC+
False Nettle	*Boehmeria cylindrica*		FACW+

Woody Vine stratum

Poison Ivy	*Toxicodendron radicans*		FAC
Ground-nut	*Apios americana*		FACW
Virginia Creeper	*Parthenocissus quinquefolia*		FACU

notes: moss covering ground
Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

Site: White Clay Creek 4 - high (WCC4)

Tree stratum

		Dominance	Status
Mockernut Hickory	*Carya tomentosa*	D	
Box Elder	*Acer negundo*		FAC+
Red Maple	*Acer rubrum*		FAC

Sapling stratum

Box Elder	*Acer negundo*		FAC+

Shrub stratum

Multiflora rose	*Rosa multiflora*		FACU
Spicebush	*Lindera benzoin*		FACW

Herbaceous stratum

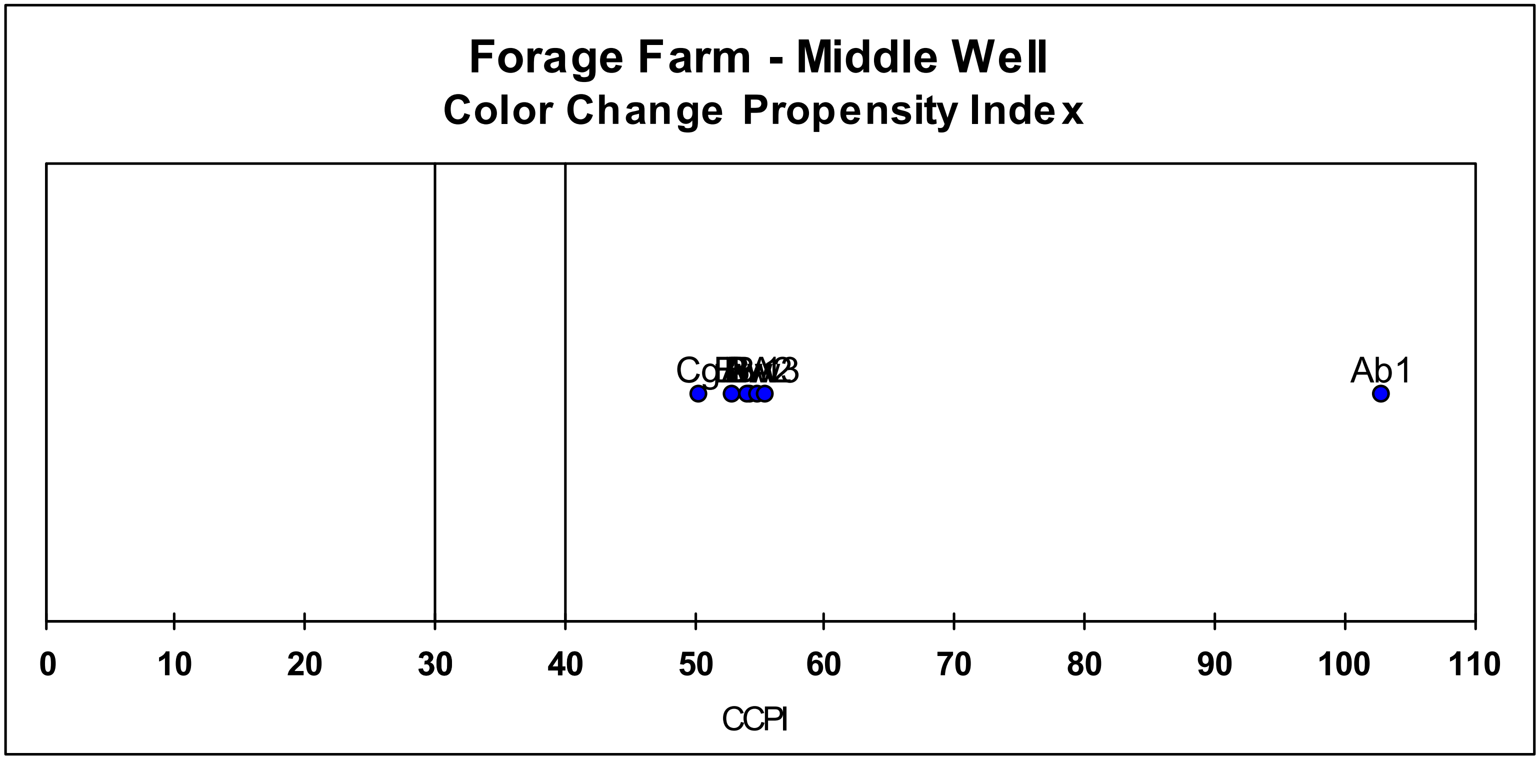
Jumpseed (Virginia Knotweed)	*Polygonum virginiana*	D	FAC
Japanese stilt grass	*Eunalia*	D	
Grass (sample at 3+4)			
Bailey's Sedge			
Spicebush	*Lindera benzoin*		FACW
Jack and the Pulpit	*Arisaema triphyllum*		FACW-
Multiflora rose	*Rosa multiflora*		FACU
Strawberry			

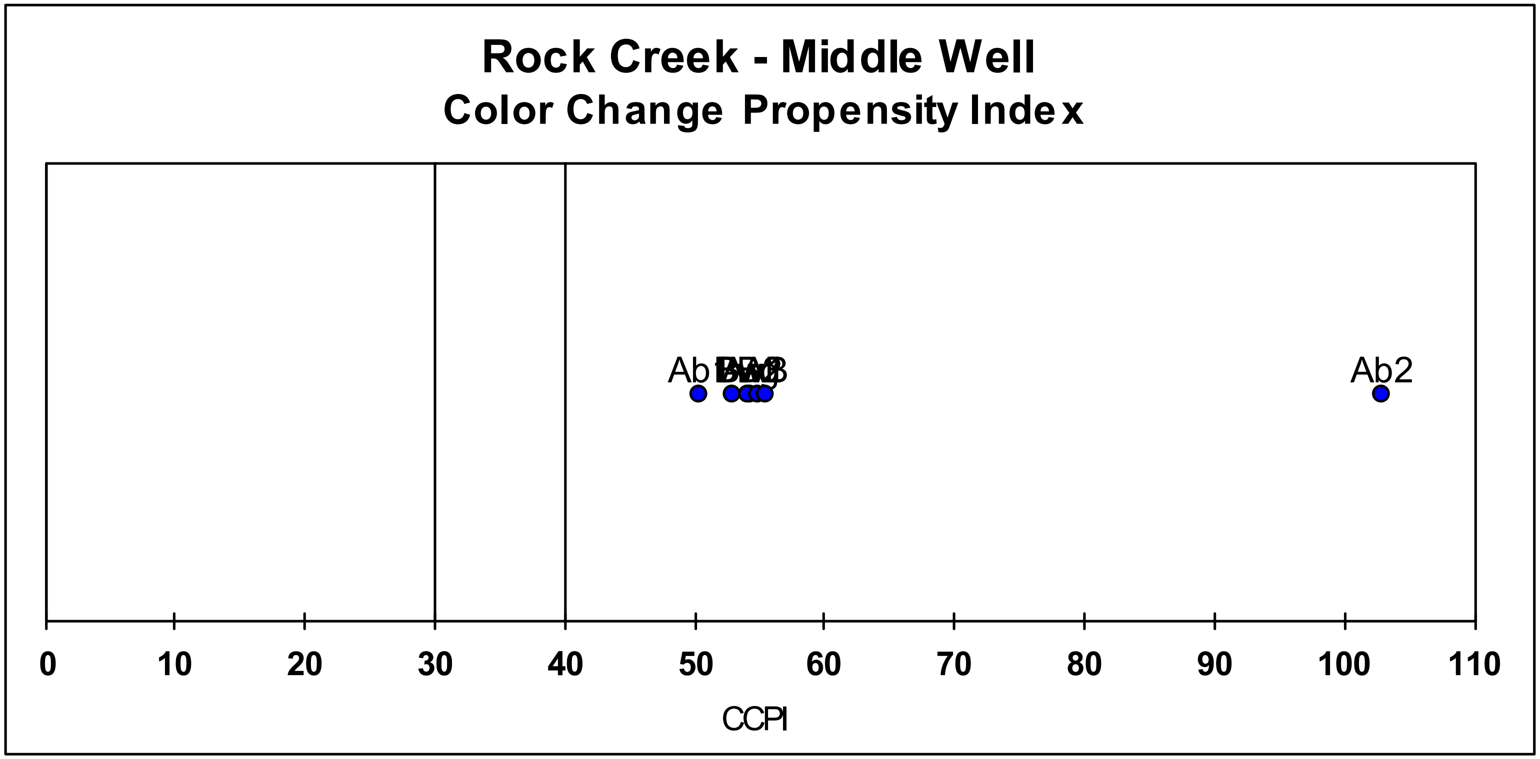
Woody Vine stratum

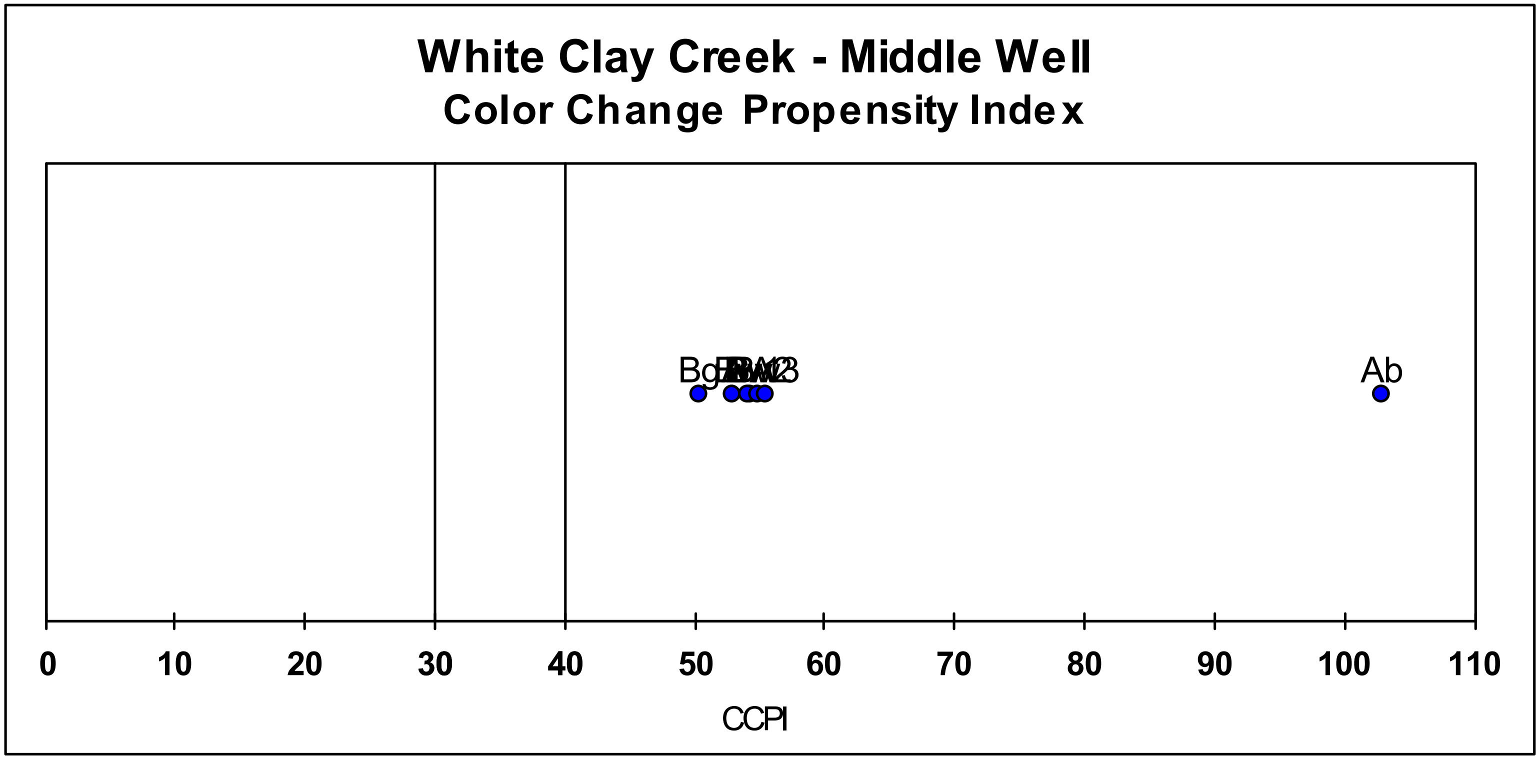
Poison Ivy	*Toxicodendron radicans*		FAC
Japanese Honeysuckle	*Lonicera japonica*		FAC-
Grape	*Vitas*		

notes: moss covering ground
Describers: Bruce Vasislas, Martin Rabenhorst, Karen Castenson, Robert Vaughan, and Phillip Zurheide

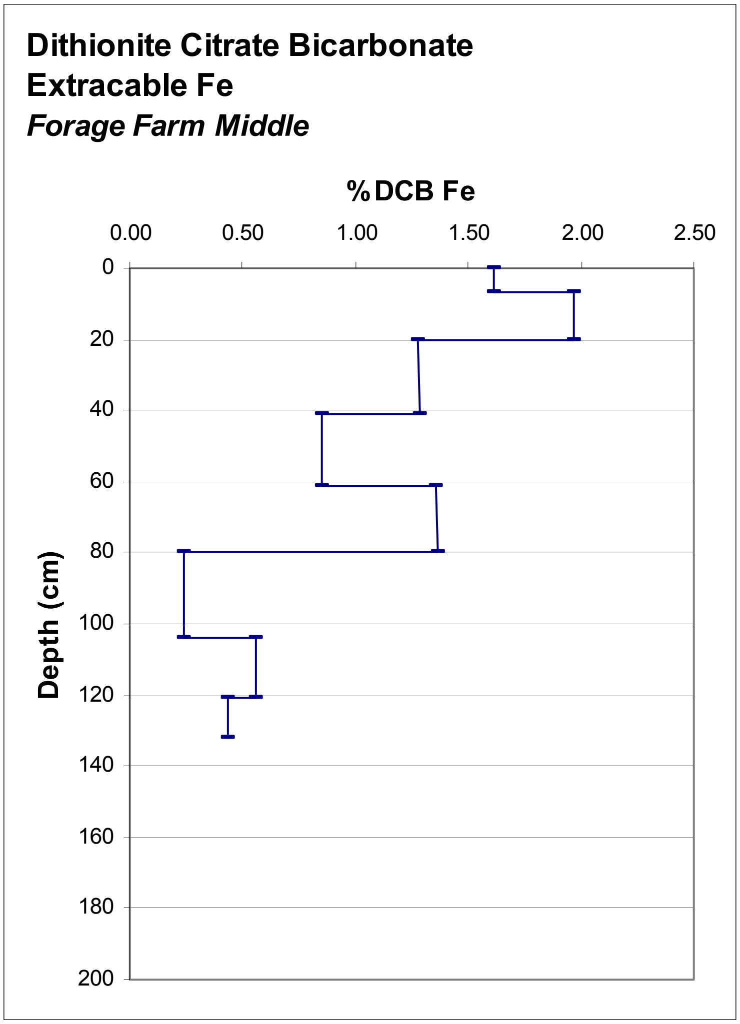
Appendix L: Color Change Propensity Index Results

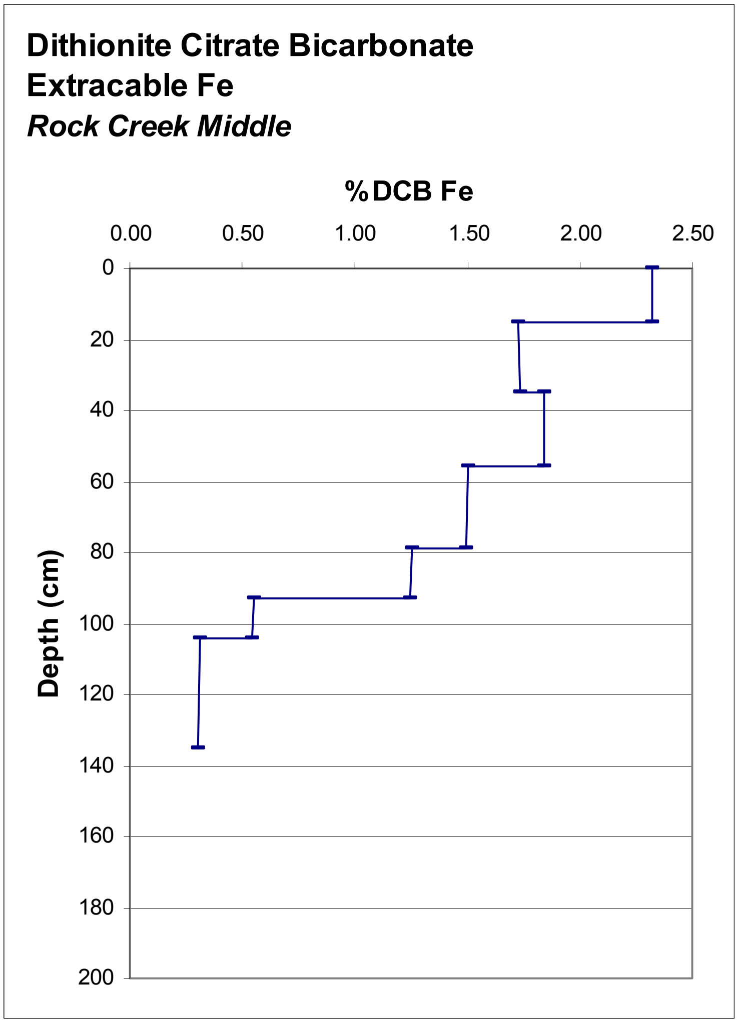


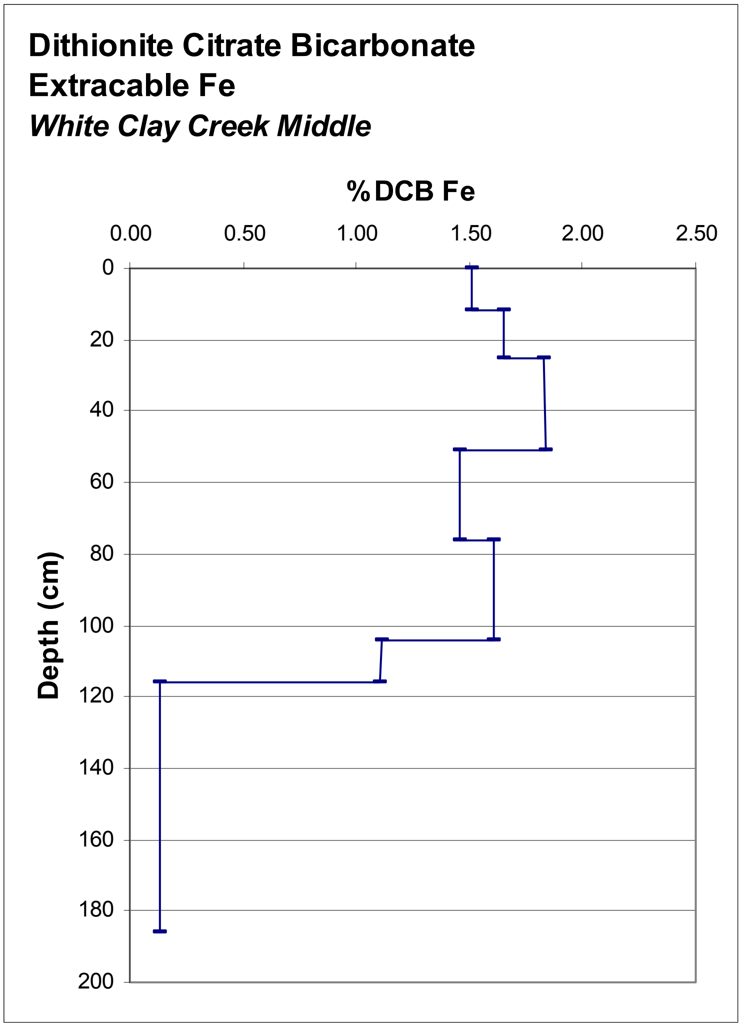

Rock Creek - Middle Well
Color Change Propensity Index
Ab
Ab2
0
10
20
30
40
50
60
70
80
90
100
110
CCPI


White Clay Creek - Middle Well
Color Change Propensity Index
Bg
Ab
0
10
20
30
40
50
60
70
80
90
100
110
CCPI

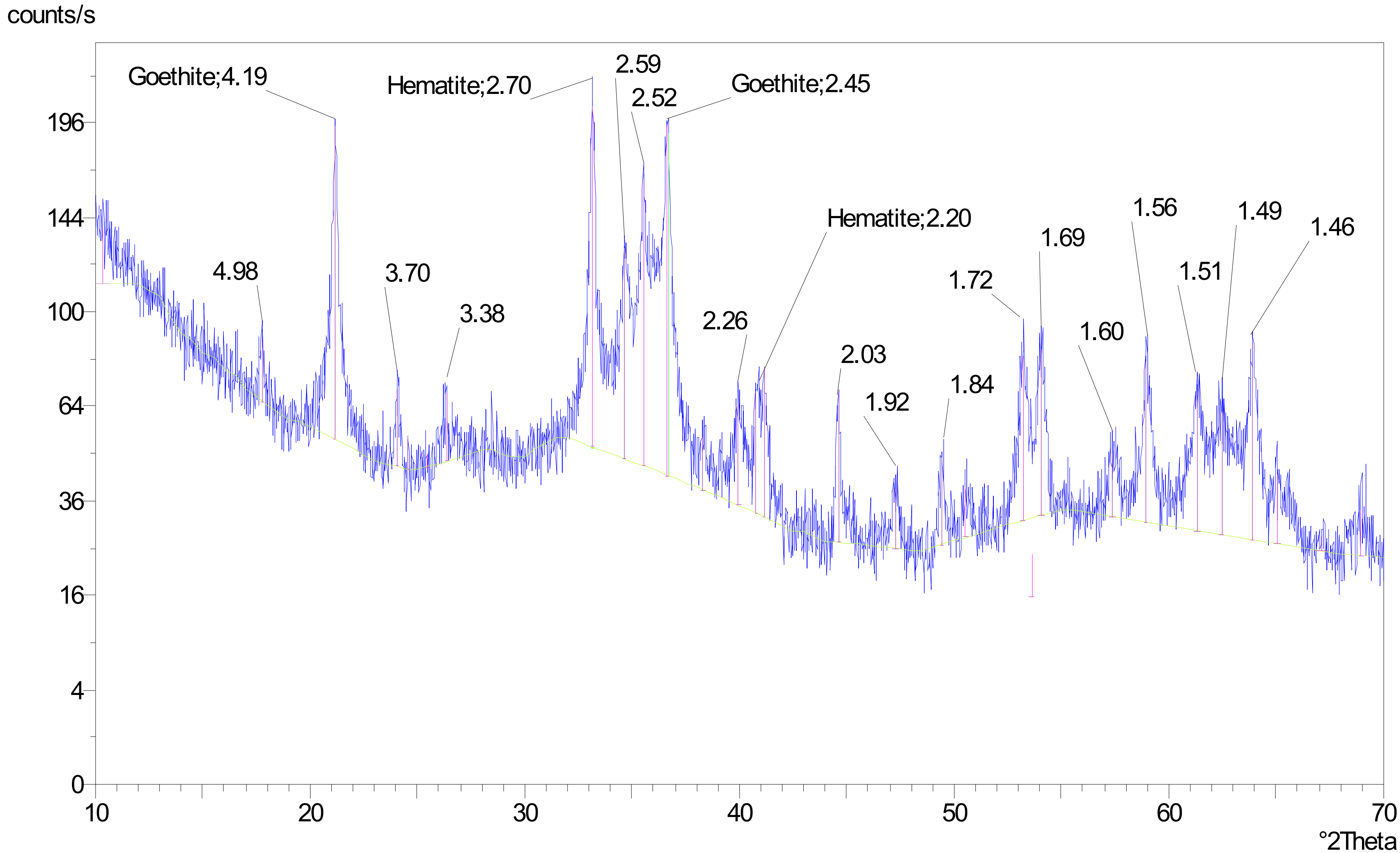
Appendix M: Dithionite Citrate Bicarbonate Extractable Iron




Dithionite Citrate Bicarbonate
Extracable Fe
Rock Creek Middle
% DCB Fe
0.00
0.50
1.00
1.50
2.00
2.50
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200


Dithionite Citrate Bicarbonate
Extracable Fe
White Clay Creek Middle
%DCB Fe
0.00
0.50
1.00
1.50
2.00
2.50
Depth (cm)
0
20
40
60
80
100
120
140
160
180
200

Appendix N: XRD Scan of Ferrihydrite Paint



Appendix O: Alternate IRIS Paper

Indicator of Reduction in Soil (IRIS): Evaluating a New Approach for Assessing Reduced Conditions in Soil

Introduction

Hydric soils are defined as those that "…formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register, 1994). Anaerobic conditions exist when oxygen has been depleted from the soil, causing heterotrophic microbes to act on alternate electron acceptors in order to oxidize organic material.

Field indicators of hydric soil are used widely throughout the United States as a method of identifying hydric soils (USDA-NRCS, 2002). These indicators describe morphological features in soil that suggest saturation for a sufficient amount of time to maintain reduced conditions. Soil morphological features are a relatively permanent element in wetlands, however, there are particular settings where the soil and or hydrology has been altered or removed. In these cases, it becomes more difficult to determine whether or not a soil is hydric as redoximorphic features indicative of the high water table may not have had sufficient time to form.

The National Technical Committee for Hydric Soils established a technical standard to be able to adopt, modify, or eliminate field indicators of hydric soils. In problematic soil settings, where field indicators may not be applicable, the technical standard can also be used in lieu of field indicators to identify hydric soils in the field. This technical standard includes requirements for saturation and redox potential (USDA-NRCS, 2002). Soil redox potential measurements can be used to determine the electrochemical status of the soil and to predict which mineral species will be theoretically stable. For this method, according to the technical standard, at least five Pt electrodes must be installed at a depth of 25 cm (for all soils except sands). Measurements of soil oxidation-reduction (redox) potential can be used to infer reduced conditions in hydric soils. The disadvantages of this method are the time and equipment necessary to make these measurements. Multiple redox potential measurements must be made throughout the year, in order to document that the soil is reduced for 14 or more consecutive days.

The use of α, α'dipyridyl dye can also be used to detect the presence of reduced iron in soil and thus infer that the soil is in a reduced condition (USDA-NRCS, 2002). A positive reaction to α, α'dipyridyl dye is indicated by a reddish pink color that appears in the presence of reduced iron. In order to meet this criteria for the technical standard, there must be a positive reaction in 10 cm of the upper 30 cm for loamy soils in two out of three samples tested.

A new procedure is being developed to monitor wet soil environments and document soil reduction. Jenkinson (2003), developed and tested indicator of reduction in soil (IRIS) polyvinyl chloride tubes that are coated in ferrihydrite paint. He installed these tubes in saturated and unsaturated soils in Indiana, North Dakota, and Minnesota. Jenkinson found a significant correlation between depth to water table and removal of Fe(III) from the IRIS tubes. Fe(III) was removed from the tube in locations where the the soil was saturated by the seasonally high water table. The Fe(III) coating was left undisturbed in locations where the soil was unsaturated. The assumption was that the iron paint was removed or translocated in soluble (Fe(II)) form from the tube surface due to reducing conditions in the soil. Jenkinson (2003) however, did not make measurements of soil redox potential for direct comparisons with the IRIS tubes.

In this study, IRIS tubes were tested to evaluate their suitability to identify the dissolution of oxidized iron in soils within a young floodplain setting. It was postulated that the IRIS tubes might indicate where iron was being reduced in the profile providing a simpler and less tedious and time consuming approach than measuring redox potential and water tables. The objective was to test the usefulness of the IRIS tubes in assessing the reducing conditions in soils by relating the removal of ferrihydrite from the tubes to measured soil redox potentials and water table levels.

Materials and Methods

Study Area

Three floodplains in the Piedmont physiographic region of Maryland and Delaware were instrumented for this study. Figure 3-1 shows the location of two sites in Maryland on the Middle Patuxent River and the North Branch of the Rock Creek, and one site in Delaware on White Clay Creek. The sites were set up along transects from a groundwater discharge wetland, across the floodplain toward drier soil nearer the stream

(Fig. 1-3). The sites at the Middle Patuxent and Rock Creek contained three monitoring stations located in the wet, backswamp area (low), intermediate area (middle), and the drier area (high) of the floodplain. White Clay Creek contained an additional fourth monitoring station (low/mid) in the wet, backswamp area.

Field Procedures

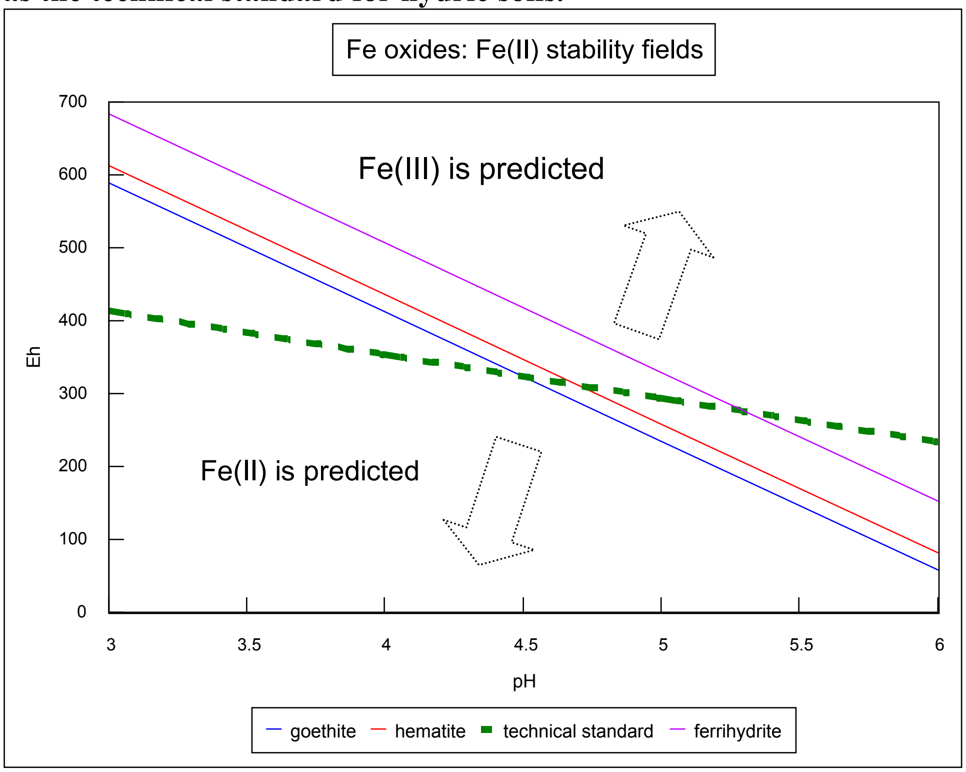
Water table measurements were made twice daily using Remote Data Systems automatic monitoring wells (RDS, Inc., Wilmington, NC).

Soil oxidation-reduction (redox) potential was measured at all well locations every two to three weeks. These measurements were made using six Pt electrodes inserted to depths of 10, 20, 30, 40, and 50 cm. A pilot hole was made with a thin steel rod to ensure the Pt tip was not damaged when inserted into the soil. The Pt tip was inserted into the hole and pressed to make solid contact with the soil. The electrodes were placed in a semi-circle around the calomel reference electrodes maintaining less than 30 cm between the Pt and reference electrodes. Redox potentials were measured with a digital multimeter and a calomel saturated KCl reference electrode. Redox measurements were converted to Eh values by adding the reference electrode conversion factor (244mV).

In order to accurately compare soil conditions with Eh/pH stability diagrams, soil pH measurements were also made at the same intervals and depths as redox measurements. pH was measured in the field on a 1:1 soil/water slurry using an Orion 420 pH meter.

Figure 7-1 shows Eh/pH stability diagram for iron species (assumed activity of 10^{-6} M). Ferrihydrite is slightly more easily reduced, than hematite, followed by goethite.

Figure 7-1: Iron stabilty diagram showing Fe(III) - Fe(II) stability fields for goethite, hematite, and ferrihydrite. Also plotted is the Fe(III) - Fe(II) line adopted as the technical standard for hydric soils.



Preparation of Indicator of Reduction in Soil Tubes

Indicator of Reduction in Soil (IRIS) tubes were constructed based on the procedure established by Jenkison (2003) in his Ph.D. dissertation. A brief synopsis of the procedure follows with modifications from the original method discussed by Jenkinson.

Ferrihydrite paint was prepared by dissolving ferric chloride salt in deionized water. 1M KOH was added to raise the pH and precipitate the ferrihydrite. This solution was centrifuged and placed in dialysis tubing in order to remove the salts. The viscosity of the paint solution was diluted to that of oil paint. It was stored in an opaque plastic container under normal room temperature.

The ferrihydrite paint was analyzed to determine specific minerals present in solution. Samples of the paint were dried and ground to be analyzed with x-ray diffraction (XRD). The XRD pattern indicated that goethite and another poorly crystalline iron mineral was present (Appendix N). Two broad peaks, typical of ferrihydrite, were identified (near 32^{o} 2 Theta and 62^{o} 2 Theta). Because XRD does not produce quantitative results, samples of the paint were extracted using dithionite-citrate-bicarbonate (DCB) extractable iron (Loeppert and Inskeep, 1996) and acid ammonium oxalate to determine the dominant iron species (Schwertmann, 1964; McKeague and Day, 1966). The DCB extracts essentially all the secondary Fe oxides while NH_4 oxalate extracts the poorly crystalline Fe oxides, particularly ferrihydrite (Scwertmann and Taylor, 1986). The ratio of NH_4 oxalate Fe to DCB Fe was 0.7, suggesting that most of the total iron was in a poorly crystalline form, assumed to be ferrihydrite.

Polyvinyl chloride (PVC) tubes, ¾ in. diameter, were cut into 60 cm lengths. Fifty cm of the tube were cleaned with acetone and sanded. Tubes were set on a lathe type device and the prepared ferrihydrite paint was painted onto the sanded portion of the tube. Jenkinson (2003) suggested two coats of paint should be applied to each tube. Approximately 25 tubes were given two coats and the remainder received one. Approximately 150 tubes were constructed for this study.

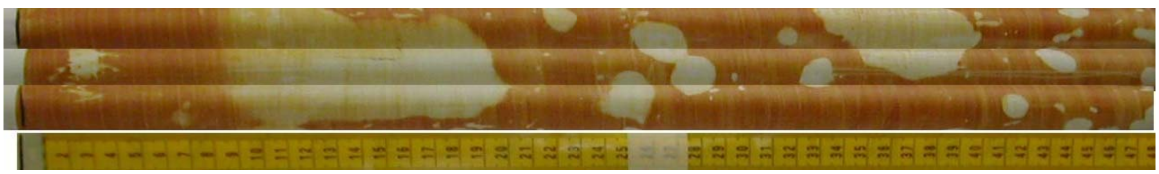
Preliminary data was collected before the beginning of this study. Tubes with two coats were installed in backswamp areas while soil temperatures were low. Upon the removal of these tubes, the amount of iron removal from the tube was not substantial, so the remainder of the tubes were made with one coat. In hindsight, low soil temperature appeared to be the reason for the lower percentage of iron removal from the tube, therefore, one or two coats would have revealed similar results.

IRIS Tube Procedures

Beginning in February 2003, duplicate IRIS tubes were installed at each well location. A 5/8 in. diameter push auger was used to make a pilot hole so the tube could be inserted into the soil with minimal scratching yet ensuring soil contact. Tubes remained in the field for 12 to 32 days at a time (averaging 20 days). Redox potential was measured on the dates the tubes were installed and removed. Upon removing a set of tubes, another set was immediately inserted into the original holes. The removed tubes were partially cleaned of soil and returned to the lab for additional cleaning.

All IRIS tubes removed from the soil were given a label and cleaned with tap water to remove any adhering soil material. Three photos were taken of each tube following 120^{o} rotation. These photos were then cropped and joined with a photo of a tape measure (cm) to form one image of the whole surface of the tube. Figure 7-2 shows an image of an IRIS tube removed on June 23 from the middle well at White Clay Creek. These images were analyzed visually for a number of attributes, including; depth to first reduction, percentage of tube surface reduced, and depth to strong reduction if first reduction was not continuous. The depth of first reduction on the IRIS tube in figure 7-2 is 2 cm below the soil surface. Consistent reduction occurred at 9 cm and 30% of the tube surface was removed of iron.

Figure 7-2: Image displaying the reduction of Fe(III) from IRIS tube at WC3 (middle well) removed 6-23-03 (top of tube is on the left). Scale along the bottom is cm.



Results and Discussion

Redox Potential and Water Table

The redox potential measured in the soil varied widely depending on the existence of saturated conditions. The soils located in the low and low/mid locations along the transects were saturated above 10 cm for the duration of the study (which ran from March 9th to July 15th). Figures 7-3, 7-4, and 7-5 show the water table data at each location along the transect. The soils in the middle locations at the three sites, were saturated above 25 cm from March through mid-June. At Rock Creek and White Clay Creek the soil was saturated above 30 cm from mid-June through mid-July and at the Middle Patuxent the soil was saturated above 55 cm from mid-June through mid-July. The soils at the high locations along the transects were saturated above 50 cm from March through mid-June and above 80 cm for the remainder of the study.

Figure 7-3: Water table data from the Middle Patuxent. Red line indicates the low well, green line indicates the middle well, and the blue line indicates the high well. Vertical lines indicate date IRIS tubes were installed and removed.

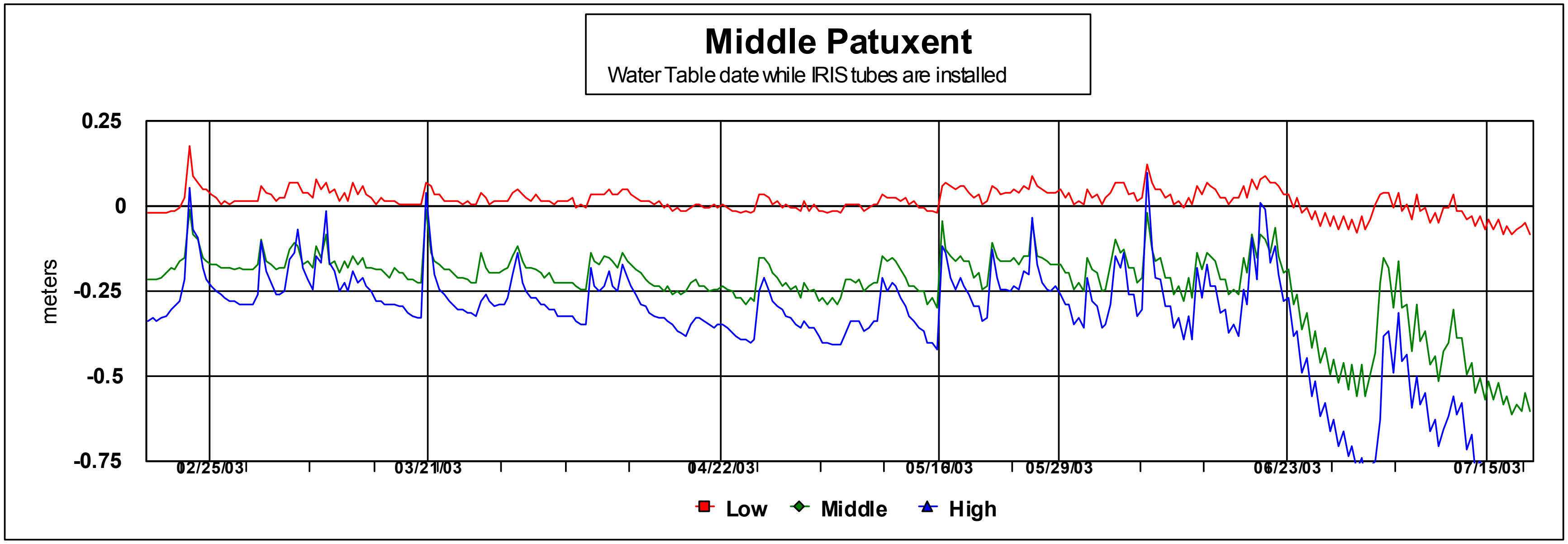


Figure 7-4: Water table data from site 2, Rock Creek. Red line indicates the low well, the green line indicates the middle well, and the blue line indicated the high well (water table at the high well may have been closer to the surface throughout the study but technical difficulties occurred throughout the study). Vertical lines indicate date IRIS tubes were removed and reinstalled.

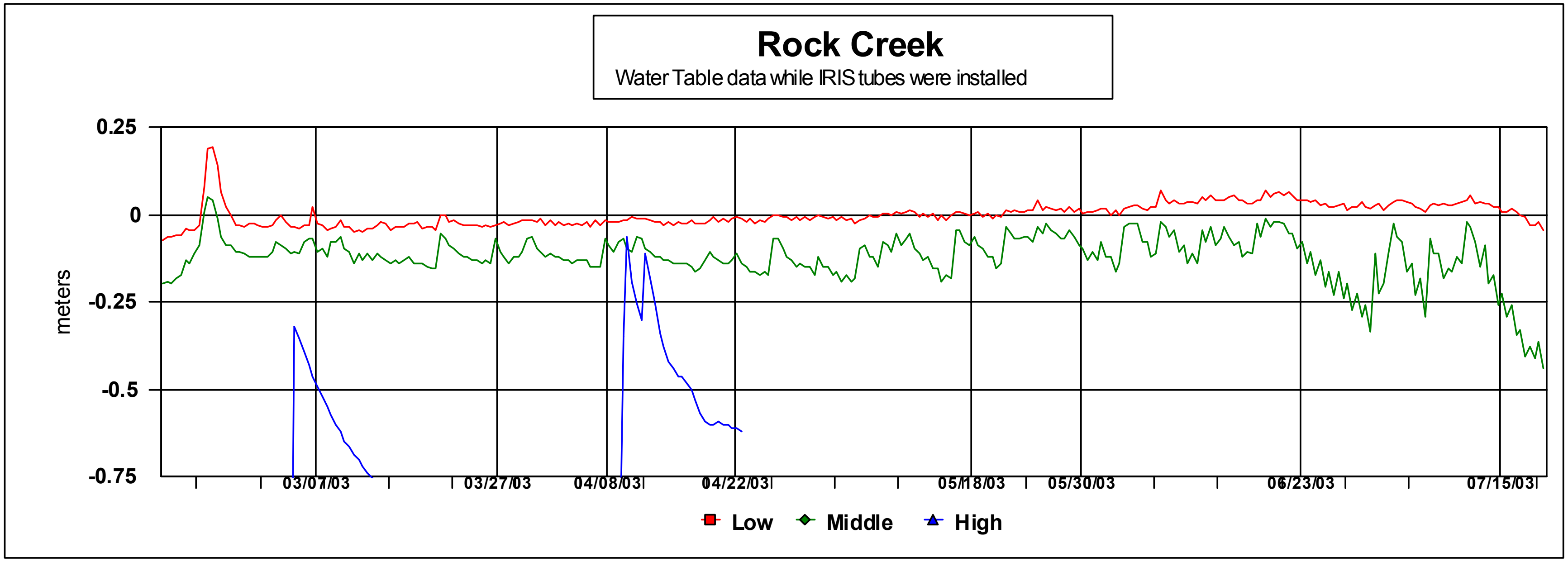
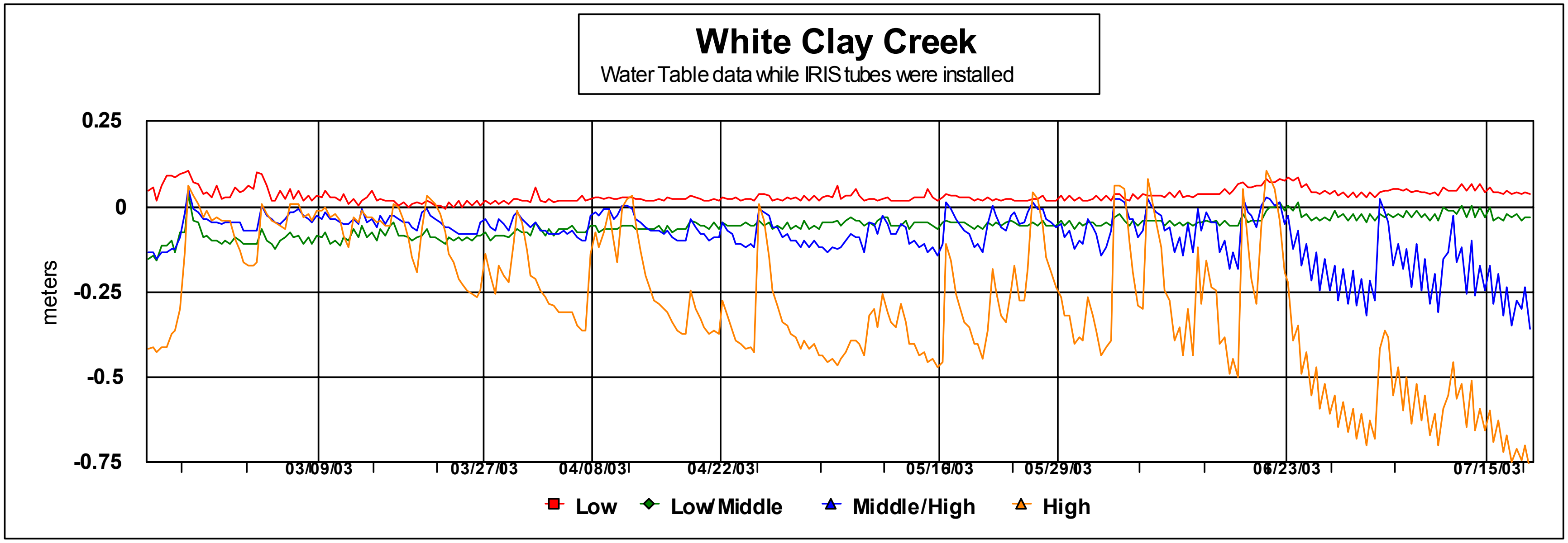


Figure 7-5: Water table data from site 3, White Clay Creek. Red line indicates the low well and the green line indicates the low/mid well, blue lines indicate the middle well, and the yellow line indicates the high well. Vertical lines indicate date IRIS tubes were removed and reinstalled.

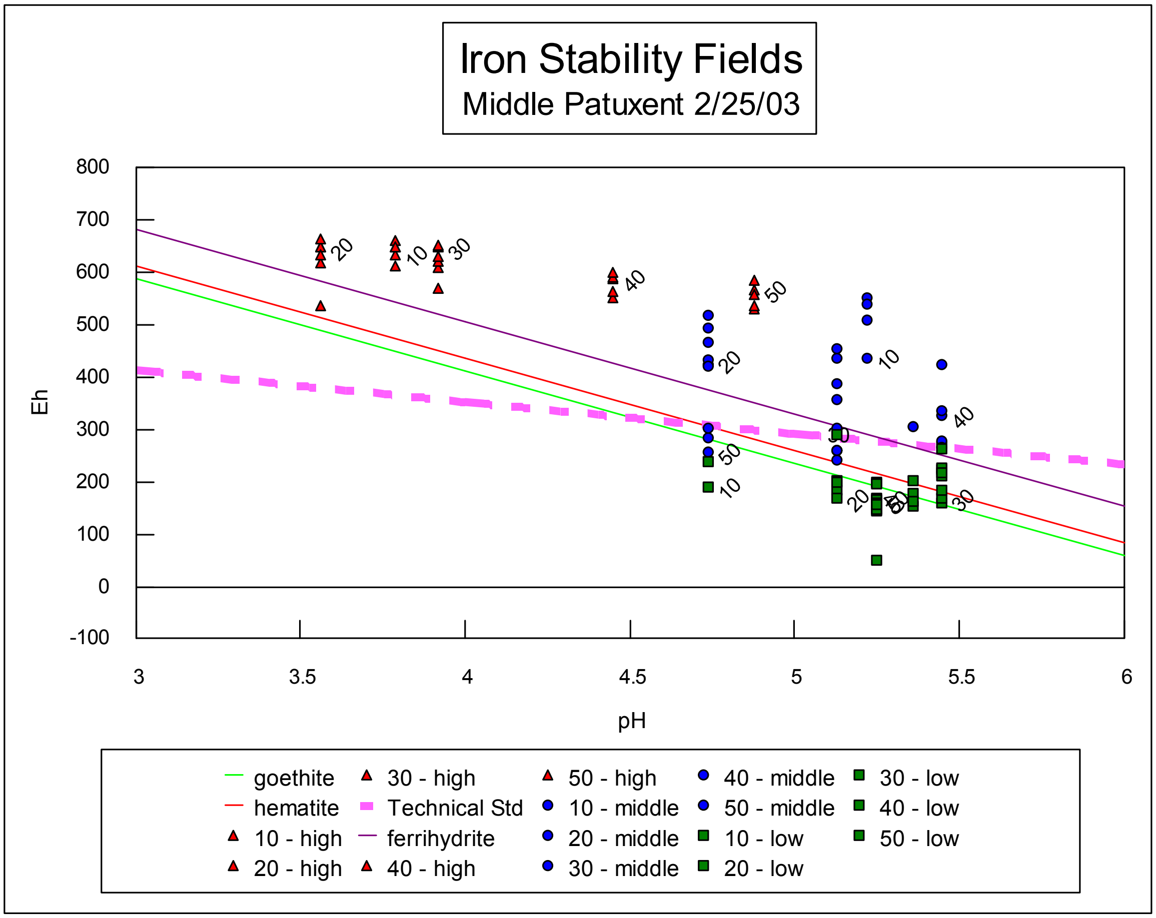


The redox potential of the soil at the low and low/mid locations was below the technical standard line for the reduction of iron nearly continuously throughout the study. Only occasionally was the redox potential at 10 cm in the low and low/mid locations at White Clay Creek elevated above the Eh-pH line defined in the technical standard. There was considerable variation in measured redox potential at the middle locations, with values fluctuating between oxidized early in the study, then being reduced during the middle, before being re-oxidized in the later drier months. The soils in the high locations along the transect also experienced fluctuating redox potentials throughout the study and with depth.

Figure 7-6 displays the redox potentials measured in soils at different locations along the floodplain transect on February 25, 2003. The redox measurements in the soil at the low well are relatively close together, and are below the technical standard line demonstrating that the soil is reduced. The potentials in the soil at the middle locations display greater variablity in comparison to measurements at both low and high sites. This is especially true at depths of 30 and 40 cm which represents the transition zone between fully reduced and oxidized conditions. At these depths, some portions of the soil are reduced and others are oxidized. The potentials measured in the soil at the high location are less varied, therefore, at this time the soil is clearly oxidized with little indication that there are microsites that are reduced.

Figure 7-6: Example of the variability in redox potential measurements at the low (green squares), middle (blue circles), and high (red triangles) soils at the Middle Patuxent. The measurements from each electrode are shown from each depth at all monitoring locations. Both the drier and wetter soils have a smaller range than the

soils in the transition between oxidized and reduced. This shows the increased variability in the soil when particular zones are saturated and reduced, and other portions maintain an oxidized state.

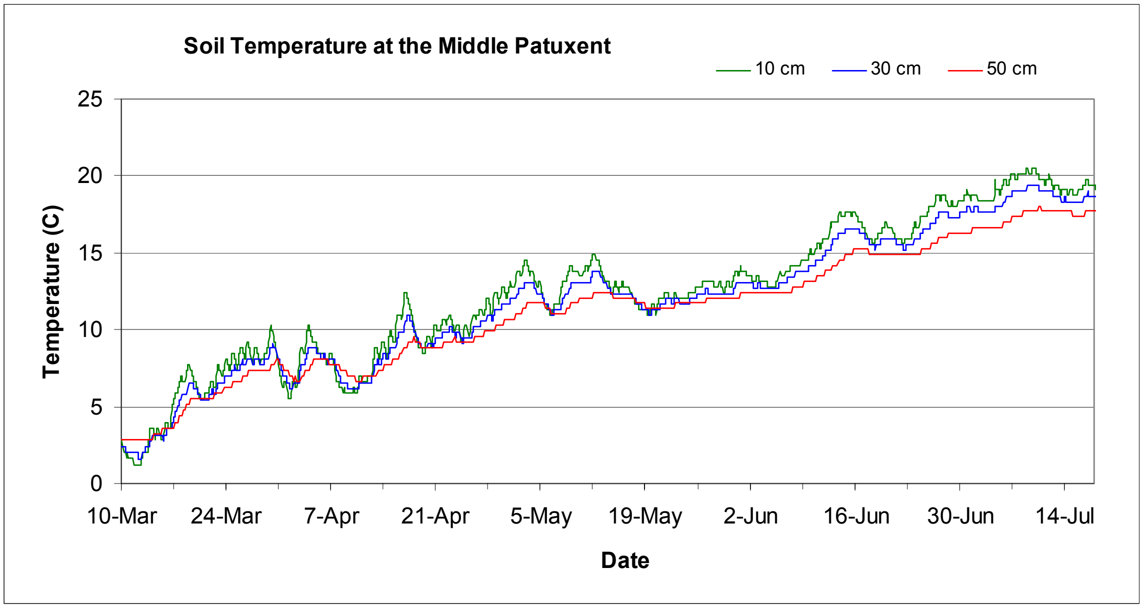


IRIS Tube Analysis

A number of trends were found while comparing the removal of iron from the IRIS tubes and the predicted stability of iron via redox measurements with Pt electrodes.

The tubes installed early in the season, while soil temperatures were low, had less incidence of reduction although the soil was saturated. Figure 7-7 shows the soil temperature at 10, 30, and 50 cm below the soil surface for the duration of the study. Soil temperature at the other two sites was comparable to the data shown for the Middle Patuxent Site.

Figure 7-7: Soil temperature at the Middle Patuxent.



Tubes removed from the soil at the low location along the transect had significantly more removal of iron than did tubes removed from the middle and high locations. The redox potential of these soils was also significantly lower and the water table was considerably higher. Correspondingly, the tubes removed from the soil at the middle locations also had more removal of iron than the tubes removed from the high locations. The redox potential of the soil in the middle locations was lower than that of the soil in the high locations, and the water tables were higher at the middle locations than at the high locations.

Middle Patuxent River

Tubes removed from the low site at the Middle Patuxent on March 21 showed strong signs of reduction of iron (Fig. 7-8). The redox potential at this location indicated that the soil was reduced the entire length of the tube (Fig. 7-9). The removal of iron from tube A is apparent for the length of the tube, while there is more variability in Fe removal shown on tube B. Tube B shows the effects of scratching of the paint upon installation or removal.

Figure 7-9: Iron stability diagram with redox potential from the low, middle, and high sites at the Middle Patuxent on 3-21-2003. Points are averages of six electrode measurements

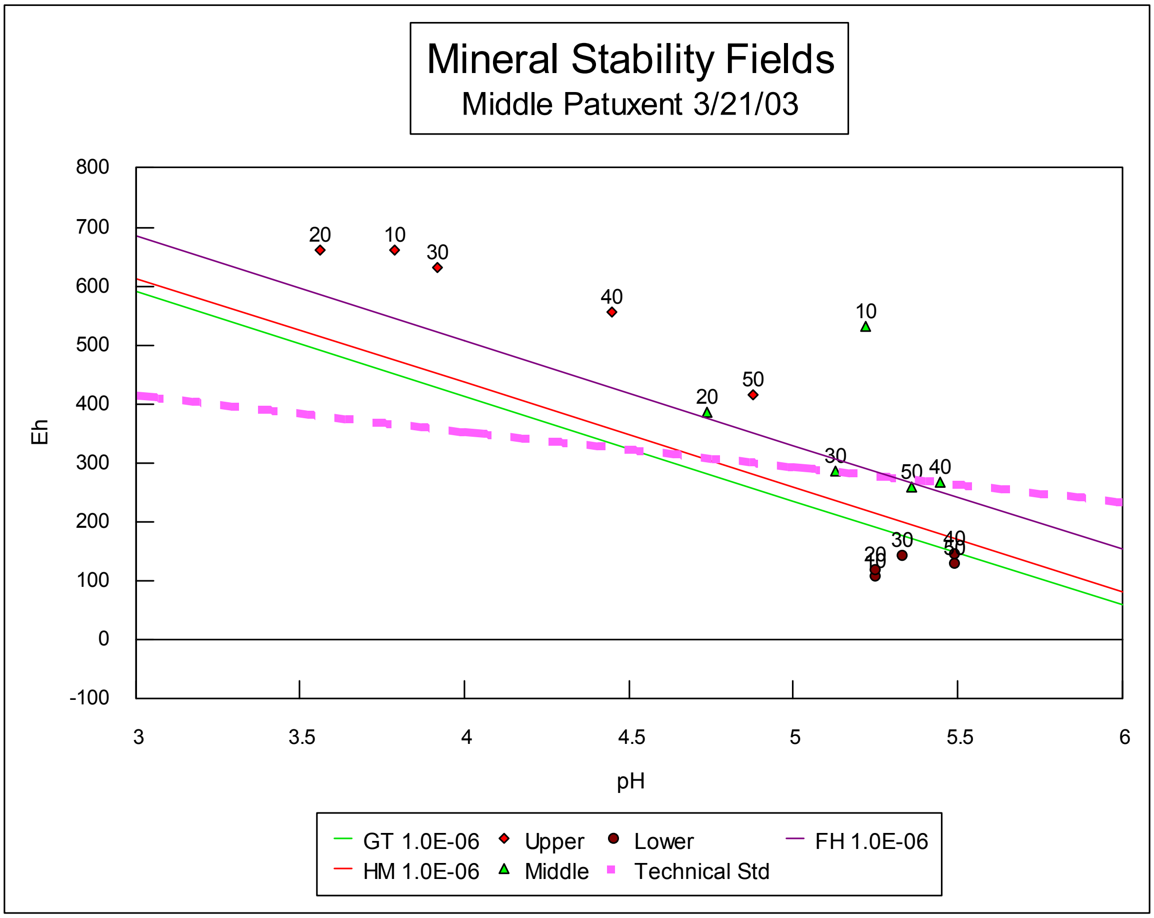
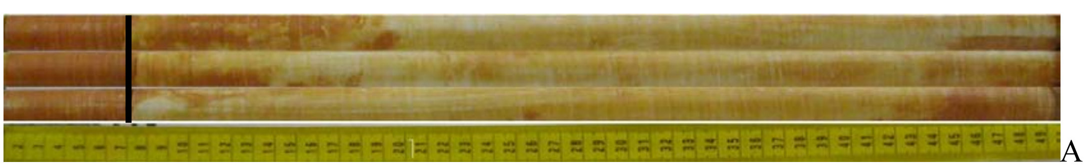
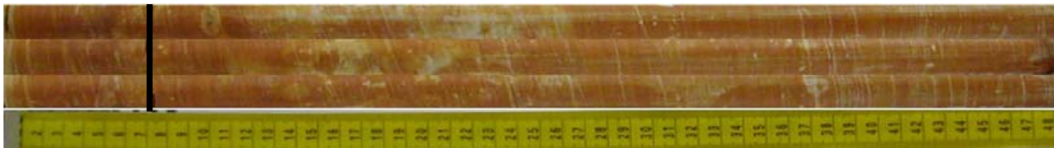


Figure 7-8: IRIS tubes removed on 3-21 from the low site at the Middle Patuxent. Soil surface is indicated by black line.

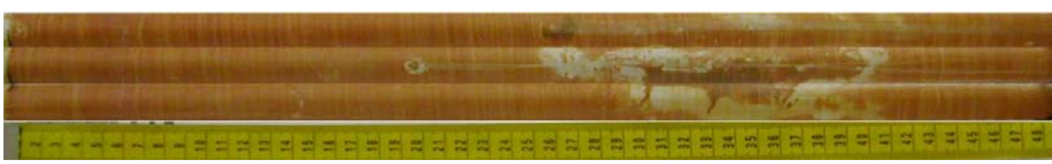



B

At the middle location, the redox potential at 30, 40, and 50 cm, measured at the time of removal of the IRIS tubes from the soil, was below the technical standard for reduced iron (Fig. 7-9). Removal of iron from the tubes is visible in splotches on tube A and more intensely on tube B between 26 and 41 cm. This is an indication that the technical standard line may be more accurate than the constructed stability lines for ferrihydrite, goethite, and hematite in predicting reduction of iron for soils with similar pH . Cool soil temperatures also likely impacted the results of both the tube and soil redox potential measurement.

Figure 7-10: IRIS tubes removed on 3-21 from the middle site at the Middle Patuxent.

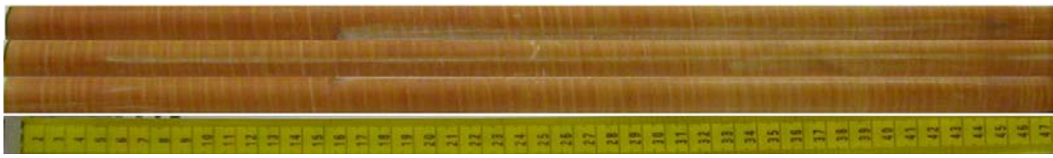

A


B

The redox potential measured at all depths in the soil at the high location at the Middle Patuxent was above the technical standard as well as the iron stability line (Fig.7-9). The IRIS tubes also indicate that all iron in the system was oxidized, therefore, no iron was removed from the tube (Fig.7-11). Table 7-1 illustrates the relationship between the soil redox potential and the IRIS tubes.

Figure 7-11: IRIS tubes removed on 3-21 from the high well at site 1.

A



B

Table 7-1 Results of the reduction of iron from the IRIS tubes compared to the measured redox potentials at the Middle Patuxent on March 21, 2003.

depth (cm)	MP low (3-21)		MP middle (3-21)		MP high (3-21)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X				
20	X	X				
30	X	X	X*	X		
40	X	X	X*	X		
50	X	X		X		

X indicates reduction of iron from the tube or Eh below the technical standard.
*replicate tube did not show same reduction pattern.

The tubes installed and removed after soil temperatures increased above 10°C showed a much stronger relationship between redox potential and the amount and depth of iron removal from the IRIS tube. The redox potential of the soil at the low site at the Middle Patuxent of April 22nd was below the technical standard and the iron stability lines for the three iron oxyhydroxides (Fig. 7-12). The tubes removed on that date shown strong reduction along the entire tube surface in contact with the soil (Fig. 7-13).

Figure 7-12: Iron stability diagram with redox potential from the low, middle, and high sites at the Middle Patuxent on 4-22-2003. Points are averages of six electrode measurements.

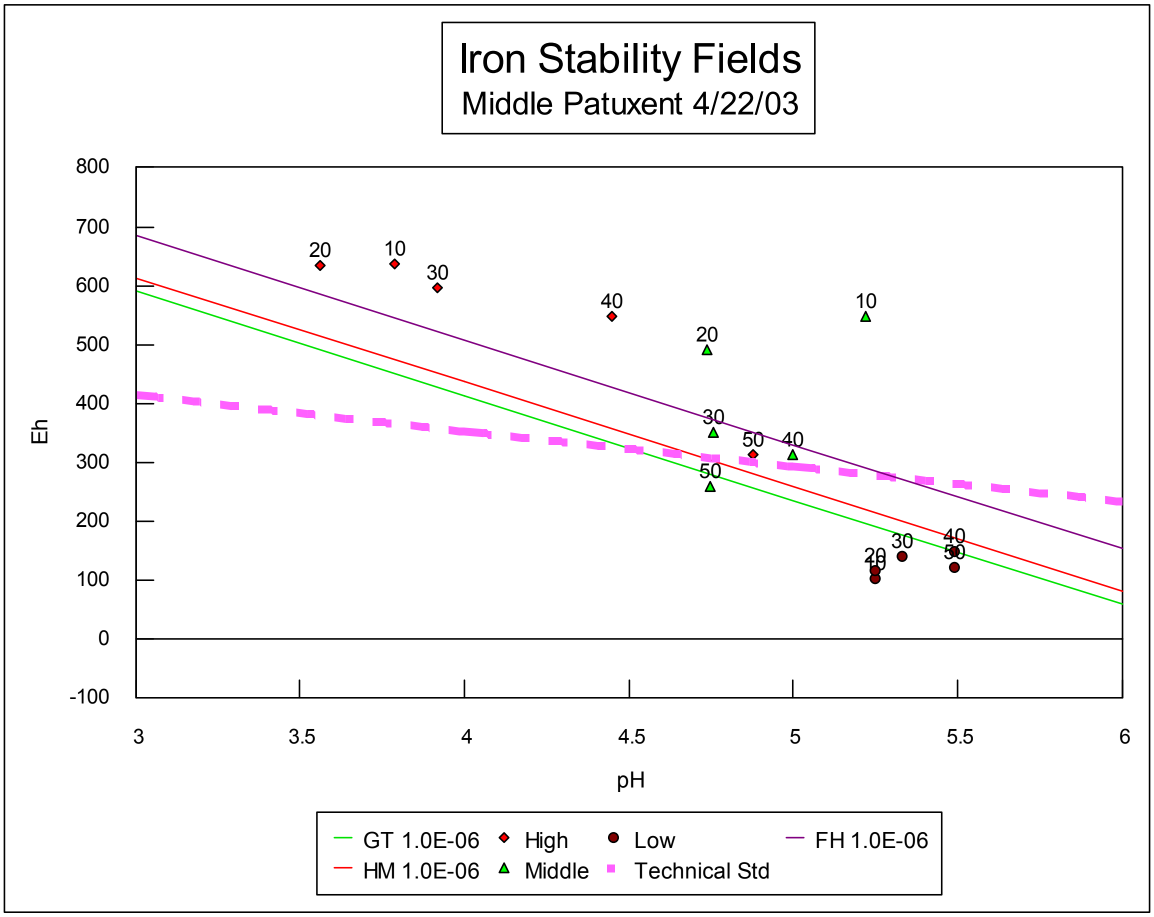
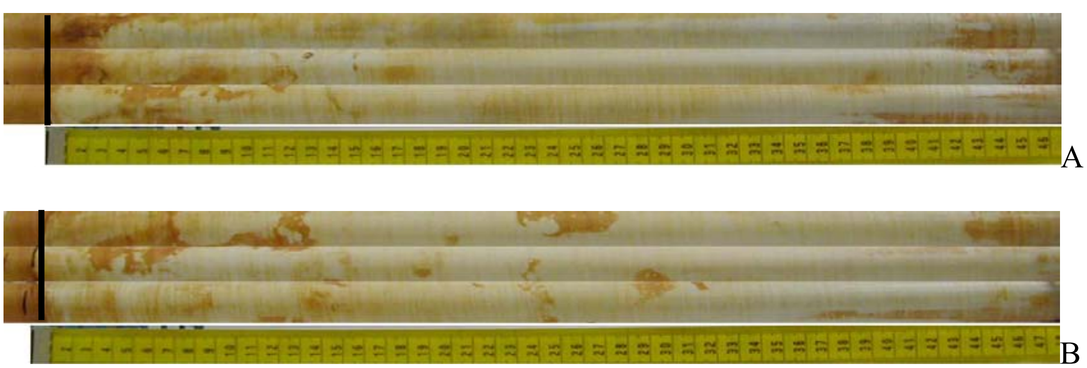
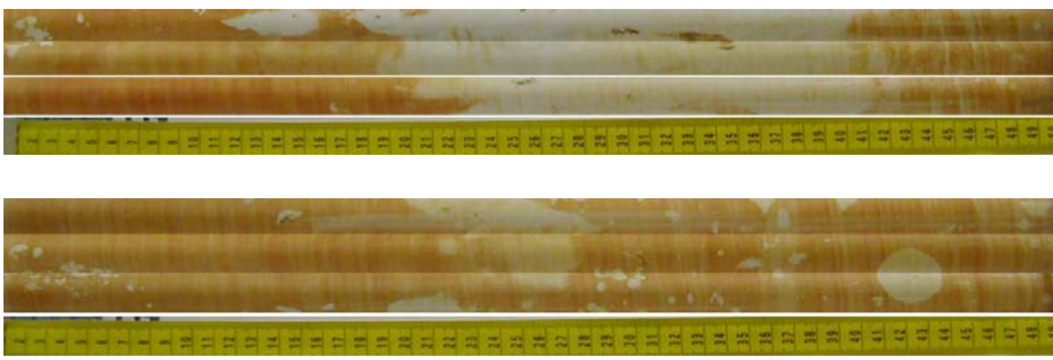


Figure 7-13: IRIS tubes removed on 4-22 from the low well at the Middle Patuxent. Black lines indicate the soil surface.



The tubes removed on April 22nd from the soil at the middle location showed signs of consistent reduction beginning at 19 and 20 cm, with some splotchy removal above this depth (Fig. 7-14). The redox potential at 50 cm was clearly below the technical standard, while measurements at 30 and 40 cm were approaching the line (Fig. 7-12). In this case, the tube has been reduced at some point during the 24 days it was in the soil, this shows that reduced conditions were present at some point during the period of time the tube was installed even though the Eh values were above the technical standard line at 20 cm. Therefore, the tubes may represent a more accurate integrating method of identifying reduced conditions in the soil, while the redox measurements are a more instantaneous measurement.

Figure 7-14: IRIS tubes removed on 4-22 from the middle site at the Middle Patuxent.



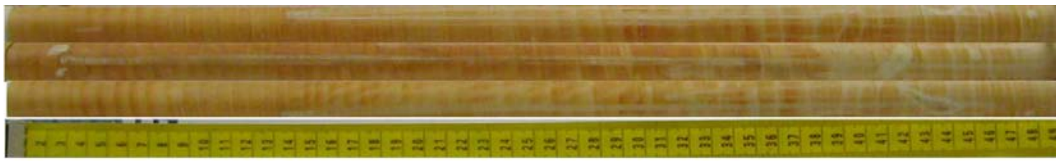
A

B

The tubes removed from the high site at the Middle Patuxent show a small amount of removal of iron from the tube in the lower 10 cm (Fig. 7-15) while the redox potential at 50 cm appears to be approaching the technical standard (Fig. 7-12). Table 7-2 illustrates the results of the tubes removed on April 22nd compared to the redox potentials.

Figure 7-15: IRIS tubes removed on 4-22 from the high well at the Middle Patuxent.

A



B

Table 7-2 Results of the reduction of iron from the IRIS tubes compared to the measured redox potentials at the Middle Patuxent on April 22, 2003.

depth (cm)	MP low (4-22)		MP middle (4-22)		MP high (4-22)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X				
20	X	X	X			
30	X	X	X	*		
40	X	X	X	*		
50	X	X		X	X	*

X indicates reduction of iron from the tube or Eh below the technical standard.

* average redox was not below the technical standard, however, there was indication that some of the replicate electrodes were in a reduced zone.

As the soil temperature rises, microbial activity is expected to increase to higher levels than during cooler temperatures. The tubes removed on June 23rd (soil temperature 18^{o}C) from the low site at the Middle Patuxent showed reduction from 0 to 50 cm (Fig 7-16). The redox potential at all depths measured was below the technical standard and the iron stability lines (Fig. 7-17). These two methods of documenting reduced conditions related well.

Figure 7-16: IRIS tubes removed on 6-23 from the low site at the Middle Patuxent.

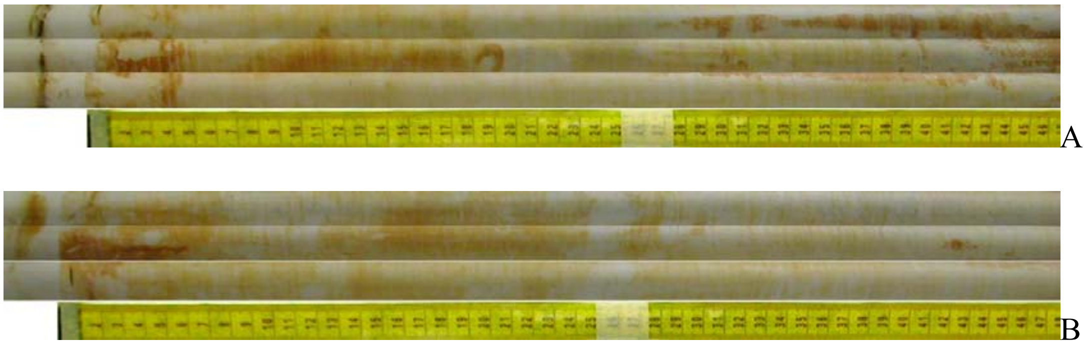
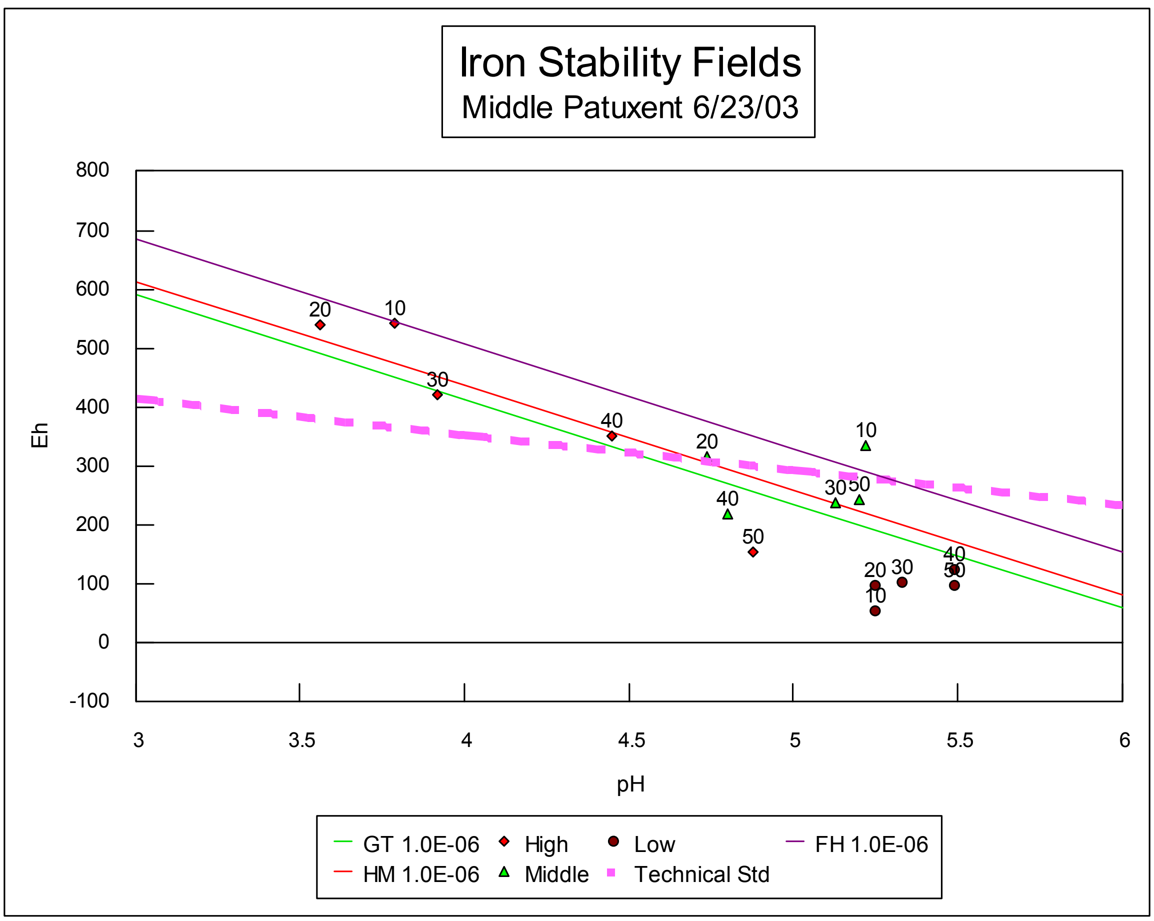
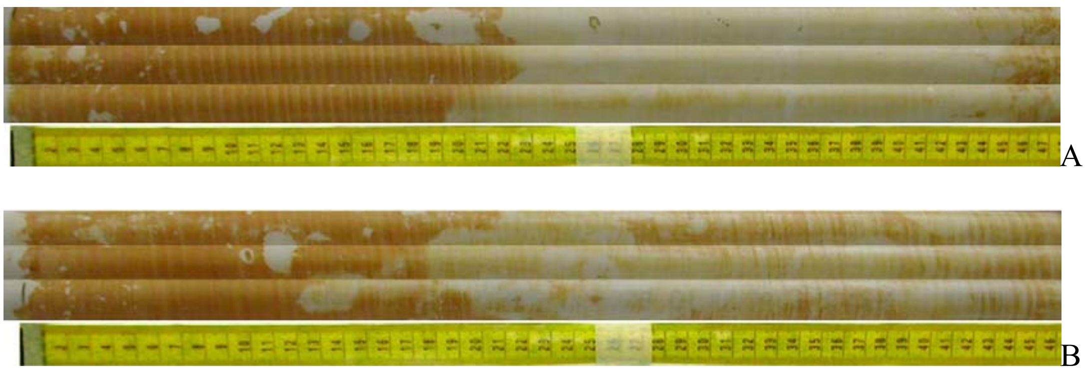


Figure 7-17: Measured redox potential at low, middle, and high sites at the Middle Patuxent. Points are averages of six electrode measurements.



The redox potential and the IRIS tubes, at the middle site at the Middle Patuxent, on June 23rd appeared to be closely related. The redox potential at 10 cm was above the technical standard and iron stability line, while the other measurements at 20 through 50 cm were below (Fig. 7-17). The iron was consistently removed from the IRIS tube beginning at 22 and 18 cm (Fig. 7-18).

Figure 7-18: IRIS tubes removed on 6-23 from the middle well at the Middle Patuxent.



The removal of iron from the tubes at the high location also related well to the soil redox potential (Fig. 7-17, Fig. 7-19). Reduced conditions existed below 40 cm based on both methods of measurement. Table 7-3 summarizes the relationship between the removal of iron from the IRIS tubes and the measured soil redox potential.

Figure 7-19: IRIS tubes removed on 6-23 from the high well at the Middle Patuxent.

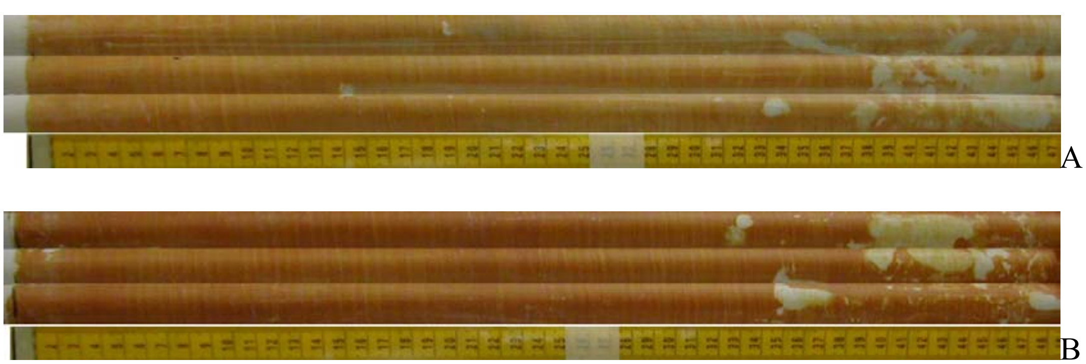


Table 7-3: Results of the reduction of iron from the IRIS tubes compared to the measured redox potentials at the Middle Patuxent on June 23, 2003.

depth (cm)	MP low (6-23)		MP middle (6-23)		MP high (6-23)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X				
20	X	X	X	X		
30	X	X	X	X		
40	X	X	X	X		
50	X	X	X	X	X	X

X indicates reduction of Fe from the tube or Eh below the technical standard.

North Branch of the Rock Creek

Similar trends were found between the soil redox potential and the IRIS tubes removed from Rock Creek. Table 7-4 provides a synopsis of the relationships found at the low, middle and high sites along the floodplain at Rock Creek. Selected results are shown for comparison to illustrate early (soil temperature ~5^{o}C), middle (soil temperature ~10^{o}C), and late (soil temperature ~15^{o}C) season results. Photographs of all tubes and redox potentials can be found in Appendix E and F.

Table 7-4: Results of the reduction of iron from the IRIS tubes compared to the measured redox potentials at the Rock Creek on selected dates.

depth (cm)	RC low (4-08)		RC middle (4-08)		RC high (4-08)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox
10		X	*	X		
20		X	*	X		
30	X	X	X	X		
40	X	X	X	X		
50	X	X	X	X		
depth (cm)	RC low (5-18)		RC middle (5-18)		RC high (5-18)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X	X	X		
20	X	X	X	X		
30	X	X	X	X		
40	X	X	X	X		
50	X	X	X	X		
depth (cm)	RC low (7-15)		RC middle (7-15)		RC high (7-15)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X	X	X		
20	X	X	X	X		
30	X	X	X	X		
40	X	X	X	X		
50	X	X	X	X	X	**

X indicates reduction of iron from the tube or Eh below the technical std.
* microsite reduction
** no redox measurement made due to dense soil.

White Clay Creek

Representative results from the tubes installed and redox potentials measured at White Clay Creek at shown in Table 7-5. As seen in the previous two sites, the redox potential and the IRIS tubes relate very well while the soil temperature is above approximately 10^{o}C. Below this temperature, decreased microbial activity may be a factor in the smaller amount of iron removed from the IRIS tubes. Although, the redox potentials are below the mineral stability line for Fe(II), therefore, iron should be reduced at these depths. The installation of duplicate tubes is essential to accurately capture the soil biogeochemical processes.

Table 7-5: Results of the reduction of iron from the IRIS tubes compared to the measured redox potentials at White Clay Creek on selected dates.

depth (cm)	WC low (4-08)		WC low/mid (4-08)		WC middle (4-08)		WC high (4-08)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X			*	X		
20	X	X	*	X	*	X		
30	X	X	*	X	*	X	*	X
40	X	X	X	X	X	X	*	X
50	X	X	X	X	X	X	X	X
depth (cm)	WC low (5-16)		WC low/mid (5-16)		WC middle (5-16)		WC high (5-16)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X	X	X	X	X		
20	X	X	X	X	X	X		
30	X	X	*	X	X	X	X	
40	X	X	*	X	X	X	X	X
50	X	X	*	X	X	X	X	X
depth (cm)	WC low (6-23)		WC low/mid (6-23)		WC middle (6-23)		WC high (6-23)	
	IRIS	Redox	IRIS	Redox	IRIS	Redox	IRIS	Redox
10	X	X	X	X	X			
20	X	X	X	X	X	X	X	X
30	X	X	X	X	X	X	X	X
40	X	X	X	X	X	X	X	X
50	X	X	X	X	X	X	X	X

X indicates reduction of iron from the tube or Eh below the technical standard.
* splotchy reduction

Conclusions

A number of trends were consistently observed across the three sites. Tubes set out earlier in the study, during cooler temperatures, had less overall removal of iron. This is probably due to the lower rates of microbial activity at cooler temperatures. Also, greater reduction of Fe occurred with depth on each tube where it was saturated for longer periods and therefore also had lower Eh. The low well locations had a significantly higher percentage of total iron removed than the tubes in the middle well locations. The middle well locations also had higher percentage of iron removed from the tubes than those in the high locations. The percentage of iron coating removed decreased towards the end of the study due to the oxidation of the soil as the water tables dropped in the summer.

A strong relationship exists between measured redox potential and incidence of reduction on the IRIS tubes at all sites. The tubes appear to be a useful tool to semi-quantitatively determine whether or not a soil has the capability to reduce iron based on the technical standard for hydric soils.

IRIS tubes integrate the continuous reduced and oxidized soil environment more readily than measurements of redox potential with Pt electrodes. Because soil is often reduced in an irregular pattern, the IRIS tube appears to obtain a more appropriate measure of reduction in soil. Due to microsite variability and the very small size of the Pt wire on the electrodes, IRIS tubes appear to be better suited than electrode measurements to depict the overall redox condition of the soil because the tube has a larger surface area and is therefore more likely to capture the variability in the soil processes.

In order to better understand the length of time necessary to have these tubes installed and the seasonal temperature effects on reduced conditions, additional research is needed. Conditions of reduction which could be documented after only a couple of days during a warm period, might take much longer during cooler months. These conditions must be interpreted through further documentation of the relation between the tubes, soil temperature, and redox potential.

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